EXHIBIT 2

US006266518B1

(12) **United States Patent**
Sorrells et al.

(10) **Patent No.: US 6,266,518 B1**
(45) **Date of Patent: *Jul. 24, 2001**

(54) **METHOD AND SYSTEM FOR DOWN-CONVERTING ELECTROMAGNETIC SIGNALS BY SAMPLING AND INTEGRATING OVER APERTURES**

(75) Inventors: **David F. Sorrells**; **Michael J. Bultman**, both of Jacksonville; **Robert W. Cook**, Switzerland; **Richard C. Looke**; **Charley D. Moses, Jr.**, both of Jacksonville, all of FL (US)

(73) Assignee: **ParkerVision, Inc.**, Jacksonville, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **09/376,359**

(22) Filed: **Aug. 18, 1999**

Related U.S. Application Data

(63) Continuation of application No. 09/176,022, filed on Oct. 21, 1998.

(51) **Int. Cl.**^{7} **H01Q 11/12**
(52) **U.S. Cl.** **455/118**; 455/113
(58) **Field of Search** 455/131, 139, 455/142, 182.1, 202, 205, 713, 317, 318, 323, 118, 113, 324; 329/345, 347; 327/9, 91; 702/66, 70

(56) **References Cited**

U.S. PATENT DOCUMENTS

Re. 35,494	4/1997	Nicollini	327/554
Re. 35,829	6/1998	Sanderford, Jr.	375/200
2,057,613	10/1936	Gardner	250/8
2,241,078	5/1941	Vreeland	179/15
2,270,385	1/1942	Skillman	179/15

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

42 37 692 C1	3/1994	(DE)	H04B/1/26
0 035 166 A1	9/1981	(EP)	H04B/1/26
0 099 265 A1	1/1984	(EP)	H03D/3/04

(List continued on next page.)

OTHER PUBLICATIONS

Translation of Specification and Claims of FR Patent No. 2245130, 3 pages.

Aghvami, H. et al., "Land Mobile Satellites Using the Highly Elliptic Orbits—The UK T–SAT Mobile Payload," 4th International Conf. On Satellite Systems for Mobile Communications and Navigation, Oct. 17–19, 1988, pp. 147–153.

Akers, N.P. et al., "RF Sampling Gates: a Brief Review," *IEE Proc.,* vol. 133, Part A, No. 1, Jan. 1986, pp. 45–49.

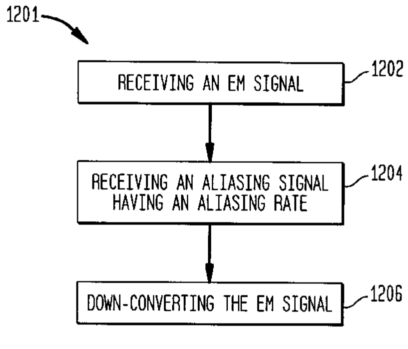
(List continued on next page.)

Primary Examiner—Vivian Chang
Assistant Examiner—Sam Bhattacharya
(74) *Attorney, Agent, or Firm*—Sterne, Kessler, Goldstein & Fox PLLC

(57) **ABSTRACT**

Methods, systems, and apparatuses for down-converting an electromagnetic (EM) signal by aliasing the EM signal are described herein. Briefly stated, such methods, systems, and apparatuses operate by receiving an EM signal and an aliasing signal having an aliasing rate. The EM signal is aliased according to the aliasing signal to down-convert the EM signal. The term aliasing, as used herein, refers to both down-converting an EM signal by under-sampling the EM signal at an aliasing rate, and down-converting an EM signal by transferring energy from the EM signal at the aliasing rate. In an embodiment, the EM signal is down-converted to an intermediate frequency (IF) signal. In another embodiment, the EM signal is down-converted to a demodulated baseband information signal. In another embodiment, the EM signal is a frequency modulated (FM) signal, which is down-converted to a non-FM signal, such as a phase modulated (PM) signal or an amplitude modulated (AM) signal.

99 Claims, 126 Drawing Sheets



GENERIC DOWN-CONVERTING FLOWCHART

U.S. PATENT DOCUMENTS

2,283,575	5/1942	Roberts	250/6
2,358,152	9/1944	Earp	179/171.5
2,410,350	10/1946	Labin et al.	179/15
2,451,430	10/1948	Barone	250/8
2,462,069	2/1949	Chatterjea et al.	250/17
2,462,181	2/1949	Grosselfinger	250/17
2,472,798	6/1949	Fredendall	178/44
2,497,859	2/1950	Boughtwood et al.	250/8
2,499,279	2/1950	Paterson	332/41
2,802,208	8/1957	Hobbs	343/176
2,985,875	5/1961	Grisdale et al.	343/100
3,023,309	2/1962	Foulkes	250/17
3,069,679	12/1962	Sweeney et al.	343/200
3,104,393	9/1963	Vogelman	343/200
3,114,106	12/1963	McManus	325/56
3,118,117	1/1964	King et al.	332/22
3,226,643	12/1965	McNair	325/40
3,258,694	6/1966	Sheperd	325/145
3,383,598	5/1968	Sanders	325/163
3,384,822	5/1968	Miyagi	325/30
3,454,718	7/1969	Perreault	178/66
3,523,291	8/1970	Pierret	340/347
3,548,342	12/1970	Maxey	332/9
3,555,428	1/1971	Perreault	325/320
3,617,892	11/1971	Hawley et al.	325/145
3,621,402	11/1971	Gardner	328/37
3,623,160	11/1971	Giles et al.	340/347
3,626,417	12/1971	Gilbert	343/203
3,629,696	12/1971	Bartelink	324/57 R
3,662,268	5/1972	Gans et al.	325/56
3,689,841	9/1972	Bello et al.	325/39
3,714,577	1/1973	Hayes	325/145
3,717,844	2/1973	Barret et al.	340/5 R
3,735,048	5/1973	Tomsa et al.	179/15 BM
3,806,811	4/1974	Thompson	325/146
3,868,601	2/1975	MacAfee	332/45
3,949,300	4/1976	Sadler	325/31
3,967,202	6/1976	Batz	325/31
3,980,945	9/1976	Bickford	325/30
3,987,280	10/1976	Bauer	235/150.53
3,991,277	11/1976	Hirata	179/15 FD
4,003,002	1/1977	Snijders et al.	332/10
4,013,966	3/1977	Campbell	325/363
4,017,798	4/1977	Gordy et al.	325/42
4,019,140	4/1977	Swerdlow	322/65
4,032,847	6/1977	Unkauf	325/323
4,035,732	7/1977	Lohmann	325/446
4,047,121	9/1977	Campbell	331/76
4,066,841	1/1978	Young	178/66 R
4,066,919	1/1978	Huntington	307/353
4,081,748	3/1978	Betz	325/56
4,130,765	12/1978	Arakelian et al.	307/220 R
4,130,806	12/1978	Van Gerwen et al.	325/487
4,142,155	2/1979	Adachi	325/47
4,170,764	10/1979	Salz et al.	332/17
4,204,171	5/1980	Sutphin, Jr.	328/167
4,210,872	7/1980	Gregorian	330/9
4,245,355	1/1981	Pascoe et al.	455/326
4,253,066	2/1981	Fisher et al.	329/50
4,253,067	2/1981	Caples et al.	329/110
4,253,069	2/1981	Nossek	330/107
4,308,614	12/1981	Fisher et al.	370/119
4,320,361	3/1982	Kikkert	332/16 R
4,320,536	3/1982	Dietrich	455/325
4,346,477	8/1982	Gordy	455/257
4,355,401	10/1982	Ikoma et al.	375/5
4,356,558	10/1982	Owen et al.	364/724
4,360,867	11/1982	Gonda	363/158
4,363,132	12/1982	Collin	455/52
4,365,217	12/1982	Berger et al.	333/165
4,370,572	1/1983	Cosand et al.	307/353
4,389,579	6/1983	Stein	307/353
4,392,255	7/1983	Del Giudice	455/328
4,393,395	7/1983	Hacke et al.	358/23
4,430,629	2/1984	Betzl et al.	333/165
4,446,438	5/1984	Chang et al.	328/127
4,456,990	6/1984	Fisher et al.	370/119
4,472,785	9/1984	Kasuga	364/718
4,479,226	10/1984	Prabhu et al.	375/1
4,481,490	11/1984	Huntley	332/41
4,481,642	11/1984	Hanson	375/9
4,485,488	11/1984	Houdart	455/327
4,504,803	3/1985	Lee et al.	332/31 R
4,517,519	5/1985	Mukaiyama	329/126
4,517,520	5/1985	Ogawa	329/145
4,518,935	5/1985	van Roermund	333/173
4,521,892	6/1985	Vance et al.	375/88
4,563,773	1/1986	Dixon, Jr. et al.	455/32
4,577,157	3/1986	Reed	329/50
4,583,239	4/1986	Vance	375/94
4,591,736	5/1986	Hirao et al.	307/267
4,602,220	7/1986	Kurihara	331/19
4,603,300	7/1986	Welles, II et al.	329/50
4,612,464	9/1986	Ishikawa et al.	307/496
4,612,518	9/1986	Gans et al.	332/21
4,616,191	10/1986	Galani et al.	331/4
4,621,217	11/1986	Saxe et al.	315/1
4,628,517	12/1986	Schwarz et al.	375/40
4,634,998	1/1987	Crawford	331/1 A
4,648,021	3/1987	Alberkrack	363/157
4,651,034	3/1987	Sato	307/556
4,675,882	6/1987	Lillie et al.	375/80
4,688,253	8/1987	Gumm	381/7
4,716,376	12/1987	Daudelin	329/107
4,716,388	12/1987	Jacobs	333/173
4,718,113	1/1988	Rother et al.	455/209
4,726,041	2/1988	Prohaska et al.	375/91
4,733,403	3/1988	Simone	375/103
4,734,591	3/1988	Ichitsubo	307/219.1
4,737,969	4/1988	Steel et al.	375/67
4,743,858	5/1988	Everard	330/10
4,745,463	5/1988	Lu	358/23
4,751,468	6/1988	Agoston	328/133
4,757,538	7/1988	Zink	381/7
4,768,187	8/1988	Marshall	370/69.1
4,769,612	9/1988	Tamakoshi et al.	328/167
4,785,463	11/1988	Janc et al.	375/1
4,791,584	12/1988	Greivenkamp, Jr.	364/525
4,801,823	1/1989	Yokoyama	307/353
4,806,790	2/1989	Sone	307/353
4,810,904	3/1989	Crawford	307/353
4,810,976	3/1989	Cowley et al.	331/117 R
4,811,362	3/1989	Yester, Jr. et al.	375/75
4,816,704	3/1989	Flori, Jr.	307/519
4,819,252	4/1989	Christopher	375/122
4,833,445	5/1989	Buchele	341/118
4,841,265	6/1989	Watanabe et al.	333/194
4,862,121	8/1989	Hochschild et al.	333/173
4,868,654	9/1989	Juri et al.	358/133
4,870,659	9/1989	Oishi et al.	375/82
4,871,987	10/1989	Kawase	332/100
4,885,587	12/1989	Wiegard et al.	42/14
4,885,756	12/1989	Fontanes et al.	375/82
4,888,557	12/1989	Puckette, IV et al.	329/341
4,890,302	12/1989	Muilwijk	375/80
4,893,316	1/1990	Janc et al.	375/44
4,893,341	1/1990	Gehring	381/7
4,894,766	1/1990	De Agro	363/159
4,896,152	1/1990	Tiemann	340/853
4,902,979	2/1990	Puckette, IV	329/343
4,908,579	3/1990	Tawfik et al.	328/167

4,910,752	3/1990	Yester, Jr. et al.	375/75
4,914,405	4/1990	Wells	331/25
4,920,510	4/1990	Senderowicz et al.	364/825
4,922,452	5/1990	Larsen et al.	365/45
4,931,921	6/1990	Anderson	363/163
4,943,974	7/1990	Motamedi	375/1
4,944,025	7/1990	Gehring et al.	455/207
4,955,079	9/1990	Connerney et al.	455/325
4,965,467	10/1990	Bilterijst	307/352
4,967,160	10/1990	Quievy et al.	328/16
4,970,703	11/1990	Hariharan et al.	367/138
4,982,353	1/1991	Jacob et al.	364/724.1
4,984,077	1/1991	Uchida	358/140
4,995,055	2/1991	Weinberger et al.	375/5
5,003,621	3/1991	Gailus	455/209
5,005,169	4/1991	Bronder et al.	370/76
5,006,810	4/1991	Popescu	328/167
5,010,585	4/1991	Garcia	455/118
5,014,304	5/1991	Nicollini et al.	379/399
5,015,963	5/1991	Sutton	329/361
5,017,924	5/1991	Guiberteau et al.	342/195
5,020,149	5/1991	Hemmie	455/325
5,020,154	5/1991	Zierhut	455/608
5,052,050	9/1991	Collier et al.	455/296
5,065,409	11/1991	Hughes et al.	375/91
5,083,050	1/1992	Vasile	307/529
5,091,921	2/1992	Minami	375/88
5,095,533	3/1992	Loper et al.	455/245
5,095,536	3/1992	Loper	455/324
5,111,152	5/1992	Makino	329/300
5,113,094	5/1992	Grace et al.	307/529
5,113,129	5/1992	Hughes	323/316
5,115,409	5/1992	Stepp	364/841
5,122,765	6/1992	Pataut	332/105
5,124,592	6/1992	Hagino	307/520
5,126,682	6/1992	Weinbert et al.	329/304
5,136,267	8/1992	Cabot	333/174
5,140,705	8/1992	Kosuga	455/318
5,150,124	9/1992	Moore et al.	342/68
5,151,661	9/1992	Caldwell et al.	328/14
5,159,710	10/1992	Cusdin	455/304
5,170,414	12/1992	Silvian	375/59
5,172,070	12/1992	Hiraiwa et al.	329/304
5,191,459	3/1993	Thompson et al.	359/133
5,204,642	4/1993	Ashgar et al.	331/135
5,212,827	5/1993	Meszko et al.	455/219
5,214,787	5/1993	Karkota, Jr.	455/3.2
5,220,583	6/1993	Solomon	375/82
5,220,680	6/1993	Lee	455/102
5,222,144	6/1993	Whikehart	381/15
5,230,097	7/1993	Currie et al.	455/226.1
5,239,686	8/1993	Downey	455/78
5,241,561	8/1993	Barnard	375/1
5,249,203	9/1993	Loper	375/97
5,251,218	10/1993	Stone et al.	370/120
5,251,232	10/1993	Nonami	375/5
5,260,970	11/1993	Henry et al.	375/10
5,263,194	11/1993	Ragan	455/316
5,263,196	11/1993	Jasper	455/324
5,267,023	11/1993	Kawasaki	358/23
5,278,826	1/1994	Murphy et al.	370/76
5,282,023	1/1994	Scarpa	358/36
5,287,516	2/1994	Schaub	375/88
5,293,398	3/1994	Hamao et al.	375/1
5,303,417	4/1994	Laws	455/314
5,307,517	4/1994	Rich	455/306
5,315,583	5/1994	Murphy et al.	370/18
5,321,852	6/1994	Seong	455/182.1
5,325,204	6/1994	Scarpa	348/607
5,337,014	8/1994	Najle et al.	324/613
5,339,054	8/1994	Taguchi	332/100
5,339,459	8/1994	Schiltz et al.	455/333
5,353,306	10/1994	Yamamoto	375/14
5,355,114	10/1994	Sutterlin et al.	340/310 A
5,361,408	11/1994	Watanabe et al.	455/324
5,369,800	11/1994	Takagi et al.	455/59
5,375,146	12/1994	Chalmers	375/103
5,379,040	1/1995	Mizomoto et al.	341/143
5,379,141	1/1995	Thompson et al.	359/125
5,388,063	2/1995	Takatori et al.	364/724.47
5,390,364	2/1995	Webster et al.	455/52.3
5,400,084	3/1995	Scarpa	348/624
5,404,127	4/1995	Lee et al.	340/310.02
5,410,541	4/1995	Hotto	370/76
5,410,743	4/1995	Seely et al.	455/326
5,412,352	5/1995	Graham	332/103
5,416,803	5/1995	Janer	375/324
5,422,913	6/1995	Wilkinson	375/347
5,423,082	6/1995	Cygan et al.	455/126
5,428,638	6/1995	Cioffi et al.	375/224
5,428,640	6/1995	Townley	375/257
5,434,546	7/1995	Palmer	332/151
5,438,692	8/1995	Mohindra	455/324
5,444,415	8/1995	Dent et al.	329/302
5,444,416	8/1995	Ishikawa et al.	329/341
5,444,865	8/1995	Heck et al.	455/86
5,446,421	8/1995	Kechkaylo	332/100
5,446,422	8/1995	Mattila et al.	332/103
5,448,602	9/1995	Ohmori et al.	375/347
5,451,899	9/1995	Lawton	329/302
5,454,007	9/1995	Dutta	375/322
5,454,009	9/1995	Fruit et al.	372/202
5,463,356	10/1995	Palmer	332/117
5,463,357	10/1995	Hobden	332/151
5,465,071	11/1995	Kobayashi et al.	329/315
5,465,410	11/1995	Hiben et al.	455/266
5,465,415	11/1995	Bien	455/326
5,471,162	11/1995	McEwan	327/92
5,479,120	12/1995	McEwan	327/91
5,479,447	12/1995	Chow et al.	375/260
5,483,193	1/1996	Kennedy et al.	329/300
5,483,549	1/1996	Weinberg et al.	375/200
5,483,691	1/1996	Heck et al.	455/234.2
5,490,173	2/1996	Whikehart et al.	375/316
5,493,581	2/1996	Young et al.	375/350
5,493,721	2/1996	Reis	355/339
5,495,200	2/1996	Kwan et al.	327/554
5,495,202	2/1996	Hsu	327/113
5,495,500	2/1996	Jovanovich et al.	375/206
5,499,267	3/1996	Ohe et al.	375/206
5,500,758	3/1996	Thompson et al.	359/189
5,515,014	5/1996	Troutman	332/178
5,517,688	5/1996	Fajen et al.	455/333
5,519,890	5/1996	Pinckley	455/307
5,523,719	6/1996	Longo et al.	327/557
5,523,726	6/1996	Kroeger et al.	332/103
5,523,760	6/1996	McEwan	342/89
5,539,770	7/1996	Ishigaki	375/206
5,555,453	9/1996	Kajimoto et al.	455/266
5,557,641	9/1996	Weinberg	375/295
5,557,642	9/1996	Williams	375/316
5,563,550	10/1996	Toth	329/347
5,574,755	11/1996	Persico	375/295
5,579,341	11/1996	Smith et al.	375/267
5,579,347	11/1996	Lindquist et al.	375/346
5,584,068	12/1996	Mohindra	455/324
5,592,131	1/1997	Labreche et al.	332/103
5,602,847	2/1997	Pagano et al.	370/484
5,602,868	2/1997	Wilson	375/219
5,604,592	2/1997	Kotidis et al.	356/357
5,604,732	2/1997	Kim et al.	370/342
5,608,531	3/1997	Honda et al.	386/1

5,610,946	3/1997	Tanaka et al.	375/269
5,617,451	4/1997	Mimura et al.	375/340
5,619,538	4/1997	Sempel et al.	375/328
5,621,455	4/1997	Rogers et al.	348/6
5,630,227	5/1997	Bella et al.	455/324
5,638,396	6/1997	Kilmek	372/92
5,640,415	6/1997	Pandula	375/202
5,640,424	6/1997	Banavong et al.	375/316
5,640,428	6/1997	Abe et al.	375/334
5,640,698	6/1997	Shen et al.	455/323
5,648,985	7/1997	Bjerede et al.	375/219
5,650,785	7/1997	Rodal	342/357
5,661,424	8/1997	Tang	327/105
5,663,878	9/1997	Walker	363/159
5,663,986	9/1997	Striffler	375/260
5,668,836	9/1997	Smith et al.	375/316
5,675,392	10/1997	Nayebi et al.	348/584
5,680,078	10/1997	Ariie	332/178
5,680,418	10/1997	Croft et al.	375/346
5,689,413	11/1997	Jaramillo et al.	363/146
5,694,096	12/1997	Ushiroku et al.	333/195
5,699,006	12/1997	Zele et al.	327/341
5,705,955	1/1998	Freeburg et al.	331/14
5,710,998	1/1998	Opas	455/324
5,714,910	2/1998	Skoczen et al.	331/3
5,715,281	2/1998	Bly et al.	375/344
5,721,514	2/1998	Crockett et al.	331/3
5,724,002	3/1998	Hulick	329/361
5,724,653	3/1998	Baker et al.	455/296
5,729,577	3/1998	Chen	375/334
5,729,829	3/1998	Talwar et al.	455/63
5,732,333	3/1998	Cox et al.	455/126
5,736,895	4/1998	Yu et al.	327/554
5,737,035	4/1998	Rotzoll	348/725
5,742,189	4/1998	Yoshida et al.	327/113
5,748,683	5/1998	Smith et al.	375/347
5,757,870	5/1998	Miya et al.	375/367
5,760,645	6/1998	Comte et al.	329/304
5,764,087	6/1998	Clark	327/105
5,767,726	6/1998	Wang	327/356
5,768,118	6/1998	Faulk et al.	363/72
5,768,323	6/1998	Kroeger et al.	375/355
5,770,985	6/1998	Ushiroku et al.	333/193
5,771,442	6/1998	Wang et al.	455/93
5,777,692	7/1998	Ghosh	348/725
5,777,771	7/1998	Smith	359/180
5,778,022	7/1998	Walley	375/206
5,786,844	7/1998	Rogers et al.	348/6
5,793,801	8/1998	Fertner	375/219
5,793,818	8/1998	Claydon et al.	375/326
5,802,463	9/1998	Zuckerman	455/208
5,809,060	9/1998	Cafarella et al.	375/206
5,812,546	9/1998	Zhou et al.	370/342
5,818,582	10/1998	Fernandez et al.	356/318
5,818,869	10/1998	Miya et al.	375/206
5,825,254	10/1998	Lee	331/25
5,834,985	11/1998	Sundegård	332/100
5,844,449	12/1998	Abeno et al.	332/105
5,864,754	1/1999	Hotto	455/280
5,872,446	2/1999	Cranford, Jr. et al.	323/315
5,881,375	3/1999	Bonds	455/118
5,892,380	4/1999	Quist	327/172
5,894,239	4/1999	Bonaccio et al.	327/176
5,896,562	4/1999	Heinonen	455/76
5,900,747	5/1999	Brauns	327/9
5,901,054	5/1999	Leu et al.	363/41
5,901,187	5/1999	Iinuma	375/347
5,901,344	5/1999	Opas	455/76
5,901,347	5/1999	Chambers et al.	455/234.1
5,901,348	5/1999	Bang et al.	455/254
5,901,349	5/1999	Guegnaud et al.	455/302
5,903,178	5/1999	Miyatsuji et al.	327/308
5,903,187	5/1999	Claverie et al.	329/342
5,903,196	5/1999	Salvi et al.	331/16
5,903,421	5/1999	Furutani et al.	361/58
5,903,553	5/1999	Sakamoto et al.	370/338
5,903,595	5/1999	Suzuki	375/207
5,903,609	5/1999	Kool et al.	375/261
5,903,827	5/1999	Kennan et al.	455/326
5,903,854	5/1999	Abe et al.	455/575
5,905,449	5/1999	Tsubouchi et al.	340/925.69
5,907,149	5/1999	Marckini	235/487
5,907,197	5/1999	Faulk	307/119
5,909,447	6/1999	Cox et al.	370/508
5,911,116	6/1999	Nosswitz	455/83
5,911,123	6/1999	Shaffer et al.	455/554
5,914,622	6/1999	Inoue	327/172
5,920,199	7/1999	Sauer	324/678
5,933,467	8/1999	Sehier et al.	375/350
5,943,370	8/1999	Smith	375/334
5,952,895	9/1999	McCune, Jr. et al.	332/128
5,960,033	9/1999	Shibano et al.	375/207
6,041,073	3/2000	Davidovici et al.	375/148
6,054,889	4/2000	Kobayashi	327/357
6,084,922	7/2000	Zhou et al.	375/316
6,125,271	9/2000	Rowland et al.	455/313
6,147,340	11/2000	Levy	250/214 R
6,147,763	11/2000	Steinlechner	356/484
6,150,890	11/2000	Damgaard et al.	331/14

FOREIGN PATENT DOCUMENTS

0 193 899 B1	6/1990	(EP)	G01S/7/52
0 380 351 A2	8/1990	(EP)	H03H/17/04
0 380 351 A3	2/1991	(EP)	H03H/17/04
0 411 840 A2	2/1991	(EP)	G01R/33/36
0 423 718 A2	4/1991	(EP)	H04N/7/01
0 411 840 A3	7/1991	(EP)	G01R/33/36
0 486 095 A1	5/1992	(EP)	H03D/3/00
0 423 718 A3	8/1992	(EP)	H04N/7/01
0 512 748 A2	11/1992	(EP)	H04N/9/64
0 548 542 A1	6/1993	(EP)	H03B/19/14
0 512 748 A3	7/1993	(EP)	H04N/9/64
0 560 228 A1	9/1993	(EP)	H03D/7/12
0 632 288 A2	1/1995	(EP)	G01S/13/75
0 411 840 B1	10/1995	(EP)	G01R/33/36
0 696 854 A1	2/1996	(EP)	H04B/1/26
0 632 288 A3	7/1996	(EP)	G01S/13/75
0 486 095 B1	2/1997	(EP)	H03D/3/00
0 782 275 A2	7/1997	(EP)	H04B/7/02
0 785 635 A1	7/1997	(EP)	H04B/1/713
0 795 978 A2	9/1997	(EP)	H04L/5/06
0 837 565 A1	4/1998	(EP)	H04B/1/69
0 862 274 A1	9/1998	(EP)	H03M/1/06
0 874 499 A2	10/1998	(EP)	H04L/25/06
0 512 748 B1	11/1998	(EP)	H04N/9/64
2 245 130	4/1975	(FR)	H03K/5/13
2 743 231-A1	7/1997	(FR)	H04B/7/12
2 161 344	1/1986	(GB)	H04B/7/12
2 215 945	9/1989	(GB)	H04L/27/00
2-39632	2/1990	(JP)	H04B/7/12
2-131629	5/1990	(JP)	H04B/7/12
2-276351	11/1990	(JP)	H04L/27/22
WO 80/01633 A1	8/1980	(WO)	H04J/1/08
WO 94/05087 A1	3/1994	(WO)	H03M/1/00
WO 96/02977 A1	2/1996	(WO)	H04B/1/26
WO 96/08078 A1	3/1996	(WO)	H03D/3/00
WO 96/39750 A1	12/1996	(WO)	H04B/1/26

WO 97/38490 A1 10/1997 (WO) H03K/7/00
WO 98/00953 A1 1/1998 (WO) H04L/27/26
WO 98/24201 A1 6/1998 (WO) H04H/1/00

OTHER PUBLICATIONS

Al–Ahmad, H.A.M. et al., "Doppler Frequency Correction for a Non–Geostationary Communications Satellite. Techniques for CERS and T–SAT," *Electronics Division Colloquium on Low Noise Oscillators and Synthesizer,* Jan. 23, 1986, pp. 4/1–4/5.

Ali, I. et al., "Doppler Characterization for LEO Satellites," *IEEE Trans. On Communications,* vol. 46, No. 3, Mar 1998, pp. 309–313.

Allan, D.W., "Statistics of Atomic Frequency Standards," *Proc. Of the IEEE Special Issue on Frequency Stability,* Feb. 1966, pp. 221–230.

Allstot, D.J. et al., "MOS Switched Capacitor Ladder Filters," *IEEE Journal of Solid–State Circuits,* vol. SC–13, No. 6, Dec. 1978, pp. 806–814.

Allstot, D.J. and Black Jr. W.C., "Technological Design Considerations for Monolithic MOS Switched–Capacitor Filtering Systems," *Proceedings of the IEEE,* vol. 71, No. 8, Aug. 1983, pp. 967–986.

Alouini, M. et al., "Channel Characterization and Modeling for Ka–Band Very Small Aperture Terminals," *Proc. Of the IEEE,* vol. 85, No. 6, Jun. 1997, pp. 981–997.

Andreyev, G.A. and Ogarev, S.A., "Phase Distortions of Keyed Millimeter–Wave Signals in the Case of Propagation in a Turbulent Atmosphere," *Telecommunications and Radio Engineering,* vol. 43, No. 12, Dec. 1988, pp. 87–90.

Antonetti, A. et al., "Optoelectronic Sampling in the Picosecond Range," *Optics Communications,* vol. 21, No. May 1977, pp. 211–214.

Austin, J. et al., "Doppler Correction of the Telecommunication Payload Oscillators in the UK T–SAT," 18th European Microwave Conference, Sep. 12–15, 1988, pp. 851–857.

Auston, D.H., "Picosecond optoelectronic switching and gating in silicon," *Applied Physics Letters,* vol. 26, No. 3, Feb. 1, 1975, pp. 101–103.

Baher, H., "Transfer Functions for Switched–Capacitor and Wave Digital Filters," *IEEE Transactions on Circuits and Systems,* vol. CAS–33, No. 11, Nov. 1986, pp. 1138–1142.

Baines, R., "The DSP Bottleneck," *IEEE Communications Magazine,* May 1995, pp. 46–54.

Banjo, O.P. and Vilar, E., "Binary Error Probabilities on Earth–Space Links Subject to Scintillation Fading" *Electronics Letters,* vol. 21, No. 7, Mar. 28, 1985, pp. 296–297.

Banjo, O.P. and Vilar E., "The Dependence of Slant Path Amplitude Scintillations on Various Meteorological Parameters," *Antennas and Propagation* (*ICAP 87*) *Part 2: Propagation,* Mar. 30–Apr. 2, 1987, pp. 277–280.

Banjo, O.P. and Vilar, E. "Measurement and Modeling of Amplitude Scintillations on Low–Elevation Earth–Space Paths and Impact on Communication Systems," *IEEE Trans. On Communications,* vol. COM–34, No. 8, Aug. 1986, pp. 774–780.

Banjo, O.P. et al., "Tropospheric Amplitude Spectra Due to Absorption and Scattering in Earth–Space Paths," *Antennas and Propagation* (*ICAP 85*) Apr. 16–19, 1985, pp. 77–82.

Basili,P. et al., "Case Study of Intense Scintillation Events on the OTS Path," *IEEE Trans. On Antennas and Propagation,* vol. 38, No. 1, Jan. 1990, pp. 107–113.

Basili, P. et al., "Observation of High C^2 and Turbulent Path Length on OTS Space–Earth Link," *Electronics Letters,* vol. 24, No. 17, Aug. 18, 1988, pp. 1114–1116.

Blakey, J.R. et al., "Measurement of Atmospheric Millimetre–Wave Phase Scintillations in an Absorption Region," *Electronics Letters,* vol. 21, No. 11, May 23, 1985, pp. 486–487.

Burgueño, A. et al., "Influence of rain gauge integration time on the rain rate statistics used in microwave communications," *annales de telecommunications,* Sep./Oct. 1988, pp. 522–527.

Burgueño, A. et al., "Influence of rain gauge integration time on the rain rate statistics used in microwave communications," *annales des telecommunications,* Sep./Oct. 1988, pp. 522–527.

Burgueño, A. et al., "Long Term Statistics of Precipitation Rate Return Periods in the Context of Microwave Communications," *Antennas and Propagation* (*ICAP 89*) *Part 2: Propagation,* Apr. 4–7, 1989, pp. 297–301.

Burgueño, A. et al., "Spectral Analysis of 49 Years of Rainfall Rate and Relation to Fade Dynamics," *IEEE Trans. On Communications,* vol. 38, No. 9, Sep. 1990, pp. 1359–1366.

Catalan, C. and Vilar, E., "Approach for satellite slant path remote sensing," *Electronics Letters,* vol. 34, No. 12, Jun. 11, 1998, pp. 1238–1240.

Chan, P. et al., "A Highly Linear 1–GHz CMOS Downconversion Mixer," European Solid State Circuits Conference, Seville, Spain, Sep. 22–24, 1993, pp. 210–213.

Copy of Declaration of Michael J. Bultman filed in patent application Ser. No. 09/176,022, which is directed to related subject matter.

Copy of Delaration of Robert W. Cook filed in patent application Ser. No. 09/176,022, which is directed to related subject matter.

Copy of Declaration of Alex Holtz filed in patent application Ser. No. 09/176,022, which is directed to related subject matter.

Copy of Declaration of Richard C. Looke filed in patent application Ser. No. 09/176,022, which is directed to related subject matter.

Copy of Declaration of Charley D. Moses, Jr. filed in patent application Ser. No. 09/176,022, which is directed to related subject matter.

Copy of Declaration of Jeffrey L. Parker and David F. Sorrells, with attachment Exhibit 1, filed in patent application Ser. No. 09/176, 022, which is directed to related subject matter.

Dewey, R.J. and Collier, C.J., "Multi–Mode Radio Receiver," pp. 3/1–3/5.

Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2–276351, published Nov. 13, 1990, (1 page).

Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2–131629, published May 21, 1990, (1 page).

Dialog File 347 (JAPIO) English Language Patent Abstract for JP 2–39632, published Feb. 8, 1990, (1 page).

Dialog File 348 (European Patents) English Language Patent Abstract for EP 0 785 635 A1, published Dec. 26, 1996, (3 pages).

Dialog File 348 (European Patents) English Language Patent Abstract for EP 35166 A1, published Feb. 18, 1981, (2 pages).

"DSO takes sampling rate to 1 Ghz," *Electronic Engineering,* Mar. 1987, pp. 77 and 79.

Erdi, G. and Henneuse, P.R., "A Precision FET–Less Sample–and–Hold with High Charge–to–Droop Current Ratio," *IEEE Journal of Solid–State Circuits,* vol. SC–13, No. 6, Dec. 1978, pp. 864–873.

Faulkner, N.D. and Vilar, E., "Subharmonic Sampling for the Measurement of Short Term Stability of Microwave Oscillators," *IEEE Trans. On Instrumentation and Measurement,* vol. IM–32, No. 1, Mar. 1983, pp. 208–213.

Faulkner, N.D. et al., "Sub–Harmonic Sampling for the Accurate Measurement of Frequency Stability of Microwave Oscillators," CPEM 82 Digest: Conf. On Precision Electromagnetic Measurements, 1982, pp. M–10 & M–11.

Faulkner, N.D. and Vilar, E., "Time Domain Analysis of Frequency Stability Using Non–Zero Dead–Time Counter Techniques," CPEM 84 Digest Conf. On Precision Electromagnetic Measurements, 1984, pp. 81–82.

Filip, M. and Vilar, E., "Optimum Utilization of the Channel Capacity of a Satellite Link in the Presence of Amplitude Scintillations and Rain Attenuation," *IEEE Trans. On Communications,* vol. 38, No. 11, Nov. 1990, pp. 1958–1965.

Fukahori, K., "A CMOS Narrow–Band Signaling Filter with Q Reduction," *Journal of Solid–State Circuits,* vol. SC–19, No. 6, Dec. 1984, pp. 926–932.

Fukuchi, H. and Otsu, Y., "Available time statistics of rain attenuation on earth–space path," *IEE Proc.,* vol. 135, pt. H, No. 6, Dec. 1988, pp. 387–390.

Gibbins, C.J. and Chadha, R., "Millimetre–wave propagation through hydrocarbon flame," *IEE Proc.,* vol. 134, pt. H, No. 2, Apr. 1987, pp. 169–173.

Gilchrist, B. et al., "Sampling hikes performance of frequency synthesizers," *Microwaves R&F,* Jan. 1984, pp. 93–94 and 110.

Gossard, E.E., "Clear weather meterological effects on propagation at frequencies above 1 Ghz," *Radio Science,* vol. 16, No. 5, Sep.–Oct. 1981, pp. 589–608.

Gregorian, R. et al., "Switched–Capacitor Circuit Design," Proceedings of the IEEE, vol. 71, No. 8, Aug. 1983, pp. 941–966.

Groshong et al., "Undersampling Techniques Simplify Digital Radio," *Electronic Design,* May 23, 1991, pp. 67–68, 70, 73–75 and 78.

Grove, W.M., "Sampling for Oscilloscopes and Other RF Systems: Dc through X–Band," *IEEE Trans. On Microwave Theory and Techniques,* Dec. 1966, pp. 629–635.

Haddon, J. et al., "Measurement of Microwave Scintillations on a Satellite Down–Line at X–Band," 2nd Int'l Conf. On Antennas and Propagation Part 2: Propagation, Apr. 13–16, 1991, pp. 113–117.

Haddon, J. and Vilar, E., "Scattering Induced Microwave Scintillations from Clear Air and Rain on Earth Space Paths and the Influence of Antenna Aperture," *IEEE Trans. On Antennas and Propagation,* vol. AP–34, No. 5, May 1986, pp. 646–657.

Hafdallah, H. et al., "2–4 Ghz MESFET Sampler," *Electronics Letters,* vol. 24, No. 3, Feb. 4, 1988, pp. 151–153.

Herben, M.H.A.J., "Amplitude and Phase Scintillation Measurements on 8–2 km Line–Of–Sight Path at 30 Ghz," *Electronics Letters,* vol. 18, No. 7, Apr. 1, 1982, pp. 287–289.

Hewitt, A. et al., "An 18 Ghz Wideband LOS Multipath Experiment," Int'l Conf. On Measurements for Telecommunication Transmission System—MITS 85, Nov. 27–28, 1985, pp. 112–116.

Hewitt, A. et al., "An Autoregressive Approach to the Identification of Multipath Ray Parameters from Field Measurements," *IEEE Trans. On Communications,* vol. 37, No. 11, Nov. 1989, pp. 1136–1143.

Hewitt, A. and Vilar, E., "Selective fading on LOS Microwave Links: Classical and Spread–Spectrum Measurement Techniques," *IEEE Trans. On Communications,* vol. 36, No. 7, Jul. 1988, pp. 789–796.

Hospitalier, E., "Instruments for Recording and Observing Rapidly Varying Phenomena," *Science Abstracts,* vol. VII, 1904, pp. 22–23.

Howard, I.M. and Swansson, N.S., "Demodulating High Frequency Resonance Signals for Bearing Fault Detection," The Institution of Engineers Australia Communications Conference, Melbourne Sep. 18–20, 1990, pp. 115–121.

Hu, X., A Switched–Current Sample–and–Hold Amplifier for FM Demodulation, Thesis for Master of Applied Science, Dept. of Electrical and Computer Engineering, University of Toronto, 1995, pp. 1–64.

Hung, H–L. A. et al., "Characterization of Microwave Integrated Circuits Using An Optical Phase–Locking and Sampling System," *IEEE MIT–S Digest,* 1991, pp. 507–510.

Hurst, P.J., "Shifting the Frequency Response of Switched–Capacitor Filters by Nonuniform Sampling," *IEEE Transactions on Circuits and Systems,* vol. 38, No. 1, Jan. 1991, pp. 12–19.

Itakura, T., "Effects of the sampling pulse width on the frequency characteristics of a sample–and–hold circuit," IEEE Proc. Circuits, Devices and Systems, vol. 141, No. 4, Aug. 1994, pp. 328–336.

Janssen, J.M.L., "An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: I. Fundamentals," *Philips Technical Review,* vol. 12, No. 2, Aug. 1950, pp. 52–59.

Janssen, J.M.L. and Michels, A.J., "An Experimental 'Stroboscopic' Oscilloscope for Frequencies up to about 50 Mc/s: II. Electrical Build–Up," *Philips Technical Review,* vol. 12, No. 3, Sep. 1950, pp. 73–82.

Jondral, V.F. et al., "Doppler Profiles for Communication Satellites," *Frequenz,* May–Jun. 1996, pp. 111–116.

Kaleh, G.K., "A Frequency Diversity Spread Spectrum System for Communication in the Presence of In–band Interference," *1995 IEEE Globecom,* pp. 66–70.

Karasawa, Y. et al., "A New Prediction Method for Tropospheric Scintillation on Earth–Space Paths," *IEEE Trans. On Antennas and Propagation,* vol. 36, No. 11, Nov. 1988, pp. 1608–1614.

Kirsten, J. and Fleming, J., "Undersampling reduces data–acquistion costs for select applicatiions," *EDN,* Jun. 21, 1990, pp. 217–222, 224, 226–228.

Lam, W.K. et al., "Measurement of the Phase Noise Characteristics of an Unlocked Communications Channel Identifier," Proc. Of the 1993 IEEE International Frequency Control Symposium, Jun. 2–4, 1993, pp. 283–288.

Lam, W.K. et al., "Wideband sounding of 11.6 Ghz transhorizon channel," *Electronics Letters,* vol. 30, No. 9, Apr. 28, 1994, pp. 738–739.

Larkin, K.G., "Efficient demodulator for bandpass sampled AM signals," *Electronics Letters,* vol. 32, No. 2, Jan. 18, 1996, pp. 101–102.

Lau, W.H. et al., "Analysis of the Time Variant Structure of Microwave Line–of–sight Multipath Phenomena," IEEE Telecommunicatiions Conference & Exhibition, Nov. 28–Dec. 1, 1988, pp. 1707–1711.

Lau, W.H. et al., "Improved Prony Algorithm to Identify Multipath Components," *Electronics Letters,* vol. 23, No. 20, Sep. 24, 1987, pp. 1059–1060.

Lesage, P. and Audoin, C., "Effect of Dead–Time on the Estimation of the Two–Sample Variance," *IEEE trans. On Instrumentation and Measurement,* vol. IM–28, No. 1, Mar. 1979, pp. 6–10.

Liechti, C.A., "Performance of Dual–gate GaAs MESFET's as Gain–Controlled Low–Noise Amplifiers and High–Speed Modulators," *IEEE Trans. On Microwave Theory and Techniques,* vol. MTT–23, No. 6, Jun. 1975, pp. 461–469.

Linnenbrink, T.E. et al., "A One Gigasample Per Second Transient Recorder," *IEEE trans. On Nuclear Science,* vol. NS–26, No. 4, Aug. 1979, pp. 4443–4449.

Liou, M.L., "A Tutorial on Computer–Aided Analysis of Switched–Capacitor Circuits," Proceedings of the IEEE, vol. 71, No. 8, Aug. 1983, pp. 987–1005.

Lo, P. et al., "Coherent Automatic Gain Control," *IEE Colloquium on Phase Locked Techniques,* Mar. 26, 1980, pp. 2/1–2/6.

Lo, P. et al., "Computation of Rain Induced Scintillations on Satellite Down–Links at Microwave Frequencies," Third Int'l Conf. On Antennas and Propagation (ICAP 83) Part 2: Propagation, Apr. 12–15, 1983, pp. 127–131.

Lo, P.S.L.O. et al., "Observations of Amplitude Scintillations on a Low–Elevation Earth–Space Path," *Electronics Letters,* vol. 20, No. 7, Mar. 29, 1984, pp. 307–308.

Madani, K. and Aithison, C.S., "A 20 Ghz Microwave Sampler," *IEEE Trans. On Microwave Theory and Techniques,* vol. 40, No. 10, Oct. 1992, pp. 1960–1963.

Marsland, R.A. et al., "130 Ghz GaAs monolithic integrated circuit sampling head," *Appl. Phys. Lett.,* vol. 55, No. 6, Aug. 7, 1989, pp. 592–594.

Martin, K. and Sedra, A.S., "Switched–Capacitor Building Blocks for Adaptive Systems," *IEEE Transactions on Circuits and Systems,* vol. CAS–28, No. 6, Jun. 1981, pp. 576–584.

Marzano, F.S. and d'Auria, G., "Model–based Prediction of Amplitude Scintillation variance due to Clear–Air Tropospheric Turbulence on Earth–Satellite Microwave Links," *IEEE Trans. On Antennas and Propagation,* vol. 46, No. 10, Oct. 1998, pp. 1506–1518.

Matricciani, E., "Prediction of fade durations due to rain in satellite communication systems," *Radio Science,* vol. 32, No. 3, May–Jun. 1997, pp. 935–941.

McQueen, J.G., "The Monitoring of High–Speed Waveforms," *Electronic Engineering,* Oct. 1952, pp. 436–441.

Merkelo, J. and Hall, R.D., "Broad–Band Thin–Film Signal Sampler," *IEEE Journal of Solid–State Circuits,* vol. SC–7, No. 1, Feb. 1972, pp. 50–54.

Merlo, U. et al., "Amplitude Scintillation Cycles in a Sirio Satellite–Earth Link," *Electronics Letters,* vol. 21, No. 23, Nov. 7, 1985, pp. 1094–1096.

Morris, D., "Radio–holographic reflector measurement of the 30–m millimeter radio telescope at 22 Ghz with a cosmic signal source," *Astronomy and Astrophysics,* vol. 203, No. 2, Sep. (II) 1988, pp. 399–406.

Moulsley, T.J. et al., "The efficient acquisition and processing of propagation statistics," *Journal of the Institution of Electronic and Radio Engineers,* vol. 55, No. 3, Mar. 1985, pp. 97–103.

Ndzi, D. et al., "Wide–Band Statistical Characterization of an Over–the–Sea Experimental Transhorizon Link," *IEE Colloquium on Radio Communications at Microwave and Millimetre Wave Frequencies,* Dec. 16, 1996, pp. 1/1–1/6.

Ndzi, D. et al., "Wideband Statistics of Signal Levels and Doppler Spread on an Over–The–Sea Transhorizon Link," *IEE Colloquium on Propagation Characteristics and Related System Techniques for Beyond Line–of–Sight Radio,* Nov. 24, 1997, pp. 9/1–9/6.

"New zero If chipset from Philips," *Electronic Engineering,* Sep. 1995, p. 10.

Ohara, H. et al., "First monolithic PCM filter cuts cost of telecomm systems," *Electronic Design,* vol. 27, No. 8, Apr. 12, 1979, (6 pages).

Oppenheim, A.V. et al., Signals and Systems, Prentice–Hall, 1983, pp. 527–531 and 561–562.

Ortgies, G., "Experimental Parameters Affecting Amplitude Scintillation Measurements on Satellite Links," *Electronics Letters,* vol. 21, No. 17, Aug. 15, 1985, pp. 771–772.

Pärssinen et al., "A 2–GHz Subharmoinc Sampler for Signal Downcoversion," *IEEE Trans. on Microwave Theory and Techniques,* vol. 45, No. 12, Dec. 1997, (7 pages).

Peetersl, G. et al., "Evaluation of Statistical Models for Clear–Air Scintillation Prediction Using Olympus Satellite Measurements," *International Journal if Satellite Communications,* vol. 15, No. 2, Mar.–Apr. 1997, pp. 73–88.

Perrey, A.G. and Schoenwetter, H.K., *NBS Technical Note 1121: A Schottky Diode Bridge Sampling Gate,* May 1980, pp. 1–14.

Poulton, K. et al., "A 1–Ghz 6–bit ADC System," *IEEE Journal of Solid–State Circuits,* vol. SC–22, No. 6, Dec. 1987, pp. 962–969.

Press Release, "Parkervision, Inc. Announces Fiscal 1993 Results," 2 pages, Apr. 6, 1994.

Press Release, "Parkervision, Inc. Announces the Appointment of Michael Baker to the New Position of National Sales Manager," 1 page, Apr. 7, 1994.

Press Release, "Parkervision's Cameraman Well–Received By Distance Learning Market," 2 pages, Apr. 8, 1994.

Press Release, "Parkervision, Inc. Announces Firest Quarter Financial Results," 2 pages, Apr. 26, 1994.

Press Release, "Parkervision, Inc. Announces The Retirement of William H. Fletcher, Chief Financial Officer," 1 page, May 11, 1994.

Press Release, "Parkervision, Inc. Announces New Cameraman System 11™At Infocomm Trade Show," 3 pages, Jun. 9, 1994.

Press Release, "Parkervision, Inc. Announces Appointments to its National Sales Force," 2 pages, Jun. 17, 1994.

Press Release, "Parkervision, Inc. Announces Second Quarter and Six Months Financial Results," 3 pages, Aug. 9, 1994.

Press Release, "Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results," 3 pages, Oct. 28, 1994.

Press Release, "Parkervision, Inc. Announces First Significant Dealer Sale of Its *Cameraman*®System II," 2 pages, Nov. 7, 1994.

Press Release, "Parkervision, Inc. Announces Fourth Quarter and Year End Results," 2 pages, Mar. 1, 1995.

Press Release, "Parkervision, Inc. Announces Joint Product Developments With VTEL," 2 pages Mar. 21, 1995.

Press Release, "Parkervision, Inc. Announces First Quarter Financial Results," 3 pages, Apr. 28, 1995.

Press Release, “Parkervision Wins Top 100 Product Districts’ Choice Award,” 1 page, Jun. 29, 1995.

Press Release, “Parkervision National Sales Manager Next President of USDLA,” 1 page, Jul. 6, 1995.

Press Release, “Parkervision Granted New Patent,” 1 page, Jul. 21, 1995.

Press Release, “Parkervision, Inc. Announces Second Quarter and Six Months Financial Results,” 2 pages, Jul. 31, 1995.

Press Release, “Parkervision, Inc. Expands Its Cameraman System II Product Line,” 2 pages, Sep. 22, 1995.

Press Release, “Parkervision Announces New Camera Control Technology,” 2 pages, Oct. 25, 1995.

Press Release, “Parkervision, Inc. Announces Completion of VTEL/Parkervision Joint Product Line,” 2 pages, Oct. 30, 1995.

Press Release, “Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results,” 2 pages, Oct. 30, 1995.

Press Release, “Parkervision’s Cameraman Personal Locator Camera System Wins Telecon XV Award,” 2 pages, Nov. 1, 1995.

Press Release, “Parkervision, Inc. Announces Purchase Commitment From VTEL Corporation,” 1 page, Feb. 26, 1996.

Press Release, “ParkerVision, Inc. Announces Fourth Quarter and Year End Results,” 2 pages, Feb. 27, 1996.

Press Release, “ParkerVision, Inc. Expands Its Product Line,” 2 pages, Mar. 7, 1996.

Press Release, “ParkerVision Files Patents for its Research of Wireless Technology,” 1 page, Mar. 28, 1996.

Press Release, “Parkervision, Inc. Announces First Significant Sale of Its Cameraman® Three–Chip System” 2 pages, Apr. 12, 1996.

Press Release, “Parkervision, Inc. Introduces New Product Line For Studio Production Market,” 2 pages, Apr. 15, 1996.

Press Release, “Parkervision, Inc. Announces Private Placement of 800,000 Shares,” 1 page, Apr. 15, 1996.

Press Release, “Parkervision, Inc. Announces First Quarter Financial Results,” 3 pages, Apr. 30, 1996.

Press Release, “ParkerVision’s New Studio Product Wins Award,” 2 pages, Jun. 5, 1996.

Press Release, “Parkervision, Inc. Announces Second Quarter and Six Months Financial Results,” 3 pages, Aug. 1, 1996.

Press Release, “Parkervision, Inc. Announces Third Quarter and Nine Months Financial Results,” 2 pages, Oct. 29, 1996.

Press Release, “PictureTel and ParkerVision Sign Reseller Agreement,” 2 pages, Oct. 30, 1996.

Press Release, “CLI and ParkerVision Bring Enhanced Ease–of–Use to Videoconferencing,” 2 pages, Jan. 30, 1997.

Press Release, “Parkervision, Inc. Announces Fourth Quarter and Year End Results,” 3 pages, Feb. 27, 1997.

Press Release, “Parkervision, Inc. Announces First Quarter Financial Results,” 3 pages, Apr. 29, 1997.

Press Release, “NEC and Parkervision Make Distance Learning Closer,” 2 pages, Jun. 18, 1997.

Press Release, “Parkervision Supplies JPL with Robotic Cameras, Cameraman Shot Director for Mars Mission,” 2 pages, Jul. 8, 1997.

Press Release, “ParkerVision and IBM Join Forces to Create Wireless Computer Peripheral,” 2 pages, Jul. 23, 1997.

Press Release, “ParkerVision, Inc. Announces Second Quarter and Six Months Financial Results,” 3 pages, Jul. 31, 1997.

Press Release, “Parkervision, Inc. Announces Private Placement of 990,000 Shares,” 2 pages, Sep. 8, 1997.

Press Release, “Wal–Mart Chooses Parkervision for Broadcast Production,” 2 pages, Oct. 24, 1997.

Press Release, “Parkervision, Inc. Announces Third Quarter Financial Results,” 3 pages, Oct. 30, 1997.

Press Release, “ParkerVision Announces Breakthrough in Wireless Radio Frequency Technology,” 3 pages, Dec. 10, 1997.

Press Release, “Parkervision, Inc. Announces The Appointment of Joseph F. Skovron to the Position of Vice President, Licensing—Wireless Technologies,” 2 pages, Jan. 8, 1998.

Press Release, “Parkervision Announces Existing Agreement with IBM Terminates—Company Continues with Strategic Focus Announced in December,” 2 pages, Jan. 27, 1998.

Press Release, “Laboratory Tests Verify Parkervision Wireless Technology,” 2 pages, Mar. 3, 1998.

Press Release, “Parkervision, Inc. Announces Fourth Quarter and Year End Financial Results,” 3 pages, Mar. 5, 1998.

Press Release, “Parkervision Awarded Editors’ Pick of Show for NAB 98,” 2 pages, Apr. 15, 1998.

Press Release, “Parkervision Announces First Quarter Financial Results,” 3 pages, May 4, 1998.

Press Release, “Parkervision ‘Direct2Data’ Introduced in Response to Market Demand,” 3 pages, Jul. 9, 1998.

Press Release, “Parkervision Expands Senior Mangement Team,” 2 pages, Jul. 29, 1998.

Press Release, “Parkervision Announces Second Quarter and Six Month Financial Results,” 4 pages, Jul. 30, 1998.

Press Release, “Parkervision Announces Third Quarter and Nine Month Financial Results,” 3 pages, Oct. 30, 1998.

Press Release, “Questar Infocomm, Inc. Invests $5 Million in Parkervision Common Stock,” 3 pages, Dec. 2, 1998.

Press Release, “Parkervision Adds Two New Directors,” 2 pages, Mar. 5, 1999.

Press Release, “Parkervision Announces Fourth Quarter and Year End Financial Results,” 3 pages, Mar. 5, 1999.

Press Release, “Joint Marketing Agreement Offers New Automated Production Solution,” 2 pages, Apr. 13, 1999.

“Project COST 205: Scintillations in Earth–satellite Links,” *Alta Frequenza: Scientific Review in Electronics,* vol. LIV, No. 3, May–Jun., 1985, pp. 209–211.

Razavi, B., RF Microelectronics, Prentice–Hall, 1998, pp. 147–149.

Reeves, R.J.D., “The Recording and Collocation of Waveforms (Part 1),” *Electronic Engineering,* Mar. 1959, pp. 130–137.

Reeves, R.J.D., “The Recording and Collocation of Waveforms (Part 2),” *Electronic Engineering,* Apr. 1959, pp. 204–212.

Rein, H.M. and Zahn, M., “Subnanosecond–Pulse Generator with Variable Pulsewidth Using Avalanche Transistors,” vol. 11, No. 1, Jan. 9, 1975, pp. 21–23.

Riad, S.M. and Nahman, N.S., “Modeling of the Feed–through Wideband (DC to 12.4 Ghz) Sampling–Head,” *IEEE MTT–S International Microwave Symposium Digest,* Jun. 27–29, 1978, pp. 267–269.

Rizzoli, V. et al., “Computer–Aided Noise Analysis of MESFET and HEMT Mixers,” *IEEE Trans. On Microwave Theory and Techniques,* vol. 37, No. 9, Sep. 1989, pp. 1401–1410.

Rowe, H.E., Signals and Noise in Communication Systems, D. Van Nostrand Company, Inc., Princeton, New Jersey, 1965, including, for example, Chapter V, Pulse Modulation Systems.

Rücker, F. and Dintelmann, F., "Effect of Antenna Size on OTS Signal Scintillations and Their Seasonal Dependence," *Electronics Letters,* vol. 19, No. 24, Nov. 24, 1983, pp. 1032–1034.

Russell, R. and Hoare, L., "Millimeter Wave Phase Locked Oscillators," *Military Microwave '78 Conference Proceedings,* Oct. 25–27, 1978, pp. 238–242.

Sabel, L.P., "A DSP Implementation of a Robust Flexible Receiver/Deumultiplexer for Broadcast Data Satellite Communications," The Institution of Engineers Austalia Communications Conference, Melbourne Oct. 16–18, 1990, pp. 218–223.

Salous, S., "IF digital generation of FMCW waveforms for wideband channel characterization," IEE Proceedings–I, vol. 139, No. 3, Jun. 1992, pp. 281–288.

"Sampling Loops Lock Sources to 23 Ghz," *Microwaves & RF,* Sep. 1990, p. 212.

Sasikumar, M. et al., "Active Compensation in the Switched–Capacitor Biquad," Proceedings of the IEEE, vol. 71, No. 8, Aug. 1983, pp. 1008–1009.

Saul, P.H., "A GaAs MESFET Sample and Hold Switch," 5th European Solid State Circuits Conference–ESSCIRC 79, 1979, pp. 5–7.

Shen, D.H. et al., "A 900–MHZ RF Front–End with Integrated Discrete–Time Filtering," *IEEE Journal of Solid–State Circuits,* vol. 31, No. 12, Dec. 1996, pp. 1945–1954.

Shen, X.D. and Vilar, E., "Anomalous transhorizon propagation and meteorological processes of a multilink path," *Radio Science,* vol. 30, No. 5, Sep.–Oct. 1995, pp. 1467–1479.

Shen, X. and Tawfik, A.N., "Dynamic Behaviour of Radio Channels Due to Trans–Horizon Propagation Mechanisms," *Electronics Letters,* vol. 29, No. 17, Aug. 19, 1993, pp. 1582–1583.

Shen, X. et al., "Modeling Enhanced Spherical Diffraction and Troposcattering on a Transhorizon Path with aid of the parabolic Equation and Ray Tracing Methods," *IEE Colloquium on Common modeling techniques for electromagnetic wave and acoustic wave propagation,* Mar. 8, 1996, pp. 4/1–4/7.

Shen, X. and Vilar, E., "Path Loss statistics and mechanisms of transhorizon propagation over a sea path," *Electronics Letters,* vol. 32, No. 3, Feb. 1, 1996, pp. 259–261.

Shen, D. et al., "A 900 MHZ Integrated Discrete–Time Filtering RF Front–End," IEEE International Solid State Circuits Conference, vol. 39, Feb. 1996, pp. 54–55 and 417.

Spillard, C. et al., "X–Band Tropospheric Transhorizon Propagation Under Differing Meterological Conditions," *Antennas and Propagation* (*ICAP 89*) *Part 2: Propagation,* Apr. 4–7, 1989, pp. 451–455.

Stafford, K.R. et al., "A Complete Monolithic Sample/Hold Amplifier," *IEEE Journal of Solid–State Circuits,* vol. SC–9, No. 6, Dec. 1974, pp. 381–387.

Staruk, W. Jr. et al., "Pushing HF Data Rates," *Defense Electronics,* May 1985, pp. 211, 213, 215, 217, 220 &222.

Stephenson, A.G., "Digitizing multiple RF signals requires an optimum sampling rate," *Electronics,* Mar. 27, 1972, pp. 106–110.

Sugarman, R., "Sampling Oscilloscope for Statistically Varying Pulses," *The Review of Scientific Instruments,* vol. 28, No. 11, Nov. 1957, pp. 933–938.

Sylvain, M., "Experimental probing of Multipath microwave channels," *Radio Science,* vol. 24, No. 2, Mar.–Apr. 1989, pp. 160–178.

Takano, T., "Novel GaAs Pet Phase Detector Operable To Ka Band," *IEEE MT–S Digest,* 1984, pp. 381–383.

Tan, M.A., "Biquadratic Transconductance Switched–Capacitor Filters," *IEEE Transactions on Circuits and Systems–I: Fundamental Theory and Applications,*vol. 40, No. 4, Apr. 1993, pp. 272–275.

Tanaka, K. et al., "Single Chip Multisystem AM Stereo Decoder IC," *IEEE Trans. On Consumer Electronics,* vol. CE–32, No. 3, Aug. 1986, pp. 482–496.

Tawfik, A.N., "Amplitude, Duration and Predictability of Long Hop Trans–Horizon X–band Signals Over the Sea," *Electronics Letters,* vol. 28, No. 6, Mar. 12, 1992, pp. 571–572.

Tawfik, A.N. and Vilar, E., "Correlation of Transhorizon Signal Level Strength with Localized Surface Meteorological Parameters," 8th International Conf. On Antennas and Propagation, Mar. 30, Apr. 2, 1993, pp. 335–339.

Tawfik, A.N. and Vilar, E., "Dynamic Structure of a Transhorizon Signal at X–band Over a Sea Path," *Antennas and Propagation* (*ICAP 89*) *Part 2: Propagation,* Apr. 4–7, 1989, pp. 446–450.

Tawfik, A.N. and Vilar, E., "Statistics of Duration and Intensity of Path Loss in a Microwave Transhorizon Sea–Path," *Electronics Letters,* vol. 26, No. 7, Mar. 29, 1990, pp. 474–476.

Tawfik, A.N. and Vilar, E., "X–Band Transhorizon Measurements of CW Transmissions Over the Sea–Part 1: Path Loss, Duration of Events, and Their Modeling," *IEEE Trans. On Antennas and Propagation,* vol. 41, No. 11, Nov. 1993, pp. 1491–1500.

Temes, G.C. and Tsividis, T., "The Special Section on Switched–Capacitor Circuits," Proceedings of the IEEE, vol. 71, No. 8, Aug. 1983, pp. 915–916.

Thomas, G.B., Calculus and Analytic Geometry, Third Edition, Addison–Wesley Publishing, 1960, pp. 119–133.

Tomassetti, Q., "An Unusual Microwave Mixer," 16th European Microwave Conference, Sept. 8–12, 1986, pp. 754–759.

Tortoli, P. et al., "Bidirectional Doppler Signal Analysis Based on a Single RF Sampling Channel," *IEEE Trans. On Ultrasonics, Ferroelectrics, and Frequency Control,* vol. 41, No. 1, Jan. 1984, pp. 1–3.

Tsividis, Y. and Antognetti, P. (Ed.), *Design of MOS VLSI Circuits for Telecommunications,* p. 304.

Tsividis, Y., "Principles of Operation and Analysis of Switched–Capacitor Circuits," Proceedings of the IEEE, vol. 71, No. 8, Aug. 1983, pp. 926–940.

Tsurumi, H. and Maeda, T., "Design Study on a Direct Conversion Receiver Front–End for 280 MHZ, 900 MHZ, and 2.6 Ghz Band Radio Communication Systems," 41st IEEE Vehicular Technology Conference, May 19–22, 1991, pp. 457–462.

Valdamanis, J.A. et al., "Picosecond and Subpicosend Optoelectronics for Measurements of Future High Speed Electronic Devices," *IEDM Technical Digest,* Dec. 5–7, 1983, pp. 597–600.

van de Kamp, M.M.J.L., "Asymmetric signal Level distribution due to tropospheric scintillation," *Electronics Letters,* vol. 34, No. 11, May 28, 1998, pp. 1145–1146.

Vasseur, H. and Vanhoenacker, D., "Characterization of tropospheric turbulent Layers from radiosonde data," *Electronics Letters,* vol. 34, No. 4, Feb. 19, 1998, pp. 318–319.

Verdone, R., "Outage Probability Analysis for Short–Range Communication Systems at 60 Ghz in ATT Urban Environments," *IEEE Trans. On Vehicular Technology,* vol. 46, No. 4, Nov. 1997, pp. 1027–1039.

Vierira–Ribeiro, S.A., Single–IF DECT Receiver Architecture using a Quadrature Sub–Sampling Band–Pass Sigma–Delta Modulator, Thesis for Degree of Master's of Engineering, Carleton University, Apr. 1995, pp. 1–180.

Vilar, E. et al., "A Comprehensive/Selective MW–Wave Satellite Downlink Experiment on Fade Dynamics," 10th International Conf. On Antennas and Propagation, Apr. 14–17, 1997, pp. 2.98–2.101.

Vilar, E. et al., "A System to Measure LOS Atmospheric Transmittance at 19 Ghz," Agard Conf. Proc. No. 346: Characteristics of the Lower Atmosphere Influencing Radio Wave Propagation, Oct. 4–7, 1983, pp. 8–1–8–16.

Vilar, E. and Smith, H., "A Theoretical and Experimental Study of Angular Scintillations in Earth Space Paths," *IEEE Trans. On Antennas and Propagation,* vol. AP–34, No. 1, Jan. 1986, pp. 2–10.

Vilar, E. et al., "A Wide Band Transhorizon Experiment at 11.6 Ghz," 8th International Conf. On Antennas and Propagation, Mar. 30–Apr. 2, 1993, pp. 441–445.

Vilar, E. and Matthews, P.A., "Amplitude Dependence of Frequency in Oscillators," *Electronics Letters,* vol. 8, No. 20, Oct. 5, 1972, pp. 509–511.

Vilar, E. et al., "An experimental mm–wave receiver system for measuring phase noise due to atmospheric turbulence," Conf. Proc. 25th Europan Microwave Conference, 1995, pp. 114–119.

Vilar, E. and Burgueño, A., "Analysis and Modeling of Time Intervals Between Rain Rate Exceedances in the Contex of Fade Dyamics," *IEEE Trans. On Communications,* vol. 39, No. 9, Sep. 1991, pp. 1306–1312.

Vilar, E. et al., "Angle of Arrival Fluctuations in High and Low Elevation Earth Space Paths," *Antennas and Propagation* (*ICAP 85*), Apr. 16–19, 1985, pp. 83–88.

Vilar, E., "Antennas and Propagation: A Telecommunications Systems Subject," *Electronics Division Colloquium on Teaching Antennas and Propagation to Undergraduates,* Mar. 8, 1988, (6 pages).

Vilar, E. et al., "CERS*. Millimetre–Wave Beacon Package and Related Payload Doppler Correction Strategies," *Electronics Division Colloquium on CERS—Communications Engineering Research Satellite,* Apr. 10, 1984, pp. 10/1–10/10.

Vilar, E. and Moulsley, T.J., "Comment and Reply: Probability Density Function of Amplitude Scintillations," *Electronics Letters,* vol. 21, No. 14, Jul. 4, 1985, pp. 620–622.

Vilar, E. et al., "Comparison of Rainfall Rate Duration Distributions for ILE–IFE and Barcelona," *Electronics Letters,* vol. 28, No. 20, Sep. 24, 1992, pp. 1922–1924.

Vilar, E., "Depolarization and Field Transmittances in Indoor Communications," *Electronics Letters,* vol. 27, No. 9, Apr. 25, 1991, pp. 732–733.

Vilar, E. and Larsen, J. R., "Elevation Dependence of Amplitude Scintillations on Low Elevation Earth Space Paths," *Antennas and Propagation* (*ICAP 89*) *Part 2: Propagation,* apr. 4–7, 1989, pp. 150–154.

Vilar, E. et al., "Experimental System and Measurements of Transhorizon Signal Levels at 11 Ghz," 18th European Microwave Conference, Sep. 12–15, 1988, pp. 429–435.

Vilar, E. and Matthews, P.A., "Importance of Amplitude Scintillations in Millimetric Radio Links," Conf. Proc. 4th European Microwave Conference, Sep. 10–13, 1974, pp. 202–206.

Vilar, E. and Haddon, J., "Measurement and Modeling of Scintillation Intensity to Estimate Turbulence Parameters in an Earth–Space Path," *IEEE Trans. On Antennas and Propagation,* vol. AP–32, No. 4, Apr. 1984, pp. 340–346.

Vilar, E. and Matthews, P.A., "Measurement of Phase Fluctuations in Millimetric Radiowave Propagation," *Electronics Letters,* vol. 7, No. 18, Sep. 9, 1971, pp. 566–568.

Vilar, E. and Wan, K.W., "Narrow and Wide Band Estimates of Field Strength for Indoor Communications in the Millimetre Band," *Electronics Division Colloquium on Radiocommunications in the Range 30–60 Ghz,* Jan. 17, 1991, pp. 5/1–5/8.

Vilar, E. and Faulkner, N.D., "Phase Noise and Frequency Stability Measurements. Numerical Techniques and Limitations," *Electronics Division Colloquium on Low Noise Oscillators and Synthesizer,* Jan. 23, 1986, (5 pages).

Vilar, E. and Senin, S., "Propagation phase noise identified using 40 Ghz satellite downlink," *Electronics Letters,* vol. 33, No. 22, Oct. 23, 1997, pp. 1901–1902.

Vilar, E. et al., "Scattering and Extinction: Dependence Upon Raindrop Size Distribution in Temperate (Barcelona) and Tropical (Belem) Regions," 10th Internaltional Conf. On Antennas and Propagation, Apr. 14–17, 1997, pp. 2.230–2.233.

Vilar, E. and Haddon, J., "Scintillation Modeling and Measurement—A Tool for Remote–Sensing Slant Paths," Agard Conf. Proc. No. 332: Propagation Aspects of Frequency Sharing. Interference And System Diversity, Oct. 18–22, 1982, pp. 27–1–27–13.

Vilar, E., "Some Limitations on Digital Transmission Through Turbulent Atmosphere," Int'l Conf. On Satellite Communication Systems Technology, Apr. 7–10, 1975, pp. 169–187.

Vilar, E. and Matthews, P.A., "Summary of Scintillation Observations in a 36 Ghz Link Across London," Int'l Conf. On Antennas and Propagation Part 2: Propagation, Nov. 28–30, 1978, pp. 36–40.

Vilar, E. et al., "Wideband Characterization of Scattering Channels," 10th International Conf. On Antennas and Propagation, Apr. 14–17, 1997, pp. 2.353–3.358.

Vollmer, A., "Complete GPS Receiver Fits on Two Chips," *Electronic Design,* Jul. 6, 1998, pp. 50, 52, 54, 56.

Voltage and Time Resolution in Digitizing Oscilloscopes: Application Note 348, Hewlett Packard, Nov. 1986, pp. 1–11.

Wan, K.W. et al., "A Novel Approach to the Simultaneous Measurement of Phase and Amplitude Noises in Oscillator," 19th European Microwave Conference Proceedings, Sep. 4–7, 1989, pp. 809–813.

Wan, K.W. et al., "Extended Variances and Autoregressive/Moving Average Algorithm for the Measurement and Synthesis of Oscillator Phase Noise," Proc. Of the 43rd Annual Symposium on Frequency Control. 1989, pp. 331–335.

Wan, K.W. et al., "Wideband Transhorizon Channel Sounder at 11 Ghz," *Electronics Division Colloquium on High Bit Rate UHF/SHF Channel Sounders—Technology and Measurement,* Dec. 3, 1993, pp. 3/1–3/5.

Wang, H., "A 1–V Multigigahertz RF Mixer Core in 0.5—μm CMOS," IEEE 1998, 3 pages.

Watson, A.W.D. et al., "Digital Conversion and Signal Processing for High Performance Communications Receivers," pp. 367–373.

Weast, R.C. et al. (Ed.), *Handbook of Mathematical Tables,* Second Edition, The Chemical Rubber Co., 1964, pp. 480–485.

Wiley, R.G., "Approximate FM Demodulation Using Zero Crossings,"*IEEE Trans. On Communications,* vol. COM–29, No. 7, Jul. 1981, pp. 1061–1065.

Worthman, W., "Convergence . . . Again," *RF Design,* Mar. 1999, p. 102.

Young, I.A. and Hodges, D.A., "MOS Switched–Capacitor Analog Sampled–Data Direct–Form Recursive Filters," *IEEE Journal of Solid–State Circuits,* vol. SC–14, No. 6, Dec. 1979, pp. 1020–1033.

FIG. 1

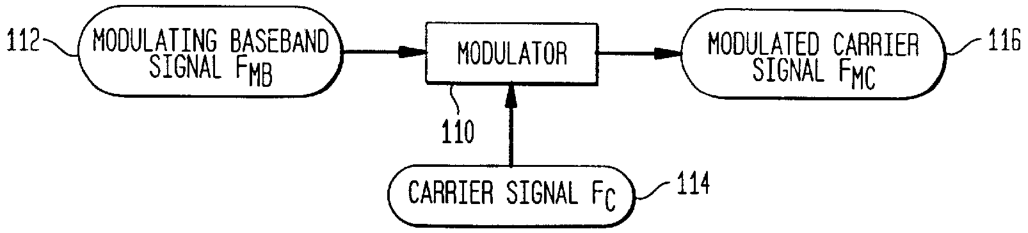


FIG. 2

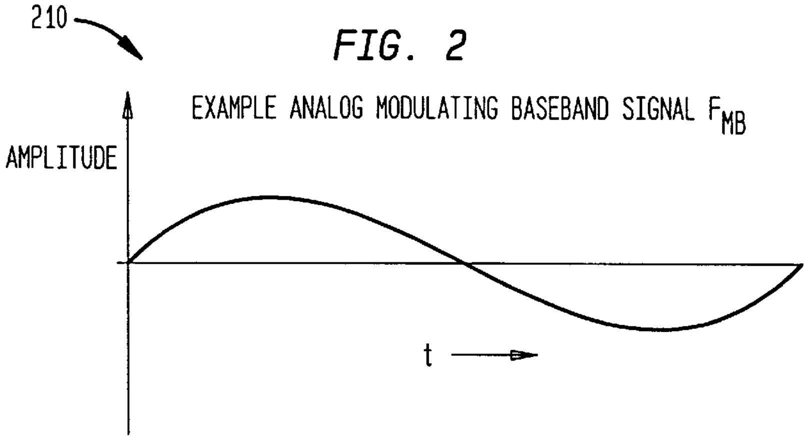


FIG. 3

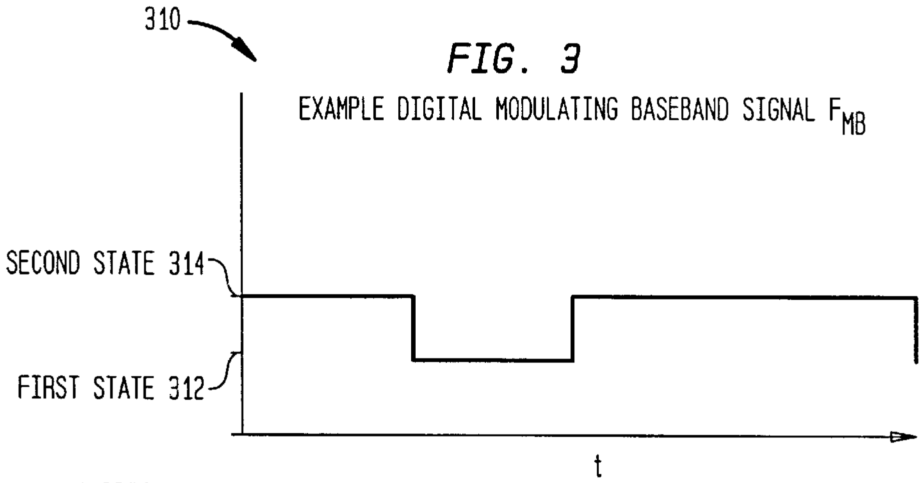


FIG. 4

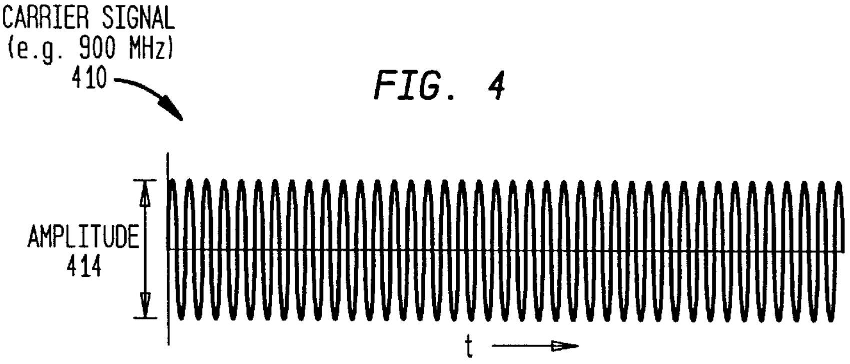


FIG. 5A

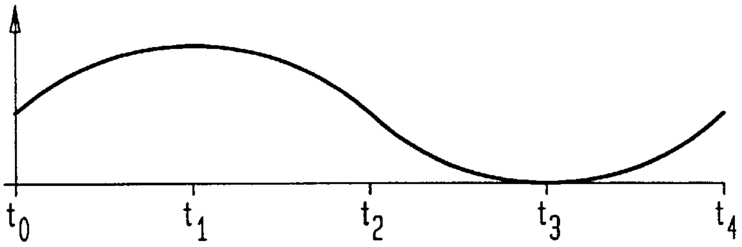


FIG. 5B

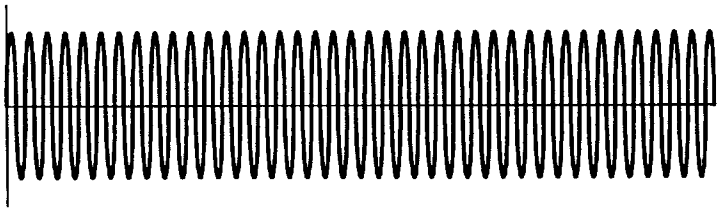


FIG. 5C

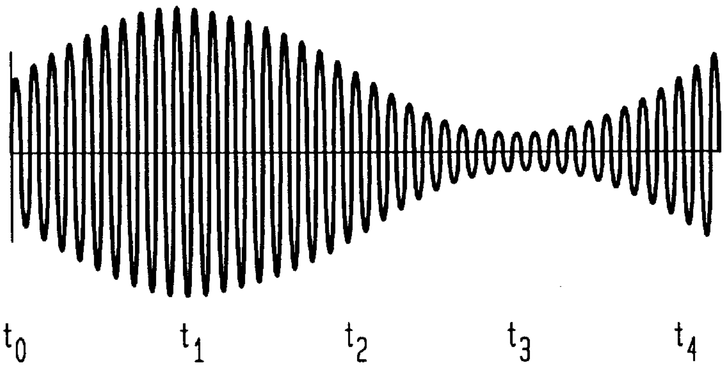


FIG. 6A

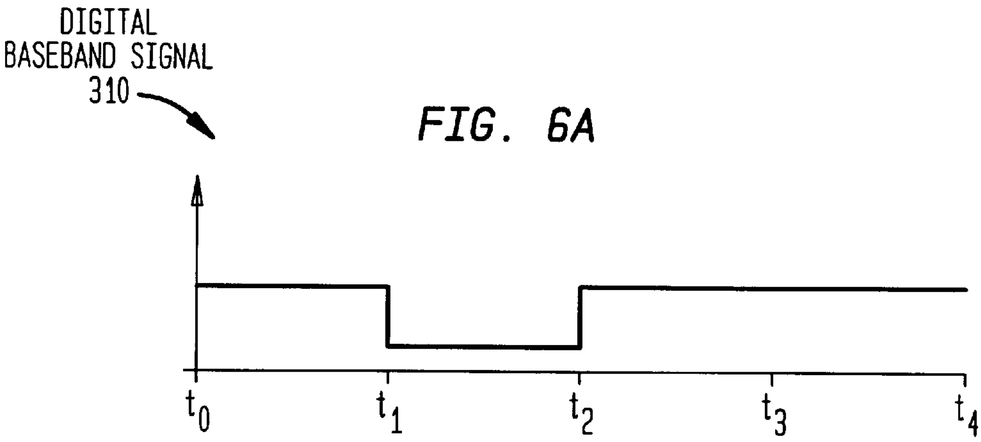


FIG. 6B

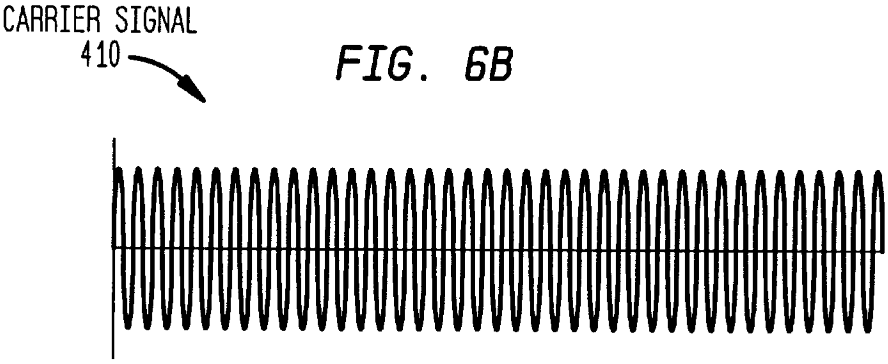


FIG. 6C

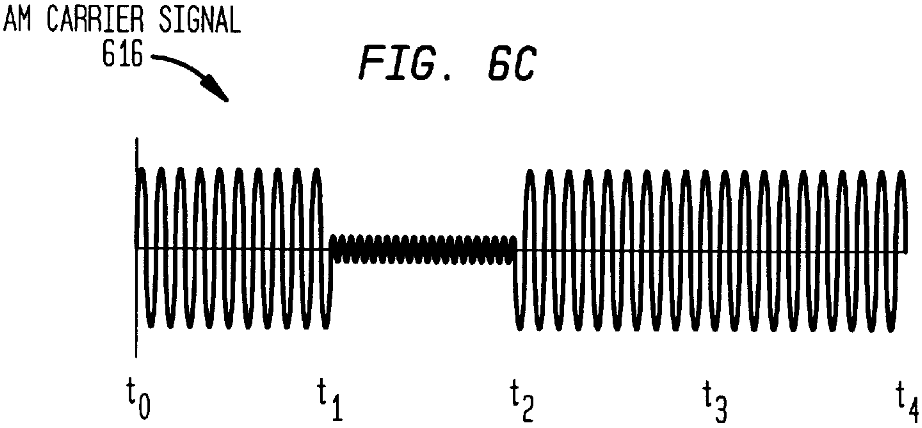


FIG. 7A

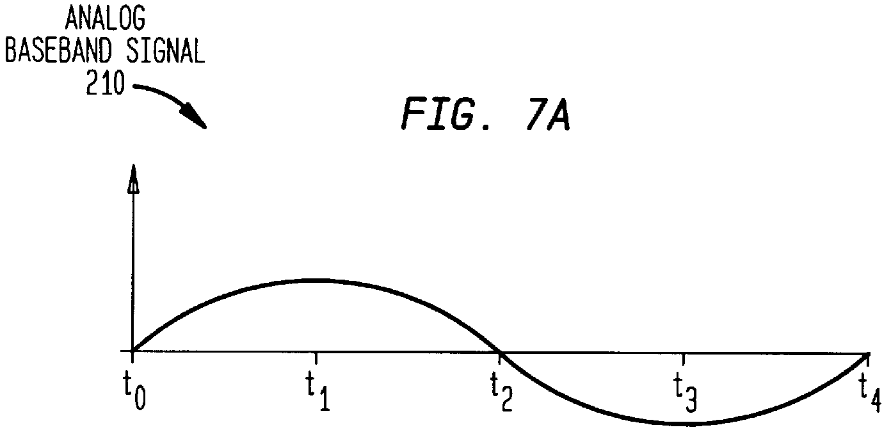


FIG. 7B

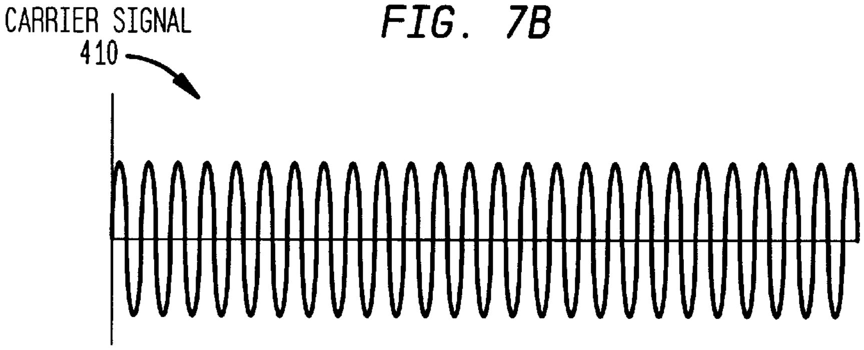


FIG. 7C

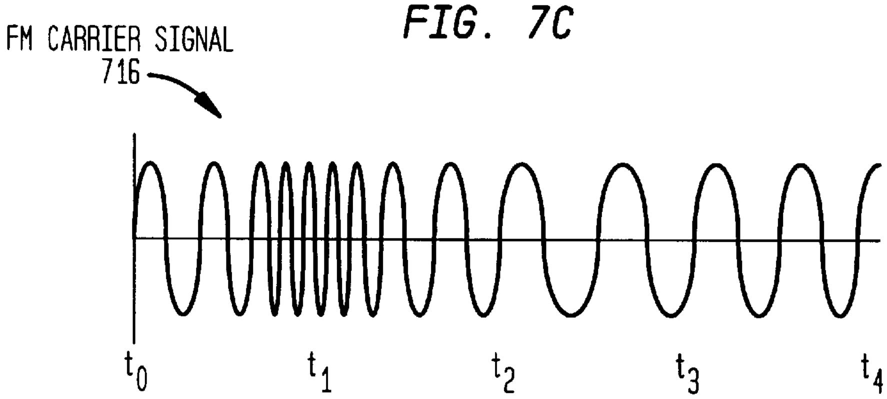


FIG. 8A

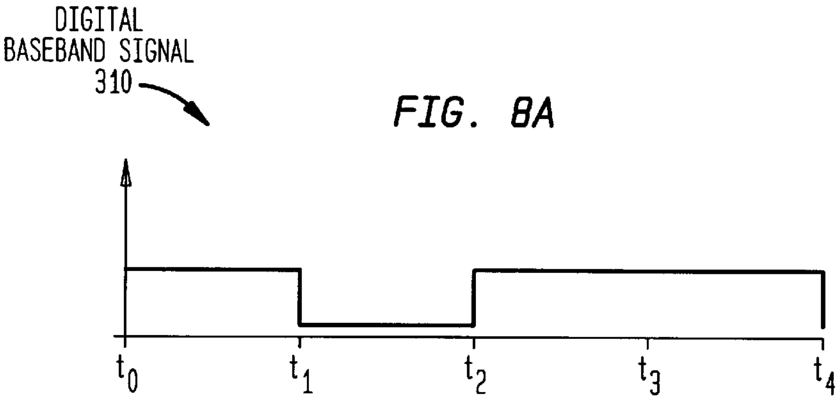


FIG. 8B

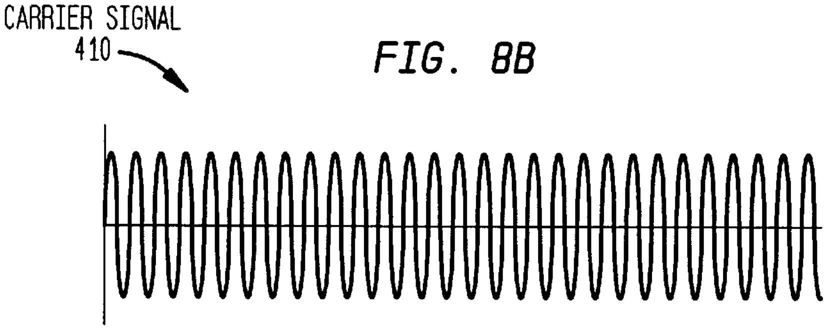


FIG. 8C

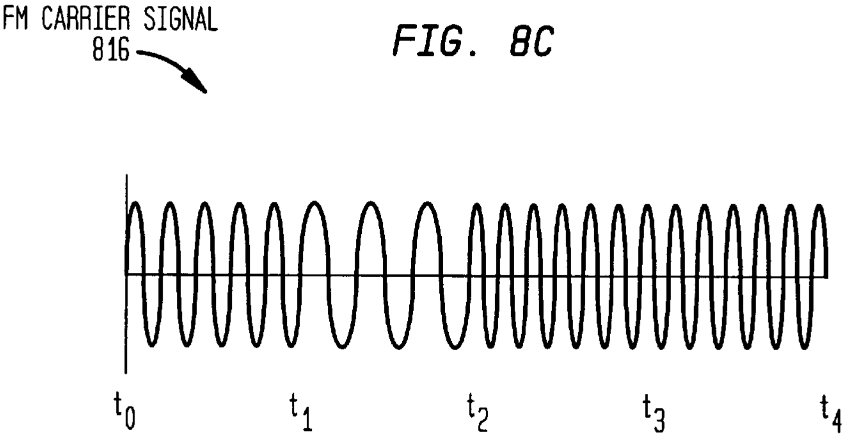


FIG. 9A

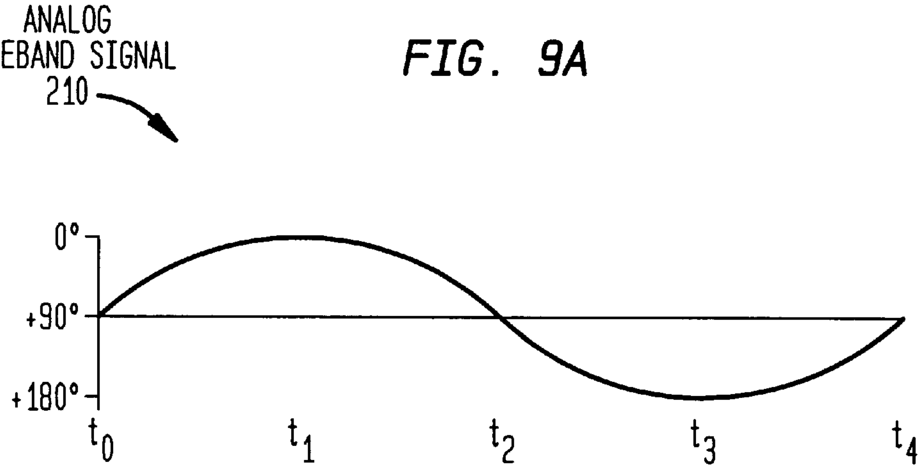


FIG. 9B

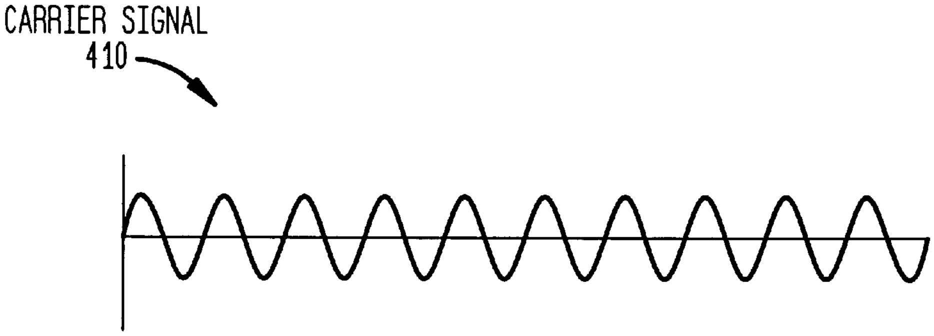
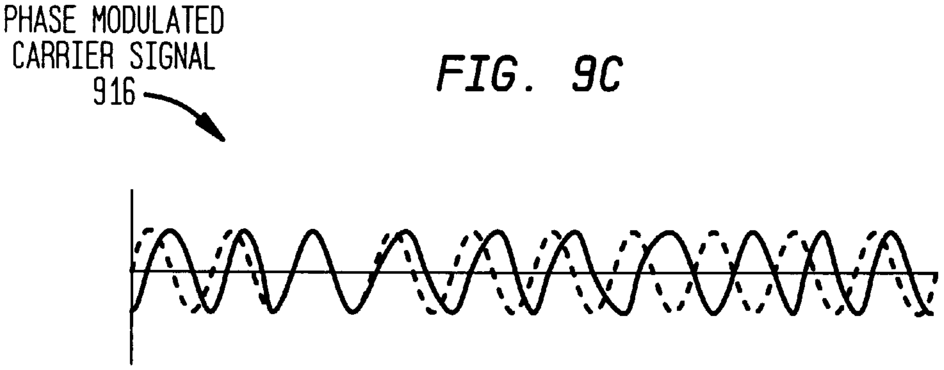


FIG. 9C



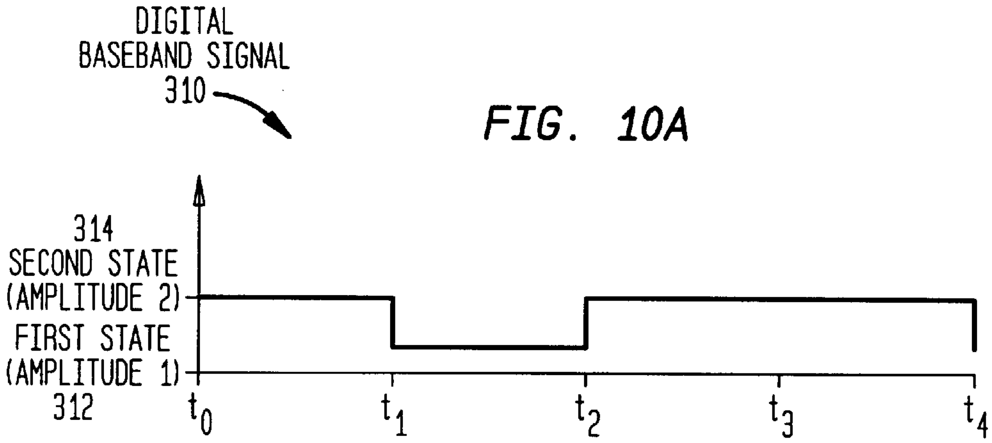


FIG. 10A

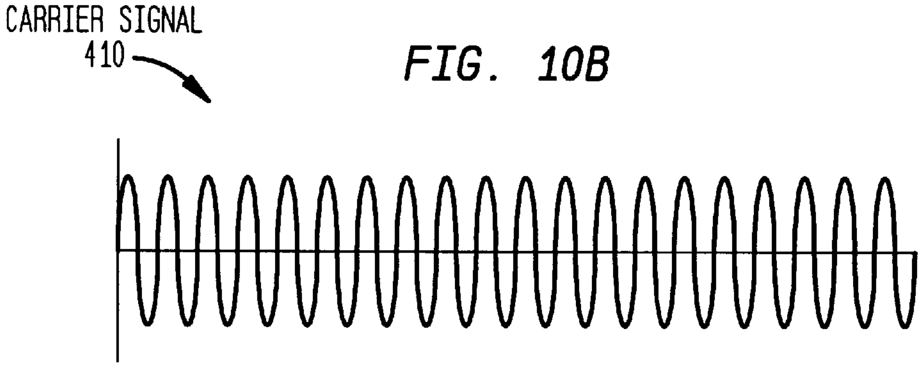


FIG. 10B

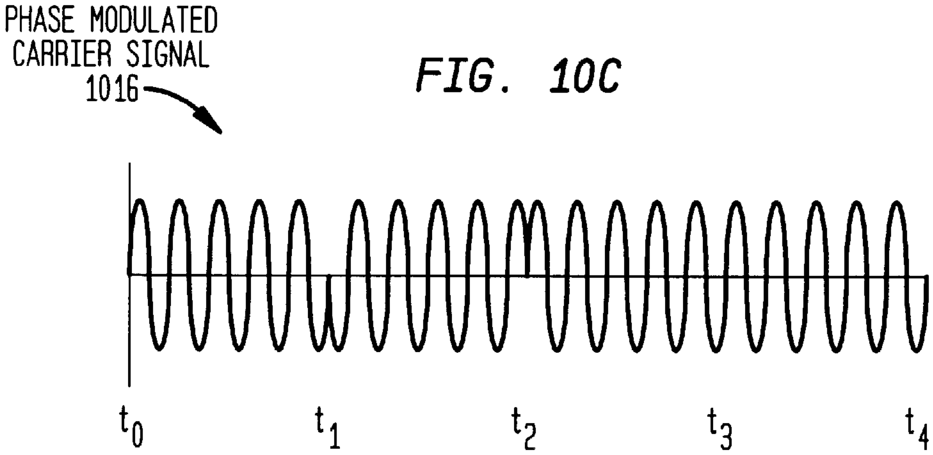


FIG. 10C

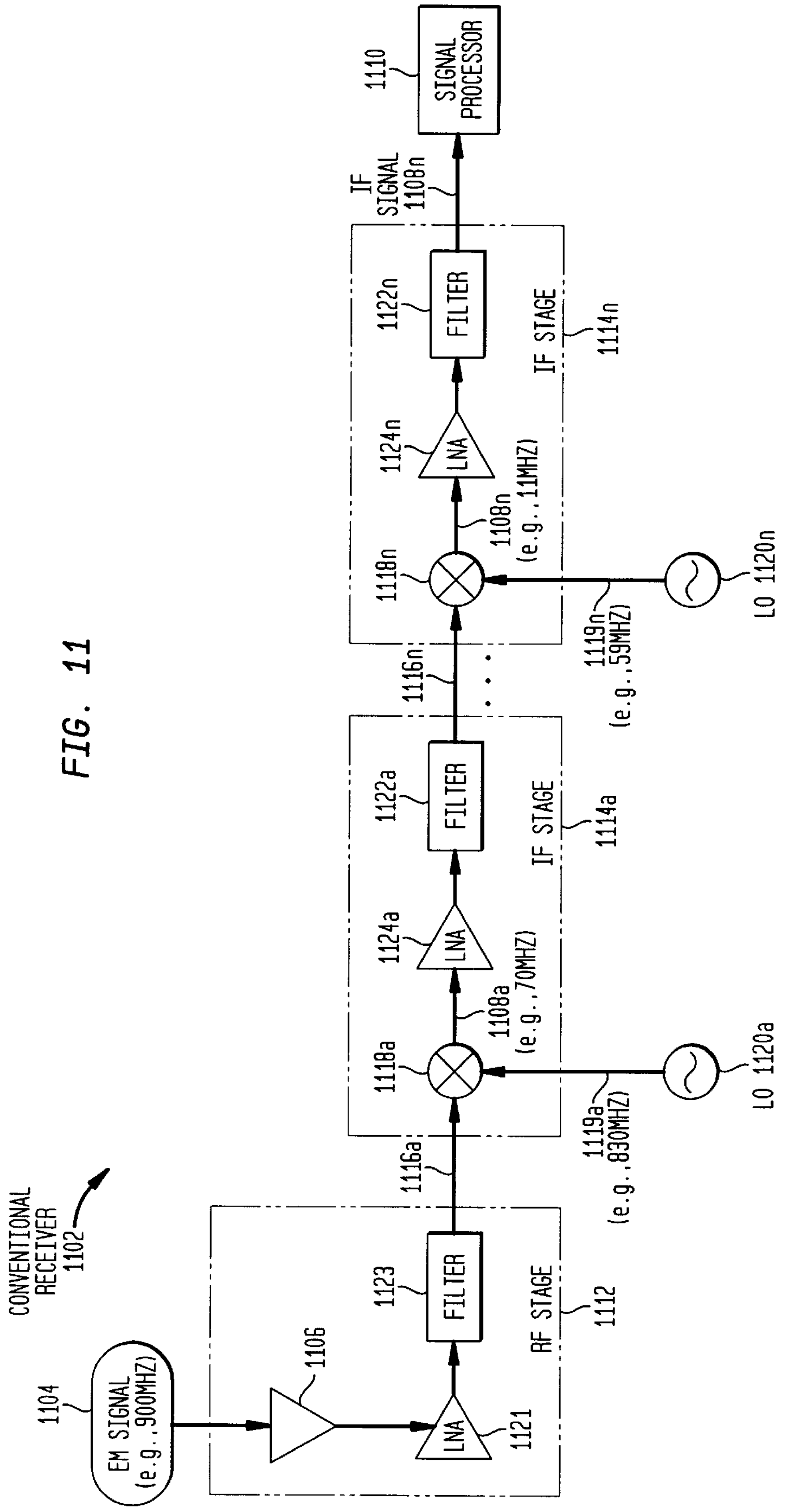
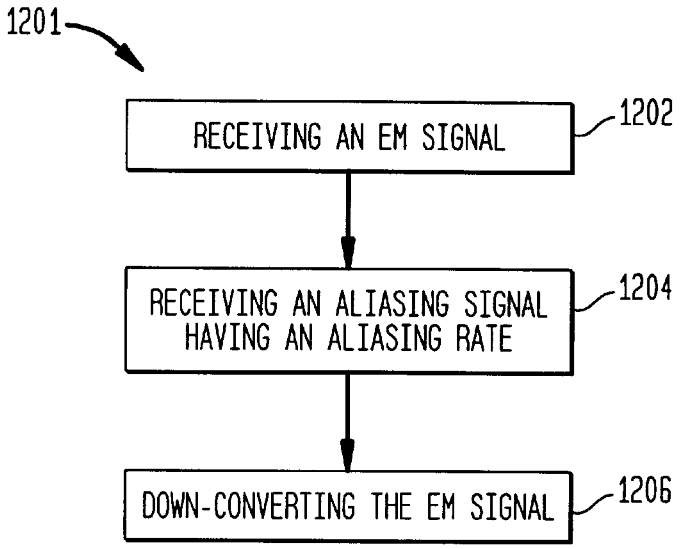

CONVENTIONAL RECEIVER 1102
1104
EM SIGNAL (e.g., 900MHZ)
1106
LNA
1121
1123
FILTER
RF STAGE
1112
1116a
1118a
1108a (e.g., 70MHZ)
1124a
LNA
1122a
FILTER
IF STAGE
1114a
1119a (e.g., 830MHZ)
LO 1120a
1116n
1118n
1108n (e.g., 11MHZ)
1124n
LNA
1122n
FILTER
IF STAGE
1114n
1119n (e.g., 59MHZ)
LO 1120n
IF SIGNAL 1108n
1110
SIGNAL PROCESSOR

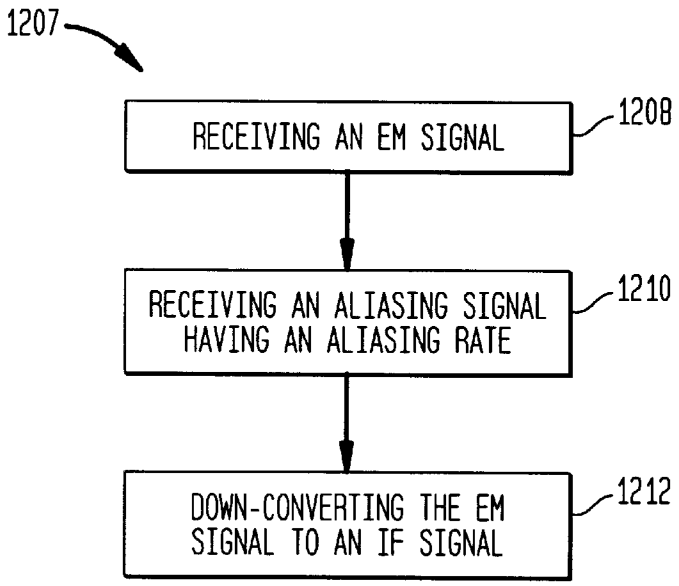
FIG. 11

FIG. 12A



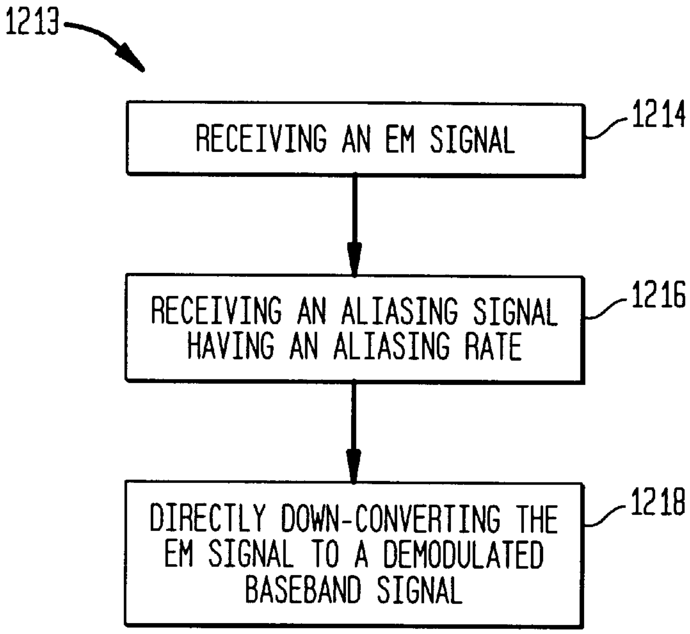
GENERIC DOWN-CONVERTING FLOWCHART

FIG. 12B



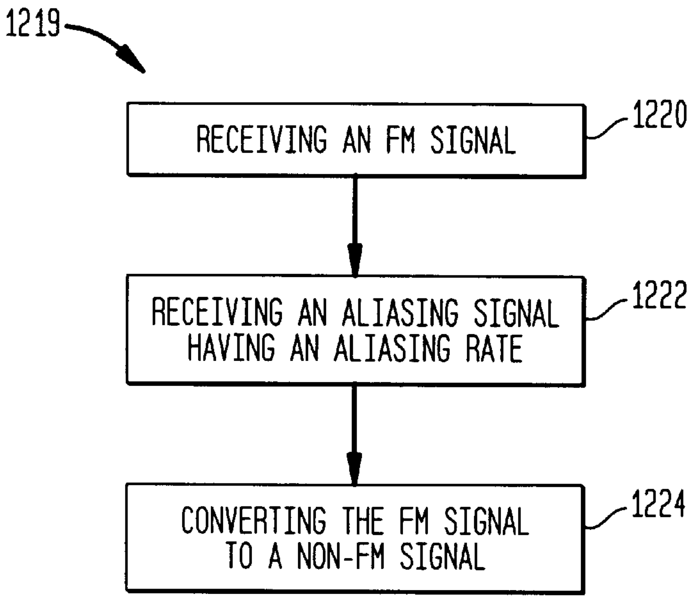
DOWN-CONVERTING AN EM SIGNAL TO AN IF SIGNAL

FIG. 12C



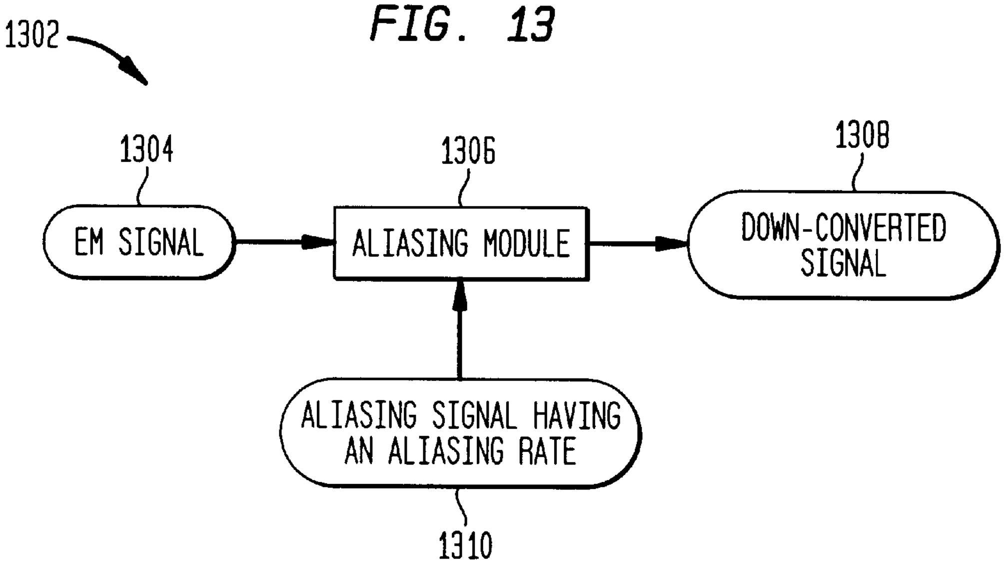
DIRECTLY DOWN-CONVERTING AN EM SIGNAL TO A DEMODULATED BASEBAND SIGNAL

FIG. 12D



MODULATION CONVERSION

FIG. 13



GENERIC DOWN-CONVERTING SYSTEM

FIG. 14A

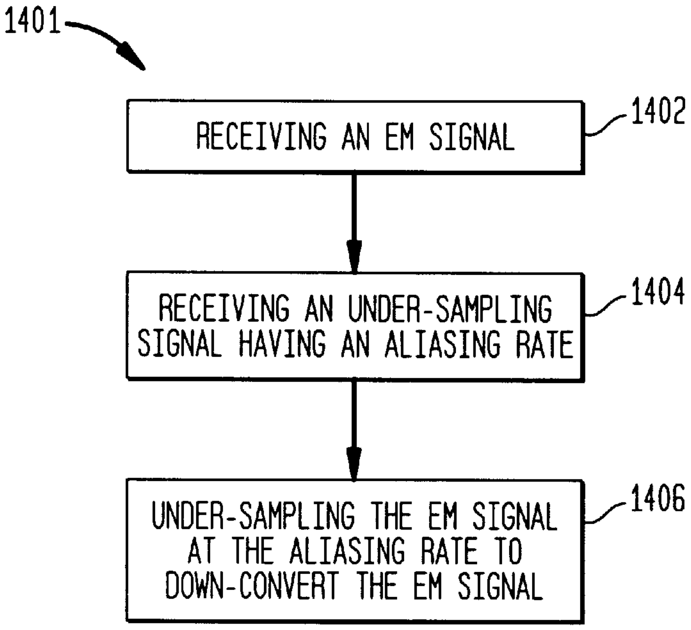


FIG. 14B

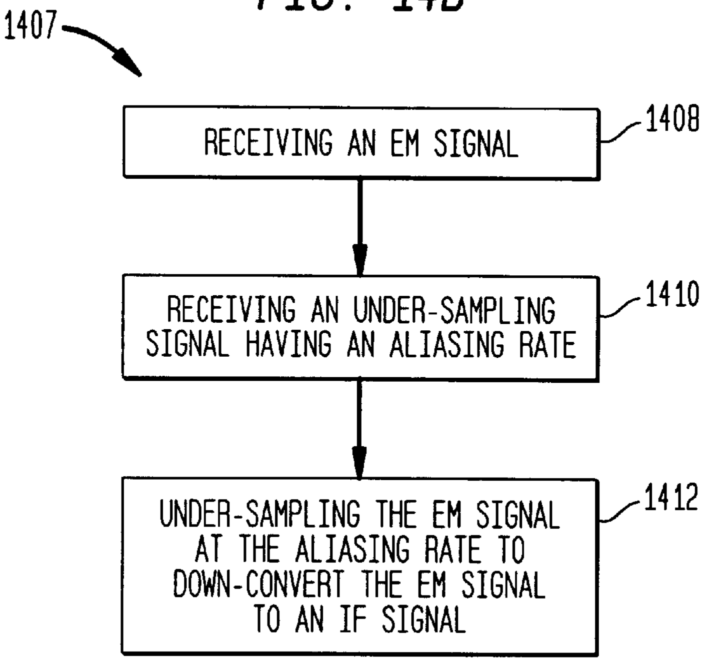


FIG. 14C

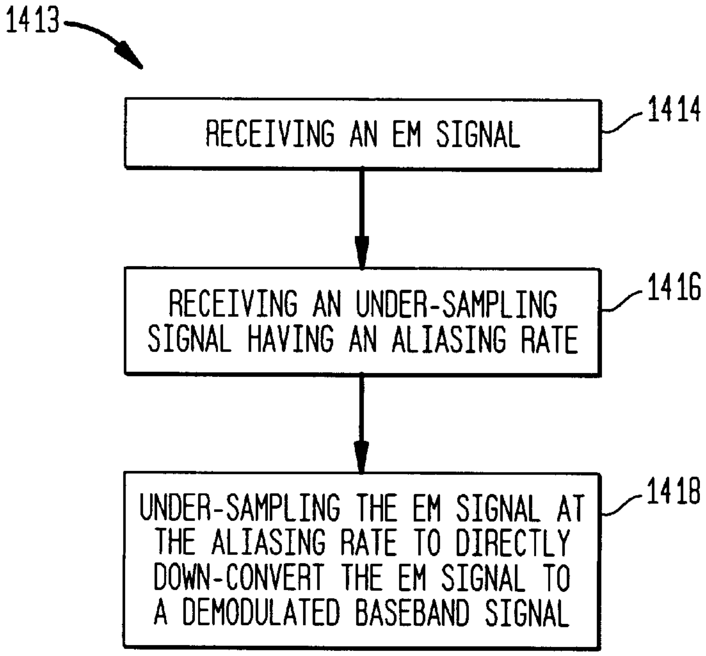


FIG. 14D

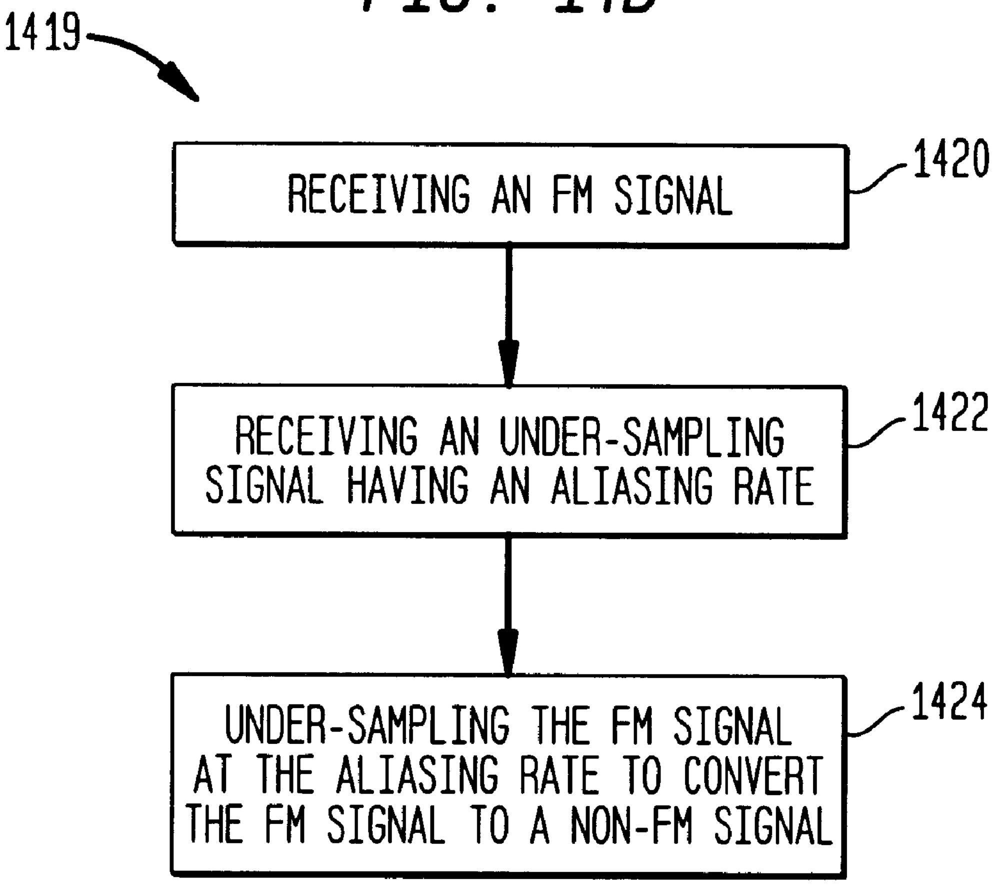

1419
RECEIVING AN FM SIGNAL
1420
RECEIVING AN UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE
1422
UNDER-SAMPLING THE FM SIGNAL AT THE ALIASING RATE TO CONVERT THE FM SIGNAL TO A NON-FM SIGNAL
1424

FIG. 15E

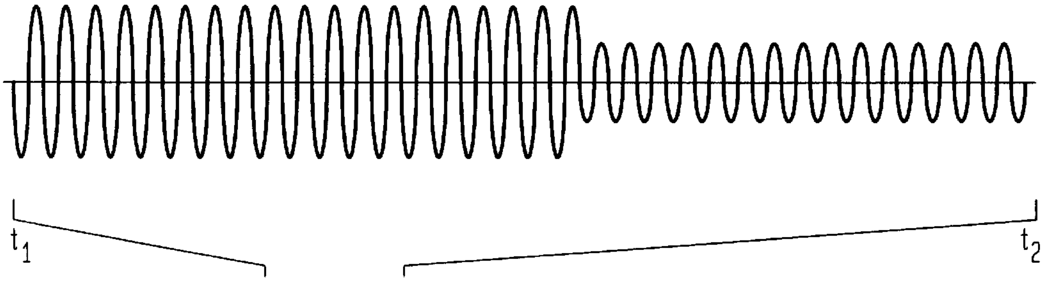


FIG. 15A

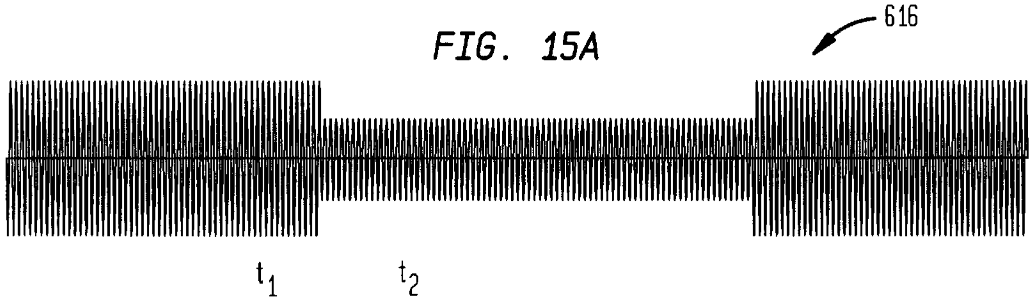


FIG. 15B

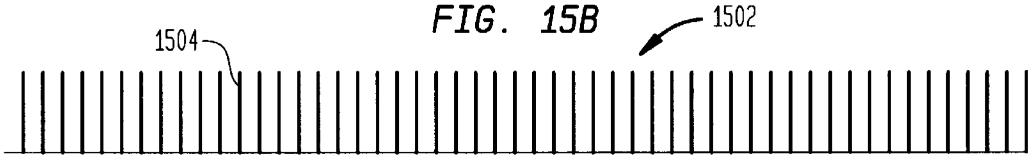


FIG. 15C

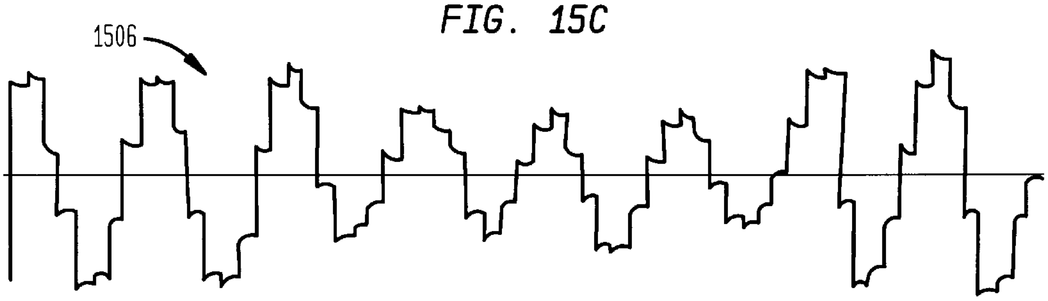


FIG. 15D

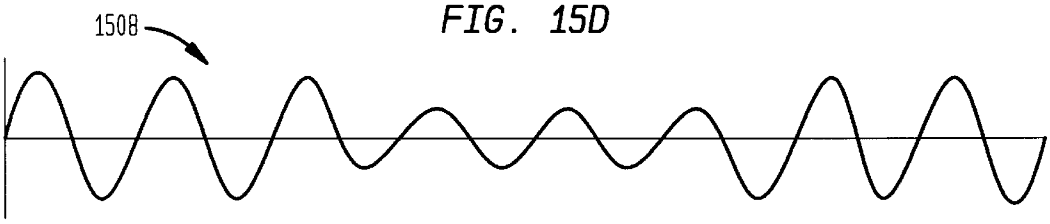


FIG. 16

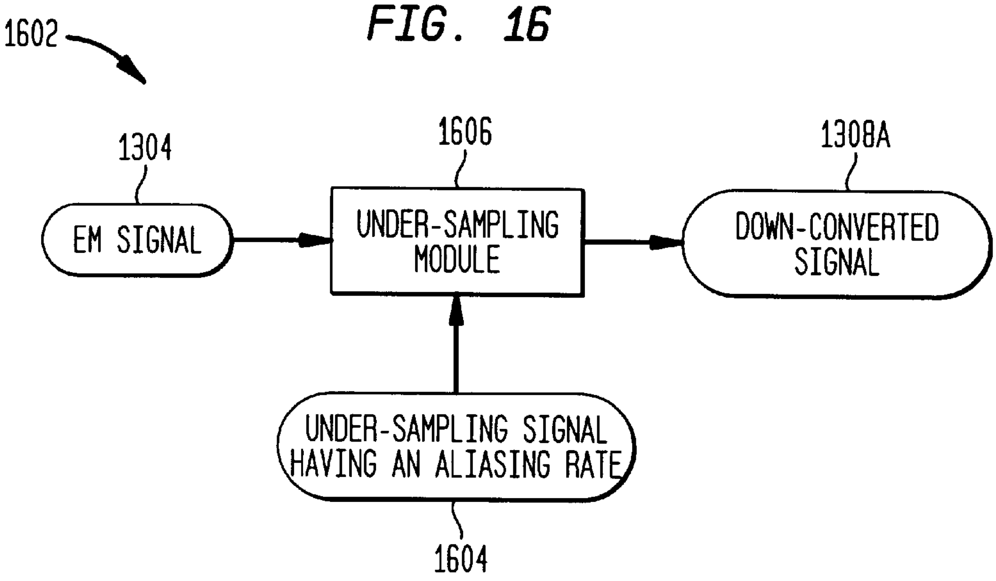

1602
1304
EM SIGNAL
1606
UNDER-SAMPLING MODULE
1308A
DOWN-CONVERTED SIGNAL
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE
1604

FIG. 17

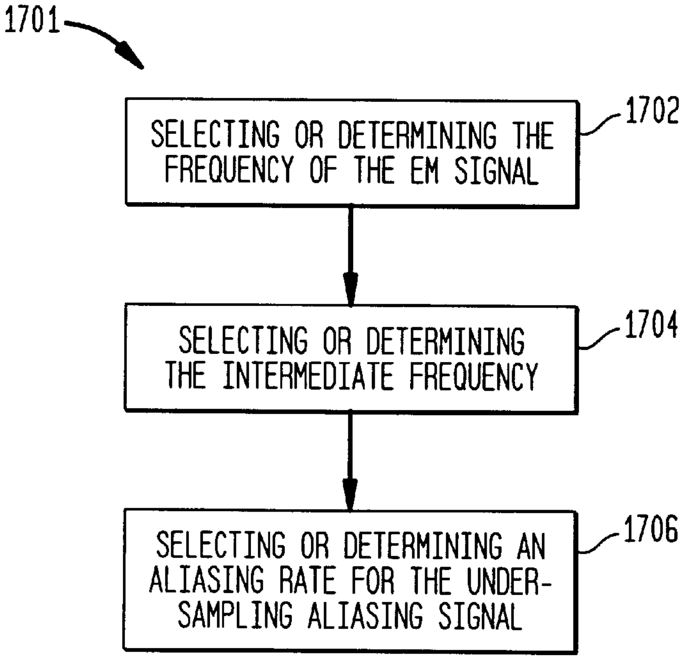

1701
SELECTING OR DETERMINING THE FREQUENCY OF THE EM SIGNAL
1702
SELECTING OR DETERMINING THE INTERMEDIATE FREQUENCY
1704
SELECTING OR DETERMINING AN ALIASING RATE FOR THE UNDER-SAMPLING ALIASING SIGNAL
1706

FIG. 18A

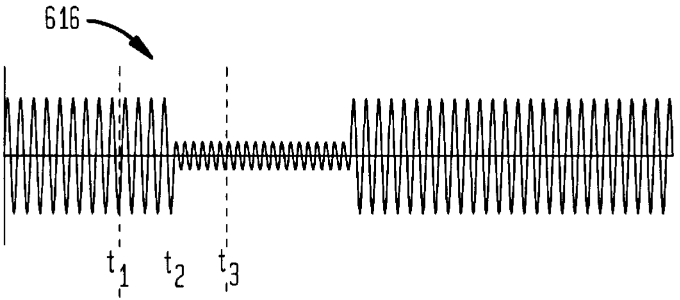


FIG. 18B

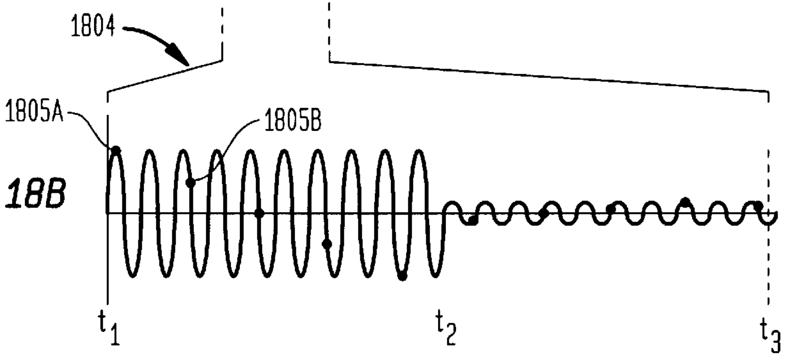


FIG. 18C

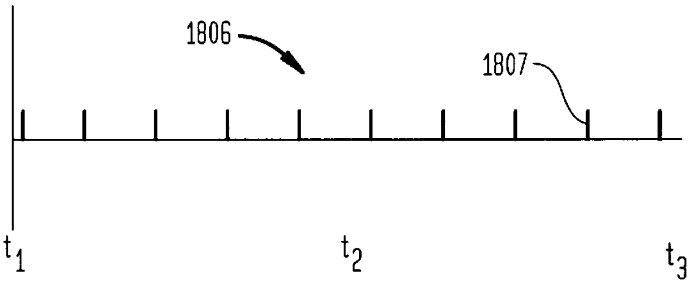


FIG. 18D

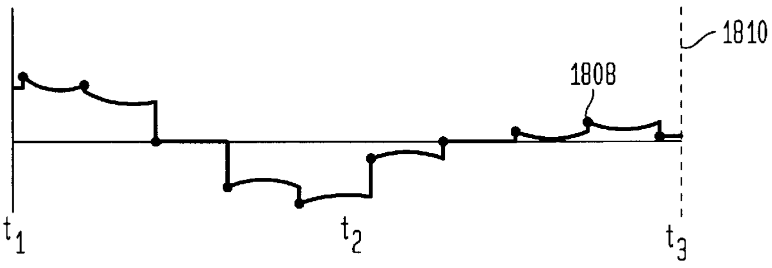


FIG. 18E

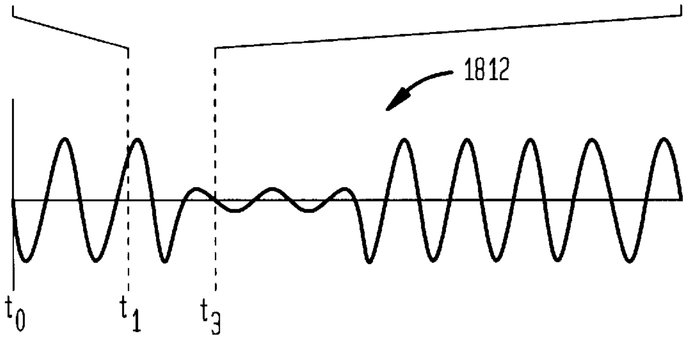


FIG. 19A

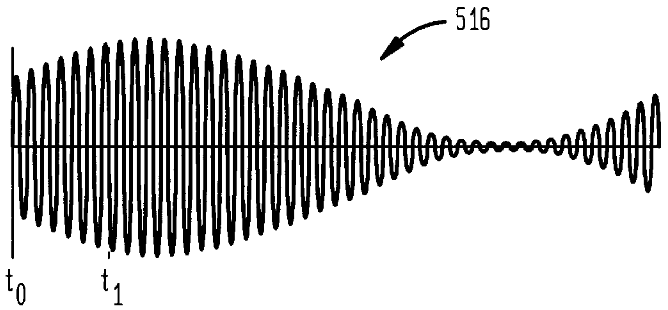


FIG. 19B

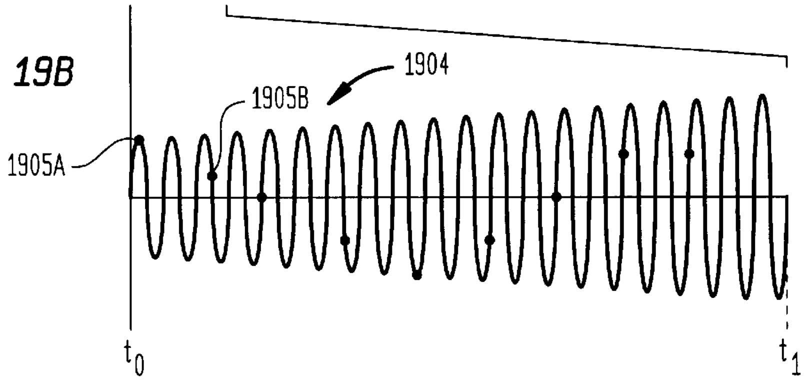


FIG. 19C

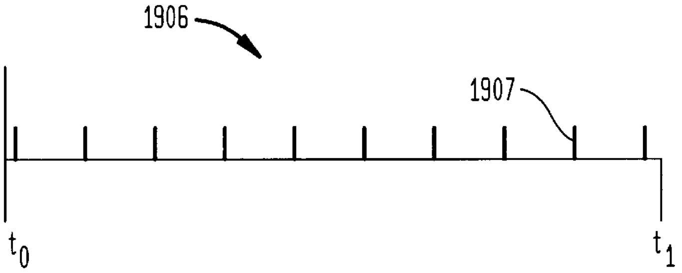


FIG. 19D

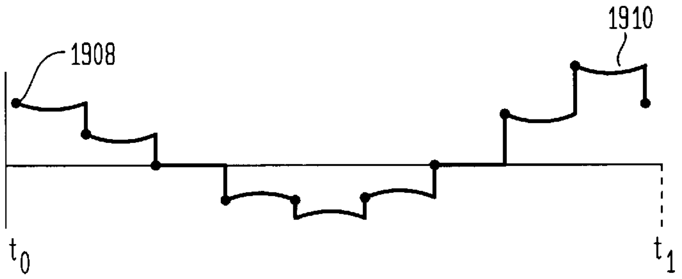


FIG. 19E

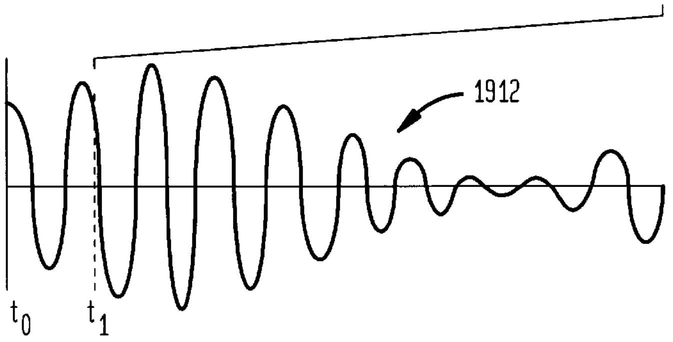


FIG. 20A

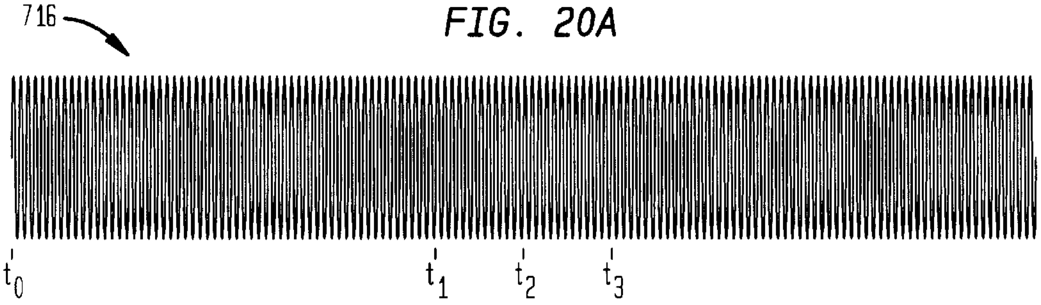


FIG. 20B

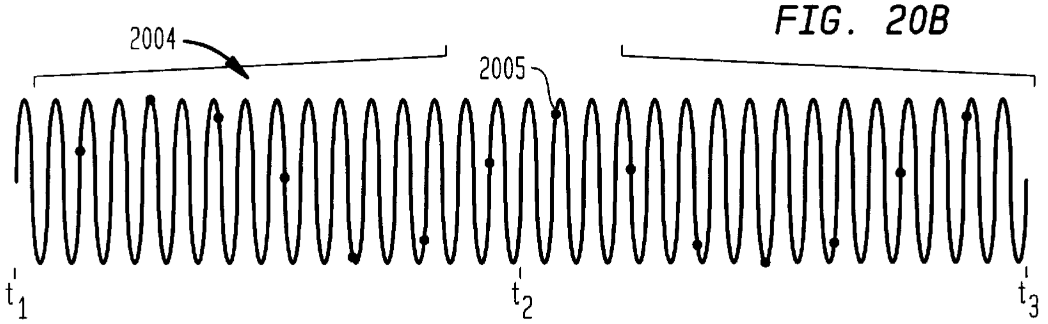


FIG. 20C

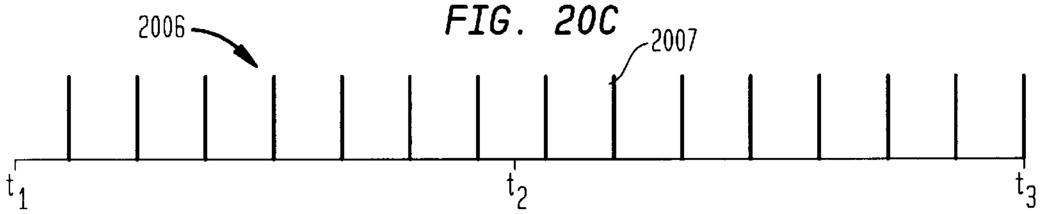


FIG. 20D

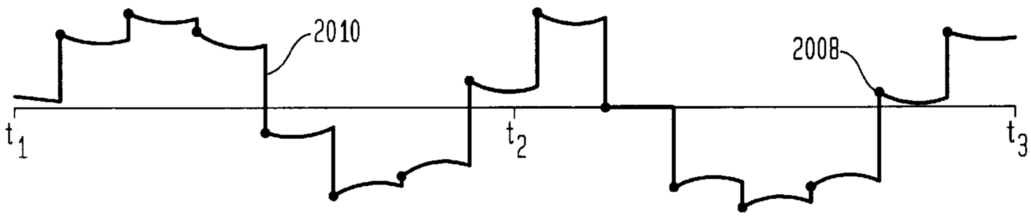


FIG. 20E

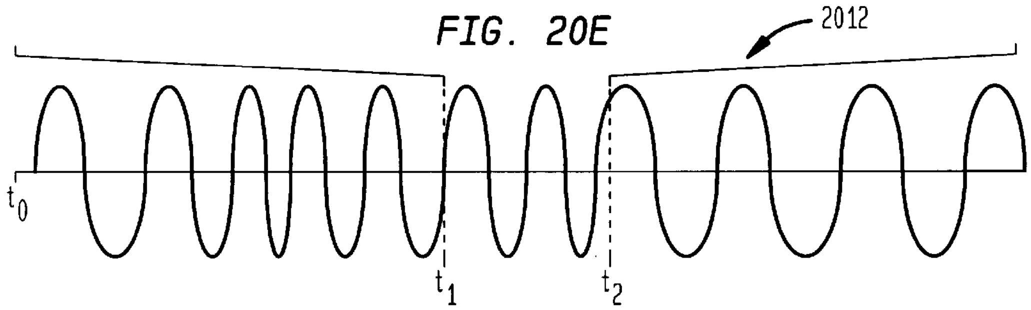


FIG. 21A

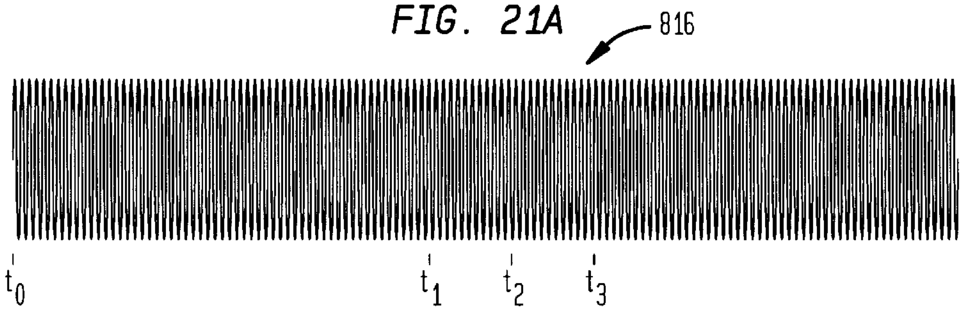


FIG. 21B

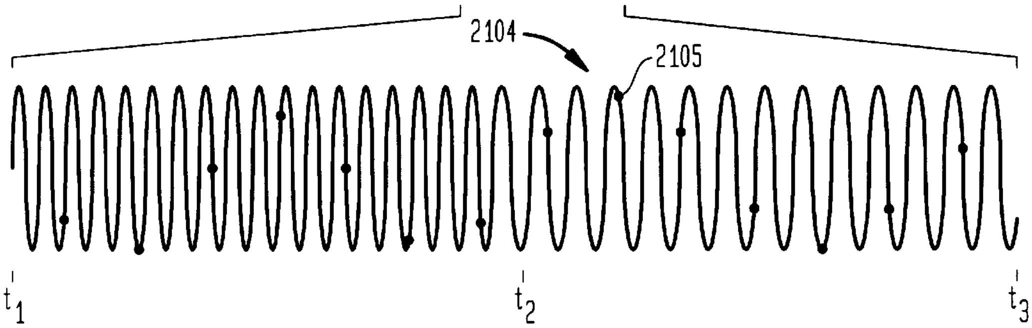


FIG. 21C

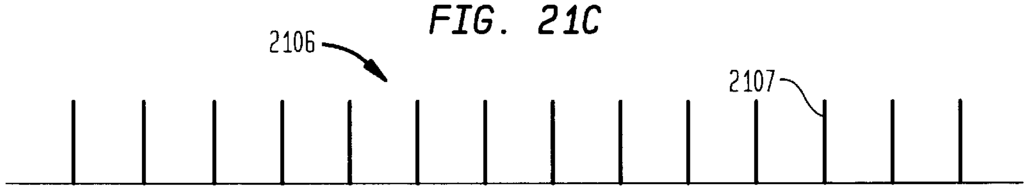


FIG. 21D

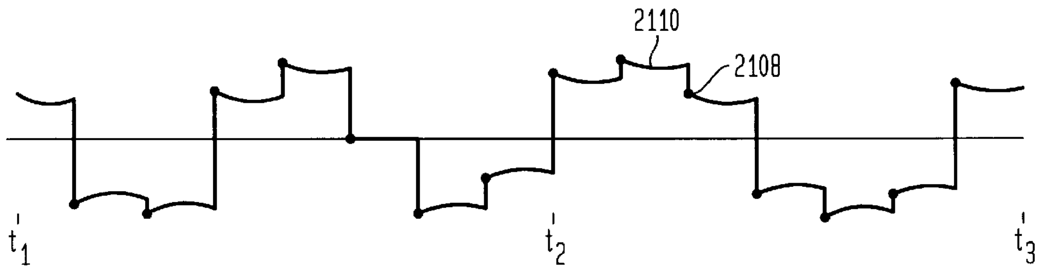


FIG. 21E

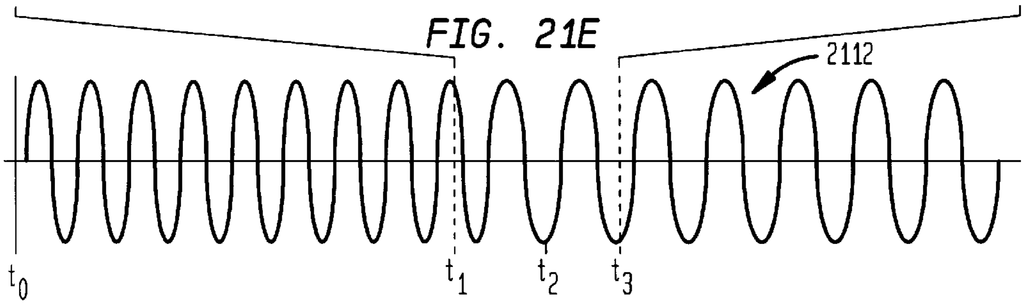


FIG. 22A

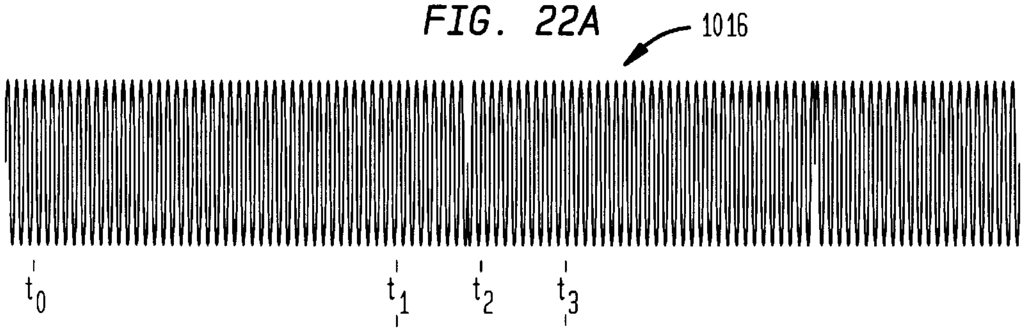


FIG. 22B

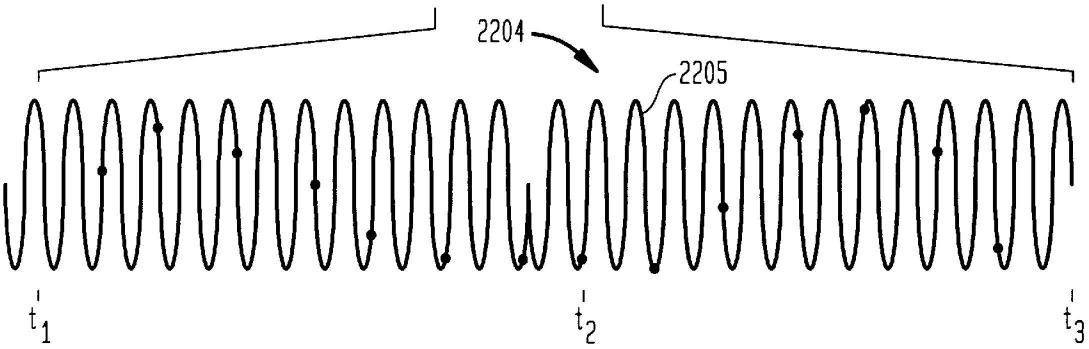


FIG. 22C

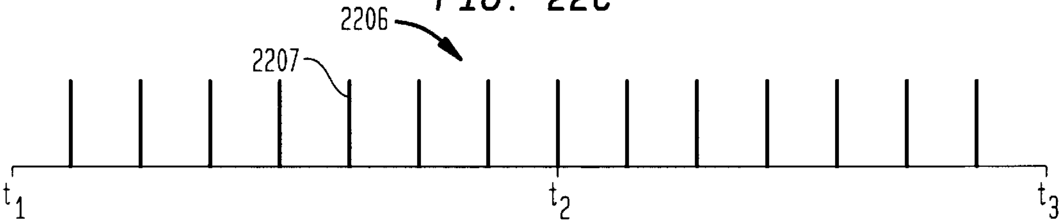


FIG. 22D

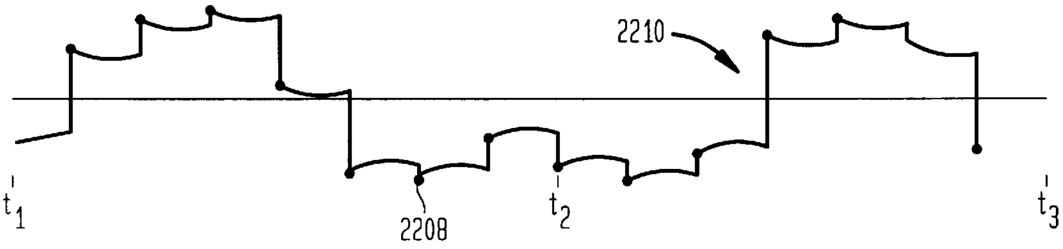


FIG. 22E

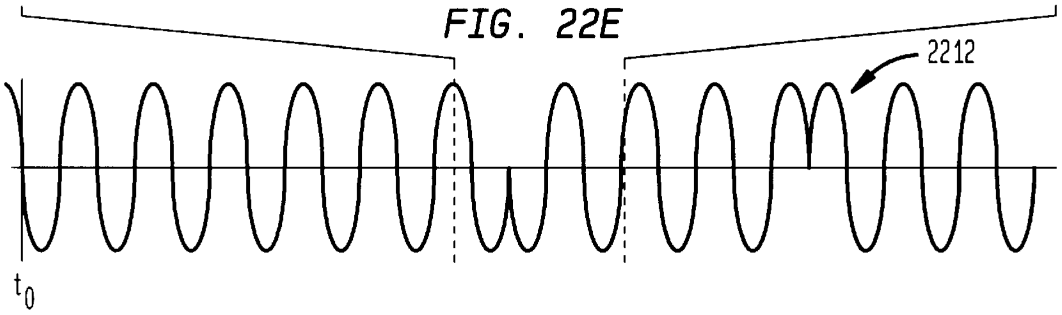


FIG. 23A

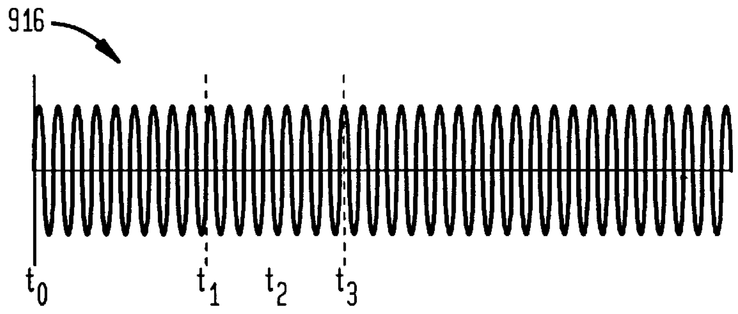


FIG. 23B

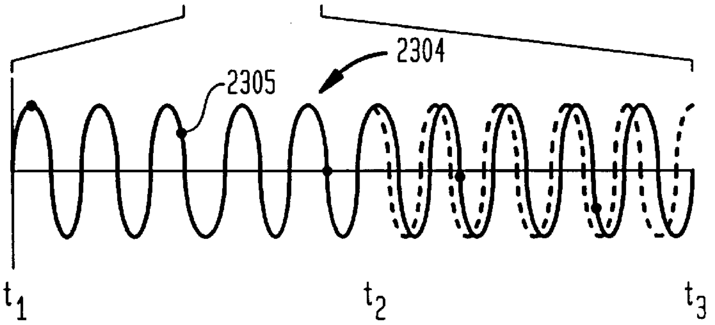


FIG. 23C

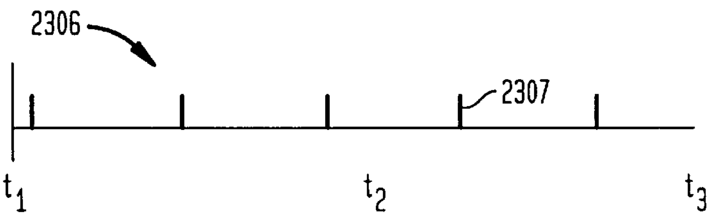


FIG. 23D

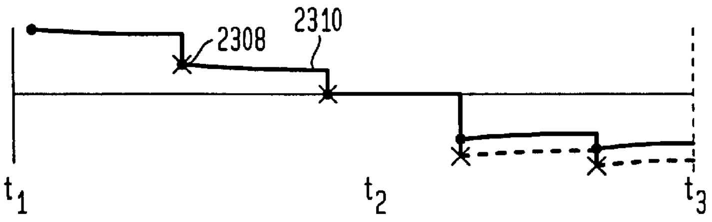


FIG. 23E

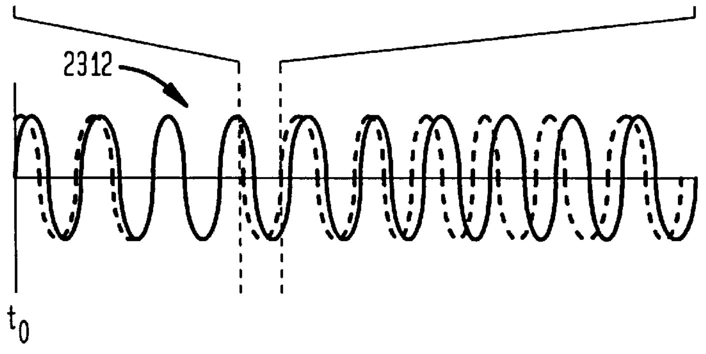


FIG. 24A

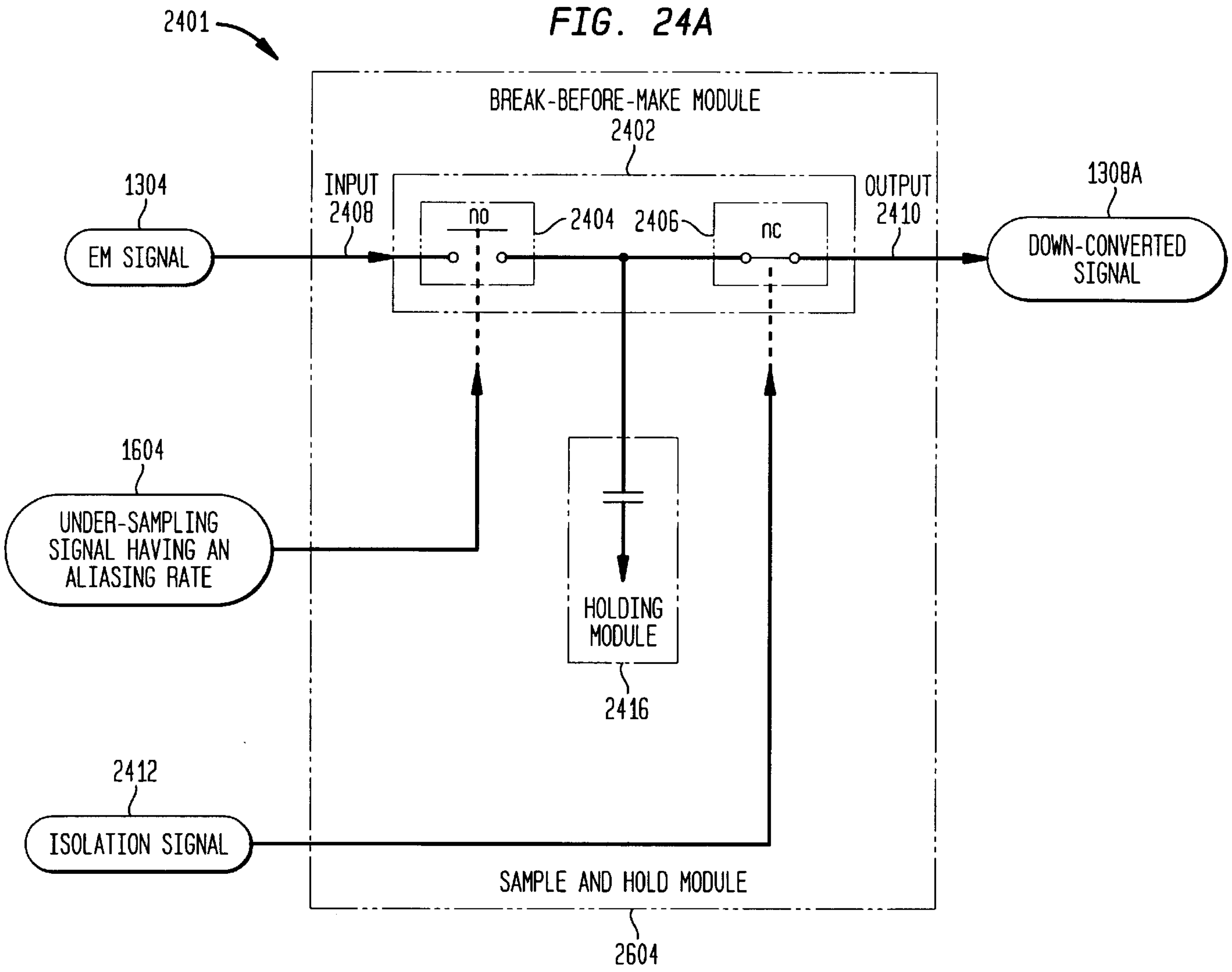

2401
BREAK-BEFORE-MAKE MODULE
2402
1304
EM SIGNAL
INPUT
2408
no
2404
2406
nc
OUTPUT
2410
1308A
DOWN-CONVERTED SIGNAL
1604
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE
HOLDING MODULE
2416
2412
ISOLATION SIGNAL
SAMPLE AND HOLD MODULE
2604

FIG. 24B

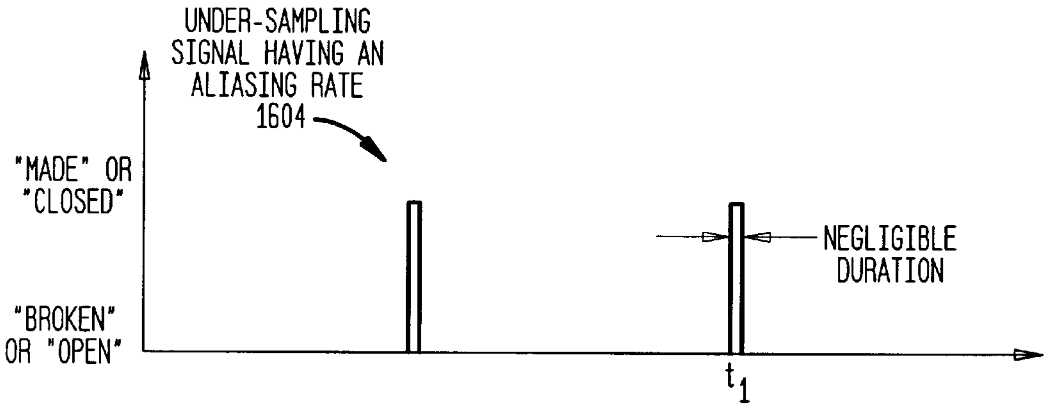
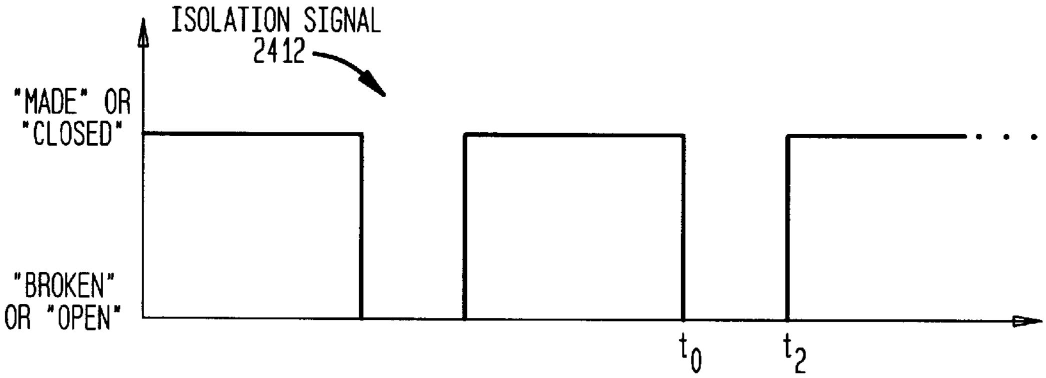


FIG. 24C



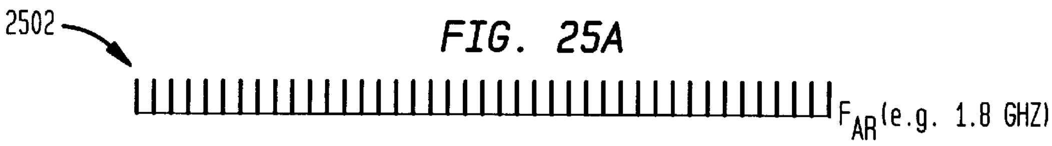


FIG. 25A

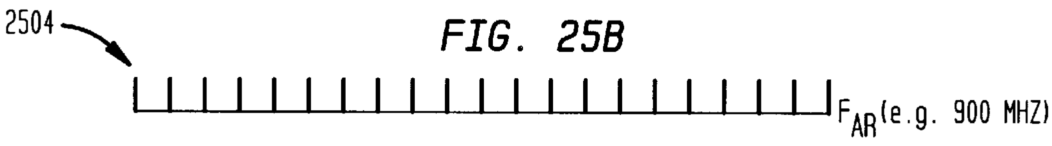


FIG. 25B

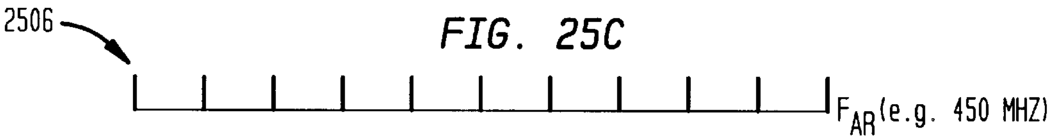


FIG. 25C

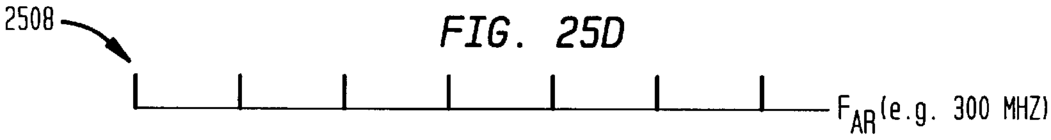


FIG. 25D

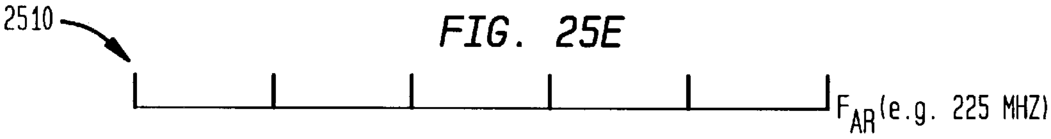


FIG. 25E

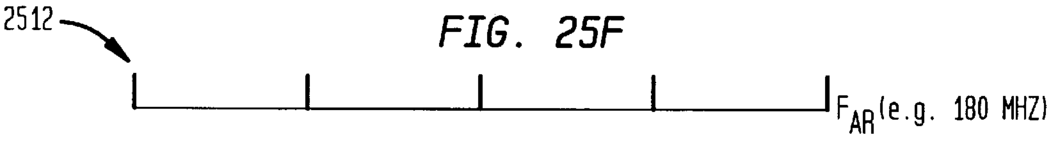


FIG. 25F

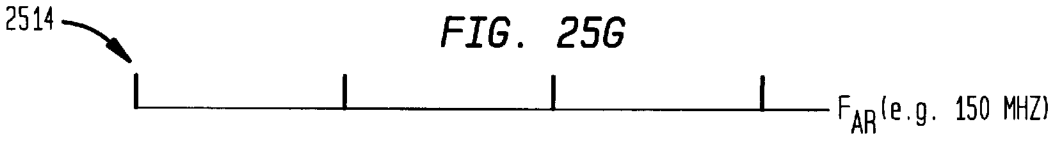


FIG. 25G

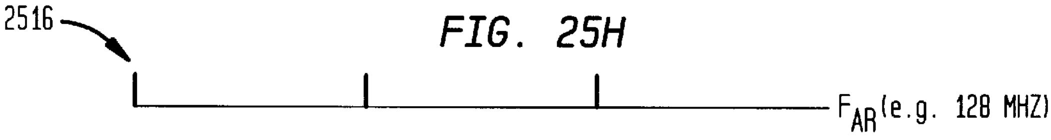


FIG. 25H

FIG. 26A

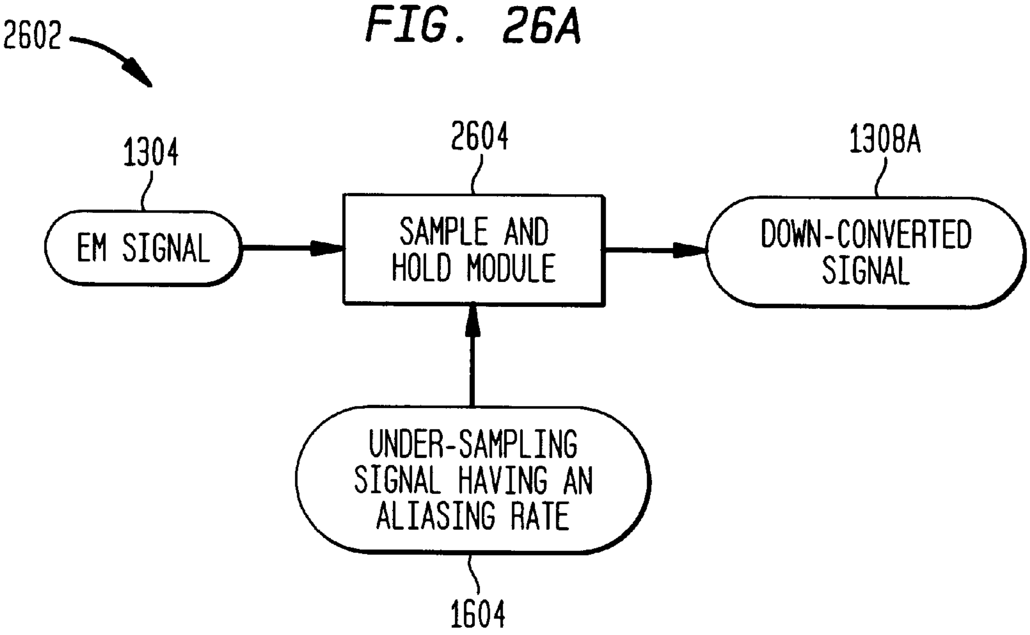


FIG. 26B

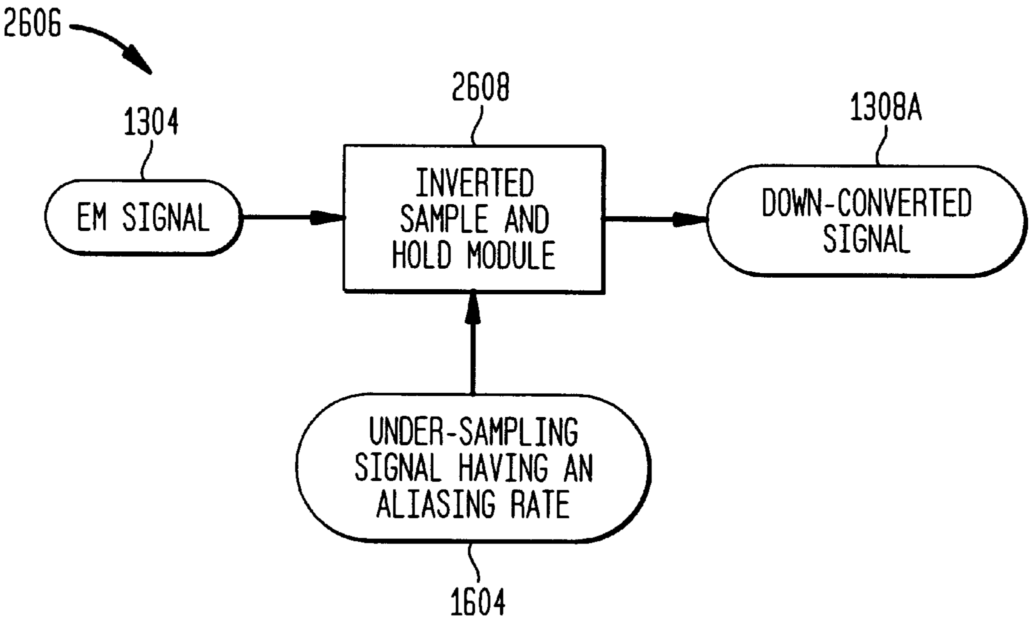


FIG. 27

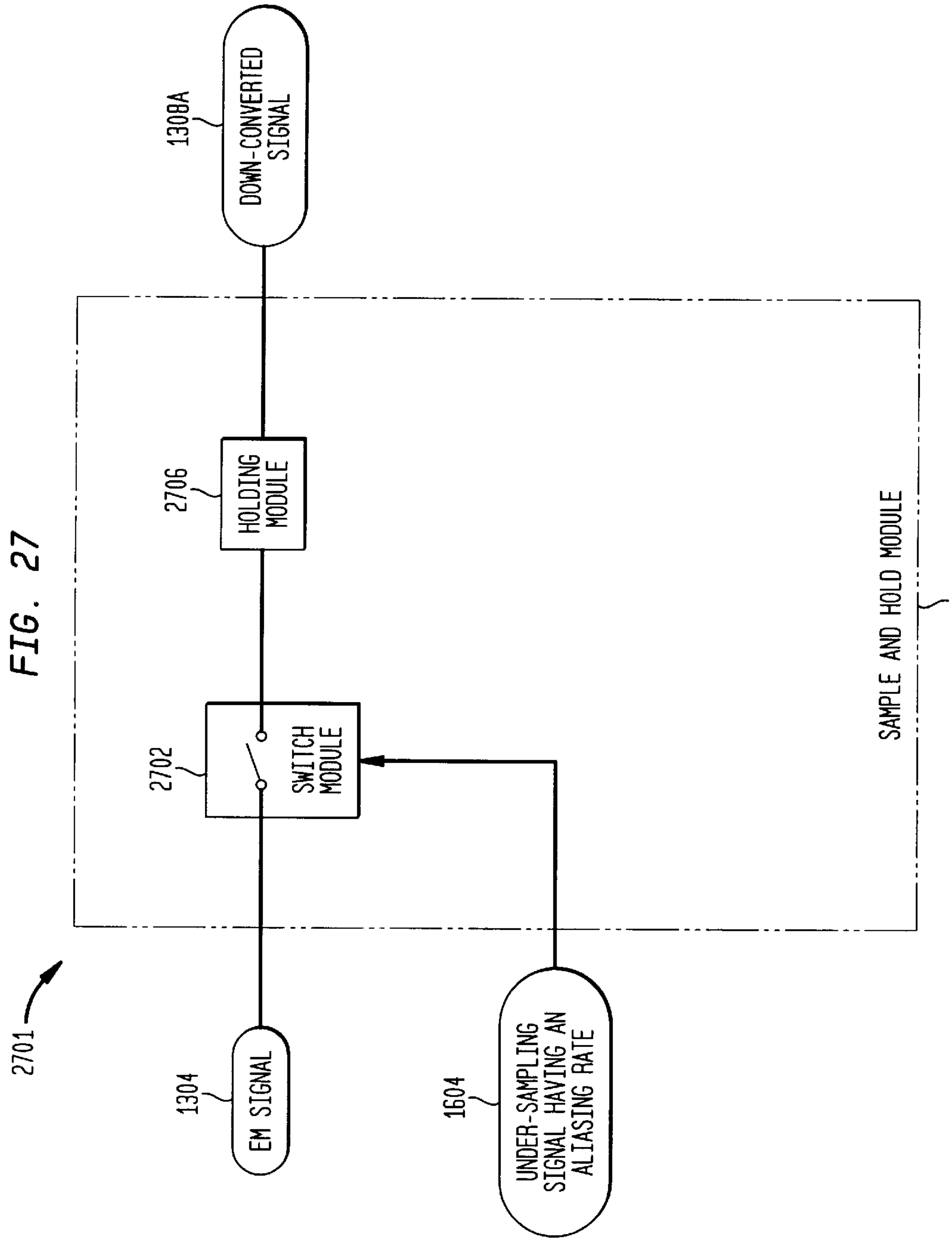

2701
1304
EM SIGNAL
1604
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE
2702
SWITCH MODULE
2706
HOLDING MODULE
1308A
DOWN-CONVERTED SIGNAL
SAMPLE AND HOLD MODULE
2604

FIG. 28A

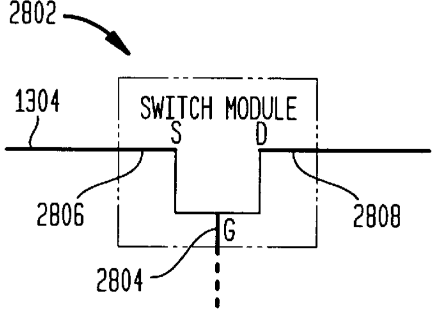


FIG. 28B

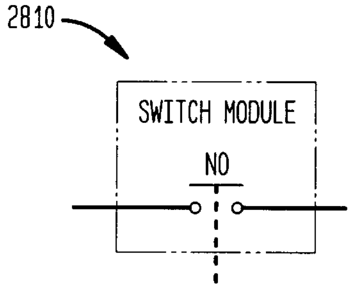


FIG. 28C

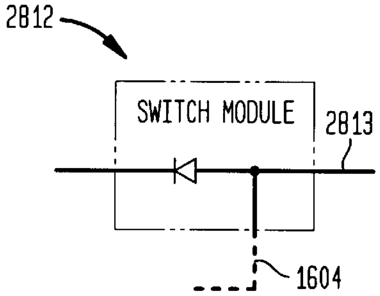


FIG. 28D

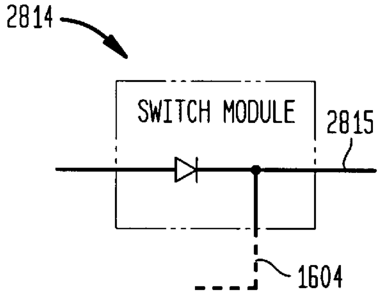


FIG. 29A

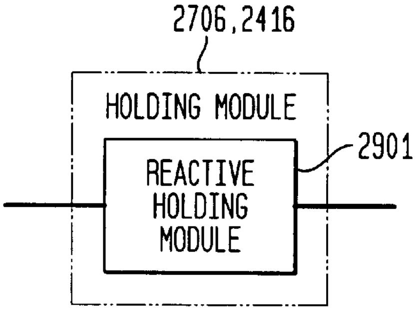


FIG. 29B

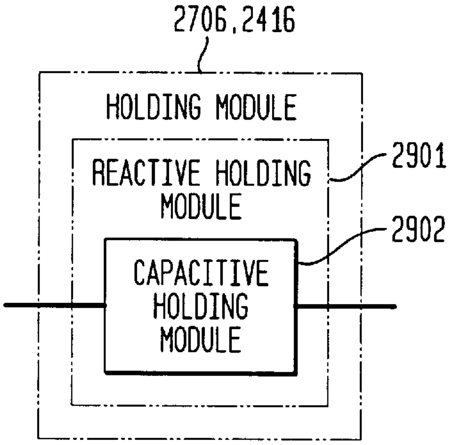


FIG. 29C

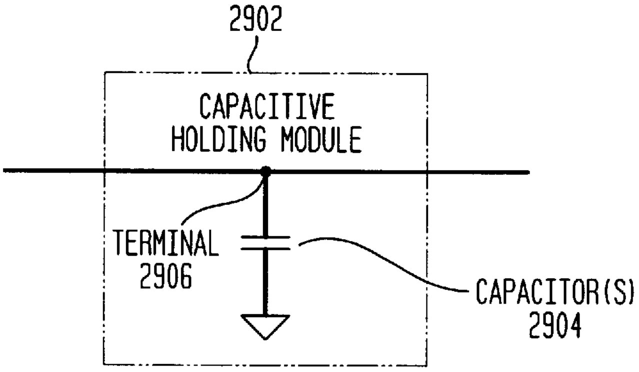


FIG. 29D

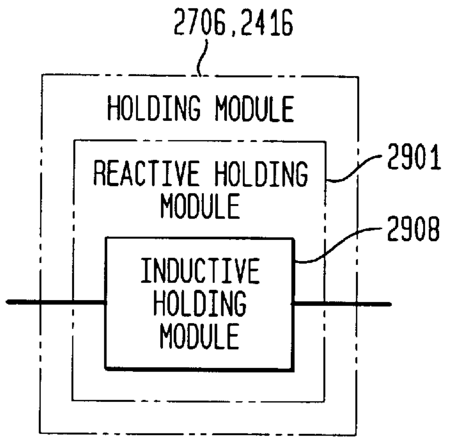


FIG. 29E

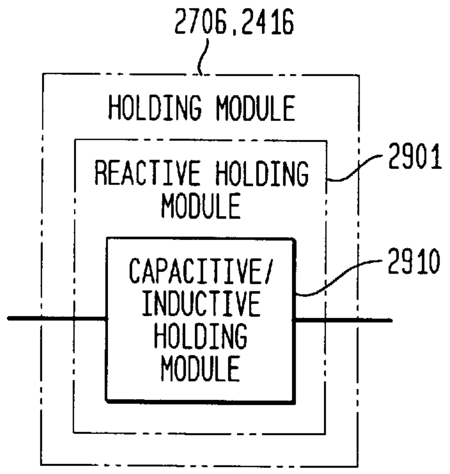


FIG. 29F

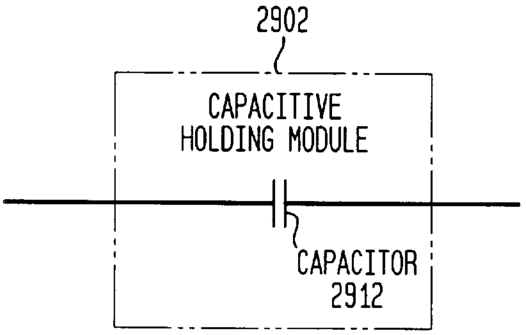


FIG. 29G

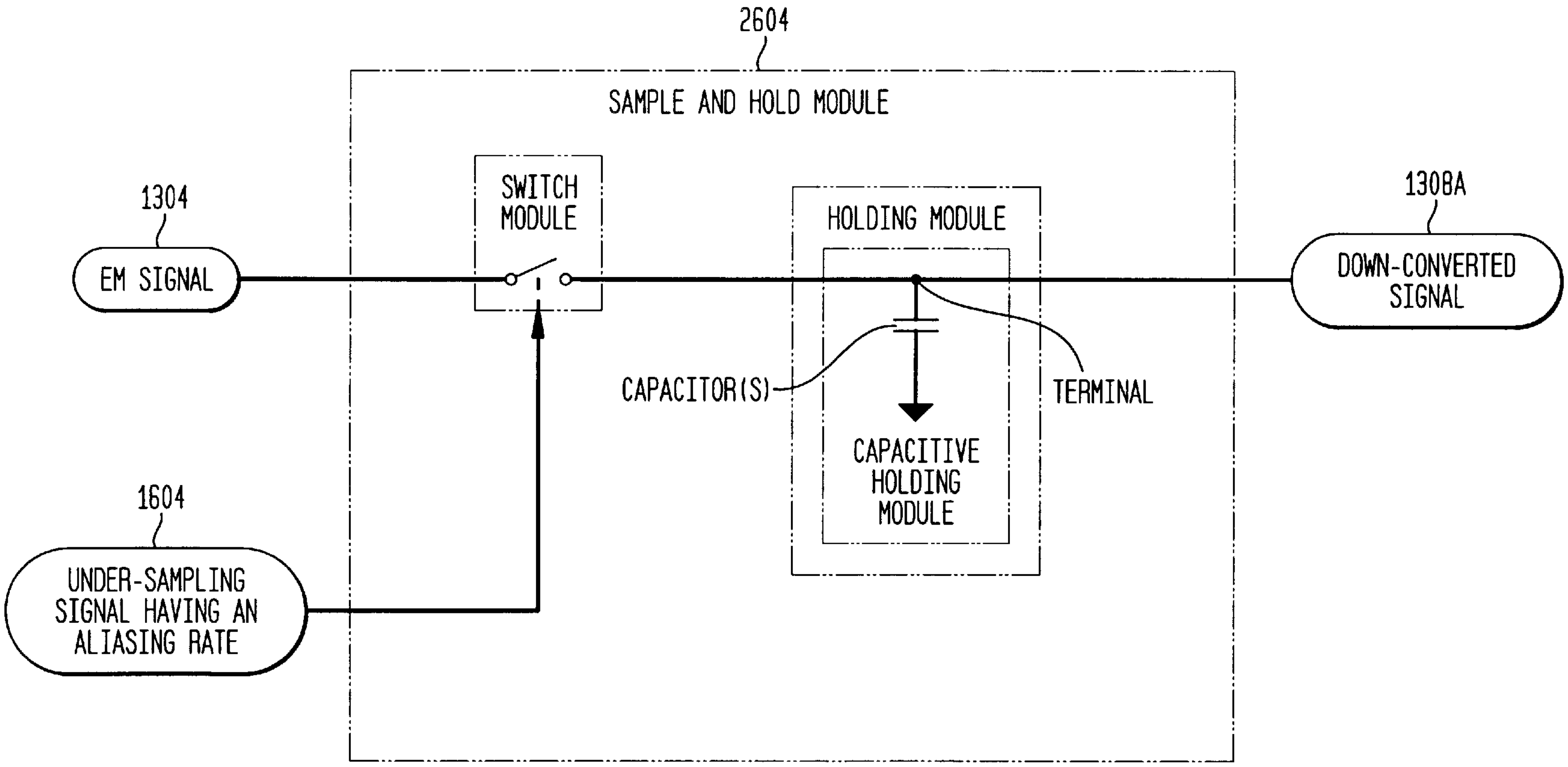
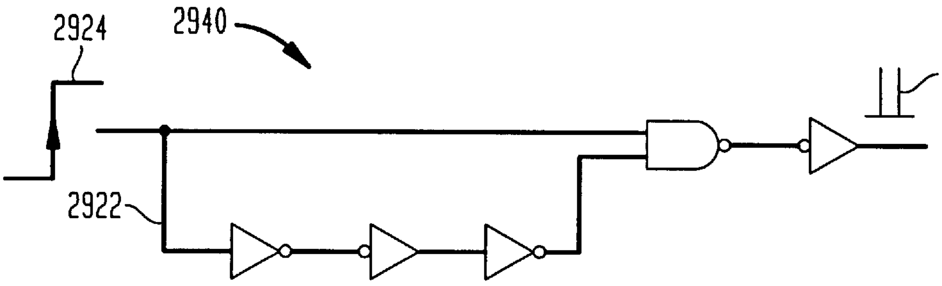
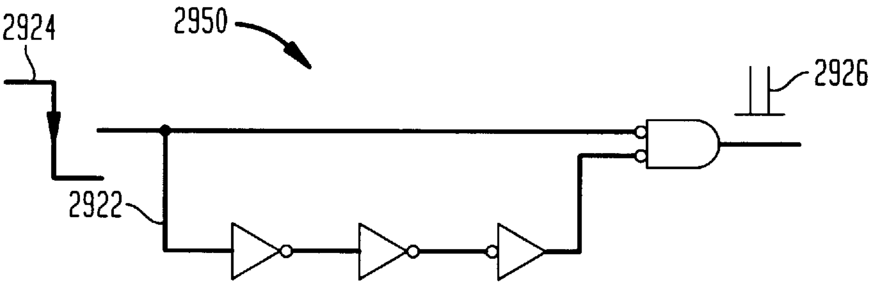

2604
SAMPLE AND HOLD MODULE
1304
EM SIGNAL
SWITCH MODULE
HOLDING MODULE
1308A
DOWN-CONVERTED SIGNAL
CAPACITOR(S)
TERMINAL
CAPACITIVE HOLDING MODULE
1604
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE

FIG. 29H



A. RISING EDGE PULSE GENERATOR

FIG. 29I



B. FALLING-EDGE PULSE GENERATOR

FIG. 29J

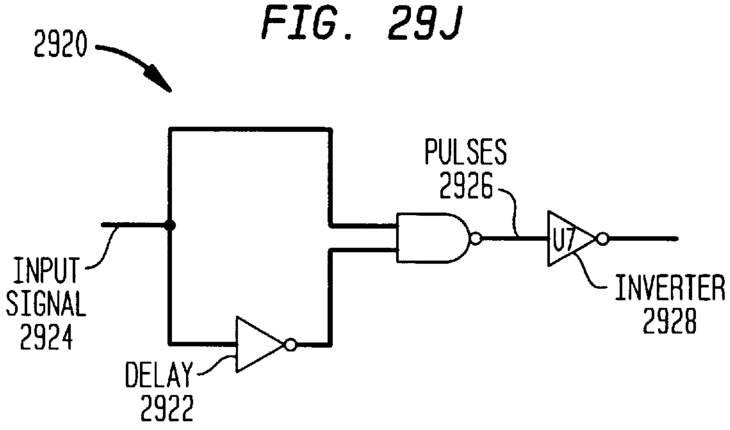


FIG. 29K

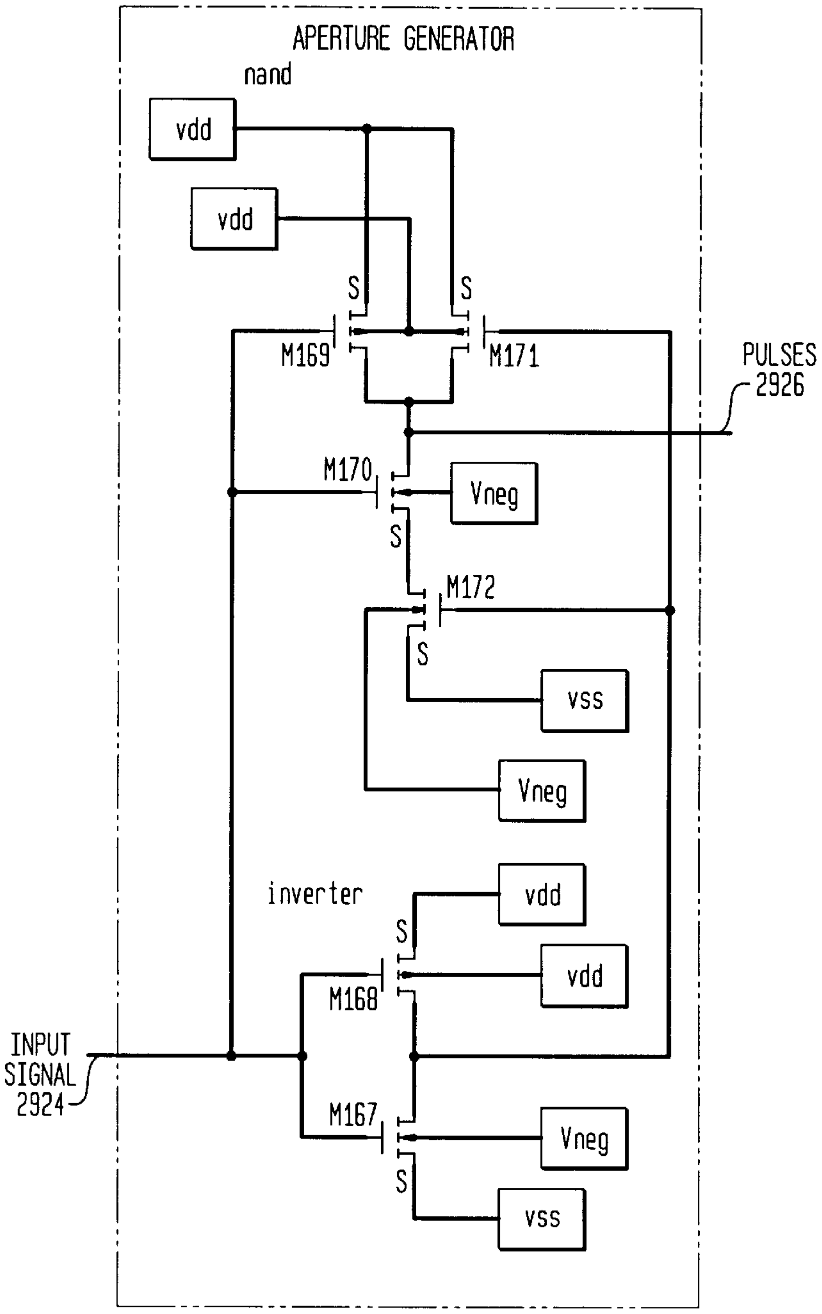


FIG. 29L

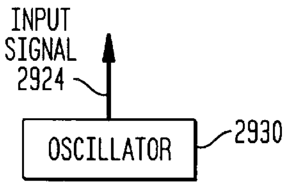


FIG. 30

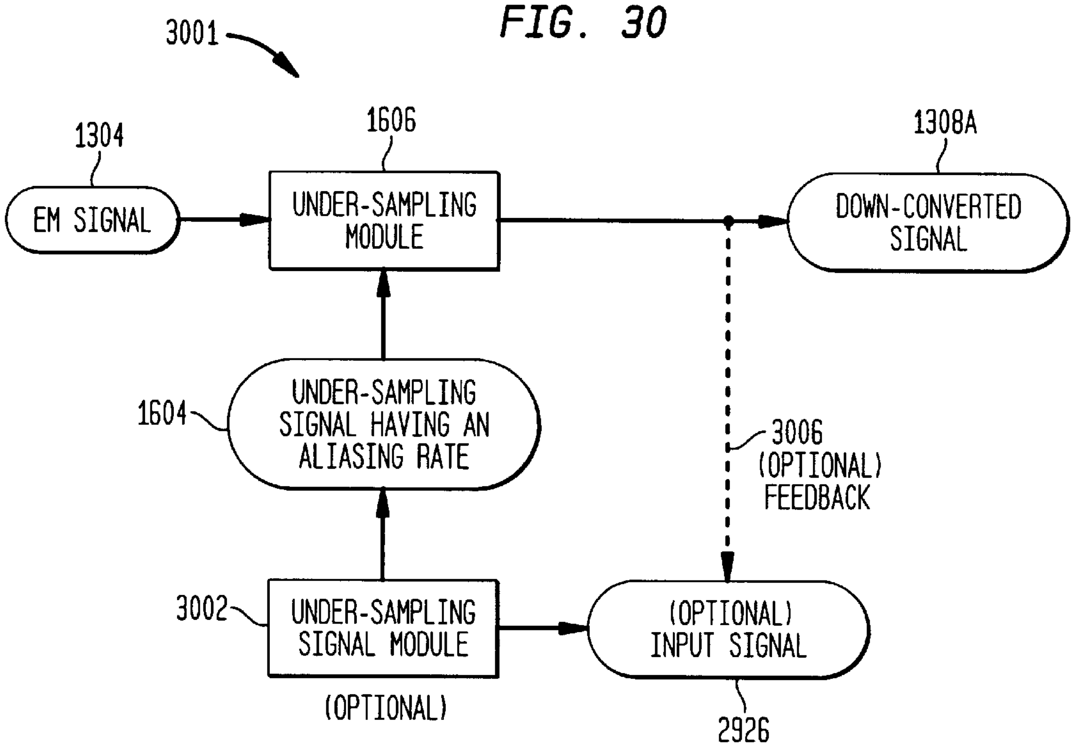

3001
1304
EM SIGNAL
1606
UNDER-SAMPLING MODULE
1308A
DOWN-CONVERTED SIGNAL
1604
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE
3006
(OPTIONAL) FEEDBACK
3002
UNDER-SAMPLING SIGNAL MODULE
(OPTIONAL)
(OPTIONAL) INPUT SIGNAL
2926

FIG. 31

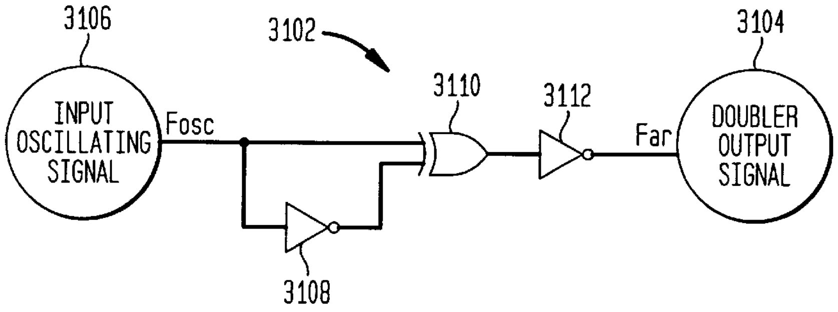


FIG. 32A

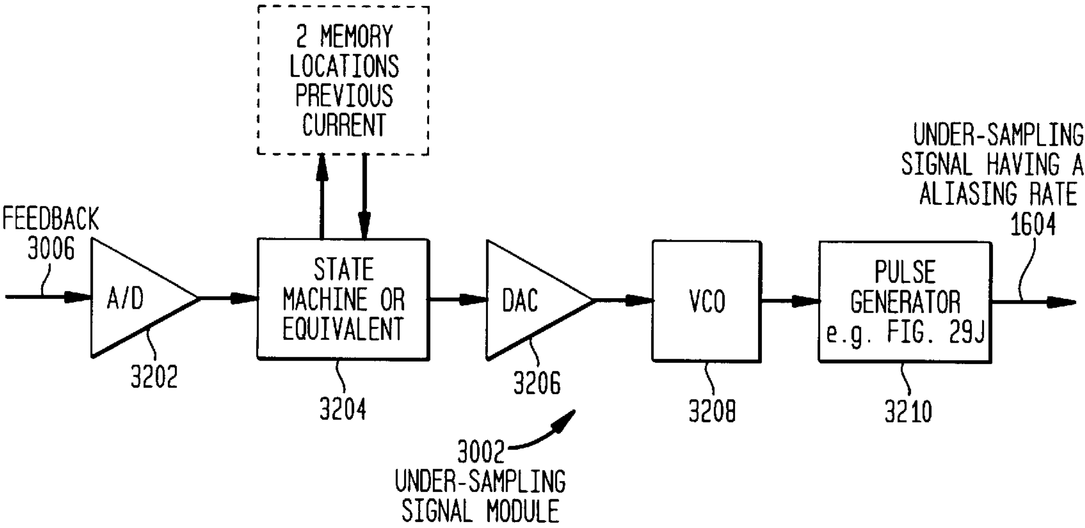
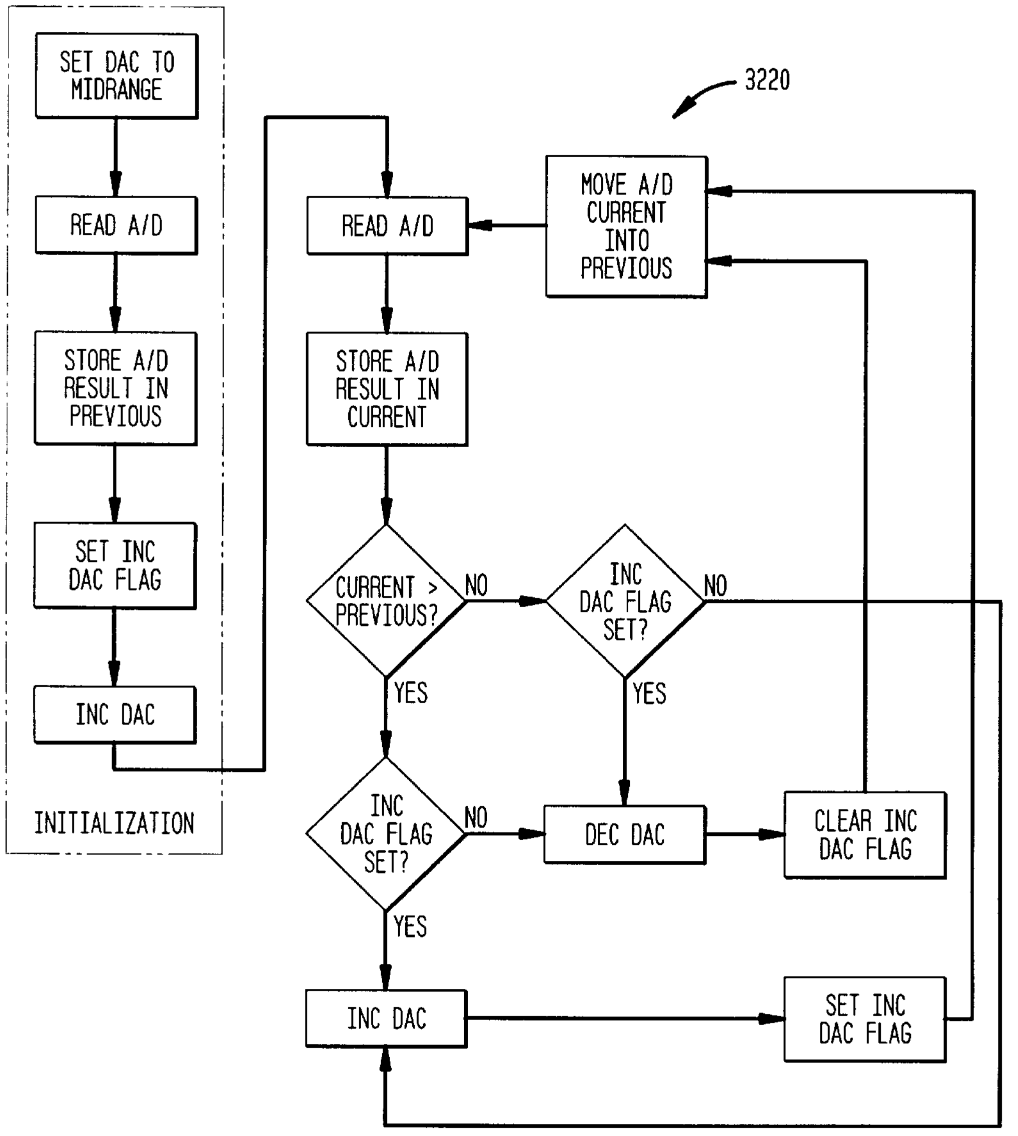
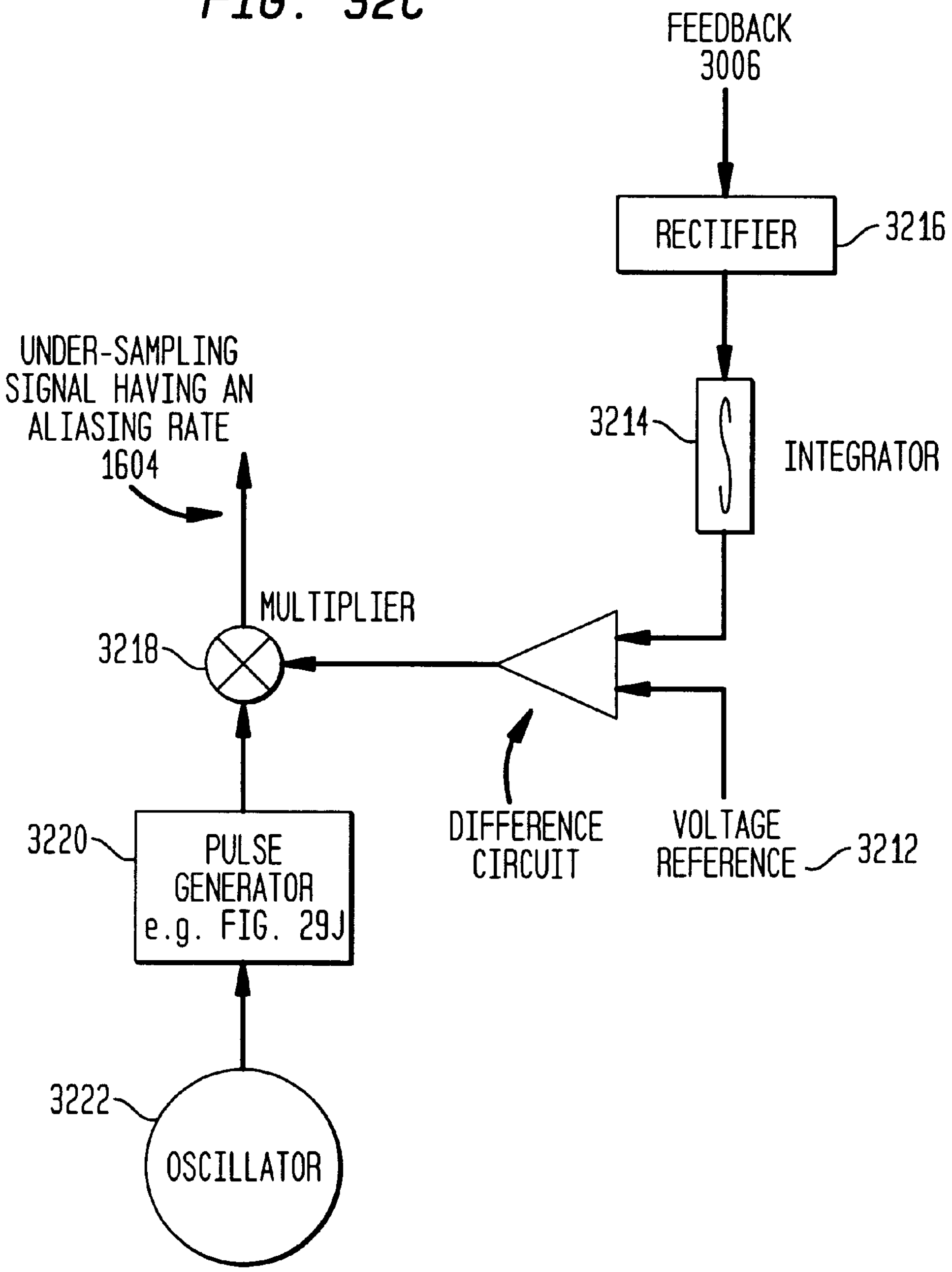


FIG. 32B



STATE MACHINE FLOWCHART

FIG. 32C



ENERGY TRANSFER SIGNAL MODULE 3002

FIG. 33A

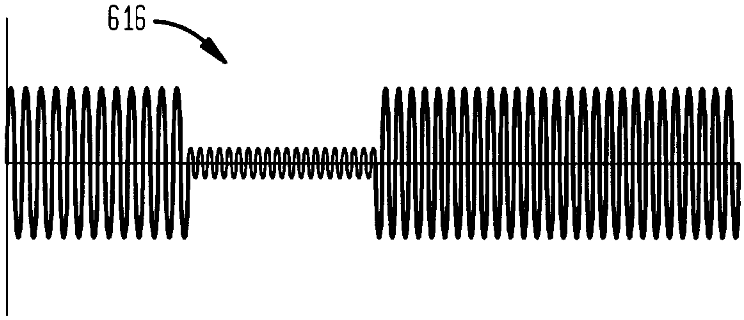


FIG. 33B

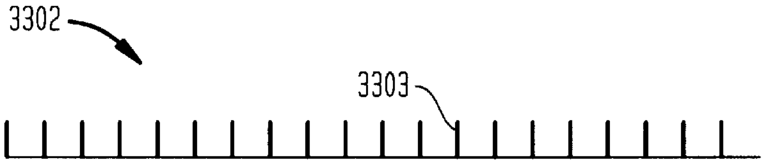


FIG. 33C

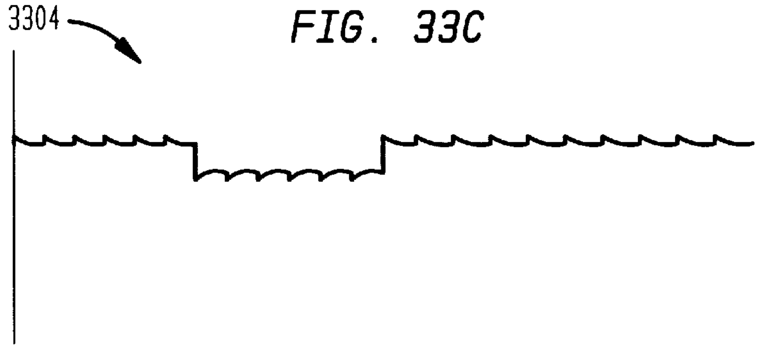
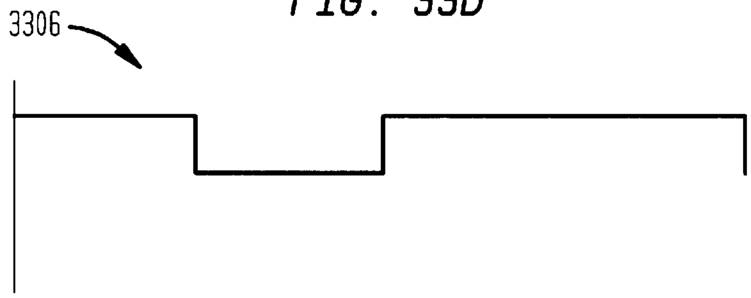


FIG. 33D



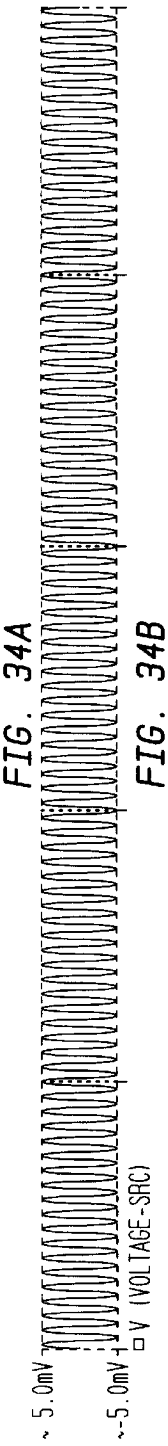


FIG. 34A

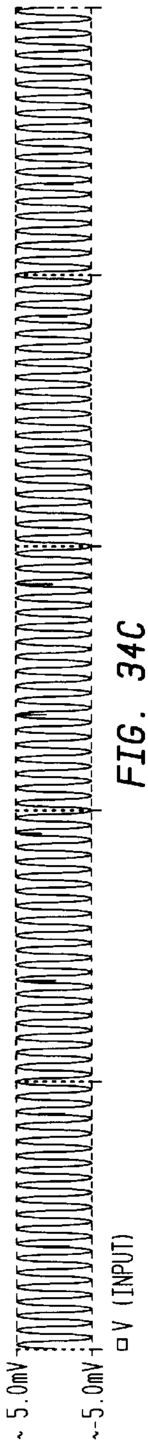


FIG. 34B

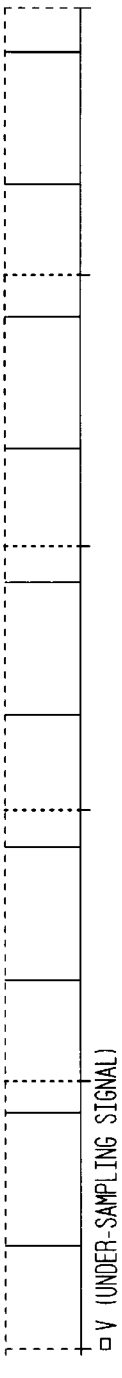


FIG. 34C

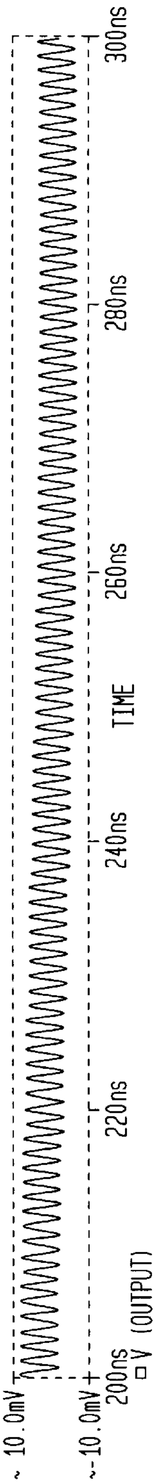


FIG. 34D

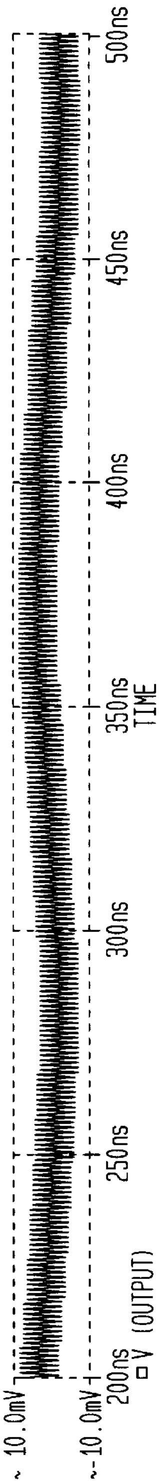


FIG. 34E

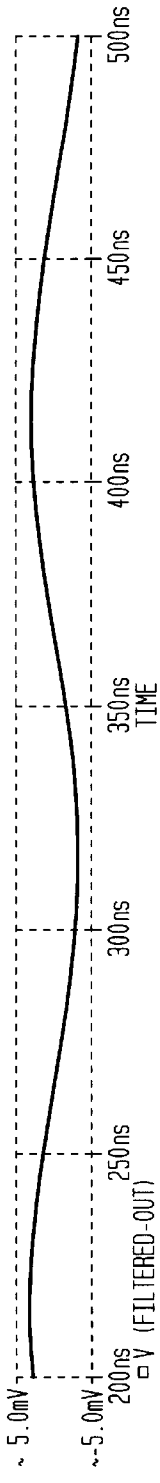


FIG. 34F

FIG. 35A

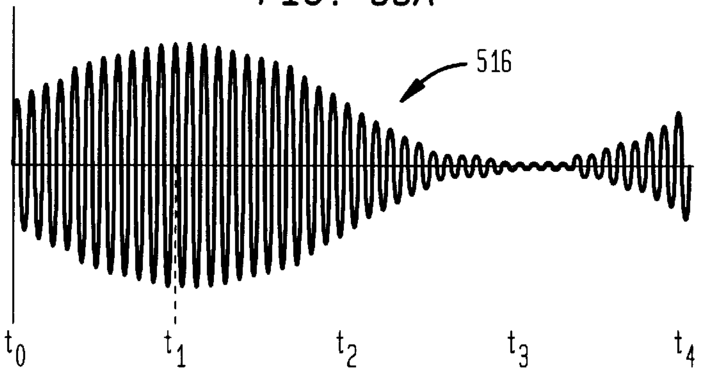


FIG. 35B

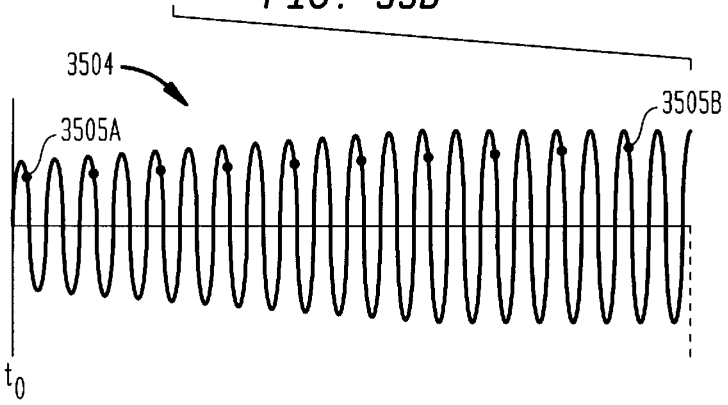


FIG. 35C

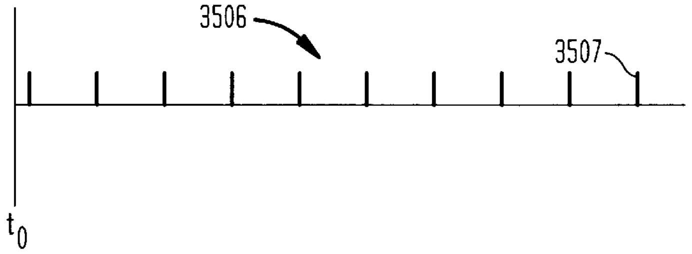


FIG. 35D

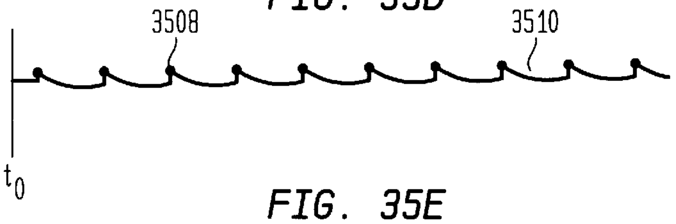


FIG. 35E

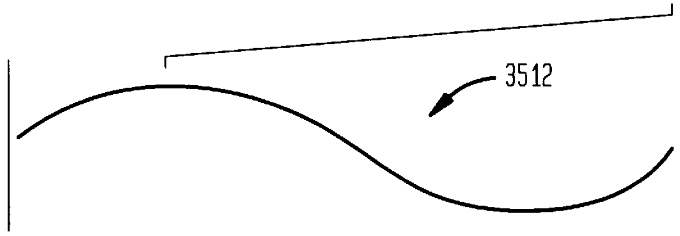


FIG. 36A

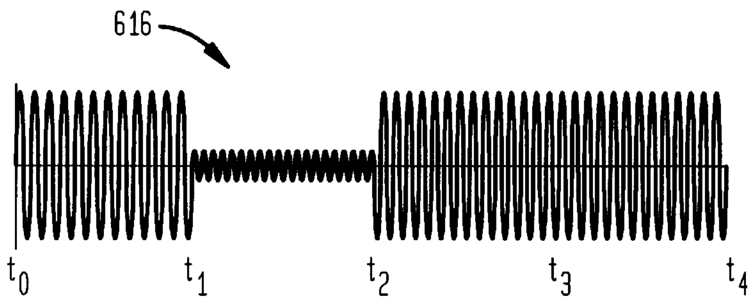


FIG. 36B

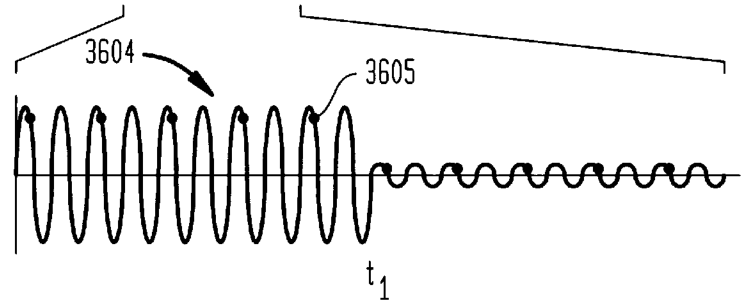


FIG. 36C

FIG. 36D

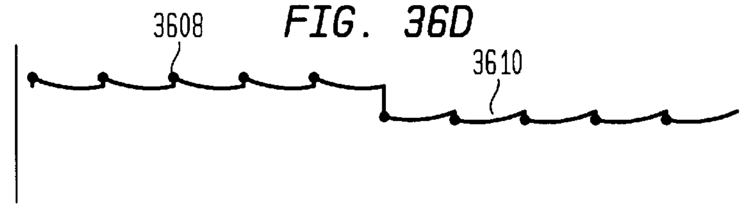


FIG. 36E

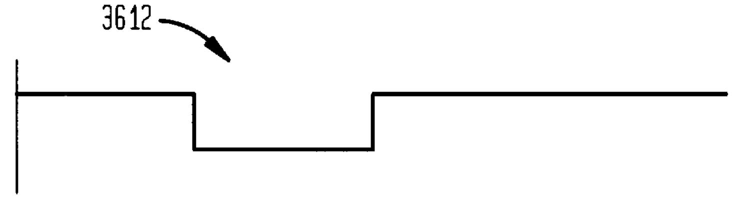


FIG. 37A

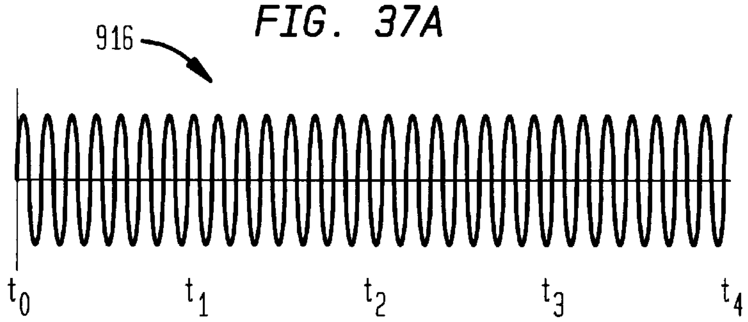


FIG. 37B

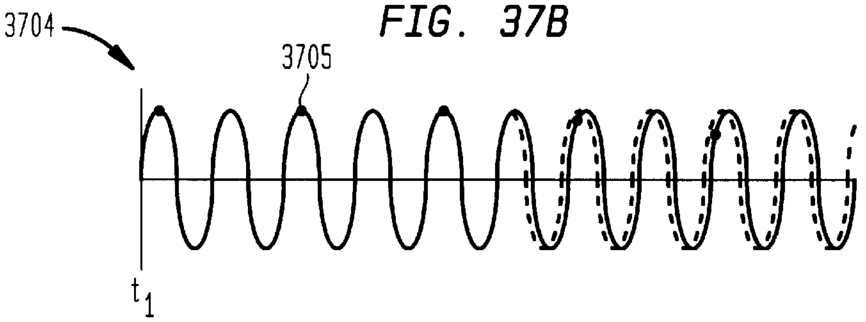


FIG. 37C

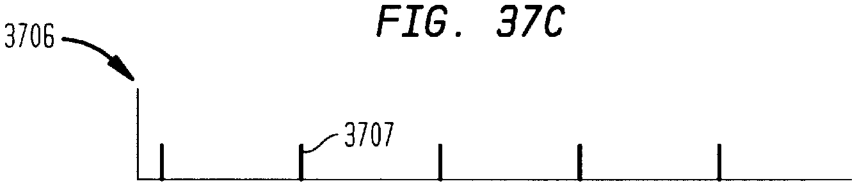


FIG. 37D

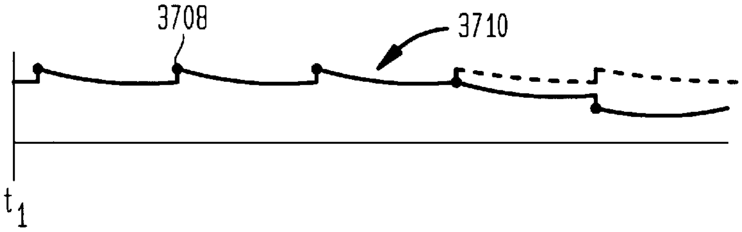


FIG. 37E

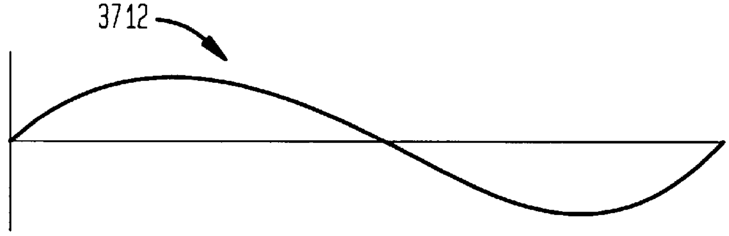


FIG. 38A

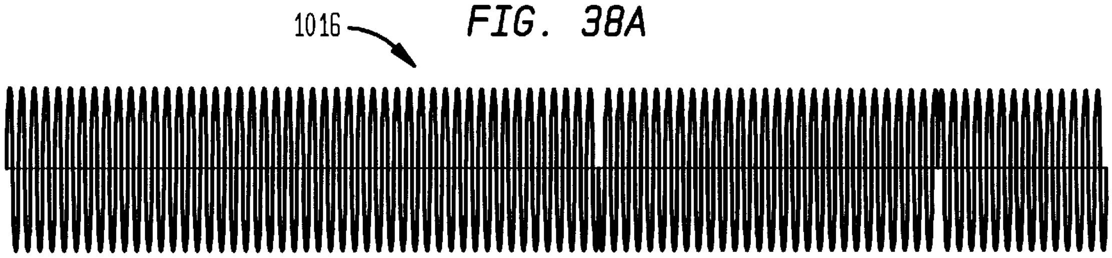


FIG. 38B

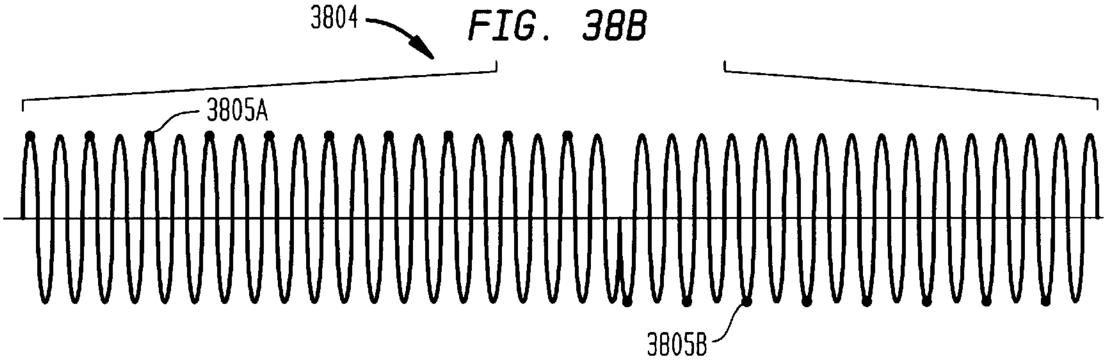


FIG. 38C

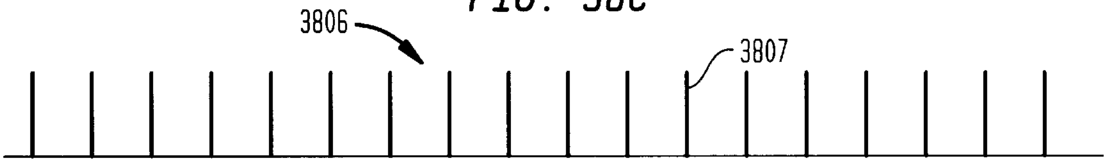


FIG. 38D

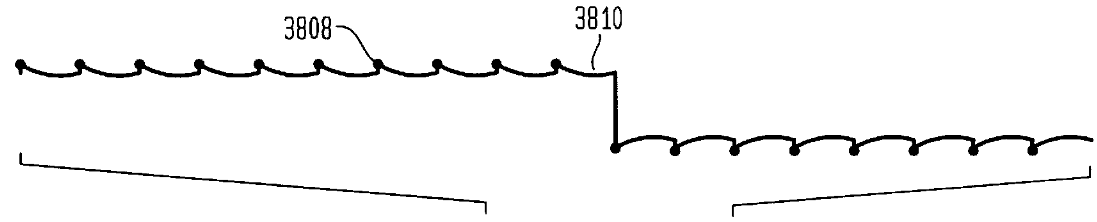


FIG. 38E

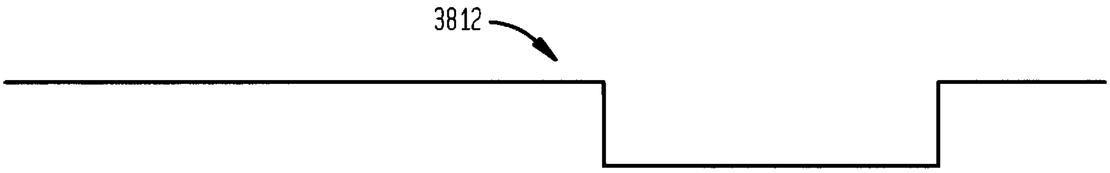


FIG. 39A

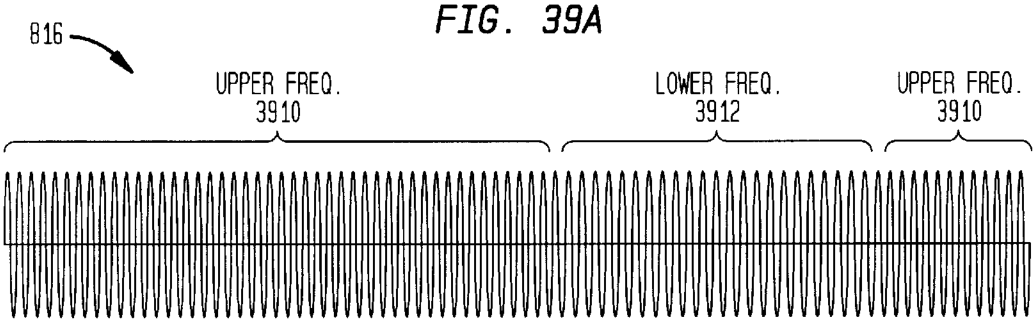


FIG. 39B

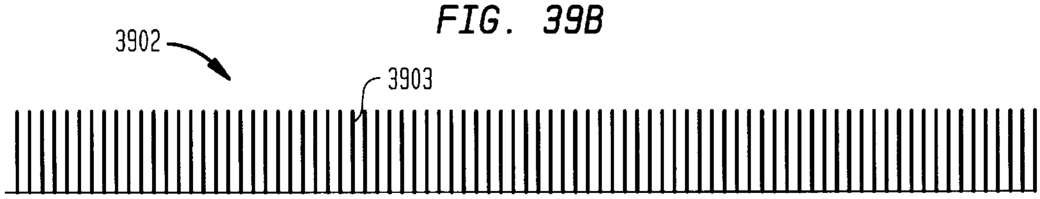


FIG. 39C

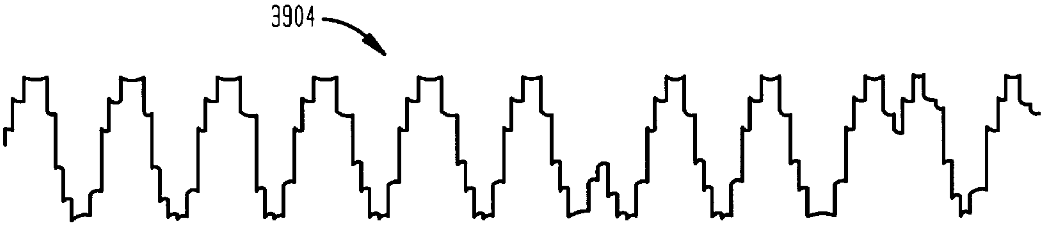


FIG. 39D

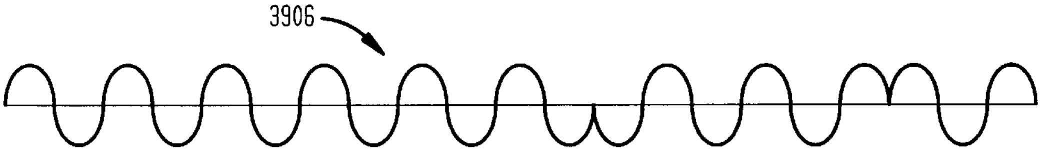


FIG. 40A

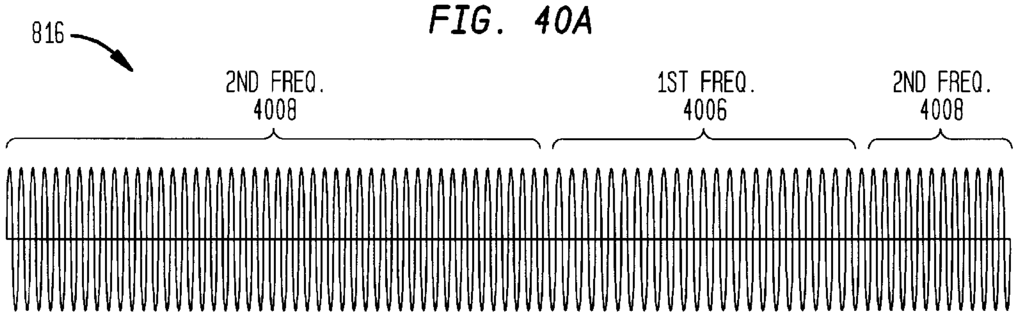


FIG. 40B

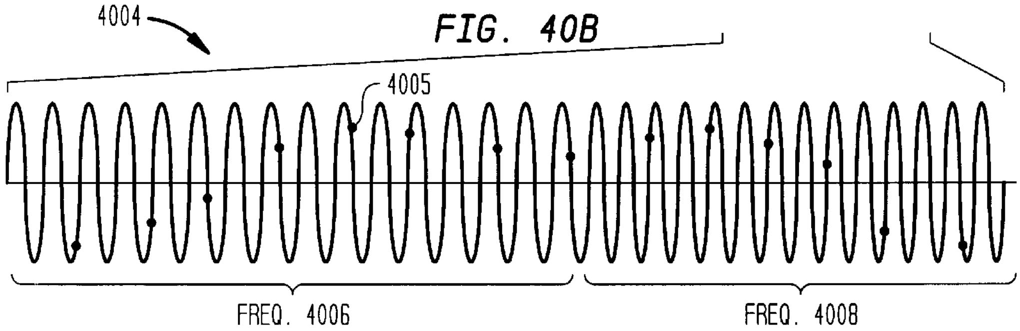


FIG. 40C

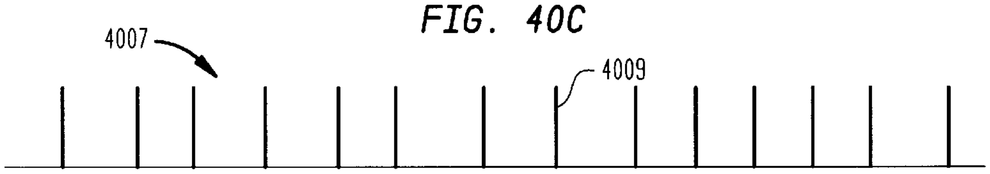


FIG. 40D

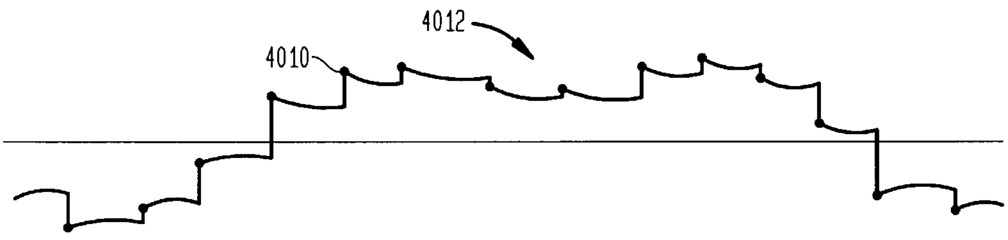


FIG. 40E

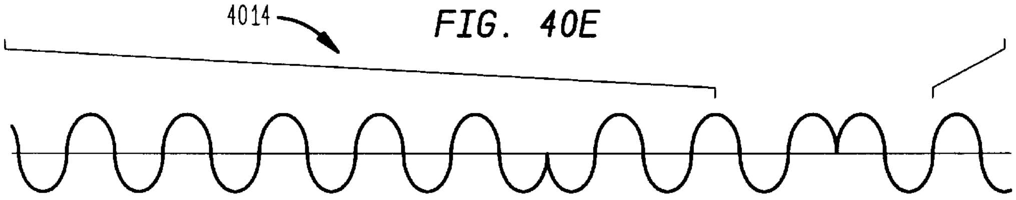


FIG. 41A

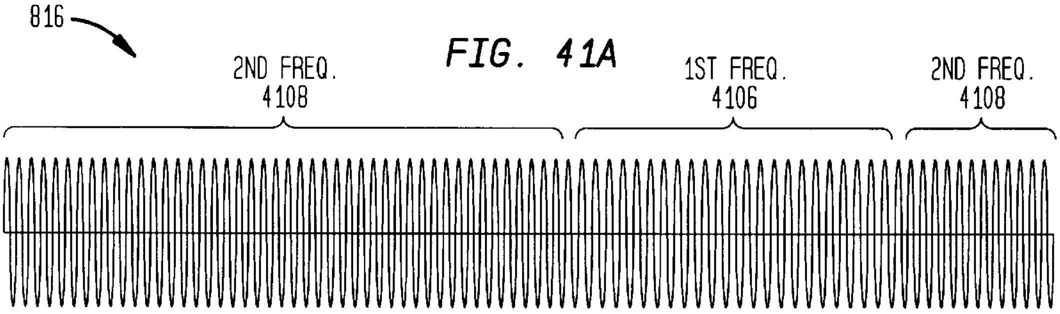


FIG. 41B

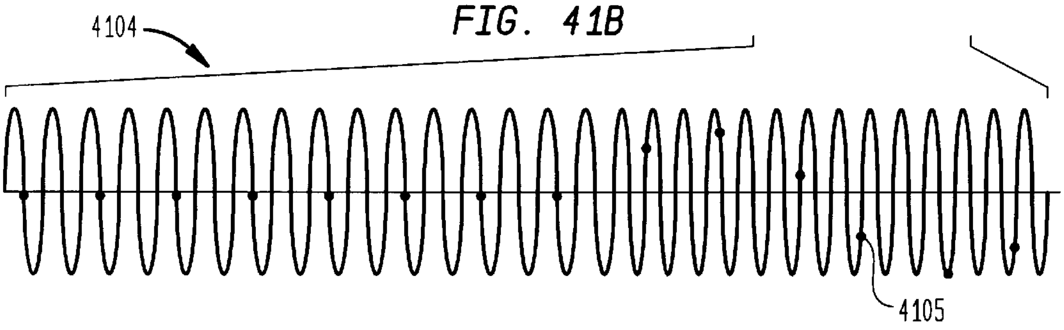


FIG. 41C

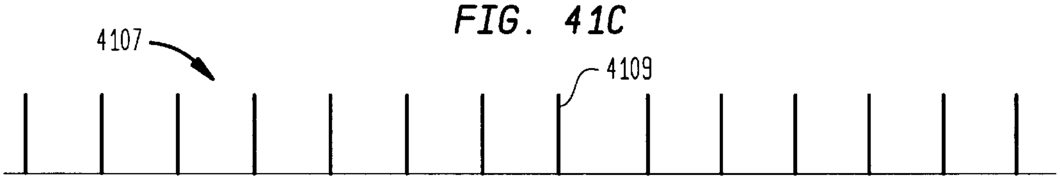


FIG. 41D

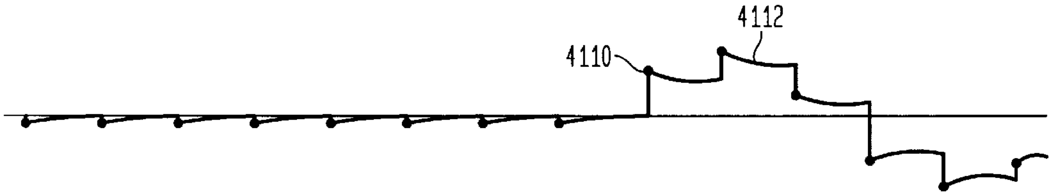


FIG. 41E

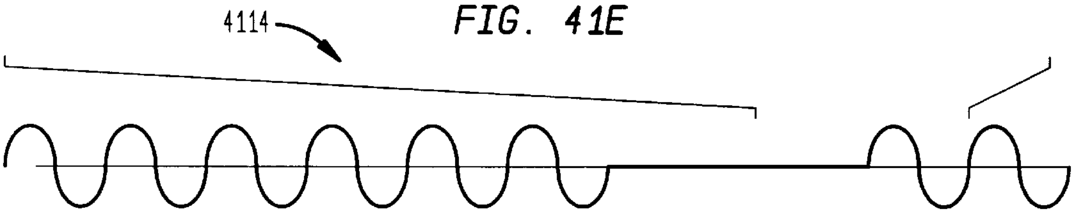
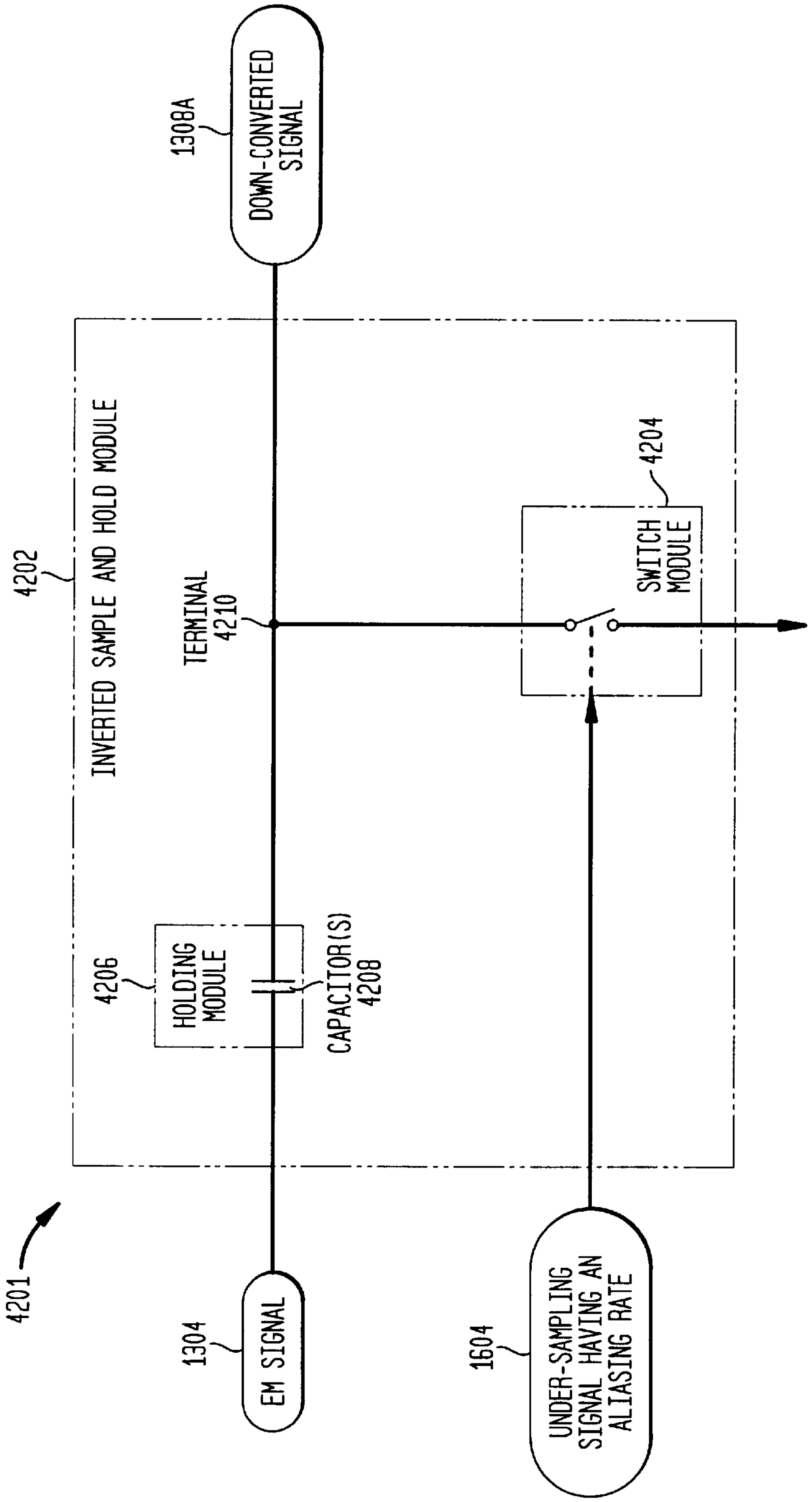


FIG. 42


1308A
DOWN-CONVERTED SIGNAL
4202
INVERTED SAMPLE AND HOLD MODULE
TERMINAL 4210
4204
SWITCH MODULE
4206
HOLDING MODULE
CAPACITOR(S) 4208
4201
1304
EM SIGNAL
1604
UNDER-SAMPLING SIGNAL HAVING AN ALIASING RATE

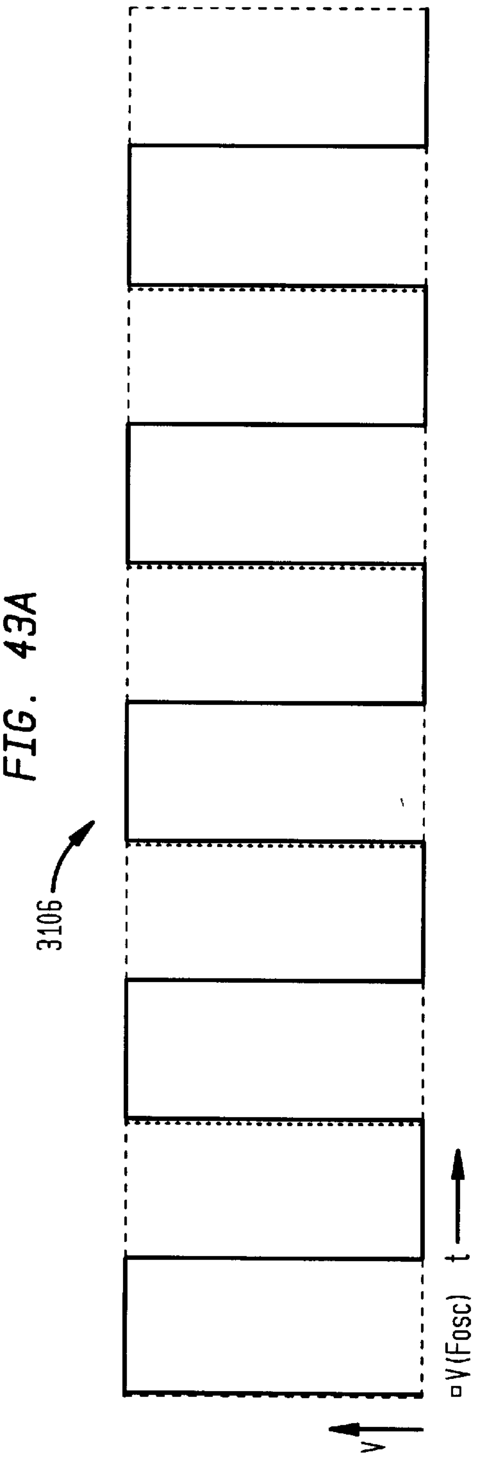


FIG. 43A

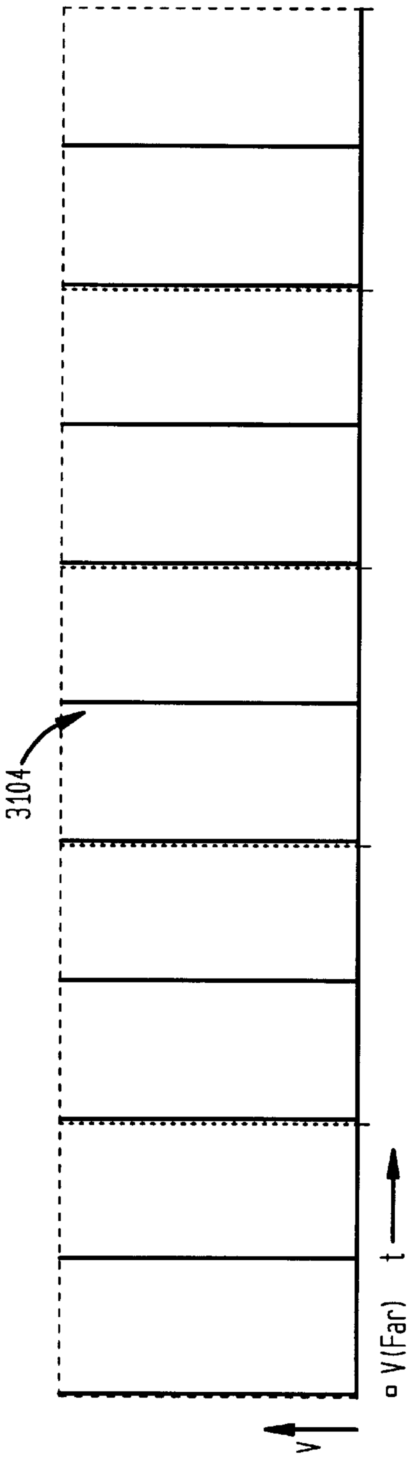


FIG. 43B

FIG. 44A

DIFFERENTIAL CONFIGURATION

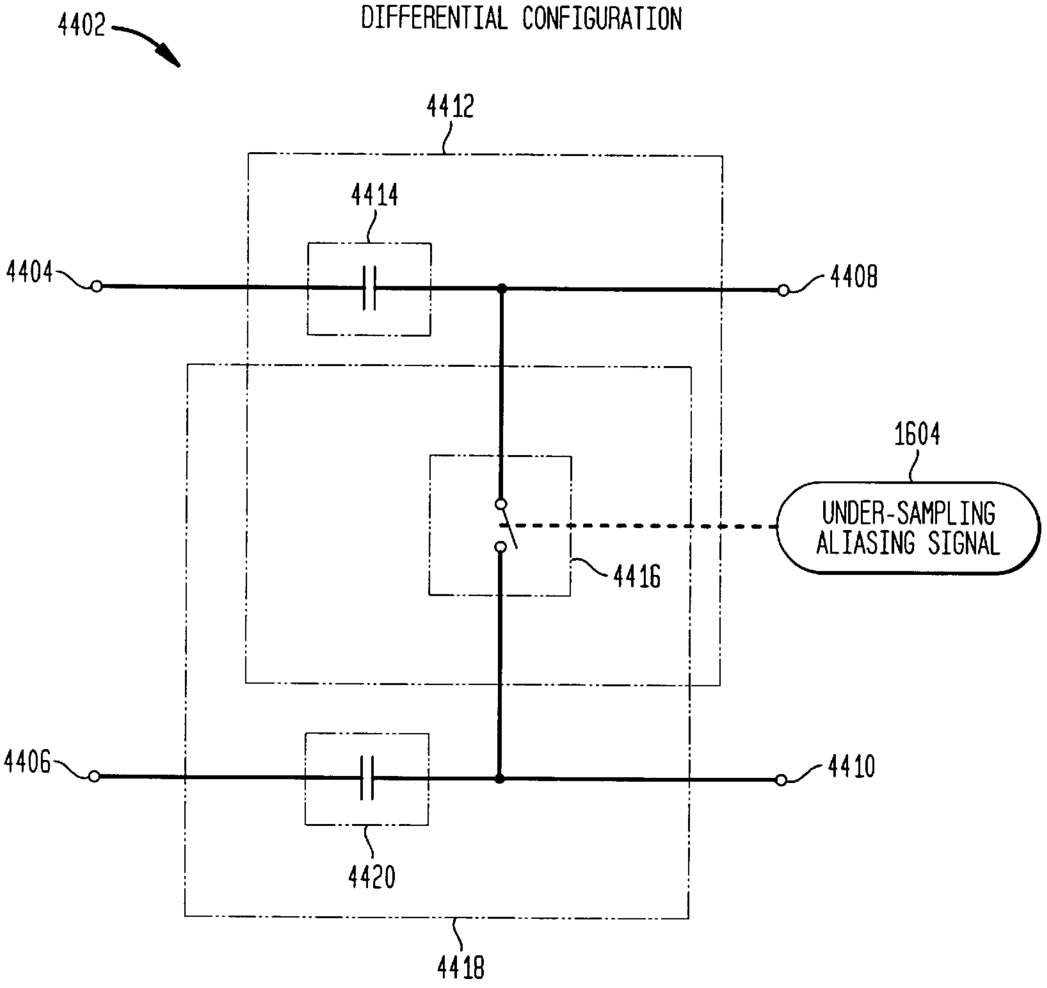


FIG. 44B

DIFFERENTIAL INPUT TO DIFFERENTIAL OUTPUT

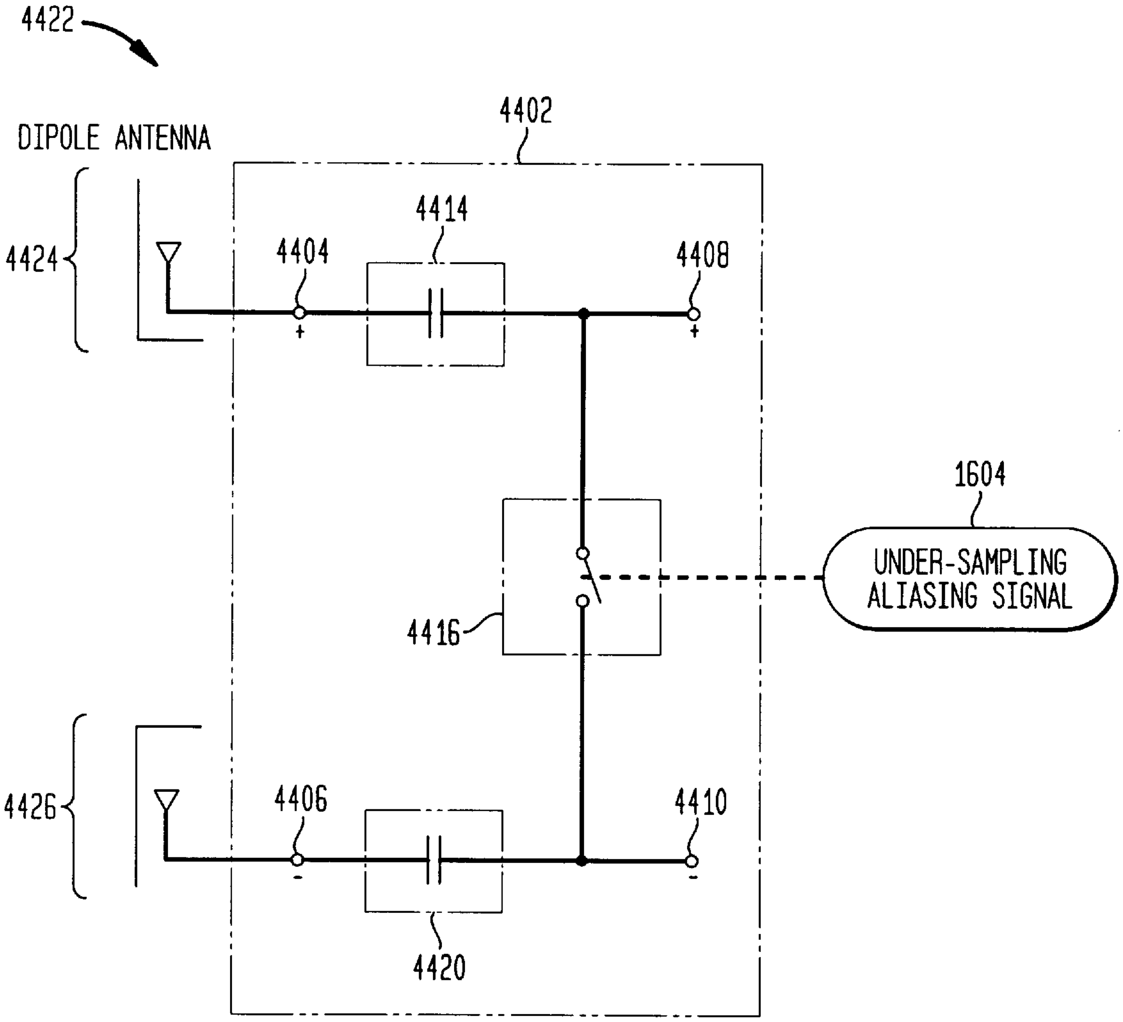


FIG. 44C

SINGLE INPUT TO DIFFERENTIAL OUTPUT

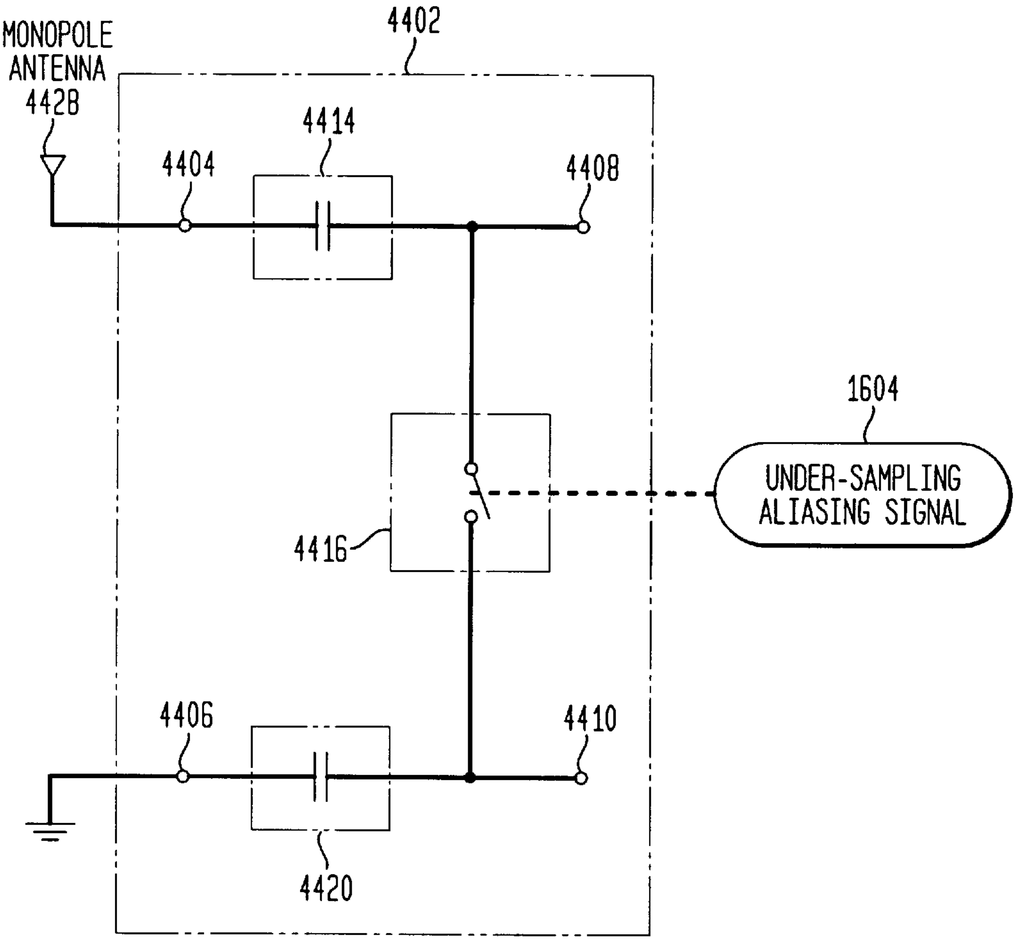


FIG. 44D

DIFFERENTIAL INPUT TO SINGLE OUTPUT

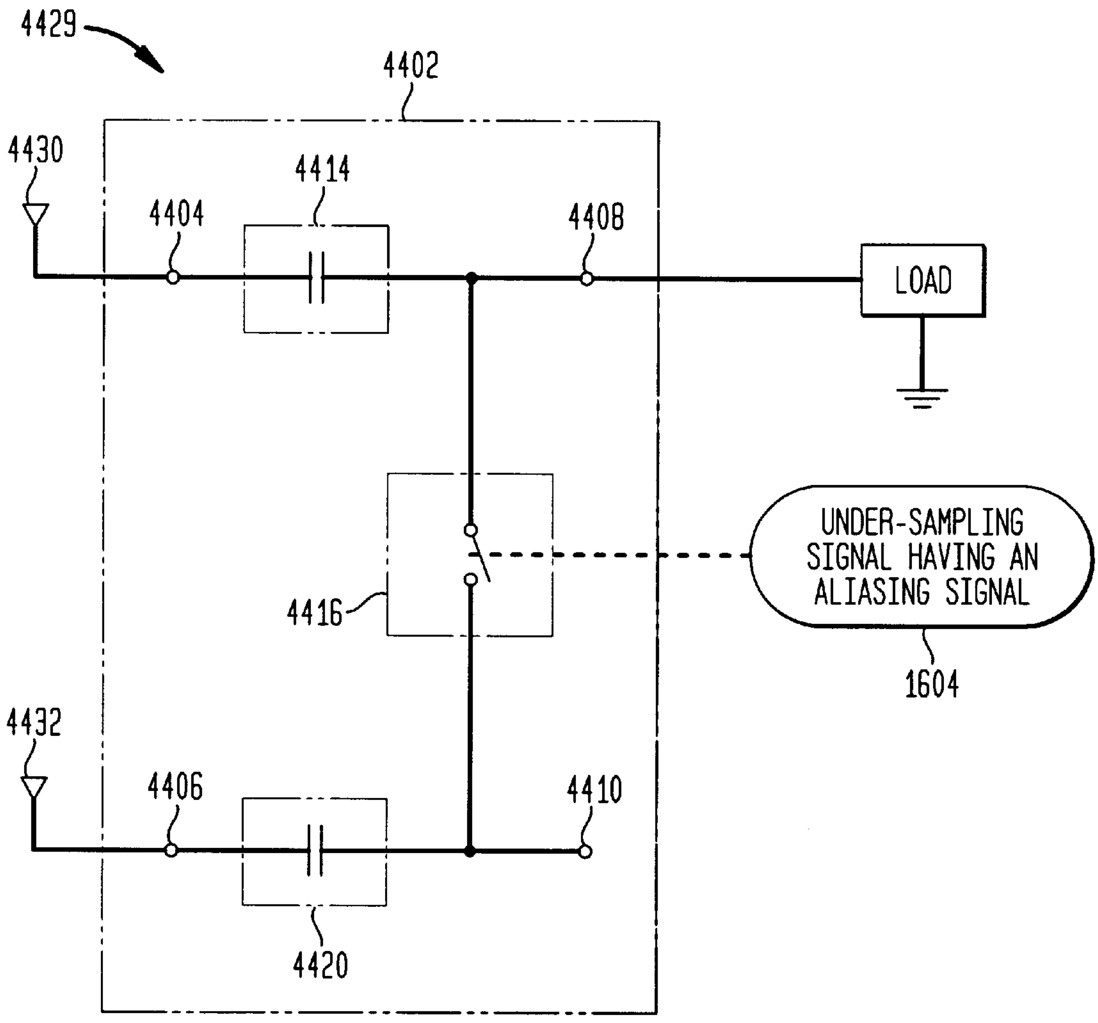


FIG. 44E

EXAMPLE INPUT/OUTPUT CIRCUITRY

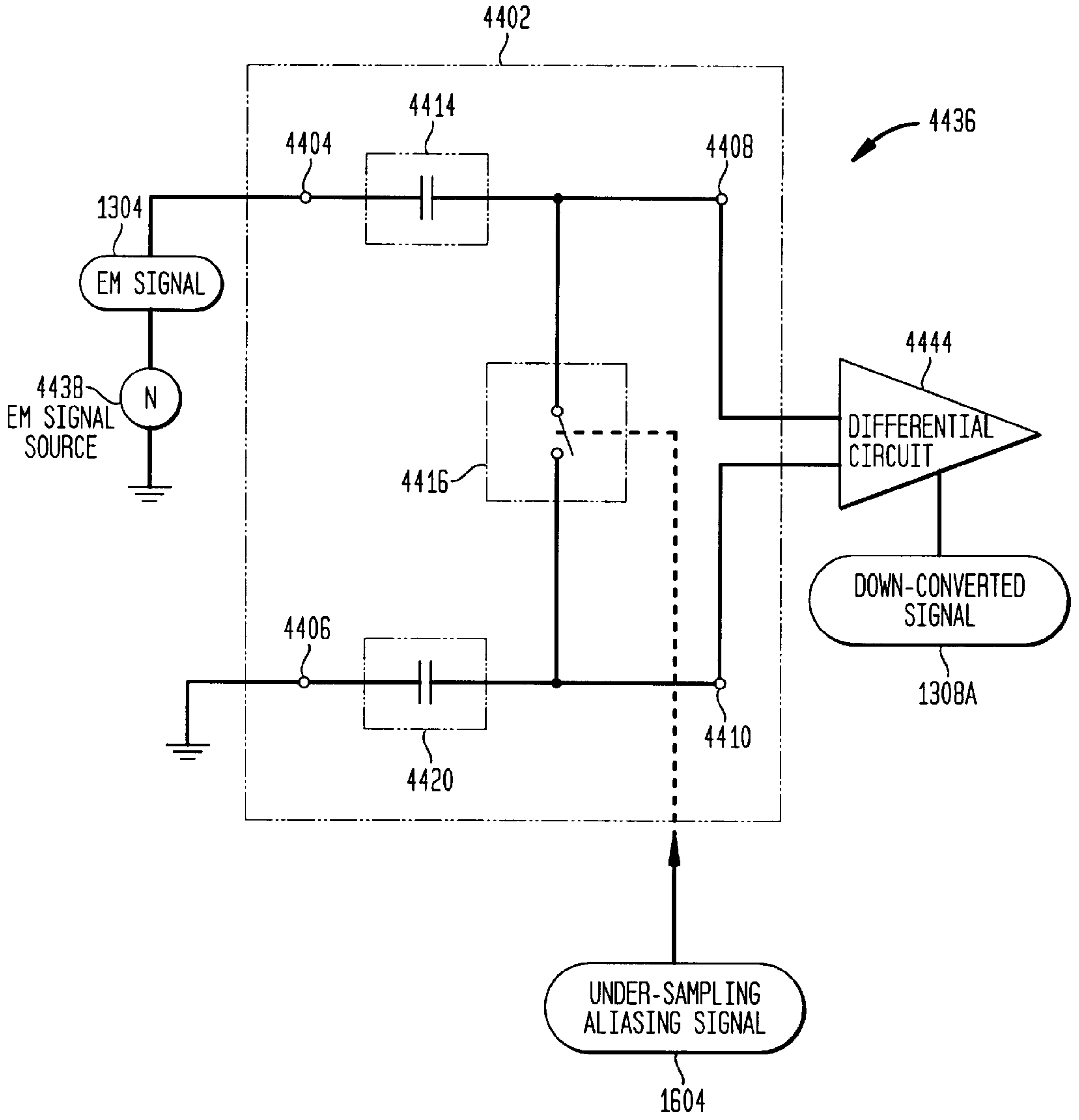


FIG. 45A

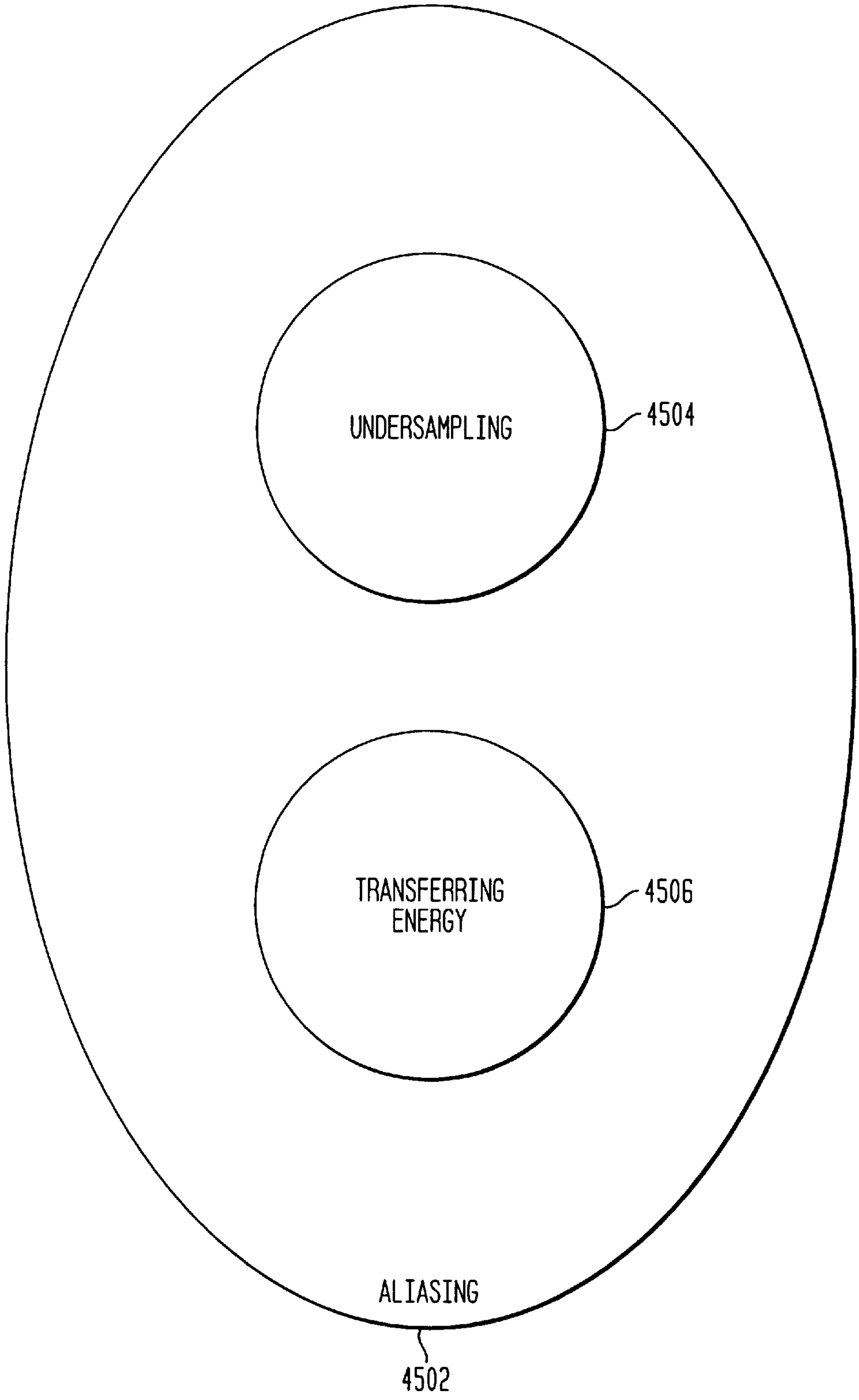

UNDERSAMPLING
4504
TRANSFERRING ENERGY
4506
ALIASING
4502

FIG. 45B

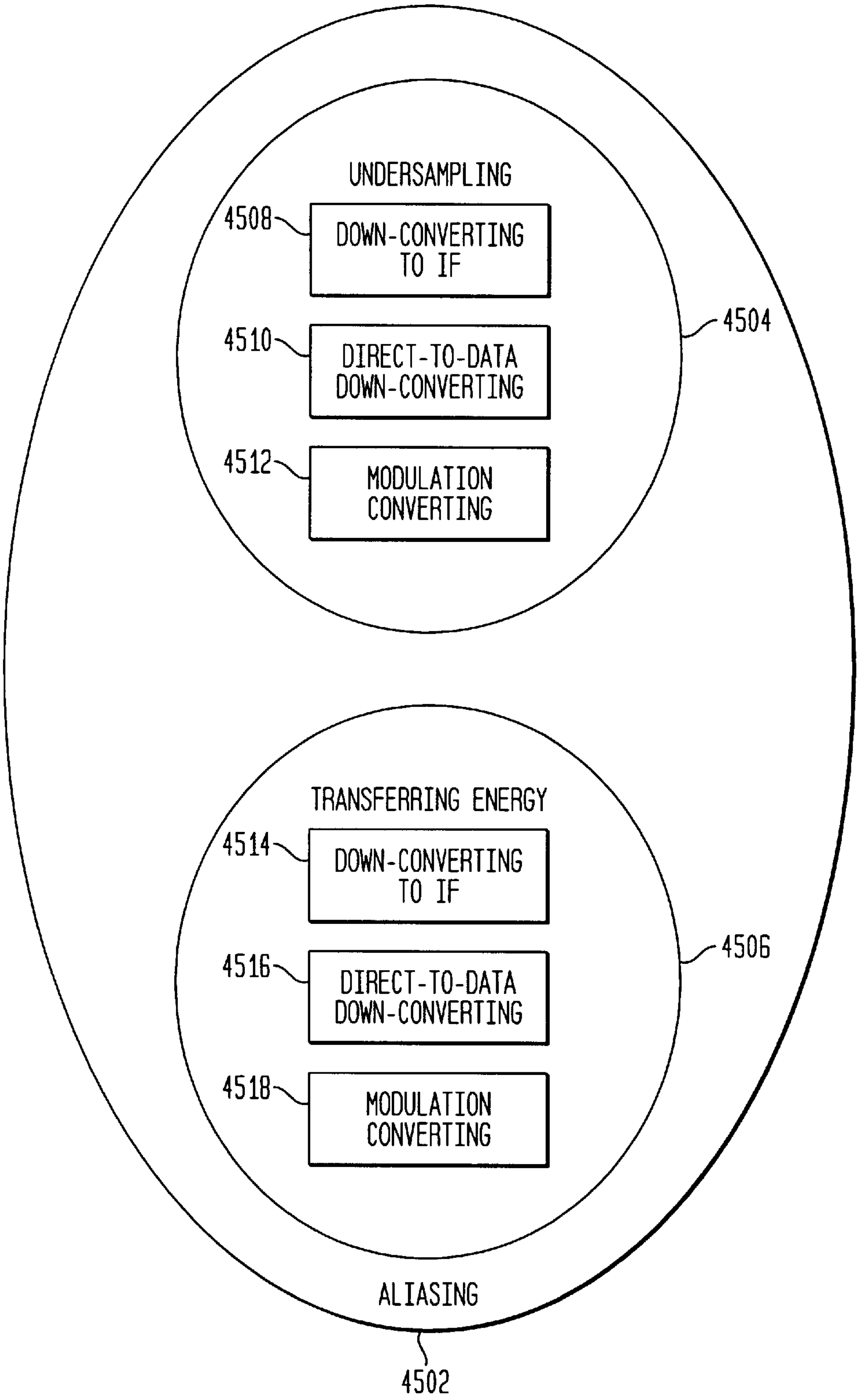

UNDERSAMPLING
4508
DOWN-CONVERTING TO IF
4510
DIRECT-TO-DATA DOWN-CONVERTING
4512
MODULATION CONVERTING
4504
TRANSFERRING ENERGY
4514
DOWN-CONVERTING TO IF
4516
DIRECT-TO-DATA DOWN-CONVERTING
4518
MODULATION CONVERTING
4506
ALIASING
4502

FIG. 46A

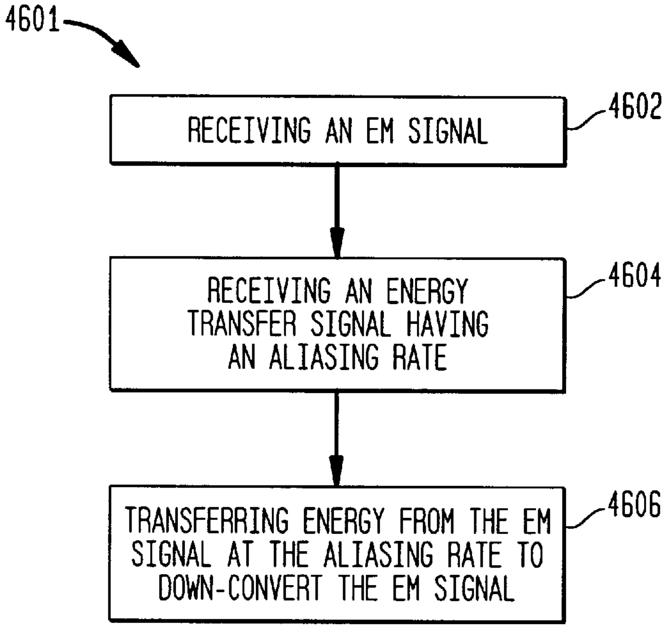


FIG. 46B

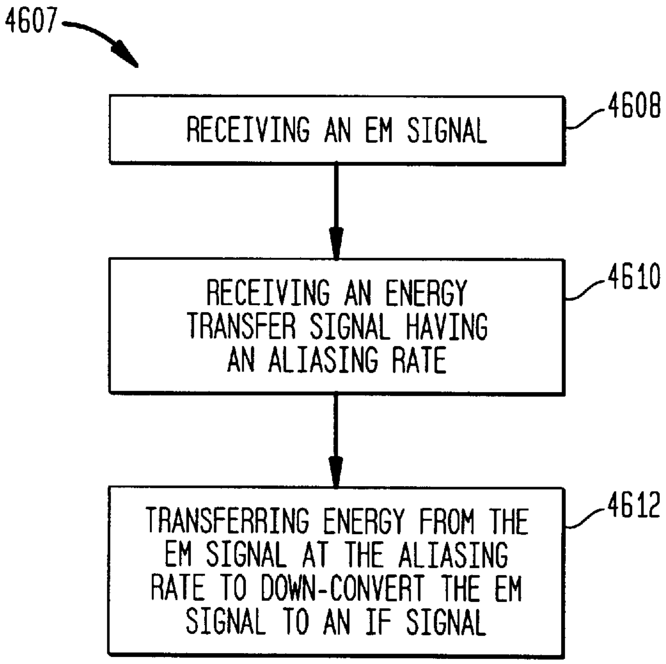


FIG. 46C

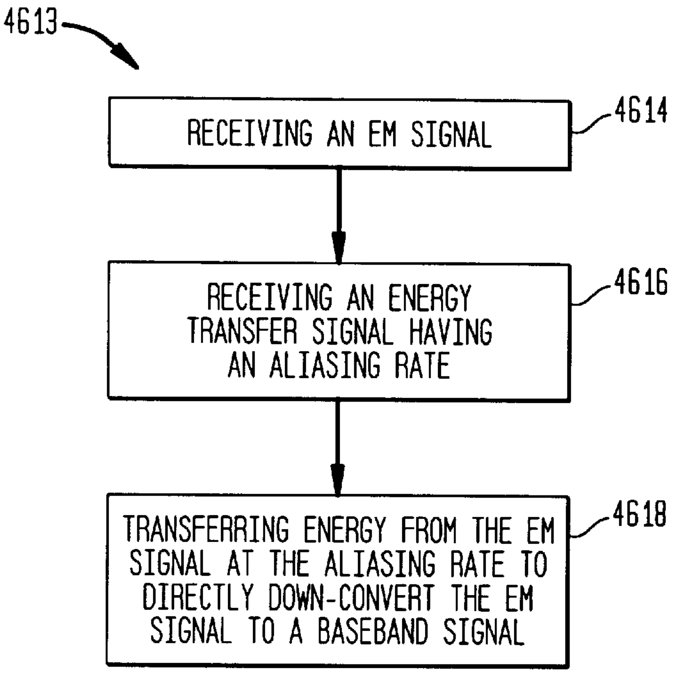


FIG. 46D

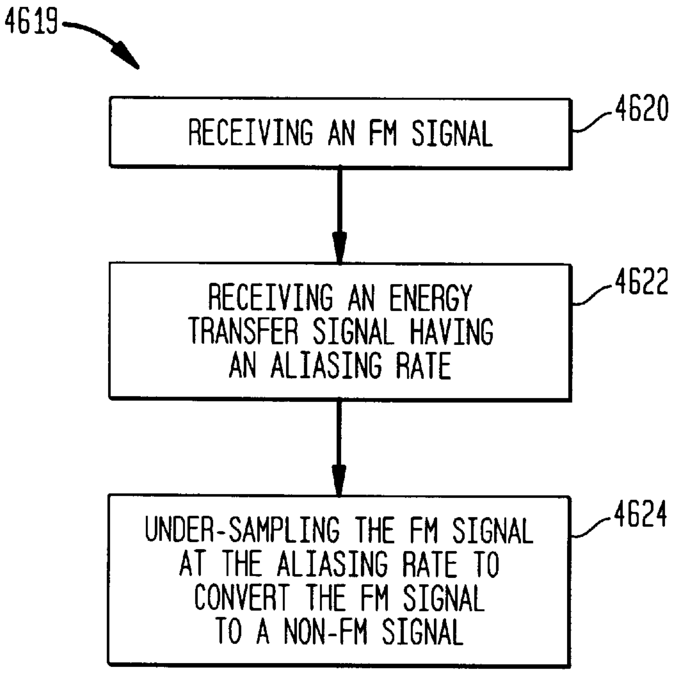


FIG. 47E

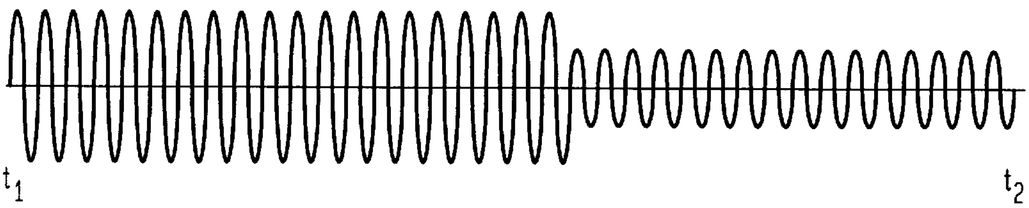


FIG. 47A

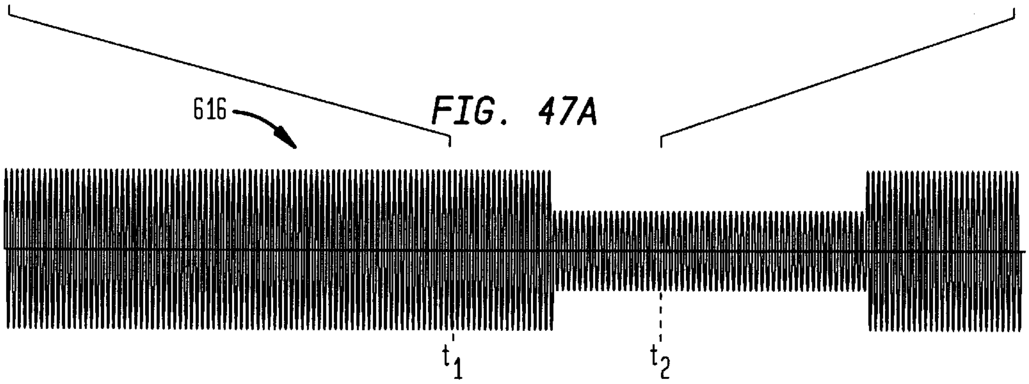


FIG. 47B

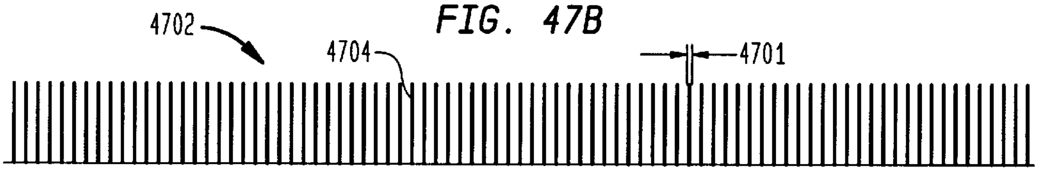


FIG. 47C

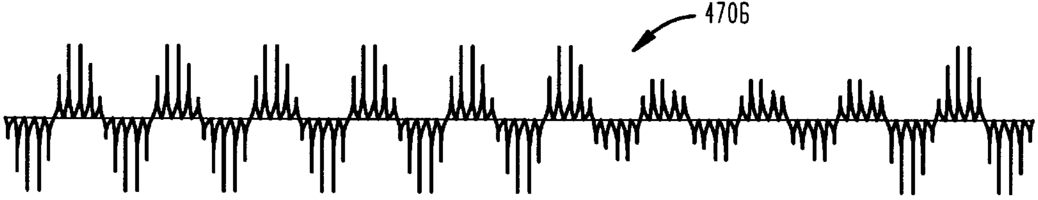


FIG. 47D

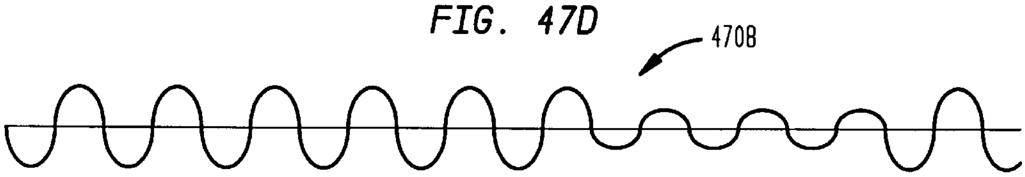


FIG. 48

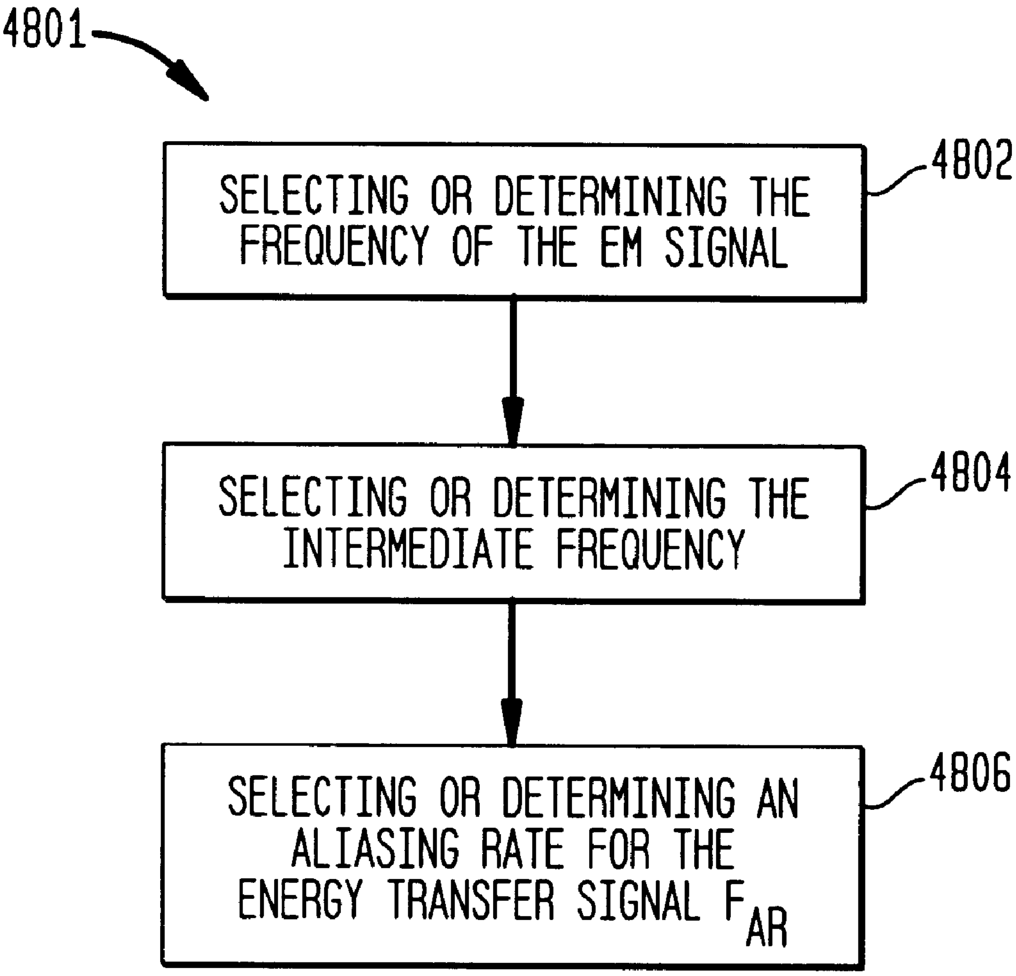

4801
SELECTING OR DETERMINING THE FREQUENCY OF THE EM SIGNAL
4802
SELECTING OR DETERMINING THE INTERMEDIATE FREQUENCY
4804
SELECTING OR DETERMINING AN ALIASING RATE FOR THE ENERGY TRANSFER SIGNAL F_{AR}
4806

FIG. 49A

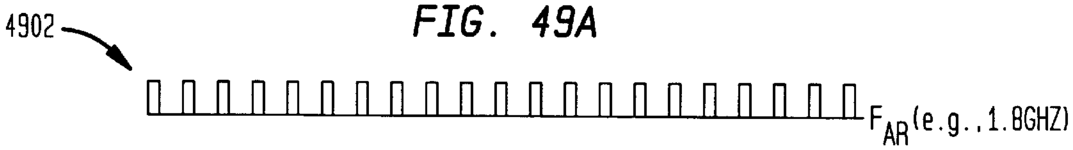


FIG. 49B

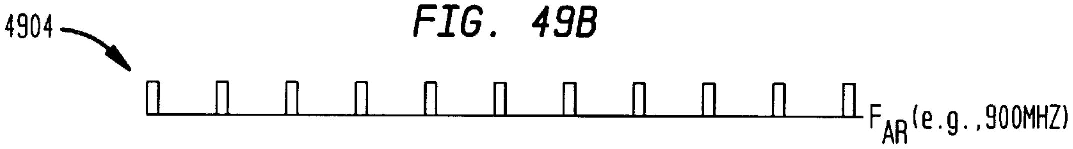


FIG. 49C

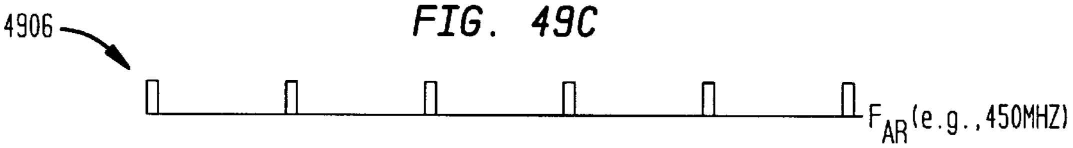


FIG. 49D

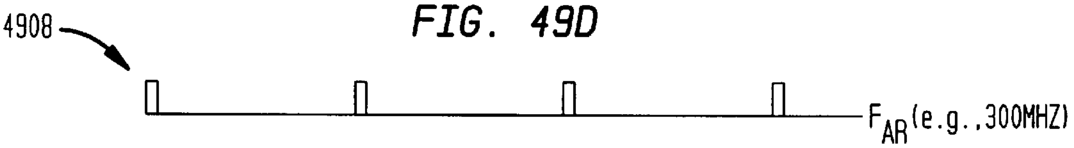


FIG. 49E

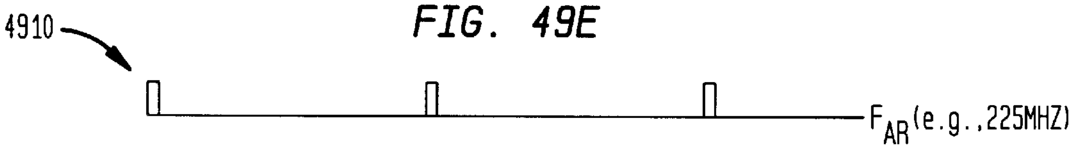


FIG. 49F

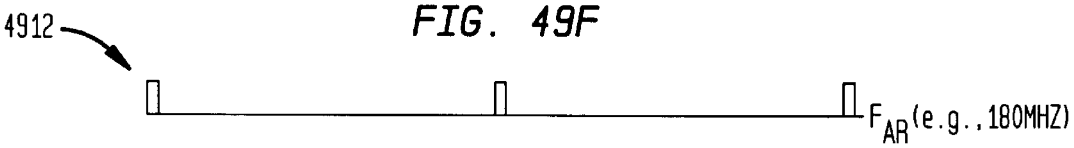


FIG. 49G

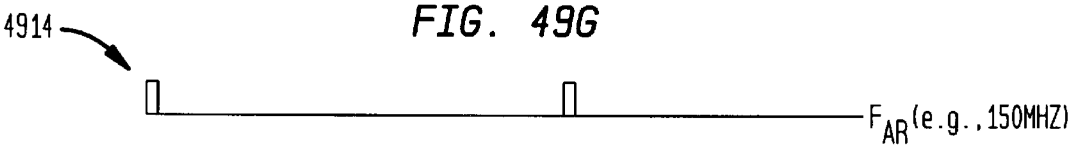
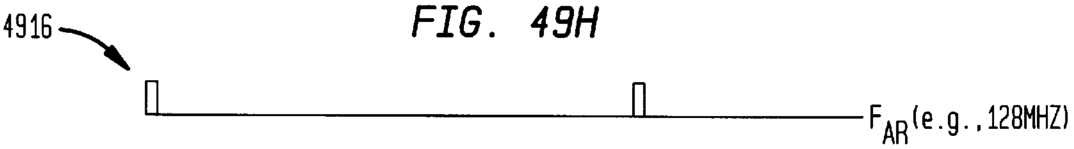


FIG. 49H



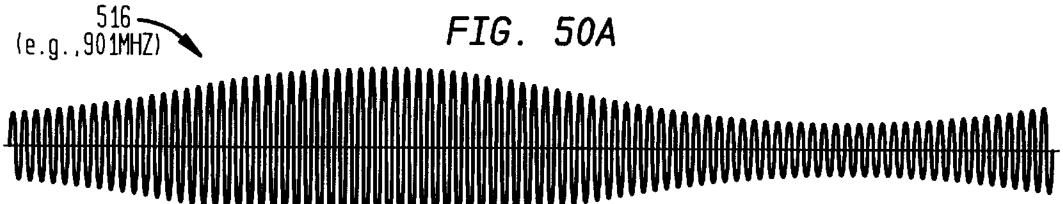


FIG. 50A

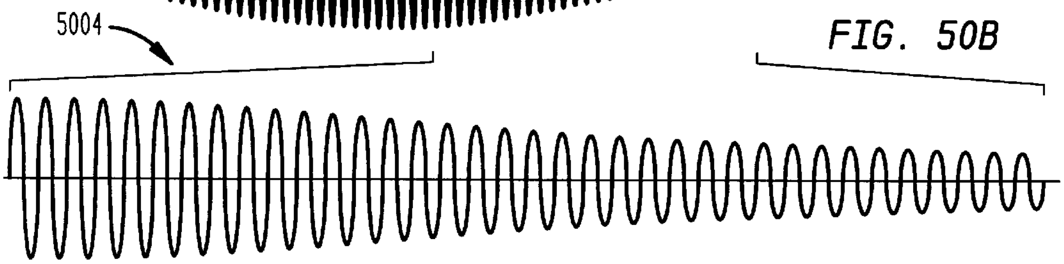


FIG. 50B

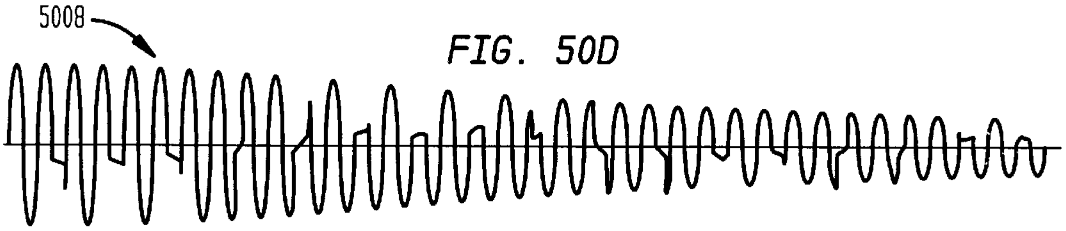


FIG. 50D

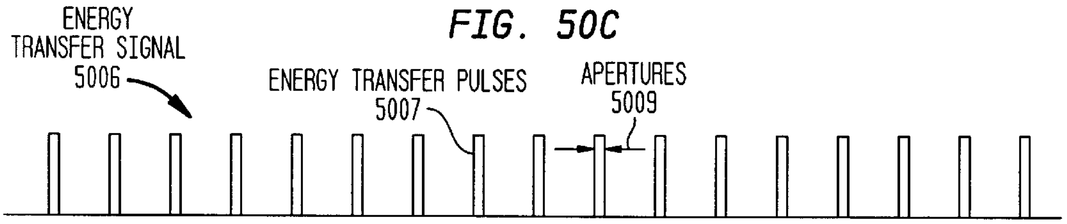


FIG. 50C

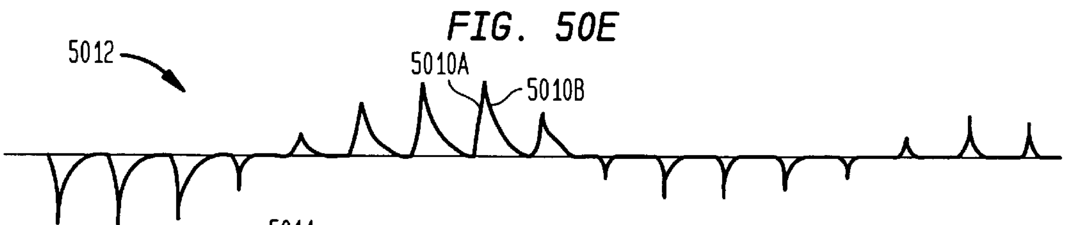


FIG. 50E

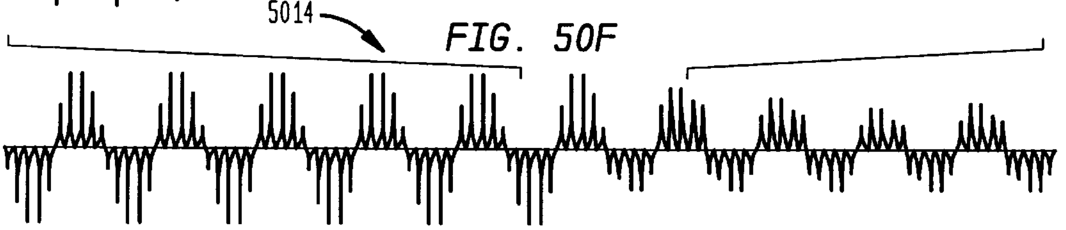


FIG. 50F

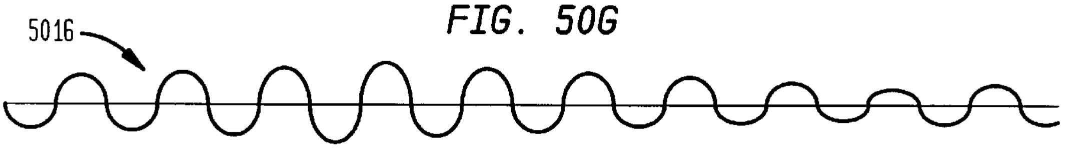


FIG. 50G

FIG. 51A

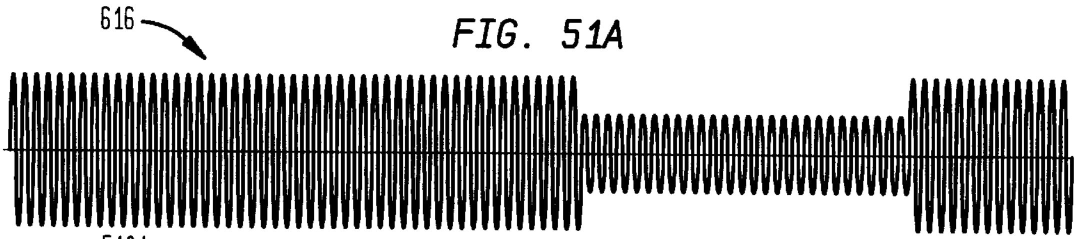


FIG. 51B

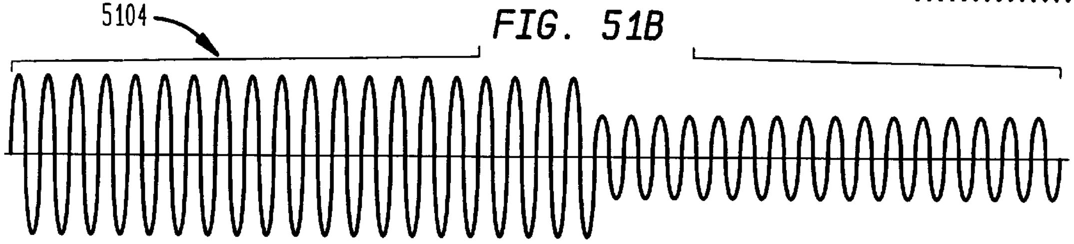


FIG. 51D

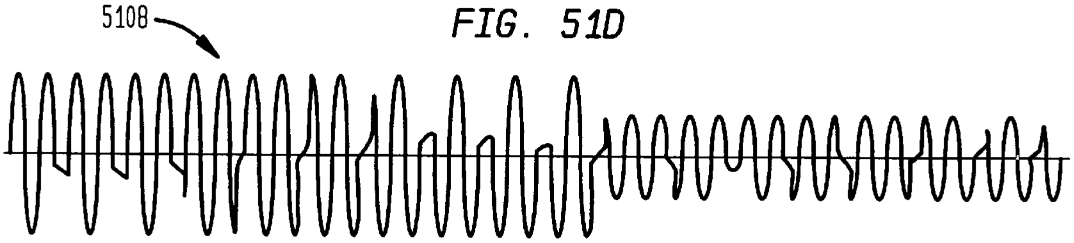


FIG. 51C

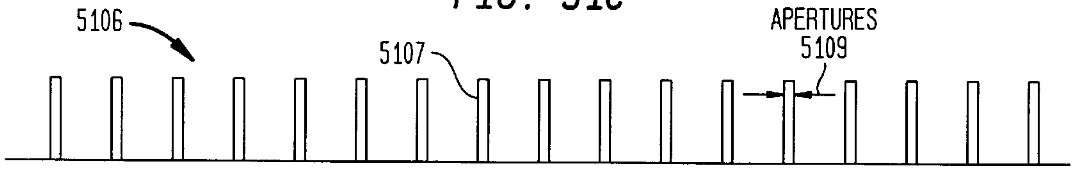


FIG. 51E

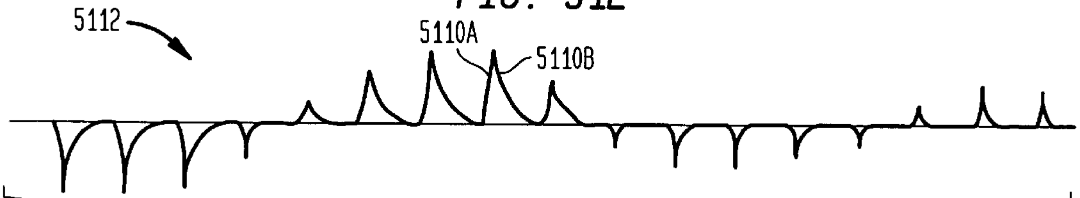


FIG. 51F

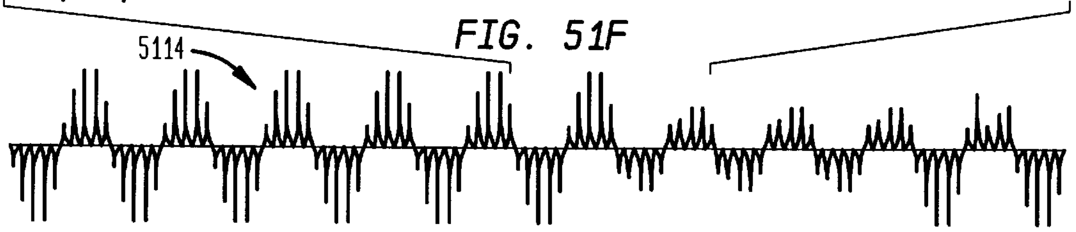


FIG. 51G

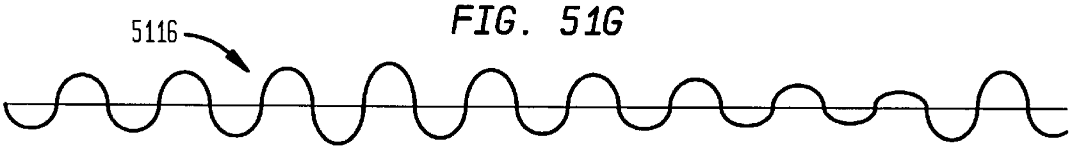


FIG. 52A

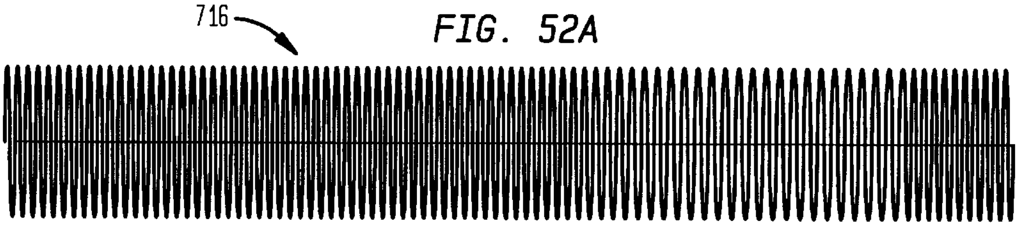


FIG. 52B

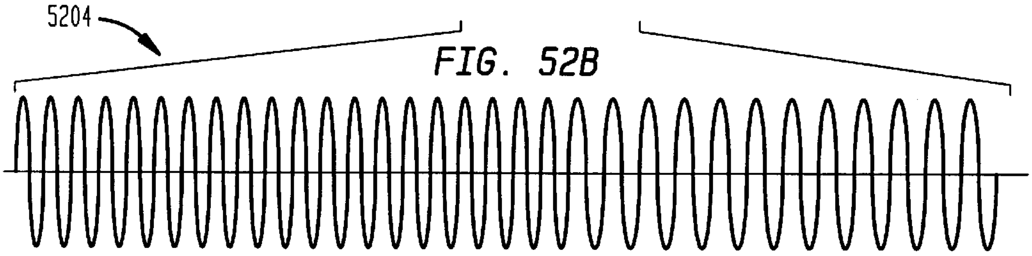


FIG. 52D

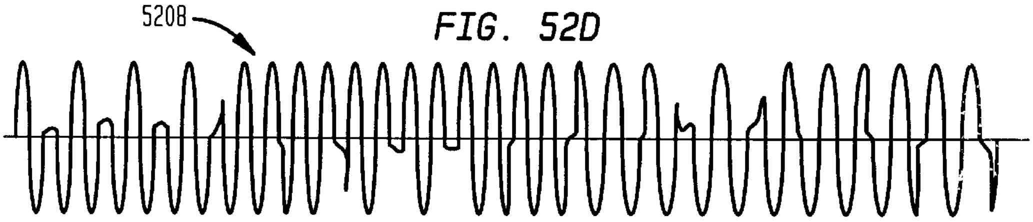


FIG. 52C

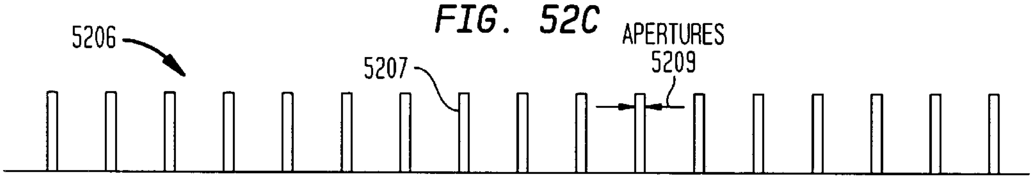


FIG. 52E

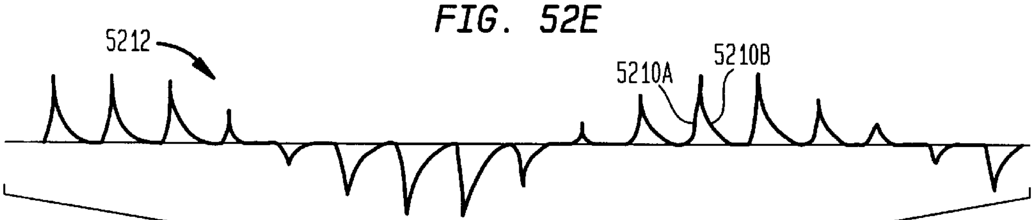


FIG. 52F

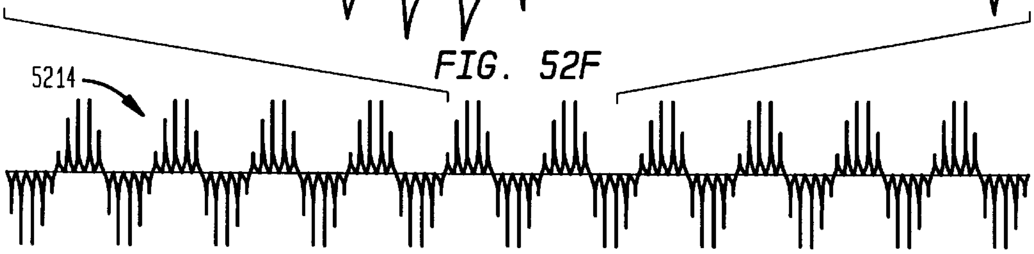


FIG. 52G

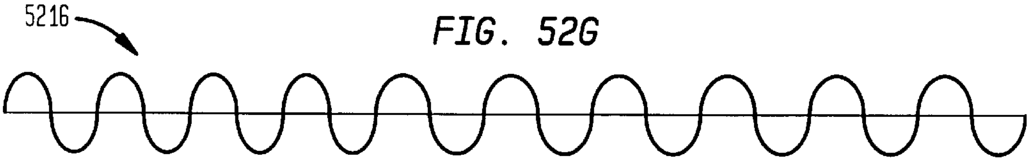


FIG. 53A

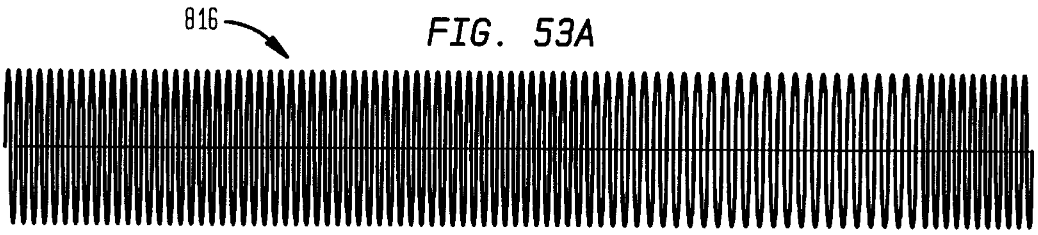


FIG. 53B

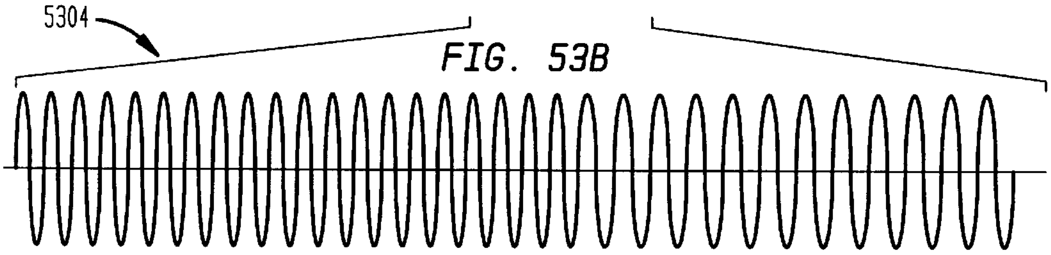


FIG. 53D

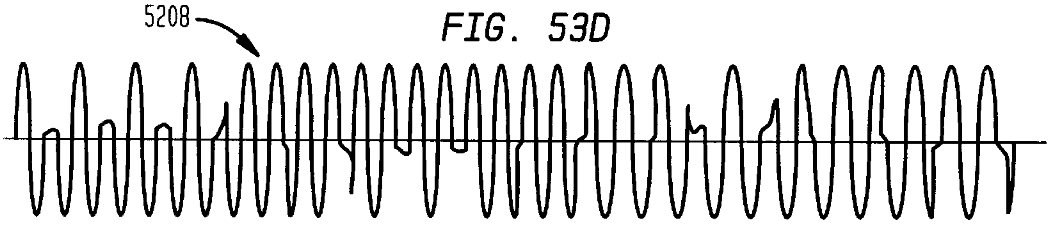


FIG. 53C

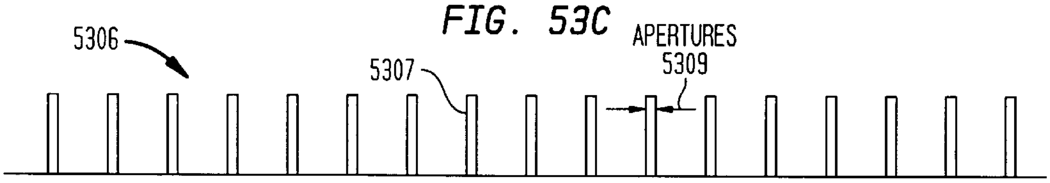


FIG. 53E

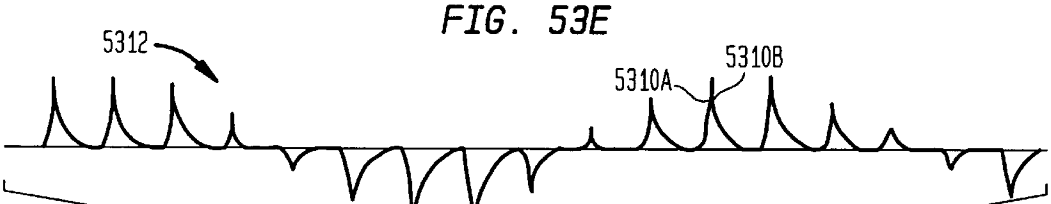


FIG. 53F

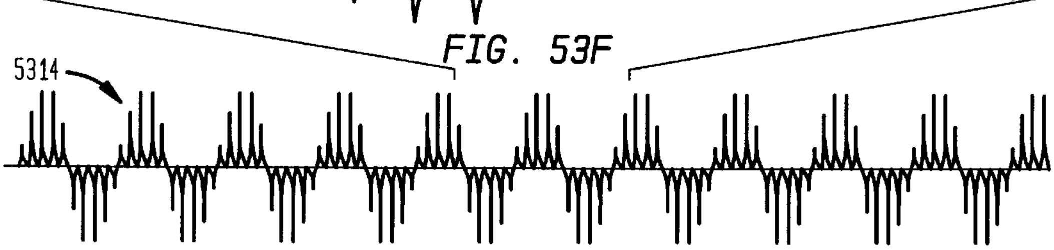


FIG. 53G

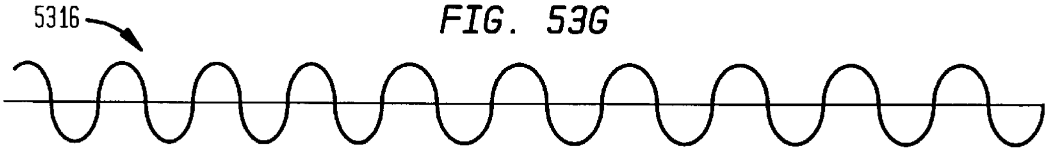


FIG. 54A

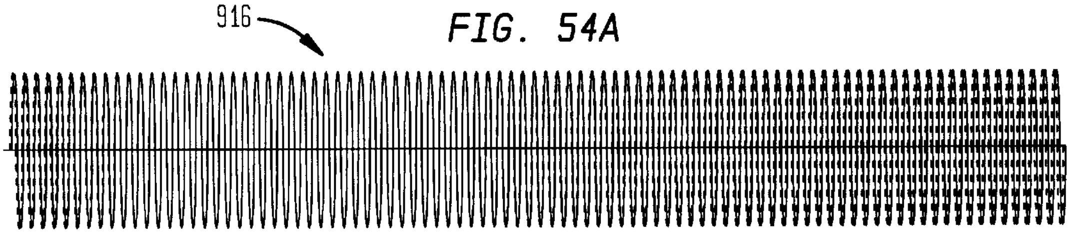


FIG. 54B

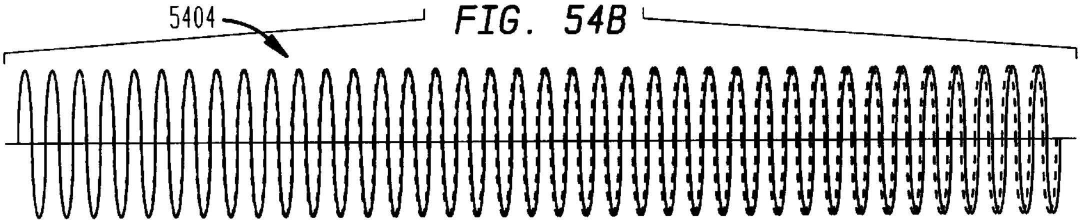


FIG. 54D

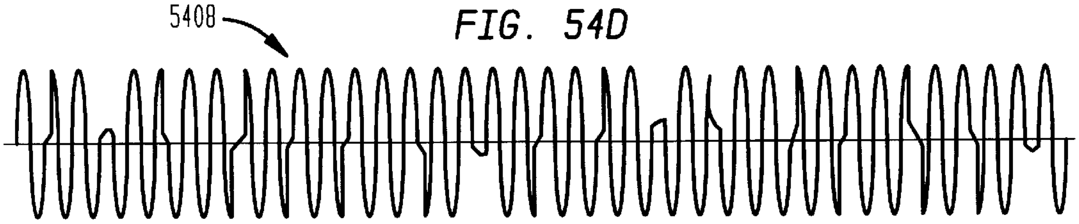


FIG. 54C

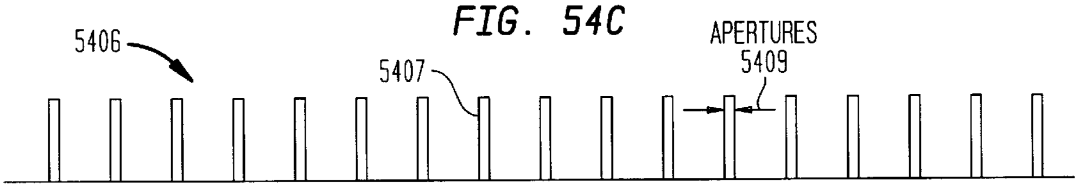


FIG. 54E

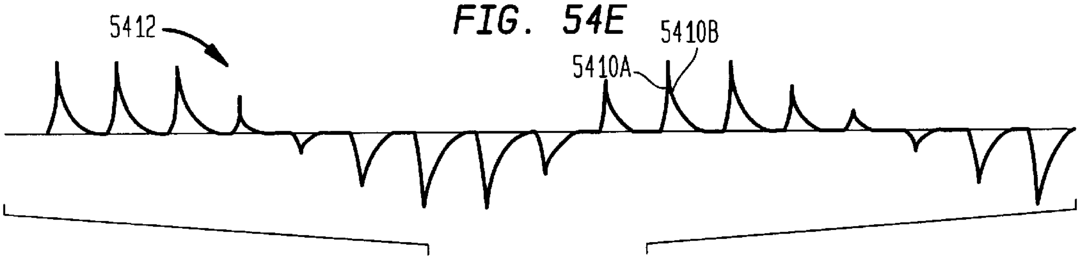


FIG. 54F

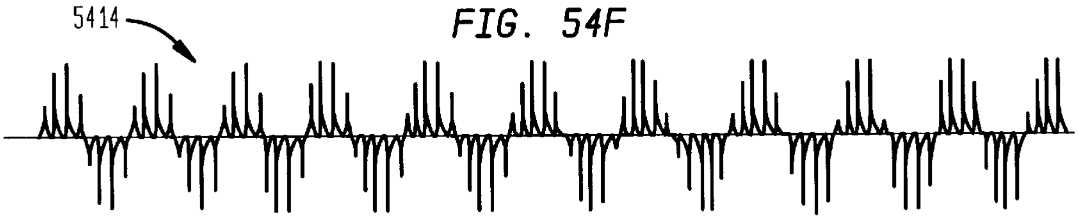
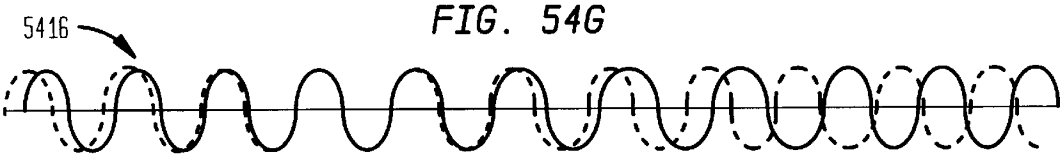


FIG. 54G



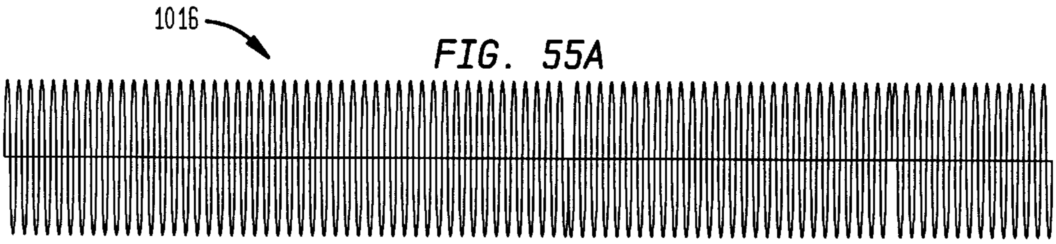


FIG. 55A

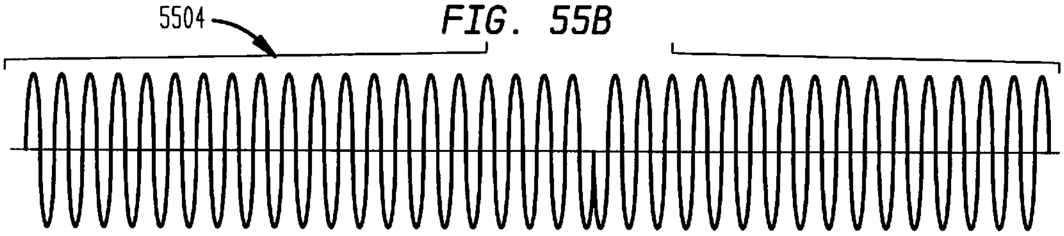


FIG. 55B

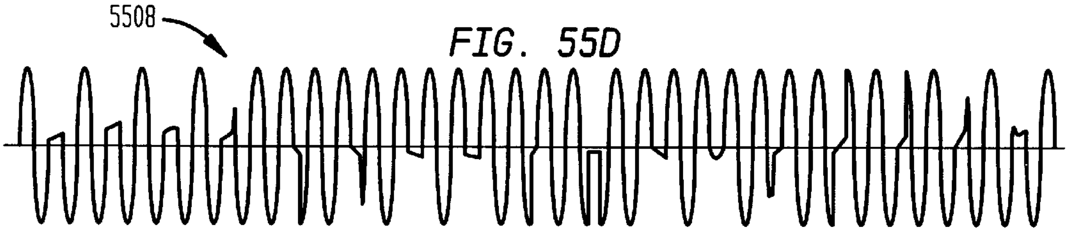


FIG. 55D

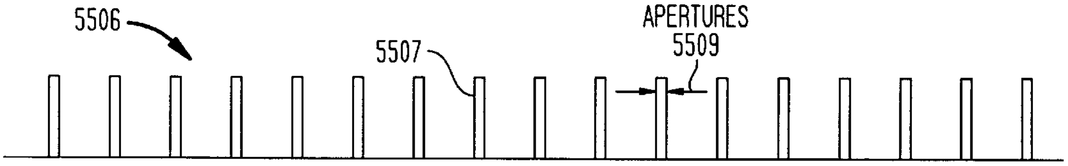


FIG. 55C

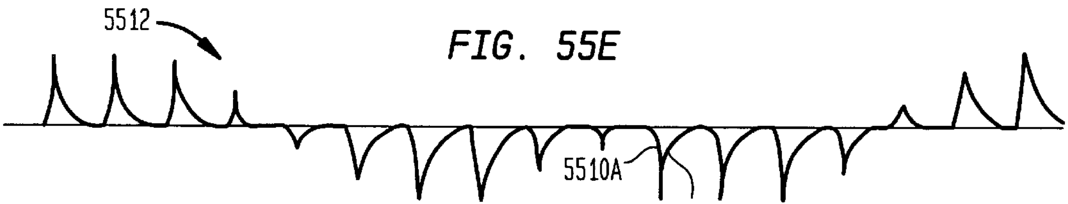


FIG. 55E

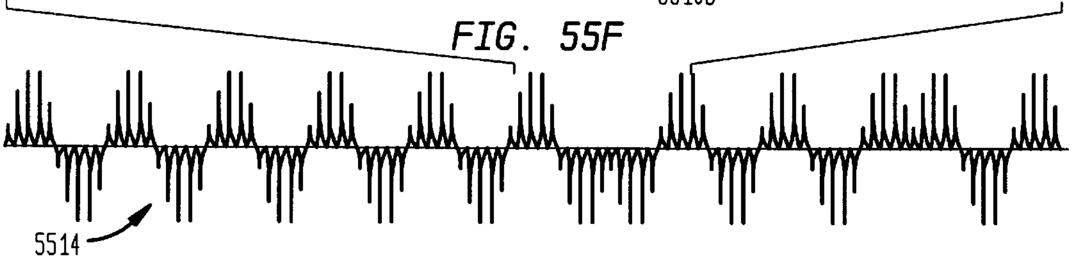


FIG. 55F

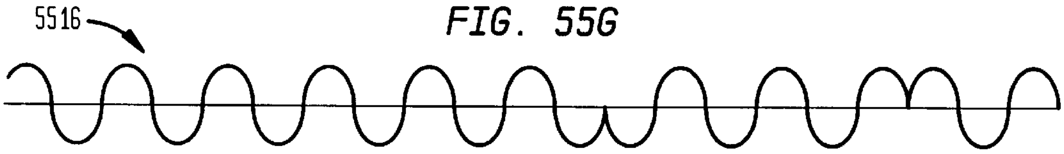


FIG. 55G

FIG. 56A

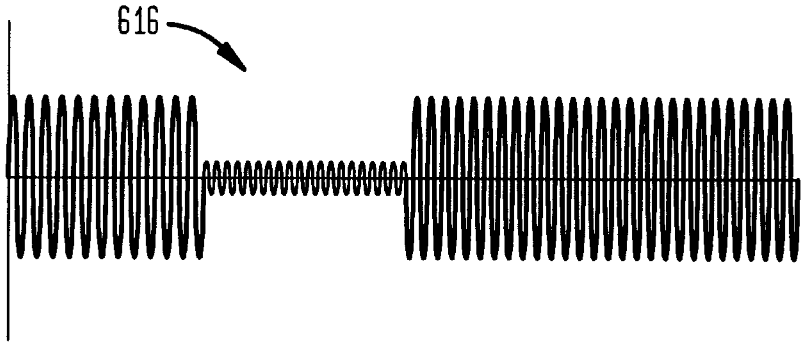


FIG. 56B

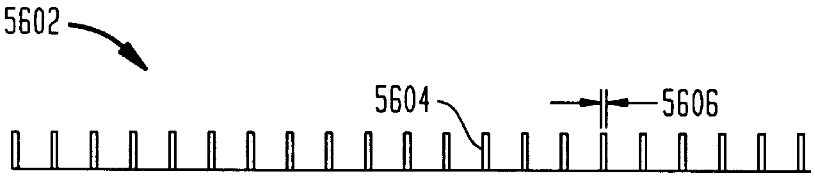


FIG. 56C

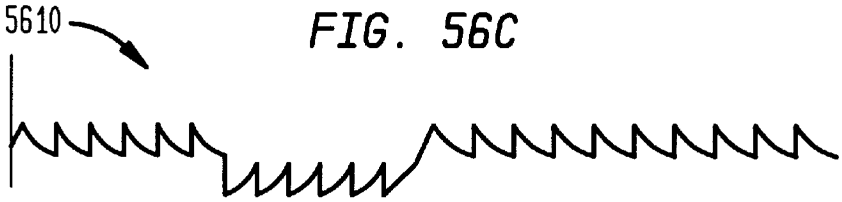


FIG. 56D

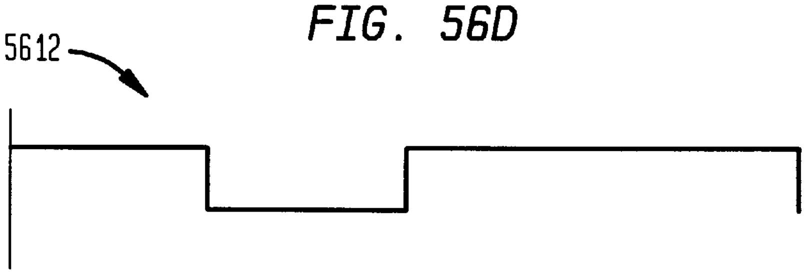


FIG. 57A

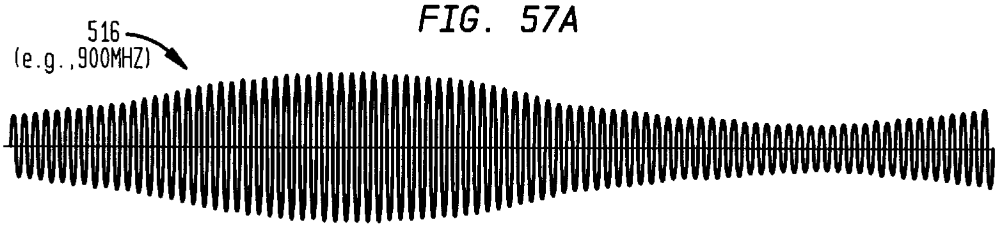


FIG. 57B

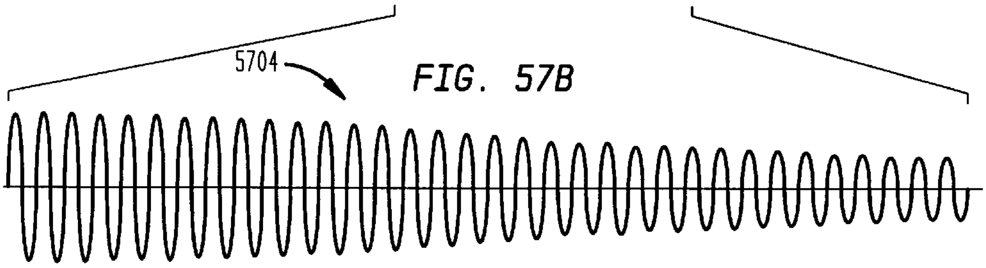


FIG. 57D

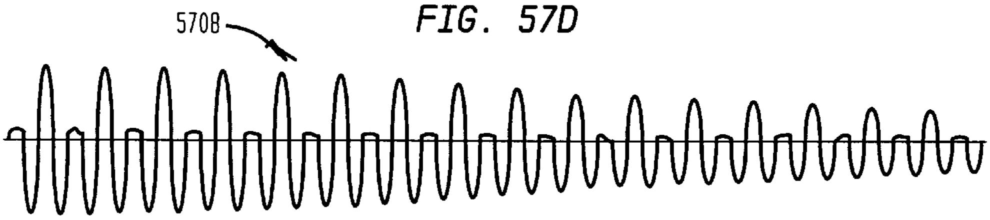


FIG. 57C

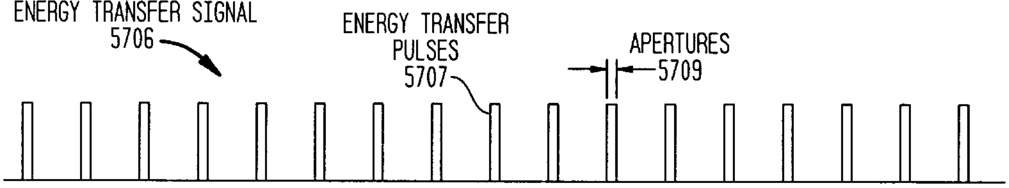


FIG. 57E

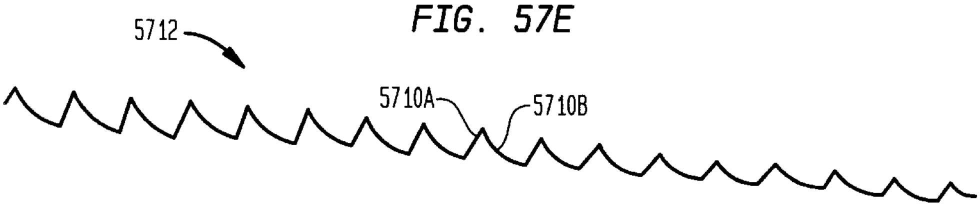


FIG. 57F

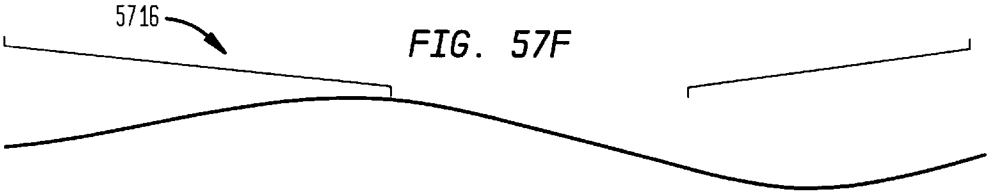


FIG. 58A

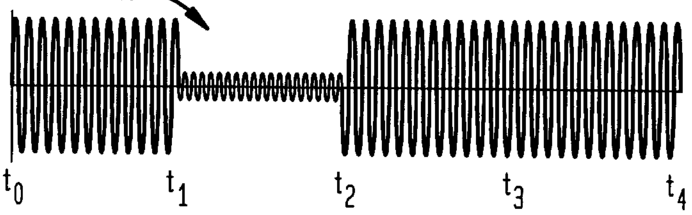


FIG. 58B

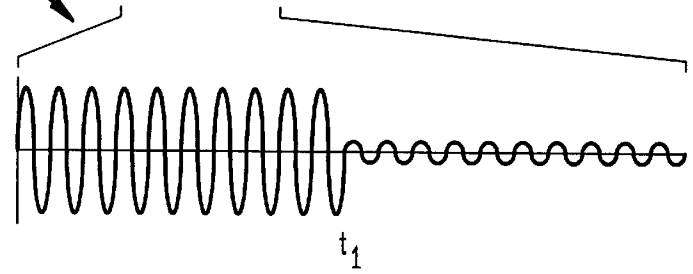


FIG. 58D

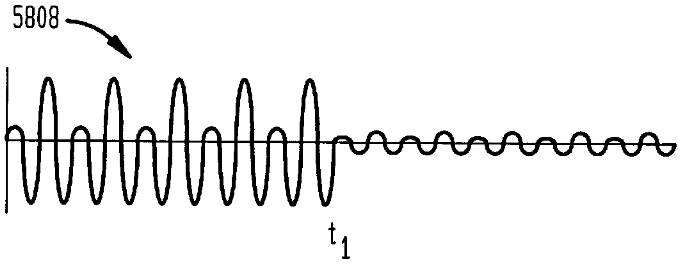


FIG. 58C

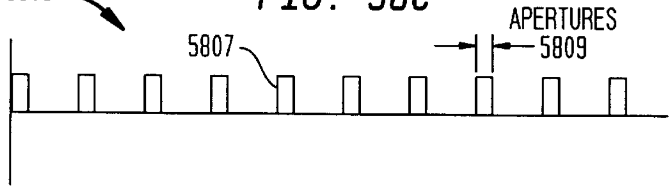


FIG. 58E

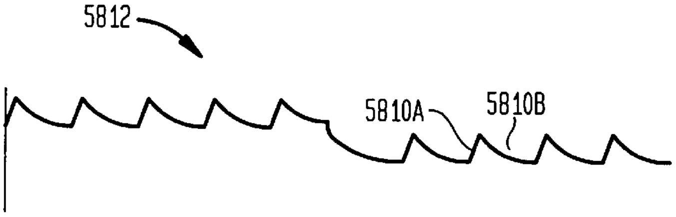


FIG. 58F

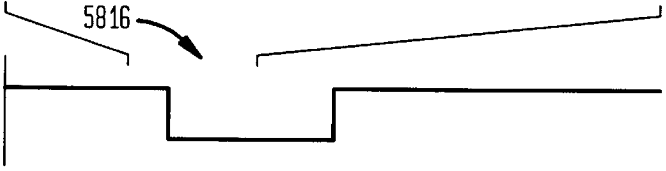


FIG. 59A

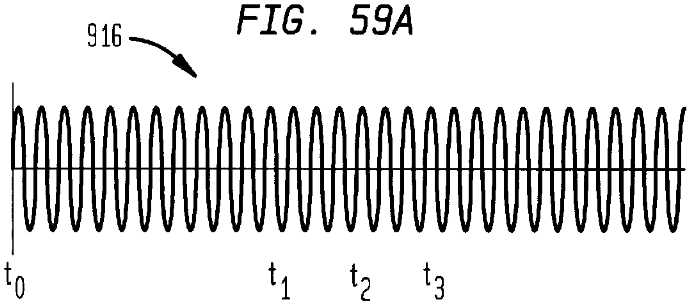


FIG. 59B

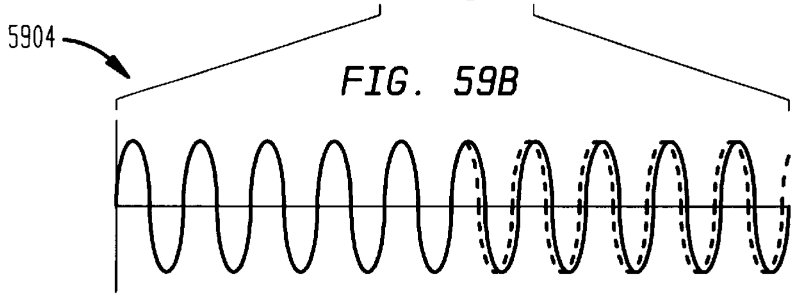


FIG. 59D

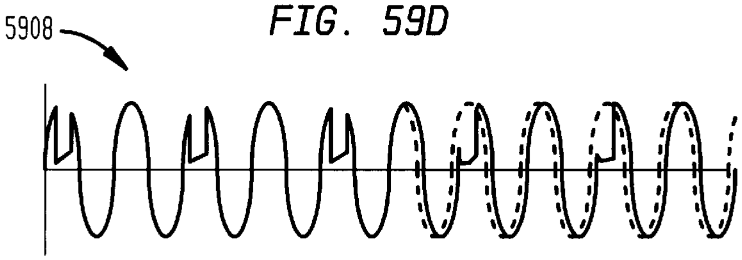


FIG. 59C

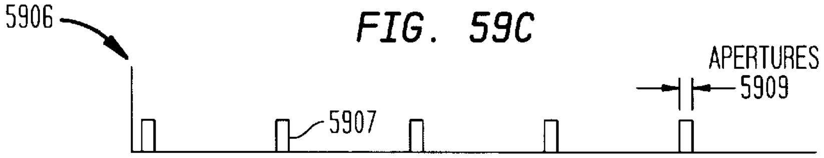


FIG. 59E

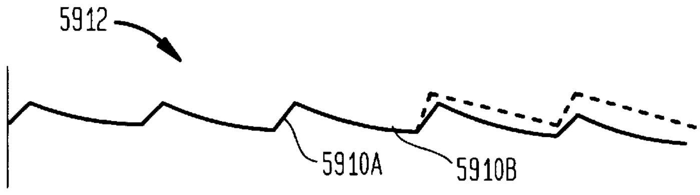


FIG. 59F

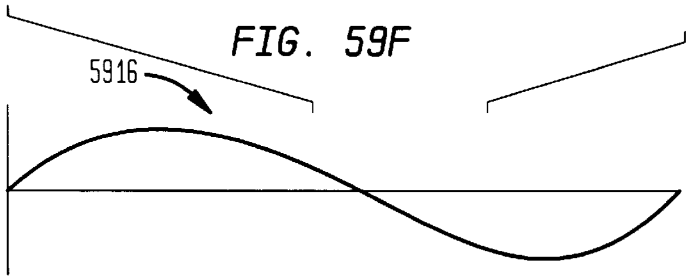


FIG. 60A

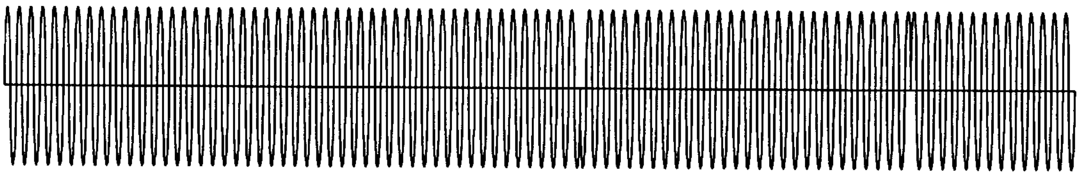


FIG. 60B

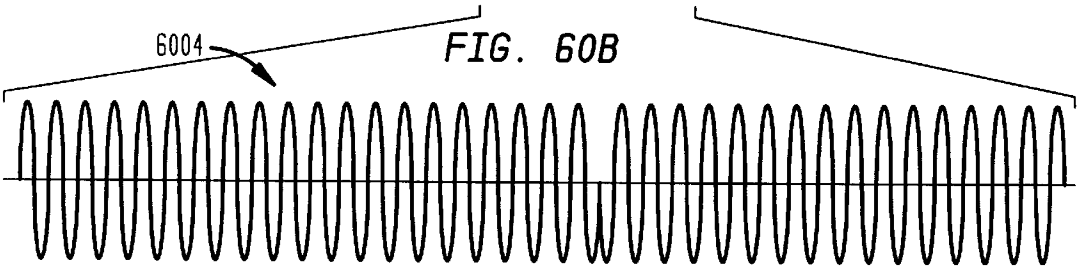


FIG. 60D

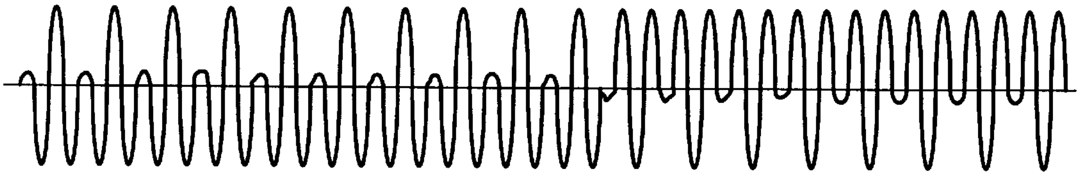


FIG. 60C

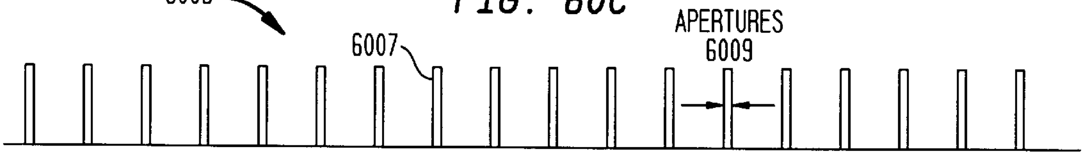


FIG. 60E

FIG. 60F

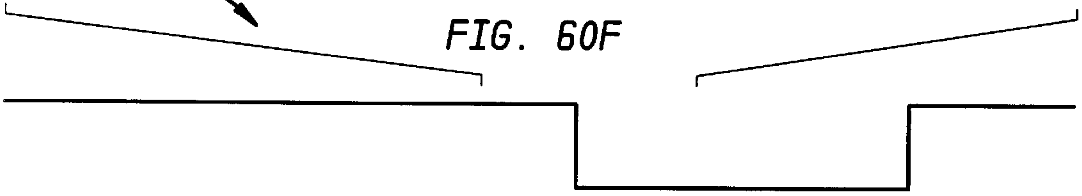


FIG. 61A

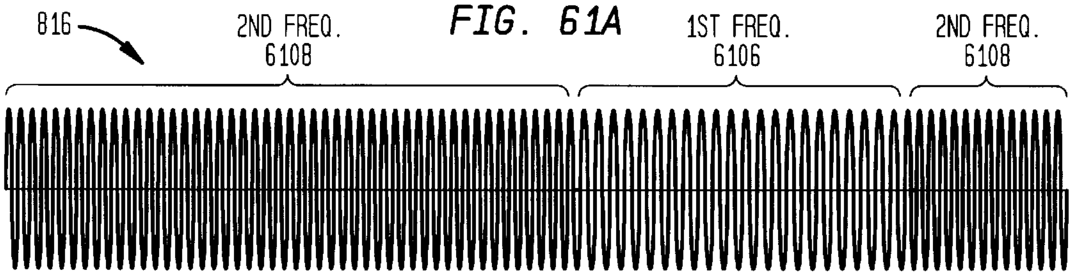


FIG. 61B

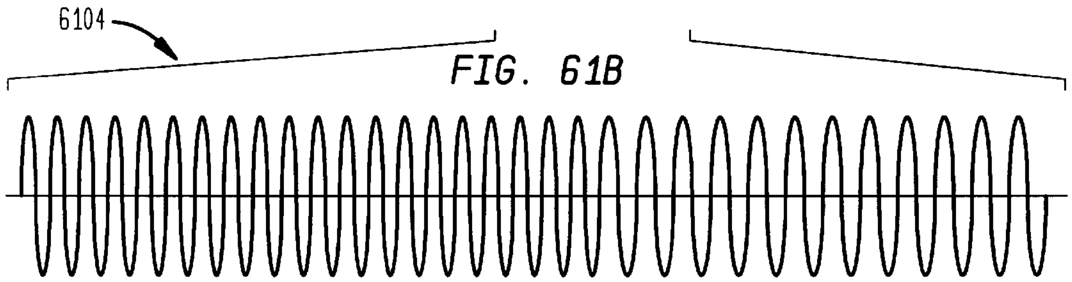


FIG. 61D

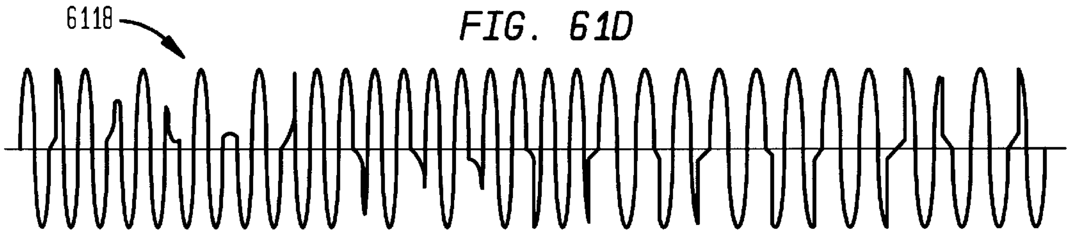


FIG. 61C

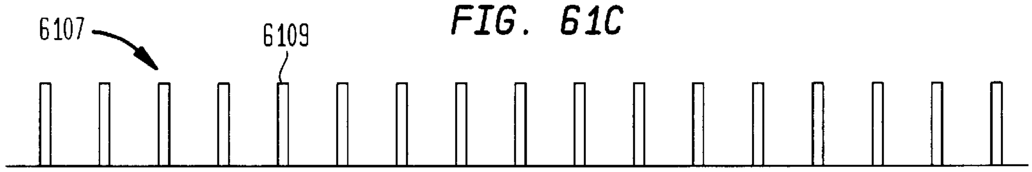


FIG. 61E

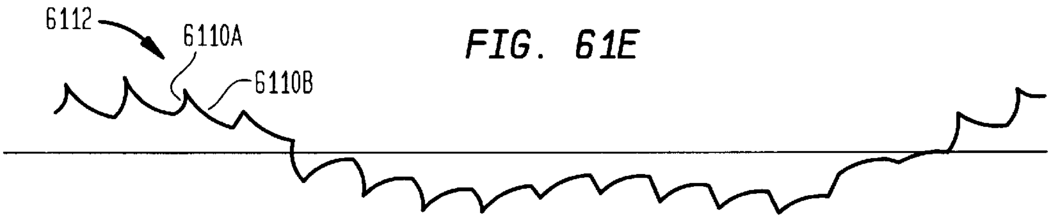


FIG. 61F

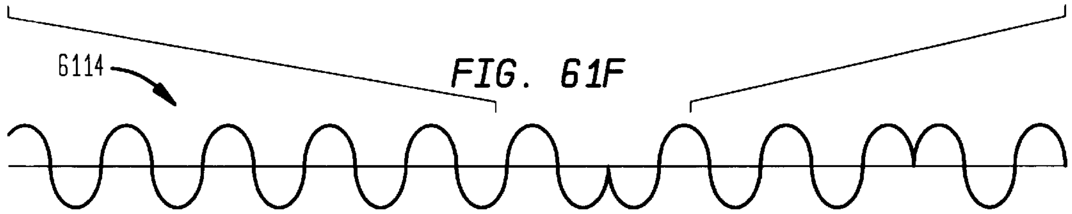


FIG. 62A

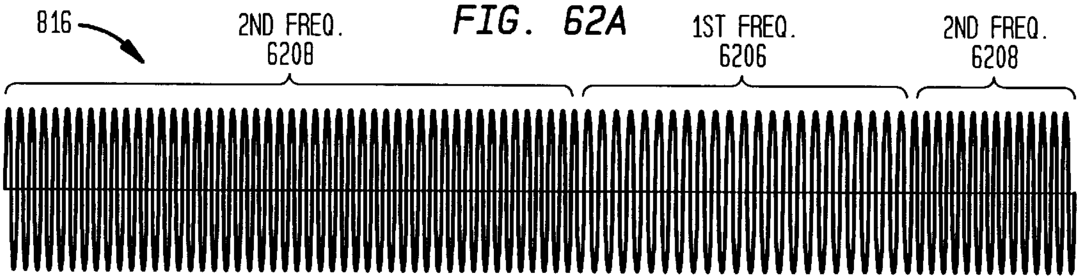


FIG. 62B

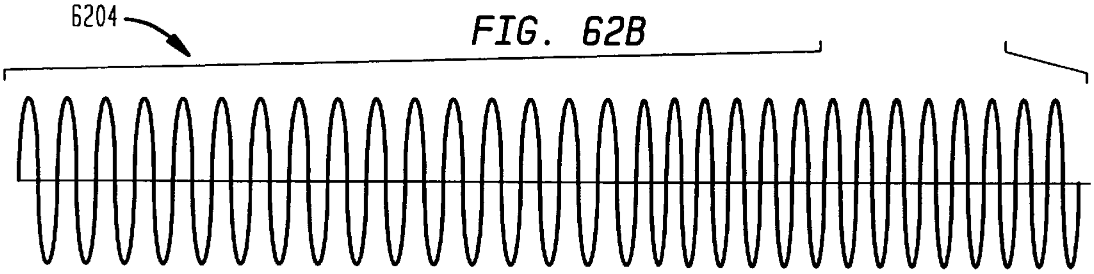


FIG. 62D

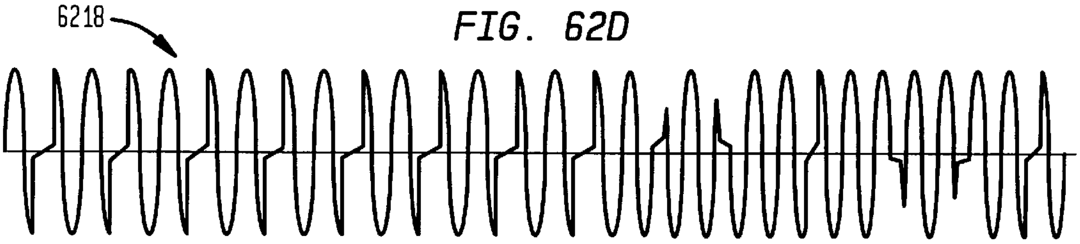


FIG. 62C

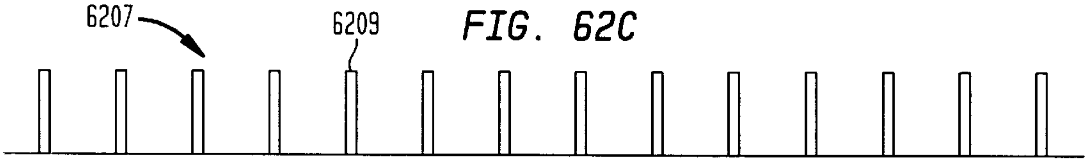


FIG. 62E

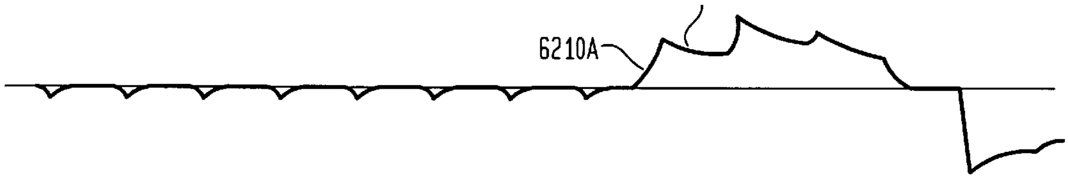


FIG. 62F

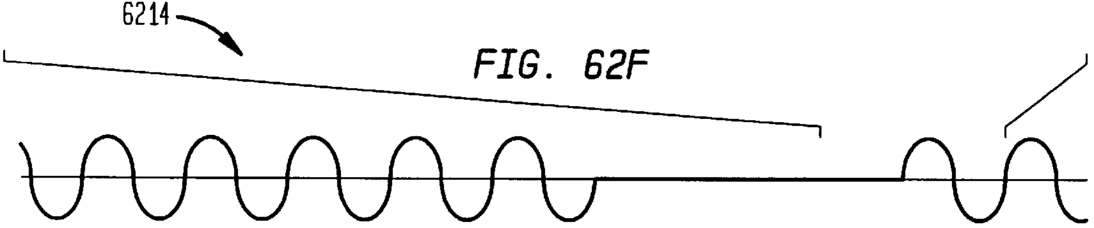


FIG. 63

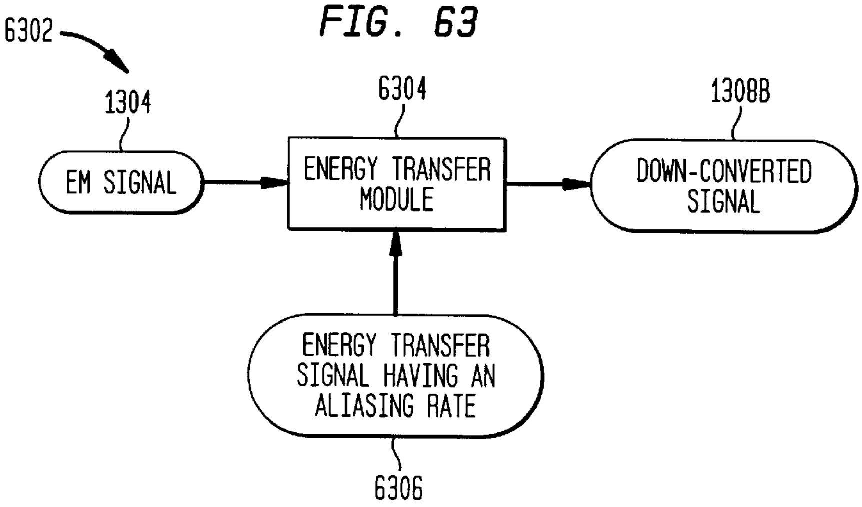


FIG. 64A

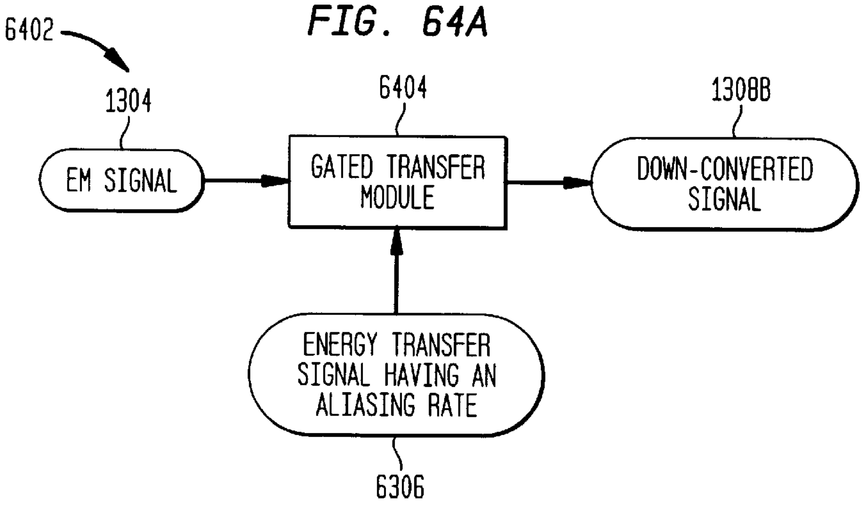


FIG. 64B

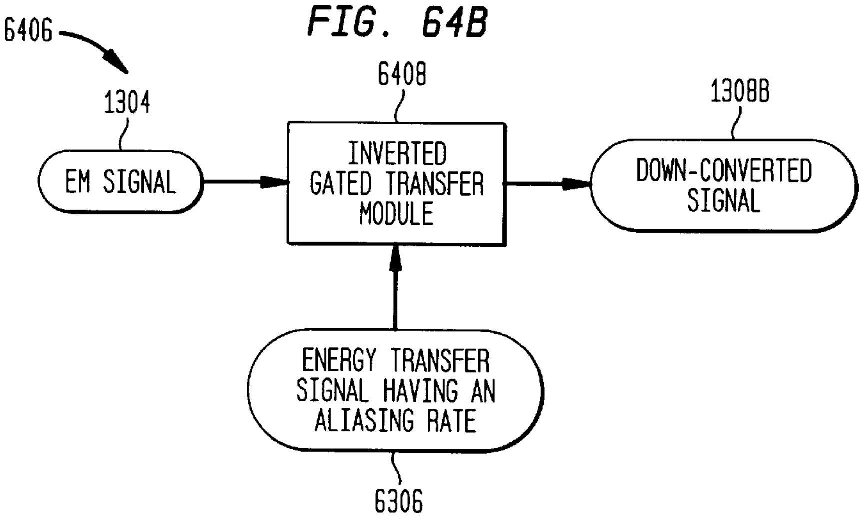


FIG. 65

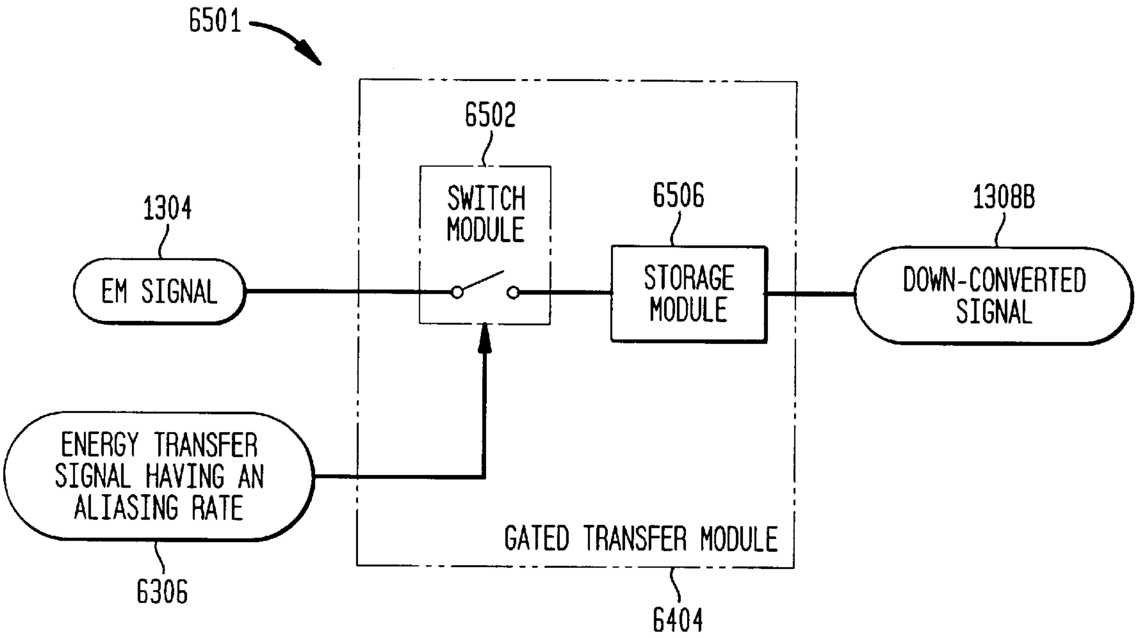


FIG. 66A

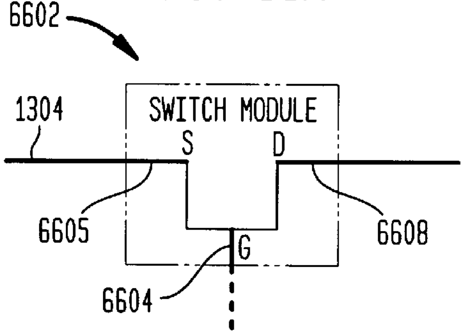


FIG. 66B

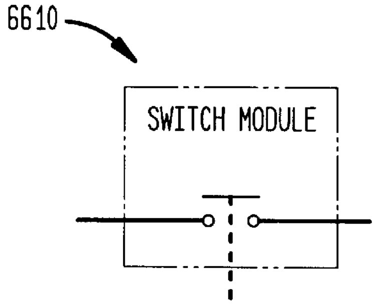


FIG. 66C

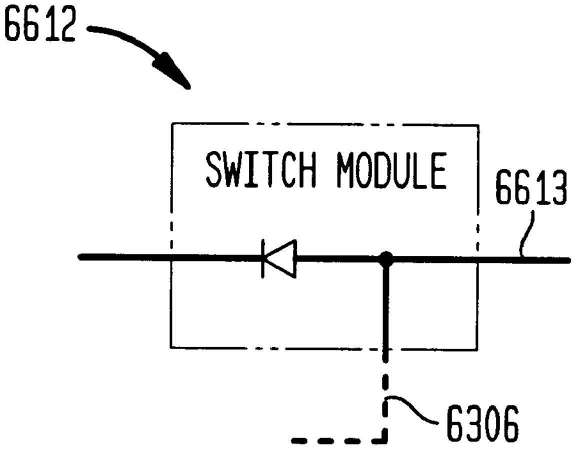
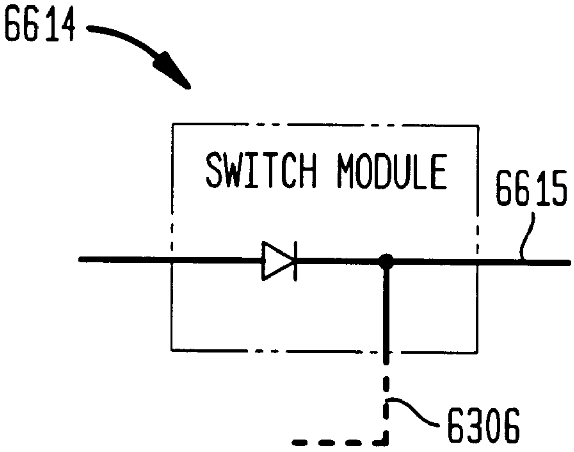


FIG. 66D



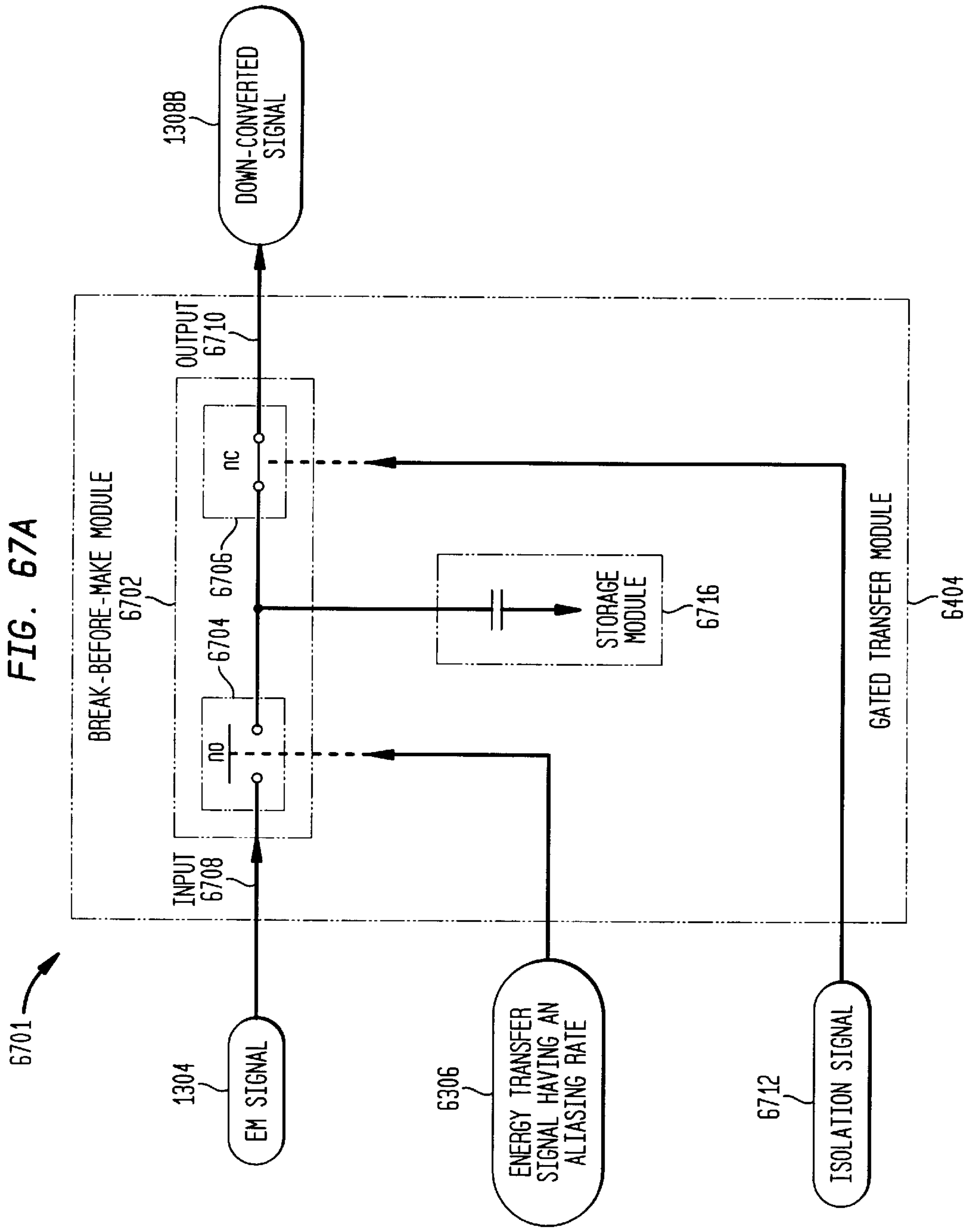

6701
1304
EM SIGNAL
6306
ENERGY TRANSFER SIGNAL HAVING AN ALIASING RATE
6712
ISOLATION SIGNAL
INPUT 6708
BREAK-BEFORE-MAKE MODULE 6702
no
6704
6706
nc
OUTPUT 6710
1308B
DOWN-CONVERTED SIGNAL
STORAGE MODULE
6716
GATED TRANSFER MODULE
6404

FIG. 67A

FIG. 67B

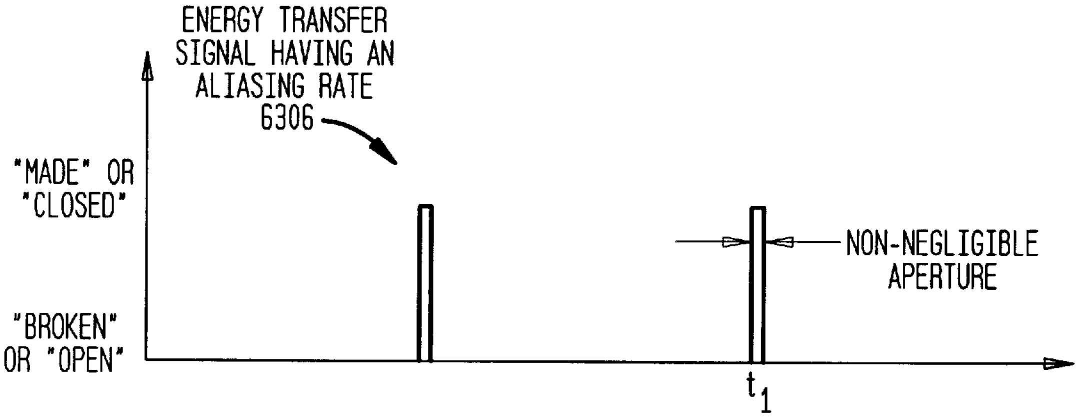


FIG. 67C

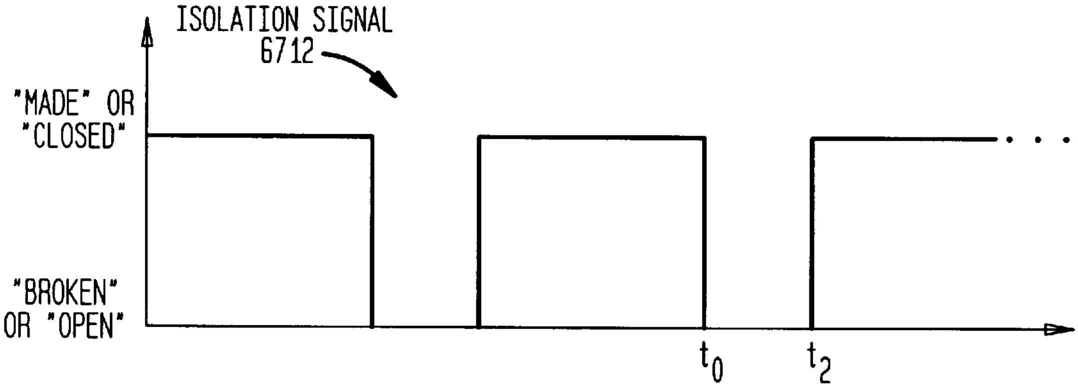


FIG. 68A

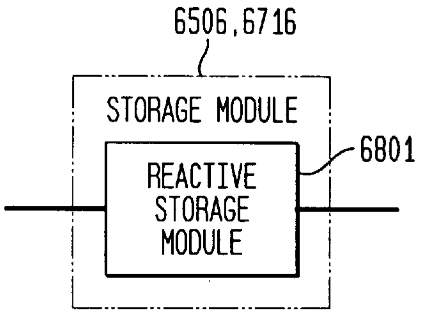


FIG. 68B

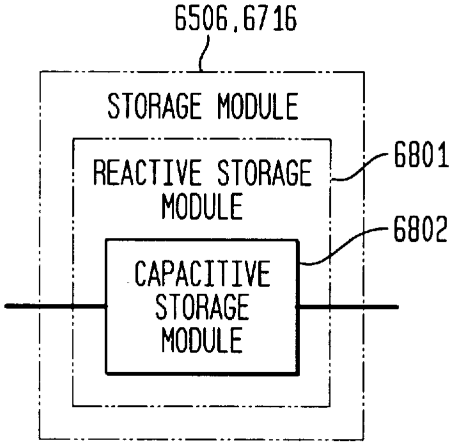


FIG. 68C

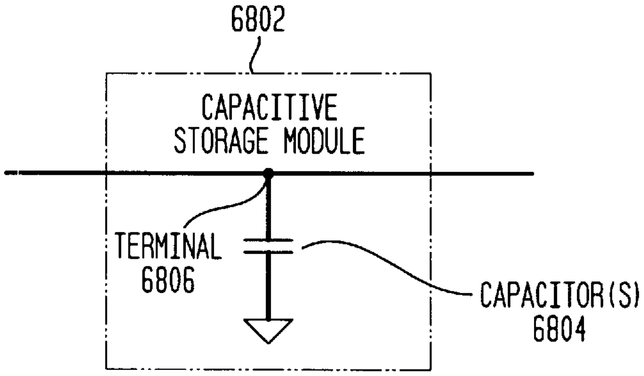


FIG. 68D

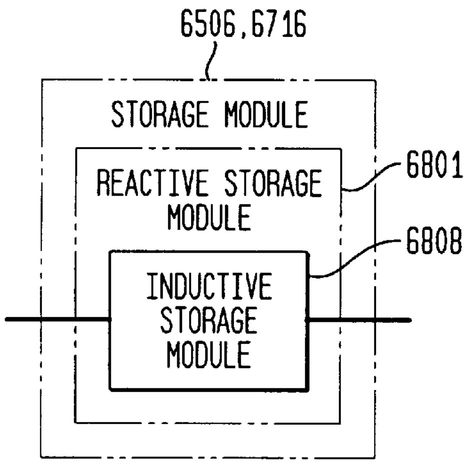


FIG. 68E

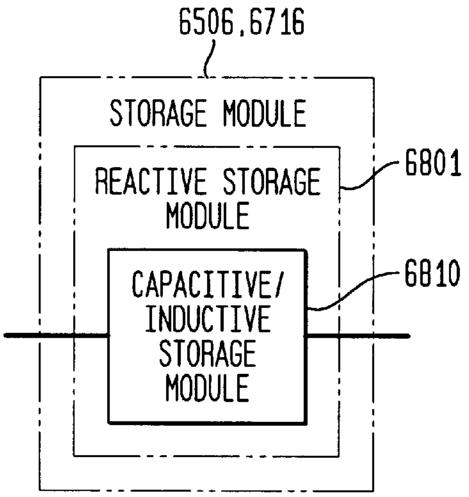
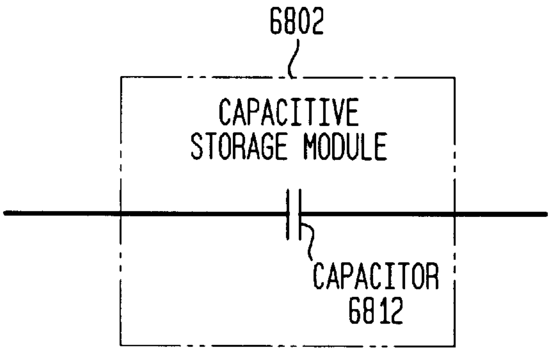


FIG. 68F



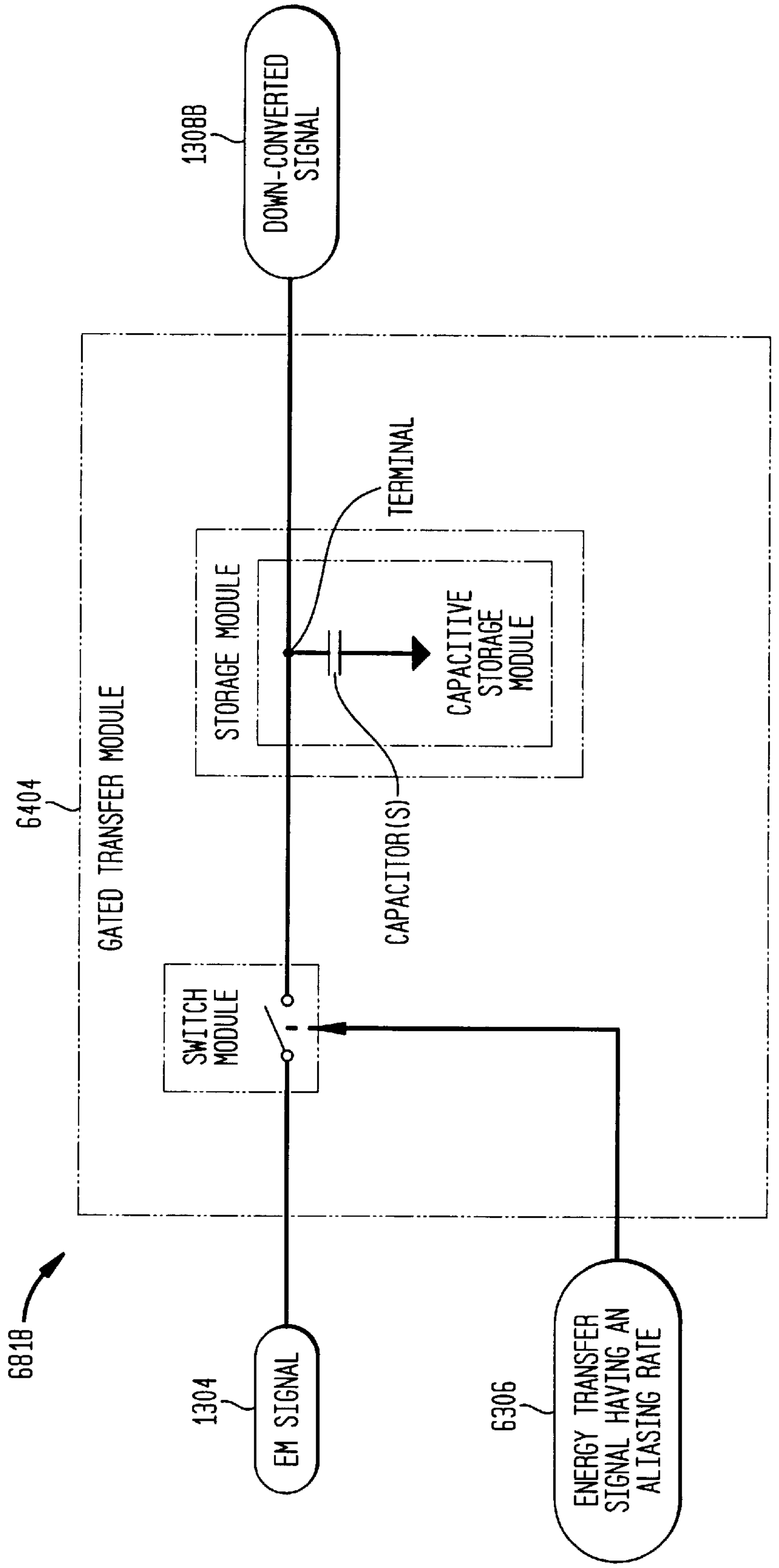
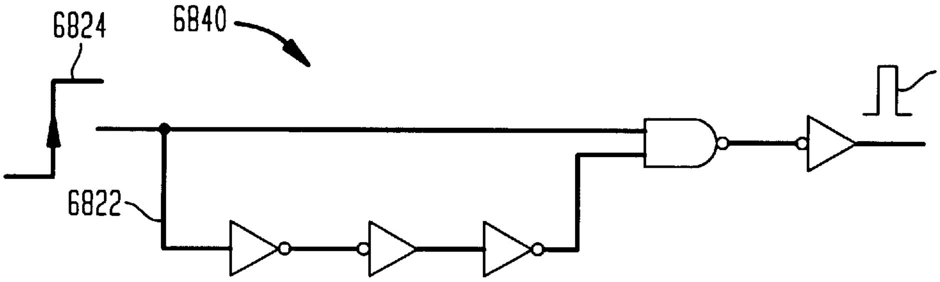

1308B
DOWN-CONVERTED SIGNAL
6404
GATED TRANSFER MODULE
STORAGE MODULE
TERMINAL
CAPACITIVE STORAGE MODULE
CAPACITOR(S)
SWITCH MODULE
6818
1304
EM SIGNAL
6306
ENERGY TRANSFER SIGNAL HAVING AN ALIASING RATE

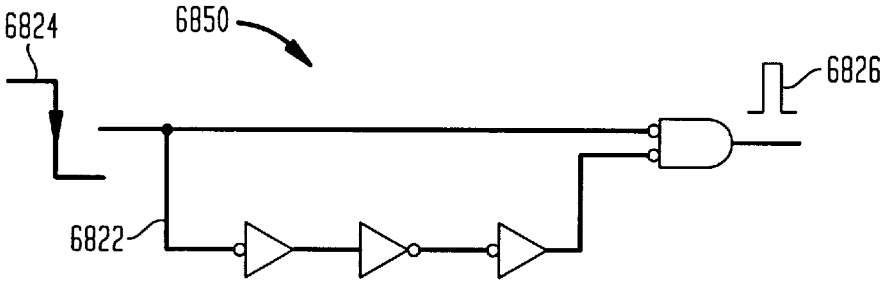
FIG. 68G

FIG. 68H



A. RISING EDGE PULSE GENERATOR

FIG. 68I



B. FALLING-EDGE PULSE GENERATOR

FIG. 68J

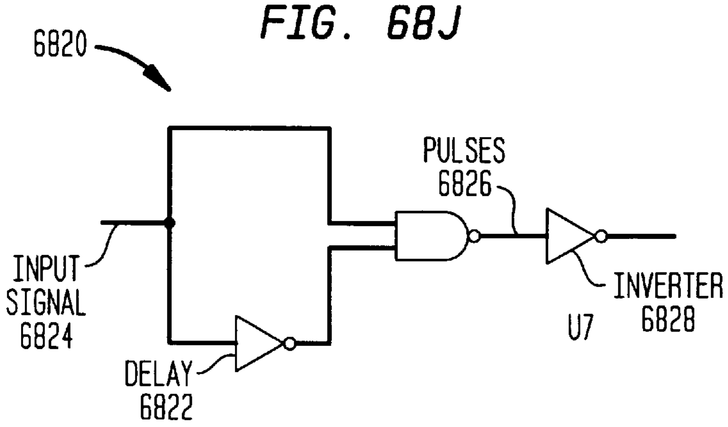


FIG. 68K

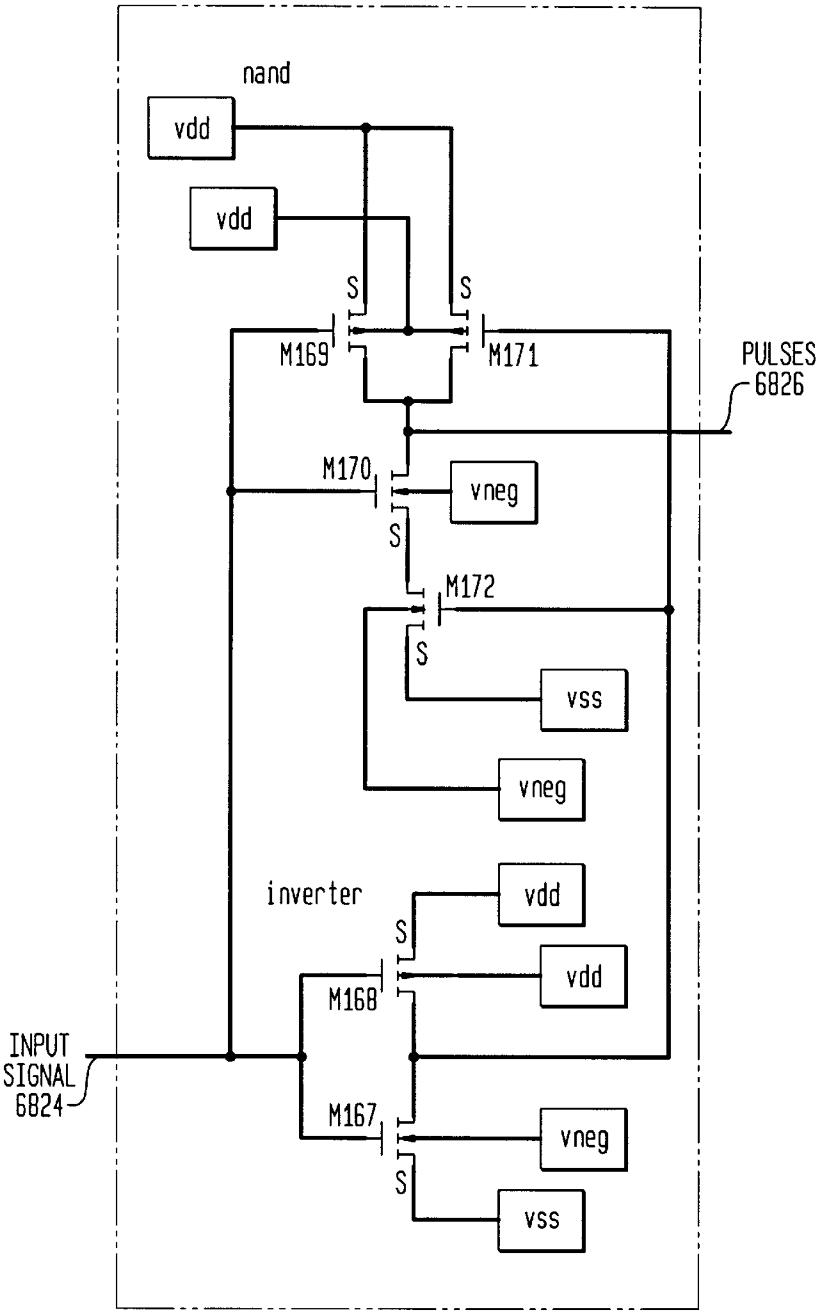


FIG. 68L

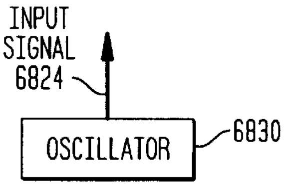


FIG. 69

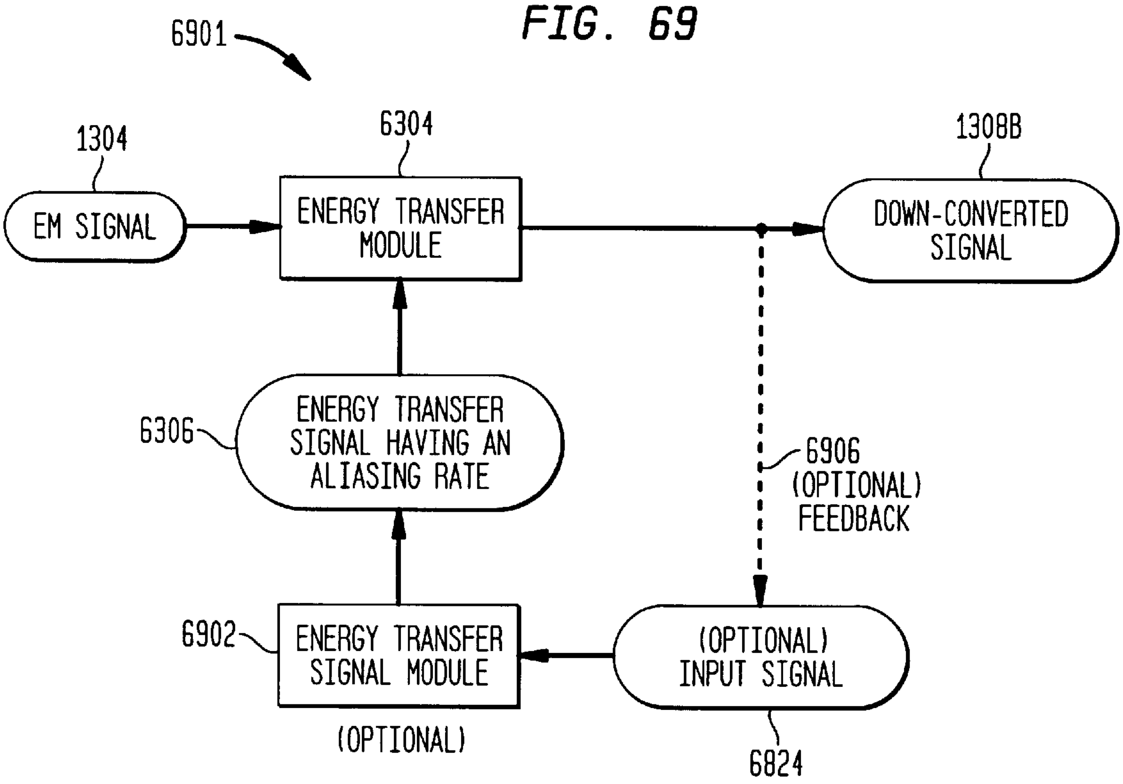

6901
1304
EM SIGNAL
6304
ENERGY TRANSFER MODULE
1308B
DOWN-CONVERTED SIGNAL
6306
ENERGY TRANSFER SIGNAL HAVING AN ALIASING RATE
6906
(OPTIONAL) FEEDBACK
6902
ENERGY TRANSFER SIGNAL MODULE
(OPTIONAL)
(OPTIONAL) INPUT SIGNAL
6824

FIG. 70

IMPEDANCE MATCHED ALIASING MODULE

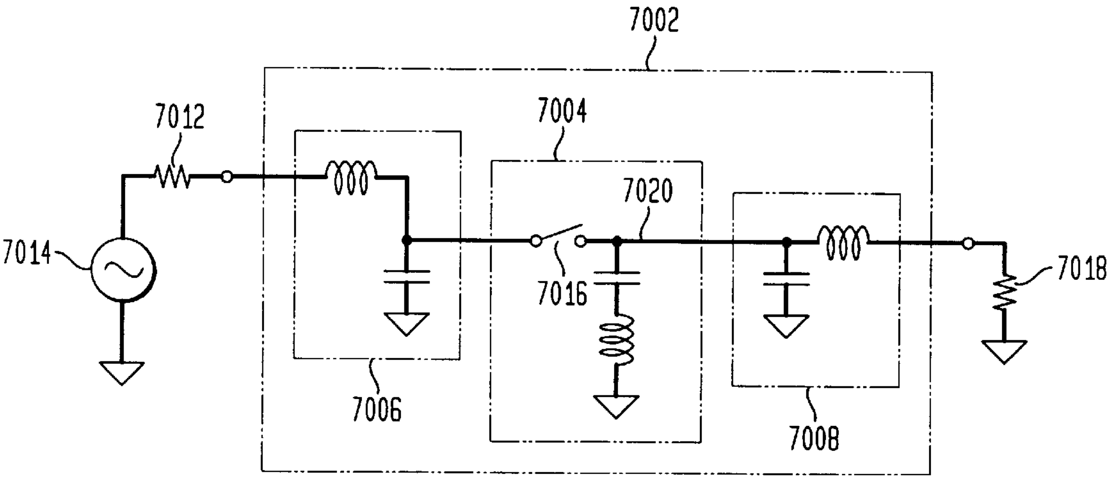
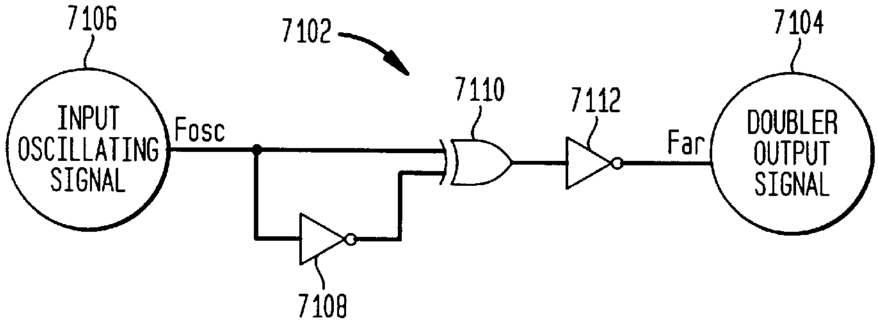


FIG. 71



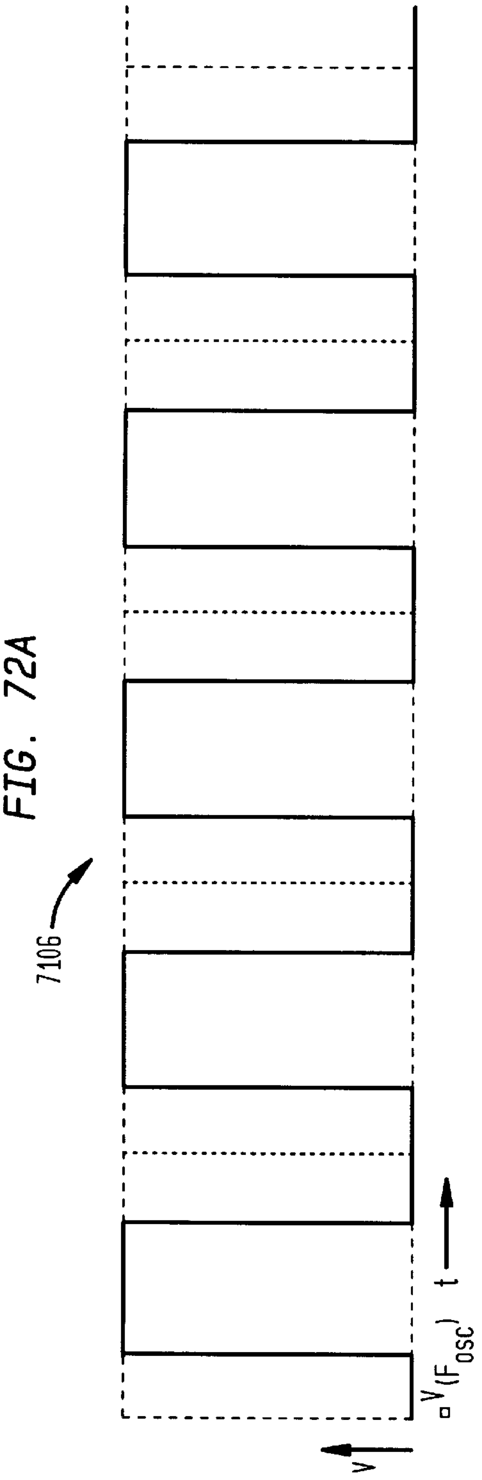


FIG. 72A

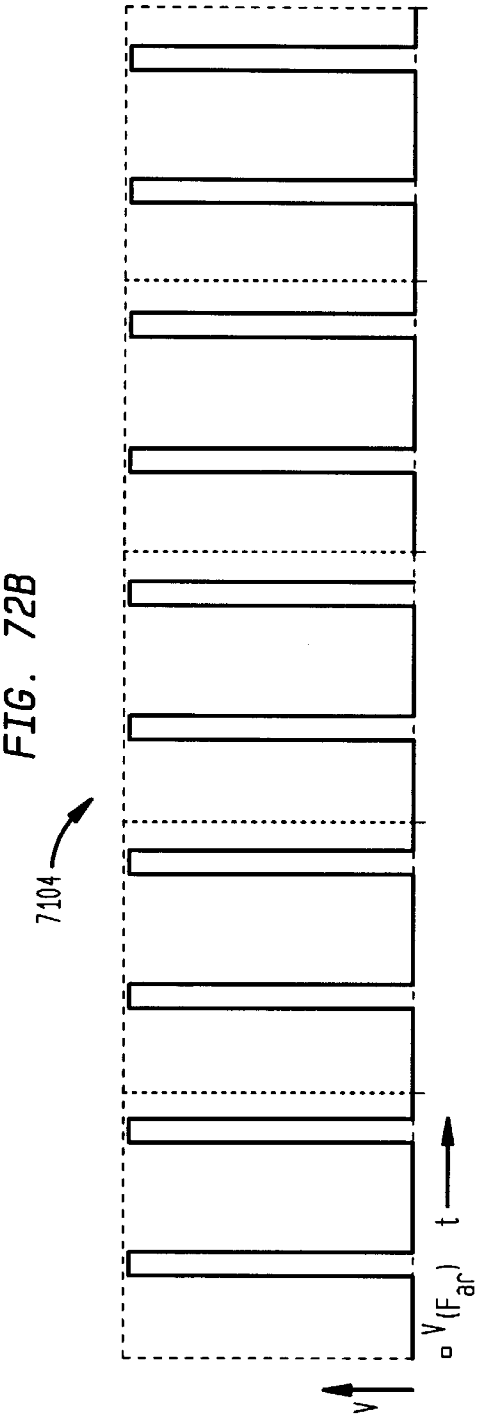


FIG. 72B

FIG. 73

ALIASING MODULE

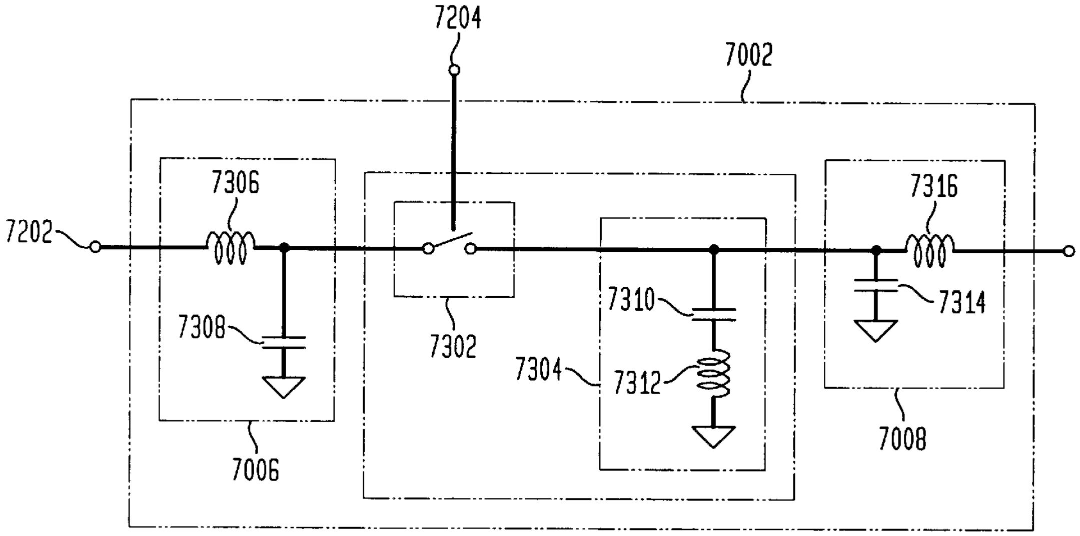


FIG. 74

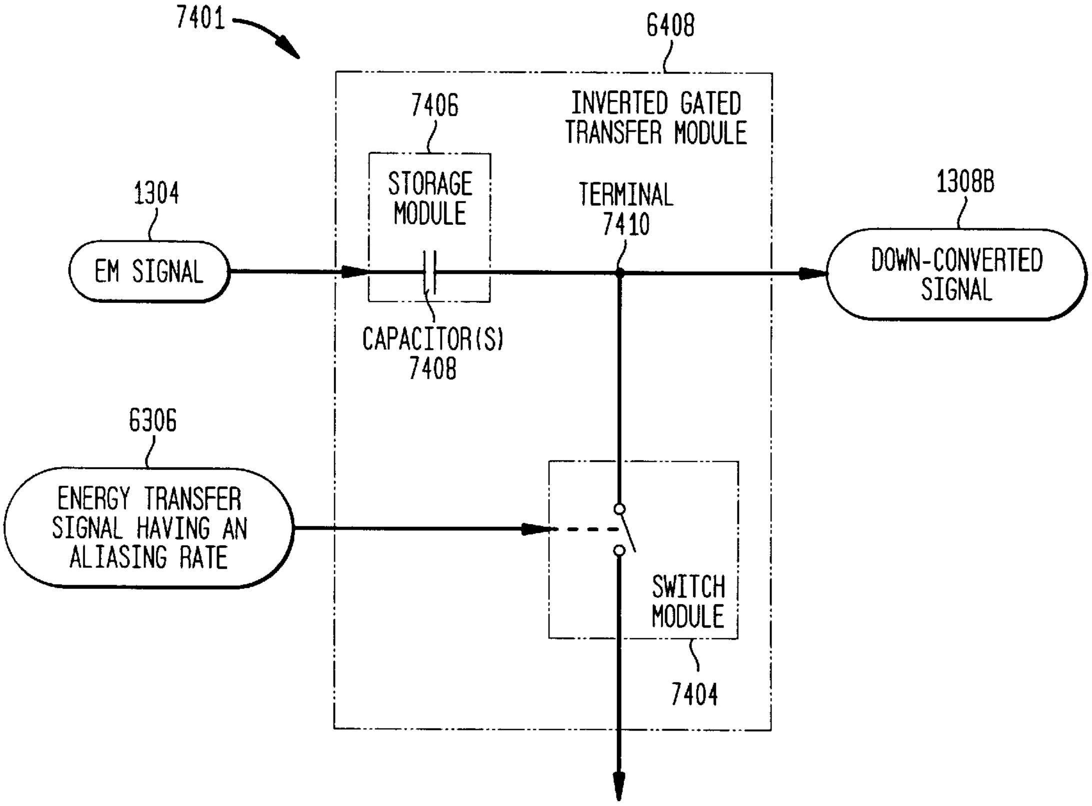


FIG. 75A

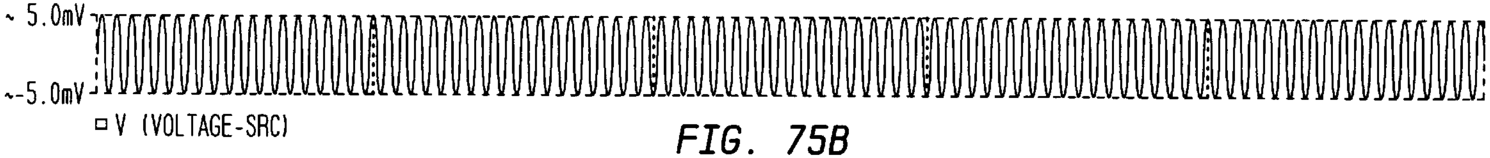


FIG. 75B

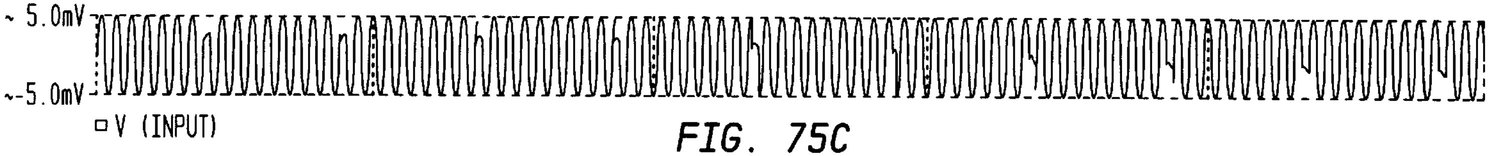


FIG. 75C

FIG. 75D

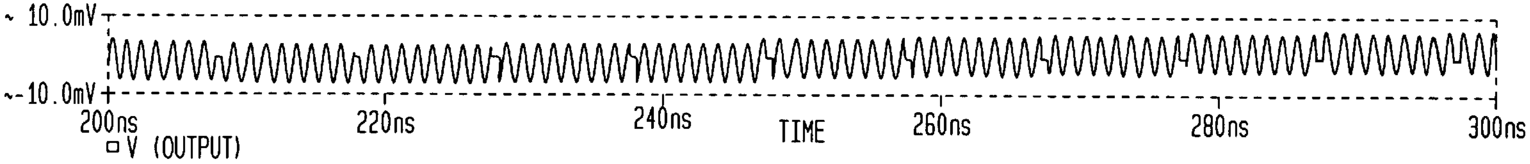


FIG. 75E

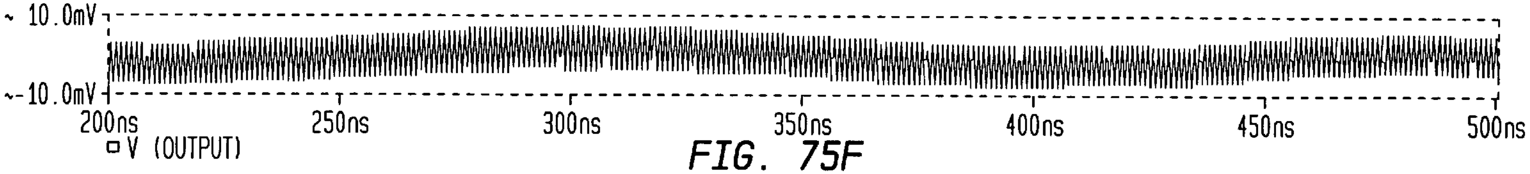


FIG. 75F

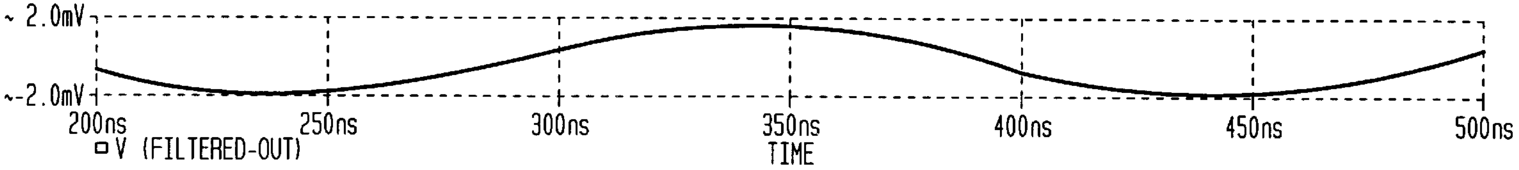


FIG. 76A

DIFFERENTIAL ENERGY TRANSFER CONFIGURATION

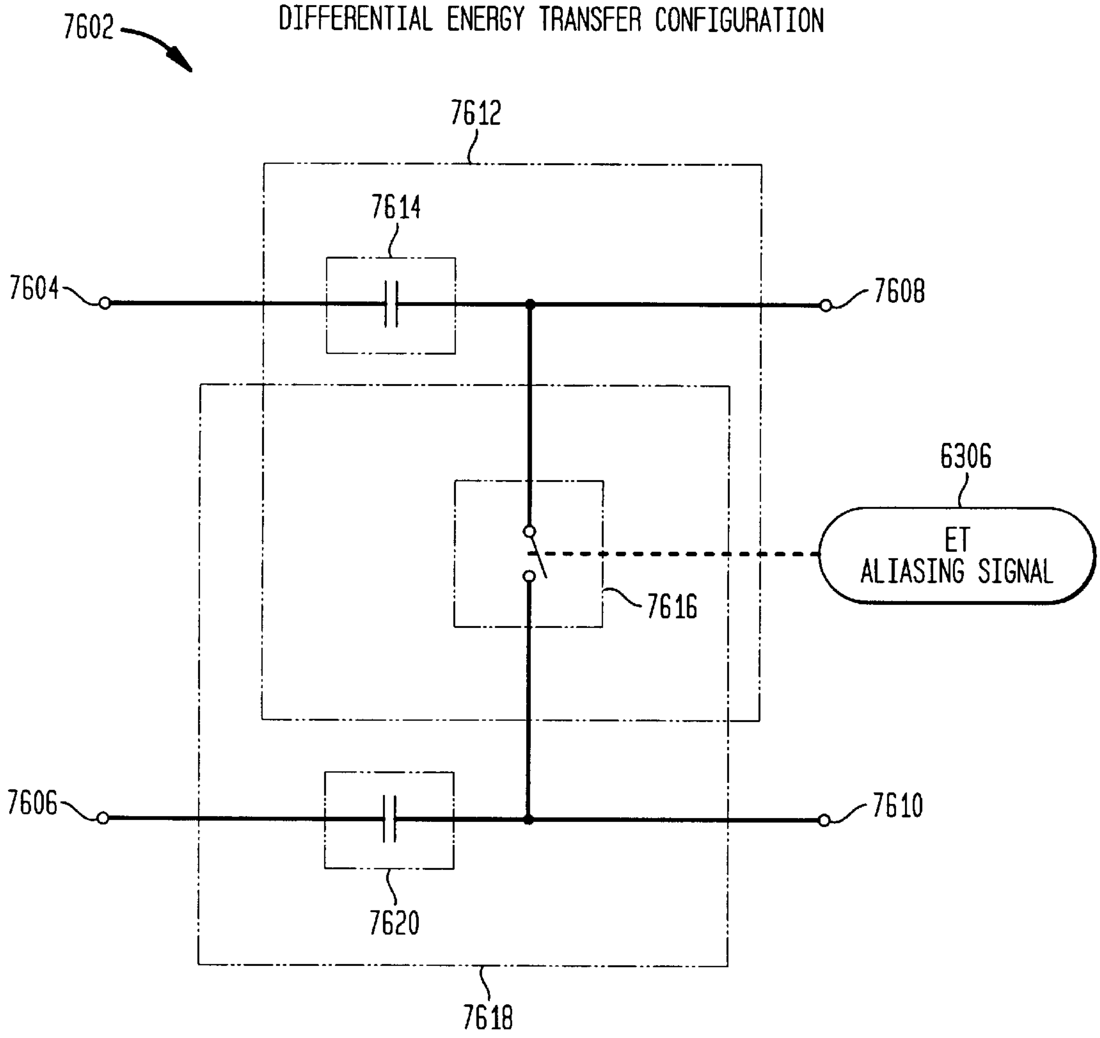


FIG. 76B

DIFFERENTIAL INPUT TO DIFFERENTIAL OUTPUT

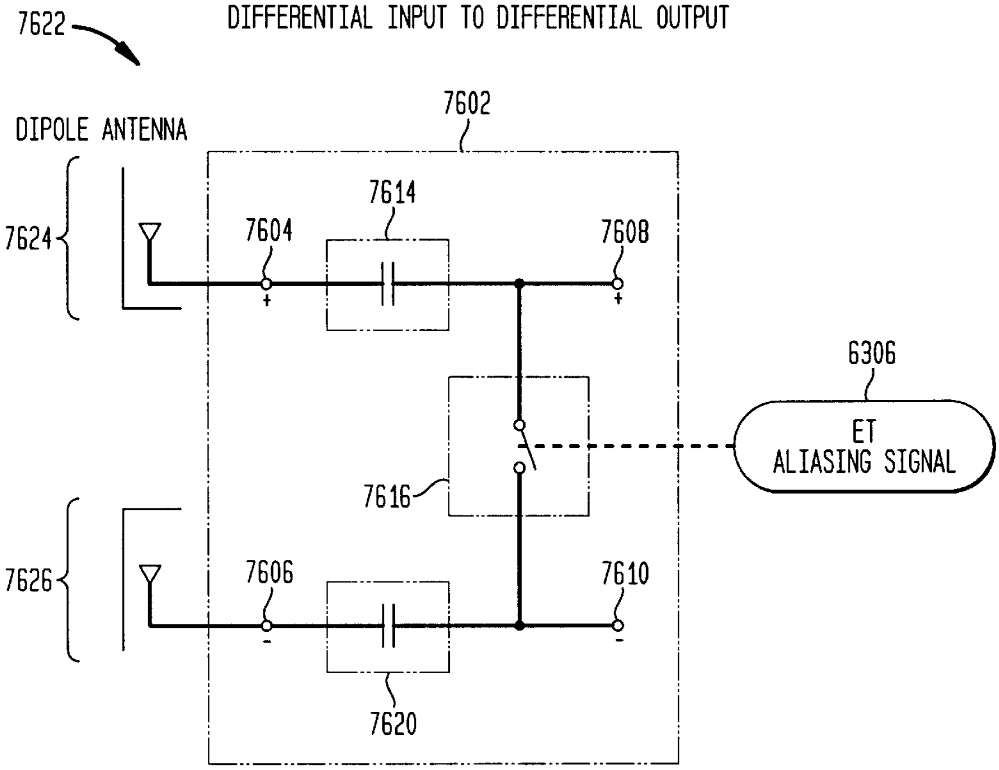


FIG. 76C

SINGLE INPUT TO DIFFERENTIAL OUTPUT

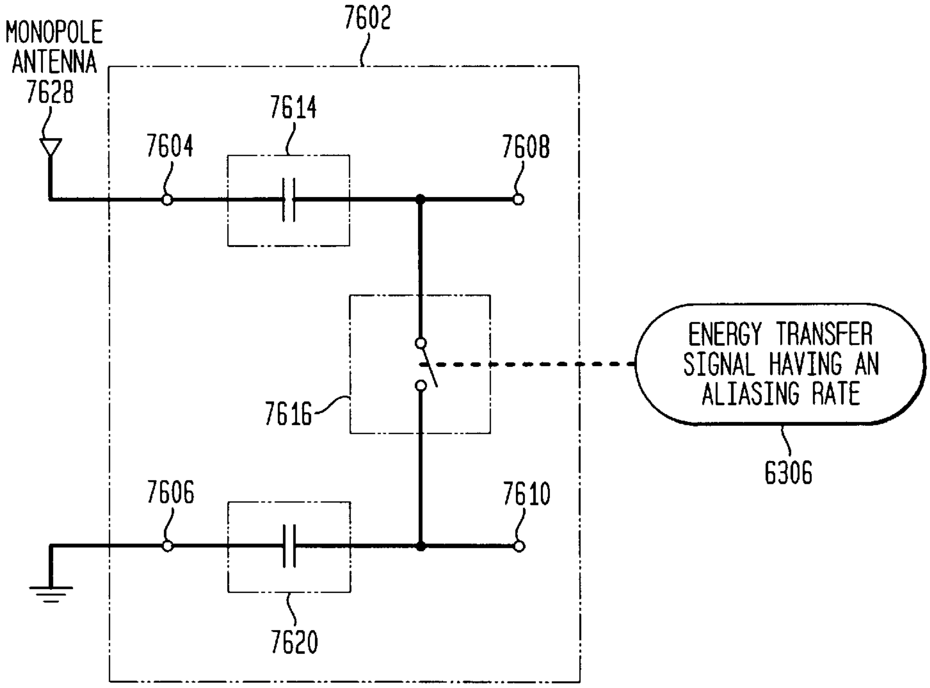


FIG. 76D

DIFFERENTIAL INPUT TO SINGLE OUTPUT

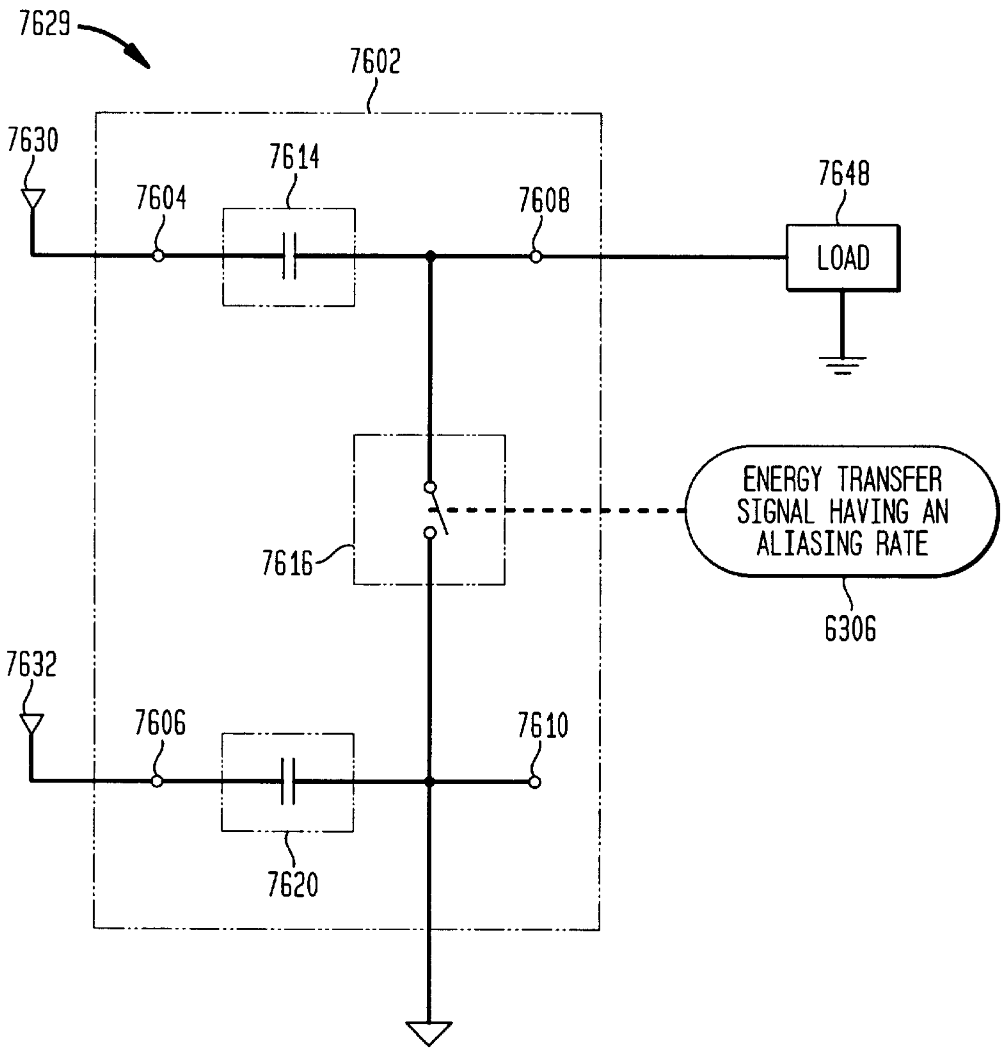


FIG. 76E
EXAMPLE INPUT/OUTPUT CIRCUITRY

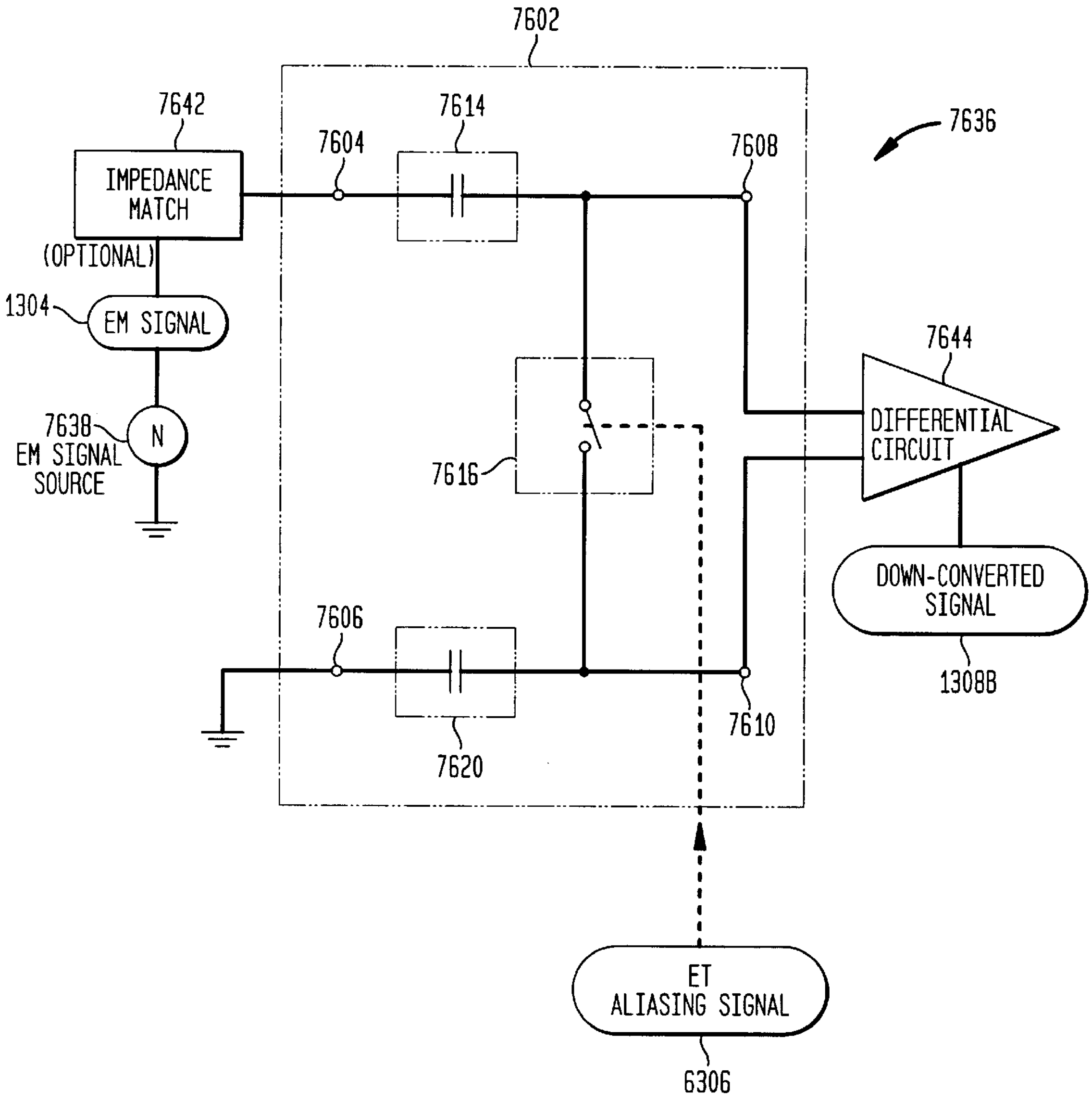


FIG. 77A

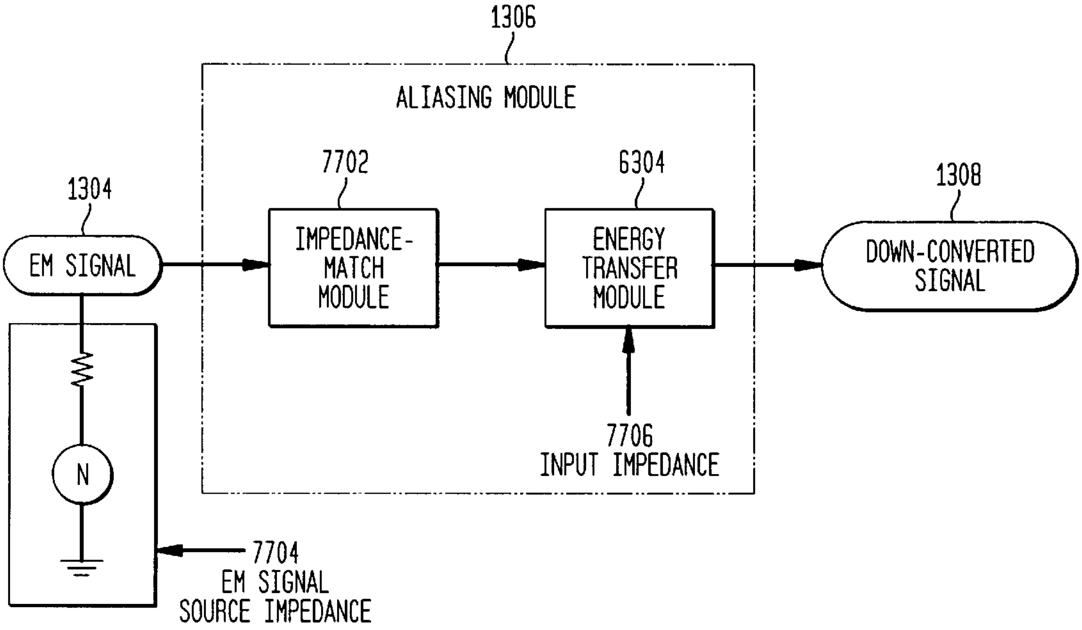


FIG. 77B

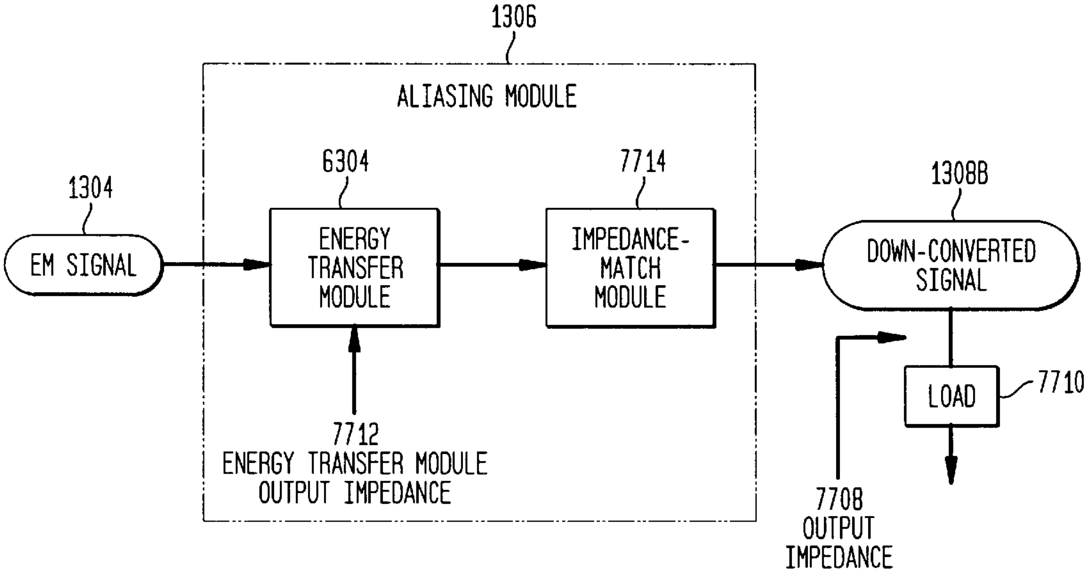


FIG. 77C

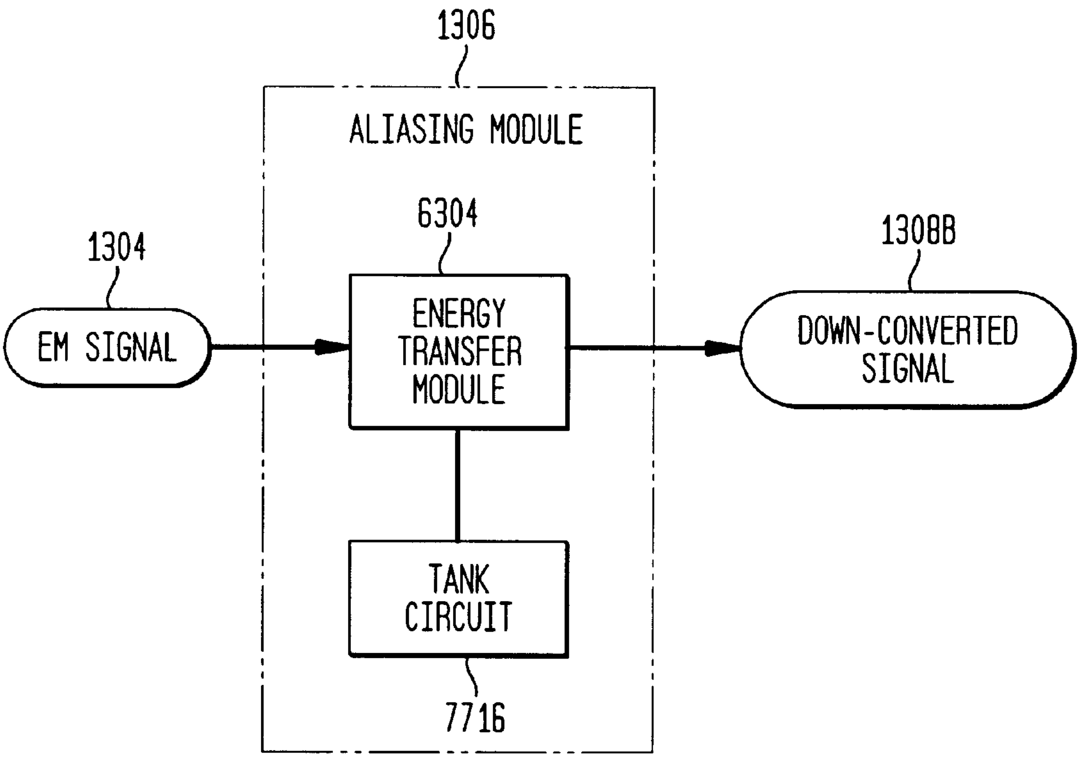

1306
ALIASING MODULE
6304
1304
EM SIGNAL
ENERGY TRANSFER MODULE
1308B
DOWN-CONVERTED SIGNAL
TANK CIRCUIT
7716

FIG. 78A

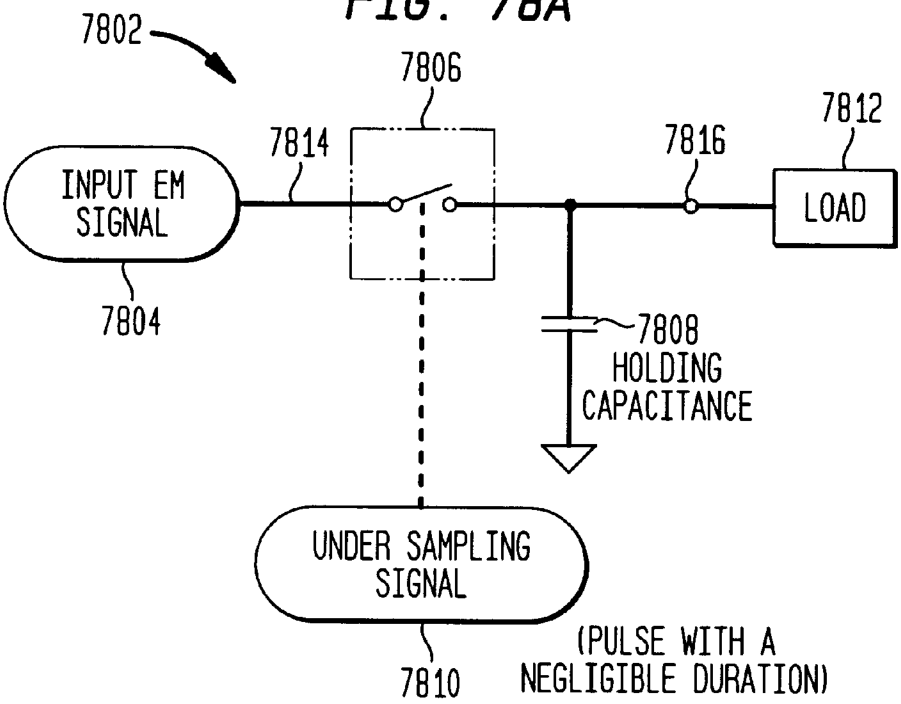


FIG. 78B

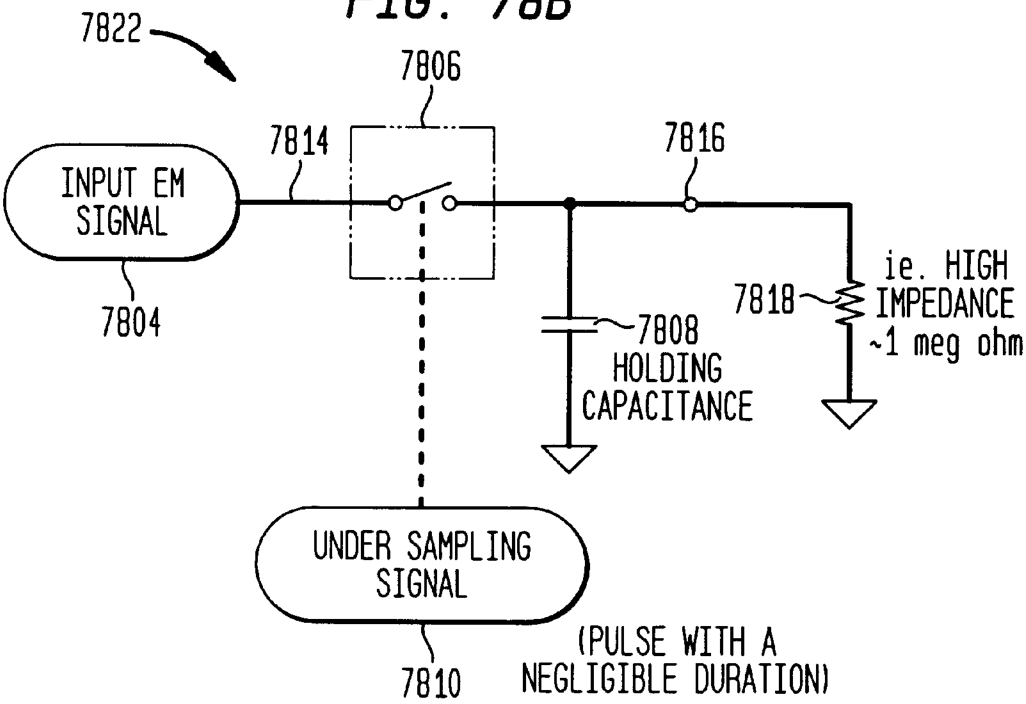


FIG. 79A

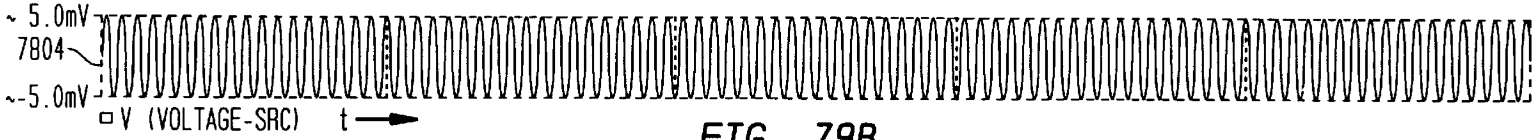


FIG. 79B

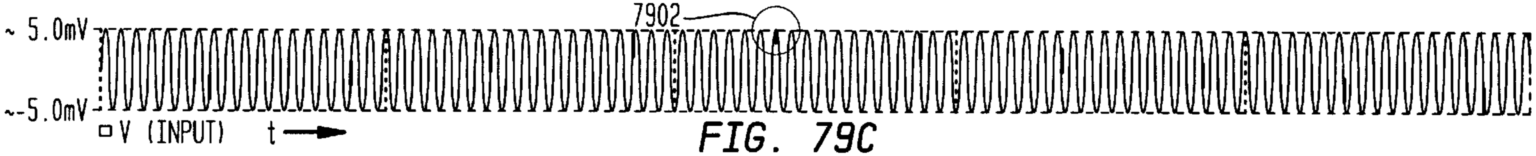


FIG. 79C

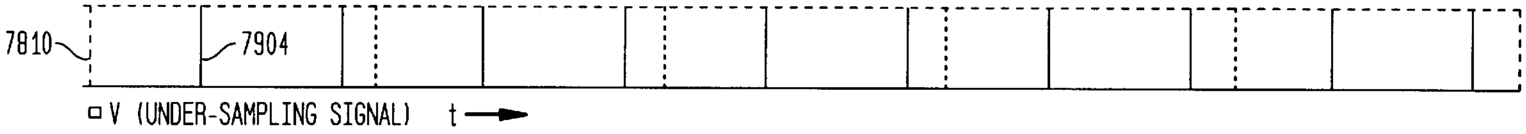


FIG. 79D

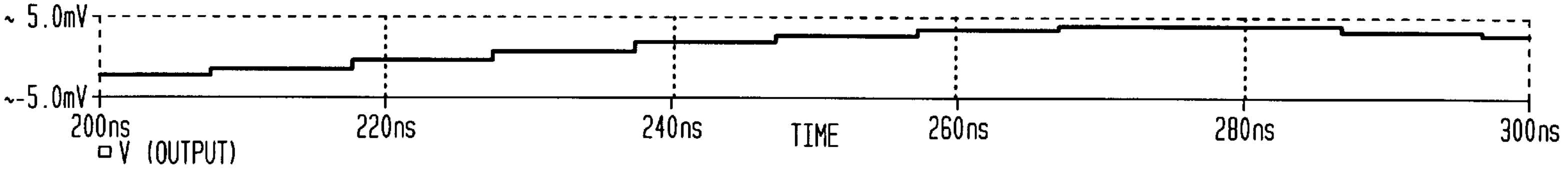


FIG. 79E

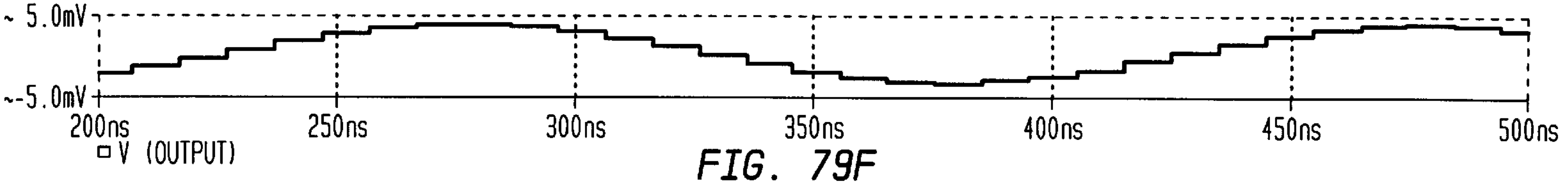


FIG. 79F

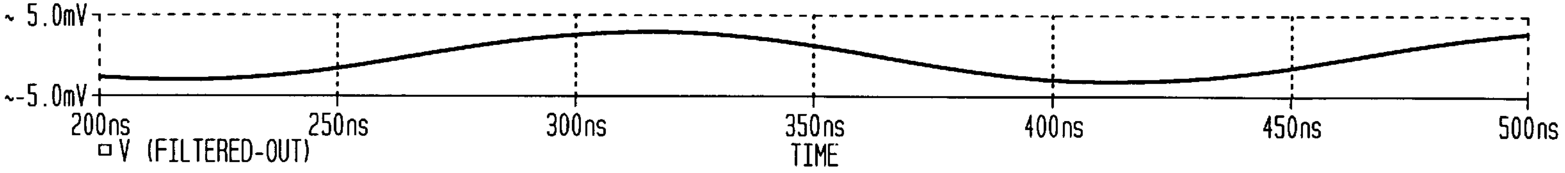


FIG. 80A

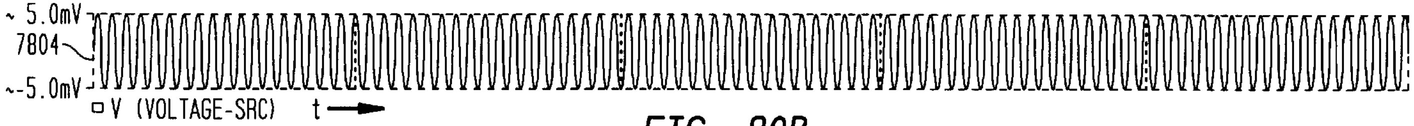


FIG. 80B

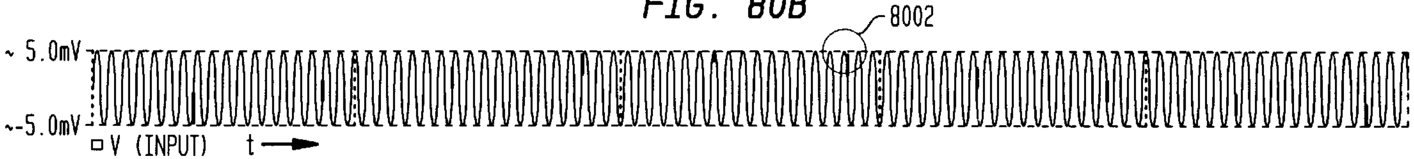


FIG. 80C

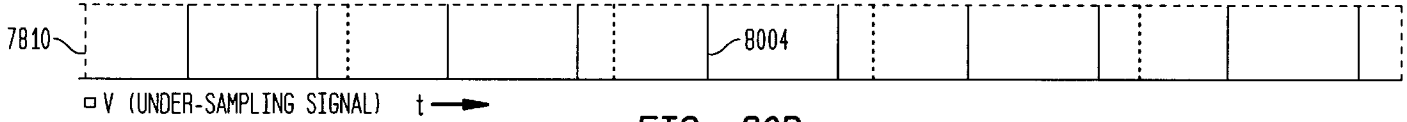


FIG. 80D

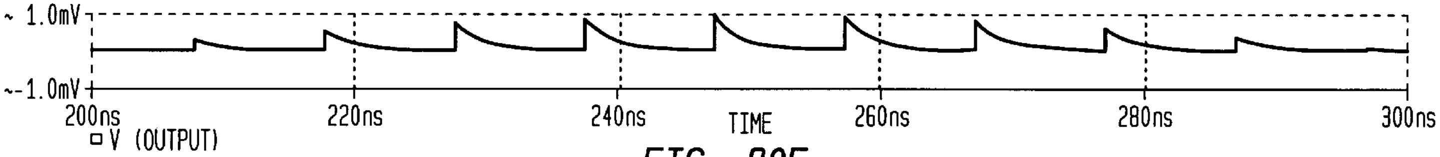


FIG. 80E

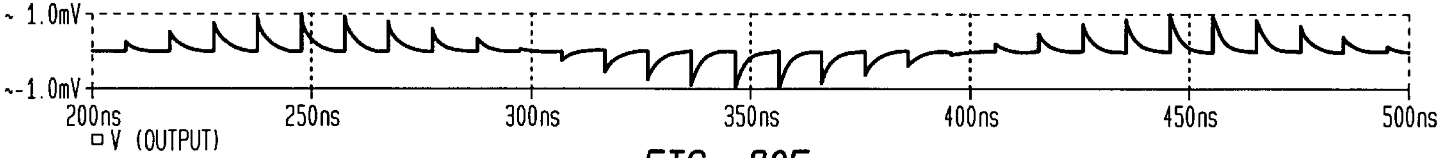


FIG. 80F

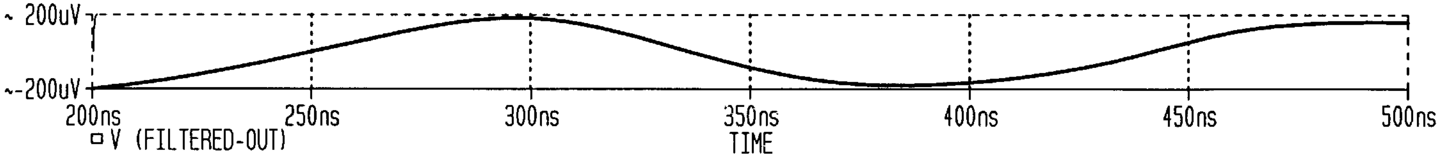


FIG. 81A

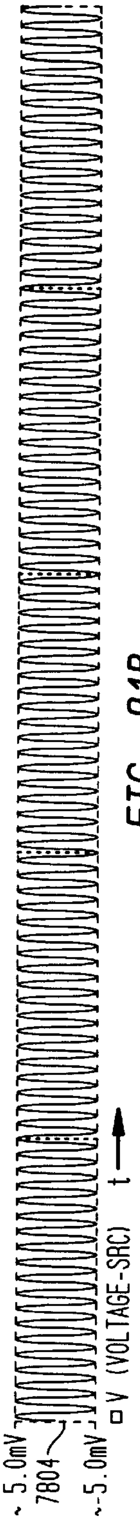


FIG. 81B

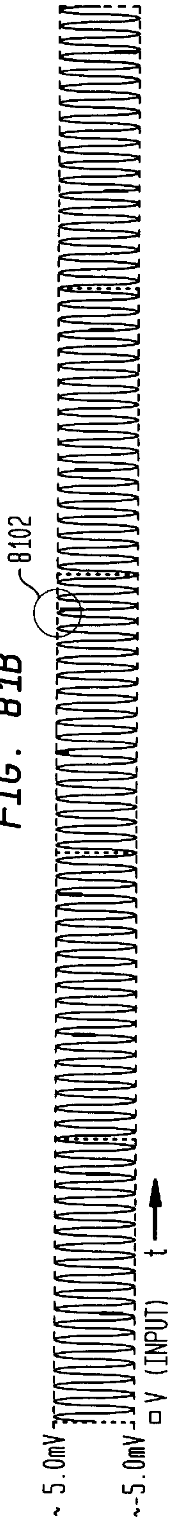


FIG. 81C

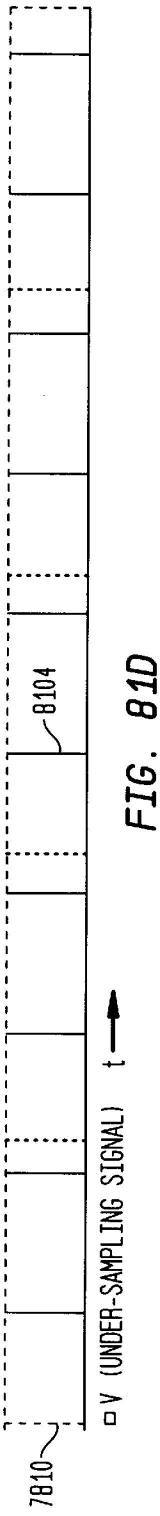


FIG. 81D

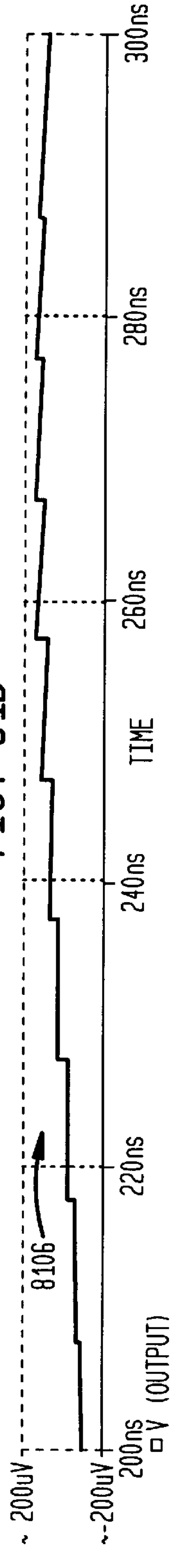


FIG. 81E

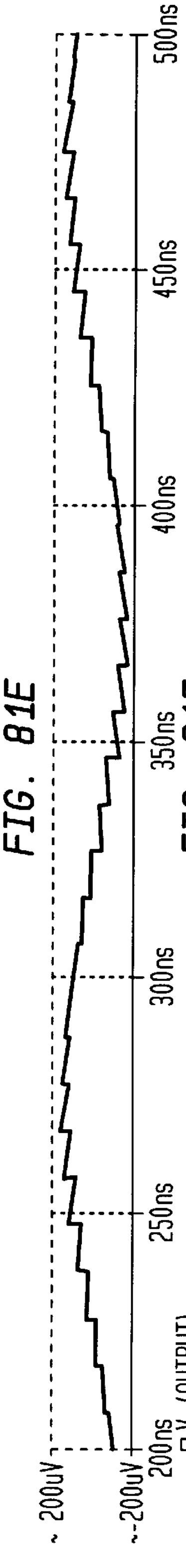


FIG. 81F

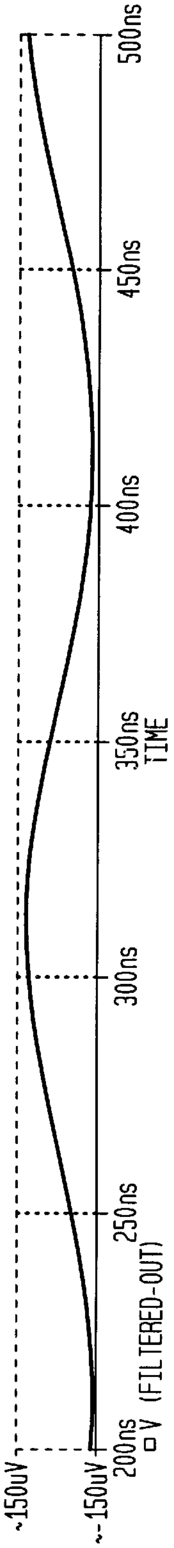


FIG. 82A

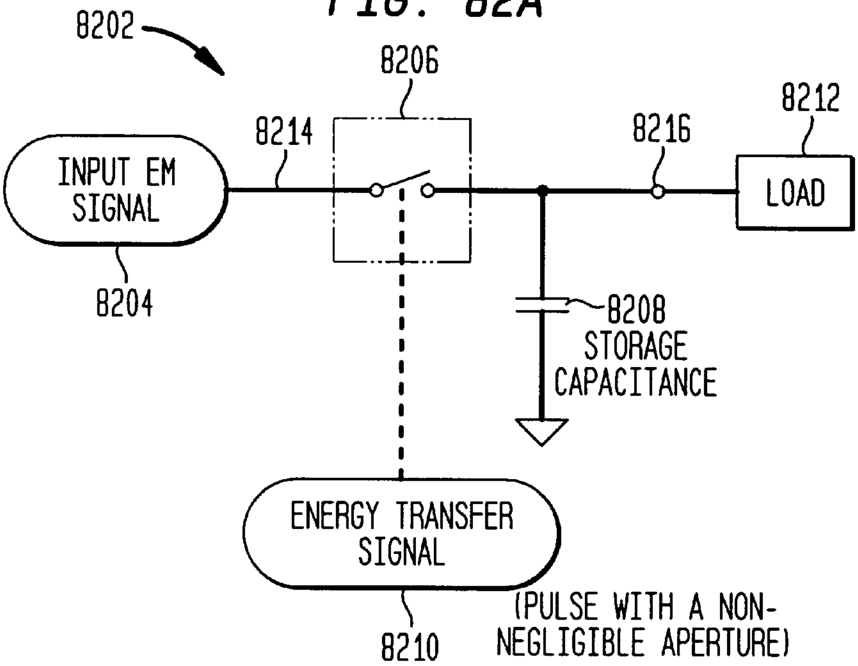


FIG. 82B

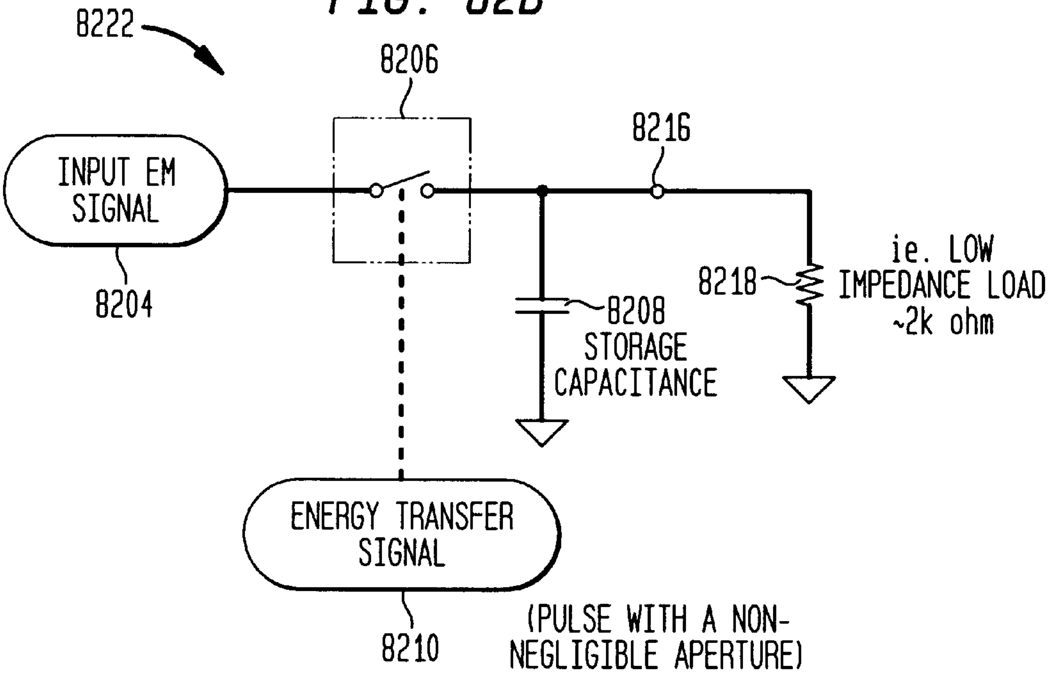


FIG. 83A

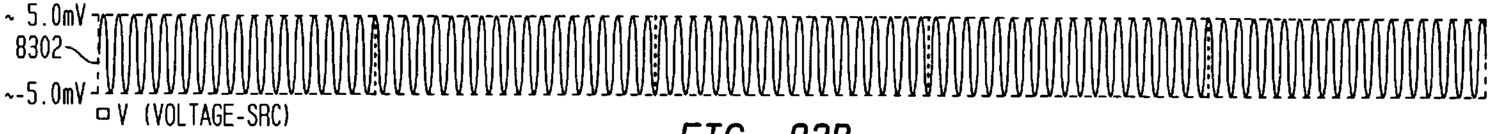


FIG. 83B

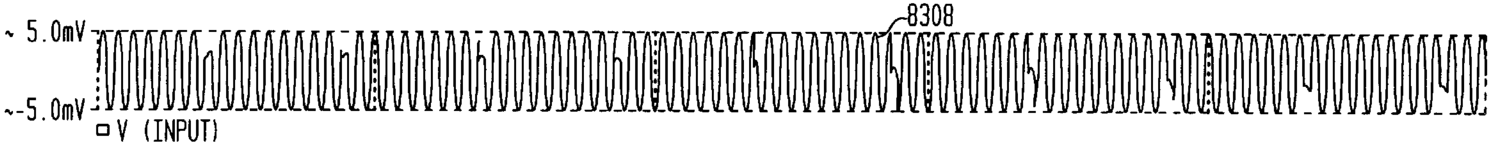


FIG. 83C

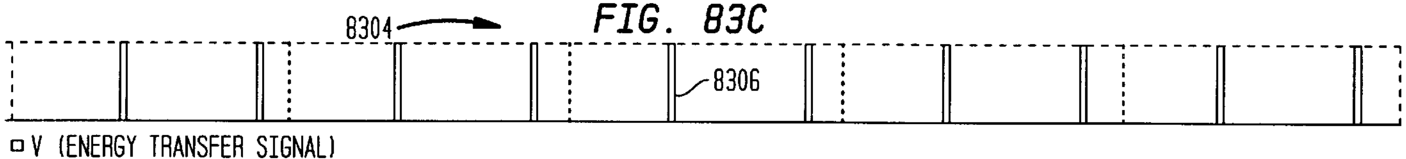


FIG. 83D

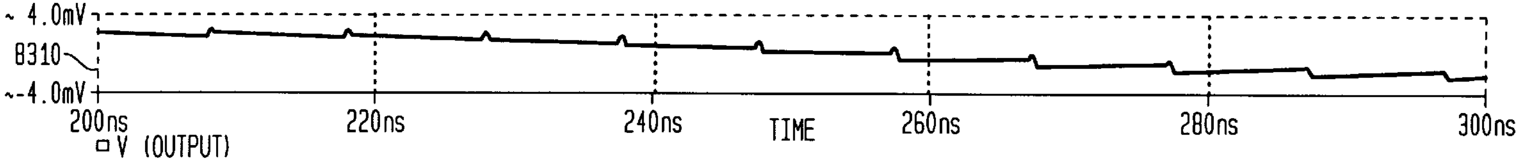


FIG. 83E

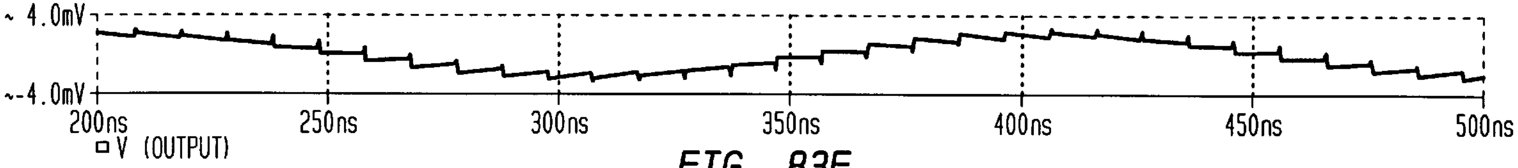


FIG. 83F

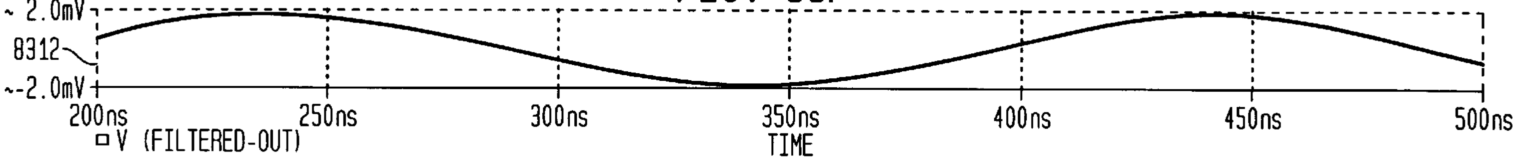


FIG. 84A

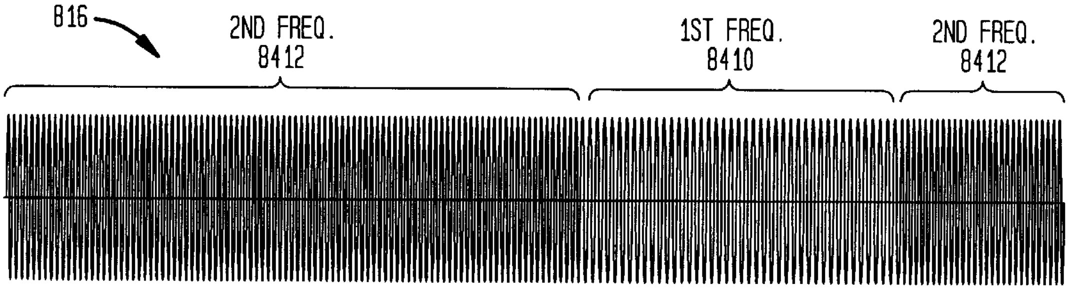


FIG. 84B

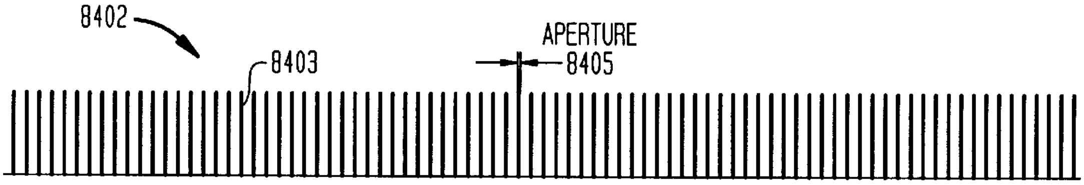


FIG. 84C

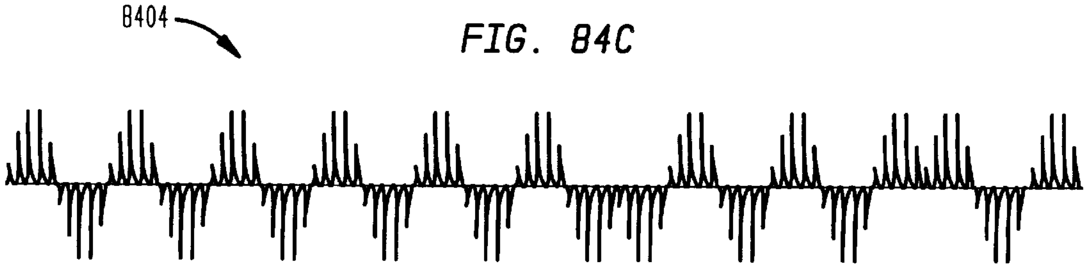


FIG. 84D

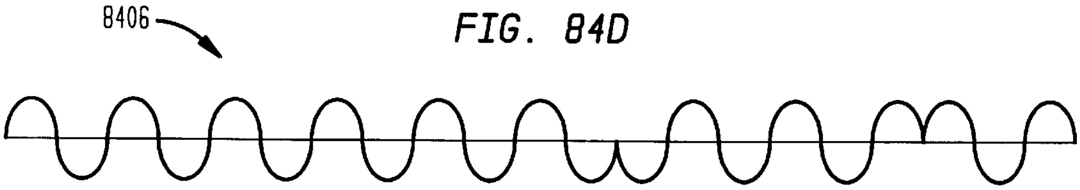


FIG. 85A

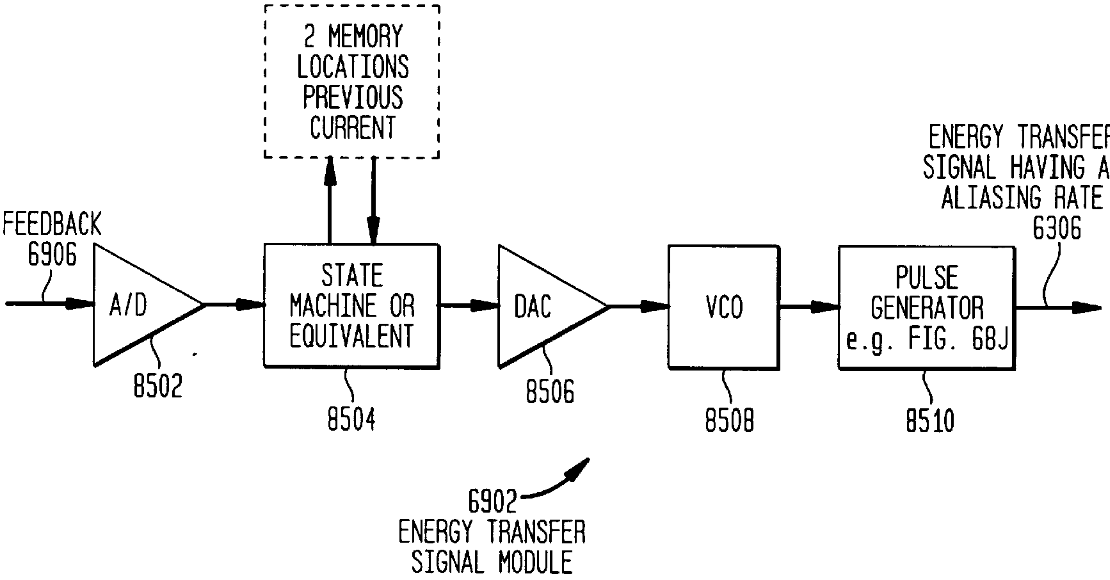
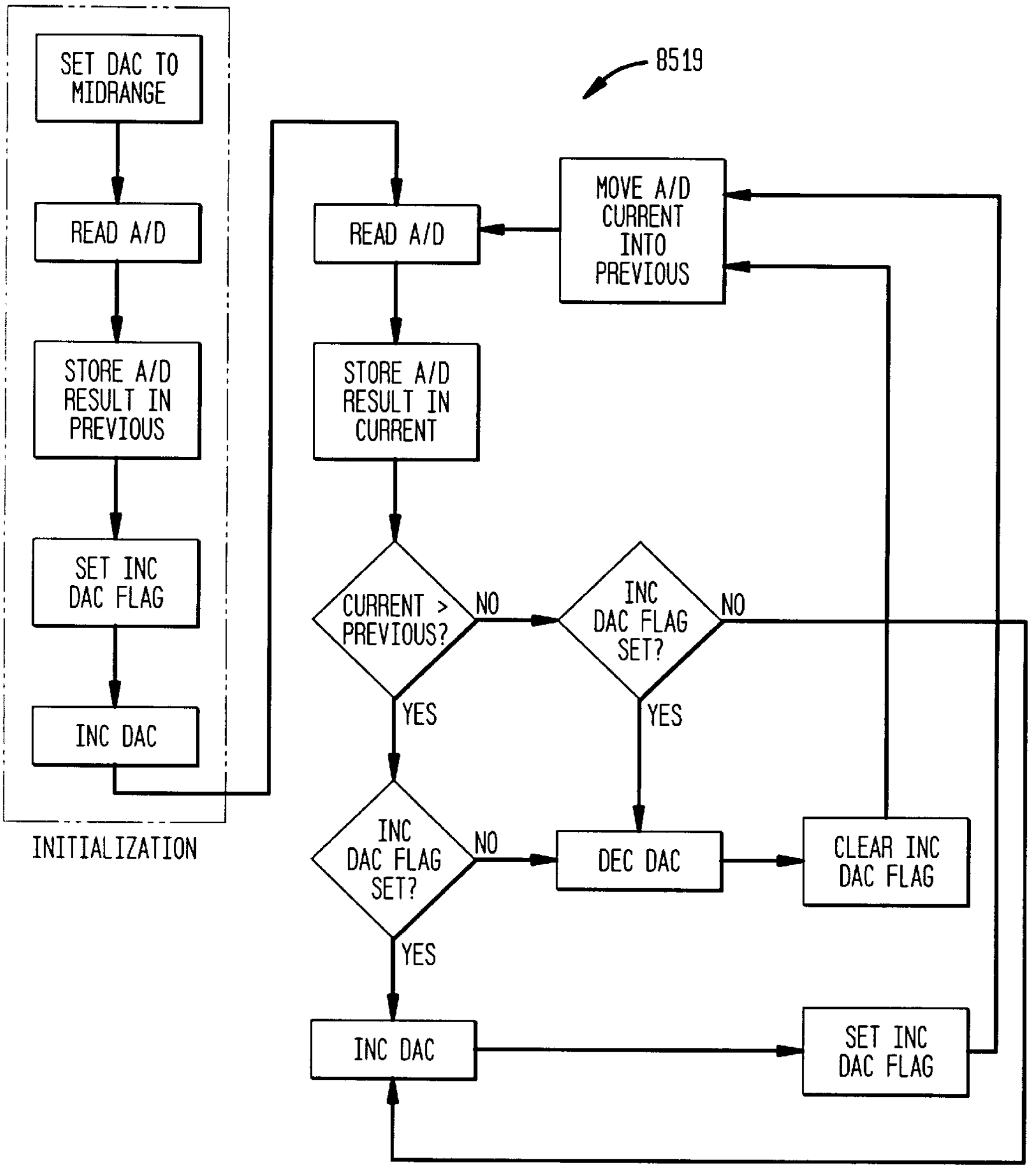
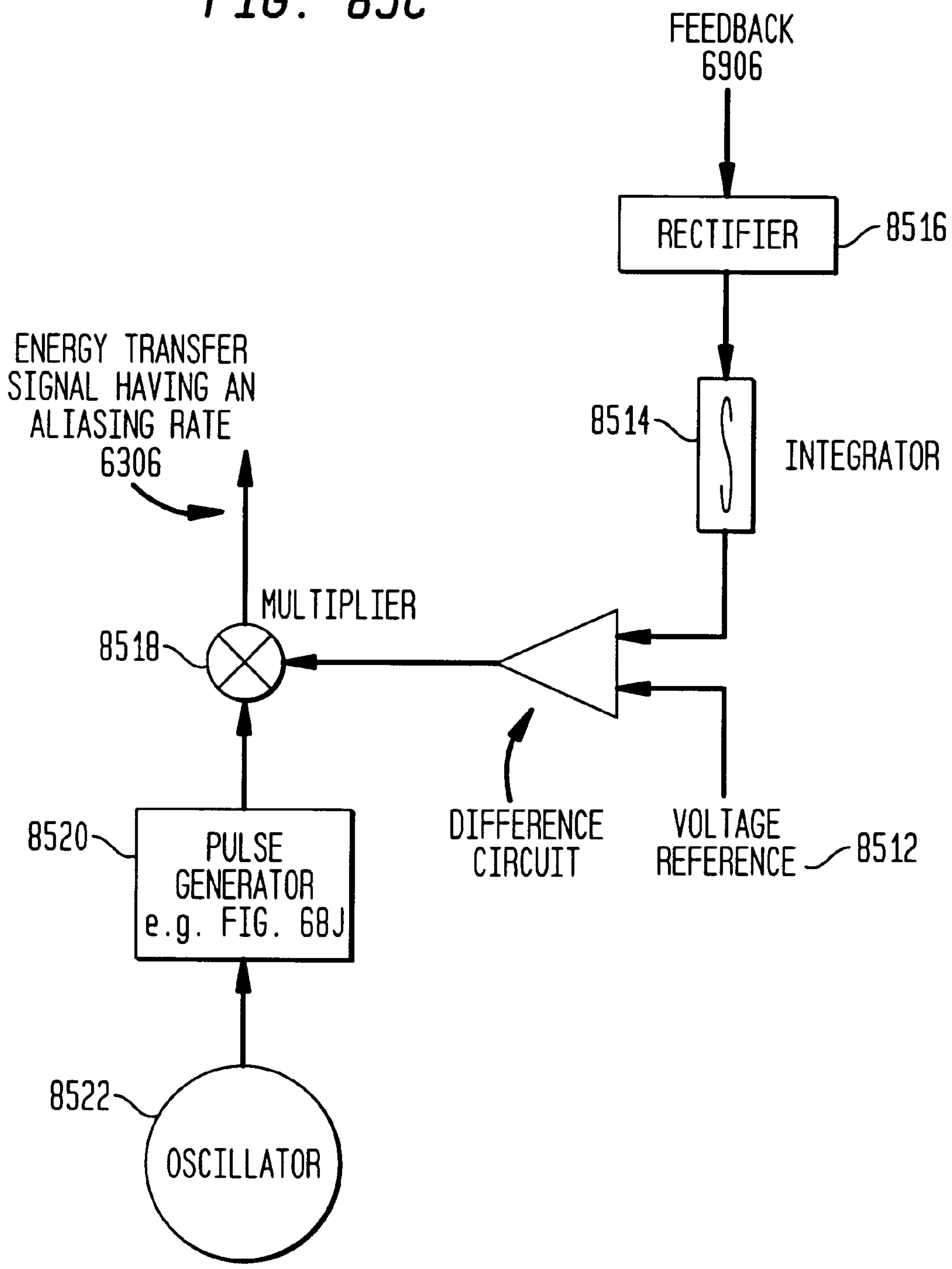

2 MEMORY
LOCATIONS
PREVIOUS
CURRENT
FEEDBACK
6906
A/D
8502
STATE
MACHINE OR
EQUIVALENT
8504
DAC
8506
VCO
8508
PULSE
GENERATOR
e.g. FIG. 68J
8510
ENERGY TRANSFER
SIGNAL HAVING AN
ALIASING RATE
6306
6902
ENERGY TRANSFER
SIGNAL MODULE

FIG. 85B



STATE MACHINE FLOWCHART

FIG. 85C



ENERGY TRANSFER SIGNAL MODULE 6902

FIG. 86

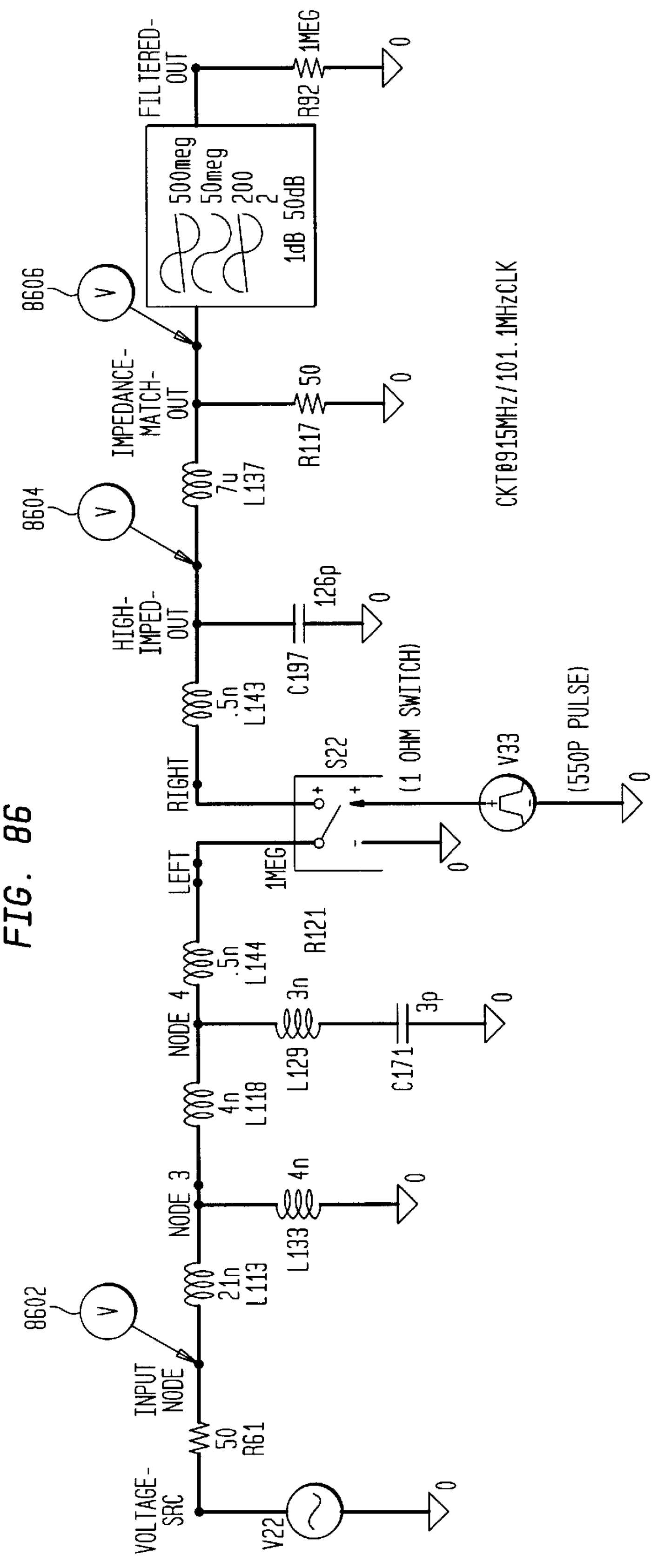
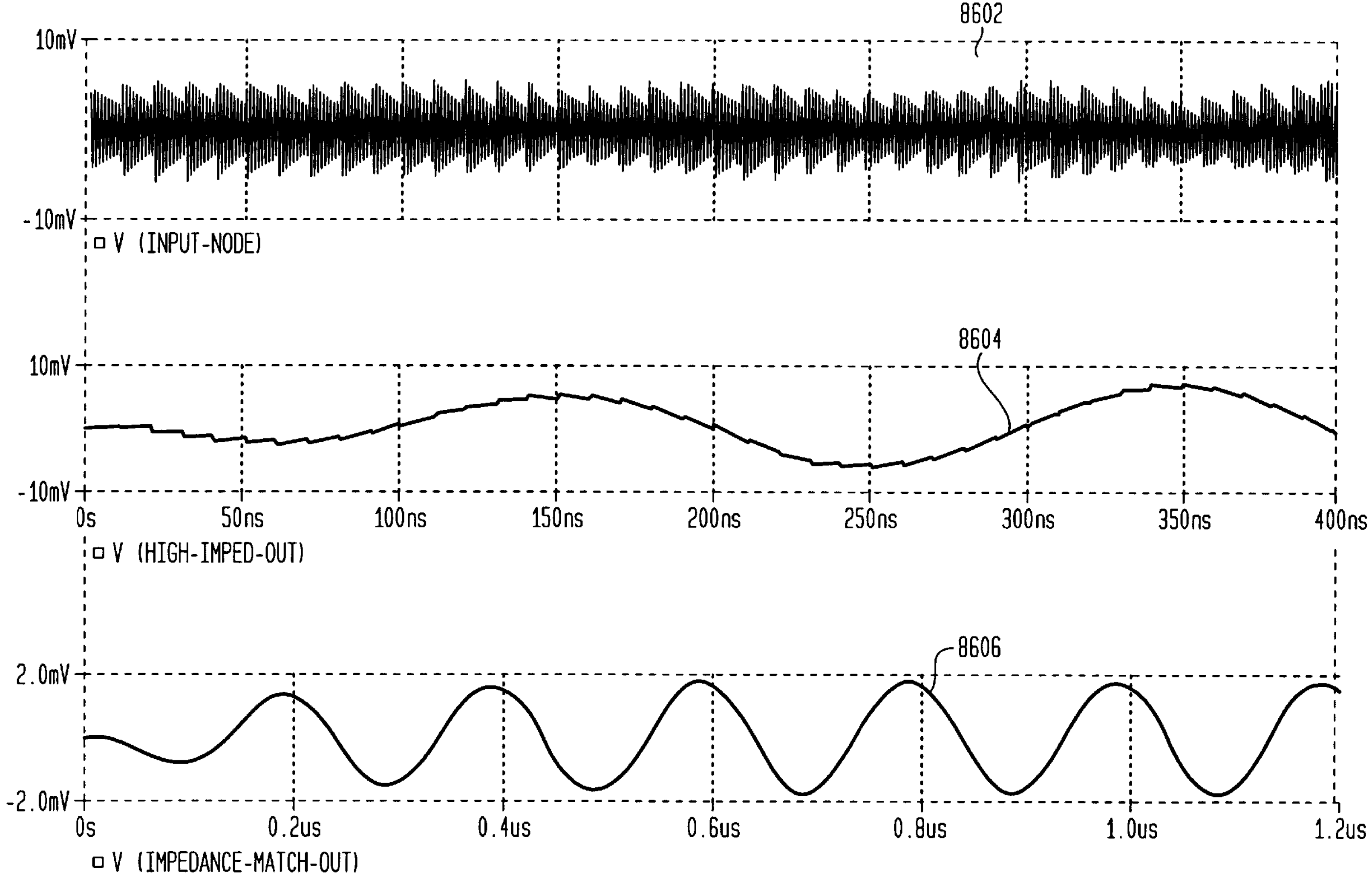

VOLTAGE-SRC
V22
0
50
R61
INPUT NODE
8602
V
21n
L113
NODE 3
4n
L133
0
4n
L118
NODE 4
3n
L129
3p
C171
0
.5n
L144
R121
LEFT
1MEG
S22
(1 OHM SWITCH)
0
V33
(550P PULSE)
0
RIGHT
.5n
L143
HIGH-IMPED-OUT
126p
C197
0
8604
V
7u
L137
IMPEDANCE-MATCH-OUT
50
R117
0
8606
V
500meg
50meg
200
2
1dB 50dB
FILTERED-OUT
1MEG
R92
0
CKT@915MHz/101.1MHzCLK

FIG. 87


8602
10mV
-10mV
□ V (INPUT-NODE)
8604
10mV
-10mV
0s
50ns
100ns
150ns
200ns
250ns
300ns
350ns
400ns
□ V (HIGH-IMPED-OUT)
8606
2.0mV
-2.0mV
0s
0.2us
0.4us
0.6us
0.8us
1.0us
1.2us
□ V (IMPEDANCE-MATCH-OUT)

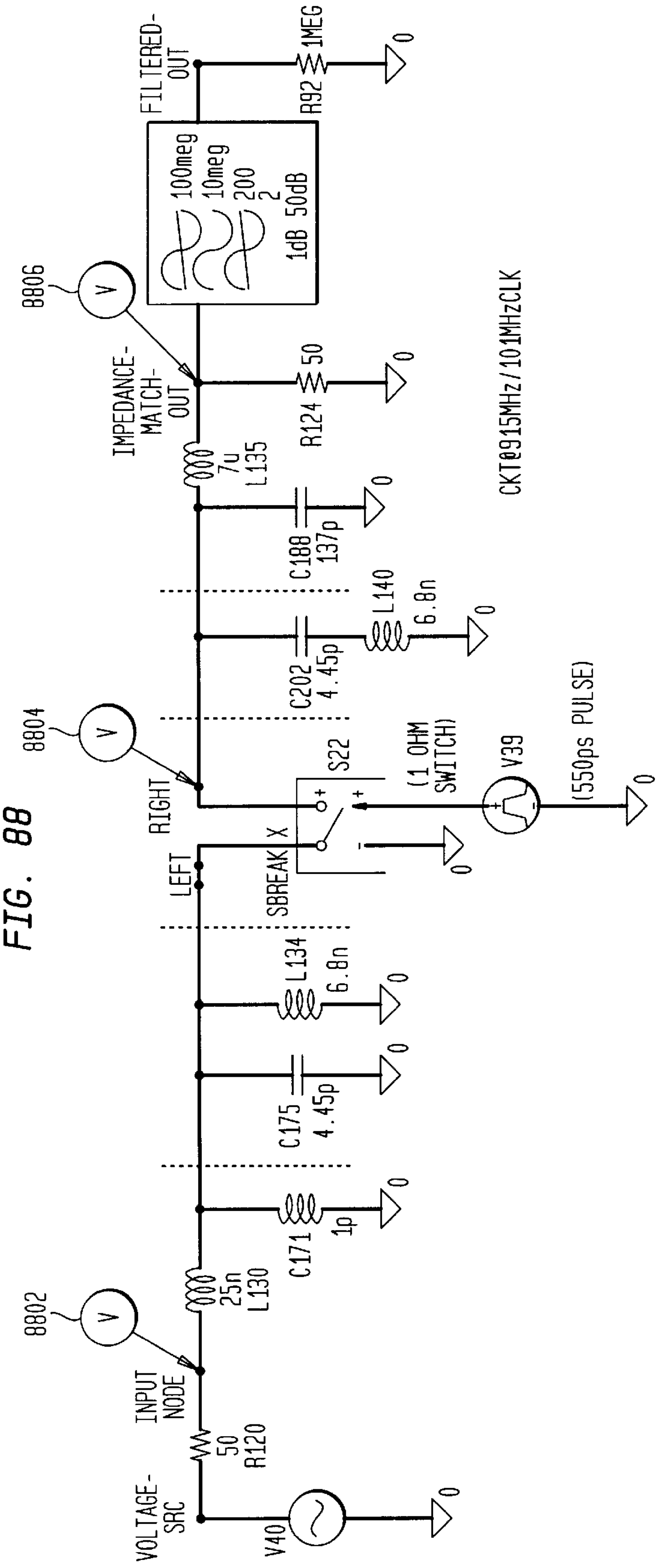

FILTERED-OUT
R92 1MEG
0
100meg
10meg
200
2
1dB 50dB
8806
V
IMPEDANCE-MATCH-OUT
R124 50
0
L135 7u
C188 137p
0
CKT@915MHz/101MHzCLK
C202 4.45p
L140 6.8n
0
8804
V
RIGHT
S22
(1 OHM SWITCH)
V39
(550ps PULSE)
0
0
LEFT
SBREAK X
L134 6.8n
0
C175 4.45p
0
C171 1p
0
8802
V
L130 25n
INPUT NODE
R120 50
VOLTAGE-SRC
V40
0

FIG. 88

FIG. 89

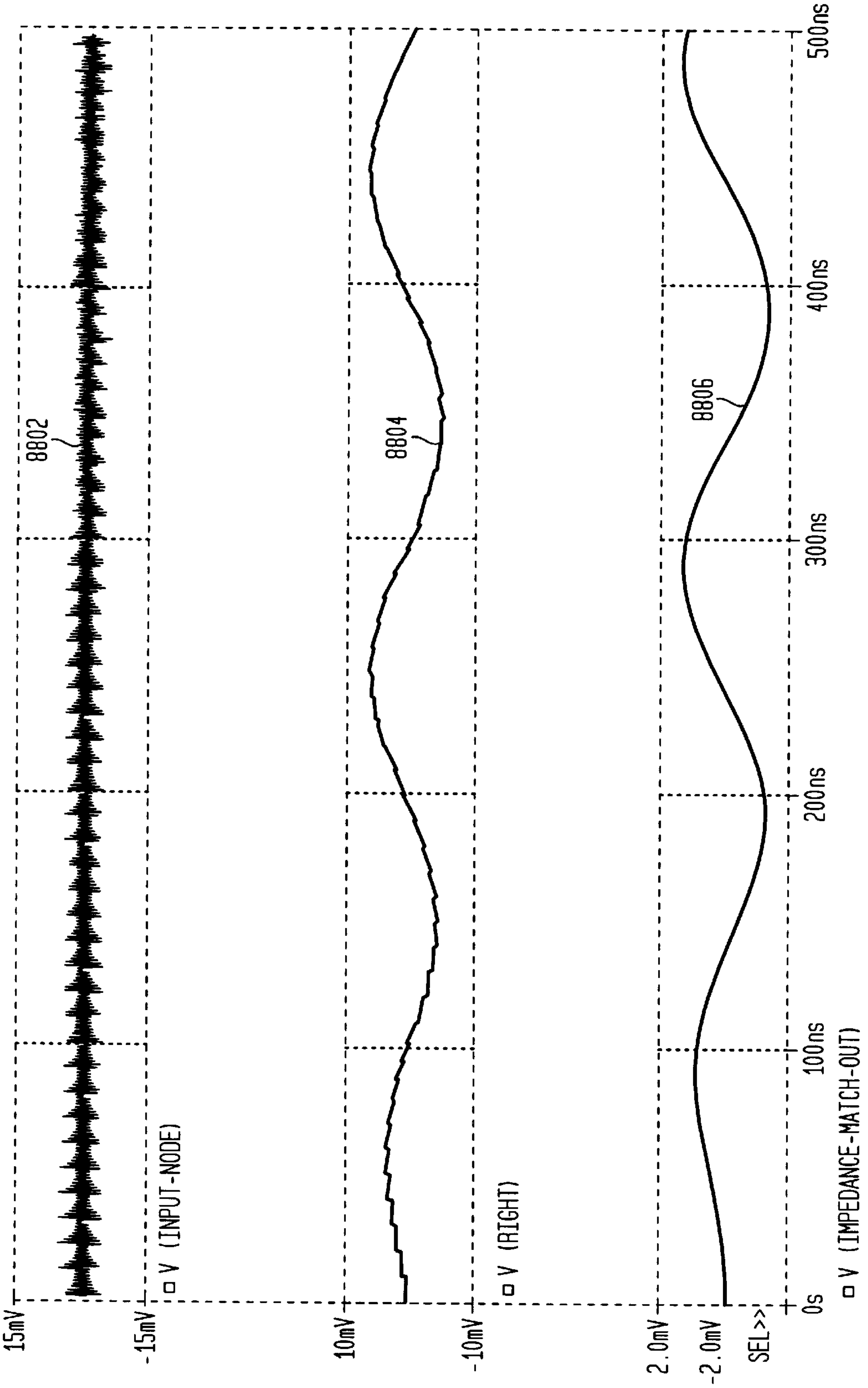

15mV
-15mV
□ V (INPUT-NODE)
8802
10mV
-10mV
□ V (RIGHT)
8804
2.0mV
-2.0mV
SEL>>
□ V (IMPEDANCE-MATCH-OUT)
8806
0s
100ns
200ns
300ns
400ns
500ns

FIG. 90

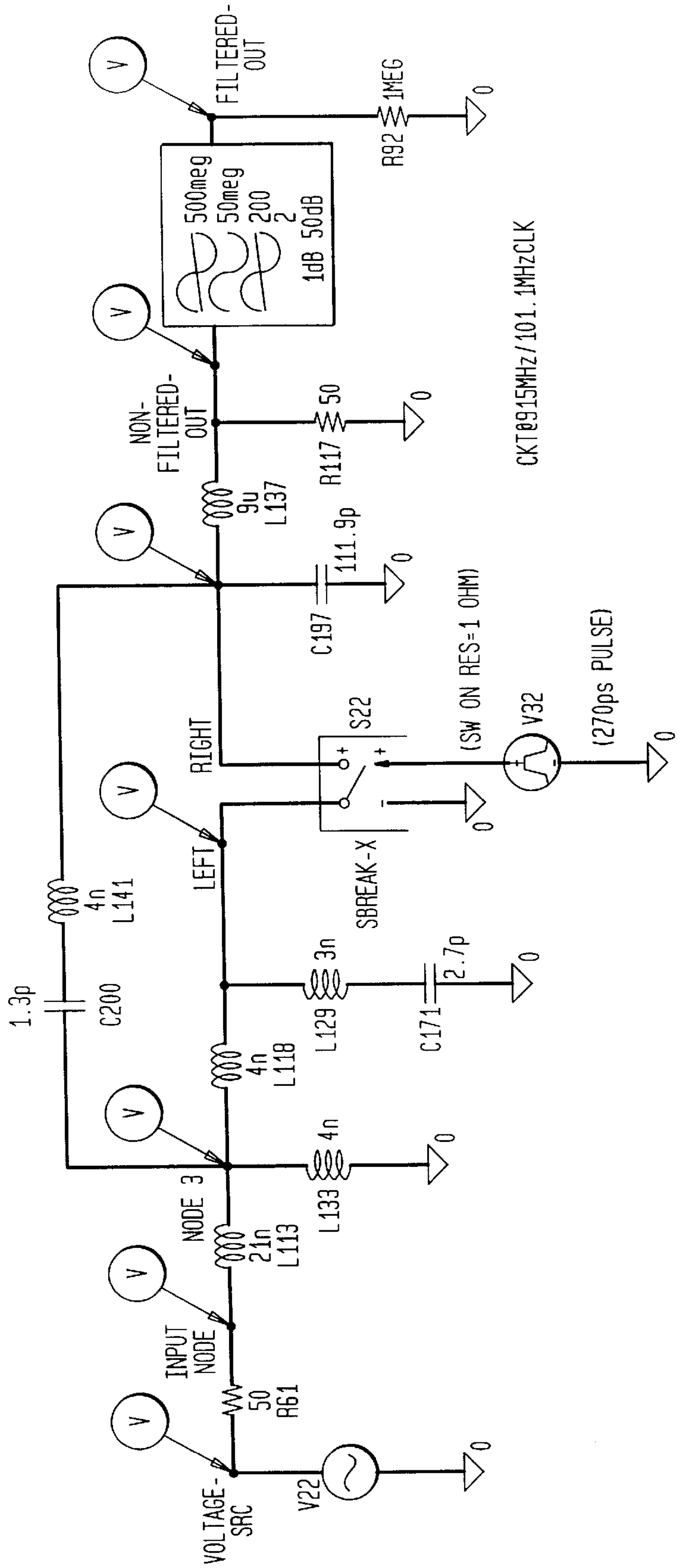
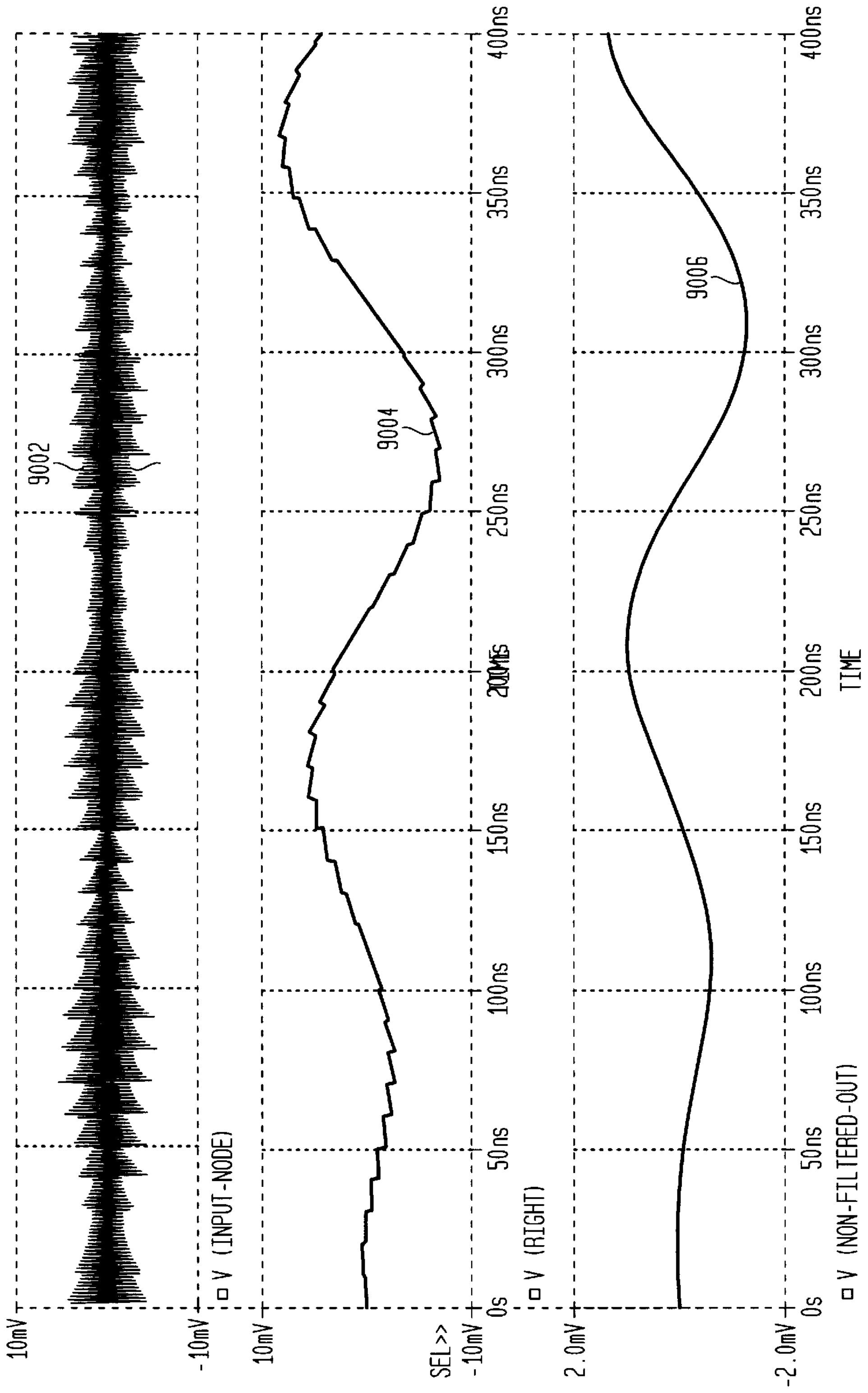

V
FILTERED-OUT
R92
1MEG
0
500meg
50meg
200
2
1dB 50dB
CKT@915MHz/101.1MHzCLK
NON-FILTERED-OUT
R117
50
L137
9u
C197
111.9p
(SW ON RES=1 OHM)
V32
(270ps PULSE)
S22
SBREAK-X
+
-
RIGHT
LEFT
L141
4n
C200
1.3p
L129
3n
C171
2.7p
L118
4n
NODE 3
L133
4n
L113
21n
INPUT NODE
R61
50
VOLTAGE-SRC
V22

FIG. 91


10mV
-10mV
□ V (INPUT-NODE)
9002
10mV
SEL>>
-10mV
□ V (RIGHT)
9004
0s
50ns
100ns
150ns
200ns
250ns
300ns
350ns
400ns
TIME
2.0mV
-2.0mV
□ V (NON-FILTERED-OUT)
9006
0s
50ns
100ns
150ns
200ns
250ns
300ns
350ns
400ns
TIME

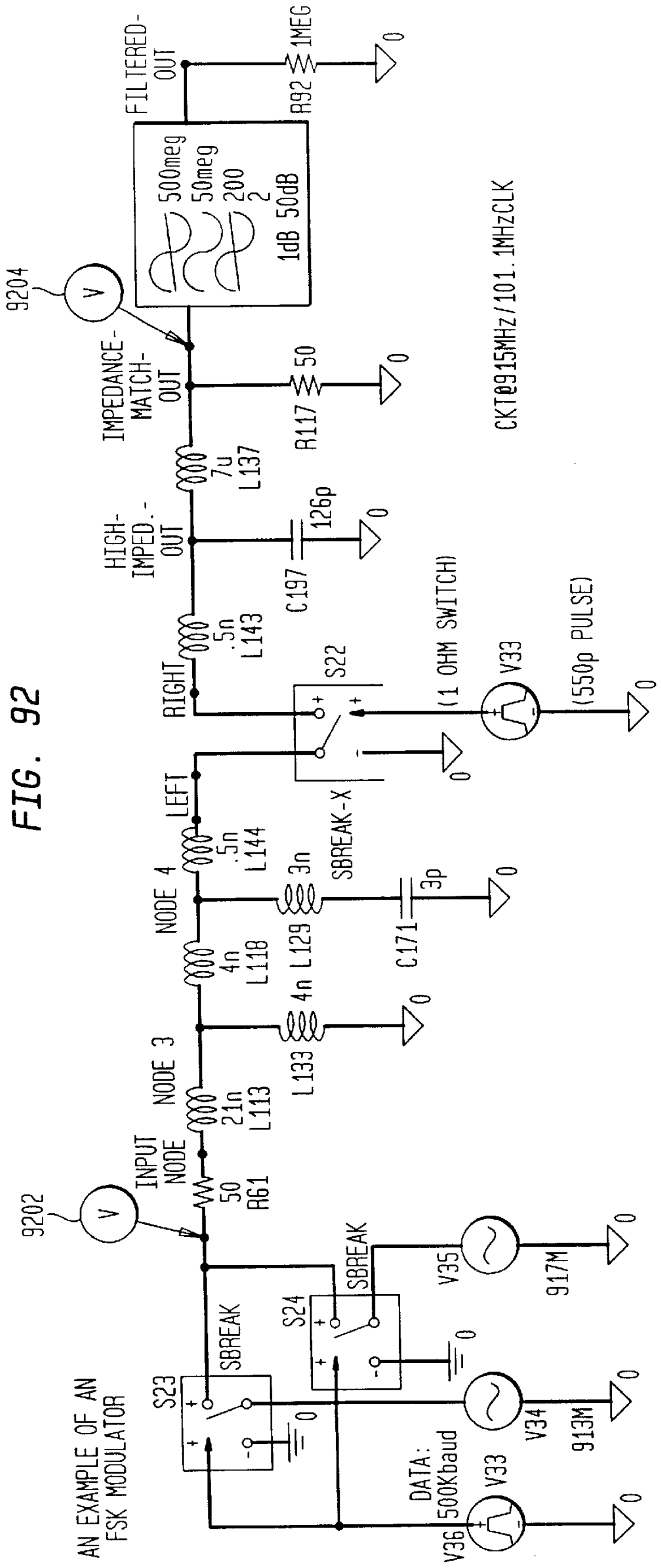

AN EXAMPLE OF AN
FSK MODULATOR
S23
SBREAK
0
S24
SBREAK
0
V36
DATA:
500Kbaud
V33
0
V34
913M
0
V35
917M
0
9202
V
50
R61
INPUT
NODE
NODE 3
21n
L113
4n
L133
0
4n
L118
L129
3n
C171
3p
0
NODE 4
.5n
L144
SBREAK-X
LEFT
S22
0
(1 OHM SWITCH)
V33
(550p PULSE)
0
RIGHT
.5n
L143
HIGH-
IMPED.-
OUT
C197
126p
0
7u
L137
IMPEDANCE-
MATCH-
OUT
R117
50
0
9204
V
500meg
50meg
200
2
1dB 50dB
FILTERED-
OUT
R92
1MEG
0
CKT@915MHz/101.1MHzCLK

FIG. 92

FIG. 93

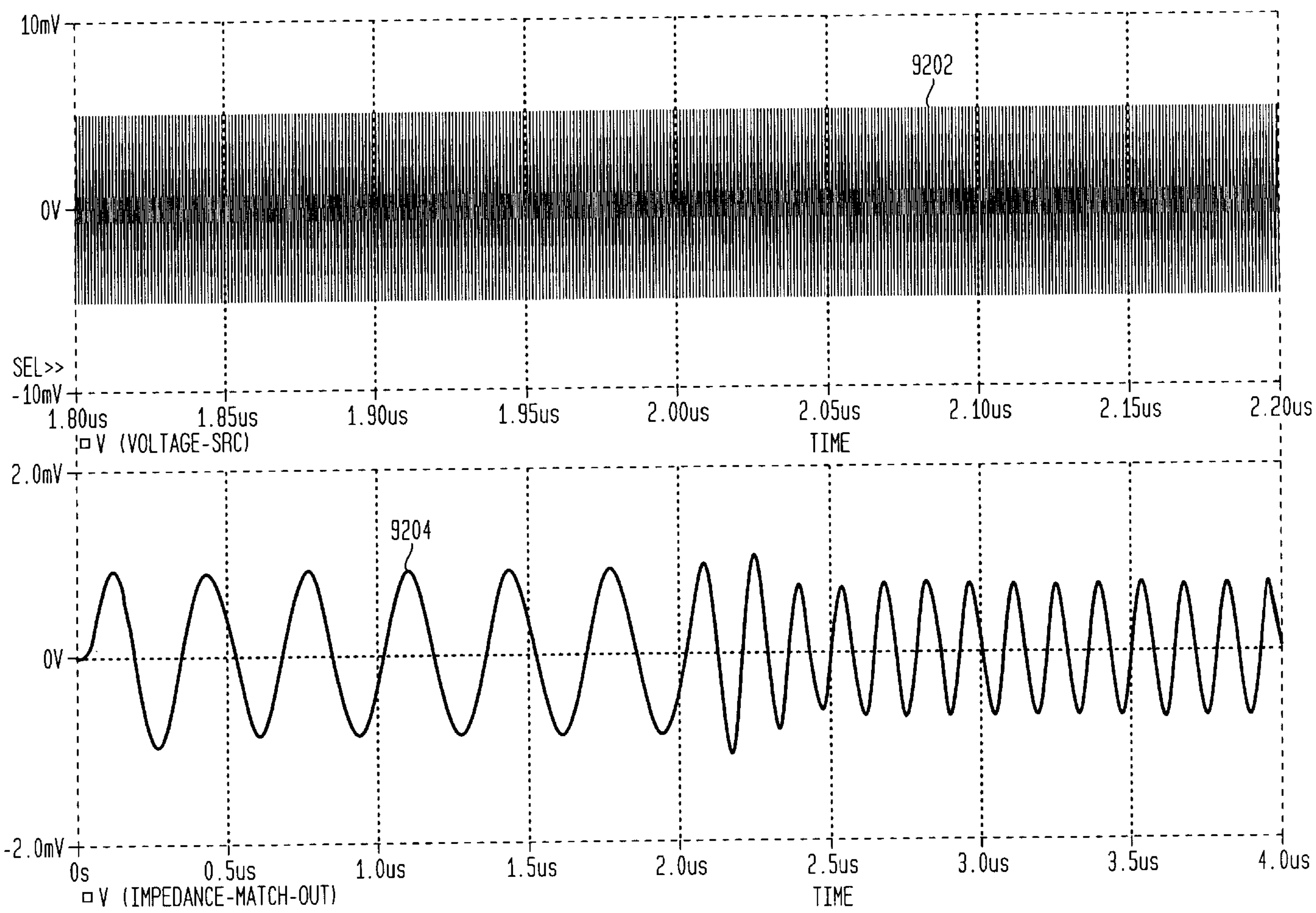
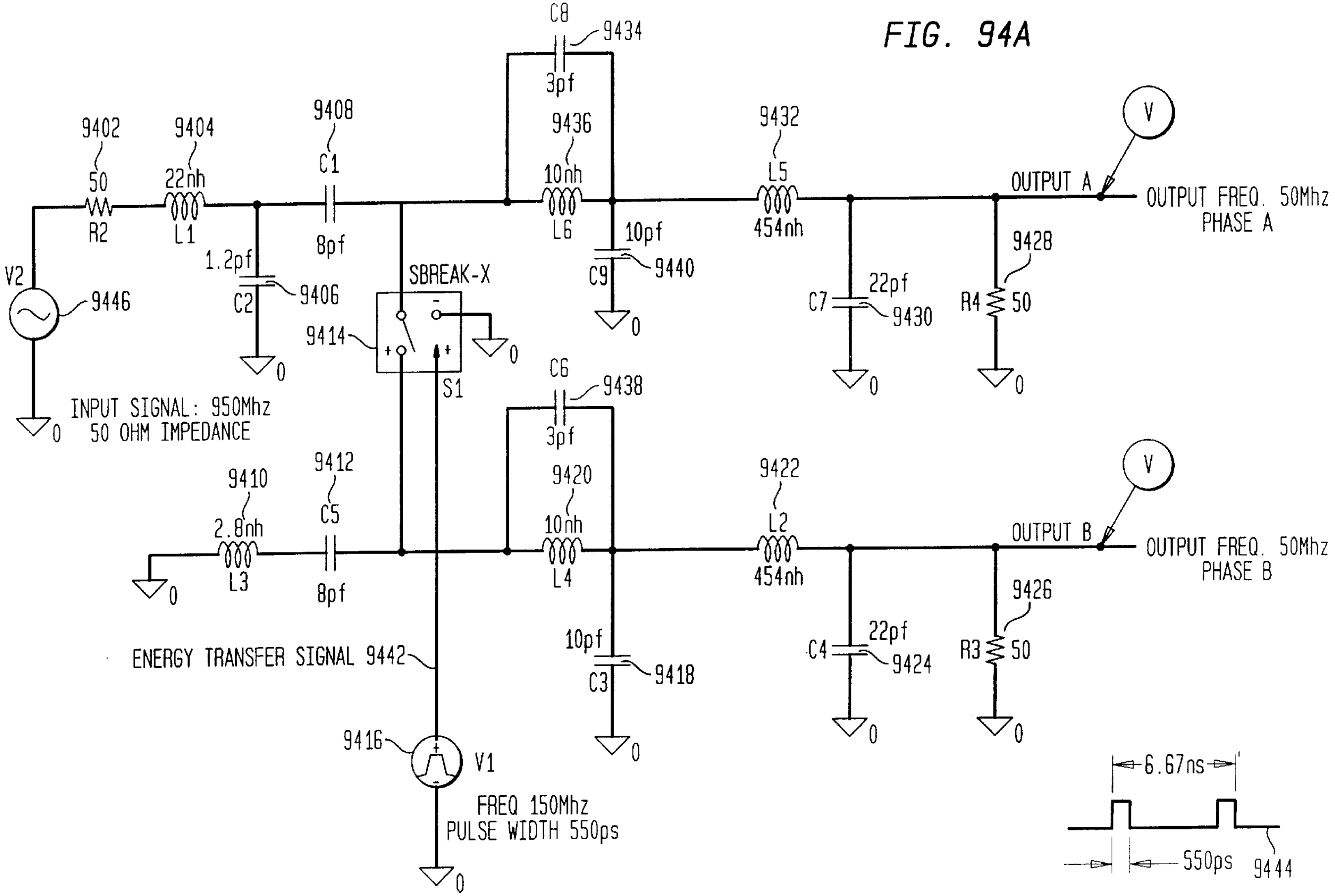

10mV
0V
SEL>>
-10mV
1.80us
1.85us
1.90us
1.95us
2.00us
2.05us
2.10us
2.15us
2.20us
□ V (VOLTAGE-SRC)
TIME
9202
2.0mV
0V
-2.0mV
0s
0.5us
1.0us
1.5us
2.0us
2.5us
3.0us
3.5us
4.0us
□ V (IMPEDANCE-MATCH-OUT)
TIME
9204

FIG. 94A


C8
9434
3pf
9402
9404
9408
9436
9432
V
50
22nh
C1
10nh
L5
OUTPUT A
OUTPUT FREQ. 50Mhz
PHASE A
R2
L1
8pf
L6
454nh
V2
1.2pf
10pf
9428
9446
C2
9406
SBREAK-X
C9
9440
C7
22pf
9430
R4
50
9414
0
S1
INPUT SIGNAL: 950Mhz
50 OHM IMPEDANCE
C6
9438
3pf
9410
9412
9420
9422
V
2.8nh
C5
10nh
L2
OUTPUT B
OUTPUT FREQ. 50Mhz
PHASE B
L3
8pf
L4
454nh
9426
10pf
C4
22pf
9424
R3
50
ENERGY TRANSFER SIGNAL 9442
C3
9418
9416
V1
FREQ 150Mhz
PULSE WIDTH 550ps
6.67ns
550ps
9444

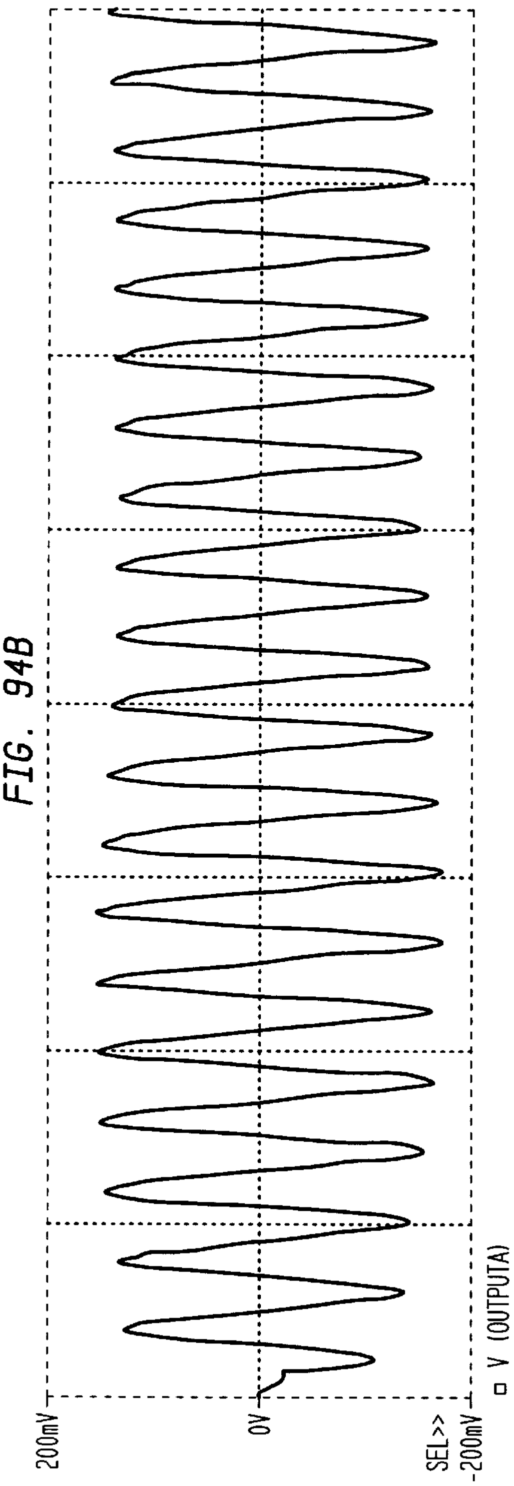


FIG. 94B

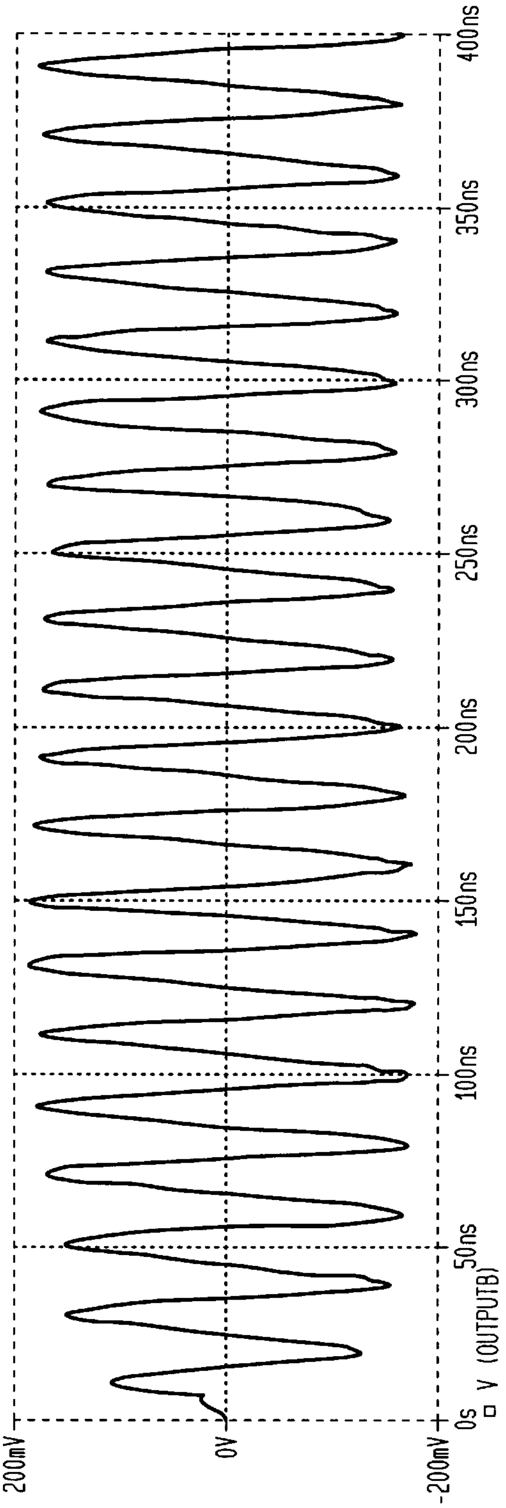


FIG. 94C

FIG. 95

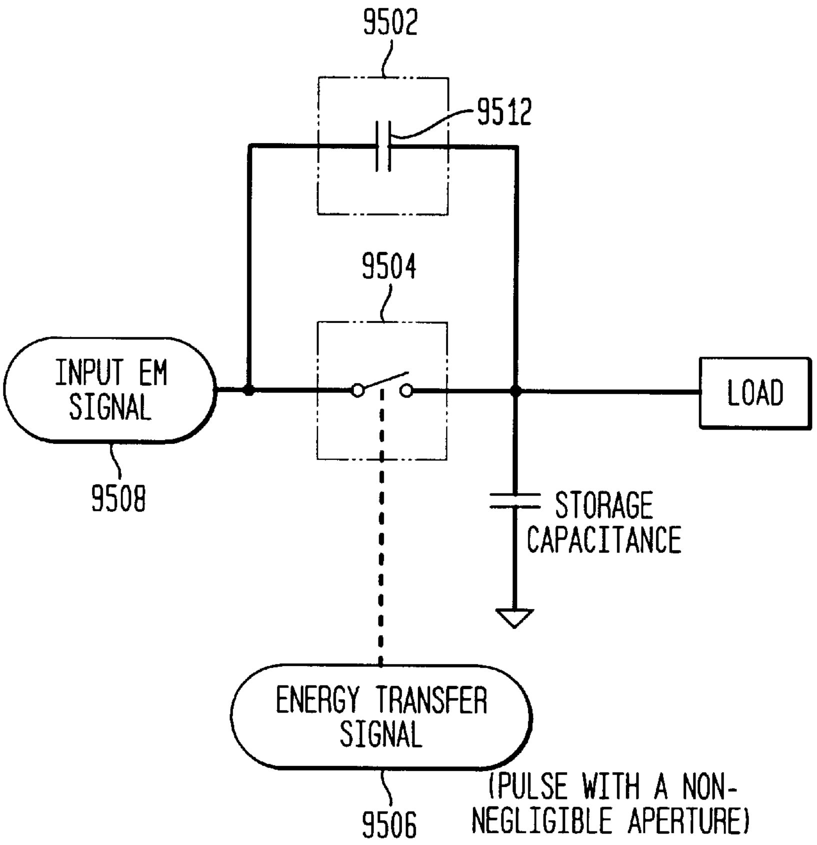
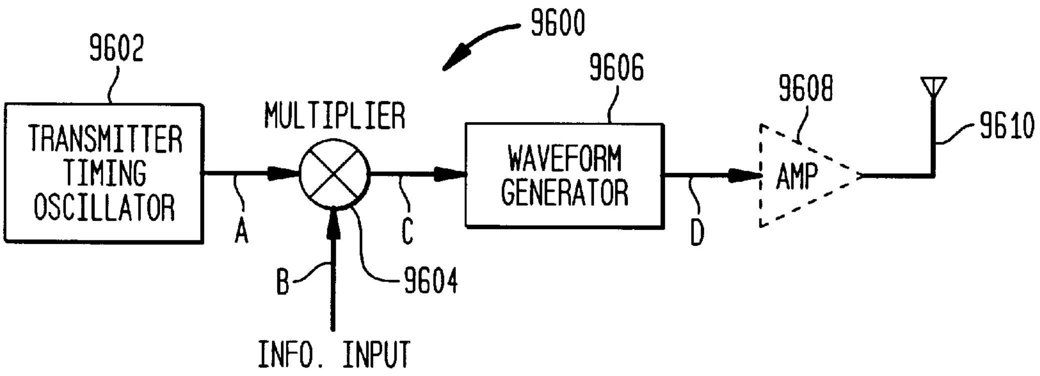

9502
9512
9504
INPUT EM SIGNAL
9508
LOAD
STORAGE CAPACITANCE
ENERGY TRANSFER SIGNAL
9506
(PULSE WITH A NON-NEGLIGIBLE APERTURE)

FIG. 96


9600
9602
TRANSMITTER TIMING OSCILLATOR
MULTIPLIER
9606
WAVEFORM GENERATOR
9608
AMP
9610
A
B
C
D
9604
INFO. INPUT

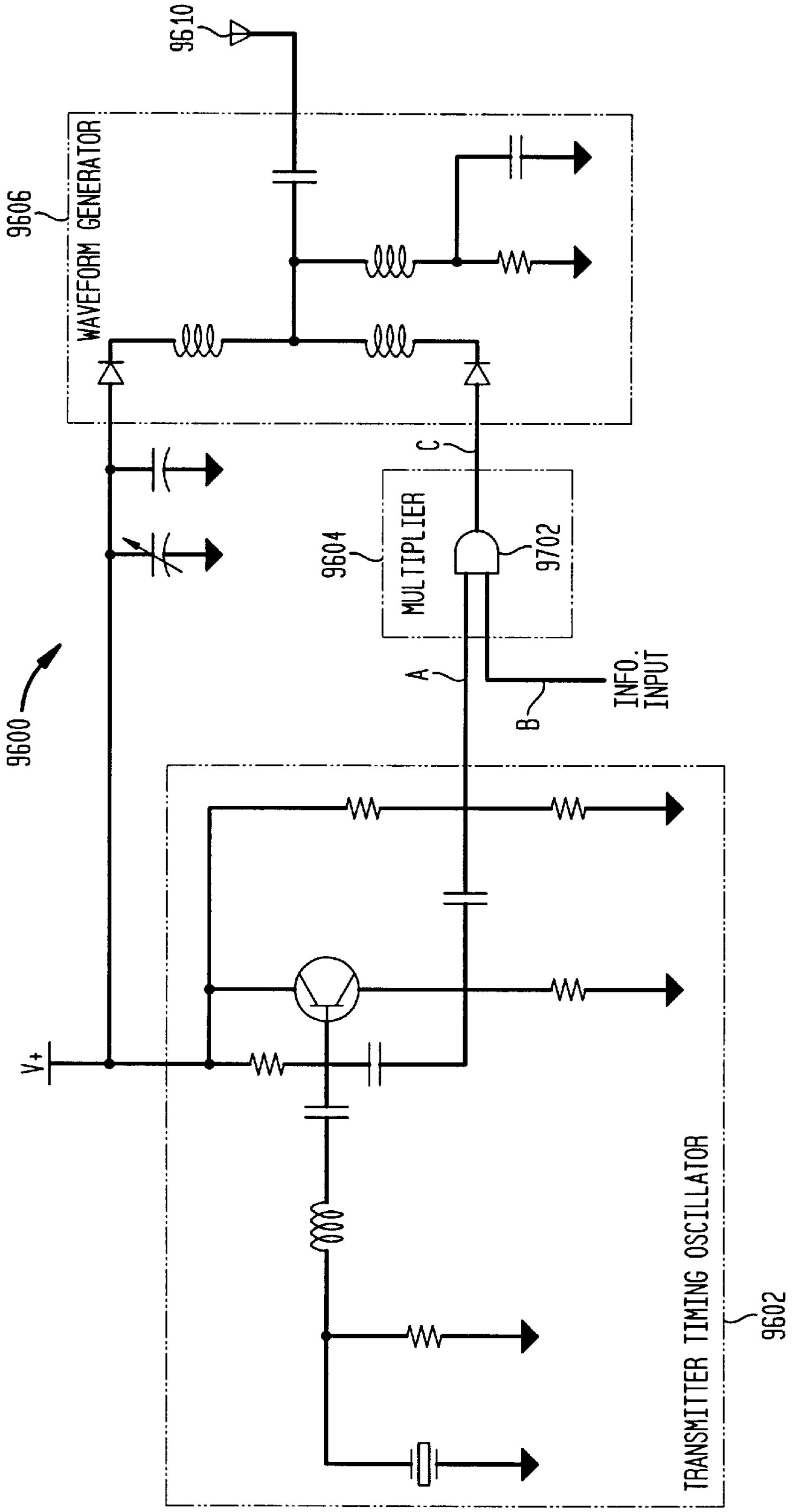

9610
9606
WAVEFORM GENERATOR
C
9604
MULTIPLIER
9702
A
B
INFO. INPUT
9600
V+
TRANSMITTER TIMING OSCILLATOR
9602

FIG. 97

FIG. 98A

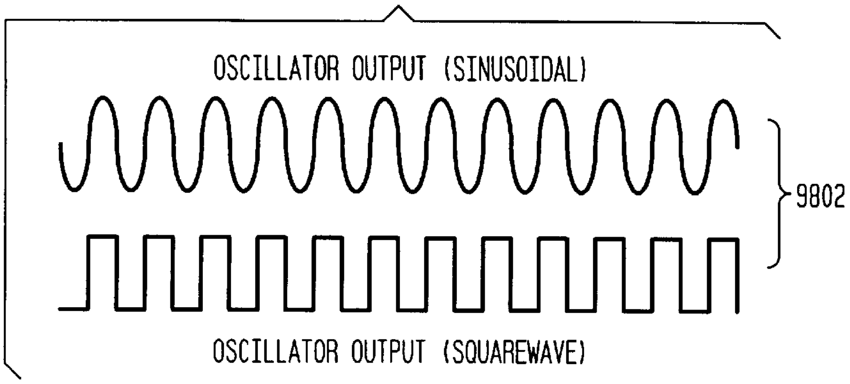


FIG. 98B

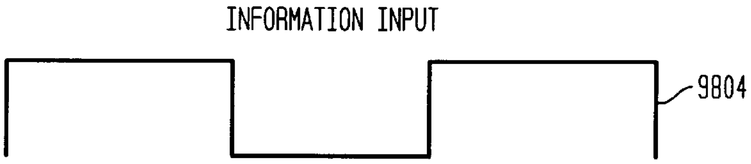


FIG. 98C

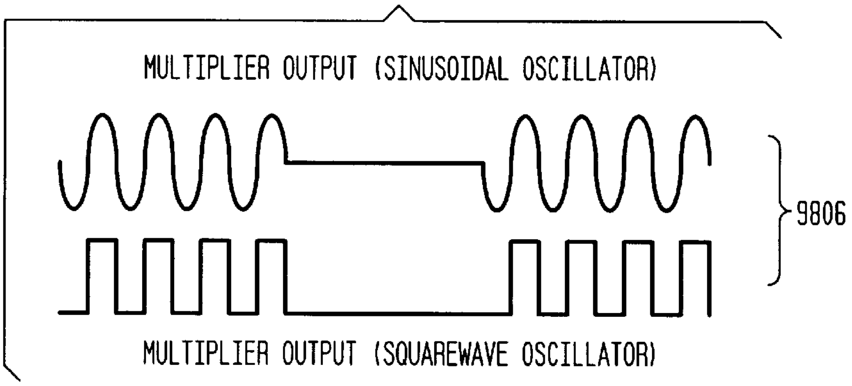


FIG. 98D

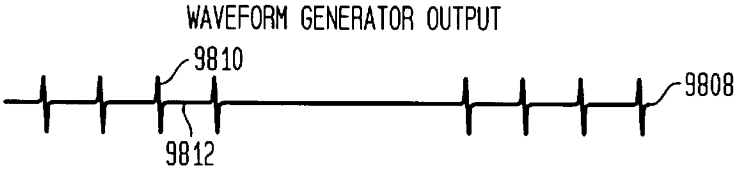


FIG. 99

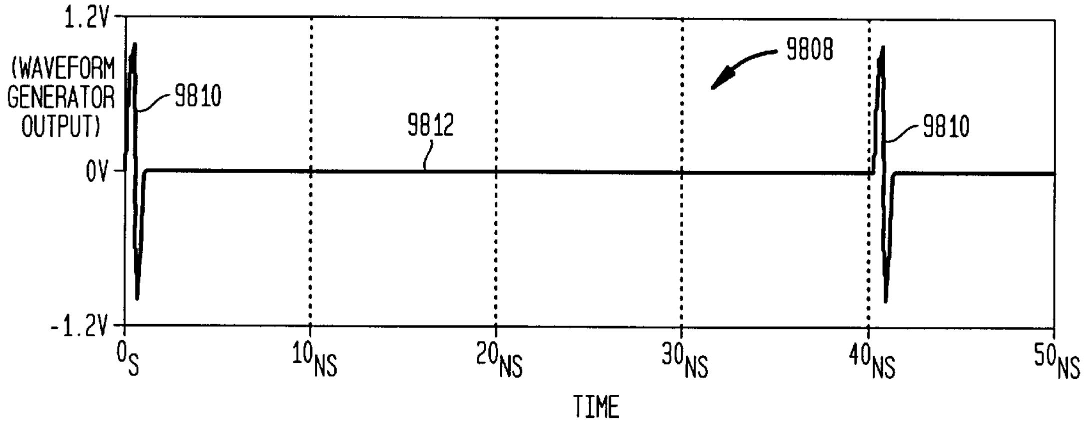


FIG. 100

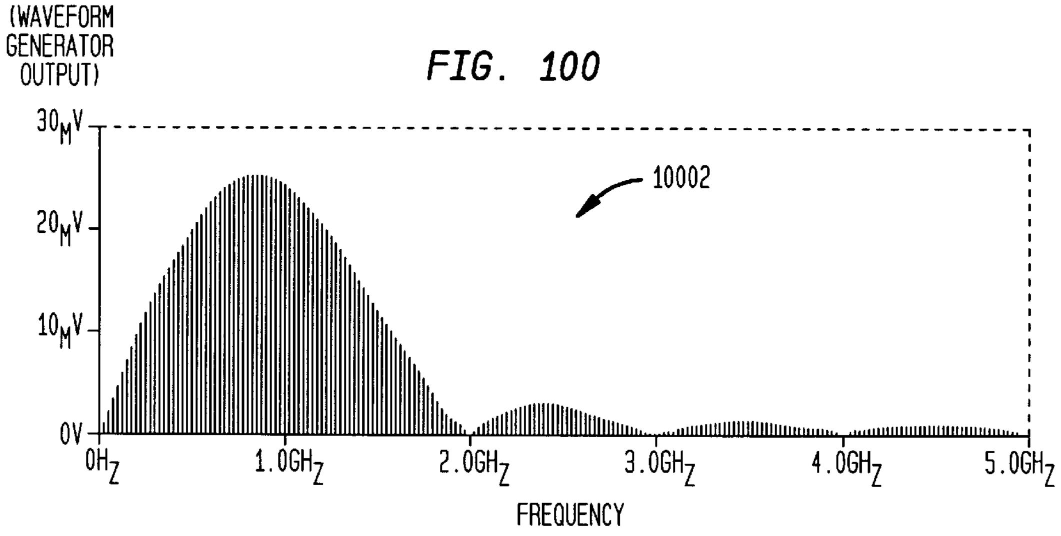


FIG. 101

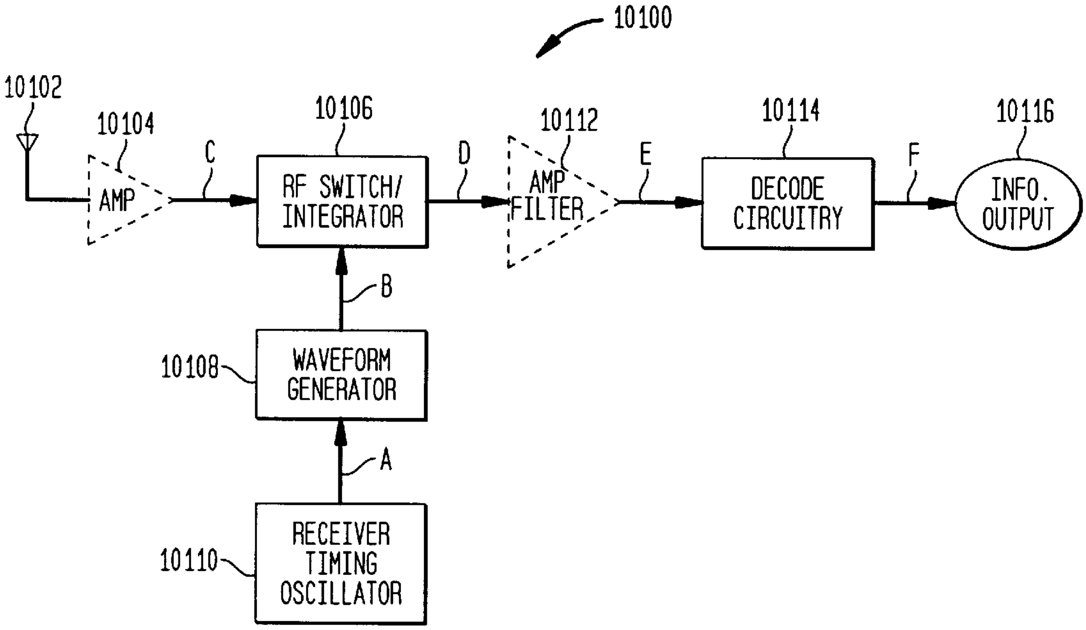

10100
10102
10104
AMP
C
10106
RF SWITCH/ INTEGRATOR
D
10112
AMP FILTER
E
10114
DECODE CIRCUITRY
F
10116
INFO. OUTPUT
B
10108
WAVEFORM GENERATOR
A
10110
RECEIVER TIMING OSCILLATOR

FIG. 102A

RECEIVER TIMING OSCILLATOR OUTPUT

FIG. 102B

WAVEFORM GENERATOR OUTPUT

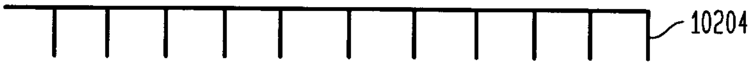


FIG. 102C

RF INPUT

FIG. 102D

RF SWITCH/INTEGRATOR OUTPUT

FIG. 102E

OPTIONAL AMPLIFIER/FILTER OUTPUT

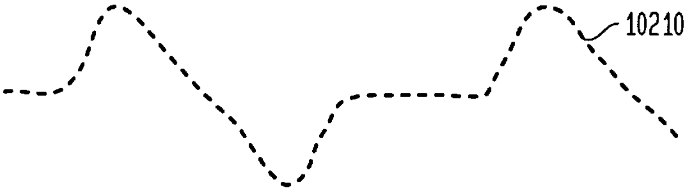


FIG. 102G

RECTIFIER/FILTER OUTPUT

VARIABLE THRESHOLD GENERATOR OUTPUT

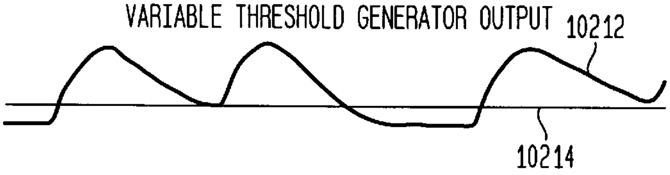


FIG. 102F

INFORMATION OUTPUT

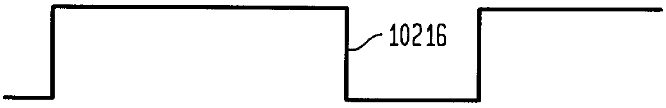
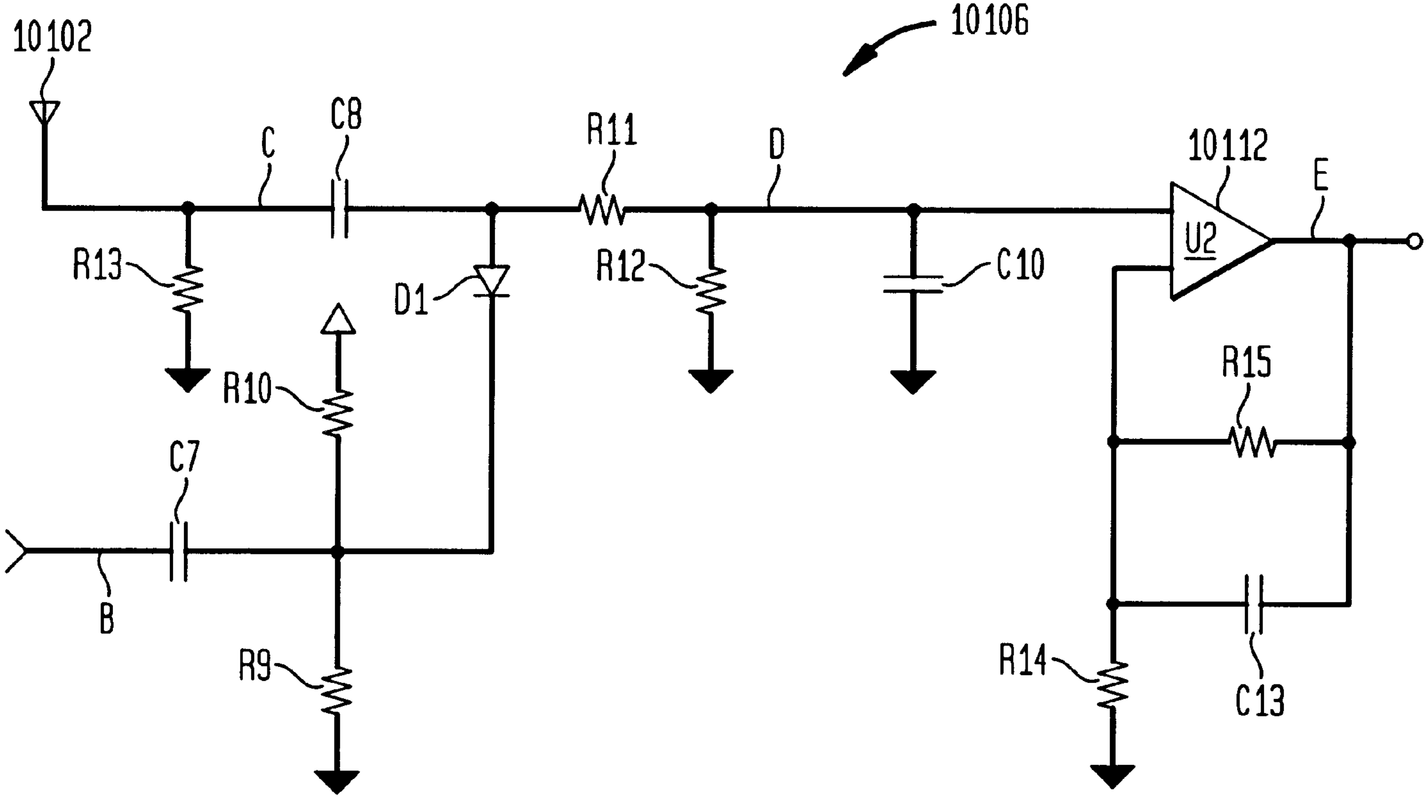


FIG. 103


10102
10106
C
C8
R11
D
10112
E
U2
R13
D1
R12
C10
R10
C7
R15
B
R9
R14
C13

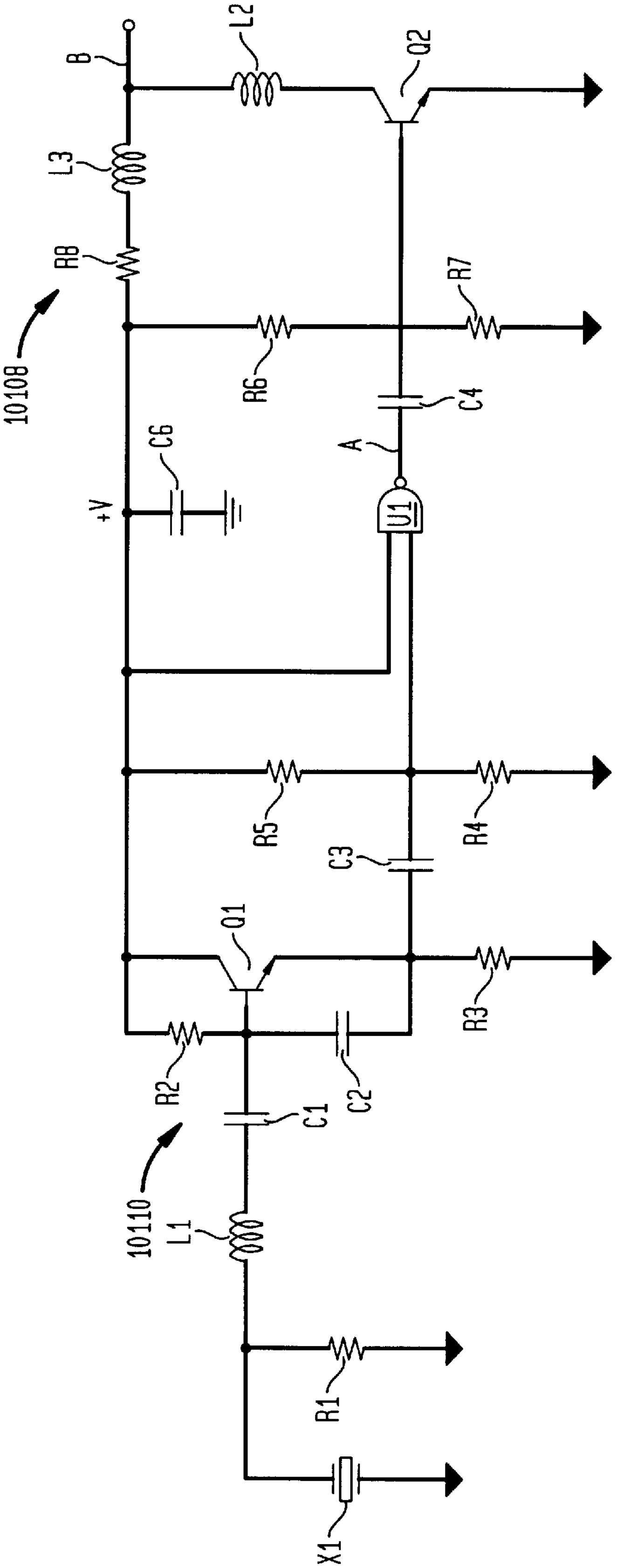

B
L2
Q2
L3
R8
R7
10108
R6
C4
A
C6
+V
U1
R5
R4
C3
Q1
R3
R2
C2
C1
10110
L1
R1
X1

FIG. 104

FIG. 105

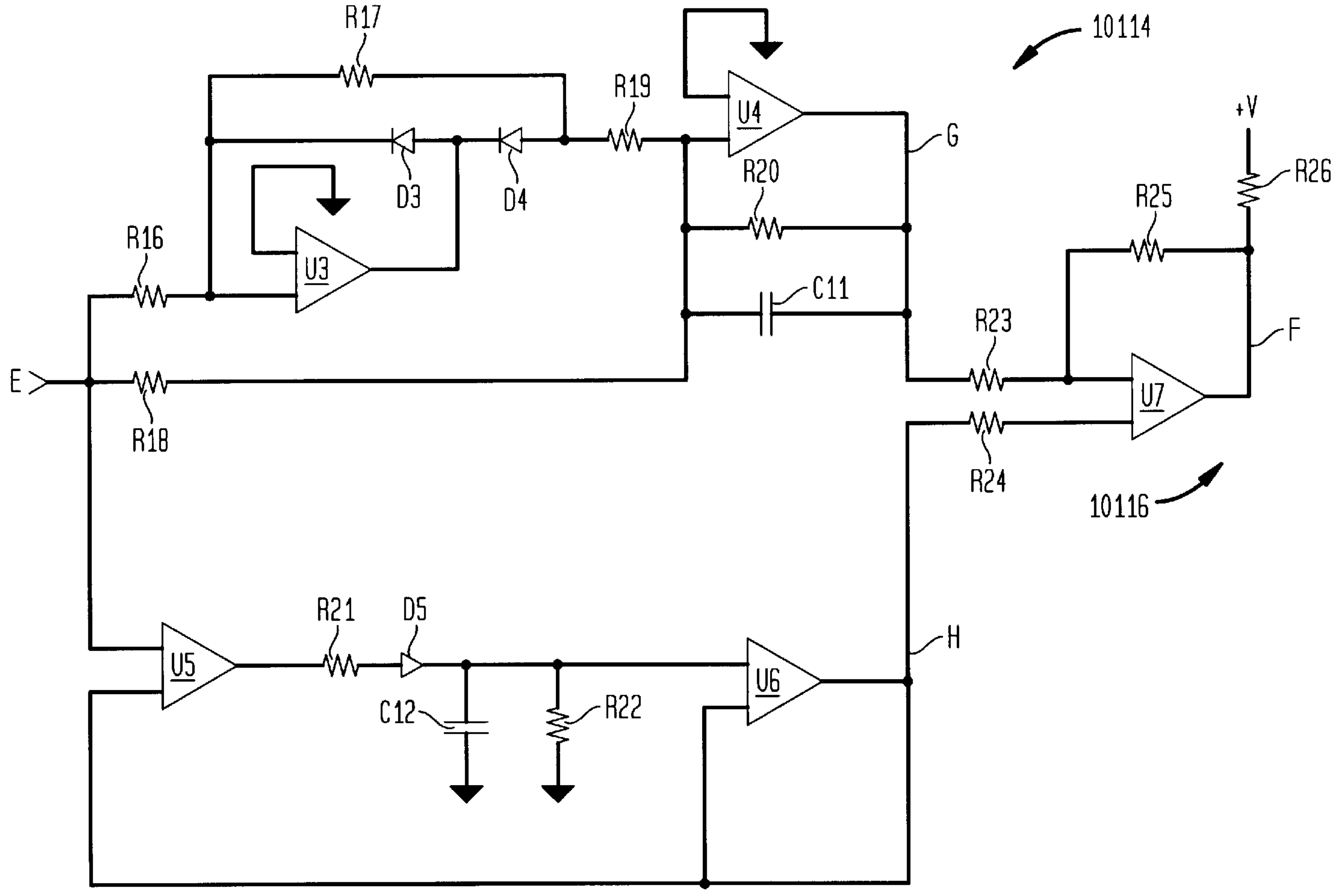

10114
R17
R19
U4
G
+V
R26
R16
D3
D4
U3
R20
R25
C11
F
E
R23
U7
R18
R24
10116
R21
D5
H
U5
U6
C12
R22

FIG. 106

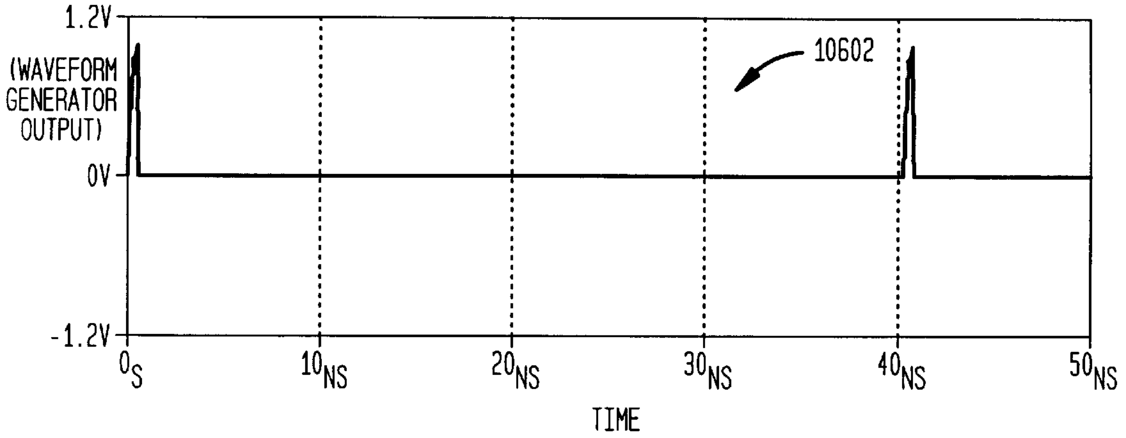


FIG. 107

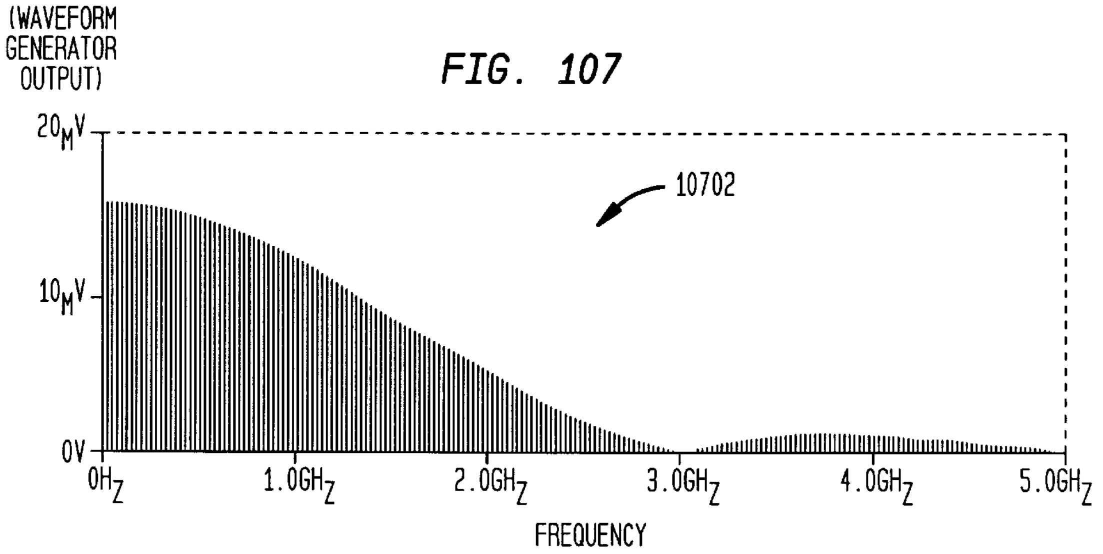


FIG. 108

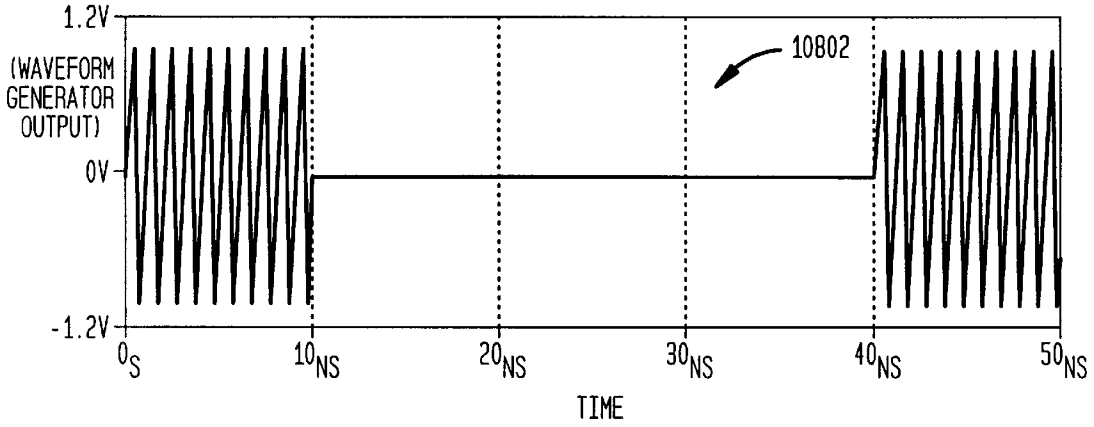


FIG. 109

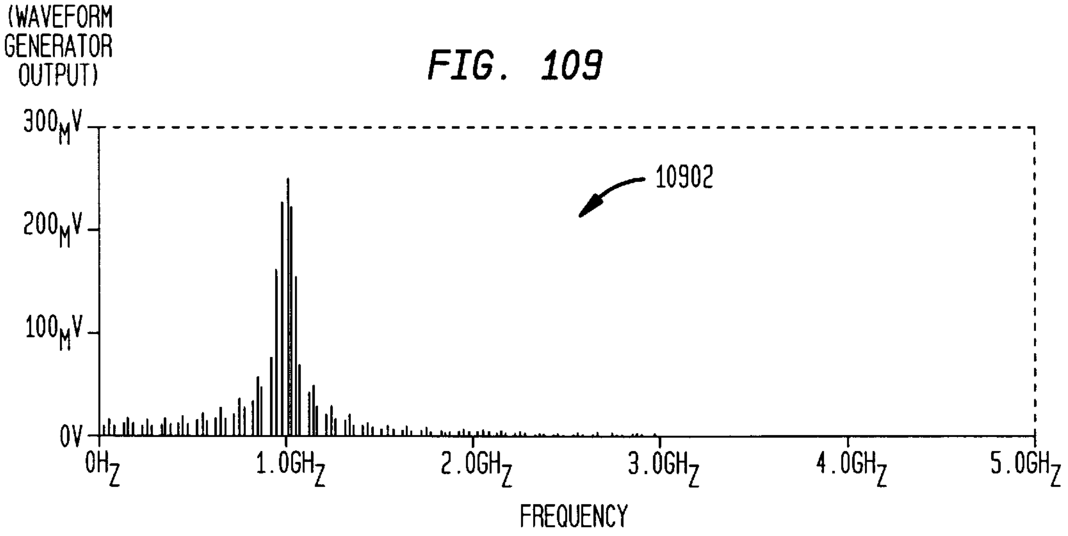
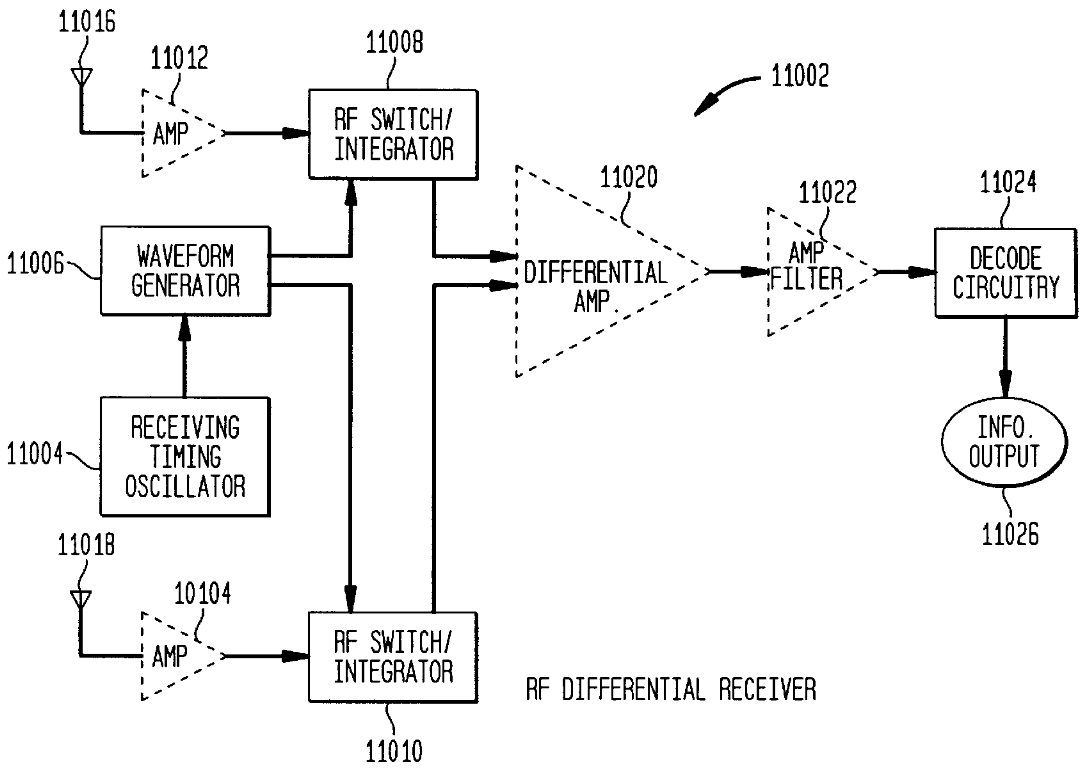
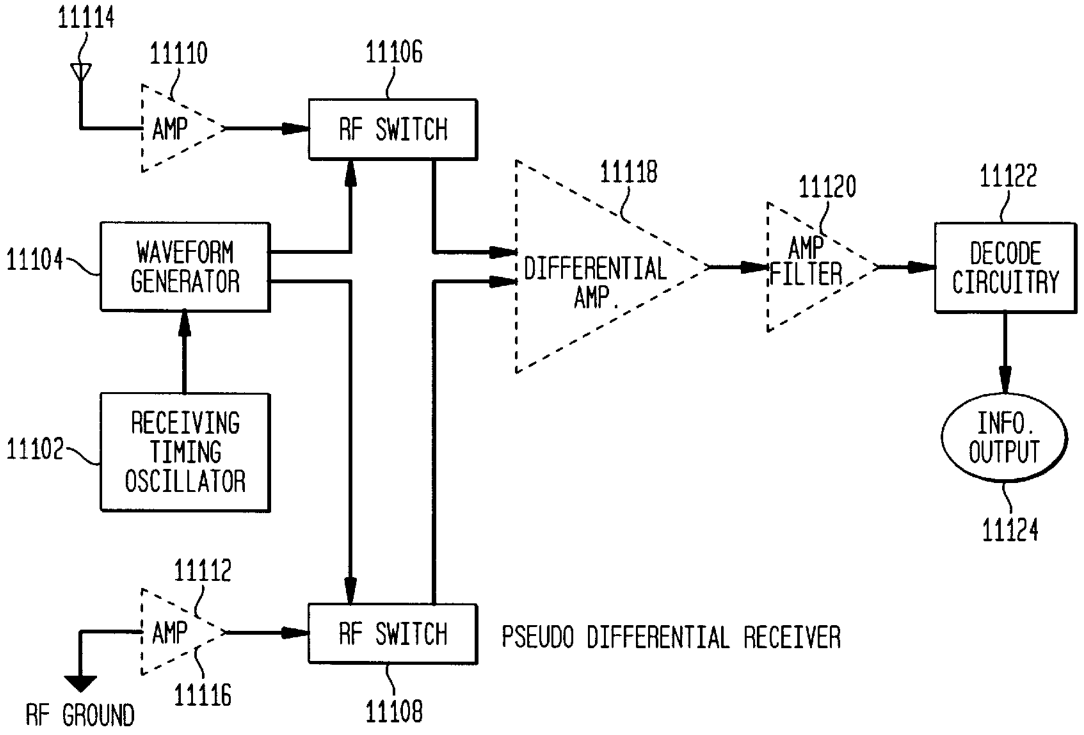


FIG. 110



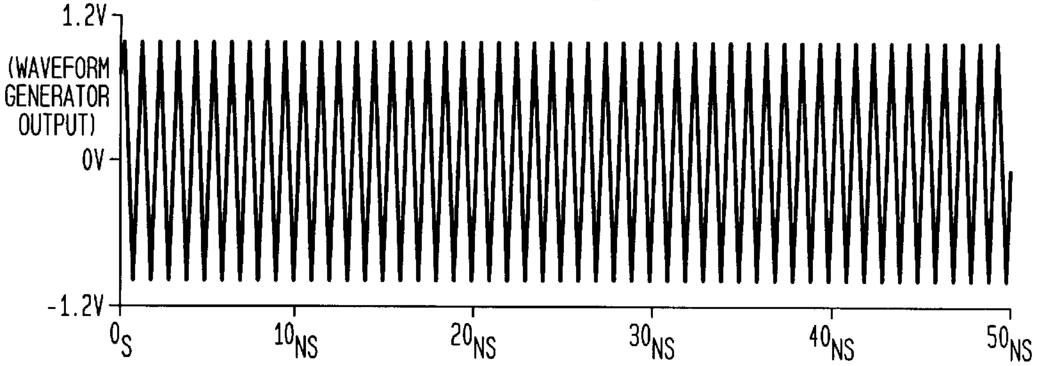
RF DIFFERENTIAL RECEIVER

FIG. 111



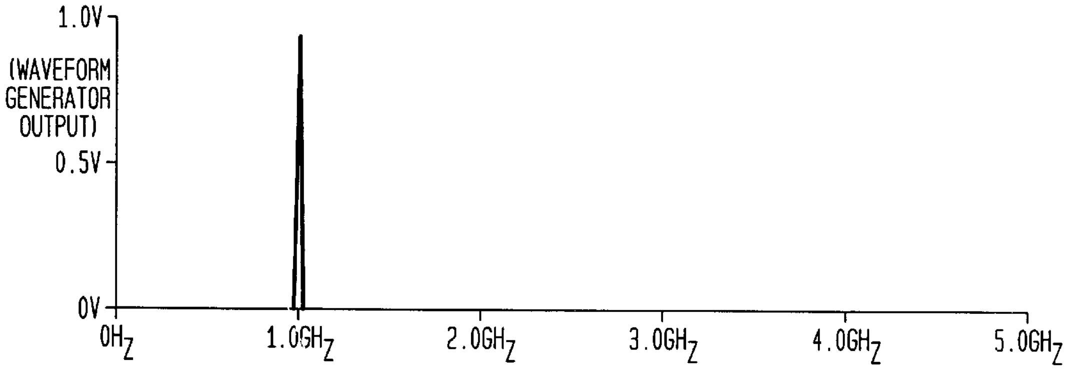
PSEUDO DIFFERENTIAL RECEIVER

FIG. 112



NARROW BAND/CONSTANT CARRIER

FIG. 113



NARROW BAND/CONSTANT CARRIER

METHOD AND SYSTEM FOR DOWN-CONVERTING ELECTROMAGNETIC SIGNALS BY SAMPLING AND INTEGRATING OVER APERTURES

CROSS-REFERENCE TO OTHER APPLICATIONS

This application is a continuation of application Ser. No. 09/176,022, filed Oct. 21, 1998, now pending.

The following applications of common assignee are related to the present application, have the same filing date as the present application, and are herein incorporated by reference in their entireties:

"Method and System for Frequency Up-Conversion," U.S. application Ser. No. 09/176,154, which is U.S. Pat. No. 6,091,940.

"Method and System for Ensuring Reception of a Communications Signal," U.S. application Ser. No. 09/176,415, which is U.S. Pat. No. 6,061,555.

"Integrated Frequency Translation and Selectivity," U.S. application Ser. No. 09/175,966, which is U.S. Pat. No. 6,049,706.

"Universal Frequency Translation, and Applications of Same," U.S. application Ser. No. 09/176,027.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to down-conversion of electromagnetic (EM) signals. More particularly, the present invention relates to down-conversion of EM signals to intermediate frequency signals, to direct down-conversion of EM modulated carrier signals to demodulated baseband signals, and to conversion of FM signals to non-FM signals. The present invention also relates to under-sampling and to transferring energy at aliasing rates.

2. Related Art

Electromagnetic (EM) information signals (baseband signals) include, but are not limited to, video baseband signals, voice baseband signals, computer baseband signals, etc. Baseband signals include analog baseband signals and digital baseband signals.

It is often beneficial to propagate EM signals at higher frequencies. This is generally true regardless of whether the propagation medium is wire, optic fiber, space, air, liquid, etc. To enhance efficiency and practicality, such as improved ability to radiate and added ability for multiple channels of baseband signals, up-conversion to a higher frequency is utilized. Conventional up-conversion processes modulate higher frequency carrier signals with baseband signals. Modulation refers to a variety of techniques for impressing information from the baseband signals onto the higher frequency carrier signals. The resultant signals are referred to herein as modulated carrier signals. For example, the amplitude of an AM carrier signal varies in relation to changes in the baseband signal, the frequency of an FM carrier signal varies in relation to changes in the baseband signal, and the phase of a PM carrier signal varies in relation to changes in the baseband signal.

In order to process the information that was in the baseband signal, the information must be extracted, or demodulated, from the modulated carrier signal. However, because conventional signal processing technology is limited in operational speed, conventional signal processing technology cannot easily demodulate a baseband signal from higher frequency modulated carrier signal directly. Instead, higher frequency modulated carrier signals must be down-converted to an intermediate frequency (IF), from where a conventional demodulator can demodulate the baseband signal.

Conventional down-converters include electrical components whose properties are frequency dependent. As a result, conventional down-converters are designed around specific frequencies or frequency ranges and do not work well outside their designed frequency range.

Conventional down-converters generate unwanted image signals and thus must include filters for filtering the unwanted image signals. However, such filters reduce the power level of the modulated carrier signals. As a result, conventional down-converters include power amplifiers, which require external energy sources.

When a received modulated carrier signal is relatively weak, as in, for example, a radio receiver, conventional down-converters include additional power amplifiers, which require additional external energy.

What is needed includes, without limitation:

- an improved method and system for down-converting EM signals;
- a method and system for directly down-converting modulated carrier signals to demodulated baseband signals;
- a method and system for transferring energy and for augmenting such energy transfer when down-converting EM signals;
- a controlled impedance method and system for down-converting an EM signal;
- a controlled aperture under-sampling method and system for down-converting an EM signal;
- a method and system for down-converting EM signals using a universal down-converter design that can be easily configured for different frequencies;
- a method and system for down-converting EM signals using a local oscillator frequency that is substantially lower than the carrier frequency;
- a method and system for down-converting EM signals using only one local oscillator;
- a method and system for down-converting EM signals that uses fewer filters than conventional down-converters;
- a method and system for down-converting EM signals using less power than conventional down-converters;
- a method and system for down-converting EM signals that uses less space than conventional down-converters;
- a method and system for down-converting EM signals that uses fewer components than conventional down-converters;
- a method and system for down-converting EM signals that can be implemented on an integrated circuit (IC); and
- a method and system for down-converting EM signals that can also be used as a method and system for up-converting a baseband signal.

SUMMARY OF THE INVENTION

Briefly stated, the present invention is directed to methods, systems, and apparatuses for down-converting an electromagnetic (EM) signal by aliasing the EM signal, and applications thereof.

Generally, the invention operates by receiving an EM signal. The invention also receives an aliasing signal having an aliasing rate. The invention aliases the EM signal according to the aliasing signal to down-convert the EM signal. The term aliasing, as used herein and as covered by the invention, refers to both down-converting an EM signal by under-sampling the EM signal at an aliasing rate, and down-converting an EM signal by transferring energy from the EM signal at the aliasing rate.

In an embodiment, the invention down-converts the EM signal to an intermediate frequency (IF) signal.

In another embodiment, the invention down-converts the EM signal to a demodulated baseband information signal.

In another embodiment, the EM signal is a frequency modulated (FM) signal, which is down-converted to a non-FM signal, such as a phase modulated (PM) signal or an amplitude modulated (AM) signal.

The invention is applicable to any type of EM signal, including but not limited to, modulated carrier signals (the invention is applicable to any modulation scheme or combination thereof) and unmodulated carrier signals.

Further features and advantages of the invention, as well as the structure and operation of various embodiments of the invention, are described in detail below with reference to the accompanying drawings. It is noted that the invention is not limited to the specific embodiments described herein. Such embodiments are presented herein for illustrative purposes only. Additional embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

The drawing in which an element first appears is typically indicated by the leftmost digit(s) in the corresponding reference number.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be described with reference to the accompanying drawings wherein:

FIG. **1** illustrates a structural block diagram of an example modulator;

FIG. **2** illustrates an example analog modulating baseband signal;

FIG. **3** illustrates an example digital modulating baseband signal;

FIG. **4** illustrates an example carrier signal;

FIGS. **5**A–**5**C illustrate example signal diagrams related to amplitude modulation;

FIGS. **6**A–**6**C illustrate example signal diagrams related to amplitude shift keying modulation;

FIGS. **7**A–**7**C illustrate example signal diagrams related to frequency modulation;

FIGS. **8**A–**8**C illustrate example signal diagrams related to frequency shift keying modulation;

FIGS. **9**A–**9**C illustrate example signal diagrams related to phase modulation;

FIGS. **10**A–**10**C illustrate example signal diagrams related to phase shift keying modulation;

FIG. **11** illustrates a structural block diagram of a conventional receiver;

FIGS. **12**A–D illustrate various flowcharts for down-converting an EM-signal according to embodiments of the invention;

FIG. **13** illustrates a structural block diagram of an aliasing system according to an embodiment of the invention;

FIGS. **14**A–D illustrate various flowcharts for down-converting an EM signal by under-sampling the EM signal according to embodiments of the invention;

FIGS. **15**A–E illustrate example signal diagrams associated with flowcharts in FIGS. **14**A–D according to embodiments of the invention;

FIG. **16** illustrates a structural block diagram of an under-sampling system according to an embodiment of the invention;

FIG. **17** illustrates a flowchart of an example process for determining an aliasing rate according to an embodiment of the invention;

FIGS. **18**A–E illustrate example signal diagrams associated with down-converting a digital AM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIGS. **19**A–E illustrate example signal diagrams associated with down-converting an analog AM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIGS. **20**A–E illustrate example signal diagrams associated with down-converting an analog FM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIGS. **21**A–E illustrate example signal diagrams associated with down-converting a digital FM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIGS. **22**A–E illustrate example signal diagrams associated with down-converting a digital PM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIGS. **23**A–E illustrate example signal diagrams associated with down-converting an analog PM signal to an intermediate frequency signal by under-sampling according to embodiments of the invention;

FIG. **24**A illustrates a structural block diagram of a make before break under-sampling system according to an embodiment of the invention;

FIG. **24**B illustrates an example timing diagram of an under sampling signal according to an embodiment of the invention;

FIG. **24**C illustrates an example timing diagram of an isolation signal according to an embodiment of the invention;

FIGS. **25**A–H illustrate example aliasing signals at various aliasing rates according to embodiments of the invention;

FIG. **26**A illustrates a structural block diagram of an exemplary sample and hold system according to an embodiment of the invention;

FIG. **26**B illustrates a structural block diagram of an exemplary inverted sample and hold system according to an embodiment of the invention;

FIG. **27** illustrates a structural block diagram of sample and hold module according to an embodiment of the invention;

FIGS. **28**A–D illustrate example implementations of a switch module according to embodiments of the invention;

FIGS. **29**A–F illustrate example implementations of a holding module according to embodiments of the present invention;

FIG. **29**G illustrates an integrated under-sampling system according to embodiments of the invention;

FIGS. **29**H–K illustrate example implementations of pulse generators according to embodiments of the invention;

FIG. **29**L illustrates an example oscillator;

FIG. **30** illustrates a structural block diagram of an under-sampling system with an under-sampling signal optimizer according to embodiments of the invention;

FIG. **31** illustrates a structural block diagram of an under-sampling signal optimizer according to embodiments of the present invention;

FIG. **32**A illustrates an example of an under-sampling signal module according to an embodiment of the invention;

FIG. **32**B illustrates a flowchart of a state machine operation associated with an under-sampling module according to embodiments of the invention;

FIG. **32**C illustrates an example under-sampling module that includes an analog circuit with automatic gain control according to embodiments of the invention;

FIGS. **33**A–D illustrate example signal diagrams associated with direct down-conversion of an EM signal to a baseband signal by under-sampling according to embodiments of the present invention;

FIGS. **34**A–F illustrate example signal diagrams associated with an inverted sample and hold module according to embodiments of the invention;

FIGS. **35**A–E illustrate example signal diagrams associated with directly down-converting an analog AM signal to a demodulated baseband signal by under-sampling according to embodiments of the invention;

FIGS. **36**A–E illustrate example signal diagrams associated with down-converting a digital AM signal to a demodulated baseband signal by under-sampling according to embodiments of the invention;

FIGS. **37**A–E illustrate example signal diagrams associated with directly down-converting an analog PM signal to a demodulated baseband signal by under-sampling according to embodiments of the invention;

FIGS. **38**A–E illustrate example signal diagrams associated with down-converting a digital PM signal to a demodulated baseband signal by under-sampling according to embodiments of the invention;

FIGS. **39**A–D illustrate down-converting a FM signal to a non-FM signal by under-sampling according to embodiments of the invention;

FIGS. **40**A–E illustrate down-converting a FSK signal to a PSK signal by under-sampling according to embodiments of the invention;

FIGS. **41**A–E illustrate down-converting a FSK signal to an ASK signal by under-sampling according to embodiments of the invention;

FIG. **42** illustrates a structural block diagram of an inverted sample and hold module according to an embodiment of the present invention;

FIGS. **43**A and B illustrate example waveforms present in the circuit of FIG. **31**;

FIG. **44**A illustrates a structural block diagram of a differential system according to embodiments of the invention;

FIG. **44**B illustrates a structural block diagram of a differential system with a differential input and a differential output according to embodiments of the invention;

FIG. **44**C illustrates a structural block diagram of a differential system with a single input and a differential output according to embodiments of the invention;

FIG. **44**D illustrates a differential input with a single output according to embodiments of the invention;

FIG. **44**E illustrates an example differential input to single output system according to embodiments of the invention;

FIGS. **45**A–B illustrate a conceptual illustration of aliasing including under-sampling and energy transfer according to embodiments of the invention;

FIGS. **46**A–D illustrate various flowchart for down-converting an EM signal by transferring energy from the EM signal at an aliasing rate according to embodiments of the invention;

FIGS. **47**A–E illustrate example signal diagrams associated with the flowcharts in FIGS. **46**A–D according to embodiments of the invention;

FIG. **48** is a flowchart that illustrates an example process for determining an aliasing rate associated with an aliasing signal according to an embodiment of the invention;

FIG. **49**A–H illustrate example energy transfer signals according to embodiments of the invention;

FIGS. **50**A–G illustrate example signal diagrams associated with down-converting an analog AM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **51**A–G illustrate example signal diagrams associated with down-converting an digital AM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **52**A–G illustrate example signal diagrams associated with down-converting an analog FM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **53**A–G illustrate example signal diagrams associated with down-converting an digital FM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **54**A–G illustrate example signal diagrams associated with down-converting an analog PM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **55**A–G illustrate example signal diagrams associated with down-converting an digital PM signal to an intermediate frequency by transferring energy at an aliasing rate according to embodiments of the invention;

FIGS. **56**A–D illustrate an example signal diagram associated with direct down-conversion according to embodiments of the invention;

FIGS. **57**A–F illustrate directly down-converting an analog AM signal to a demodulated baseband signal according to embodiments of the invention;

FIGS. **58**A–F illustrate directly down-converting an digital AM signal to a demodulated baseband signal according to embodiments of the invention;

FIGS. **59**A–F illustrate directly down-converting an analog PM signal to a demodulated baseband signal according to embodiments of the invention;

FIGS. **60**A–F illustrate directly down-converting an digital PM signal to a demodulated baseband signal according to embodiments of the invention;

FIGS. **61**A–F illustrate down-converting an FM signal to a PM signal according to embodiments of the invention;

FIGS. **62**A–F illustrate down-converting an FM signal to a AM signal according to embodiments of the invention;

FIG. **63** illustrates a block diagram of an energy transfer system according to an embodiment of the invention;

FIG. **64**A illustrates an exemplary gated transfer system according to an embodiment of the invention;

FIG. **64**B illustrates an exemplary inverted gated transfer system according to an embodiment of the invention;

FIG. **65** illustrates an example embodiment of the gated transfer module according to an embodiment of the invention;

FIGS. **66**A–D illustrate example implementations of a switch module according to embodiments of the invention;

FIG. **67**A illustrates an example embodiment of the gated transfer module as including a break-before-make module according to an embodiment of the invention;

FIG. **67**B illustrates an example timing diagram for an energy transfer signal according to an embodiment of the invention;

FIG. **67**C illustrates an example timing diagram for an isolation signal according to an embodiment of the invention;

FIGS. **68**A–F illustrate example storage modules according to embodiments of the invention;

FIG. **68**G illustrates an integrated gated transfer system according to an embodiment of the invention;

FIGS. **68**H–K illustrate example aperature generators;

FIG. **68**L illustrates an oscillator according to an embodiment of the present invention;

FIG. **69** illustrates an energy transfer system with an optional energy transfer signal module according to an embodiment of the invention;

FIG. **70** illustrates an aliasing module with input and output impedance match according to an embodiment of the invention;

FIG. **71** illustrates an example pulse generator;

FIGS. **72**A and B illustrate example waveforms related to the pulse generator of FIG. **71**;

FIG. **73** illustrates an example energy transfer module with a switch module and a reactive storage module according to an embodiment of the invention;

FIG. **74** illustrates an example inverted gated transfer module as including a switch module and a storage module according to an embodiment of the invention;

FIGS. **75**A–F illustrate an example signal diagrams associated with an inverted gated energy transfer module according to embodiments of the invention;

FIGS. **76**A–E illustrate energy transfer modules in configured in various differential configurations according to embodiments of the invention;

FIGS. **77**A–C illustrate example impedance matching circuits according to embodiments of the invention;

FIGS. **78**A–B illustrate example under-sampling systems according to embodiments of the invention;

FIGS. **79**A–F illustrate example timing diagrams for under-sampling systems according to embodiments of the invention;

FIGS. **80**A–F illustrate example timing diagrams for an under-sampling system when the load is a relatively low impedance load according to embodiments of the invention;

FIGS. **81**A–F illustrate example timing diagrams for an under-sampling system when the holding capacitance has a larger value according to embodiments of the invention;

FIGS. **82**A–B illustrate example energy transfer systems according to embodiments of the invention;

FIGS. **83**A–F illustrate example timing diagrams for energy transfer systems according to embodiments of the present invention;

FIGS. **84**A–D illustrate down-converting an FSK signal to a PSK signal according to embodiments of the present invention;

FIG. **85**A illustrates an example energy transfer signal module according to an embodiment of the present invention;

FIG. **85**B illustrates a flowchart of state machine operation according to an embodiment of the present invention;

FIG. **85**C is an example energy transfer signal module;

FIG. **86** is a schematic diagram of a circuit to down-convert a 915 MHZ signal to a 5 MHZ signal using a 101.1 MHZ clock according to an embodiment of the present invention;

FIG. **87** shows simulation waveforms for the circuit of FIG. **86** according to embodiments of the present invention;

FIG. **88** is a schematic diagram of a circuit to down-convert a 915 MHZ signal to a 5 MHz signal using a 101 MHZ clock according to an embodiment of the present invention;

FIG. **89** shows simulation waveforms for the circuit of FIG. **88** according to embodiments of the present invention;

FIG. **90** is a schematic diagram of a circuit to down-convert a 915 MHZ signal to a 5 MHZ signal using a 101.1 MHZ clock according to an embodiment of the present invention;

FIG. **91** shows simulation waveforms for the circuit of FIG. **90** according to an embodiment it of the present invention;

FIG. **92** shows a schematic of the circuit in FIG. **86** connected to an FSK source that alternates between 913 and 917 MHZ at a baud rate of 500 Kbaud according to an embodiment of the present invention;

FIG. **93** shows the original FSK waveform 9202 and the down-converted waveform 9204 at the output of the load impedance match circuit according to an embodiment of the present invention;

FIG. **94**A illustrates an example energy transfer system according to an embodiment of the invention;

FIGS. **94**B–C illustrate example timing diagrams for the example system of FIG. **94**A;

FIG. **95** illustrates an example bypass network according to an embodiment of the invention;

FIGS. **96** and **97** illustrate the amplitude and pulse width modulated transmitter according to embodiments of the present invention;

FIGS. **98**A–D, **99**, **100** illustrate example signal diagrams associated with the amplitude and pulse width modulated transmitter according to embodiments of the present invention;

FIG. **101** shows an embodiment of a receiver block diagram to recover the amplitude or pulse width modulated information;

FIGS. **102**A–F illustrates example signal diagrams associated with a waveform generator according to embodiments of the present invention;

FIGS. **103**–**105** are example schematic diagrams illustrating various circuits employed in the receiver of FIG. A**6**;

FIGS. **106**–**109** illustrate time and frequency domain diagrams of alternative transmitter output waveforms;

FIGS. **110**–**111** illustrate differential receivers in accord with embodiments of the present invention; and

FIGS. **112** and **113** illustrate time and frequency domains for a narrow bandwidth/constant carrier signal in accord with an embodiment of the present invention.

TABLE OF CONTENTS

1. GENERAL TERMINOLOGY

For illustrative purposes, the operation of the invention is often represented by flowcharts, such as flowchart **1201** in FIG. **12**A. It should be understood, however, that the use of flowcharts is for illustrative purposes only, and is not limiting. For example, the invention is not limited to the operational embodiment(s) represented by the flowcharts. Instead, alternative operational embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein. Also, the use of flowcharts should not be interpreted as limiting the invention to discrete or digital operation. In practice, as will be appreciated by persons skilled in the relevant art(s) based on the herein discussion, the invention can be achieved via discrete or continuous operation, or a combination thereof. Further, the flow of control represented by the flowcharts is provided for illustrative purposes only. As will be appreciated by persons skilled in the relevant art(s), other operational control flows are within the scope and spirit of the present invention. Also, the ordering of steps may differ in various embodiments.

Various terms used in this application are generally described in this section. The description in this section is provided for illustrative and convenience purposes only, and is not limiting. The meaning of these terms will be apparent to persons skilled in the relevant art(s) based on the entirety of the teachings provided herein. These terms may be discussed throughout the specification with additional detail.

The term modulated carrier signal, when used herein, refers to a carrier signal that is modulated by a baseband signal.

The term unmodulated carrier signal, when used herein, refers to a signal having an amplitude that oscillates at a substantially uniform frequency and phase.

The term baseband signal, when used herein, refers to an information signal including, but not limited to, analog information signals, digital information signals and direct current (DC) information signals.

The term carrier signal, when used herein, and unless otherwise specified when used herein, refers to modulated carrier signals and unmodulated carrier signals.

The term electromagnetic (EM) signal, when used herein, refers to a signal in the EM spectrum. EM spectrum includes all frequencies greater than zero hertz. EM signals generally include waves characterized by variations in electric and magnetic fields. Such waves may be propagated in any medium, both natural and manmade, including but not limited to air, space, wire, cable, liquid, waveguide, microstrip, strip-line, optical fiber, etc. Unless stated otherwise, all signals discussed herein are EM signals, even when not explicitly designated as such.

The term intermediate frequency (IF) signal, when used herein, refers to an EM signal that is substantially similar to another EM signal except that the IF signal has a lower frequency than the other signal. An IF signal frequency can be any frequency above zero HZ. Unless otherwise stated, the terms lower frequency, intermediate frequency, intermediate and IF are used interchangeably herein.

The term analog signal, when used herein, refers to a signal that is constant or continuously variable, as contrasted to a signal that changes between discrete states.

The term baseband, when used herein, refers to a frequency band occupied by any generic information signal desired for transmission and/or reception.

The term baseband signal, when used herein, refers to any generic information signal desired for transmission and/or reception.

The term carrier frequency, when used herein, refers to the frequency of a carrier signal. Typically, it is the center frequency of a transmission signal that is generally modulated.

The term carrier signal, when used herein, refers to an EM wave having at least one characteristic that may be varied by modulation, that is capable of carrying information via modulation.

The term demodulated baseband signal, when used herein, refers to a signal that results from processing a modulated signal. In some cases, for example, the demodulated baseband signal results from demodulating an intermediate frequency (IF) modulated signal, which results from down converting a modulated carrier signal. In another case, a signal that results from a combined downconversion and demodulation step.

The term digital signal, when used herein, refers to a signal that changes between discrete states, as contrasted to a signal that is continuous. For example, the voltage of a digital signal may shift between discrete levels.

The term electromagnetic (EM) spectrum, when used herein, refers to a spectrum comprising waves characterized by variations in electric and magnetic fields. Such waves may be propagated in any communication medium, both natural and manmade, including but not limited to air, space, wire, cable, liquid, waveguide, microstrip, stripline, optical fiber, etc. The EM spectrum includes all frequencies greater than zero hertz.

The term electromagnetic (EM) signal, when used herein, refers to a signal in the EM spectrum. Also generally called an EM wave. Unless stated otherwise, all signals discussed herein are EM signals, even when not explicitly designated as such.

The term modulating baseband signal, when used herein, refers to any generic information signal that is used to modulate an oscillating signal, or carrier signal.

1.1 Modulation

It is often beneficial to propagate electromagnetic (EM) signals at higher frequencies. This includes baseband signals, such as digital data information signals and analog information signals. A baseband signal can be up-converted to a higher frequency EM signal by using the baseband signal to modulate a higher frequency carrier signal, F_C. When used in this manner, such a baseband signal is herein called a modulating baseband signal F_M.

Modulation imparts changes to the carrier signal F_C that represent information in the modulating baseband signal F_{MB}. The changes can be in the form of amplitude changes, frequency changes, phase changes, etc., or any combination thereof. The resultant signal is referred to herein as a modulated carrier signal F_{MC}. The modulated carrier signal F_{MC} includes the carrier signal F_C modulated by the modulating baseband signal, F_{MB}, as in:

$$F_{MB} \text{ combined with } F_C \rightarrow F_{MC}$$

The modulated carrier signal F_{MC} oscillates at, or near the frequency of the carrier signal F_C and can thus be efficiently propagated.

FIG. **1** illustrates an example modulator **110**, wherein the carrier signal F_C is modulated by the modulating baseband signal F_{MB}, thereby generating the modulated carrier signal F_{MC}.

Modulating baseband signal F_{MB} can be an analog baseband signal, a digital baseband signal, or a combination thereof.

FIG. **2** illustrates the modulating baseband signal F_{MB} as an exemplary analog modulating baseband signal **210**. The exemplary analog modulating baseband signal **210** can represent any type of analog information including, but not limited to, voice/speech data, music data, video data, etc. The amplitude of analog modulating baseband signal **210** varies in time.

Digital information includes a plurality of discrete states. For ease of explanation, digital information signals are discussed below as having two discrete states. But the invention is not limited to this embodiment.

FIG. **3** illustrates the modulating baseband signal F_{MB} as an exemplary digital modulating baseband signal **310**. The digital modulating baseband signal **310** can represent any type of digital data including, but not limited to, digital computer information and digitized analog information. The digital modulating baseband signal **310** includes a first state **312** and a second state **314**. In an embodiment, first state **312** represents binary state 0 and second state **314** represents binary state 1. Alternatively, first state **312** represents binary state 1 and second state **314** represents binary state 0. Throughout the remainder of this disclosure, the former convention is followed, whereby first state **312** represents binary state zero and second state **314** represents binary state one. But the invention is not limited to this embodiment. First state **312** is thus referred to herein as a low state and second state **314** is referred to herein as a high state.

Digital modulating baseband signal **310** can change between first state **312** and second state **314** at a data rate, or baud rate, measured as bits per second.

Carrier signal F_C is modulated by the modulating baseband signal F_{MB}, by any modulation technique, including, but not limited to, amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), etc., or any combination thereof. Examples are provided below for amplitude modulating, frequency modulating, and phase modulating the analog modulating baseband signal **210** and the digital modulating baseband signal **310**, on the carrier signal F_C. The examples are used to assist in the description of the invention. The invention is not limited to, or by, the examples.

FIG. **4** illustrates the carrier signal F_C as a carrier signal **410**. In the example of FIG. **4**, the carrier signal **410** is illustrated as a 900 MHZ carrier signal. Alternatively, the carrier signal **410** can be any other frequency. Example modulation schemes are provided below, using the examples signals from FIGS. **2**, **3** and **4**.

1.1.1 Amplitude Moduhition

In amplitude modulation (AM), the amplitude of the modulated carrier signal F_{MC} is a function of the amplitude of the modulating baseband signal F_{MB}. FIGS. **5**A–**5**C illustrate example timing diagrams for amplitude modulating the carrier signal **410** with the analog modulating baseband signal **210**. FIGS. **6**A–**6**C illustrate example timing diagrams for amplitude modulating the carrier signal **410** with the digital modulating baseband signal **310**.

FIG. **5**A illustrates the analog modulating baseband signal **210**. FIG. **5**B illustrates the carrier signal **410**. FIG. **5**C illustrates an analog AM carrier signal **516**, which is generated when the carrier signal **410** is amplitude modulated using the analog modulating baseband signal **210**. As used herein, the term "analog AM carrier signal" is used to indicate that the modulating baseband signal is an analog signal.

The analog AM carrier signal **516** oscillates at the frequency of carrier signal **410**. The amplitude of the analog AM carrier signal **516** tracks the amplitude of analog modulating baseband signal **210**, illustrating that the information contained in the analog modulating baseband signal **210** is retained in the analog AM carrier signal **516**.

FIG. **6**A illustrates the digital modulating baseband signal **310**. FIG. **6**B illustrates the carrier signal **410**. FIG. **6**C illustrates a digital AM carrier signal **616**, which is generated when the carrier signal **410** is amplitude modulated using the digital modulating baseband signal **310**. As used herein, the term "digital AM carrier signal" is used to indicate that the modulating baseband signal is a digital signal.

The digital AM carrier signal **616** oscillates at the frequency of carrier signal **410**. The amplitude of the digital AM carrier signal **616** tracks the amplitude of digital modulating baseband signal **310**, illustrating that the information contained in the digital modulating baseband signal **310** is retained in the digital AM signal **616**. As the digital modulating baseband signal **310** changes states, the digital AM signal **616** shifts amplitudes. Digital amplitude modulation is often referred to as amplitude shift keying (ASK), and the two terms are used interchangeably throughout the specification.

1.1.2 Frequency Modulation

In frequency modulation (FM), the frequency of the modulated carrier signal F_{MC} varies as a function of the amplitude of the modulating baseband signal F_{MB}. FIGS. **7**A–**7**C illustrate example timing diagrams for frequency modulating the carrier signal **410** with the analog modulating baseband signal **210**. FIGS. **8**A–**8**C illustrate example timing diagrams for frequency modulating the carrier signal **410** with the digital modulating baseband signal **310**.

FIG. **7**A illustrates the analog modulating baseband signal **210**. FIG. **7**B illustrates the carrier signal **410**. FIG. **7**C illustrates an analog FM carrier signal **716**, which is generated when the carrier signal **410** is frequency modulated using the analog modulating baseband signal **210**. As used herein, the term "analog FM carrier signal" is used to indicate that the modulating baseband signal is an analog signal.

The frequency of the analog FM carrier signal **716** varies as a function of amplitude changes on the analog baseband signal **210**. In the illustrated example, the frequency of the analog FM carrier signal **716** varies in proportion to the amplitude of the analog modulating baseband signal **210**. Thus, at time t1, the amplitude of the analog baseband signal **210** and the frequency of the analog FM carrier signal **716** are at maximums. At time t3, the amplitude of the analog baseband signal **210** and the frequency of the analog FM carrier signal **716** are at minimums.

The frequency of the analog FM carrier signal **716** is typically centered around the frequency of the carrier signal **410**. Thus, at time t2, for example, when the amplitude of the analog baseband signal **210** is at a mid-point, illustrated here as zero volts, the frequency of the analog FM carrier signal **716** is substantially the same as the frequency of the carrier signal **410**.

FIG. **8**A illustrates the digital modulating baseband signal **310**. FIG. **8**B illustrates the carrier signal **410**. FIG. **8**C illustrates a digital FM carrier signal **816**, which is generated when the carrier signal **410** is frequency modulated using the digital baseband signal **310**. As used herein, the term "digital FM carrier signal" is used to indicate that the modulating baseband signal is a digital signal.

The frequency of the digital FM carrier signal **816** varies as a function of amplitude changes on the digital modulating baseband signal **310**. In the illustrated example, the frequency of the digital FM carrier signal **816** varies in proportion to the amplitude of the digital modulating baseband signal **310**. Thus, between times t0 and t1, and between times t2 and t4, when the amplitude of the digital baseband signal **310** is at the higher amplitude second state, the frequency of the digital FM carrier signal **816** is at a maximum. Between times t1 and t2, when the amplitude of the digital baseband signal **310** is at the lower amplitude first state, the frequency of the digital FM carrier signal **816** is at a minimum. Digital frequency modulation is often referred to as frequency shift keying (FSK), and the terms are used interchangeably throughout the specification.

Typically, the frequency of the digital FM carrier signal **816** is centered about the frequency of the carrier signal **410**, and the maximum and minimum frequencies are equally offset from the center frequency. Other variations can be employed but, for ease of illustration, this convention will be followed herein.

1.1.3 Phase Modulation

In phase modulation (PM), the phase of the modulated carrier signal F_{MC} varies as a function of the amplitude of the modulating baseband signal F_{MB}. FIGS. **9**A–**9**C illustrate example timing diagrams for phase modulating the carrier signal **410** with the analog modulating baseband signal **210**. FIGS. **10**A–**10**C illustrate example timing diagrams for phase modulating the carrier signal **410** with the digital modulating baseband signal **310**.

FIG. **9**A illustrates the analog modulating baseband signal **210**. FIG. **9**B illustrates the carrier signal **410**. FIG. **9**C illustrates an analog PM carrier signal **916**, which is generated by phase modulating the carrier signal **410** with the analog baseband signal **210**. As used herein, the term "analog PM carrier signal" is used to indicate that the modulating baseband signal is an analog signal.

Generally, the frequency of the analog PM carrier signal **916** is substantially the same as the frequency of carrier signal **410**. But the phase of the analog PM carrier signal **916** varies with amplitude changes on the analog modulating baseband signal **210**. For relative comparison, the carrier signal **410** is illustrated in FIG. **9**C by a dashed line.

The phase of the analog PM carrier signal **916** varies as a function of amplitude changes of the analog baseband signal **210**. In the illustrated example, the phase of the analog PM signal **916** lags by a varying amount as determined by the amplitude of the baseband signal **210**. For example, at time t1, when the amplitude of the analog baseband signal **210** is at a maximum, the analog PM carrier signal **916** is in phase with the carrier signal **410**. Between times t1 and t3, when the amplitude of the analog baseband signal **210** decreases to a minimum amplitude, the phase of the analog PM carrier signal **916** lags the phase of the carrier signal **410**, until it reaches a maximum out of phase value at time t3. In the illustrated example, the phase change is illustrated as approximately 180 degrees. Any suitable amount of phase change, varied in any manner that is a function of the baseband signal, can be utilized.

FIG. **10**A illustrates the digital modulating baseband signal **310**. FIG. **10**B illustrates the carrier signal **410**. FIG. **10**C illustrates a digital PM carrier signal **1016**, which is generated by phase modulating the carrier signal **410** with the digital baseband signal **310**. As used herein, the term "digital PM carrier signal" is used to indicate that the modulating baseband signal is a digital signal.

The frequency of the digital PM carrier signal **1016** is substantially the same as the frequency of carrier signal **410**. The phase of the digital PM carrier signal **1016** varies as a function of amplitude changes on the digital baseband signal **310**. In the illustrated example, when the digital baseband signal **310** is at the first state **312**, the digital PM carrier signal **1016** is out of phase with the carrier signal **410**. When the digital baseband signal **310** is at the second state **314**, the digital PM carrier signal **1016** is in-phase with the carrier signal **410**. Thus, between times t1 and t2, when the amplitude of the digital baseband signal **310** is at the first state **312**, the digital PM carrier signal **1016** is out of phase with the carrier signal **410**. Between times to and t1, and between times t2 and t4, when the amplitude of the digital baseband signal **310** is at the second state **314**, the digital PM carrier signal **1016** is in phase with the carrier signal **410**.

In the illustrated example, the out of phase value between times t1 and t3 is illustrated as approximately 180 degrees out of phase. Any suitable amount of phase change, varied in any manner that is a function of the baseband signal, can be utilized. Digital phase modulation is often referred to as phase shift keying (PSK), and the terms are used interchangeably throughout the specification.

1.2 Demodulation

When the modulated carrier signal F_{MC} is received, it can be demodulated to extract the modulating baseband signal F_{MB}. Because of the typically high frequency of modulated carrier signal F_{MC}, however, it is generally impractical to demodulate the baseband signal F_{MB} directly from the modulated carrier signal F_{MC}. Instead, the modulated carrier signal F_{MC} must be down-converted to a lower frequency signal that contains the original modulating baseband signal.

When a modulated carrier signal is down-converted to a lower frequency signal, the lower frequency signal is referred to herein as an intermediate frequency (IF) signal F_{IF}. The IF signal F_{IF} oscillates at any frequency, or frequency band, below the frequency of the modulated carrier frequency F_{MC}. Down-conversion of F_{MC} to F_{IF} is illustrated as:

$$F_{MC} \rightarrow F_{IF}$$

After F_{MC} is down-converted to the IF modulated carrier signal F_{IF}, F_{IF} can be demodulated to a baseband signal F_{DMB}, as illustrated by:

$$F^{IF} \rightarrow F_{DMB}$$

F_{DMB} is intended to be substantially similar to the modulating baseband signal F_{MB}, illustrating that the modulating baseband signal F_{MB} can be substantially recovered.

It will be emphasized throughout the disclosure that the present invention can be implemented with any type of EM signal, including, but not limited to, modulated carrier signals and unmodulated carrier signals. The above examples of modulated carrier signals are provided for illustrative purposes only. Many variations to the examples are possible. For example, a carrier signal can be modulated with a plurality of the modulation types described above. A carrier signal can also be modulated with a plurality of baseband signals, including analog baseband signals, digital baseband signals, and combinations of both analog and digital baseband signals.

2. OVERVIEW OF THE INVENTION

Conventional signal processing techniques follow the Nyquist sampling theorem, which states that, in order to faithfully reproduce a sampled signal, the signal must be sampled at a rate that is greater than twice the frequency of the signal being sampled. When a signal is sampled at less than or equal to twice the frequency of the signal, the signal is said to be under-sampled, or aliased. Conventional signal processing thus teaches away from under-sampling and aliasing, in order to faithfully reproduce a sampled signal.

2.1 Aspects of the Invention

Contrary to conventional wisdom, the present invention is a method and system for down-converting an electromagnetic (EM) signal by aliasing the EM signal. Aliasing is represented generally in FIG. **45**A as **4502**.

By taking a carrier and aliasing it at an aliasing rate, the invention can down-convert that carrier to lower frequencies. One aspect that can be exploited by this invention is realizing that the carrier is not the item of interest, the lower baseband signal is of interest to reproduce sufficiently. This baseband signal's frequency content, even though its carrier may be aliased, does satisfy the Nyquist criteria and as a result, the baseband information can be sufficiently reproduced.

FIG. **12**A depicts a flowchart **1201** that illustrates a method for aliasing an EM signal to generate a down-converted signal. The process begins at step **1202**, which includes receiving the EM signal. Step **1204** includes receiving an aliasing signal having an aliasing rate. Step **1206** includes aliasing the EM signal to down-convert the EM signal. The term aliasing, as used herein, refers to both down-converting an EM signal by under-sampling the EM signal at an aliasing rate and to down-converting an EM signal by transferring energy from the EM signal at the aliasing rate. These concepts are described below.

FIG. **13** illustrates a block diagram of a generic aliasing system **1302**, which includes an aliasing module **1306**. In an embodiment, the aliasing system **1302** operates in accordance with the flowchart **1201**. For example, in step **1202**, the aliasing module **1306** receives an EM signal **1304**. In step **1204**, the aliasing module **1306** receives an aliasing signal **1310**. In step **1206**, the aliasing module **1306** down-converts the EM signal **1304** to a down-converted signal **1308**. The generic aliasing system **1302** can also be used to implement any of the flowcharts **1207**, **1213** and **1219**.

In an embodiment, the invention down-converts the EM signal to an intermediate frequency (IF) signal. FIG. **12**B depicts a flowchart **1207** that illustrates a method for under-sampling the EM signal at an aliasing rate to down-convert the EM signal to an IF signal. The process begins at step **1208**, which includes receiving an EM signal. Step **1210** includes receiving an aliasing signal having an aliasing rate

F_{AR}. Step **1212** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to an IF signal.

In another embodiment, the invention down-converts the EM signal to a demodulated baseband information signal. FIG. **12**C depicts a flowchart **1213** that illustrates a method for down-converting the EM signal to a demodulated baseband signal. The process begins at step **1214**, which includes receiving an EM signal. Step **1216** includes receiving an aliasing signal having an aliasing rate F_{AR}. Step **1218** includes down-converting the EM signal to a demodulated baseband signal. The demodulated baseband signal can be processed without further down-conversion or demodulation.

In another embodiment, the EM signal is a frequency modulated (FM) signal, which is down-converted to a non-FM signal, such as a phase modulated (PM) signal or an amplitude modulated (AM) signal. FIG. **12**D depicts a flowchart **1219** that illustrates a method for down-converting the FM signal to a non-FM signal. The process begins at step **1220**, which includes receiving an EM signal. Step **1222** includes receiving an aliasing signal having an aliasing rate. Step **1224** includes down-converting the FM signal to a non-FM signal.

The invention down-converts any type of EM signal, including, but not limited to, modulated carrier signals and unmodulated carrier signals. For ease of discussion, the invention is further described herein using modulated carrier signals for examples. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert signals other than carrier signals as well. The invention is not limited to the example embodiments described above.

In an embodiment, down-conversion is accomplished by under-sampling an EM signal. This is described generally in Section I2.2. below and in detail in Section II and its sub-sections. In another embodiment, down-conversion is achieved by transferring non-negligible amounts of energy from an EM signal. This is described generally in Section I.2.3. below and in detail in Section III.

2.2 Down-Converting by Under-Sampling

The term aliasing, as used herein, refers both to down-converting an EM signal by under-sampling the EM signal at an aliasing rate and to down-converting an EM signal by transferring energy from the EM signal at the aliasing rate. Methods for under-sampling an EM signal to down-convert the EM signal are now described at an overview level. FIG. **14**A depicts a flowchart **1401** that illustrates a method for under-sampling the EM signal at an aliasing rate to down-convert the EM signal. The process begins at step **1402**, which includes receiving an EM signal. Step **1404** includes receiving an under-sampling signal having an aliasing rate. Step **1406** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal.

Down-converting by under-sampling is illustrated by **4504** in FIG. **45**A and is described in greater detail in Section II.

2.2.1 Down-Converting to an Intermediate Frequency (IF) Signal

In an embodiment, an EM signal is under-sampled at an aliasing rate to down-convert the EM signal to a lower, or intermediate frequency (IF) signal. The EM signal can be a modulated carrier signal or an unmodulated carrier signal. In an exemplary example, a modulated carrier signal F_{MC} is down-converted to an IF signal F_{IF}.

$$F_{MC} \rightarrow F_{IF}$$

FIG. **14**B depicts a flowchart **1407** that illustrates a method for under-sampling the EM signal at an aliasing rate to down-convert the EM signal to an IF signal. The process begins at step **1408**, which includes receiving an EM signal. Step **1410** includes receiving an under-sampling signal having an aliasing rate. Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to an IF signal.

This embodiment is illustrated generally by **4508** in FIG. **45**B and is described in Section II.1.

2.2.2 Direct-to-Data Down-Converting

In another embodiment, an EM signal is directly down-converted to a demodulated baseband signal (direct-to-data down-conversion), by under-sampling the EM signal at an aliasing rate. The EM signal can be a modulated EM signal or an unmodulated EM signal. In an exemplary embodiment, the EM signal is the modulated carrier signal F_{MC}, and is directly down-converted to a demodulated baseband signal F_{DMB}.

$$F_{MC} \rightarrow F_{DMB}$$

FIG. **14**C depicts a flowchart **1413** that illustrates a method for under-sampling the EM signal at an aliasing rate to directly down-convert the EM signal to a demodulated baseband signal. The process begins at step **1414**, which includes receiving an EM signal. Step **1416** includes receiving an under-sampling signal having an aliasing rate. Step **1418** includes under-sampling the EM signal at the aliasing rate to directly down-convert the EM signal to a baseband information signal.

This embodiment is illustrated generally by **4510** in FIG. **45**B and is described in Section II.2

2.2.3 Modulation Conversion

In another embodiment, a frequency modulated (FM) carrier signal F_{FMC} is converted to a non-FM signal $F_{(NON-FM)}$, by under-sampling the FM carrier signal F_{FMC}.

$$F_{FMC} \rightarrow F_{(NON-FM)}$$

FIG. **14**D depicts a flowchart **1419** that illustrates a method for under-sampling an FM signal to convert it to a non-FM signal. The process begins at step **1420**, which includes receiving the FM signal. Step **1422** includes receiving an under-sampling signal having an aliasing rate. Step **1424** includes under-sampling the FM signal at the aliasing rate to convert the FM signal to a non-FM signal. For example, the FM signal can be under-sampled to convert it to a PM signal or an AM signal.

This embodiment is illustrated generally by **4512** in FIG. **45**B, and described in Section II.3

2.3 Down-Converting by Transfering Energy

The term aliasing, as used herein, refers both to down-converting an EM signal by under-sampling the EM signal at an aliasing rate and to down-converting an EM signal by transferring non-negligible amounts energy from the EM signal at the aliasing rate. Methods for transferring energy from an EM signal to down-convert the EM signal are now described at an overview level. More detailed descriptions are provided in Section III.

FIG. **46**A depicts a flowchart **4601** that illustrates a method for transferring energy from the EM signal at an aliasing rate to down-convert the EM signal. The process begins at step **4602**, which includes receiving an EM signal. Step **4604** includes receiving an energy transfer signal having an aliasing rate. Step **4606** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal.

Down-converting by transferring energy is illustrated by **4506** in FIG. **45**A and is described in greater detail in Section III.

2.3.1 Down-Converting to an Intermediate Frequency (IF) Signal

In an embodiment, EM signal is down-converted to a lower, or intermediate frequency (IF) signal, by transferring energy from the EM signal at an aliasing rate. The EM signal can be a modulated carrier signal or an unmodulated carrier signal. In an exemplary example, a modulated carrier signal F_{MC} is down-converted to an IF signal F_{IF}.

$$F_{MC} \rightarrow F_{IF}$$

FIG. **46**B depicts a flowchart **4607** that illustrates a method for transferring energy from the EM signal at an aliasing rate to down-convert the EM signal to an IF signal. The process begins at step **4608**, which includes receiving an EM signal. Step **4610** includes receiving an energy transfer signal having an aliasing rate. Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to an IF signal.

This embodiment is illustrated generally by **4514** in FIG. **45**B and is described in Section III.1.

2.3.2 Direct-to-Data Down-Converting

In another embodiment, an EM signal is down-converted to a demodulated baseband signal by transferring energy from the EM signal at an aliasing rate. This embodiment is referred to herein as direct-to-data down-conversion. The EM signal can be a modulated EM signal or an unmodulated EM signal. In an exemplary embodiment, the EM signal is the modulated carrier signal F_{MC}, and is directly down-converted to a demodulated baseband signal F_{DMB}.

$$F_{MC} \rightarrow F_{DMB}$$

FIG. **46**C depicts a flowchart **4613** that illustrates a method for transferring energy from the EM signal at an aliasing rate to directly down-convert the EM signal to a demodulated baseband signal. The process begins at step **4614**, which includes receiving an EM signal. Step **4616** includes receiving an energy transfer signal having an aliasing rate. Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to a baseband signal.

This embodiment is illustrated generally by **4516** in FIG. **45**B and is described in Section III.2

2.3.3 Modulation Conversion

In another embodiment, a frequency modulated (FM) carrier signal F_{FMC} is converted to a non-FM signal $F_{(NON-FM)}$, by transferring energy from the FM carrier signal F_{FMC} at an aliasing rate.

$$F_{FMC} \rightarrow F_{(NON-FM)}$$

The FM carrier signal F_{FMC} can be converted to, for example, a phase modulated (PM) signal or an amplitude modulated (AM) signal. FIG. **46**D depicts a flowchart **4619** that illustrates a method for transferring energy from an FM signal to convert it to a non-FM signal. Step **4620** includes receiving the FM signal. Step **4622** includes receiving an energy transfer signal having an aliasing rate. In FIG. **46**D, step **4612** includes transferring energy from the FM signal to convert it to a non-FM signal. For example, energy can be transferred from an FSK signal to convert it to a PSK signal or an ASK signal.

This embodiment is illustrated generally by **4518** in FIG. **45**B, and described in Section III.3

2.4 Determining the Aliasing Rate

In accordance with the definition of aliasing, the aliasing rate is equal to, or less than, twice the frequency of the EM carrier signal. Preferably, the aliasing rate is much less than the frequency of the carrier signal. The aliasing rate is preferably more than twice the highest frequency component of the modulating baseband signal F_{MB} that is to be reproduced. The above requirements are illustrated in EQ. (1).

$$2 \cdot F_{MC} \geqq F_{AR} > 2 \cdot (\text{Highest Freq. Component of } F_{MB}) \qquad \text{EQ. (1)}$$

In other words, by taking a carrier and aliasing it at an aliasing rate, the invention can down-convert that carrier to lower frequencies. One aspect that can be exploited by this invention is that the carrier is not the item of interest; instead the lower baseband signal is of interest to be reproduced sufficiently. The baseband signal's frequency content, even though its carrier may be aliased, satisfies the Nyquist criteria and as a result, the baseband information can be sufficiently reproduced, either as the intermediate modulating carrier signal F_{IF} or as the demodulated direct-to-data baseband signal F_{DMB}.

In accordance with the invention, relationships between the frequency of an EM carrier signal, the aliasing rate, and the intermediate frequency of the down-converted signal, are illustrated in EQ. (2).

$$F_C = n \cdot F_{AR} \pm F_{IF} \qquad \text{EQ. (2)}$$

Where:

F_C is the frequency of the EM carrier signal that is to be aliased;

F_{AR} is the aliasing rate;

n identifies a harmonic or sub-harmonic of the aliasing rate (generally, n=0.5, 1, 2, 3, 4, . . .); and

F_{IF} is the intermediate frequency of the down-converted signal.

Note that as $(n \cdot F_{AR})$ approaches F_C, F_{IF} approaches zero. This is a special case where an EM signal is directly down-converted to a demodulated baseband signal. This special case is referred to herein as Direct-to-Data down-conversion. Direct-to-Data down-conversion is described in later sections.

High level descriptions, exemplary embodiments and exemplary implementations of the above and other embodiments of the invention are provided in sections below.

3. BENEFITS OF THE INVENTION USING AN EXAMPLE CONVENTIONAL RECEIVER FOR COMPARISON

FIG. **11** illustrates an example conventional receiver system **1102**. The conventional system **1102** is provided both to help the reader to understand the functional differences between conventional systems and the present invention, and to help the reader to understand the benefits of the present invention.

The example conventional receiver system **1102** receives an electromagnetic (EM) signal **1104** via an antenna **1106**. The EM signal **1104** can include a plurality of EM signals such as modulated carrier signals. For example, the EM signal **1104** includes one or more radio frequency (RF) EM signals, such as a 900 MHZ modulated carrier signal. Higher frequency RF signals, such as 900 MHZ signals, generally cannot be directly processed by conventional signal processors. Instead, higher frequency RF signals are typically down-converted to lower intermediate frequencies (IF) for processing. The receiver system **1102** down-converts the EM signal **1104** to an intermediate frequency (IF) signal **1108***n*, which can be provided to a signal processor **1110**. When the EM signal **1104** includes a modulated carrier signal, the signal processor **1110** usually includes a demodulator that demodulates the IF signal **1108***n* to a baseband information signal (demodulated baseband signal).

Receiver system **1102** includes an RF stage **1112** and one or more IF stages **1114**. The RF stage **1112** receives the EM signal **1104**. The RF stage **1112** includes the antenna **1106** that receives the EM signal **1104**.

The one or more IF stages **1114***a*–**1114***n* down-convert the EM signal **1104** to consecutively lower intermediate frequencies. Each of the one or more IF sections **1114***a*–**1114***n* includes a mixer **1118***a*–**1118***n* that down-converts an input EM signal **1116** to a lower frequency IF signal **1108**. By cascading the one or more mixers **1118***a*–**1118***n*, the EM signal **1104** is incrementally down-converted to a desired IF signal **1108***n*.

In operation, each of the one or more mixers **1118** mixes an input EM signal **1116** with a local oscillator (LO) signal **1119**, which is generated by a local oscillator (LO) **1120**. Mixing generates sum and difference signals from the input EM signal **1116** and the LO signal **1119**. For example, mixing an input EM signal **1116***a*, having a frequency of 900 MHZ, with a LO signal **1119***a*, having a frequency of 830 MHZ, results in a sum signal, having a frequency of 900 MHZ+830 MHZ=1.73 GHZ, and a difference signal, having a frequency of 900 MHZ–830 MHZ=70 MHZ.

Specifically, in the example of FIG. **11**, the one or more mixers **1118** generate a sum and difference signals for all signal components in the input EM signal **1116**. For example, when the EM signal **1116***a* includes a second EM signal, having a frequency of 760 MHZ, the mixer **1118***a* generates a second sum signal, having a frequency of 760 MHZ+830 MHZ=1.59 GHZ, and a second difference signal, having a frequency of 830 MHZ–760 MHZ=70 MHZ. In this example, therefore, mixing two input EM signals, having frequencies of 900 MHZ and 760 MHZ, respectively, with an LO signal having a frequency of 830 MHZ, results in two IF signals at 70 MHZ.

Generally, it is very difficult, if not impossible, to separate the two 70 MHZ signals. Instead, one or more filters **1122** and **1123** are provided upstream from each mixer **1118** to filter the unwanted frequencies, also known as image frequencies. The filters **1122** and **1123** can include various filter topologies and arrangements such as bandpass filters, one or more high pass filters, one or more low pass filters, combinations thereof, etc.

Typically, the one or more mixers **1118** and the one or more filters **1122** and **1123** attenuate or reduce the strength of the EM signal **1104**. For example, a typical mixer reduces the EM signal strength by 8 to 12 dB. A typical filter reduces the EM signal strength by 3 to 6 dB.

As a result, one or more low noise amplifiers (LNAs) **1121** and **1124***a*–**1124***n* are provided upstream of the one or more filters **1123** and **1122***a*–**1122***n*. The LNAs and filters can be in reversed order. The LNAs compensate for losses in the mixers **1118**, the filters **1122** and **1123**, and other components by increasing the EM signal strength prior to filtering and mixing. Typically, for example, each LNA contributes 15 to 20 dB of amplification.

However, LNAs require substantial power to operate. Higher frequency LNAs require more power than lower frequency LNAs. When the receiver system **1102** is intended to be portable, such as a cellular telephone receiver, for example, the INAs require a substantial portion of the total power.

At higher frequencies, impedance mismatches between the various stages further reduce the strength of the EM signal **1104**. In order to optimize power transferred through the receiver system **1102**, each component should be impedance matched with adjacent components. Since no two components have the exact same impedance characteristics, even for components that were manufactured with high tolerances, impedance matching must often be individually fine tuned for each receiver system **1102**. As a result, impedance matching in conventional receivers tends to be labor intensive and more art than science. Impedance matching requires a significant amount of added time and expense to both the design and manufacture of conventional receivers. Since many of the components, such as LNA, filters, and impedance matching circuits, are highly frequency dependent, a receiver designed for one application is generally not suitable for other applications. Instead, a new receiver must be designed, which requires new impedance matching circuits between many of the components.

Conventional receiver components are typically positioned over multiple IC substrates instead of on a single IC substrate. This is partly because there is no single substrate that is optimal for both RF, IF, and baseband frequencies. Other factors may include the sheer number of components, their various sizes and different inherent impedance characteristics, etc. Additional signal amplification is often required when going from chip to chip. Implementation over multiple substrates thus involves many costs in addition to the cost of the ICs themselves.

Conventional receivers thus require many components, are difficult and time consuming to design and manufacture, and require substantial external power to maintain sufficient signal levels. Conventional receivers are thus expensive to design, build, and use.

In an embodiment, the present invention is implemented to replace many, if not all, of the components between the antenna **1106** and the signal processor **1110**, with an aliasing module that includes a universal frequency translator (UIT) module. The UFT is able to down-convert a wide range of EM signal frequencies using very few components. The UFT is easy to design and build, and requires very little external power. The UFr design can be easily tailored for different frequencies or frequency ranges. For example, UFF design can be easily impedance matched with relatively little tuning. In a direct-to-data embodiment of the invention, where an EM signal is directly down-converted to a demodulated baseband signal, the invention also eliminates the need for a demodulator in the signal processor **1110**.

When the invention is implemented in a receiver system, such as the receiver system **1102**, power consumption is significantly reduced and signal to noise ratio is significantly increased.

In an embodiment, the invention can be implemented and tailored for specific applications with easy to calculate and easy to implement impedance matching circuits. As a result, when the invention is implemented as a receiver, such as the receiver **1102**, specialized impedance matching experience is not required.

In conventional receivers, components in the IF sections comprise roughly eighty to ninety percent of the total components of the receivers. The UFI design eliminates the IF section(s) and thus eliminates the roughly eighty to ninety percent of the total components of conventional receivers.

Other advantages of the invention include, but are not limited to:

- The invention can be implemented as a receiver with only a single local oscillator;
- The invention can be implemented as a receiver with only a single, lower frequency, local oscillator;
- The invention can be implemented as a receiver using few filters;
- The invention can be implemented as a receiver using unit delay filters;
- The invention can be implemented as a receiver that can change frequencies and receive different modulation formats with no hardware changes;
- The invention can be also be implemented as frequency up-converter in an EM signal transmitter;
- The invention can be also be implemented as a combination up-converter (transmitter) and down-converter (receiver), referred to herein as a transceiver;
- The invention can be implemented as a method and system for ensuring reception of a communications signal, as disclosed in co-pending patent application titled, "Method and System for Ensuring Reception of a Communications Signal," Attorney Docket No. 1744.0030000, incorporated herein by reference in its entirety;
- The invention can be implemented in a differential configuration, whereby signal to noise ratios are increased;
- A receiver designed in accordance with the invention can be implemented on a single IC substrate, such as a silicon-based IC substrate;
- A receiver designed in accordance with the invention and implemented on a single IC substrate, such as a silicon-based IC substrate, can down-convert EM signals from frequencies in the giga Hertz range;
- A receiver built in accordance with the invention has a relatively flat response over a wide range of frequencies. For example, in an embodiment, a receiver built in accordance with the invention to operate around 800 MHZ has a substantially flat response (i.e., plus or minus a few dB of power) from 100 MHZ to 1 GHZ. This is referred to herein as a wide-band receiver; and
- A receiver built in accordance with the invention can include multiple, user-selectable, Impedance match modules, each designed for a different wide-band of frequencies, which can be used to scan an ultra-wide-band of frequencies.

II. Down-Converting by Under-Sampling

1. DOWN-CONVERTING AN EM CARRIER SIGNAL TO AN EM INTERMEDIATE SIGNAL BY UNDER-SAMPLING THE EM CARRIER SIGNAL AT THE ALIASING RATE

In an embodiment, the invention down-converts an EM signal to an IF signal by under-sampling the EM signal. This embodiment is illustrated by **4508** in FIG. **45**B.

This embodiment can be implemented with modulated and unmodulated EM signals. This embodiment is described herein using the modulated carrier signal F_{MC} in FIG. **1**, as an example. In the example, the modulated carrier signal F_{MC} is down-converted to an IF signal F_{IF}. The IF signal F_{IF}

can then be demodulated, with any conventional demodulation technique to obtain a demodulated baseband signal F_{DMB}. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any EM signal, including but not limited to, modulated carrier signals and unmodulated carrier signals.

The following sections describe example methods for down-converting the modulated carrier signal F_{MC} to the IF signal F_{IF}, according to embodiments of the invention. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

1.1 High Level Description

This section (including its subsections) provides a high-level description of down-converting an EM signal to an IF signal F_{IF}, according to the invention. In particular, an operational process of under-sampling a modulated carrier signal F_{MC} to down-convert it to the IF signal F_{IF}, is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

1.1.1 Operational Description

FIG. **14**B depicts a flowchart **1407** that illustrates an exemplary method for under-sampling an EM signal to down-convert the EM signal to an intermediate signal F_{IF}. The exemplary method illustrated in the flowchart **1407** is an embodiment of the flowchart **1401** in FIG. **14**A.

Any and all combinations of modulation techniques are valid for this invention. For ease of discussion, the digital AM carrier signal **616** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed flowcharts and descriptions for AM, FM and PM example embodiments. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of EM signal, including any form of modulated carrier signal and unmodulated carrier signals.

The method illustrated in the flowchart **1407** is now described at a high level using the digital AM carrier signal **616** of FIG. **6**C. The digital AM carrier signal **616** is re-illustrated in FIG. **15**A for convenience. FIG. **15**E illustrates a portion **1510** of the AM carrier signal **616**, between time t1 and t2, on an expanded time scale.

The process begins at step **1408**, which includes receiving an EM signal. Step **1408** is represented by the digital AM carrier signal **616**.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **15**B illustrates an example under-sampling signal **1502**, which includes a train of pulses **1504** having negligible apertures that tend toward zero time in duration. The pulses **1504** repeat at the aliasing rate, or pulse repetition rate. Aliasing rates are discussed below.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. When down-converting an EM signal to an IF signal, the frequency or aliasing rate of the pulses **1504** sets the IF.

FIG. **15**C illustrates a stair step AM intermediate signal **1506**, which is generated by the down-conversion process. The AM intermediate signal **1506** is similar to the AM carrier signal **616** except that the AM intermediate signal **1506** has a lower frequency than the AM carrier signal **616**. The AM carrier signal **616** has thus been down-converted to the AM intermediate signal **1506**. The AM intermediate signal **1506** can be generated at any frequency below the frequency of the AM carrier signal **616** by adjusting the aliasing rate.

FIG. **15**D depicts the AM intermediate signal **1506** as a filtered output signal **1508**. In an alternative embodiment, the invention outputs a stair step, non-filtered or partially filtered output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

The intermediate frequency of the down-converted signal F_{IF}, which in this example is the AM intermediate signal **1506**, can be determined from EQ. (2), which is reproduced below for convenience.

$$F_C=n\cdot P_{AR}\pm F_{IF} \qquad \text{EQ. (2)}$$

A suitable aliasing rate F_{AR} can be determined in a variety of ways. An example method for determining the aliasing rate F_{AR}, is provided below. After reading the description herein, one skilled in the relevant art(s) will understand how to determine appropriate aliasing rates for EM signals, including ones in addition to the modulated carrier signals specifically illustrated herein.

In FIG. **17**, a flowchart **1701** illustrates an example process for determining an aliasing rate F_{AR}. But a designer may choose, or an application may dictate, that the values be determined in an order that is different than the illustrated order. The process begins at step **1702**, which includes determining, or selecting, the frequency of the EM signal. The frequency of the FM carrier signal **616** can be, for example, 901 MHZ.

Step **1704** includes determining, or selecting, the intermediate frequency. This is the frequency to which the EM signal will be down-converted. The intermediate frequency can be determined, or selected, to match a frequency requirement of a down-stream demodulator. The intermediate frequency can be, for example, 1 MHZ.

Step **1706** includes determining the aliasing rate or rates that will down-convert the EM signal to the IF specified in step **1704**.

EQ. (2) can be rewritten as EQ. (3):

$$n\bullet F_{AR}=F_C\pm F_{IF} \qquad \text{EQ. (3)}$$

Which can be rewritten as EQ. (4):

$$n=\frac{F_C\pm F_{IF}}{F_{AR}} \qquad \text{EQ. (4)}$$

or as EQ. (5):

$$F_{AR}=\frac{F_C\pm F_{IF}}{n} \qquad \text{EQ. (5)}$$

$(F_C\pm F_{IF})$ can be defined as a difference value F_{DIFF}, as illustrated in EQ. (6):

$$(F_C\pm F_{IF})=F_{DIFF} \qquad \text{EQ. (6)}$$

EQ. (4) can be rewritten as EQ. (7):

$$n=\frac{F_{DIFF}}{F_{AR}} \qquad \text{EQ. (7)}$$

From EQ. (7), it can be seen that, for a given n and a constant F_{AR}, F_{DIFF} is constant. For the case of $F_{DIFF}=F_C-F_{IF}$, and for a constant F_{DIFF}, as F_C increases, F_{IF} necessarily increases. For the case of $F_{DIFF}=F_C+F_{IF}$, and for a constant F_{DIFF}, as F_C increases, F_{IF} necessarily decreases. In the latter case of $F_{DIFF}=F_C+F_{IF}$, any phase or frequency changes on F_C correspond to reversed or inverted phase or frequency changes on F_{IF}. This is mentioned to teach the reader that if $F_{DIFF}=F_C+F_{IF}$ is used, the above effect will affect the phase and frequency response of the modulated intermediate signal F_{IF}.

EQs. (2) through (7) can be solved for any valid n. A suitable n can be determined for any given difference frequency F_{DIFF} and for any desired aliasing rate $F_{AR(Desired)}$. EQs. (2) through (7) can be utilized to identify a specific harmonic closest to a desired aliasing rate $F_{AR(Desired)}$ that will generate the desired intermediate signal F_{IF}.

An example is now provided for determining a suitable n for a given difference frequency F_{DIFF} and for a desired aliasing rate $F_{AR(Desired)}$. For ease of illustration, only the case of (F_C-F_{IF}) is illustrated in the example below.

$$n=\frac{F_C-F_{IF}}{F_{AR(Desired)}}=\frac{F_{DIFF}}{F_{AR(Desired)}}$$

The desired aliasing rate $F_{AR(Desired)}$ can be, for example, 140 MHZ. Using the previous examples, where the carrier frequency is 901 MHZ and the IF is 1 MHZ, an initial value of n is determined as:

$$n=\frac{901\text{ MHZ}-1\text{ MHZ}}{140\text{ MHZ}}=\frac{900}{140}=6.4$$

The initial value 6.4 can be rounded up or down to the valid nearest n, which was defined above as including (0.5, 1, 2, 3, . . .). In this example, 6.4 is rounded down to 6.0, which is inserted into EQ. (5) for the case of $(F_C-F_{IF})=F_{DIFF}$:

$$F_{AR}=\frac{F_c-F_{IF}}{n}$$

$$F_{AR}=\frac{901\text{ MHZ}-1\text{ MHZ}}{6}=\frac{900\text{ MHZ}}{6}=150\text{ MHZ}$$

In other words, under-sampling a 901 MHZ EM carrier signal at 150 MHZ generates an intermediate signal at 1 MHZ. When the under-sampled EM carrier signal is a modulated carrier signal, the intermediate signal will also substantially include the modulation. The modulated intermediate signal can be demodulated through any conventional demodulation technique.

Alternatively, instead of starting from a desired aliasing rate, a list of suitable aliasing rates can be determined from the modified form of EQ. (5), by solving for various values of n. Example solutions are listed below.

$$F_{AR} = \frac{(F_C - F_{IF})}{n} = \frac{F_{DIFF}}{n} = \frac{901\text{ MHZ} - 1\text{ MHZ}}{n} = \frac{900\text{ MHZ}}{n}$$

Solving for n=0.5, 1, 2, 3, 4, 5 and 6:

900 MHZ/0.5=1.8 GHZ (i.e., second harmonic, illustrated in FIG. **25**A as **2502**);

900 MHZ/1=900 MHZ (i.e., fundamental frequency, illustrated in FIG. **25**B as **2504**);

900 MHZ/2=450 MHZ (i.e., second sub-harmonic, illustrated in FIG. **25**C as **2506**);

900 MHZ/3=300 MHZ (i.e., third sub-harnonic, illustrated in FIG. **25**D as **2508**);

900 MHZ/4=225 MHZ (i.e., fourth sub-harmonic, illustrated in FIG. **25**E as **2510**);

900 MHZ/5=180 MHZ(i.e., fifth sub-harmonic, illustrated in FIG. **25**F as **2512**); and

900 MHZ/6=150 MHZ(i.e., sixth subharmonic, illustrated in FIG. **25**G as **2514**).

The steps described above can be performed for the case of (F_C+F_{IF}) in a similar fashion. The results can be compared to the results obtained from the case of (F_C−F_{IF}) to determine which provides better result for an application.

In an embodiment, the invention down-converts an EM signal to a relatively standard IF in the range of, for example, 100 KHZ to 200 MHZ. In another embodiment, referred to herein as a small off-set implementation, the invention down-converts an EM signal to a relatively low frequency of, for example, less than 100 KHZ. In another embodiment, referred to herein as a large off-set implementation, the invention down-converts an EM signal to a relatively higher IF signal, such as, for example, above 200 MHZ.

The various off-set implementations provide selectivity for different applications. Generally, lower data rate applications can operate at lower intermediate frequencies. But higher intermediate frequencies can allow more information to be supported for a given modulation technique.

In accordance with the invention, a designer picks an optimum information bandwidth for an application and an optimum intermediate frequency to support the baseband signal. The intermediate frequency should be high enough to support the bandwidth of the modulating baseband signal F_{MB}.

Generally, as the aliasing rate approaches a harmonic or sub-harmonic frequency of the EM signal, the frequency of the down-onverted IF signal decreases. Similarly, as the aliasing rate moves away from a harmonic or sub-harmonic frequency of the EM signal, the IF increases.

Aliased frequencies occur above and below every harmonic of the aliasing frequency. In order to avoid mapping other aliasing frequencies in the band of the aliasing frequency (IF) of interest, the IF of interest is preferably not near one half the aliasing rate.

As described in example implementations below, an aliasing module, including a universal frequency translator (UFT) module built in accordance with the invention, provides a wide range of flexibility in frequency selection and can thus be implemented in a wide range of applications. Conventional systems cannot easily offer, or do not allow, this level of flexibility in frequency selection.

1.1.2 Structural Description

FIG. **16** illustrates a block diagram of an under-sampling system **1602** according to an embodiment of the invention. The under-sampling system **1602** is an example embodiment of the generic aliasing system **1302** in FIG. **13**. The under-sampling system **1602** includes an under-sampling module **1606**. The under-sampling module **1606** receives the EM signal **1304** and an under-sampling signal **1604**, which includes under-sampling pulses having negligible apertures that tend towards zero time, occurring at a frequency equal to the aliasing rate F_{AR}. The under-sampling signal **1604** is an example embodiment of the aliasing signal **1310**. The under-sampling module **1606** under-samples the EM signal **1304** at the aliasing rate F_{AR} of the under-sampling signal **1604**. The under-sampling system **1602** outputs a down-converted signal **1308**A.

Preferably, the under-sampling module **1606** under-samples the EM signal **1304** to down-convert it to the intermediate signal F_{IF} in the manner shown in the operational flowchart **1407** of FIG. **14**B. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **1407**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein. In an embodiment, the aliasing rate F_{AR} of the under-sampling signal **1604** is chosen in the manner discussed in Section II.1.1.1 so that the under-sampling module **1606** under-samples the EM carrier signal **1304** generating the intermediate frequency F_{IF}.

The operation of the under-sampling system **1602** is now described with reference to the flowchart **1407** and to the timing diagrams in FIGS. **15**A–D. In step **1408**, the under-sampling module **1606** receives the AM signal **616** (FIG. **15**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **1502** (FIG. **15**B). In step **1412**, the under-sampling module **1606** under-samples the AM carrier signal **616** at the aliasing rate of the under-sampling signal **1502**, or a multiple thereof, to down-convert the AM carrier signal **616** to the intermediate signal **1506** (FIG. **15**D).

Example implementations of the under-samnpling module **1606** are provided in Sections 4 and 5 below.

1.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting the EM signal **1304** to the intermediate signal F_{IF}, illustrated in the flowchart **1407** of FIG. **14**B, can be implemented with any type of EM signal, including unmodulated EM carrier signals and modulated carrier signals including, but not limited. to, AM, FM, PM, etc., or any combination thereof. Operation of the flowchart **1407** of FIG. **14**B is described below for AM, FM and PM carrier signals. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

1.2.1 First Example Embodiment: Amplitude Modulation

1.2.1.1 Operational Description

Operation of the exemplary process of the flowchart **1407** in FIG. **14**B is described below for the analog AM carrier signal **516**, illustrated in FIG. **5**C, and for the digital AM carrier signal **616**, illustrated in FIG. **6**C.

1.2.1.1.1 Analog AM Carrier Signal

A process for down-converting the analog AM carrier signal **516** in FIG. **5**C to an analog AM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The analog AM carrier signal **516** is re-illustrated in FIG. **19**A for convenience. For this example, the analog AM carrier signal **516** oscillates at approximately 901 MHZ. In FIG. **19**B, an analog AM carrier signal **1904** illustrates a portion of the analog AM carrier signal **516** on an expanded time scale.

The process begins at step **1408**, which includes receiving tie EM signal. This is represented by the analog AM carrier signal **516** in FIG. **19**A.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **19**C illustrates an example under-sampling signal **1906** on approximately the same time scale as FIG. **19**B. The under-sampling signal **1906** includes a train of pulses **1907** having negligible apertures that tend towards zero time in duration. The pulses **1907** repeat at the aliasing rate, or pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. For this example, the aliasing rate is approximately 450 MHZ.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **19**B by under-sample points **1905**.

Because a harmonic of the aliasing rate is off-set from the AM carrier signal **516**, the under-sample points **1905** "walk through" the analog AM carrier signal **516**. In this example, the under-sample points **1905** "walk through" the analog AM carrier signal **516** at approximately a one megahertz rate. In other words, the under-sample points **1905** occur at different locations on subsequent cycles of the AM carrier signal **516**. As a result, the under-sample points **1905** capture varying amplitudes of the analog AM signal **516**. For example, under-sample point **1905**A has a larger amplitude than under-sample point **1905**B.

In FIG. **19**D, the under-sample points **1905** correlate to voltage points **1908**. In an embodiment, the voltage points **1908** form an analog AM intermediate signal **1910**. This can be accomplished in many ways. For example, each voltage point **1908** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as discussed below.

In FIG. **19**E, an AM intermediate signal **1912** represents the AM intermediate signal **1910**, after filtering, on a compressed time scale. Although FIG. **19**E illustrates the AM intermediate signal **1912** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The AM intermediate signal **1912** is substantially similar to the AM carrier signal **516**, except that the AM intermediate signal **1912** is at the 1 MHZ intermediate frequency. The AM intermediate signal **1912** can be demodulated through any conventional AM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the AM intermediate signal **1910** in FIG. **19**D and the AM intermediate signal **1912** in FIG. **19**E illustrate that the AM carrier signal **516** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.1.1.2 Digital AM Carrier Signal

A process for down-converting the digital AM carrier signal **616** in FIG. **6**C to a digital AM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The digital AM carrier signal **616** is re-illustrated in FIG. **18**A for convenience. For this example, the digital AM carrier signal **616** oscillates at approximately 901 MHZ. In FIG. **18**B, an AM carrier signal **1804** illustrates aportion of the AM signal **616**, from time t0 to t1, on an expanded time scale.

The process begins at step **1408**, which includes receiving an EM signal. This is represented by the AM signal **616** in FIG. **18**A.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **18**C illustrates an example under-sampling signal **1806** on approximately the same time scale as FIG. **18**B. The under-sampling signal **1806** includes a train of pulses **1807** having negligible apertures that tend towards zero time in duration. The pulses **1807** repeat at the aliasing rate, or pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. For this example, the aliasing rate is approximately 450 MHZ.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **18**B by under-sample points **1805**.

Because a harmonic of the aliasing rate is off-set from the AM carrier signal **616**, the under-sample points **1805** walk through the AM carrier signal **616**. In other words, the under-sample points **1805** occur at different locations of subsequent cycles of the AM signal **616**. As a result, the under-sample points **1805** capture various amplitudes of the AM signal **616**. In this example, the under-sample points **1805** walk through the AM carrier signal **616** at approximately a 1 MHZ rate. For example, under-sample point **1805**A has a larger amplitude than under-sample point **1805**B.

In FIG. **18**D, the under-sample points **1805** correlate to voltage points **1808**. In an embodiment, the voltage points **1805** form an AM intermediate signal **1810**. This can be accomplished in many ways. For example, each voltage point **1808** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as discussed below.

In FIG. **18**E, an AM intermediate signal **1812** represents the AM intermediate signal **1810**, afterfiltering, on acompressed time scale. Although FIG. **18**E illustrates the AM intermediate signal **1812** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The AM intermediate signal **1812** is substantially similar to the AM carrier signal **616**, except that the AM intermediate signal **1812** is at the 1 MHZ intermediate frequency. The AM intermediate signal **1812** can be demodulated through any conventional AM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the AM intermediate signal **1810** in FIG. **18**D and the AM intermediate signal **1812** in FIG. **18**E illustrate that the AM carrier signal **616** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.1.2 Structural Description

The operation of the under-sampling system **1602** is now described for the analog AM carrier signal **516**, with reference to the flowchart **1407** and to the timing diagrams of FIGS. **19**A–E. In step **1408**, the under-sampling module **1606** receives the AM carrier signal **516** (FIG. **19**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **1906** (FIG. **19**C). In step **1412**, the under-sampling module **1606** under-samples the AM carrier signal **516** at the aliasing rate of the under-sampling signal **1906** to down-conved it to the AM intermediate signal **1912** (FIG. **19**E).

The operation of the under-sampling system **1602** is now described for the digital AM carrier signal **616**, with reference to the flowchart **1407** and to the timing diagrams of FIGS. **18**A–E. In step **1408**, the under-sampling module **1606** receives the AM carrier signal **616** (FIG. **18**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **1806** (FIG. **18**C). In step **1412**, the under-sampling module **1606** under-samples the AM carrier signal **616** at the aliasing rate of the under-sampling signal **1806** to down-convert it to the AM intermediate signal **1812** (FIG. **18**E).

Example implementations of the under-sampling module **1606** are provided in Sections 4 and 5 below.

1.2.2 Second Example Embodiment: Frequency Modulation

1.2.2.1 Operational Description

Operation of the exemplary process of the flowchart **1407** in FIG. **14**B is described below for the analog FM carrier signal **716**, illustrated in FIG. **7**C, and for the digital FM carrier signal **816**, illustrated in FIG. **8**C.

1.2.2.1.1 Analog FM Carrier Signal

A process for down-converting the analog FM carrier signal **716** to an analog FM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The analog FM carrier signal **716** is re-illustrated in FIG. **20**A for convenience. For this example, the analog FM carrier signal **716** oscillates at approximately 901 MHZ. In FIG. **20**B, an FM carrier signal **2004** illustrates a portion of the analog FM carrier signal **716**, from time t1 to t3, on an expanded time scale.

The process begins at step **1408**, which includes receiving an EM signal. This is represented in FIG. **20**A by the FM carrier signal **716**.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **20**C illustrates an example under-sampling signal **2006** on approximately the same time scale as FIG. **20**B. The under-sampling signal **2006** includes a train of pulses **2007** having negligible apertures that tend towards zero time in duration. The pulses **2007** repeat at the aliasing rate or pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. For this exanple, where the FM carrier signal **716** is centered around 901 MHZ, the aliasing rate is approximately 450 MHZ.

Step **1412** includes under-sampling the EM signal at the aliasing rate to downconvert the EM signal to the intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **20**B by under-sample points **2005**.

Because a harmonic of the aliasing rate is off-set from the FM carrier signal **716**, the under-sample points **2005** occur at different locations of subsequent cycles of the under-sampled signal **716**. In other words, the under-sample points **2005** walk through the signal **716**. As a result, the under-sample points **2005** capture various amplitudes of the FM carrier signal **716**.

In FIG. **20**D, the under-sample points **2005** correlate to voltage points **2008**. In an embodiment, the voltage points **2005** form an analog FM intermediate signal **2010**. This can be accomplished in many ways. For example, each voltage point **2008** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as discussed below.

In FIG. **20**E, an FM intermediate signal **2012** illustrates the FM intermediate signal **2010**, after filtering, on a compressed time scale. Although FIG. **20**E illustrates the FM intermediate signal **2012** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The FM intermediate signal **2012** is substantially similar to the FM carrier signal **716**, except that the FM intermediate signal **2012** is at the 1 MHZ intermediate frequency. The FM intermediate signal **2012** can be demodulated through any conventional FM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the FM intermediate signal **2010** in FIG. **20**D and the FM intermediate signal **2012** in FIG. **20**E illustrate that the FM carrier signal **716** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.2.1.2 Digital FM Carrier Signal

A process for down-converting the digital FM carrier signal **816** to a digital FM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The digital FM carrier signal **816** is re-illustrated in FIG. **21**A for convenience. For this example, the digital FM carrier signal **816** oscillates at approximately 901 MHZ. In FIG. **21**B, an FM carrier signal **2104** illustrates a portion of the FM carrier signal **816**, from time t1 to t3, on an expanded time scale.

The process begins at step **1408**, which includes receiving an EM signal. This is represented in FIG. **21**A, by the FM carrier signal **816**.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **21**C illustrates an example under-sampling signal **2106** on approximately the same time scale as FIG. **21**B. The under-sampling signal **2106** includes a train of pulses **2107** having negligible apertures that tend toward zero time in duration. The pulses **2107** repeat at the aliasing rate, or pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. In this example, where the FM carrier signal **816** is centered around 901 MHZ, the aliasing rate is selected as approximately 450 MHZ, which is a sub-harmonic of 900 MHZ, which is off-set by 1 MHZ from the center frequency of the FM carrier signal **816**.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to an intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **21**B by under-sample points **2105**.

Because a harmonic of the aliasing rate is off-set from the FM carrier signal **816**, the under-sample points **2105** occur at different locations of subsequent cycles of the FM carrier signal **816**. In other words, the under-sample points **2105** walk through the signal **816**. As a result, the under-sample points **2105** capture various amplitudes of the signal **816**.

In FIG. **21**D, the under-sample points **2105** correlate to voltage points **2108**. In an embodiment, the voltage points

2108 form a digital FM intermediate signal **2110**. This can be accomplished in many ways. For example, each voltage point **2108** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **21**E, an FM intermediate signal **2112** represents the FM intermediate signal **2110**, after filtering, on acompressed time scale. Although FIG. **21**E illustrates the FM intermediate signal **2112** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The FM intermediate signal **2112** is substantially similar to the FM carrier signal **816**, except that the FM intermediate signal **2112** is at the 1 MHZ intermediate frequency. The FM intermediate signal **2112** can be demodulated through any conventional FM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the FM intermediate signal **2110** in FIG. **21**D and the FM intermediate signal **2112** in FIG. **21**E illustrate that the FM carrier signal **816** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.2.2 Structural Description

The operation of the under-sampling system **1602** is now described for the analog FM carrier signal **716**, with reference to the flowchart **1407** and the timing diagrams of FIGS. **20**A–E. In step **1408**, the under-sampling module **1606** receives the FM carrier signal **716** (FIG. **20**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **2006** (FIG. **20**C). In step **1412**, the under-sampling module **1606** under-samples the FM carrier signal **716** at the aliasing rate of the under-sampling signal **2006** to down-convert the FM carrier signal **716** to the FM intermediate signal **2012** (FIG. **20**E).

The operation of the under-sampling system **1602** is now described for thc digital FM carrier signal **816**, with reference to the flowchart **1407** and the timing diagrams of FIGS. **21**A–E. In step **1408**, the under-sampling module **1606** receives the FM carrier signal **816** (FIG. **21**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **2106** (FIG. **21**C). In step **1412**, the under-sampling module **1606** under-samples the FM carrier signal **816** at the aliasing rate of the under-sampling signal **2106** to down-convert the FM carrier signal **816** to the FM intermediate signal **2112** (FIG. **21**E).

Example implementations of the under-sampling module **1606** are provided in Sections 4 and 5 below.

1.2.3 Third Example Embodiment: Phase Modulation

1.2.3.1 Operational Description

Operation of the exemplary process of the flowchart **1407** in FIG. **14**B is described below for the analog PM carrier signal **916**, illustrated in FIG. **9**C, and for the digital PM carrier signal **1016**, illustrated in FIG. **10**C.

1.2.3.1.1 Analog PM Carrier Signal

A process for down-converting the analog PM carrier signal **916** to an analog PM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The analog PM carrier signal **916** is re-illustrated in FIG. **23**A for convenience. For this example, the analog PM carrier signal **916** oscillates at approximately 901 MHZ. In FIG. **23**B, a PM carrier signal **2304** illustrates a portion of the analog PM carrier signal **916**, from time t1 to t3, on an expanded time scale.

The process of down-converting the PM carrier signal **916** to a PM intermediate signal begins at step **1408**, which includes receiving an EM signal. This is represented in FIG. **23**A, by the analog PM carrier signal **916**.

Step **1410** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **23**C illustrates an example under-sampling signal **2306** on approximately the same time scale as FIG. **23**B. The under-sampling signal **2306** includes a train of pulses **2307** having negligible apertures that tend towards zero time in duration. The pulses **2307** repeat at the aliasing rate, or pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. In this example, the aliasing rate is approximately 450 MHZ.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **23**B by under-sample points **2305**.

Because a harmonic of the aliasing rate is off-set from the PM carrier signal **916**, the under-sample points **2305** occur at different locations of subsequent cycles of the PM carrier signal **916**. As a result, the under-sample points capture various amplitudes of the PM carrier signal **916**.

In FIG. **23**D, voltage points **2308** correlate to the under-sample points **2305**. In an embodiment, the voltage points **2308** form an analog PM intermediate signal **2310**. This can be accomplished in many ways. For example, each voltage point **2308** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **23**E, an analog PM intermediate signal **2312** illustrates the analog PM intermediate signal **2310**, after filtering, on a compressed time scale. Although FIG. **23**E illustrates the PM intermediate signal **2312** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The analog PM intermediate signal **2312** is substantially similar to the analog PM carrier signal **916**, except that the analog PM intermediate signal **2312** is at the 1 MHZ intermediate frequency. The analog PM intermediate signal **2312** can be demodulated through any conventional PM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the analog PM intermediate signal **2310** in FIG. **23**D and the analog PM intermediate signal **2312** in FIG. **23**E illustrate that the analog PM carrier signal **2316** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.3.1.2 Digital PM Carrier Signal

A process for down-converting the digital PM carrier signal **1016** to a digital PM intermediate signal is now described with reference to the flowchart **1407** in FIG. **14**B. The digital PM carrier signal **1016** is re-illustrated in FIG. **22**A for convenience. For this example, the digital PM carrier signal **1016** oscillates at approximately 901 MHZ. In FIG. **22**B, a PM carrier signal **2204** illustrates a portion of the digital PM carrier signal **1016**, from time t1 to t3, on an expanded time scale.

The process begins at step **1408**, which includes receiving an EM signal. This is represented in FIG. **22**A by the digital PM carrier signal **1016**.

Step **1408** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **22**C illustrates example under-sampling signal **2206** on approximately the same time scale as FIG. 22B. The under-sampling signal **2206** includes a train of pulses **2207** having negligible apertures that tend towards zero time in duration. The pulses **2207** repeat at the aliasing rate, or a pulse repetition rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}. In this example, the aliasing rate is approximately 450 MHZ.

Step **1412** includes under-sampling the EM signal at the aliasing rate to down-convert the EM signal to an intermediate signal F_{IF}. Step **1412** is illustrated in FIG. **22**B by under-sample points **2205**.

Because a harmonic of the aliasing rate is off-set from the PM carrier signal **1016**, the under-sample points **2205** occur at different locations of subsequent cycles of the PM carrier signal **1016**.

In FIG. **22**D, voltage points **2208** correlate to the under-sample points **2205**. In an embodiment, the voltage points **2208** form a digital PM intermediate signal **2210**. This can be accomplished in many ways. For example, each voltage point **2208** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **22**E, a digital PM intermediate signal **2212** represents the digital PM intermediate signal **2210** on a compressed time scale. Although FIG. **22**E illustrates the PM intermediate signal **2212** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The digital PM intermediate signal **2212** is substantially similar to the digital PM carrier signal **1016**, except that the digital PM intermediate signal **2212** is at the 1 MHZ intermediate frequency. The digital PM carrier signal **2212** can be demodulated through any conventional PM demodulation technique.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the digital PM intermediate signal **2210** in FIG. **22**D and the digital PM intermediate signal **2212** in FIG. **22**E illustrate that the digital PM carrier signal **1016** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.3.2 Structural Description

The operation of the under-sampling system **1602** is now described for the analog PM carrier signal **916**, with reference to the flowchart **1407** and the timing diagrams of FIGS. **23**A–E. In step **1408**, the under-sampling module **1606** receives the PM carrier signal **916** (FIG. **23**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **2306** (FIG. **23**C). In step **1412**, the under-sampling module **1606** under-samples the PM carrier signal **916** at the aliasing rate of the under-sampling signal **2306** to down-convert the PM carrier signal **916** to the PM intermediate signal **2312** (FIG. **23**E).

The operation of the under-sampling system **1602** is now described for the digital PM carrier signal **1016**, with reference to the flowchart **1407** and the timing diagrams of FIGS. **22**A–E. In step **1408**, the under-sampling module **1606** receives the PM carrier signal **1016** (FIG. **22**A). In step **1410**, the under-sampling module **1606** receives the under-sampling signal **2206** (FIG. **22**C). In step **1412**, the under-sampling module **1606** under-samples the PM carrier signal **1016** at the aliasing rate of the under-sampling signal **2206** to down-convert the PM carrier signal **1016** to the PM intermediate signal **2212** (FIG. **22**E).

Example implementations of the under-sampling module **1606** are provided in Sections 4 and 5 below.

1.2.4 Other Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention. Example implementations of the under-sampling module **1606** are provided in Sections 4 and 5 below.

1.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. The implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

2. DIRECTLY DOWN-CONVERTING AN EM SIGNAL TO A BASEBAND SIGNAL (Direct-to-Data)

In an embodiment, the invention directly down-converts an EM signal to a baseband signal, by under-sampling the EM signal. This embodiment is referred to herein as direct-to-data down-conversion and is illustrated in FIG. **45**B as **4510**.

This embodiment can be implemented with modulated and unmodulated EM signals. This embodiment is described herein using the modulated carrier signal F_{MC} in FIG. **1**, as an example. In the example, the modulated carrier signal F_{MC} is directly down-converted to the demodulated baseband signal F_{DMB}. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention is applicable to down-convert any EM signal, including but not limited to, modulated carrier signals and unmodulated carrier signals.

The following sections describe example methods for directly down-converting the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB}. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

2.1 High Level Description

This section (including its subsections) provides a high-level description of directly down-converting the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB}, according to the invention. In particular, an operational process of directly down-converting the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB} is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. The structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

2.1.1 Operational Description

FIG. **14**C depicts a flowchart **1413** that illustrates an exemplary method for directly down-converting an EM signal to a demodulated baseband signal F_{DMB}. The exemplary method illustrated in the flowchart **1413** is an embodiment of the flowchart **1401** in FIG. **14**A.

Any and all combinations of modulation techniques are valid for this invention. For ease of discussion, the digital AM carrier signal **616** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed descriptions for AM and PM example embodiments. FM presents special considerations that are dealt with separately in Section II.3, below. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of EM signal, including any form of modulated carrier signal and unmodulated carrier signals.

The method illustrated in the flowchart **1413** is now described at a high level using the digital AM carrier signal **616**, from FIG. **6**C. The digital AM carrier signal **616** is re-illustrated in FIG. **33**A for convenience.

The process of the flowchart **1413** begins at step **1414**, which includes receiving an EM signal. Step **1414** is represented by the digital AM carrier signal **616** in FIG. **33**A.

Step **1416** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **33**B illustrates an example under-sampling signal **3302** which includes a train of pulses **3303** having negligible apertures that tend towards zero time in duration. The pulses **3303** repeat at the aliasing rate or pulse repetition rate. The aliasing rate is determined in accordance with EQ. (2), reproduced below for convenience.

$$F_C=n\bullet F_{AR}\pm F_{IF} \qquad \text{EQ. (2)}$$

When directly down-converting an EM signal to baseband (i.e., zero IF), EQ. (2) becomes:

$$F_C=n\bullet F_{AR} \qquad \text{EQ. (8)}$$

Thus, to directly down-convert the AM signal **616** to a demodulated baseband signal, the aliasing rate is substantially equal to the frequency of the AM signal **616** or to a harmonic or sub-harmonic thereof. Although the aliasing rate is too low to permit reconstruction of higher frequency components of the AM signal **616** (i.e., the carrier frequency), it is high enough to permit substantial reconstruction of the lower frequency modulating baseband signal **310**.

Step **1418** includes under-sampling the EM signal at the aliasing rate to directly down-convert it to the demodulated baseband signal F_{DMB}. FIG. **33**C illustrates a stair step demodulated baseband signal **3304**, which is generated by the direct down-conversion process. The demodulated baseband signal **3304** is similar to the digital modulating baseband signal **310** in FIG. **3**.

FIG. **33**D depicts a filtered demodulated baseband signal **3306**, which can be generated from the stair step demodulated baseband signal **3304**. The invention can thus generate a filtered output signal, a partially filtered output signal, or a relatively unfiltered stair step output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

2.1.2 Structural Description

FIG. **16** illustrates the block diagram of the under-sampling system **1602** according to an embodiment of the invention. The under-sampling system **1602** is an example embodiment of the generic aliasing system **1302** in FIG. **13**.

In a direct to data embodiment, the frequency of the under-sampling signal **1604** is substantially equal to a harmonic of the EM signal **1304** or, more typically, a sub-harmonic thereof. Preferably, the under-sampling module **1606** under-samples the EM signal **1304** to directly down-convert it to the demodulated baseband signal F_{DMB}, in the manner shown in the operational flowchart **1413**. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **1413**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the aliasing system **1602** is now described for the digital AM carrier signal **616**, with reference to the flowchart **1413** and to the timing diagrams in FIGS. **33**A–D. In step **1414**, the under-sampling module **1606** receives the AM carrier signal **616** (FIG. **33**A). In step **1416**, the under-sampling module **1606** receives the under-sampling signal **3302** (FIG. **33**B). In step **1418**, the under-sampling module **1606** under-samples the AM carrier signal **616** at the aliasing rate of the under-sampling signal **3302** to directly down-convert the AM carrier signal **616** to the demodulated baseband signal **3304** in FIG. **33**C or the filtered demodulated baseband signal **3306** in FIG. **33**D.

Example implementations of the under-sampling module **1606** are provided in Sections 4 and 5 below.

2.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting the EM signal **1304** to the demodulated baseband signal F_{DMB}, illustrated in the flowchart **1413** of FIG. **14**C, can be implemented with any type EM signal, including modulated carrier signals, including but not limited to, AM, PM, etc., or any combination thereof. Operation of the flowchart **1413** of FIG. **14**C is described below for AM and PM carrier signals. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

2.2.1 First Example Embodiment: Amplitude Modulation

2.2.1.1 Operational Description

Operation of the exemplary process of the flowchart **1413** in FIG. **14**C is described below for the analog AM carrier signal **516**, illustrated in FIG. **5**C and for the digital AM carrier signal **616**, illustrated in FIG. **6**C.

2.2.1.1.1 Analog AM Carrier Signal

A process for directly down-converting the analog AM carrier signal **516** to a demodulated baseband signal is now described with reference to the flowchart **1413** in FIG. **14**C. The analog AM carrier signal **516** is re-illustrated in **35**A for convenience. For this example, the analog AM carrier signal **516** oscillates at approximately 900 MHZ. In FIG. **35**B, an analog AM carrier signal **3504** illustrates a portion of the analog AM carrier signal **516** on an expanded time scale.

The process begins at step **1414**, which includes receiving an EM signal. This is represented by the analog AM carrier signal **516**.

Step **1416** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **35**C illustrates an example under-sampling signal **3506** on approximately the same time scale as FIG. **35**B. The under-sampling signal **3506** includes a train of pulses **3507** having negligible apertures that tend towards zero time in duration. The pulses **3507** repeat at the aliasing rate or pulse repetition rate, which is determined or selected as previously described. Generally, when directly down-converting to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the under-sampled signal. In this example, the aliasing rate is approximately 450 MHZ.

Step **1418** includes under-sampling the EM signal at the aliasing rate to directly down-convert it to the demodulated baseband signal F_{DMB}. Step **1418** is illustrated in FIG. **35**B by under-sample points **3505**. Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **516**, essentially no IF is produced. The only substantial aliased component is the baseband signal.

In FIG. **35**D, voltage points **3508** correlate to the under-sample points **3505**. In an embodiment, the voltage points **3508** form a demodulated baseband signal **3510**. This can be accomplished in many ways. For example, each voltage point **3508** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **35**E, a demodulated baseband signal **3512** represents the demodulated baseband signal **3510**, after filtering, on a compressed time scale. Although FIG. **35**E illustrates the demodulated baseband signal **3512** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The demodulated baseband signal **3512** is substantially similar to the modulating baseband signal **210**. The demodulated baseband signal **3512** can be processed using any signal processing technique(s) without further down-conversion or demodulation.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and polarity, as desired.

In the example above, the under-sample points **3505** occur at positive locations of the AM carrier signal **516**. Alternatively, the under-sample points **3505** can occur at other locations including negative points of the analog AM carrier signal **516**. When the under-sample points **3505** occur at negative locations of the AM carrier signal **516**, the resultant demodulated baseband signal is inverted relative to the modulating baseband signal **210**.

The drawings referred to herein illustrate direct to data down-conversion in accordance with the invention. For example, the demodulated baseband signal **3510** in FIG. **35**D and the demodulated baseband signal **3512** in FIG. **35**E illustrate that the AM carrier signal **516** was successfully down-converted to the demodulated baseband signal **3510** by retaining enough baseband information for sufficient reconstruction.

2.2.1.1.2 Digital AM Carrier Signal

A process for directly down-converting the digital AM carrier signal **616** to a demodulated baseband signal is now described with reference to the flowchart **1413** in FIG. **14**C. The digital AM carrier signal **616** is re-illustrated in FIG. **36**A for convenience. For this example, the digital AM carrier signal **616** oscillates at approximately 901 MHZ. In FIG. **36**B, a digital AM carrier signal **3604** illustrates a portion of the digital AM carrier signal **616** on an expanded time scale.

The process begins at step **1414**, which includes receiving an EM signal. This is represented by the digital AM carrier signal **616**.

Step **1416** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **36**C illustrates an example under-sampling signal **3606** on approximately the same time scale as FIG. **36**B. The under-sampling signal **3606** includes a train of pulses **3607** having negligible apertures that tend towards zero time in duration. The pulses **3607** repeat at the aliasing rate or pulse repetition rate, which is determined or selected as previously described. Generally, when directly down-converting to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the under-sampled signal. In this example, the aliasing rate is approximately 450 MHZ.

Step **1418** includes under-sampling the EM signal at the aliasing rate to directly down-convert it to the demodulated baseband signal F_{DMB}. Step **1418** is illustrated in FIG. **36**B by under-sample points **3605**. Because the aliasing rate is substantially equal to the AM carrier signal **616**, or to a harmonic or sub-harmonic thereof, essentially no IF is produced. The only substantial aliased component is the baseband signal.

In FIG. **36**D, voltage points **3608** correlate to the under-sample points **3605**. In an embodiment, the voltage points **3608** form a demodulated baseband signal. **3610**. This can be in accomplished in many ways. For example, each voltage point **3608** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **36**E, a demodulated baseband signal **3612** represents the demodulated baseband signal **3610**, after filtering, on a compressed time scale. Although FIG. **36**E illustrates the demodulated baseband signal **3612** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The demodulated baseband signal **3612** is substantially similar to the digital modulating baseband signal **310**. The demodulated analog baseband signal **3612** can be processed using any signal processing technique(s) without further down-conversion or demodulation.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and polarity, as desired.

In the example above, the under-sample points **3605** occur at positive locations of signal portion **3604**. Alternatively, the under-sample points **3605** can occur at other locations including negative locations of the signal portion **3604**. When the under-sample points **3605** occur at negative points, the resultant demodulated baseband signal is inverted with respect to the modulating baseband signal **310**.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the demodulated baseband signal **3610** in FIG. **36**D and the demodulated baseband signal **3612** in FIG. **36**E illustrate that the digital AM carrier signal **616** was successfully down-converted to the demodulated baseband signal **3610** by retaining enough baseband information for sufficient reconstruction.

2.2.1.2 Structural Description

The operation of the under-sampling module **1606** is now described for the analog AM carrier signal **516**, with reference to the flowchart **1413** and the timing diagrams of FIGS. **35**A–E. In step **1414**, the under-sampling module **1606** receives the analog AM carrier signal **516** (FIG. **35**A). In step **1416**, the under-sampling module **1606** receives the under-sampling signal **3506** (FIG. **35**C). In step **1418**, the under-sampling module **1606** under-samples the analog AM carrier signal **516** at the aliasing rate of the under-sampling signal **3506** to directly to down-convert the AM carrier signal **516** to the demodulated analog baseband signal **3510** in FIG. **35**D or to the filtered demodulated analog baseband signal **3512** in FIG. **35**E.

The operation of the under-sampling system **1602** is now described for the digital AM carrier signal **616**, with reference to the flowchart **1413** and the timing diagrams of FIGS. **36**A–E. In step **1414**, the under-sampling module **1606** receives the digital AM carrier signal **616** (FIG. **36**A). In step **1416**, the under-sampling module **1606** receives the under-sampling signal **3606** (FIG. **36**C). In step **1418**, the under-sampling module **1606** under-samples the digital AM carrier signal **616** at the aliasing rate of the under-sampling signal **3606** to down-convert the digital AM carrier signal **616** to the demodulated digital baseband signal **3610** in FIG. **36**D or to the filtered demodulated digital baseband signal **3612** in FIG. **36**E.

Example implementations of the under-sampling, module **1606** are provided in Sections 4 and 5 below.

2.2.2 Second Example Embodiment: Phase Modulation

2.2.2.1 Operational Description

Operation of the exemplary process of the flowchart **1413** in FIG. **14**C is described below for the analog PM carrier signal **916**, illustrated in FIG. **9**C, and for the digital PM carrier signal **1016**, illustrated in FIG. **10**C.

2.2.2.1.1 Analog PM Carrier Signal

A process for directly down-converting the analog PM carrier signal **916** to a demodulated baseband signal is now described with reference to the flowchart **1413** in FIG. **14**C. The analog PM carrier signal **916** is re-illustrated in **37**A for convenience. For this example, the analog PM carrier signal **916** oscillates at approximately 900 MHZ. In FIG. **37**B, an analog PM carrier signal **3704** illustrates a portion of the analog PM carrier signal **916** on an expanded time scale.

The process begins at step **1414**, which includes receiving an EM signal. This is represented by the analog PM signal **916**.

Step **1416** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **37**C illustrates an example under-sampling signal **3706** on approximately the same time scale as FIG. **37**B. The under-sampling signal **3706** includes a train of pulses **3707** having negligible apertures that tend towards zero time in duration. The pulses **3707** repeat at the aliasing rate or pulse repetition rate, which is determined or selected as previously described. Generally, when directly down-converting to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the under-sampled signal. In this example, the aliasing rate is approximately 450 MHZ.

Step **1418** includes under-sampling the analog PM carrier signal **916** at the aliasing rate to directly down-convert it to a demodulated baseband signal. Step **1418** is illustrated in FIG. **37**B by under-sample points **3705**.

Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **916**, or substantially equal to a harmonic or sub-harmonic thereof, essentially no IF is produced. The only substantial aliased component is the baseband signal.

In FIG. **37**D, voltage points **3708** correlate to the under-sample points **3705**. In an embodiment, the voltage points **3708** form a demodulated baseband signal **3710**. This can be accomplished in many ways. For example, each voltage point **3708** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **37**E, a demodulated baseband signal **3712** represents the demodulated baseband signal **3710**, after filtering, on a compressed time scale. Although FIG. **37**E illustrates the demodulated baseband signal **3712** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The demodulated baseband signal **3712** is substantially similar to the analog modulating baseband signal **210**. The demodulated baseband signal **3712** can be processed without further down-conversion or demodulation.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and polarity, as desired.

In the example above, the under-sample points **3705** occur at positive locations of the analog PM carrier signal **916**. Alternatively, the under-sample points **3705** can occur at other locations include negative points of the analog PM carrier signal **916**. When the under-sample points **3705** occur at negative locations of the analog PM carrier signal **916**, the resultant demodulated baseband signal is inverted relative to the modulating baseband signal **210**.

The drawings referred to herein illustrate direct to data down-conversion in accordance with the invention. For example, the demodulated baseband signal **3710** in FIG. **37**D and the demodulated baseband signal **3712** in FIG. **37**E illustrate that the analog PM carrier signal **916** was successfully down-converted to the demodulated baseband signal **3710** by retaining enough baseband information for sufficient reconstruction.

2.2.2.1.2 Digital PM Carrier Signal

A process for directly down-converting the digital PM carrier signal **1016** to a demodulated baseband signal is now described with reference to the flowchart **1413** in FIG. **14**C. The digital PM carrier signal **1016** is re-illustrated in **38**A for convenience. For this example, the digital PM carrier signal **1016** oscillates at approximately 900 MHZ. In FIG. **38**B, a digital PM carrier signal **3804** illustrates a portion of the digital PM carrier signal **1016** on an expanded time scale.

The process begins at step **1414**, which includes receiving an EM signal. This is represented by the digital PM signal **1016**.

Step **1416** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **38**C illustrates an example under-sampling signal **3806** on approximately the same time scale as FIG. **38**B. The under-sampling signal **3806** includes a train of pulses **3807** having negligible apertures that tend towards zero time in duration. The pulses **3807** repeat at the aliasing rate or pulse repetition rate, which is determined or selected as described above. Generally, when directly down-converting to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the under-sampled signal. In this example, the aliasing rate is approximately 450 MHZ.

Step **1418** includes under-sampling the digital PM carrier signal **1016** at the aliasing rate to directly down-convert it to a demodulated baseband signal. This is illustrated in FIG. **38**B by under-sample points **3705**.

Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **1016**, essentially no IF is produced. The only substantial aliased component is the baseband signal.

In FIG. **38**D, voltage points **3808** correlate to the under-sample points **3805**. In an embodiment, the voltage points **3808** form a demodulated baseband signal **3810**. This can be accomplished in many ways. For example, each voltage point **3808** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **38**E, a demodulated baseband signal **3812** represents the demodulated baseband signal **3810**, after filtering, on a compressed time scale. Although FIG. **38**E illustrates the demodulated baseband signal **3812** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications.

The demodulated baseband signal **3812** is substantially similar to the digital modulating baseband signal **310**. The demodulated baseband signal **3812** can be processed without further down-conversion or demodulation.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and polarity, as desired.

In the example above, the under-sample points **3805** occur at positive locations of the digital PM carrier signal **1016**. Alternatively, the under-sample points **3805** can occur at other locations include negative points of the digital PM carrier signal **1016**. When the under-sample points **3805** occur at negative locations of the digital PM carrier signal **1016**, the resultant demodulated baseband signal is inverted relative to the modulating baseband signal **310**.

The drawings referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the demodulated baseband signal **3810** in FIG. **38**D and the demodulated baseband signal **3812** in FIG. **38**E illustrate that the digital PM carrier signal **1016** was successfully down-converted to the demodulated baseband signal **3810** by retaining enough baseband information for sufficient reconstruction.

2.2.2.2 Structural Description

The operation of the under-sampling system **1602** is now described for the analog PM carrier signal **916**, with reference to the flowchart **1413** and the timing diagrams of FIGS. **37**A–E. In step **1414**, the under-sampling module **1606** receives the analog PM carrier signal **916** (FIG. **37**A). In step **1416**, the under-sampling module **1606** receives the under-sampling signal **3706** (FIG. **37**C). In step **1418**, the under-sampling module **1606** under-samples the analog PM carrier signal **916** at the aliasing rate of the under-sampling signal **3706** to down-convert the PM carrier signal **916** to the demodulated analog baseband signal **3710** in FIG. **37**D or to the filtered demodulated analog baseband signal **3712** in FIG. **37**E.

The operation of the under-sampling system **1602** is now described for the digital PM carrier signal **1016**, with reference to the flowchart **1413** and the timing diagrams of FIGS. **38**A–E. In step **1414**, the under-sampling module **1606** receives the digital PM carrier signal **1016** (FIG. **38**A). In step **1416**, the under-sampling module **1606** receives the under-sampling signal **3806** (FIG. **38**C). In step **1418**, the under-sampling module **1606** under-samples the digital PM carrier signal **1016** at the aliasing rate of the under-sampling signal **3806** to down-convert the digital PM carrier signal **1016** to the demodulated digital baseband signal **3810** in FIG. **38**D or to the filtered demodulated digital baseband signal **3812** in FIG. **38**E.

2.2.3 Other Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

2.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. These implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

3. MODULATION CONVERSION

In an embodiment, the invention down-converts an FM carrier signal FF_{MC} to a non-FM signal $F_{(NON-FM)}$, by under-sampling the FM carrier signal F_{FMC}. This embodiment is illustrated in FIG. **45**B as **4512**.

In an example embodiment, the FM carrier signal F_{FMC} is down-converted to a phase modulated (PM) signal F_{PM}. In another example embodiment, the FM carrier signal F_{FMC} is down-converted to an amplitude modulated (AM) signal F_{AM}. The invention is not limited to these embodiments. The down-onverted signal can be demodulated with any conventional demodulation technique to obtain a demodulated baseband signal F_{DMB}.

The invention can be implemented with any type of FM signal. Exemplary embodiments are provided below for down-converting a frequency shift keying (FSK) signal to a non-FSK signal. FSK is a sub-set of FM, wherein an FM signal shifts or switches between two or more frequencies. FSK is typically used for digital modulating baseband signals, such as the digital modulating baseband signal **310** in FIG. **3**. For example, in FIG. **8**, the digital FM signal **816** is an FSK signal that shifts between an upper frequency and a lower frequency, corresponding to amplitude shifts in the digital modulating baseband signal **310**. The FSK signal **816** is used in example embodiments below.

In a first example embodiment, the FSK signal **816** is under-sampled at an aliasing rate that is based on a mid-point between the upper and lower frequencies of the FSK signal **816**. When the aliasing rate is based on the mid-point, the FSK signal **816** is down-converted to a phase shift keying (PSK) signal. PSK is a sub-set of phase modulation, wherein a PM signal shifts or switches between two or more phases. PSK is typically used for digital modulating baseband signals. For example, in FIG. **10**, the digital PM signal **1016** is a PSK signal that shifts between two phases. The PSK signal **1016** can be demodulated by any conventional PSK demodulation technique(s).

In a second example embodiment, the FSK signal **816** is under-sampled at an aliasing rate that is based upon either the upper frequency or the lower frequency of the FSK signal **816**. When the aliasing rate is based upon the upper frequency or the lower frequency of the FSK signal **816**, the FSK signal **816** is down-converted to an amplitude shift keying (ASK) signal. ASK is a sub-set of amplitude modulation, wherein an AM signal shifts or switches between two or more amplitudes. ASK is typically used for digital modulating baseband signals. For example, in FIG. **6**, the digital AM signal **616** is an ASK signal that shifts between the first amplitude and the second amplitude. The ASK signal **616** can be demodulated by any conventional ASK demodulation technique(s).

The following sections describe methods for under-sampling an FM carrier signal F_{FMC} to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

3.1 High Level Description

This section (including its subsections) provides a high-level description of under-sampling the FM carrier signal F_{FM} to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$, according to the invention. In particular, an operational process for down-converting the FM carrier signal F_{FM} to the non-FM signal $F_{(NON\text{-}FM)}$ is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. The structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

3.1.1 Operational Description

FIG. **14D** depicts a flowchart **1419** that illustrates an exemplary method for down-converting the FM carrier signal F_{FMC} to the non-FM signal $F_{(NON\text{-}FM)}$. The exemplary method illustrated in the flowchart **1419** is an embodiment of the flowchart **1401** in FIG. **14**A.

Any and all forms of frequency modulation techniques are valid for this invention. For ease of discussion, the digital FM carrier (FSK) signal **816** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed flowcharts and descriptions for the FSK signal **816**. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of FM signal.

The method illustrated in the flowchart **1419** is described below at a high level for down-converting the FSK signal **816** in FIG. **8**C to a PSK signal. The FSK signal **816** is re-illustrated in FIG. **39**A for convenience.

The process of the flowchart **1419** begins at step **1420**, which includes receiving an FM signal. This is represented by the FSK signal **816**. The FSK signal **816** shifts between an upper frequency **3910** and a lower-frequency **3912**. In an exemplary embodiment, the upper frequency **3910** is approximately 901 MHZ and the lower frequency **3912** is approximately 899 MHZ.

Step **1422** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **39**B illustrates an example under-sampling signal **3902** which includes a train of pulses **3903** having negligible apertures that tend towards zero time in duration. The pulses **3903** repeat at the aliasing rate or pulse repetition rate.

When down-converting an FM carrier signal F_{FMC} to a non-FM signal $F_{(NON\text{-}FM)}$, the aliasing rate is substantially equal to a frequency contained within the FM signal, or substantially equal to a harmonic or sub-harmonic thereof. In this example overview embodiment, where the FSK signal **816** is to be down-converted to a PSK signal, the aliasing rate is based on a mid-point between the upper frequency **3910** and the lower frequency **3912**. For this example, the mid-point is approximately 900 MHZ. In another embodiment described below, where the FSK signal **816** is to be down-converted to an ASK signal, the aliasing rate is based on either the upper frequency **3910** or the lower frequency **3912**, not the mid-point.

Step **1424** includes under-sampling the FM signal F_{FMC} at the aliasing rate to down-convert the FM carrier signal F_{FMC} to the non-FM signal $F_{(NON\text{-}FM)}$. Step **1424** is illustrated in FIG. **39**C, which illustrates a stair step PSK signal **3904**, which is generated by the modulation conversion process.

When the upper frequency **3910** is under-sampled, the PSK signal **3904** has a frequency of approximately 1 MHZ and is used as a phase reference. When the lower frequency **3912** is under-sampled, the PSK signal **3904** has a frequency of 1 MHZ and is phase shifted 180 degrees from the phase reference.

FIG. **39**D depicts a PSK signal **3906**, which is a filtered version of the PSK signal **3904**. The invention can thus generate a filtered output signal, a partially filtered output signal, or a relatively unfiltered stair step output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

Detailed exemplary embodiments for down-converting an FSK signal to a PSK signal and for down-converting an FSK signal to an ASK signal are provided below.

3.1.2 Structural Description

FIG. **16** illustrates the block diagram of the under-sampling system **1602** according to an embodiment of the invention. The under-sampling system **1602** includes the under-sampling module **1606**. The under-sampling system **1602** is an example embodiment of the generic aliasing system **1302** in FIG. **13**.

In a modulation conversion embodiment, the EM signal **1304** is an FM carrier signal and the under-sampling module **1606** under-samples the FM carrier signal at a frequency that is substantially equal to a harmonic of a frequency within the FM signal or, more typically, substantially equal to a sub-harmonic of a frequency within the FM signal. Preferably, the under-sampling module **1606** under-samples the FM carrier signal F_{FMC} to down-convert it to a non-FM signal $F_{(NON\text{-}FM)}$ in the manner shown in the operational flowchart **1419**. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **1419**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the under-sampling system **1602** shall now be described with reference to the flowchart **1419** and the timing diagrams of FIGS. **39**A–**39**D. In step **1420**, the under-sampling module **1606** receives the FSK signal **816**. In step **1422**, the under-sampling module **1606** receives the under-sampling signal **3902**. In step **1424**, the under-sampling module **1606** under-samples the FSK signal **816** at the aliasing rate of the under-sampling signal **3902** to down-convert the FSK signal **816** to the PSK signal **3904** or **3906**.

Example implementations of the under-sampling module **1606** are provided in Section 4 below.

3.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting an FM carrier signal F_{FMC} to a non-FM signal, $F_{(NON\text{-}FM)}$, illustrated in the flowchart **1419** of FIG. **14**D, can be implemented with any type of FM carrier signal including, but not limited to, FSK signals. The flowchart **1419** is described in detail below for down-converting an FSK signal to a PSK signal and for down-converting an PSK signal to an FSK signal. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

3.2.1 First Example Embodiment: Down-Converting an FM Signal to a PM Signal

3.2.1.1 Operational Description

Operation of the exemplary process of the flowchart **1419** in FIG. **14**D is now described for down-converting the FSK signal **816** illustrated in FIG. **8**C to a PSK signal. The FSK signal **816** is re-illustrated in FIG. **40**A for convenience.

The FSK signal **816** shifts between a first frequency **4006** and a second frequency **4008**. In the exemplary embodiment, the first frequency **4006** is lower than the second frequency **4008**. In an alternative embodiment, the first frequency **4006** is higher than the second frequency **4008**. For this example, the first frequency **4006** is approximately 899 MHZ and the second frequency **4008** is approximately 901 MHZ.

FIG. **40**B illustrates an FSK signal portion **4004** that represents a portion of the FSK signal **816** on an expanded time scale.

The process of down-converting the FSK signal **816** to a PSK signal begins at step **1420**, which includes receiving an FM signal. This is represented by the FSK signal **816**.

Step **1422** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **40**C illustrates an example under-sampling signal **4007** on approximately the same time scale as FIG. **40**B. The under-sampling signal **4007** includes a train of pulses **4009** having negligible apertures that tend towards zero time in duration. The pulses **4009** repeat at the aliasing rate, which is determined or selected as described above. Generally, when down-converting an FM signal to a non-FM signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of a frequency contained within the FM signal.

In this example, where an FSK signal is being down-converted to a PSK signal, the aliasing rate is substantially equal to a harmonic of the mid-point between the frequencies **4006** and **4008** or, more typically, substantially equal to a sub-harmonic of the mid-point between the frequencies **4006** and **4008**. In this example, where the first frequency **4006** is 899 MHZ and second frequency **4008** is 901 MHZ, the mid-point is approximately 900 MHZ Suitable aliasing rates include 1.8 GHZ, 900 MHZ, 450 MHZ, etc. In this example, the aliasing rate of the under-sampling signal **4008** is approximately 450 MHZ.

Step **1424** includes under-sampling the FM signal at the aliasing rate to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$. Step **1424** is illustrated in FIG. **40**B by under-sample points **4005**. The under-sample points **4005** occur at the aliasing rate of the pulses **4009**.

In FIG. **40**D, voltage points **4010** correlate to the under-sample points **4005**. In an embodiment, the voltage points **4010** form a PSK signal **4012**. This can be accomplished in many ways. For example, each voltage point **4010** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

When the first frequency **4006** is under-sampled, the PSK signal **4012** has a frequency of approximately 1 MHZ and is used as a phase reference. When the second frequency **4008** is under-sampled, the PSK signal **4012** has a frequency of 1 MHZ and is phase shifted 180 degrees from the phase reference.

In FIG. **40**E, a PSK signal **4014** illustrates the PSK signal **4012**, after filtering, on a compressed time scale. Although FIG. **40**E illustrates the PSK signal **4012** as a filtered output signal **4014**, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications. The PSK signal **4014** can be demodulated through any conventional phase demodulation technique.

The aliasing rate of the under-sampling signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

In the example above, the under-sample points **4005** occur at positive locations of the FSK signal **816**. Alternatively, the under-sample points **4005** can occur at other locations including negative points of the FSK signal **816**. When the under-sample points **4005** occur at negative locations of the FSK signal **816**, the resultant PSK signal is inverted relative to the PSK signal **4014**.

The drawings referred to herein illustrate modulation conversion in accordance with the invention. For example, the PSK signal **4014** in FIG. **40**E illustrates that the FSK signal **816** was successfully down-converted to the PSK signal **4012** and **4014** by retaining enough baseband information for sufficient reconstruction.

3.2.1.2 Structural Description

The operation of the under-sampling system **1602** is now described for down-converting the FSK signal **816** to a PSK signal, with reference to the flowchart **1419** and to the timing diagrams of FIGS. **40**A–E. In step **1420**, the under-sampling module **1606** receives the FSK signal **816** (FIG. **40**A). In step **1422**, the under-sampling module **1606** receives the under-sampling signal **4007** (FIG. **40**C). In step **1424**, the under-sampling module **1606** under-samples the FSK signal

816 at the aliasing rate of the under-sampling signal **4007** to down-convert the FSK signal **816** to the PSK signal **4012** in FIG. **40**D or the PSK signal **4014** in FIG. **40**E.

3.2.2 Second Example Embodiment: Down-Converting an FM Signal to an AM Signal

3.2.2.1 Operational Description

Operation of the exemplary process of FIG. **14**D is now described for down-converting the FSK signal **816**, illustrated in FIG. **8**C, to an ASK signal. The FSK signal **816** is re-illustrated in FIG. **41**A for convenience.

The FSK signal **816** shifts between a first frequency **4106** and a second frequency **4108**. In the exemplary embodiment, the first frequency **4106** is lower than the second frequency **4108**. In an alternative embodiment, the first frequency **4106** is higher than the second frequency **4108**. For this example, the first frequency **4106** is approximately 899 MHZ and the second frequency **4108** is approximately 901 MHZ.

FIG. **41**B illustrates an FSK signal portion **4104** that represents a portion of the FSK signal **816** on an expanded time scale.

The process of down-converting the FSK signal **816** to an ASK signal begins at step **1420**, which includes receiving an FM signal. This is represented by the FSK signal **816**.

Step **1422** includes receiving an under-sampling signal having an aliasing rate F_{AR}. FIG. **41**C illustrates an example under-sampling signal **4107** illustrated on approximately the same time scale as FIG. **42**B. The under-sampling signal **4107** includes a train of pulses **4109** having negligible apertures that tend towards zero time in duration. The pulses **4109** repeat at the aliasing rate, or pulse repetition rate. The aliasing rate is determined or selected as described above.

Generally, when down-converting an FM signal to a non-FM signal, the aliasing rate is substantially equal to a harmonic of a frequency within the FM signal or, more typically, to a sub-harmonic of a frequency within the FM signal. When an FSK signal **816** is being down-converted to an ASK signal, the aliasing rate is substantially equal to a harmonic of the first frequency **4106** or the second frequency **4108** or, more typically, substantially equal to a sub-harmonic of the first frequency **4106** or the second frequency **4108**. In this example, where the first frequency **4106** is 899 MHZ and the second frequency **4108** is 901 MHZ, the aliasing rate can be substantially equal to a harmonic or sub-harmonic of 899 MHZ or 901 MHZ. In this example the aliasing rate is approximately 449.5 MHZ, which is a sub-harmonic of the first frequency **4106**.

Step **1424** includes under-sampling the FM signal at the aliasing rate to down-convert it to a non-FM signal $F_{(NON\text{-}FM)}$. Step **1424** is illustrated in FIG. **41**B by under-sample points **4105**. The under-sample points **4105** occur at the aliasing rate of the pulses **4109**. When the first frequency **4106** is under-sampled, the aliasing pulses **4109** and the under-sample points **4105** occur at the same location of subsequent cycles of the FSK signal **816**. This generates a relatively constant output level. But when the second frequency **4108** is under-sampled, the aliasing pulses **4109** and the under-sample points **4005** occur at different locations of subsequent cycles of the FSK signal **816**. This generates an oscillating pattern at approximately (901 MHZ−899 MHZ)=2 MHZ.

In FIG. **41**D, voltage points **4110** correlate to the under-sample points **4105**. In an embodiment, the voltage points **4110** form an ASK signal **4112**. This can be accomplished in many ways. For example, each voltage point **41110** can be held at a relatively constant level until the next voltage point is received. This results in a stair-step output which can be smoothed or filtered if desired, as described below.

In FIG. **41**E, an ASK signal **4114** illustrates the ASK signal **4112**, after filtering, on a compressed time scale. Although FIG. **41**E illustrates the ASK signal **4114** as a filtered output signal, the output signal does not need to be filtered or smoothed to be within the scope of the invention. Instead, the output signal can be tailored for different applications. The ASK signal **4114** can be demodulated through any conventional amplitude demodulation technique When down-converting from FM to AM, the aliasing rate of the under-sampling signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and/or polarity, as desired.

In an alternative embodiment, the aliasing rate is based on the second frequency and the resultant ASK signal is reversed relative to the ASK signal **4114**.

The drawings referred to herein illustrate modulation conversion in accordance with the invention. For example, the ASK signal **4114** in FIG. **41**E illustrates that the FSK carrier signal **816** was successfully down-converted to the ASK signal **4114** by retaining enough baseband information for sufficient reconstruction.

3.2.2.2 Structural Description

The operation of the under-sampling system **1602** is now described for down-converting the FSK signal **816** to an ASK signal, with reference to the flowchart **1419** and to the timing diagrams of FIGS. **41**A–E. In step **1420**, the under-sampling module **1606** receives the FSK signal **816** (FIG. **41**A). In step **1422**, the under-sampling module **1606** receives the under-sampling signal **4107** (FIG. **41**C). In step **1424**, the under-sampling module **1606** under-samples the FSK signal **816** at the aliasing of the under-sampling signal **4107** to down-convert the FSK signal **816** to the ASK signal **4112** of FIG. **41**D or the ASK signal **4114** in FIG. **41**E.

3.2.3 Other Example Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

3.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. These implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

4. IMPLEMENTATION EXAMPLES

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described in the Sub-Sections above are presented in this section (and its subsections). These implementations are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described herein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

FIG. **13** illustrates a generic aliasing system **1302**, including an aliasing module **1306**. FIG. **16** illustrates an under-sampling system **1602**, which includes an under-sampling module **1606**. The under-sampling module **1606** receives an under-sampling signal **1604** having an aliasing rate F_{AR}.

The under-sampling signal **1604** includes a train of pulses having negligible apertures that tend towards zero time in duration. The pulses repeat at the aliasing rate F_{AR}. The under-sampling system **1602** is an example implementation of the generic aliasing system **1303**. The under-sampling system **1602** outputs a down-converted signal **1308**A.

FIG. **26**A illustrates an exemplary sample and hold system **2602**, which is an exemplary implementation of the under-sampling system **1602**. The sample and hold system **2602** is described below.

FIG. **26**B illustrates an exemplary inverted sample and hold system **2606**, which is an alternative example implementation of the under-sampling system **1602**. The inverted sample and hold system **2606** is described below.

4.1 The Under-Sampling System as a Sample and Hold System

FIG. **26**A is a block diagram of a the sample and hold system **2602**, which is an example embodiment of the under-sampling module **1606** in FIG. **16**, which is an example embodiment of the generic aliasing module **1306** in FIG. **13**.

The sample and hold system **2602** includes a sample and hold module **2604**, which receives the EM signal **1304** and the under-sampling signal **1604**. The sample and hold module **2604** under-samples the EM signal at the aliasing rate of the under-samnpling signal **1604**, as described in the sections above with respect to the flowcharts **1401** in FIG. **14**A, **1407** in FIG. **14**B, **1413** in FIG. **14**C and **1419** in FIG. **14**D. The under-sampling system **1602** outputs a down-converted signal **1308**A.

FIG. **27** illustrates an under-sampling system **2701** as a sample and hold system, which is an example implementation of the under-sampling system **2602**. The under-sampling system **2701** includes a switch module **2702** and a holding module **2706**. The under-sampling system **2701** is described below.

FIG. **24**A illustrates an under-sampling system **2401** as a break before make under-sampling system, which is an alternative implementation of the under-sampling system **2602**. The break before make under-sampling system **2401** is described below.

4.1.1 The Sample and Hold System as a Switch Module and a Holding Module

FIG. **27** illustrates an exemplary embodiment of the sample and hold module **2604** from FIG. **26**A. In the exemplary embodiment, the sample and hold module **2604** includes a switch module **2702**, and a holding module **2706**.

Preferably, the switch module **2702** and the holding module **2706** under-sample the EM signal **1304** to down-convert it in any of the manners shown in the operation flowcharts **1401**, **1407**, **1413** and **1419**. For example, the sample and hold module **2604** can receive and under-sample any of the modulated carrier signal signals described above, including, but not limited to, the analog AM signal **516**, the digital AM signal **616**, the analog FM signal **716**, the digital FM signal **816**, the analog PM signal **916**, the digital PM signal **1016**, etc., and any combinations thereof.

The switch module **2702** and the holding module **2706** down-convert the EM signal **1304** to an intermediate signal, to a demodulated baseband or to a different modulation scheme, depending upon the aliasing rate.

For example, operation of the switch module **2702** and the holding module **2706** are now described for down-converting the EM signal **1304** to an intermediate signal, with reference to the flowchart **1407** and the example timing diagrams in FIGS. **79**A–F.

In step **1408**, the switch module **2702** receives the EM signal **1304** (FIG. **79**A). In step **1410**, the switch module **2702** receives the under-sampling signal **1604** (FIG. **79**C). In step **1412**, the switch module **2702** and the holding module **2706** cooperate to under-sample the EM signal **1304** and down-convert it to an intermediate signal. More specifically, during step **1412**, the switch module **2702** closes during each under-sampling pulse to couple the EM signal **1304** to the holding module **2706**. In an embodiment, the switch module **2702** closes on rising edges of the pulses. In an alternative embodiment, the switch module **2702** closes on falling edges of the pulses. When the EM signal **1304** is coupled to the holding module **2706**, the amplitude of the EM signal **1304** is captured by the holding module **2706**. The holding module **2706** is designed to capture and hold the amplitude of the EM signal **1304** within the short time frame of each negligible aperture pulse. FIG. **79**B illustrates the EM signal **1304** after under-sampling.

The holding module **2706** substantially holds or maintains each under-sampled amplitude until a subsequent under-sample. (FIG. **79**D). The holding module **2706** outputs the under-sampled amplitudes as the down-converted signal **1308**A. The holding module **2706** can output the down-converted signal **1308**A as an unfiltered signal, such as a stair step signal (FIG. **79**E), as a filtered down-converted signal (FIG. **79**F) or as a partially filtered down-converted signal.

4.1.2 The Sample and Hold System as Break-Before-Make Module

FIG. **24**A illustrates a break-before-make under-sampling system **2401**, which is an alternative implementation of the under-sampling system **2602**.

Preferably, the break-before-make under-sampling system **2401** under-samples the EM signal **1304** to down-convert it in any of the manners shown in the operation flowcharts **1401**, **1407**, **1413** and **1419**. For example, the sample and hold module **2604** can receive and under-sample any of the unmodulated or modulated carrier signal signals described above, including, but not limited to, the analog AM signal **516**, the digital AM signal **616**, the analog FM signal **716**, the digital FM signal **816**, the analog PM signal **916**, the digital PM signal **1016**, etc., and combinations thereof.

The break-before-make under-sampling system **2401** down-converts the EM signal **1304** to an intermediate signal, to a demodulated baseband or to a different modulation scheme, depending upon the aliasing rate.

FIG. **24**A includes a break-before-make switch **2402**. The break-before-make switch **2402** includes a normally open switch **2404** and a normally closed switch **2406**. The normally open switch **2404** is controlled by the under-sampling signal **1604**, as previously described. The normally closed switch **2406** is controlled by an isolation signal **2412**. In an embodiment, the isolation signal **2412** is generated from the under-sampling signal **1604**. Alternatively, the under-sampling signal **1604** is generated from the isolation signal **2412**. Alternatively, the isolation signal **2412** is generated independently from the under-sampling signal **1604**. The break-before-make module **2402** substantially isolates a sample and hold input **2408** from a sample and hold output **2410**.

FIG. **24**B illustrates an example timing diagram of the under-sampling signal **1604** that controls the normally open switch **2404**. FIG. **24**C illustrates an example timing diagram of the isolation signal **2412** that controls the normally closed switch **2406**. Operation of the break-before-make module **2402** is described with reference to the example timing diagrams in FIGS. **24**B and **24**C.

Prior to time t0, the normally open switch **2404** and the normally closed switch **2406** are at their normal states.

At time t0, the isolation signal **2412** in FIG. **24**C opens the normally closed switch **2406**.

Then, just after time t0, the normally open switch **2404** and the normally closed switch **2406** are open and the input **2408** is isolated from the output **2410**.

At time t1, the under-sampling signal **1604** in FIG. **24**B briefly closes the normally open switch **2404**. This couples the EM signal **1304** to the holding module **2416**.

Prior to t2, the under-sampling signal **1604** in FIG. **24**B opens the normally open switch **2404**. This de-couples the EM signal **1304** from the holding module **2416**.

At time t2, the isolation signal **2412** in FIG. **24**C closes the normally closed switch **2406**. This couples the holding module **2416** to the output **2410**.

The break-before-make under-sampling system **2401** includes a holding module **2416**, which can be similar to the holding module **2706** in FIG. **27**. The break-before-make under-sampling system **2401** down-converts the EM signal **1304** in a manner similar to that described with reference to the under-sampling system **2702** in FIG. **27**.

4.1.3 Example Implementations of the Switch Module

The switch module **2702** in FIG. **27** and the switch modules **2404** and **2406** in FIG. **24**A can be any type of switch device that preferably has a relatively low impedance when closed and a relatively high impedance when open. The switch modules **2702**, **2404** and **2406** can be implemented with normally open or normally closed switches. The switch device need not be an ideal switch device. FIG. **28**B illustrates the switch modules **2702**,**2404** and **2406** as, for example, a switch module **2810**.

The switch device **2810** (e.g., switch modules **2702**, **2404** and **2406**) can be implemented with any type of suitable switch device, including, but not limited to mechanical switch devices and electrical switch devices, optical switch devices, etc., and combinations thereof. Such devices include, but are not limited to transistor switch devices, diode switch devices, relay switch devices, optical switch devices, micro-machine switch devices, etc.

In an embodiment, the switch module **2810** can be implemented as a transistor, such as, for example, a field effect transistor (FET), a bi-polar transistor, or any other suitable circuit switching device.

In FIG. **28**A, the switch module **2810** is illustrated as a FET **2802**. The FET **2802** can be any type of FET, including, but not limited to, a MOSFET, a JFET, a GaAsFET, etc. The FET **2802** includes a gate **2804**, a source **2806** and a drain **2808**. The gate **2804** receives the under-sampling signal **1604** to control the switching action between the source **2806** and the drain **2808**. Generally, the source **2806** and the drain **2808** are interchangeable.

It should be understood that the illustration of the switch module **2810** as a FET **2802** in FIG. **28**A is for example purposes only. Any device having switching capabilities could be used to implement the switch module **2810** (e.g., switch modules **2702**, **2404** and **2406**), as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

In FIG. **28**C, the switch module **2810** is illustrated as a diode switch **2812**, which operates as a two lead device when the under-sampling signal **1604** is coupled to the output **2813**.

In FIG. **28**D, the switch module **2810** is illustrated as a diode switch **2814**, which operates as a two lead device when the under-sampling signal **1604** is coupled to the output **2815**.

4.1.4 Example Implementations of the Holding Module

The holding modules **2706** and **2416** preferably captures and holds the amplitude of the original, unaffected, EM signal **1304** within the short time frame of each negligible aperture under-sampling signal pulse.

In an exemplary embodiment, holding modules **2706** and **2416** are implemented as a reactive holding module **2901** in FIG. **29**A, although the invention is not limited to this embodiment. A reactive holding module is a holding module that employs one or more reactive electrical components to preferably quickly charge to the amplitude of the EM signal **1304**. Reactive electrical components include, but are not limited to, capacitors and inductors.

In an embodiment, the holding modules **2706** and **2416** include one or more capacitive holding elements, illustrated in FIG. **29**B as a capacitive holding module **2902**. In FIG. **29**C, the capacitive holding module **2902** is illustrated as one or more capacitors illustrated generally as capacitor(s) **2904**. Recall that the preferred goal of the holding modules **2706** and **2416** is to quickly charge to the amplitude of the EM signal **1304**. In accordance with principles of capacitors, as the negligible aperture of the under-sampling pulses tends to zero time in duration, the capacitive value of the capacitor **2904** can tend towards zero Farads. Example values for the capacitor **2904** can range from tens of pico Farads to fractions of pico Farads. A terminal **2906** serves as an output of the sample and hold module **2604**. The capacitive holding module **2902** provides the under-samples at the terminal **2906**, where they can be measured as a voltage. FIG. **29**F illustrates the capacitive holding module **2902** as including a series capacitor **2912**, which can be utilized in an inverted sample and hold system as described below.

In an alternative embodiment, the holding modules **2706** and **2416** include one or more inductive holding elements, illustrated in FIG. **29**D as an inductive holding module **2908**.

In an alternative embodiment, the holding modules **2706** and **2416** include a combination of one or more capacitive holding elements and one or more inductive holding elements, illustrated in FIG. **29**E as a capacitive/inductive holding module **2910**.

FIG. **29**G illustrates an integrated under-sampling system that can be implemented to down-convert the EM signal **1304** as illustrated in, and described with reference to, FIGS. **79**A–F.

4.1.5 Optional Under-Sampling Signal Module

FIG. **30** illustrates an under-sampling system **3001**, which is an example embodiment of the under-sampling system **1602**. The under-sampling system **3001** includes an optional under-sampling signal module **3002** that can perform any of a variety of functions or combinations of functions, including, but not limited to, generating the under-sampling signal **1604**.

In an embodiment, the optional under-sampling signal module **3002** includes an aperture generator, an example of which is illustrated in FIG. **29**J as an aperture generator **2920**. The aperture generator **2920** generates negligible aperture pulses **2926** from an input signal **2924**. The input signal **2924** can be any type of periodic signal, including, but not limited to, a sinusoid, a square wave, a saw-tooth wave, etc. Systems for generating the input signal **2924** are described below.

The width or aperture of the pulses **2926** is determined by delay through the branch **2922** of the aperture generator **2920**. Generally, as the desired pulse width decreases, the tolerance requirements of the aperture generator **2920** increase. In other words, to generate negligible aperture pulses for a given input EM frequency, the components utilized in the example aperture generator **2920** require greater reaction times, which are typically obtained with more expensive elements, such as gallium arsenide (GaAs), etc.

The example logic and implementation shown in the aperture generator **2920** are provided for illustrative purposes only, and are not limiting. The actual logic employed can take many forms. The example aperture generator **2920** includes an optional inverter **2928**, which is shown for polarity consistency with other examples provided herein. An example implementation of the aperture generator **2920** is illustrated in FIG. **29**K.

Additional examples of aperture generation logic is provided in FIGS. **29**H and **29**I. FIG. **29**H illustrates a rising edge pulse generator **2940**, which generates pulses **2926** on rising edges of the input signal **2924**. FIG. **29**I illustrates a falling edge pulse generator **2950**, which generates pulses **2926** on falling edges of the input signal **2924**.

In an embodiment, the input signal **2924** is generated externally of the under-sampling signal module **3002**, as illustrated in FIG. **30**. Alternatively, the input signal **2924** is generated internally by the under-sampling signal module **3002**. The input signal **2924** can be generated by an oscillator, as illustrated in FIG. **29**L by an oscillator **2930**. The oscillator **2930** can be internal to the under-sampling signal module **3002** or external to the under-sampling signal module **3002**. The oscillator **2930** can be external to the under-sampling system **3001**.

The type of down-conversion performed by the under-sampling system **3001** depends upon the aliasing rate of the under-sampling signal **1604**, which is determined by the frequency of the pulses **2926**. The frequency of the pulses **2926** is determined by the frequency of the input signal **2924**. For example, when the frequency of the input signal **2924** is substantially equal to a harmonic or a sub-harmonic of the EM signal **1304**, the EM signal **1304** is directly down-converted to baseband (e.g. when the EM signal is an AM signal or a PM signal), or converted from FM to a non-FM signal. When the frequency of the input signal **2924** is substantially equal to a harmonic or a sub-harmonic of a difference frequency, the EM signal **1304** is down-converted to an intermediate signal.

The optional under-sampling signal module **3002** can be implemented in hardware, software, firmware, or any combination thereof.

4.2 The Under-Sampling System as an Inverted Sample and Hold

FIG. **26**B illustrates an exemplary inverted sample and hold system **2606**, which is an alternative example implementation of the under-sampling system **1602**.

FIG. **42** illustrates a inverted sample and hold system **4201**, which is an example implementation of the inverted sample and hold system **2606** in FIG. **26**B. The sample and hold system **4201** includes a sample and hold module **4202**, which includes a switch module **4204** and a holding module **4206**. The switch module **4204** can be implemented as described above with reference to FIGS. **28**A–D.

The holding module **4206** can be implemented as described above with reference to FIGS. **29**A–F, for the holding modules **2706** and **2416**. In the illustrated embodiment, the holding module **4206** includes one or more capacitors **4208**. The capacitor(s) **4208** are selected to pass higher frequency components of the EM signal **1304** through to a terminal **4210**, regardless of the state of the switch module **4204**. The capacitor **4208** stores charge from the EM signal **1304** during aliasing pulses of the under-sampling signal **1604** and the signal at the terminal **4210** is thereafter off-set by an amount related to the charge stored in the capacitor **4208**.

Operation of the inverted sample and hold system **4201** is illustrated in FIGS. **34**A–F. FIG. **34**A illustrates an example EM signal **1304**. FIG. **34**B illustrates the EM signal **1304** after under-sampling. FIG. **34**C illustrates the under-sampling signal **1606**, which includes a train of aliasing pulses having negligible apertures.

FIG. **34**D illustrates an example down-onverted signal **1308**A. FIG. **34**E illustrates the down-converted signal **1308**A on a compressed time scale. Since the holding module **4206** is series element, the higher frequencies (e.g., RF) of the EM signal **1304** can be seen on the down-converted signal. This can be filtered as illustrated in FIG. **34**F.

The inverted sample and hold system **4201** can be used to down-convert any type of EM signal, including modulated carrier signals and unmodulated carrier signals, to IF signals and to demodulated baseband signals.

4.3 Other Implementations

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

5. OPTIONAL OPTIMIZATIONS OF UNDER-SAMPLING AT AN ALIASING RATE

The methods and systems described in sections above can be optionally optimized with one or more of the optimization methods or systems described below.

5.1 Doubling the Aliasing Rate (F_{AR}) of the Under-Sampling Signal

In an embodiment, the optional under-sampling signal module **3002** in FIG. **30** includes a pulse generator module that generates aliasing pulses at a multiple of the frequency of the oscillating source, such as twice the frequency of the oscillating source. The input signal **2926** may be any suitable oscillating source.

FIG. **31** illustrates an example circuit **3102** that generates a doubler output signal **3104** (FIGS. **31** and **43**B) that may be used as an under-sampling signal **1604**. The example circuit **3102** generates pulses on rising and falling edges of the input oscillating signal **3106** of FIG. **31**B. Input oscillating signal **3106** is one embodiment of optional input signal **2926**. The circuit **3102** can be implemented as a pulse generator and aliasing rate (F_{AR}) doubler, providing the under-sampling signal **1604** to under-sampling module **1606** in FIG. **30**.

The aliasing rate is twice the frequency of the input oscillating signal F_{OSC} **3106**, as shown by EQ. (9) below.

$$F_{AR}=2\bullet F_{OSC} \quad \text{EQ. (9)}$$

The aperture width of the aliasing pulses is determined by the delay through a first inverter **3108** of FIG. **31**. As the delay is increased, the aperture is increased. A second inverter **3112** is shown to maintain polarity consistency with examples described elsewhere. In an alternate embodiment inverter **3112** is omitted. Preferably, the pulses have negligible aperture widths that tend toward zero time. The doubler output signal **3104** may be further conditioned as appropriate to drive a switch module with negligible aperture pulses. The circuit **3102** may be implemented with integrated circuitry, discretely, with equivalent logic circuitry, or with any valid fabrication technology.

5.2 Differential Implementations

The invention can be implemented in a variety of differential configurations. Differential configurations are useful for reducing common mode noise. This can be very useful in receiver systems where common mode interference can be caused by intentional or unintentional radiators such as cellular phones, CB radios, electrical appliances etc. Differential configurations are also useful in reducing any common mode noise due to charge injection of the switch in the switch module or due to the design and layout of the system in which the invention is used. Any spurious signal that is induced in equal magnitude and equal phase in both input leads of the invention will be substantially reduced or eliminated. Some differential configurations, including some of the configurations below, are also useful for increasing the voltage and/or for increasing the power of the down-converted signal **1308**A. While an example of a differential under-sampling module is shown below, the example is shown for the purpose of illustration, not limitation. Alternate embodiments (including equivalents, extensions, variations, deviations, etc.) of the embodiment described herein will be apparent to those skilled in the relevant art based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

FIG. **44**A illustrates an example differential system **4402** that can be included in the under-sampling module **1606**. The differential system **4202** includes an inverted under-sampling design similar to that described with reference to FIG. **42**. The differential system **4402** includes inputs **4404** and **4406** and outputs **4408** and **4410**. The differential system **4402** includes a first inverted sample and hold module **4412**, which includes a holding module **4414** and a switch module **4416**. The differential system **4402** also includes a second inverted sample and hold module **4418**, which includes a holding module **4420** and the switch module **4416**, which it shares in common with sample and hold module **4412**.

One or both of the inputs **4404** and **4406** are coupled to an EM signal source. For example, the inputs can be coupled to an EM signal source, wherein the input voltages at the inputs **4404** and **4406** are substantially equal in amplitude but 180 degrees out of phase with one another. Alternatively, where dual inputs are unavailable, one of the inputs **4404** and **4406** can be coupled to ground.

In operation, when the switch module **4416** is closed, the holding modules **4414** and **4420** are in series and, provided they have similar capacitive values, they charge to equal amplitudes but opposite polarities. When the switch module **4416** is open, the voltage at the output **4408** is relative to the input **4404**, and the voltage at the output **4410** is relative to the voltage at the input **4406**.

Portions of the voltages at the outputs **4408** and **4410** include voltage resulting from charge stored in the holding modules **4414** and **4420**, respectively, when the switch module **4416** was closed. The portions of the voltages at the outputs **4408** and **4410** resulting from the stored charge are generally equal in amplitude to one another but 180 degrees out of phase.

Portions of the voltages at the outputs **4408** and **4410** also include ripple voltage or noise resulting from the switching action of the switch module **4416**. But because the switch module is positioned between the two outputs, the noise introduced by the switch module appears at the outputs **4408** and **4410** as substantially equal and in-phase with one another. As a result, the ripple voltage can be substantially filtered out by inverting the voltage at one of the outputs **4408** or **4410** and adding it to the other remaining output. Additionally, any noise that is impressed with substantially equal amplitude and equal phase onto the input terminals **4404** and **4406** by any other noise sources will tend to be canceled in the same way.

The differential system **4402** is effective when used with a differential front end (inputs) and a differential back end (outputs). It can also be utilized in the following configurations, for example:

a) A single-input front end and a differential back end; and

b) A differential front end and single-output back end.

Examples of these system are provided below.

5.2.1 Differential Input-to-Differential Output

FIG. **44**B illustrates the differential system **4402** wherein the inputs **4404** and **4406** are coupled to equal and opposite EM signal sources, illustrated here as dipole antennas **4424** and **4426**. In this embodiment, when one of the outputs **4408** or **4410** is inverted and added to the other output, the common mode noise due to the switching module **4416** and other common mode noise present at the input terminals **4404** and **4406** tend to substantially cancel out.

5.2.2 Single Input-to-Differential Output

FIG. **44**C illustrates the differential system **4402** wherein the input **4404** is coupled to an EM signal source such as a monopole antenna **4428** and the input **4406** is coupled to ground.

FIG. **44**E illustrates an example single input to differential output receiver/down-converter system **4436**. The system **4436** includes the differential system **4402** wherein the input **4406** is coupled to ground. The input **4404** is coupled to an EM signal source **4438**.

The outputs **4408** and **4410** are coupled to a differential circuit **4444** such as a filter, which preferably inverts one of the outputs **4408** or **4410** and adds it to the other output **4408** or **4410**. This substantially cancels common mode noise generated by the switch module **4416**. The differential In circuit **4444** preferably filters the higher frequency components of the EM signal **1304** that pass through the holding modules **4414** and **4420**. The resultant filtered signal is output as the down-converted signal **1308**A.

5.2.3 Differential Input-to-Single Output

FIG. **44**D illustrates the differential system **4402** wherein the inputs **4404** and **4406** are coupled to equal and opposite EM signal sources illustrated here as dipole antennas **4430** and **4432**. The output is taken from terminal **4408**.

5.3 Smoothing the Down-Converted Signal

The down-converted signal **1308**A may be smoothed by filtering as desired. The differential circuit **4444** implemented as a filter in FIG. **44**E illustrates but one example. Filtering may be accomplished in any of the described embodiments by hardware, firmware and software implementation as is well known by those skilled in the arts.

5.4 Load Impedance and Input/Output Buffering

Some of the characteristics of the down-converted signal **1308**A depend upon characteristics of a load placed on the down-converted signal **1308**A. For example, in an embodiment, when the down-converted signal **1308**A is coupled to a high impedance load, the charge that is applied to a holding module such as holding module **2706** in FIG. **27** or **2416** in FIG. **24**A during a pulse generally remains held by the holding module until the next pulse. This results in a substantially stair-step-like representation of the down-converted signal **1308**A as illustrated in FIG. **15**C, for example. A high impedance load enables the under-sampling system **1606** to accurately represent the voltage of the original unaffected input signal.

The down-converted signal **1308**A can be buffered with a high impedance amplifier, if desired.

Alternatively, or in addition to buffering the down-converted signal **1308**A, the input EM signal may be buffered or amplified by a low noise amplifier.

5.5 Modifying the Under-Sampling Signal Utilizing Feedback

FIG. **30** shows an embodiment of a system **3001** which uses down-converted signal **1308**A as feedback **3006** to control various characteristics of the under-sampling module **1606** to modify the down-converted signal **1308**A.

Generally, the amplitude of the down-converted signal **1308**A varies as a function of the frequency and phase differences between the EM signal **1304** and the under-sampling signal **1604**. In an embodiment, the down-converted signal **1308**A is used as the feedback **3006** to control the frequency and phase relationship between the EM signal **1304** and the under-sampling signal **1604**. This can be accomplished using the example block diagram shown in FIG. **32**A. The example circuit illustrated in FIG. **32**A can be included in the under-sampling signal module **3002**. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention. In this embodiment a state-machine is used for clarity, and is not limiting.

In the example of FIG. **32**A, a state machine **3204** reads an analog to digital converter, A/D **3202**, and controls a digital to analog converter (DAC) **3206**. In an embodiment, the state machine **3204** includes 2 memory locations, Previous and Current, to store and recall the results of reading A/D **3202**. In an embodiment, the state machine **3204** utilizes at least one memory flag.

DAC **3206** controls an input to a voltage controlled oscillator, VCO **3208**. VCO **3208** controls a frequency input of a pulse generator **3210**, which, in an embodiment, is substantially similar to the pulse generator shown in FIG. **29**J. The pulse generator **3210** generates the under-sampling signal **1604**.

In an embodiment, the state machine **3204** operates in accordance with the state machine flowchart **3220** in FIG. **32**B. The result of this operation is to modify the frequency and phase relationship between the under-sampling signal **1604** and the EM signal **1304**, to substantially maintain the amplitude of the down-converted signal **1308**A at an optimum level.

The amplitude of the down-converted signal **1308**A can be made to vary with the amplitude of the under-sampling signal **1604**. In an embodiment where Switch Module **2702** is a FET as shown in FIG. **28**A, wherein the gate **2804** receives the under-sampling signal **1604**, the amplitude of the under-sampling signal **1604** can determine the "on" resistance of the FET, which affects the amplitude of down-converted signal **1308**A. Under-sampling signal module **3002**, as shown in FIG. **32**C, can be an analog circuit that enables an automatic gain control function. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention.

III. Down-Converting by Transferring Energy

The energy transfer embodiments of the invention provide enhanced signal to noise ratios and sensitivity to very small signals, as well as permitting the down-converted signal to drive lower impedance loads unassisted. The energy transfer aspects of the invention are represented generally by **4506** in FIGS. **45**A and **45**B. Fundamental descriptions of how this is accomplished is presented step by step beginning with a comparison with an under-sampling system.

0.1 Energy Transfer Compared to Under-Sampling

Section II above disclosed methods and systems for down-converting an EM signal by under-sampling. The under-sampling systems utilize a sample and hold system controlled by an under-sampling signal. The under-sampling signal includes a train of pulses having negligible apertures that tend towards zero time in duration. The negligible aperture pulses minimize the amount of energy transferred from the EM signal. This protects the under-sampled EM signal from distortion or destruction. The negligible aperture pulses also make the sample and hold system a high impedance system. An advantage of under-sampling is that the high impedance input allows accurate voltage reproduction of the under-sampled EM signal. The methods and systems disclosed in Section II are thus useful for many situations including, but not limited to, monitoring EM signals without distorting or destroying them.

Because the under-sampling systems disclosed in Section II transfer only negligible amounts of energy, they are not suitable for all situations. For example, in radio communications, received radio frequency (RF) signals are typically very weak and must be amplified in order to distinguish them over noise. The negligible amounts of energy transferred by the under-sampling systems disclosed in Section II may not be sufficient to distinguish received RF signals over noise.

In accordance with an aspect of the invention, methods and systems are disclosed below for down-converting EM signals by transferring non-negligible amounts of energy from the EM signals. The resultant down-converted signals have sufficient energy to allow the down-converted signals to be distinguishable from noise. The resultant down-converted signals also have sufficient energy to drive lower impedance circuits without buffering.

Down-converting by transferring energy is introduced below in an incremental fashion to distinguish it from under-sampling. The introduction begins with further descriptions of under-sampling.

0.1.1 Review of Under-Sampling

FIG. **78**A illustrates an exemplary under-sampling system **7802** for down-converting an input EM signal **7804**. The under-sampling system **7802** includes a switching module **7806** and a holding module shown as a holding capacitance **7808**. An under-sampling signal **7810** controls the switch module **7806**. The under-sampling signal **7810** includes a train of pulses having negligible pulse widths that tend toward zero time. An example of a negligible pulse width or duration can be in the range of 1–10 psec for under-sampling a 900 MHZ signal. Any other suitable negligible pulse duration can be used as well, where accurate reproduction of the original unaffected input signal voltage is desired without substantially affecting the original input signal voltage.

In an under-sampling environment, the holding capacitance **7808** preferably has a small capacitance value. This allows the holding capacitance **7808** to substantially charge to the voltage of the input EM signal **7804** during the negligible apertures of the under-sampling signal pulses. For example, in an embodiment, the holding capacitance **7808** has a value in the range of 1 pF. Other suitable capacitance values can be used to achieve substantially the voltage of the original unaffected input signal. Various capacitances can be employed for certain effects, which are described below.

The under-sampling system is coupled to a load **7812**. In FIG. **78**B, the load **7812** of FIG. **78**A is illustrated as a high impedance load **7818**. A high impedance load is one that is relatively insignificant to an output drive impedance of the system for a given output frequency. The high impedance load **7818** allows the holding capacitance **7808** to substantially maintain the charge accumulated during the under-sampling pulses.

FIGS. **79**A–F illustrate example timing diagrams for the under-sampling system **7802**. FIG. **79**A illustrates an example input EM signal **7804**.

FIG. **79**C illustrates an example under-sampling signal **7810**, including pulses **7904** having negligible apertures that tend towards zero time in duration.

FIG. **79**B illustrates the negligible effects to the input EM signal **7804** when under-sampled, as measured at a terminal **7814** of the under-sampling system **7802**. In FIG. **79**B, negligible distortions **7902** correlate with the pulses of the under-sampling signal **7810**. In this embodiment, the negligible distortions **7902** occur at different locations of subsequent cycles of the input EM signal **7804**. As a result, the input EM signal will be down-converted. The negligible distortions **7902** represent negligible amounts of energy, in the form of charge that is transferred to the holding capacitance **7808**.

When the load **7812** is a high impedance load, the holding capacitance **7808** does not significantly discharge between pulses **7904**. As a result, charge that is transferred to the holding capacitance **7808** during a pulse **7904** tends to "hold" the voltage value sampled constant at the terminal **7816** until the next pulse **7904**. When voltage of the input EM signal **7804** changes between pulses **7904**, the holding capacitance **7808** substantially attains the new voltage and the resultant voltage at the terminal **7816** forms a stair step pattern, as illustrated in FIG. **79**D.

FIG. **79**E illustrates the stair step voltage of FIG. **79**D on a compressed time scale. The stair step voltage illustrated in FIG. **79**E can be filtered to produce the signal illustrated in FIG. **79**F. The signals illustrated in FIGS. **79**D, E, and F have substantially all of the baseband characteristics of the input EM signal **7804** in FIG. **79**A, except that the signals illustrated in FIGS. **79**D, E, and F have been successfully down-converted.

Note that the voltage level of the down-converted signals illustrated in FIGS. **79**E and **79**F are substantially close to the voltage level of the input EM signal **7804**. The under-sampling system **7802** thus down-converts the input EM signal **7804** with reasonable voltage reproduction, without substantially affecting the input EM signal **7804**. But also

note that the power available at the output is relatively negligible (e.g.: V^2/R; ~5 mV and 1 MOhm), given the input EM signal **7804** would typically have a driving impedance, in an RF environment, of 50 Ohms (e.g.: V^2/R; ~5 mV and 50 Ohms).

0.1.1.1 Effects of Lowering the Impedance of the Load

Effects of lowering the impedance of the load **7812** are now described. FIGS. **80**A–E illustrate example timing diagrams for the under-sampling system **7802** when the load **7812** is a relatively low impedance load, one that is significant relative to the output drive impedance of the system for a given output frequency.

FIG. **80**A illustrates an example input EM signal **7804**, which is substantially similar to that illustrated in FIG. **79**A.

FIG. **80**C illustrates an example under-sampling signal **7810**, including pulses **8004** having negligible apertures that tend towards zero time in duration. The example under-sampling signal **7810** illustrated in FIG. **80**C is substantially similar to that illustrated in FIGS. **79**C.

FIG. **80**B illustrates the negligible effects to the input EM signal **7804** when under-sampled, as measured at a terminal **7814** of the under-sampling system **7802**. In FIG. **80**B, negligible distortions **8002** correlate with the pulses **8004** of the under-sampling signal **7810** in FIG. **80**C. In this example, the negligible distortions **8002** occur at different locations of subsequent cycles of the input EM signal **7804**. As a result, the input EM signal **7804** will be down-converted. The negligible distortions **8002** represent negligible amounts of energy, in the form of charge that is transferred to the holding capacitance **7808**.

When the load **7812** is a low impedance load, the holding capacitance **7808** is significantly discharged by the load between pulses **8004** (FIG. **80**C). As a result, the holding capacitance **7808** cannot reasonably attain or "hold" the voltage of the original EM input signal **7804**, as was seen in the case of FIG. **79**D. Instead, the charge appears as the output illustrated in FIG. **80**D.

FIG. **80**E illustrates the output from FIG. **80**D on a compressed time scale. The output in FIG. **80**E can be filtered to produce the signal illustrated in FIG. **80**F. The down-converted signal illustrated in FIG. **80**F is substantially similar to the down-converted signal illustrated in FIG. **79**F, except that the signal illustrated in FIG. **80**F is substantially smaller in magnitude than the amplitude of the down-converted signal illustrated in FIG. **79**F. This is because the low impedance of the load **7812** prevents the holding capacitance **7808** from reasonably attaining or "holding" the voltage of the original EM input signal **7804**. As a result, the down-converted signal illustrated in FIG. **80**F cannot provide optimal voltage reproduction, and has relatively negligible power available at the output (e.g.: V^2/R; ~200 μV and 2 KOhms), given the input EM signal **7804** would typically have a driving impedance, in an RF environment, of **50** Ohms (e.g.: V^2/R; ~5 mV and 50 Ohms).

0.1.1.2 Effects of Increasing the Value of the Holding Capacitance

Effects of increasing the value of the holding capacitance **7808**, while having to drive a low impedance load **7812**, is now described. FIGS. **81**A–F illustrate example timing diagrams for the under-sampling system **7802** when the holding capacitance **7808** has a larger value, in the range of 18 pF for example.

FIG. **81**A illustrates an example input EM signal **7804**, which is substantially similar to that ID illustrated in FIGS. **79**A and **80**A.

FIG. **81**C illustrates an example under-sampling signal **7810**, including pulses **8104** having negligible apertures that tend towards zero time in duration. The example under-sampling signal **7810**, illustrated in FIG. **81**C is substantially similar to that illustrated in FIGS. **79**C and **80**C.

FIG. **81**B illustrates the negligible effects to the input EM signal **7804** when under-sampled, as measured at a terminal **7814** of the under-sampling system **7802**. In FIG. **81**B, negligible distortions **8102** correlate with the pulses **8104** of the under-samnpling signal **7810** in FIG. **81**C. Upon close inspection, the negligible distortions **8102** occur at different locations of subsequent cycles of the input EM signal **7804**. As a result, the input EM signal **7804** will be down-converted. The negligible distortions **8102** represent negligible amounts of energy, in the form of charge that is transferred to the holding capacitance **7808**.

FIG. **81**D illustrates the voltage measured at the terminal **7816**, which is a result of the holding capacitance **7808** attempting to attain and "hold" the original input EM signal voltage, but failing to do so, during the negligible apertures of the pulses **8104** illustrated in FIG. **81**C.

Recall that when the load **7812** is a low impedance load, the holding capacitance **7808** is significantly discharged by the load between pulses **8104** (FIG. **81**C), this again is seen in FIGS. **81**D and E. As a result, the holding capacitance **7808** cannot reasonably attain or "hold" the voltage of the original EM input signal **7804**, as was seen in the case of FIG. **79**D. Instead, the charge appears as the output illustrated in FIG. **81**D.

FIG. **81**E illustrates the down-converted signal **8106** on a compressed time scale. Note that the amplitude of the down-converted signal **8106** is significantly less than the amplitude of the down-converted signal illustrated in FIGS. **80**D and **80**E. This is due to the higher capacitive value of the holding capacitance **7808**. Generally, as the capacitive value increases, it requires more charge to increase the voltage for a given aperture. Because of the negligible aperture of the pulses **8104** in FIG. **81**C, there is insufficient time to transfer significant amounts of energy or charge from the input EM signal **7804** to the holding capacitance **7808**. As a result, the amplitudes attained by the holding capacitance **7808** are significantly less than the amplitudes of the down-converted signal illustrated in FIGS. **80**D and **80**E.

In FIGS. **80**E and **80**F, the output signal, non-filtered or filtered, cannot provide optimal voltage reproduction, and has relatively negligible power available at the output (e.g.: V^2/R; ~150 μV and 2 KOhms), given the input EM signal **7804** would typically have a driving impedance, in an RF environment, of 50 Ohms (e.g.: V^2/R; ~5 mV and 50 Ohms).

In summary, under-sampling systems, such as the under-sampling system **7802** illustrated in FIG. **78**, are well suited for down-converting EM signals with relatively accurate voltage reproduction. Also, they have a negligible affect on the original input EM signal. As illustrated above, however, the under-sampling systems, such as the under-sampling system **7802** illustrated in FIG. **78**, are not well suited for transferring energy or for driving lower impedance loads.

0.1.2 Introduction to Energy Transfer

In an embodiment, the present invention transfers energy from an EM signal by utilizing an energy transfer signal instead of an under-sampling signal. Unlike under-sampling signals that have negligible aperture pulses, the energy transfer signal includes a train of pulses having non-negligible apertures that tend away from zero. This provides more time to transfer energy from an EM input signal. One direct benefit is that the input impedance of the system is reduced so that practical impedance matching circuits can be implemented to further improve energy transfer and thus overall efficiency. The non-negligible transferred energy significantly improves the signal to noise ratio and sensitivity to very small signals, as well as permitting the down-converted signal to drive lower impedance loads unassisted. Signals that especially benefit include low power ones typified by RF signals. One benefit of a non-negligible aperture is that phase noise within the energy transfer signal does not have as drastic of an effect on the down-converted output signal as under-sampling signal phase noise or conventional sampling signal phase noise does on their respective outputs.

FIG. **82**A illustrates an exemplary energy transfer system **8202** for down-converting an input EM signal **8204**. The energy transfer system **8202** includes a switching module **8206** and a storage module illustrated as a storage capacitance **8208**. The terms storage module and storage capacitance, as used herein, are distinguishable from the terms holding module and holding capacitance, respectively. Holding modules and holding capacitances, as used above, identify systems that store negligible amounts of energy from an under-sampled input EM signal with the intent of "holding" a voltage value. Storage modules and storage capacitances, on the other hand, refer to systems that store non-negligible amounts of energy from an input EM signal.

The energy transfer system **8202** receives an energy transfer signal **8210**, which controls the switch module **8206**. The energy transfer signal **8210** includes a train of energy transfer pulses having non-negligible pulse widths that tend away from zero time in duration. The non-negligible pulse widths can be any non-negligible amount. For example, the non-negligible pulse widths can be ½ of a period of the input EM signal. Alternatively, the non-negligible pulse widths can be any other fraction of a period of the input EM signal, or a multiple of a period plus a fraction. In an example embodiment, the input EM signal is approximately 900 MHZ and the non-negligible pulse width is approximately 550 pico seconds. Any other suitable non-negligible pulse duration can be used.

In an energy transfer environment, the storage module, illustrated in FIG. **82** as a storage capacitance **8208**, preferably has the capacity to handle the power being transferred, and to allow it to accept a non-negligible amount of power during a non-negligible aperture period. This allows the storage capacitance **8208** to store energy transferred from the input EM signal **8204**, without substantial concern for accurately reproducing the original, unaffected voltage level of the input EM signal **8204**. For example, in an embodiment, the storage capacitance **8208** has a value in the range of 18 pF. Other suitable capacitance values and storage modules can be used.

One benefit of the energy transfer system **8202** is that, even when the input EM signal **8204** is a very small signal, the energy transfer system **8202** transfers enough energy from the input EM signal **8204** that the input EM signal can be efficiently down-converted.

The energy transfer system **8202** is coupled to a load **8212**. Recall from the overview of under-sampling that loads can be classified as high impedance loads or low impedance loads. A high impedance load is one that is relatively insignificant to an output drive impedance of the system for a given output frequency. A low impedance load is one that is relatively significant. Another benefit of the energy transfer system **8202** is that the non-negligible amounts of transferred energy permit the energy transfer system **8202** to effectively drive loads that would otherwise be classified as low impedance loads in under-sampling systems and conventional sampling systems. In other words, the non-negligible amounts of transferred energy ensure that, even for lower impedance loads, the storage capacitance **8208** accepts and maintains sufficient energy or charge to drive the load **8202**. This is illustrated below in the timing diagrams of FIGS. **83**A–F.

FIGS. **83**A–F illustrate example timing diagrams for the energy transfer system **8202** in FIG. **82**. FIG. **83**A illustrates an example input EM signal **8302**.

FIG. **83**C illustrates an example under-sampling signal **8304**, including energy transfer pulses **8306** having non-negligible apertures that tend away from zero time in duration.

FIG. **83**B illustrates the effects to the input EM signal **8302**, as measured at a terminal **8214** in FIG. **82**A, when non-negligible amounts of energy are transfer from it. In FIG. **83**B, non-negligible distortions **8308** correlate with the energy transfer pulses **8306** in FIG. **83**C. In this example, the non-negligible distortions **8308** occur at different locations of subsequent cycles of the input EM signal **8302**. The non-negligible distortions **8308** represent non-negligible amounts of transferred energy, in the form of charge that is transferred to the storage capacitance **8208** in FIG. **82**.

FIG. **83**D illustrates a down-converted signal **8310** that is formed by energy transferred from the input EM signal **8302**.

FIG. **83**E illustrates the down-converted signal **8310** on a compressed time scale. The down-converted signal **8310** can be filtered to produce the down-converted signal **8312** illustrated in FIG. **83**F. The down-converted signal **8312** is similar to the down-converted signal illustrated in FIG. **79**F, except that the down-converted signal **8312** has substantially more power (e.g.: V^2/R; approximately (~) 2 mV and 2K Ohms) than the down-converted signal illustrated in FIG. **79**F (e.g.: V^2/R; ~5 mV and 1M Ohms). As a result, the down-converted signals **8310** and **8312** can efficiently drive lower impedance loads, given the input EM signal **8204** would typically have a driving impedance, in an RF environment, of 50 Ohms (V^2/R; ~5 mV and 50 Ohms).

The energy transfer aspects of the invention are represented generally by **4506** in FIGS. **45**A and **45**B.

1. DOWN-CONVERTING AN EM SIGNAL TO AN IF EM SIGNAL BY TRANSFERING ENERGY FROM THE EM SIGNAL AT AN ALIASING RATE

In an embodiment, the invention down-converts an EM signal to an IF signal by transferring energy from the EM signal at an aliasing rate. This embodiment is illustrated by **4514** in FIG. **45**B.

This embodiment can be implemented with any type of EM signal, including, but not limited to, modulated carrier signals and unmodulated carrier signals. This embodiment is described herein using the modulated carrier signal F_{MC} in FIG. **1** as an example. In the example, the modulated carrier signal F_{MC} is down-converted to an intermediate frequency (IF) signal F_{IF}. The intermediate frequency signal F_{IF} can be demodulated to a baseband signal F_{DMB} using conventional demodulation techniques. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any EM signal, including, but not limited to, modulated carrier signals and unmodulated carrier signals.

The following sections describe methods for down-converting an EM signal to an IF signal F_{IF} by transferring energy from the EM signal at an aliasing rate. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below.

Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

1.1 High Level Description

This section (including its subsections) provides a high-level description of down-converting an EM signal to an IF signal F_{IF} by transferring energy, according to the invention. In particular, an operational process of down-converting the modulated carrier signal F_{MC} to the IF modulated carrier signal F_{IF}, by transferring energy, is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. This structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

1.1.1 Operational Description

FIG. **46**B depicts a flowchart **4607** that illustrates an exemplary method for down-converting an EM signal to an intermediate signal F_{IF}, by transferring energy from the EM signal at an aliasing rate. The exemplary method illustrated in the flowchart **4607** is an embodiment of the flowchart **4601** in FIG. **46**A.

Any and all combinations of modulation techniques are valid for this invention. For ease of discussion, the digital AM carrier signal **616** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed flowcharts and descriptions for AM, FM and PM example embodiments. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of EM signal, including any form of modulated carrier signal and unmodulated carrier signals.

The method illustrated in the flowchart **4607** is now described at a high level using the digital AM carrier signal **616** of FIG. **6**C. Subsequent sections provide detailed flowcharts and descriptions for AM, FM and PM example embodiments. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of EM signal, including any form of modulated carrier signal and unmodulated carrier signals.

The process begins at step **4608**, which includes receiving an EM signal. Step **4608** is illustrated by the digital AM carrier signal **616**. The digital AM carrier signal **616** of FIG. **6**C is re-illustrated in FIG. **47**A for convenience. FIG. **47**E illustrates a portion of the digital AM carrier signal **616** on an expanded time scale.

Step **4610** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **47**B illustrates an example energy transfer signal **4702**. The energy transfer signal **4702** includes a train of energy transfer pulses **4704** having non-negligible apertures **4701** that tend away from zero time duration. Generally, the apertures **4701** can be any time duration other than the period of the EM signal. For example, the apertures **4701** can be greater or less than a period of the EM signal. Thus, the apertures **4701** can be approximately 1/10, 1/4, 1/2, 3/4, etc., or any other fraction of the period of the EM signal. Alternatively, the apertures **4701** can be approximately equal to one or more periods of the EM signal plus ⅒, ¼, ½, ¾, etc., or any other fraction of a period of the EM signal. The apertures **4701** can be optimized based on one or more of a variety of criteria, as described in sections below.

The energy transfer pulses **4704** repeat at the aliasing rate. A suitable aliasing rate can be determined or selected as described below. Generally, when down-converting an EM signal to an intermediate signal, the aliasing rate is substantially equal to a difference frequency, which is described below, or substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. FIG. **47**C illustrates transferred energy **4706**, which is transferred from the EM signal during the energy transfer pulses **4704**. Because a harmonic of the aliasing rate occurs at an off-set of the frequency of the AM signal **616**, the pulses **4704** "walk through" the AM signal **616** at the off-set frequency. By "walking through" the AM signal **616**, the transferred energy **4706** forms an AM intermediate signal **4706** that is similar to the AM carrier signal **616**, except that the AM intermediate signal has a lower frequency than the AM carrier signal **616**. The AM carrier signal **616** can be down-converted to any frequency below the AM carrier signal **616** by adjusting the aliasing rate F_{AR}, as described below.

FIG. **47**D depicts the AM intermediate signal **4706** as a filtered output signal **4708**. In an alternative embodiment, the invention outputs a stair step, or non-filtered output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

The intermediate frequency of the down-converted signal F_{IF}, which, in this example, is the intermediate signal **4706** and **4708**, can be determined from EQ. (2), which is reproduced below for convenience.

$$F_C = n \cdot F_{AR} \pm F_{IF} \qquad \text{EQ. (2)}$$

A suitable aliasing rate F_{AR} can be determined in a variety of ways. An example method for determining the aliasing rate F_{AR}, is provided below. After reading the description herein, one skilled in the relevant art(s) will understand how to determine appropriate aliasing rates for EM signals, including ones in addition to the modulated carrier signals specifically illustrated herein.

In FIG. **48**, a flowchart **4801** illustrates an example process for determining an aliasing rate F_{AR}. But a designer may choose, or an application may dictate, that the values be determined in an order that is different than the illustrated order. The process begins at step **4802**, which includes determining, or selecting, the frequency of the EM signal. The frequency of the AM carrier signal **616** can be, for example, 901 MHZ.

Step **4804** includes determining, or selecting, the intermediate frequency. This is the frequency to which the EM signal will be down-converted. The intermediate frequency can be determined, or selected, to match a frequency requirement of a down-stream demodulator. The intermediate frequency can be, for example, 1 MHZ.

Step **4806** includes determining the aliasing rate or rates that will down-convert the EM signal to the IF specified in step **4804**.

EQ. (2) can be rewritten as EQ. (3):

$$n \bullet FAR = FC \pm FIF \qquad \text{EQ. (3)}$$

Which can be rewritten as EQ. (4):

$$n = \frac{F_C \pm F_{IF}}{F_{AR}} \qquad \text{EQ. (4)}$$

or as EQ. (5):

$$F_{AR} = \frac{F_C \pm F_{IF}}{n} \qquad \text{EQ. (5)}$$

$(F_C \pm F_{IF})$ can be defined as a difference value F_{DIFF}, as illustrated in EQ. (6):

$$(F_C \pm F_{IF}) = F_{DIFF} \qquad \text{EQ. (6)}$$

EQ. (4) can be rewritten as EQ. (7):

$$n = \frac{F_{DIFF}}{F_{AR}} \qquad \text{EQ. (7)}$$

From EQ. (7), it can be seen that, for a given n and a constant F_{AR}, F_{DIFF} is constant. For the case of $F_{DIFF}=F_C-F_{IF}$, and for a constant F_{DIFF}, as F_C increases, F_{IF} necessarily increases. For the case of $F_{DIFF}=F_C+F_{IF}$, and for a constant F_{DIFF}, as F_C increases, F_{IF} necessarily decreases. In the latter case of $F_{DIFF}=F_C+F_{IF}$, any phase or frequency changes on F_C correspond to reversed or inverted phase or frequency changes on F_{IF}. This is mentioned to teach the reader that if $F_{DIFF}=F_C+F_{IF}$ is used, the above effect will occur to the phase and frequency response of the modulated intermediate signal F_{IF}.

EQs. (2) through (7) can be solved for any valid n. A suitable n can be determined for any given difference frequency F_{DIFF} and for any desired aliasing rate $F_{AR(Desired)}$. EQs. (2) through (7) can be utilized to identify a specific harmonic closest to a desired aliasing rate $F_{AR(Desired)}$ that will generate the desired intermediate signal F_{IF}.

An example is now provided for determining a suitable n for a given difference frequency F_{DIFF} and for a desired aliasing rate $F_{AR(Desired)}$. For ease of illustration, only the case of (F_C-F_{IF}) is illustrated in the example below.

$$n = \frac{F_C - F_{IF}}{F_{AR(Desired)}} = \frac{F_{DIFF}}{F_{AR(Desired)}}$$

The desired aliasing rate $F_{AR(Desired)}$ can be, for example, 140 MHZ. Using the previous examples, where the carrier frequency is 901 MHZ and the IF is 1 MHZ, an initial value of n is determined as:

$$n = \frac{901\text{ MHZ} - 1\text{ MHZ}}{140\text{ MHZ}} = \frac{900}{140} = 6.4$$

The initial value 6.4 can be rounded up or down to the valid nearest n, which was defined above as including (0.5, 1, 2, 3, . . .). In this example, 6.4 is rounded down to 6.0, which is inserted into EQ. (5) for the case of $(F_C-F_{IF})=F_{DIFF}$:

$$F_{AR} = \frac{F_c - F_{IF}}{n}$$

$$F_{AR} = \frac{901\text{ MHZ} - 1\text{ MHZ}}{6} = \frac{900\text{ MHZ}}{6} = 150\text{ MHZ}$$

In other words, transferring energy from a 901 MHZ EM carrier signal at 150 MHZ generates an intermediate signal at 1 MHZ. When the EM carrier signal is a modulated carrier signal, the intermediate signal will also substantially include the modulation. The modulated intermediate signal can be demodulated through any conventional demodulation technique.

Alternatively, instead of starting from a desired aliasing rate, a list of suitable aliasing rates can be determined from the modified form of EQ. (5), by solving for various values of n. Example solutions are listed below.

$$F_{AR} = \frac{(F_C - F_{IF})}{n} = \frac{F_{DIFF}}{n} = \frac{901\text{ MHZ} - 1\text{ MHZ}}{n} = \frac{900\text{ MHZ}}{n}$$

Solving for n=b **0.5**, **1**, **2**, **3**, **4**, **5**and 6:

900 MHZ/0.5=1.8 GHZ (i.e., second harmonic);
900 MHZ/1=900 MHZ (i.e., fundamental frequency);
900 MHZ/2=450 MHZ (i.e., second sub-harmonic);
900 MHZ/3=300 MHZ (i.e., third sub-harmonic);
900 MHZ/4=225 MHZ (i.e., fourth subhanmonic);
900 MHZ/5=180 MHZ(i.e., fifth sub-harmonic); and
900 MHZ/6=150 MHZ(i.e., sixth sub-harmonic).

The steps described above can be performed for the case of (F_C+F_{IF}) in a similar fashion. The results can be compared to the results obtained from the case of (F_C–F_{IF}), to determine which provides better result for an application.

In an embodiment, the invention down-converts an EM signal to a relatively standard IF in the range of, for example, 100 KHZ to 200 MHZ. In another embodiment, referred to herein as a small off-set implementation, the invention down-converts an EM signal to a relatively low frequency of, for example, less than 100 KHZ. In another embodiment, referred to herein as a large off-set implementation, the invention down-converts an EM signal to a relatively higher IF signal, such as, for example, above 200 MHZ.

The various off-set implementations provide selectivity for different applications. Generally, lower data rate applications can operate at lower intermediate frequencies. But higher intermediate frequencies can allow more information to be supported for a given modulation technique.

In accordance with the invention, a designer picks an optimum information bandwidth for an application and an optimum intermediate frequency to support the baseband signal. The intermediate frequency should be high enough to support the bandwidth of the modulating baseband signal F_{MB}.

Generally, as the aliasing rate approaches a harmonic or sub-harmonic frequency of the EM signal, the frequency of the down-converted IF signal decreases. Similarly, as the aliasing rate moves away from a harmonic or sub-harmonic frequency of the EM signal, the IF increases.

Aliased frequencies occur above and below every harmonic of the aliasing frequency. In order to avoid mapping other aliasing frequencies in the band of the aliasing frequency (IF) of interest, the IF of interest should not be near one half the aliasing rate.

As described in example implementations below, an aliasing module, including a universal frequency translator (UFT) module built in accordance with the invention provides a wide range of flexibility in frequency selection and can thus be implemented in a wide range of applications. Conventional systems cannot easily offer, or do not allow, this level of flexibility in frequency selection.

1.1.2 Structural Description

FIG. **63** illustrates a block diagram of an energy transfer system **6302** according to an embodiment of the invention. The energy transfer system **6302** is an example embodiment of the generic aliasing system **1302** in FIG. **13**. The energy transfer system **6302** includes an energy transfer module **6304**. The energy transfer module **6304** receives the EM signal **1304** and an energy transfer signal **6306**, which includes a train of energy transfer pulses having non-negligible apertures that tend away from zero time in duration, occurring at a frequency equal to the aliasing rate F_{AR}. The energy transfer signal **6306** is an example embodiment of the aliasing signal **1310** in FIG. **13**. The energy transfer module **6304** transfers energy from the EM signal **1304** at the aliasing rate F_{AR} of the energy transfer signal **6306**.

Preferably, the energy transfer module **6304** transfers energy from the EM signal **1304** to down-convert it to the intermediate signal F in the manner shown in the operational flowchart **4607** of FIG. **46**B. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **4607**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the energy transfer system **6302** is now described in detail with reference to the flowchart **4607** and to the timing diagrams illustrated in FIGS. **47**A–E. In step **4608**, the energy transfer module **6304** receives the AM carrier signal **616**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **4702**. In step **4612**, the energy transfer module **6304** transfers energy from the AM carrier signal **616** at the aliasing rate to down-convert the AM carrier signal **616** to the intermediate signal **4706** or **4708**.

Example implementations of the energy transfer system **6302** are provided in Sections 4 and 5 below.

1.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting the EM signal **1304** by transferring energy can be implemented with any type of EM signal, including modulated carrier signals and unmodulated carrier signals. For example, the method of the flowchart **4601** can be implemented to down-convert AM signals, FM signals, PM signals, etc., or any combination thereof. Operation of the flowchart **4601** of FIG. **46**A is described below for down-converting AM, FM and PM. The down-conversion descriptions include down-converting to intermediate signals, directly down-converting to demodulated baseband signals, and down-converting FM signals to non-FM signals. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

1.2.1 First Example Embodiment: Amplitude Modulation

1.2.1.1 Operational Description

Operation of the exemplary process of the flowchart **4607** in FIG. **46**B is described below for the analog AM carrier signal **516**, illustrated in FIG. **5**C, and for the digital AM carrier signal it **616**, illustrated in FIG. **6**C.

1.2.1.1.1 Analog AM Carrier Signal

A process for down-converting the analog AM carrier signal **516** in FIG. **5**C to an analog AM intermediate signal is now described for the flowchart **4607** in FIG. **46**B. The analog AM carrier signal **516** is re-illustrated in FIG. **50**A for convenience. For this example, the analog AM carrier signal **516** oscillates at approximately 901 MHZ. In FIG. **50**B, an analog AM carrier signal **5004** illustrates a portion of the analog AM carrier signal **516** on an expanded time scale.

The process begins at step **4608**, which includes receiving the EM signal. This is represented by the analog AM carrier signal **516**.

Step **4610** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **50**C illustrates an example energy transfer signal **5006** on approximately the same time scale as FIG. **50**B. The energy transfer signal **5006** includes a train of energy transfer pulses **5007** having non-negligible apertures **5009** that tend away from zero time in duration. The energy transfer pulses **5007** repeat at the aliasing rate F_{AR}, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to an intermediate signal F_{IF}. In FIG. **50**D, an affected analog AM carrier signal **5008** illustrates effects of transferring energy from the analog AM carrier signal **516** at the aliasing rate F_{AR}. The affected analog AM carrier signal **5008** is illustrated on substantially the same time scale as FIGS. **50**B and **50**C.

FIG. **50**E illustrates a down-converted AM intermediate signal **5012**, which is generated by the down-conversion process. The AM intermediate signal **5012** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The down-converted signal **5012** includes portions **5010**A, which correlate with the energy transfer pulses **5007** in FIG. **50**C, and portions **5010**B, which are between the energy transfer pulses **5007**. Portions **5010**A represent energy transferred from the AM analog signal **516** to a storage device, while simultaneously driving an output load. The portions **5010**A occur when a switching module is closed by the energy transfer pulses **5007**. Portions **5010**B represent energy stored in a storage device continuing to drive the load. Portions **5010**B occur when the switching module is opened after energy transfer pulses **5007**.

Because a harmonic of the aliasing rate is off-set from the analog AM carrier signal **516**, the energy transfer pulses **5007** "walk through" the analog AM carrier signal **516** at the difference frequency F_{DIFF}. In other words, the energy transfer pulses **5007** occur at different locations of subsequent cycles of the AM carrier signal **516**. As a result, the energy transfer pulses **5007** capture varying amounts of energy from the analog AM carrier signal **516**, as illustrated by portions **5010**A, which provides the AM intermediate signal **5012** with an oscillating frequency F_{IF}.

In FIG. **50**F, an AM intermediate signal **5014** illustrates the AM intermediate signal **5012** on a compressed time scale. In FIG. **50**G, an AM intermediate signal **5016** represents a filtered version of the AM intermediate signal **5014**. The AM intermediate signal **5016** is substantially similar to the AM carrier signal **516**, except that the AM intermediate signal **5016** is at the intermediate frequency. The AM intermediate signal **5016** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered AM intermediate signal **5014**, the filtered AM intermediate signal **5016**, a partially filtered AM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the AM intermediate signals **5014** in FIG. **50**F and **5016** in FIG. **50**G illustrate that the AM carrier signal **516** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.1.1.2 Digital AM Carrier Signal

A process for down-converting the digital AM carrier signal **616** to a digital AM intermediate signal is now described for the flowchart **4607** in FIG. **46**B. The digital AM carrier signal **616** is re-illustrated in FIG. **51**A for convenience. For this example, the digital AM carrier signal **616** oscillates at approximately 901 MHZ. In FIG. **51**B, a digital AM carrier signal **5104** illustrates a portion of the digital AM carrier signal **616** on an expanded time scale.

The process begins at step **4608**, which includes receiving an EM signal. This is represented by the digital AM carrier signal **616**.

Step **4610** includes receiving an energy transfersignal having an aliasing rate F_{AR}. FIG. **51**C illustrates an example energy transfer signal **5106** on substantially the same time scale as FIG. **51**B. The energy transfer signal **5106** includes a train of energy transfer pulses **5107** having non-negligible apertures **5109** that tend away from zero time in duration. The energy transfer pulses **5107** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to the intermediate signal F_{IF}. In FIG. **51**D, an affected digital AM carrier signal **5108** illustrates effects of transferring energy from the digital AM carrier signal **616** at the aliasing rate F_{AR}. The affected digital AM carrier signal **5108** is illustrated on substantially the same time scale as FIGS. **51**B and **51**C.

FIG. **51**E illustrates a down-converted AM intermediate signal **5112**, which is generated by the down-conversion process. The AM intermediate signal **5112** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The down-converted signal **5112** includes portions **5110**A, which correlate with the energy transfer pulses **5107** in FIG. **51**C, and portions **5110**B, which are between the energy transfer pulses **5107**. Portions **5110**A represent energy transferred from the digital AM carrier signal **616** to a storage device, while simultaneously driving an output load. The portions **5110**A occur when a switching module is closed by the energy transfer pulses **5107**. Portions **5110**B represent energy stored in a storage device continuing to drive the load. Portions **5110**B occur when the switching module is opened after energy transfer pulses **5107**.

Because a harmonic of the aliasing rate is off-set from the frequency of the digital AM carrier signal **616**, the energy transfer pulses **5107** "walk through" the digital AM signal **616** at the difference frequency F_{DIFF}. In other words, the energy transfer pulse **5107** occur at different locations of subsequent cycles of the digital AM carrier signal **616**. As a result, the energy transfer pulses **5107** capture varying amounts of energy from the digital AM carrier signal **616**, as illustrated by portions **5110**, which provides the AM intermediate signal **5112** with an oscillating frequency F_{IF}.

In FIG. **51**F, a digital AM intermediate signal **5114** illustrates the AM intermediate signal **5112** on acompressed time scale. In FIG. **51**G, an AM intermediate signal **5116** represents a filtered version of the AM intermediate signal **5114**. The AM intermediate signal **5116** is substantially similar to the AM carrier signal **616**, except that the AM intermediate signal **5116** is at the intermediate frequency. The AM intermediate signal **5116** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered AM intermediate signal **5114**, the filtered AM intermediate signal **5116**, a partially filtered AM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the AM intermediate signals **5114** in FIG. **51**F and **5116** in FIG. **51**G illustrate that the AM carrier signal **616** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.1.2 Structural Description

The operation of the energy transfer system **6302** is now described for the analog AM carrier signal **516**, with reference to the flowchart **4607** and to the timing diagrams in FIGS. **50**A–G. In step **4608**, the energy transfer module **6304** receives the analog AM carrier signal **616**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5006**. In step **4612**, the energy transfer module **6304** transfers energy from the analog AM carrier signal **616** at the aliasing rate of the energy transfer signal **5006**, to down-convert the analog AM carrier signal **616** to the AM intermediate signal **5012**.

The operation of the energy transfer system **6302** is now described for the digital AM carrier signal **616**, with reference to the flowchart **1401** and the timing diagrams in FIGS. **51**A–G. In step **4608**, the energy transfer module **6304** receives the digital AM carrier signal **616**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5106**. In step **4612**, the energy transfer module **6304** transfers energy from the digital AM carrier signal **616** at the aliasing rate of the energy transfer signal **5106**, to down-convert the digital AM carrier signal **616** to the AM intermediate signal **5112**.

Example embodiments of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

1.2.2 Second Example Embodiment: Frequency Modulation

1.2.2.1 Operational Description

Operation of the exemplary process of the flowchart **4607** in FIG. **46**B is described below for the analog FM carrier signal **716**, illustrated in FIG. **7**C, and for the digital FM carrier signal **816**, illustrated in FIG. **8**C.

1.2.2.1.1 Analog FM Carrier Signal

A process for down-converting the analog FM carrier signal **716** in FIG. **7**C to an FM intermediate signal is now described for the flowchart **4607** in FIG. **46**B. The analog FM carrier signal **716** is re-illustrated in FIG. **52**A for convenience. For this example, the analog FM carrier signal **716** oscillates around approximately 901 MHZ. In FIG. **52**B, an analog FM carrier signal **5204** illustrates a portion of the analog FM carrier signal **716** on an expanded time scale.

The process begins at step **4608**, which includes receiving an EM signal. This is represented by the analog FM carrier signal **716**.

Step **4610** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **52**C illustrates an example energy transfer signal **5206** on approximately the same time scale as FIG. **52**B. The energy transfer signal **5206** includes a train of energy transfer pulses **5207** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **5207** repeat at the aliasing rate F_{AR}, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to an intermediate signal F_{IF}. In FIG. **52**D, an affected analog FM carrier signal **5208** illustrates effects of transferring energy from the analog FM carrier signal **716** at the aliasing rate F_{AR}. The affected analog FM carrier signal **5208** is illustrated on substantially the same time scale as FIGS. **52**B and **52**C.

FIG. **52**E illustrates a down-converted FM intermediate signal **5212**, which is generated by the down-conversion process. The FM intermediate signal **5212** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The down-converted signal **5212** includes portions **5210**A, which correlate with the energy transfer pulses **5207** in FIG. **52**C, and portions **5210**B, which are between the energy transfer pulses **5207**. Portions **5210**A represent energy transferred from the analog FM carrier signal **716** to a storage device, while simultaneously driving an output load. The portions **5210**A occur when a switching module is closed by the energy transfer pulses **5207**. Portions **5210**B represent energy stored in a storage device continuing to drive the load. Portions **5210**B occur when the switching module is opened after energy transfer pulses **5207**.

Because a harmonic of the aliasing rate is off-set from the frequency of the analog FM carrier signal **716**, the energy transfer pulses **5207** "walk through" the analog FM carrier signal **716** at the difference frequency F_{DIFF}. In other words, the energy transfer pulse **5207** occur at different locations of subsequent cycles of the analog FM carrier signal **716**. As a result, the energy transfer pulses **5207** capture varying amounts of energy from the analog FM carrier signal **716**, as illustrated by portions **5210**, which provides the FM intermediate signal **5212** with an oscillating frequency F_{IF}.

In FIG. **52**F, an analog FM intermediate signal **5214** illustrates the FM intermediate signal **5212** on a compressed time scale. In FIG. **52**G, an FM intermediate signal **5216** represents a filtered version of the FM intermediate signal **5214**. The FM intermediate signal **5216** is substantially similar to the analog FM carrier signal **716**, except that the FM intermediate signal **5216** is at the intermediate frequency. The FM intermediate signal **5216** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered FM intermediate signal **5214**, the filtered FM intermediate signal **5216**, a partially filtered FM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the FM intermediate signals **5214** in FIG. **52**F and **5216** in FIG. **52**G illustrate that the FM carrier signal **716** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.2.1.2 Digital FM Carrier Signal

A process for down-converting the digital FM carrier signal **816** in FIG. **8**C is now described for the flowchart **4607** in FIG. **46**B. The digital FM carrier signal **816** is re-illustrated in FIG. **53**A for convenience. For this example, the digital FM carrier signal **816** oscillates at approximately 901 MHZ. In FIG. **53**B, a digital FM carrier signal **5304** illustrates a portion of the digital FM carrier signal **816** on an expanded time scale.

The process begins at step **4608**, which includes receiving an EM signal. This is represented by the digital FM carrier signal **816**.

Step **4610** includes receiving an energy-transfer signal having an aliasing rate F_{AR}. FIG. **53**C illustrates an example energy transfer signal **5306** on substantially the same time scale as FIG. **53**B. The energy transfer signal **5306** includes a train of energy transfer pulses **5307** having non-negligible apertures **5309** that tend away from zero time in duration. The energy transfer pulses **5307** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to the an intermediate signal F_{IF}. In FIG. **53**D, an affected digital FM carrier signal **5308** illustrates effects of transferring energy from the digital FM carrier signal **816** at the aliasing rate F_{AR}. The affected digital FM carrier signal **5308** is illustrated on substantially the same time scale as FIGS. **53**B and **53**C.

FIG. **53**E illustrates a down-converted FM intermediate signal **5312**, which is generated by the down-conversion process. The down-converted signal **5312** includes portions **5310**A, which correlate with the energy transfer pulses **5307** in FIG. **53**C, and portions **5310**B, which are between the energy transfer pulses **5307**. Down-converted signal **5312** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

Portions **5310**A represent energy transferred from the digital FM carrier signal **816** to a storage device, while simultaneously driving an output load. The portions **5310**A occur when a switching module is closed by the energy transfer pulses **5307**.

Portions **5310**B represent energy stored in a storage device continuing to drive the load. Portions **5310**B occur when the switching module is opened after energy transfer pulses **5307**.

Because a harmonic of the aliasing rate is off-set from the frequency of the digital FM carrier signal **816**, the energy transfer pulses **5307** "walk through" the digital FM carrier signal **816** at the difference frequency F_{DIFF}. In other words, the energy transfer pulse **5307** occur at different locations of subsequent cycles of the digital FM carrier signal **816**. As a result, the energy transfer pulses **5307** capture varying amounts of energy from the digital FM carrier signal **816**, as illustrated by portions **5310**, which provides the FM intermediate signal **5312** with an oscillating frequency F_{IF}.

In FIG. **53**F, a digital FM intermediate signal **5314** illustrates the FM intermediate signal **5312** on a compressed time scale. In FIG. **53**G, an FM intermediate signal **5316** represents a filtered version of the FM intermediate signal **5314**. The FM intermediate signal **5316** is substantially similar to the digital FM carrier signal **816**, except that the FM intermediate signal **5316** is at the intermediate frequency. The FM intermediate signal **5316** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered FM intermediate signal **5314**, the filtered FM intermediate signal **5316**, a partially filtered FM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the FM intermediate signals **5314** in FIG. **53**F and **5316** in FIG. **53**G illustrate that the FM carrier signal **816** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.2.2 Structural Description

The operation of the energy transfer system **6302** is now described for the analog FM carrier signal **716**, with reference to the flowchart **4607** and the timing diagrams in FIGS. **52**A–G. In step **4608**, the energy transfer module **6304** receives the analog FM carrier signal **716**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5206**. In step **4612**, the energy transfer module **6304** transfers energy from the analog FM carrier signal **716** at the aliasing rate of the energy transfer signal **5206**, to down-convert the analog FM carrier signal **716** to the FM intermediate signal **5212**.

The operation of the energy transfer system **6302** is now described for the digital FM carrier signal **816**, with reference to the flowchart **4607** and the timing diagrams in FIGS. **53**A–G. In step **4608**, the energy transfer module **6304** receives the digital FM carrier signal **816**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5306**. In step **4612**, the energy transfer module **6304** transfers energy from the digital FM carrier signal **816** at the aliasing rate of the energy transfer signal **5306**, to down-convert the digital FM carrier signal **816** to the FM intermediate signal **5212**.

Example embodiments of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

1.2.3 Third Example Embodiment: Phase Modulation

1.2.3.1 Operational Description

Operation of the exemplary process of the flowchart **4607** in FIG. **46**B is described below for the analog PM carrier signal **916**, illustrated in FIG. **9**C, and for the digital PM carrier signal **1016**, illustrated in FIG. **10**C.

1.2.3.1.1 Analog PM Carrier Signal

A process for down-converting the analog PM carrier signal **916** in FIG. **9**C to an analog PM intermediate signal is now described for the flowchart **4607** in FIG. **46**B. The analog PM carrier signal **916** is re-illustrated in FIG. **54**A for convenience. For this example, the analog PM carrier signal **916** oscillates at approximately 901 MHZ. In FIG. **54**B, an analog PM carrier signal **5404** illustrates a portion of the analog PM carrier signal **916** on an expanded time scale.

The process begins at step **4608**, which includes receiving an EM signal. This is represented by the analog PM carrier signal **916**.

Step **4610** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **54**C illustrates an example energy transfer signal **5406** on approximately the same time scale as FIG. **54**B. The energy transfer signal **5406** includes a train of energy transfer pulses **5407** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **5407** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to the IF signal F_{IF}. In FIG. **54**D, an affected analog PM carrier signal **5408** illustrates effects of transferring energy from the analog PM carrier signal **916** at the aliasing rate F_{AR}. The affected analog PM carrier signal **5408** is illustrated on substantially the same time scale as FIGS. **54**B and **54**C.

FIG. **54**E illustrates a down-converted PM intermediate signal **5412**, which is generated by the down-conversion process. The down-converted PM intermediate signal **5412** includes portions **5410**A, which correlate with the energy transfer pulses **5407** in FIG. **54**C, and portions **5410**B, which are between the energy transfer pulses **5407**. Down-onverted signal **5412** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

Portions **5410**A represent energy transferred from the analog PM carrier signal **916** to a storage device, while simultaneously driving an output load. The portions **5410**A occur when a switching module is closed by the energy transfer pulses **5407**.

Portions **5410**B represent energy stored in a storage device continuing to drive the load. Portions **5410**B occur when the switching module is opened after energy transfer pulses **5407**.

Because a harmonic of the aliasing rate is off-set from the frequency of the analog PM carrier signal **916**, the energy transfer pulses **5407** "walk through" the analog PM carrier signal **916** at the difference frequency F_{DIFF}. In other words, the energy transfer pulse **5407** occur at different locations of subsequent cycles of the analog PM carrier signal **916**. As a result, the energy transfer pulses **5407** capture varying amounts of energy from the analog PM carrier signal **916**, as illustrated by portions **5410**, which provides the PM intermediate signal **5412** with an oscillating frequency F_{IF}.

In FIG. **54**F, an analog PM intermediate signal **5414** illustrates the PM intermediate signal **5412** on a compressed time scale. In FIG. **54**G, an PM intermediate signal **5416** represents a filtered version of the PM intermediate signal **5414**. The PM intermediate signal **5416** is substantially similar to the analog PM carrier signal **916**, except that the PM intermediate signal **5416** is at the intermediate frequency. The PM intermediate signal **5416** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered PM intermediate signal **5414**, the filtered PM intermediate signal **5416**, a partially filtered PM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the PM intermediate signals **5414** in FIG. **54**F and **5416** in FIG. **54**G illustrate that the PM carrier signal **916** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.3.1.2 Digital PM Carrier Signal

A process for down-converting the digital PM carrier signal **1016** in FIG. **10**C to a digital PM signal is now described for the flowchart **3607** in FIG. **46**B. The digital PM carrier signal **1016** is re-illustrated in FIG. **55**A for convenience. For this example, the digital PM carrier signal **1016** oscillates at approximately 901 MHZ. In FIG. **55**B, a digital PM carrier signal **5504** illustrates a portion of the digital PM carrier signal **1016** on an expanded time scale.

The process begins at step **4608**, which includes receiving an EM signal. This is represented by the digital PM carrier signal **1016**.

Step **4610** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **55**C illustrates an example energy transfer signal **5506** on substantially the same time scale as FIG. **55**B. The energy transfer signal **5506** includes a train of energy transfer pulses **5507** having non-negligible apertures **5509** that tend away from zero time in duration. The energy transfer pulses **5507** repeat at an aliasing rate, which is determined or selected as previously described. Generally, when down-converting to an intermediate signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the difference frequency F_{DIFF}.

Step **4612** includes transferring energy from the EM signal at the aliasing rate to down-convert the EM signal to an intermediate signal F_{IF}. In FIG. **55**D, an affected digital PM carrier signal **5508** illustrates effects of transferring energy from the digital PM carrier signal **1016** at the aliasing rate F_{AR}. The affected digital PM carrier signal **5508** is illustrated on substantially the same time scale as FIGS. **55**B and **55**C.

FIG. **55**E illustrates a down-converted PM intermediate signal **5512**, which is generated by the down-conversion process. The down-converted PM intermediate signal **5512** includes portions **5310**A, which correlate with the energy transfer pulses **5507** in FIG. **55**C, and portions **5510**B, which are between the energy transfer pulses **5507**. Down-converted signal **5512** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

Portions **5510**A represent energy transferred from the digital PM carrier signal **1016** to a storage device, while simultaneously driving an output load. The portions **5510**A occur when a switching module is closed by the energy transfer pulses **5507**.

Portions **5510**B represent energy stored in a storage device continuing to drive the load. Portions **5510**B occur when the switching module is opened after energy transfer pulses **5507**.

Because a harmonic of the aliasing rate is off-set from the frequency of the digital PM carrier signal **716**, the energy transfer pulses **5507** "walk through" the digital PM carrier signal **1016** at the difference frequency F_{DIFF}. In other words, the energy transfer pulse **5507** occur at different locations of subsequent cycles of the digital PM carrier signal **1016**. As a result, the energy transfer pulses **5507** capture varying amounts of energy from the digital PM carrier signal **1016**, as illustrated by portions **5510**, which provides the PM intermediate signal **5512** with an oscillating frequency F_{IF}.

In FIG. **55**F, a digital PM intermediate signal **5514** illustrates the PM intermediate signal **5512** on a compressed time scale. In FIG. **55**G, an PM intermediate signal **5516** represents a filtered version of the PM intermediate signal **5514**. The PM intermediate signal **5516** is substantially similar to the digital PM carrier signal **1016**, except that the PM intermediate signal **5516** is at the intermediate frequency. The PM intermediate signal **5516** can be demodulated through any conventional demodulation technique.

The present invention can output the unfiltered PM intermediate signal **5514**, the filtered PM intermediate signal **5516**, a partially filtered PM intermediate signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The signals referred to herein illustrate frequency down-conversion in accordance with the invention. For example, the PM intermediate signals **5514** in FIG. **55**F and **5516** in

FIG. **55**G illustrate that the PM carrier signal **1016** was successfully down-converted to an intermediate signal by retaining enough baseband information for sufficient reconstruction.

1.2.3.2 Structural Description

Operation of the energy transfer system **6302** is now described for the analog PM carrier signal **916**, with reference to the flowchart **4607** and the timing diagrams in FIGS. **54**A–G. In step **4608**, the energy transfer module **6304** receives the analog PM carrier signal **916**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5406**. In step **4612**, the energy transfer module **6304** transfers energy from the analog PM carrier signal **916** at the aliasing rate of the energy transfer signal **5406**, to down-convert the analog PM carrier signal **916** to the PM intermediate signal **5412**.

Operation of the energy transfer system **6302** is now described for the digital PM carrier signal **1016**, with reference to the flowchart **4607** and the timing diagrams in FIGS. **55**A–G. In step **4608**, the energy transfer module **6304** receives the digital PM carrier signal **1016**. In step **4610**, the energy transfer module **6304** receives the energy transfer signal **5506**. In step **4612**, the energy transfer module **6304** transfers energy from the digital PM carrier signal **1016** at the aliasing rate of the energy transfer signal **5506**, to down-convert the digital PM carrier signal **1016** to the PM intermediate signal **5512**.

Example embodiments of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

1.2.4 Other Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention. Example implementations of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

1.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. These implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

2. DIRECTLY DOWN-CONVERTING AN EM SIGNAL TO AN DEMODULATED BASEBAND SIGNAL BY TRANSFERRING ENERGY FROM THE EM SIGNAL

In an embodiment, the invention directly down-converts an EM signal to a baseband signal, by transferring energy from the EM signal. This embodiment is referred to herein as direct-to-data down-conversion and is illustrated by **4516** in FIG. **45**B.

This embodiment can be implemented with modulated and unmodulated EM signals. This embodiment is described herein using the modulated carrier signal F_{MC} in FIG. **1**, as an example. In the example, the modulated carrier signal F_{MC} is directly down-converted to the demodulated baseband signal F_{DMB}. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any EM signal, including but not limited to, modulated carrier signals and unmodulated carrier signals.

The following sections describe methods for directly down-converting the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB}. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

2.1 High Level Description

This section (including its subsections) provides a high-level description of transferring energy from the modulated carrier signal F_{MC} to directly down-convert the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB}, according to the invention. In particular, an operational process of directly down-converting the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB} is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. The structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

2.1.1 Operational Description

FIG. **46**C depicts a flowchart **4613** that illustrates an exemplary method for transferring energy from the modulated carrier signal F_{MC} to directly down-convert the modulated carrier signal F_{MC} to the demodulated baseband signal F_{DMB}. The exemplary method illustrated in the flowchart **4613** is an embodiment of the flowchart **4601** in FIG. **46**A.

Any and all combinations of modulation techniques are valid for this invention. For ease of discussion, the digital AM carrier signal **616** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed flowcharts and descriptions for AM and PM example embodiments. FM presents special considerations that are dealt with separately in Section III.3. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of EM signal, including any form of modulated carrier signal and unmodulated carrier signals.

The high-level process illustrated in the flowchart **4613** is now described at a high level using the digital AM carrier signal **616**, from FIG. **6**C. The digital AM carrier signal **616** is re-illustrated in FIG. **56**A for convenience.

The process of the flowchart **4613** begins at step **4614**, which includes receiving an EM signal. Step **4614** is represented by the digital AM carrier signal **616**.

Step **4616** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **56**B illustrates an example energy transfer signal **5602**, which includes a train of energy transfer pulses **5604** having apertures **5606** that are optimized for energy transfer. The optimized apertures **5606** are non-negligible and tend away from zero.

The non-negligible apertures **5606** can be any width other than the period of the EM signal, or a multiple thereof. For example, the non-negligible apertures **5606** can be less than the period of the signal **616** such as, ⅛, ¼, ½, ¾, etc., of the period of the signal **616**. Alternatively, the non-negligible apertures **5606** can be greater than the period of the signal **616**. The width and amplitude of the apertures **5606** can be optimized based on one or more of a variety of criteria, as described in sections below.

The energy transfer pulses **5604** repeat at the aliasing rate or pulse repetition rate. The aliasing rate is determined in accordance with EQ. (2), reproduced below for convenience.

$$F_C = n \cdot F_{AR} \pm F_{IF} \qquad \text{EQ. (2)}$$

When directly down-converting an EM signal to baseband (i.e., zero IF), EQ. (2) becomes:

$$F_C = n \cdot F_{AR} \qquad \text{EQ. (8)}$$

Thus, to directly down-convert the AM signal **616** to a demodulated baseband signal, the aliasing rate is substantially equal to the frequency of the AM signal **616** or to a harmonic or sub-harmonic thereof. Although the aliasing rate is too low to permit reconstruction of higher frequency components of the AM signal **616** (i.e., the carrier frequency), it is high enough to permit substantial reconstruction of the lower frequency modulating baseband signal **310**.

Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to a demodulated baseband signal F_{DMB}. FIG. **56**C illustrates a demodulated baseband signal **5610** that is generated by the direct down-conversion process. The demodulated baseband signal **5610** is similar to the digital modulating baseband signal **310** in FIG. **3**.

FIG. **56**D depicts a filtered demodulated baseband signal **5612**, which can be generated from the demodulated baseband signal **5610**. The invention can thus generate a filtered output signal, a partially filtered output signal, or a relatively unfiltered output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

2.1.2 Structural Description

In an embodiment, the energy transfer system **6302** transfers energy from any type of EM signal, including modulated carrier signals and unmodulated carrier signal, to directly down-convert the EM signal to a demodulated baseband signal. Preferably, the energy transfer system **6302** transfers energy from the EM signal **1304** to down-convert it to demodulated baseband signal in the manner shown in the operational flowchart **4613**. However, it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **4613**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

Operation of the energy transfer system **6302** is now described in at a high level for the digital AM carrier signal **616**, with reference to the flowchart **4613** and the timing diagrams illustrated in FIGS. **56**A–D. In step **4614**, the energy transfer module **6304** receives the digital AM carrier signal **616**. In step **4616**, the energy transfer module **6304** receives the energy transfer signal **5602**. In step **4618**, the energy transfer module **6304** transfers energy from the digital AM carrier signal **616** at the aliasing rate to directly down-convert it to the demodulated baseband signal **5610**.

Example implementations of the energy transfer system **6302** are disclosed in Sections 4 and 5 below.

2.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting the EM signal to the demodulated baseband signal F_{DMB}, illustrated in the flowchart **4613** of FIG. **46**C, can be implemented with various types of modulated carrier signals including, but not limited to, AM, PM, etc., or any combination thereof. The flowchart **4613** of FIG. **46**C is described below for AM and PM. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

2.2.1 First Example Embodiment: Amplitude Modulation

2.2.1.1 Operational Description

Operation of the exemplary process of the flowchart **4613** in FIG. **46**C is described below for the analog AM carrier signal **516**, illustrated in FIG. **5**C, and for the digital AM carrier signal **616**, illustrated in FIG. **6**C.

2.2.1.1.1 Analog AM Carrier Signal

A process for directly down-converting the analog AM carrier signal **516** in FIG. **5**C to a demodulated baseband signal is now described with reference to the flowchart **4613** in FIG. **46**C. The analog AM carrier signal **516** is re-illustrated in **57**A for convenience. For this example, the analog AM carrier signal **516** oscillates at approximately 900 MHZ. In FIG. **57**B, an analog AM carrier signal portion **5704** illustrates a portion of the analog AM carrier signal **516** on an expanded time scale.

The process begins at step **4614**, which includes receiving an EM signal. This is represented by the analog AM carrier signal **516**.

Step **4616** includes receiving an energy transfer signal having an aliasing rate F_{AR}. In FIG. **57**C, an example energy transfer signal **5706** is illustrated on approximately the same time scale as FIG. **57**B. The energy transfer signal **5706** includes a train of energy transfer pulses **5707** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **5707** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when down-converting an EM signal to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a subharmonic of the EM signal.

Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to the demodulated baseband signal F_{DMB}. In FIG. **57**D, an affected analog AM carrier signal **5708** illustrates effects of transferring energy from the analog AM carrier signal **516** at the aliasing rate F_{AR}. The affected analog AM carrier signal **5708** is illustrated on substantially the same time scale as FIGS. **57**B and **57**C.

FIG. **57**E illustrates a demodulated baseband signal **5712**, which is generated by the down-conversion process. Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **516**, essentially no IF is produced. The only substantial aliased component is the baseband signal. The demodulated baseband signal **5712** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The demodulated baseband signal **5712** includes portions **5710**A, which correlate with the energy transfer pulses **5707** in FIG. **57**C, and portions **5710**B, which are between the energy transfer pulses **5707**. Portions **5710**A represent energy transferred from the analog AM carrier signal **516** to a storage device, while simultaneously driving an output load. The portions **5710**A occur when a switching module is closed by the energy transfer pulses **5707**. Portions **5710**B represent energy stored in a storage device continuing to drive the load. Portions **5710**B occur when the switching module is opened after energy transfer pulses **5707**.

In FIG. **57**F, a demodulated baseband signal **5716** represents a filtered version of the demodulated baseband signal **5712**, on a compressed time scale. The demodulated baseband signal **5716** is substantially similar to the modulating baseband signal **210** and can be further processed using any signal processing technique(s) without further down-conversion or demodulation.

The present invention can output the unfiltered demodulated baseband signal **5712**, the filtered demodulated baseband signal **5716**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The aliasing rate of the energy transfer signal is preferably controlled to optimize the demodulated baseband signal for amplitude output and polarity, as desired.

The drawings referred to herein illustrate direct down-conversion in accordance with the invention. For example, the demodulated baseband signals **5712** in FIG. **57**E and **5716** in FIG. **57**F illustrate that the analog AM carrier signal **516** was directly down-converted to a demodulated baseband signal by retaining enough baseband information for sufficient reconstruction.

2.2.1.1.2 Digital AM Carrier Signal

A process for directly down-converting the digital AM carrier signal **616** in FIG. **6**C to a demodulated baseband signal is now described for the flowchart **4613** in FIG. **46**C. The digital AM carrier signal **616** is re-illustrated in **58**A for convenience. For this example, the digital AM carrier signal **616** oscillates at approximately 900 MHZ. In FIG. **58**B, a digital AM carrier signal portion **5804** illustrates a portion of the digital AM carrier signal **616** on an expanded time scale.

The process begins at step **4614**, which includes receiving an EM signal. This is represented by the digital AM carrier signal **616**.

Step **4616** includes receiving an energy transfer signal having an aliasing rate F_{AR}. In FIG. **58**C, an example energy transfer signal **5806** is illustrated on approximately the same time scale as FIG. **58**B. The energy transfer signal **5806** includes a train of energy transfer pulses **5807** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **5807** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when directly down-converting an EM signal to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the EM signal.

Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to the demodulated baseband signal F_{DMB}. In FIG. **58**D, an affected digital AM carrier signal **5808** illustrates effects of transferring energy from the digital AM carrier signal **616** at the aliasing rate F_{AR}. The affected digital AM carrier signal **5808** is illustrated on substantially the same time scale as FIGS. **58**B and **58**C.

FIG. **58**E illustrates a demodulated baseband signal **5812**, which is generated by the down-conversion process. Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **616**, essentially no IF is produced. The only substantial aliased component is the baseband signal. The demodulated baseband signal **5812** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The demodulated baseband signal **5812** includes portions **5810**A, which correlate with the energy transfer pulses **5807** in FIG. **58**C, and portions **5810**B, which are between the energy transfer pulses **5807**. Portions **5810**A represent energy transferred from the digital AM carrier signal **616** to a storage device, while simultaneously driving an output load. The portions **5810**A occur when a switching module is closed by the energy transfer pulses **5807**. Portions **5810**B represent energy stored in a storage device continuing to drive the load. Portions **5810**B occur when the switching module is opened after energy transfer pulses **5807**.

In FIG. **58**F, a demodulated baseband signal **5816** represents a filtered version of the demodulated baseband signal **5812**, on a compressed time scale. The demodulated baseband signal **5816** is substantially similar to the modulating baseband signal **310** and can be further processed using any signal processing technique(s) without further down-conversion or demodulation.

The present invention can output the unfiltered demodulated baseband signal **5812**, the filtered demodulated baseband signal **5816**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

The drawings referred to herein illustrate direct down-conversion in accordance with the invention. For example, the demodulated baseband signals **5812** in FIG. **58**E and **5816** in FIG. **58**F illustrate that the digital AM carrier signal **616** was directly down-onverted to a demodulated baseband signal by retaining enough baseband information for sufficient reconstruction.

2.2.1.2 Structural Description

In an embodiment, the energy transfer module **6304** preferably transfers energy from the EM signal to directly down-convert it to a demodulated baseband signal in the manner shown in the operational flowchart **4613**. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **1413**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

Operation of the energy transfer system **6302** is now described for the analog AM carrier signal **516**, with reference to the flowchart **4613** and the timing diagrams in FIGS. **57**A–F. In step **4612**, the energy transfer module **6304** receives the analog AM carrier signal **516**. In step **4614**, the energy transfer module **6304** receives the energy transfer signal **5706**. In step **4618**, the energy transfer module **6304** transfers energy from the analog AM carrier signal **516** at the aliasing rate of the energy transfer signal **5706**, to directly down-convert the analog AM carrier signal **516** to the demodulated baseband signals **5712** or **5716**.

The operation of the energy transfer system **6302** is now described for the digital AM carrier signal **616**, with reference to the flowchart **4613** and the timing diagrams in FIGS. **58**A–F. In step **4614**, the energy transfer module **6304** receives the digital AM carrier signal **616**. In step **4616**, the energy transfer module **6304** receives the energy transfer signal **5806**. In step **4618**, the energy transfer module **6304** transfers energy from the digital AM carrier signal **616** at the aliasing rate of the energy transfer signal **5806**, to directly down-convert the digital AM carrier signal **616** to the demodulated baseband signals **5812** or **5816**.

Example implementations of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

2.2.2 Second Example Embodiment: Phase Modulation

2.2.2.1 Operational Description

Operation of the exemplary process of flowchart **4613** in FIG. **46**C is described below for the analog PM carrier signal **916**, illustrated in FIG. **9**C and for the digital PM carrier signal **1016**, illustrated in FIG. **10**C.

2.2.2.1.1 Analog PM Carrier Signal

A process for directly down-converting the analog PM carrier signal **916** to a demodulated baseband signal is now described for the flowchart **4613** in FIG. **46**C. The analog PM carrier signal **916** is re-illustrated in **59**A for convenience. For this example, the analog PM carrier signal **916** oscillates at approximately 900 MHZ. In FIG. **59**B, an analog PM carrier signal portion **5904** illustrates a portion of the analog PM carrier signal **916** on an expanded time scale.

The process begins at step **4614**, which includes receiving an EM signal. This is represented by the analog PM carrier signal **916**.

Step **4616** includes receiving an energy transfer signal having an aliasing rate F_{AR}. In FIG. **59**C, an example energy transfer signal **5906** is illustrated on approximately the same time scale as FIG. **59**B. The energy transfer signal **5906** includes a train of energy transfer pulses **5907** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **5907** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when directly down-converting an EM signal to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the EM signal.

Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to the demodulated baseband signal F_{DMB}. In FIG. **59**D, an affected analog PM carrier signal **5908** illustrates effects of transferring energy from the analog PM carrier signal **916** at the aliasing rate F_{AR}. The affected analog PM carrier signal **5908** is illustrated on substantially the same time scale as FIGS. **59**B and **59**C.

FIG. **59**E illustrates a demodulated baseband signal **5912**, which is generated by the down-conversion process. Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **916**, essentially no IF is produced. The only substantial aliased component is the baseband signal. The demodulated baseband signal **5912** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The demodulated baseband signal **5912** includes portions **5910**A, which correlate with the energy transfer pulses **5907** in FIG. **59**C, and portions **5910**B, which are between the energy transfer pulses **5907**. Portions **5910**A represent energy transferred from the analog PM carrier signal **916** to a storage device, while simultaneously driving an output load. The portions **5910**A occur when a switching module is closed by the energy transfer pulses **5907**. Portions **5910**B represent energy stored in a storage device continuing to drive the load. Portions **5910**B occur when the switching module is opened after energy transfer pulses **5907**.

In FIG. **59**F, a demodulated baseband signal **5916** represents a filtered version of the demodulated baseband signal **5912**, on a compressed time scale. The demodulated baseband signal **5916** is substantially similar to the modulating baseband signal **210** and can be further processed using any signal processing technique(s) without further down-conversion or demodulation.

The present invention can output the unfiltered demodulated baseband **5912**, the filtered demodulated baseband signal **5916**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

The drawings referred to herein illustrate direct down-conversion in accordance with the invention. For example, the demodulated baseband signals **5912** in FIG. **59**E and **5916** in FIG. **59**F illustrate that the analog PM carrier signal **916** was successfully down-converted to a demodulated baseband signal by retaining enough baseband information for sufficient reconstruction.

2.2.2.1.2 Digital PM Carrier Signal

A process for directly down-converting the digital PM carrier signal **1016** in FIG. **6**C to a demodulated baseband signal is now described for the flowchart **4613** in FIG. **46**C. The digital PM carrier signal **1016** is re-illustrated in **60**A for convenience. For this example, the digital PM carrier signal **1016** oscillates at approximately 900 MHZ. In FIG. **60**B, a digital PM carrier signal portion **6004** illustrates a portion of the digital PM carrier signal **1016** on an expanded time scale.

The process begins at step **4614**, which includes receiving an EM signal. This is represented by the digital PM carrier signal **1016**.

Step **4616** includes receiving an energy transfer signal F_{AR}. In FIG. **60**C, an example energy transfer signal **6006** is illustrated on approximately the same time scale as FIG. **60**B. The energy transfer signal **6006** includes a train of energy transfer pulses **6007** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **6007** repeat at the aliasing rate, which is determined or selected as previously described. Generally, when directly down-converting an EM signal to a demodulated baseband signal, the aliasing rate F_{AR} is substantially equal to a harmonic or, more typically, a sub-harmonic of the EM signal.

Step **4618** includes transferring energy from the EM signal at the aliasing rate to directly down-convert the EM signal to the demodulated baseband signal F_{DMB}. In FIG. **60**D, an affected digital PM carrier signal **6008** illustrates effects of transferring energy from the digital PM carrier signal **1016** at the aliasing rate F_{AR}. The affected digital PM carrier signal **6008** is illustrated on substantially the same time scale as FIGS. **60**B and **60**C.

FIG. **60**E illustrates a demodulated baseband signal **6012**, which is generated by the down-conversion process. Because a harmonic of the aliasing rate is substantially equal to the frequency of the signal **1016**, essentially no IF is produced. The only substantial aliased component is the baseband signal. The demodulated baseband signal **6012** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The demodulated baseband signal **6012** includes portions **6010**A, which correlate with the energy transfer pulses **6007** in FIG. **60**C, and portions **6010**B, which are between the energy transfer pulses **6007**. Portions **6010**A represent energy transferred from the digital PM carrier signal **1016** to a storage device, while simultaneously driving an output load. The portions **6010**A occur when a switching module is closed by the energy transfer pulses **607**. Portions **6010**B represent energy stored in a storage device continuing to drive the load. Portions **6010**B occur when the switching module is opened after energy transfer pulses **6007**.

In FIG. **60**F, a demodulated baseband signal **6016** represents a filtered version of the demodulated baseband signal **6012**, on a compressed time scale. The demodulated baseband signal **6016** is substantially similar to the modulating baseband signal **310** and can be further processed using any signal processing technique(s) without further down-conversion or demodulation.

The present invention can output the unfiltered demodulated baseband signal **6012**, the filtered demodulated baseband signal **6016**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention.

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

The drawings referred to herein illustrate direct down-conversion in accordance with the invention. For example, the demodulated baseband signals **6012** in FIG. **60**E and **6016** in FIG. **60**F illustrate that the digital PM carrier signal **1016** was successfully down-converted to a demodulated baseband signal by retaining enough baseband information for sufficient reconstruction.

2.2.2.2 Structural Description

In an embodiment, the energy transfer system **6302** preferably transfers energy from an EM signal to directly down-convert it to a demodulated baseband signal in the manner shown in the operational flowchart **4613**. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **1413**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

Operation of the energy transfer system **6302** is now described for the analog PM carrier signal **916**, with reference to the flowchart **4613** and the timing diagrams in FIGS. **59**A–F. In step **4614**, the energy transfer module **6304** receives the analog PM carrier signal **916**. In step **4616**, the energy transfer module **6304** receives the energy transfer signal **5906**. In step **4618**, the energy transfer module **6304** transfers energy from the analog PM carrier signal **916** at the aliasing rate of the energy transfer signal **5906**, to directly down-convert the analog PM carrier signal **916** to the demodulated baseband signals **5912** or **5916**.

Operation of the energy transfer system **6302** is now described for the digital PM carrier signal **1016**, with reference to the flowchart **4613** and to the timing diagrams in FIGS. **60**A–F. In step **4614**, the energy transfer module **6304** receives the digital PM carrier signal **1016**. In step **4616**, the energy transfer module **6304** receives the energy transfer signal **6006**. In step **4618**, the energy transfer module **6304** transfers energy from the digital PM carrier signal **1016** at the aliasing rate of the energy transfer signal **6006**, to directly down-convert the digital PM carrier signal **1016** to the demodulated baseband signal **6012** or **6016**.

Example implementations of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

2.2.3 Other Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention. Example implementations of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

2.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. These implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

3. MODULATION CONVERSION

In an embodiment, the invention down-converts an FM carrier signal F_{FMC} to a non-FM signal $F_{(NON\text{-}FM)}$, by transferring energy from the FM carrier signal F_{FMC} at an aliasing rate. This embodiment is illustrated in FIG. **45**B as **4518**.

In an example embodiment, the FM carrier signal F_{FMC} is down-converted to a phase modulated (PM) signal F_{PM}. In another example embodiment, the FM carrier signal F_{FMC} is down-converted to an amplitude modulated (AM) signal F_{AM}. The down-converted signal can be demodulated with any conventional demodulation technique to obtain a demodulated baseband signal F_{DMB}.

The invention can be implemented with any type of FM signal. Exemplary embodiments are provided below for down-converting a frequency shift keying (FSK) signal to a non-FSK signal. FSK is a sub-set of FM, wherein an FM signal shifts or switches between two or more frequencies. FSK is typically used for digital modulating baseband signals, such as the digital modulating baseband signal **310** in FIG. **3**. For example, in FIG. **8**, the digital FM signal **816** is an FSK signal that shifts between an upper frequency and a lower frequency, corresponding to amplitude shifts in the digital modulating baseband signal **310**. The FSK signal **816** is used in example embodiments below.

In a first example embodiment, energy is transferred from the FSK signal **816** at an aliasing rate that is based on a mid-point between the upper and lower frequencies of the FSK signal **816**. When the aliasing rate is based on the mid-point, the FSK signal **816** is down-converted to a phase shift keying (PSK) signal. PSK is a sub-set of phase modulation, wherein a PM signal shifts or switches between two or more phases. PSK is typically used for digital modulating baseband signals. For example, in FIG. **10**, the digital PM signal **1016** is a PSK signal that shifts between two phases. The PSK signal **1016** can be demodulated by any conventional PSK demodulation technique(s).

In a second example embodiment, energy is transferred from the FSK signal **816** at an aliasing rate that is based upon either the upper frequency or the lower frequency of the FSK signal **816**. When the aliasing rate is based upon the upper frequency or the lower frequency of the FSK signal **816**, the FSK signal **816** is down-converted to an amplitude shift keying (ASK) signal. ASK is a sub-set of amplitude modulation, wherein an AM signal shifts or switches between two or more amplitudes. ASK is typically used for digital modulating baseband signals. For example, in FIG. **6**, the digital AM signal **616** is an ASK signal that shifts between the first amplitude and the second amplitude. The ASK signal **616** can be demodulated by any conventional ASK demodulation technique(s).

The following sections describe methods for transferring energy from an FM carrier signal F_{FMC} to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$. Exemplary structural embodiments for implementing the methods are also described. It should be understood that the invention is not limited to the particular embodiments described below. Equivalents, extensions, variations, deviations, etc., of the following will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such equivalents, extensions, variations, deviations, etc., are within the scope and spirit of the present invention.

The following sections include a high level discussion, example embodiments, and implementation examples.

3.1 High Level Description

This section (including its subsections) provides a high-level description of transferring energy from the FM carrier signal F_{FM} to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$, according to the invention. In particular, an operational process for down-converting the FM carrier signal F_{FM} to the non-FM signal $F_{(NON\text{-}FM)}$ is described at a high-level. Also, a structural implementation for implementing this process is described at a high-level. The structural implementation is described herein for illustrative purposes, and is not limiting. In particular, the process described in this section can be achieved using any number of structural implementations, one of which is described in this section. The details of such structural implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein.

3.1.1 Operational Description

FIG. **46**D depicts a flowchart **4619** that illustrates an exemplary method for down-converting the FM carrier signal F_{FMC} to the non-FM signal $F_{(NON\text{-}FM)}$. The exemplary method illustrated in the flowchart **4619** is an embodiment of the flowchart **4601** in FIG. **46**A.

Any and all forms of frequency modulation techniques are valid for this invention. For ease of discussion, the digital FM carrier (FSK) signal **816** is used to illustrate a high level operational description of the invention. Subsequent sections provide detailed flowcharts and descriptions for the FSK signal **816**. Upon reading the disclosure and examples therein, one skilled in the relevant art(s) will understand that the invention can be implemented to down-convert any type of FM signal.

The method illustrated in the flowchart **4619** is described below at a high level for down-converting the FSK signal **816** in FIG. **8**C to a PSK signal. The FSK signal **816** is re-illustrated in FIG. **84**A for convenience.

The process of the flowchart **4619** begins at step **4620**, which includes receiving an FM signal. This is represented by the FSK signal **816**. The FSK signal **816** shifts between a first frequency **8410** and a second frequency **8412**. The first frequency **8410** can be higher or lower than the second frequency **8412**. In an exemplary embodiment, the first frequency **8410** is approximately 899 MHZ and the second frequency **8412** is approximately 901 MHZ.

Step **4622** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **84**B illustrates an example energy transfer signal **8402** which includes a train of energy transfer pulses **8403** having non-negligible apertures **8405** that tend away from zero time in duration.

The energy transfer pulses **8403** repeat at the aliasing rate F_{AR}, which is determined or selected as previously described. Generally, when down-converting an FM carrier signal F_{FMC} to a non-FM signal $F_{(NON\text{-}FM)}$, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of a frequency within the FM signal. In this example overview embodiment, where the FSK signal **816** is to be down-converted to a PSK signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of the mid-point between the first frequency **8410** and the second frequency **8412**. For the present example, the mid-point is approximately 900 MHZ.

Step **4624** includes transferring energy from the FM carrier signal FEmc at the aliasing rate to down-convert the FM signal F_{FMC} to the non-FM signal $F_{(NON\text{-}FM)}$. FIG. **84**C illustrates a PSK signal **8404**, which is generated by the modulation conversion process.

When the second frequency **8412** is under-sampled, the PSK signal **8404** has a frequency of approximately 1 MHZ and is used as a phase reference. When the first frequency **8410** is under-sampled, the PSK signal **8404** has a frequency of 1 MHZ and is phase shifted 180 degrees from the phase reference.

FIG. **84**D depicts a PSK signal **8406**, which is a filtered version of the PSK signal **8404**. The invention can thus generate a filtered output signal, a partially filtered output signal, or a relatively unfiltered stair step output signal. The choice between filtered, partially filtered and non-filtered output signals is generally a design choice that depends upon the application of the invention.

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

Detailed exemplary embodiments for down-converting an FSK signal to a PSK signal and for down-converting an FSK signal to an ASK signal are provided below.

3.1.2 Structural Description

FIG. **63** illustrates the energy transfer system **6302** according to an embodiment of the invention. The energy transfer system **6302** includes the energy transfer module **6304**. The energy transfer system **6302** is an example embodiment of the generic aliasing system **1302** in FIG. **13**.

In a modulation conversion embodiment, the EM signal **1304** is an FM carrier signal F_{FMC} and the energy transfer module **6304** transfers energy from FM carrier signal at a harmonic or, more typically, a sub-harmonic of a frequency within the FM frequency band. Preferably, the energy transfer module **6304** transfers energy from the FM carrier signal F_{FMC} to down-convert it to a non-FM signal $F_{(NON\text{-}FM)}$ in the manner shown in the operational flowchart **4619**. But it should be understood that the scope and spirit of the invention includes other structural embodiments for performing the steps of the flowchart **4619**. The specifics of the other structural embodiments will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

The operation of the energy transfer system **6302** shall now be described with reference to the flowchart **4619** and the timing diagrams of FIGS. **84**A–**84**D. In step **4620**, the energy transfer module **6304** receives the FSK signal **816**. In step **4622**, the energy transfer module **6304** receives the energy transfer signal **8402**. In step **4624**, the energy transfer module **6304** transfers energy from the FSK signal **816** at the aliasing rate of the energy transfer signal **8402** to down-convert the FSK signal **816** to the PSK signal **8404** or **8406**.

Example implementations of the energy transfer module **6304** are provided in Section 4 below.

3.2 Example Embodiments

Various embodiments related to the method(s) and structure(s) described above are presented in this section (and its subsections). These embodiments are described herein for purposes of illustration, and not limitation. The invention is not limited to these embodiments. Alternate embodiments (including equivalents, extensions, variations, deviations, etc., of the embodiments described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

The method for down-converting an FM carrier signal F_{FMC} to a non-FM signal, $F_{(NON\text{-}FM)}$, illustrated in the flowchart **4619** of FIG. **46**D, can be implemented with any type of FM carrier signal including, but not limited to, FSK signals. The flowchart **4619** is described in detail below for down-converting an FSK signal to a PSK signal and for down-converting an FSK signal to an ASK signal. The exemplary descriptions below are intended to facilitate an understanding of the present invention. The present invention is not limited to or by the exemplary embodiments below.

3.2.1 First Example Embodiment: Down-Converting an FM Signal to a PM Signal

3.2.1.1 Operational Description

A process for down-converting the FSK signal **816** in FIG. **8**C to a PSK signal is now described for the flowchart **4619** in FIG. **46**D.

The FSK signal **816** is re-illustrated in FIG. **61**A for convenience. The FSK signal **816** shifts between a first frequency **6106** and a second frequency **6108**. In the exemplary embodiment, the first frequency **6106** is lower than the second frequency **6108**. In an alternative embodiment, the first frequency **6106** is higher than the second frequency **6108**. For this example, the first frequency **6106** is approximately 899 MHZ and the second frequency **6108** is approximately 901 MHZ.

FIG. **61**B illustrates an FSK signal portion **6104** that represents a portion of the FSK signal **816** on an expanded time scale.

The process begins at step **4620**, which includes receiving an FM signal. This is represented by the FSK signal **816**.

Step **4622** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **61**C illustrates an example energy transfer signal **6107** on approximately the same time scale as FIG. **61**B. The energy transfer signal **6107** includes a train of energy transfer pulses **6109** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **6109** repeat at the aliasing rate F_{AR}, which is determined or selected as described above. Generally, when down-converting an FM signal to a non-FM signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of a frequency within the FM signal.

In this example, where an FSK signal is being down-converted to a PSK signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic, of the mid-point between the frequencies **6106** and **6108**. In this example, where the first frequency **6106** is 899 MHZ and second frequency **6108** is 901 MHZ, the mid-point is approximately 900 MHZ. Suitable aliasing rates thus include 1.8 GHZ, 900 MHZ, 450 MHZ, etc.

Step **4624** includes transferring energy from the FM signal at the aliasing rate to down-convert it to the non-FM signal $F_{(NON\text{-}FM)}$. In FIG. **61**D, an affected FSK signal **6118** illustrates effects of transferring energy from the FSK signal **816** at the aliasing rate F_{AR}. The affected FSK signal **6118** is illustrated on substantially the same time scale as FIGS. **61**B and **61**C.

FIG. **61**E illustrates a PSK signal **6112**, which is generated by the modulation conversion process. PSK signal **6112** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The PSK signal **6112** includes portions **611**A, which correlate with the energy transfer pulses **6107** in FIG. **61**C. The PSK signal **6112** also includes portions **6110**B, which are between the energy transfer pulses **6109**. Portions **6110**A represent energy transferred from the FSK **816** to a storage device, while simultaneously driving an output load. The portions **6110**A occur when a switching module is closed by the energy transfer pulses **6109**. Portions **6110**B represent energy stored in a storage device continuing to drive the load. Portions **6110**B occur when the switching module is opened after energy transfer pulses **6107**.

In FIG. **61**F, a PSK signal **6114** represents a filtered version of the PSK signal **6112**, on a compressed time scale. The present invention can output the unfiltered demodulated baseband signal **6112**, the filtered demodulated baseband signal **6114**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention. The PSK signals **6112** and **6114** can be demodulated with a conventional demodulation technique(s).

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and polarity, as desired.

The drawings referred to herein illustrate modulation conversion in accordance with the invention. For example, the PSK signals **6112** in FIG. **61**E and **6114** in FIG. **61**F illustrate that the FSK signal **816** was successfully down-converted to a PSK signal by retaining enough baseband information for sufficient reconstruction.

3.2.1.2 Structural Description

The operation of the energy transfer system **1602** is now described for down-converting the FSK signal **816** to a PSK signal, with reference to the flowchart **4619** and to the timing diagrams of FIGS. **61**A–E. In step **4620**, the energy transfer module **1606** receives the FSK signal **816** (FIG. **61**A). In step **4622**, the energy transfer module **1606** receives the energy transfer signal **6107** (FIG. **61**C). In step **4624**, the energy transfer module **1606** transfers energy from the FSK signal **816** at the aliasing rate of the energy transfer signal **6107** to down-convert the FSK signal **816** to the PSK signal **6112** in FIG. **61**E or the PSK signal **6114** in FIG. **61**F.

3.2.2 Second Example Embodiment: Down-Converting an FM Signal to an AM Signal

3.2.2.1 Operational Description

A process for down-converting the FSK signal **816** in FIG. **8**C to an ASK signal is now described for the flowchart **4619** in FIG. **46**D.

The FSK signal **816** is re-illustrated in FIG. **62**A for convenience. The FSK signal **816** shifts between a first frequency **6206** and a second frequency **6208**. In the exemplary embodiment, the first frequency **6206** is lower than the second frequency **6208**. In an alternative embodiment, the first frequency **6206** is higher than the second frequency

6208. For this example, the first frequency **6206** is approximately 899 MHZ and the second frequency **6208** is approximately 901 MHZ.

FIG. **62**B illustrates an FSK signal portion **6204** that represents a portion of the FSK signal **816** on an expanded time scale.

The process begins at step **4620**, which includes receiving an FM signal. This is represented by the FSK signal **816**.

Step **4622** includes receiving an energy transfer signal having an aliasing rate F_{AR}. FIG. **62**C illustrates an example energy transfer signal **6207** on approximately the same time scale as FIG. **62**B. The energy transfer signal **6207** includes a train of energy transfer pulses **6209** having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses **6209** repeat at the aliasing rate F_{AR}, which is determined or selected as described above. Generally, when down-converting an FM signal to a non-FM signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic of a frequency within the FM signal.

In this example, where an FSK signal is being down-converted to an ASK signal, the aliasing rate is substantially equal to a harmonic or, more typically, a sub-harmonic, of either the first frequency **6206** or the second frequency **6208**. In this example, where the first frequency **6206** is 899 MHZ and the second frequency **6208** is 901 MHZ, the aliasing rate can be substantially equal to a harmonic or sub-harmonic of 899 MHZ or 901 MHZ.

Step **4624** includes transferring energy from the FM signal at the aliasing rate to down-convert it to the non-FM signal $F_{(NON-FM)}$. In FIG. **62**D, an affected FSK signal **6218** illustrates effects of transferring energy from the FSK signal **816** at the aliasing rate F_{AR}. The affected FSK signal **6218** is illustrated on substantially the same time scale as FIGS. **62**B and **62**C.

FIG. **62**E illustrates an ASK signal **6212**, which is generated by the modulation conversion process. ASK signal **6212** is illustrated with an arbitrary load impedance. Load impedance optimizations are discussed in Section 5 below.

The ASK signal **6212** includes portions **6210**A, which correlate with the energy transfer pulses **6209** in FIG. **62**C. The ASK signal **6212** also includes portions **6210**B, which are between the energy transfer pulses **6209**. Portions **6210**A represent energy transferred from the FSK **816** to a storage device, while simultaneously driving an output load. Portions **6210**A occur when a switching module is closed by the energy transfer pulses **6207**. Portions **6210**B represent energy stored in a storage device continuing to drive the load. Portions **6210**B occur when the switching module is opened after energy transfer pulses **6207**.

FIG. **62**F, an ASK signal **6214** represents a filtered version of the ASK signal **6212**, on a compressed time scale. The present invention can output the unfiltered demodulated baseband signal **6212**, the filtered demodulated baseband signal **6214**, a partially filtered demodulated baseband signal, a stair step output signal, etc. The choice between these embodiments is generally a design choice that depends upon the application of the invention. The ASK signals **6212** and **6214** can be demodulated with a conventional demodulation technique(s).

The aliasing rate of the energy transfer signal is preferably controlled to optimize the down-converted signal for amplitude output and/or polarity, as desired.

The drawings referred to herein illustrate modulation conversion in accordance with the invention. For example, the ASK signals **6212** in FIG. **62**E and **6214** in FIG. **62**F illustrate that the FSK signal **816** was successfully down-converted to an ASK signal by retaining enough baseband information for sufficient reconstruction.

3.2.2.2 Structural Description

The operation of the energy transfer system **6302** is now described for down-converting the FSK signal **816** to an ASK signal, with reference to the flowchart **4619** and to the timing diagrams of FIGS. **62**A–F. In step **4620**, the energy transfer module **6304** receives the FSK signal **816** (FIG. **62**A). In step **4622**, the energy transfer module **6304** receives the energy transfer signal **6207** (FIG. **62**C). In step **4624**, the energy transfer module **6304** transfers energy from the FSK signal **818** at the aliasing rate of the energy transfer signal **6207** to down-convert the FSK signal **816** to the ASK signal **6212** in FIG. **62**E or the ASK signal **6214** in FIG. **62**F.

3.2.3 Other Example Embodiments

The embodiments described above are provided for purposes of illustration. These embodiments are not intended to limit the invention. Alternate embodiments, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate embodiments fall within the scope and spirit of the present invention.

Example implementations of the energy transfer module **6304** are disclosed in Sections 4 and 5 below.

3.3 Implementation Examples

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in Sections 4 and 5 below. These implementations are presented for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described therein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

4. IMPLEMENTATION EXAMPLES

Exemplary operational and/or structural implementations related to the method(s), structure(s), and/or embodiments described above are presented in this section (and its subsections). These implementations are presented herein for purposes of illustration, and not limitation. The invention is not limited to the particular implementation examples described herein. Alternate implementations (including equivalents, extensions, variations, deviations, etc., of those described herein) will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

FIG. **63** illustrates an energy transfer system **6302**, which is an exemplary embodiment of the generic aliasing system **1302** in FIG. **13**. The energy transfer system **6302** includes an energy transfer module **6304**, which receives the EM signal **1304** and an energy transfer signal **6306**. The energy transfer signal **6306** includes a train of energy transfer pulses having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses repeat at an aliasing rate F_{AR}.

The energy transfer module **6304** transfers energy from the EM signal **1304** at the aliasing rate of the energy transfer signal **6306**, as described in the sections above with respect to the flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D. The energy transfer module **6304** outputs a down-converted signal **1308**B, which includes non-negligible amounts of energy transferred from the EM signal **1304**.

FIG. **64**A illustrates an exemplary gated transfer system **6402**, which is an example of the energy transfer system **6302**. The gated transfer system **6402** includes a gated transfer module **6404**, which is described below.

FIG. **64**B illustrates an exemplary inverted gated transfer system **6406**, which is an alternative example of the energy transfer system **6302**. The inverted gated transfer system **6406** includes an inverted gated transfer module **6408**, which is described below.

4.1 The Energy Transfer System as a Gated Transfer System

FIG. **64**A illustrates the exemplary gated transfer system **6402**, which is an exemplary implementation of the energy transfer system **6302**. The gated transfer system **6402** includes the gated transfer module **6404**, which receives the EM signal **1304** and the energy transfer signal **6306**. The energy transfer signal **6306** includes a train of energy transfer pulses having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses repeat at an aliasing rate F_{AR}.

The gated transfer module **6404** transfers energy from the EM signal **1304** at the aliasing rate of the energy transfer signal **6306**, as described in the sections above with respect to the flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D. The gated transfer module **6404** outputs the down-onverted signal **1308**B, which includes non-negligible amounts of energy transferred from the EM signal **1304**.

4.1.1 The Gated Transfer System as a Switch Module and a Storage Module

FIG. **65** illustrates an example embodiment of the gated transfer module **6404** as including a switch module **6502** and a storage module **6506**. Preferably, the switch module **6502** and the storage module **6506** transfer energy from the EM signal **1304** to down-convert it in any of the manners shown in the operational flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D.

For example, operation of the switch module **6502** and the storage module **6506** is now described for down-converting the EM signal **1304** to an intermediate signal, with reference to the flowchart **4607** and the example timing diagrams in FIGS. **83**A–F.

In step **4608**, the switch module **6502** receives the EM signal **1304** (FIG. **83**A). In step **4610**, the switch module **6502** receives the energy transfer signal **6306** (FIG. **83**C). In step **4612**, the switch module **6502** and the storage module **6506** cooperate to transfer energy from the EM signal **1304** and down-convert it to an intermediate signal. More specifically, during step **4612**, the switch module **6502** closes during each energy transfer pulse to couple the EM signal **1304** to the storage module **6506**. In an embodiment, the switch module **6502** closes on rising edges of the energy transfer pulses. In an alternative embodiment, the switch module **6502** closes on falling edges of the energy transfer pulses. While the EM signal **1304** is coupled to the storage module **6506**, non-negligible amounts of energy are transferred from the EM signal **1304** to the storage module **6506**. FIG. **83**B illustrates the EM signal **1304** after the energy is transferred from it. FIG. **83**D illustrates the transferred energy stored in the storage module **6506**. The storage module **6506** outputs the transferred energy as the down-converted signal **1308**B. The storage module **6506** can output the down-converted signal **1308**B as an unfiltered signal such as signal shown in FIG. **83**E, or as a filtered down-converted signal (FIG. **83**F).

4.1.2 The Gated Transfer System as Break-Before-Make Module

FIG. **67**A illustrates an example embodiment of the gated transfer module **6404** as including a break-before-make module **6702** and a storage module **6716**. Preferably, the break before make module **6702** and the storage module **6716** transfer energy from the EM signal **1304** to down-convert it in any of the manners shown in the operational flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D.

In FIG. **67**A, the break-before-make module **6702** includes a includes a normally open switch **6704** and a normally closed switch **6706**. The normally open switch **6704** is controlled by the energy transfer signal **6306**. The normally closed switch **6706** is controlled by an isolation signal **6712**. In an embodiment, the isolation signal **6712** is generated from the energy transfer signal **6306**. Alternatively, the energy transfer signal **6306** is generated from the isolation signal **6712**. Alternatively, the isolation signal **6712** is generated independently from the energy transfer signal **6306**. The break-before-make module **6702** substantially isolates an input **6708** from an output **6710**.

FIG. **67**B illustrates an example timing diagram of the energy transfer signal **6306**, which controls the normally open switch **6704**. FIG. **67**C illustrates an example timing diagram of the isolation signal **6712**, which controls the normally closed switch **6706**. Operation of the break-before-make module **6702** is now described with reference to the example timing diagrams in FIGS. **67**B and **67**C.

Prior to time t0, the normally open switch **6704** and the normally closed switch **6706** are at their normal states.

At time t0, the isolation signal **6712** in FIG. **67**C opens the normally closed switch **6706**. Thus, just after time t0, the normally open switch **6704** and the normally closed switch **6706** are open and the input **6708** is isolated from the output **6710**.

At time t1, the energy transfer signal **6306** in FIG. **67**B closes the normally open switch **6704** for the non-negligible duration of a pulse. This couples the EM signal **1304** to the storage module **6716**.

Prior to t2, the energy transfer signal **6306** in FIG. **67**B opens the normally open switch **6704**. This de-couples the EM signal **1304** from the storage module **6716**.

At time t2, the isolation signal **6712** in FIG. **67**C closes the normally closed switch **6706**. This couples the storage module **6716** to the output **6710**.

The storage module **6716**, is similar to the storage module **6506** FIG. **65**. The break-before-make gated transfer system **6701** down-converts the EM signal **1304** in a manner similar to that described with reference to the gated transfer system **6501** in FIG. **65**.

4.1.3 Example Implementations of the Switch Module

The switch module **6502** in FIG. **65** and the switch modules **6704** and **6706** in FIG. **67**A can be any type of switch device that preferably has a relatively low impedance when closed and a relatively high impedance when open. The switch modules **6502**, **6704** and **6706** can be implemented with normally open or normally closed switches. The switch modules need not be ideal switch modules.

FIG. **66**B illustrates the switch modules **6502**, **6704** and **6706** as a switch module **6610**. Switch module **6610** can be implemented in either normally open or normally closed architecture. The switch module **6610** (e.g., switch modules **6502**, **6704** and **6706**) can be implemented with any type of suitable switch device, including, but not limited, to mechanical switch devices and electrical switch devices, optical switch devices, etc., and combinations thereof. Such devices include, but are not limited to transistor switch devices, diode switch devices, relay switch devices, optical switch devices, micro-machine switch devices, etc., or combinations thereof.

In an embodiment, the switch module **6610** can be implemented as a transistor, such as, for example, a field effect transistor (FET), a bi-polar transistor, or any other suitable circuit switching device.

In FIG. **66**A, the switch module **6610** is illustrated as a FET **6602**. The FET **6602** can be any type of FET, including, but not limited to, a MOSFET, a JFET, a GaAsFET, etc. The FET **6602** includes a gate **6604**, a source **6606** and a drain **6608**. The gate **6604** receives the energy transfer signal **6306** to control the switching action between the source **6606** and the drain **6608**. In an embodiment, the source **6606** and the drain **6608** are interchangeable.

It should be understood that the illustration of the switch module **6610** as a FET **6602** in FIG. **66**A is for example purposes only. Any device having switching capabilities could be used to implement the switch module **6610** (i.e., switch modules **6502**, **6704** and **6706**), as will be apparent to persons skilled in the relevant art(s) based on the discussion contained herein.

In FIG. **66**C, the switch module **6610** is illustrated as a diode switch **6612**, which operates as a two lead device when the energy transfer signal **6306** is coupled to the output **6613**.

In FIG. **66**D, the switch module **6610** is illustrated as a diode switch **6614**, which operates as a two lead device when the energy transfer signal **6306** is coupled to the output **6615**.

4.1.4 Example Implementations of the Storage Module

The storage modules **6506** and **6716** store non-negligible amounts of energy from the EM signal **1304**. In an exemplary embodiment, the storage modules **6506** and **6716** are implemented as a reactive storage module **6801** in FIG. **68**A, although the invention is not limited to this embodiment. A reactive storage module is a storage module that employs one or more reactive electrical components to store energy transferred from the EM signal **1304**. Reactive electrical components include, but are not limited to, capacitors and inductors.

In an embodiment, the storage modules **6506** and **6716** include one or more capacitive storage elements, illustrated in FIG. **68**B as a capacitive storage module **6802**. In FIG. **68**C, the capacitive storage module **6802** is illustrated as one or more capacitors illustrated generally as capacitor(s) **6804**.

The goal of the storage modules **6506** and **6716** is to store non-negligible amounts of energy transferred from the EM signal **1304**. Amplitude reproduction of the original, unaffected EM input signal is not necessarily important. In an energy transfer environment, the storage module preferably has the capacity to handle the power being transferred, and to allow it to accept a non-negligible amount of power during a non-negligible aperture period.

A terminal **6806** serves as an output of the capacitive storage module **6802**. The capacitive storage module **6802** provides the stored energy at the terminal **6806**. FIG. **68**F illustrates the capacitive storage module **6802** as including a series capacitor **6812**, which can be utilized in an inverted gated transfer system described below.

In an alternative embodiment, the storage modules **6506** and **6716** include one or more inductive storage elements, illustrated in FIG. **68**D as an inductive storage module **6808**.

In an alternative embodiment, the storage modules **6506** and **6716** include a combination of one or more capacitive storage elements and one or more inductive storage elements, illustrated in FIG. **68**E as a capacitive/inductive storage module **6810**.

FIG. **68**G illustrates an integrated gated transfer system **6818** that can be implemented to down-convert the EM signal **1304** as illustrated in, and described with reference to, FIGS. **83**A–F.

4.1.5 Optional Energy Transfer Signal Module

FIG. **69** illustrates an energy transfer system **6901**, which is an example embodiment of the energy transfer system **6302**. The energy transfer system **6901** includes an optional energy transfer signal module **6902**, which can perform any of a variety of functions or combinations of functions including, but not limited to, generating the energy transfer signal **6306**.

In an embodiment, the optional energy transfer signal module **6902** includes an aperture generator, an example of which is illustrated in FIG. **68**J as an aperture generator **6820**. The aperture generator **6820** generates non-negligible aperture pulses **6826** from an input signal **6824**. The input signal **6824** can be any type of periodic signal, including, but not limited to, a sinusoid, a square wave, a saw-tooth wave, etc. Systems for generating the input signal **6824** are described below.

The width or aperture of the pulses **6826** is determined by delay through the branch **6822** of the aperture generator **6820**. Generally, as the desired pulse width increases, the difficulty in meeting the requirements of the aperture generator **6820** decrease. In other words, to generate non-negligible aperture pulses for a given EM input frequency, the components utilized in the example aperture generator **6820** do not require as fast reaction times as those that are required in an under-sampling system operating with the same EM input frequency.

The example logic and implementation shown in the aperture generator **6820** are provided for illustrative purposes only, and are not limiting. The actual logic employed can take many forms. The example aperture generator **6820** includes an optional inverter **6828**, which is shown for polarity consistency with other examples provided herein.

An example implementation of the aperture generator **6820** is illustrated in FIG. **68**K. Additional examples of aperture generation logic are provided in FIGS. **68**H and **68**I. FIG. **68**H illustrates a rising edge pulse generator **6840**, which generates pulses **6826** on rising edges of the input signal **6824**. FIG. **68**I illustrates a falling edge pulse generator **6850**, which generates pulses **6826** on falling edges of the input signal **6824**.

In an embodiment, the input signal **6824** is generated externally of the energy transfer signal module **6902**, as illustrated in FIG. **69**. Alternatively, the input signal **6924** is generated internally by the energy transfer signal module **6902**. The input signal **6824** can be generated by an oscillator, as illustrated in FIG. **68**L by an oscillator **6830**. The oscillator **6830** can be internal to the energy transfer signal module **6902** or external to the energy transfer signal module **6902**. The oscillator **6830** can be external to the energy transfer system **6901**. The output of the oscillator **6830** may be any periodic waveform.

The type of down-conversion performed by the energy transfer system **6901** depends upon the aliasing rate of the energy transfer signal **6306**, which is determined by the frequency of the pulses **6826**. The frequency of the pulses **6826** is determined by the frequency of the input signal **6824**. For example, when the frequency of the input signal

6824 is substantially equal to a harmonic or a sub-harmonic of the EM signal **1304**, the EM signal **1304** is directly down-converted to baseband (e.g. when the EM signal is an AM signal or a PM signal), or converted from FM to a non-FM signal. When the frequency of the input signal **6824** is substantially equal to a harmonic or a sub-harmonic of a difference frequency, the EM signal **1304** is down-converted to an intermediate signal.

The optional energy transfer signal module **6902** can be implemented in hardware, software, firmware, or any combination thereof.

4.2 The Energy Transfer System as an Inverted Gated Transfer System

FIG. **64**B illustrates an exemplary inverted gated transfer system **6406**, which is an exemplary implementation of the energy transfer system **6302**. The inverted gated transfer system **6406** includes an inverted gated transfer module **6408**, which receives the EM signal **1304** and the energy transfer signal **6306**. The energy transfer signal **6306** includes a train of energy transfer pulses having non-negligible apertures that tend away from zero time in duration. The energy transfer pulses repeat at an aliasing rate F_{AR}. The inverted gated transfer module **6408** transfers energy from the EM signal **1304** at the aliasing rate of the energy transfer signal **6306**, as described in the sections above with respect to the flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D. The inverted gated transfer module **6408** outputs the down-converted signal **1308**B, which includes non-negligible amounts of energy transferred from the EM signal **1304**.

4.2.1 The Inverted Gated Transfer System as a Switch Module and a Storage Module

FIG. **74** illustrates an example embodiment of the inverted gated transfer module **6408** as including a switch module **7404** and a storage module **7406**. Preferably, the switch module **7404** and the storage module **7406** transfer energy from the EM signal **1304** to down-convert it in any of the manners shown in the operational flowcharts **4601** in FIG. **46**A, **4607** in FIG. **46**B, **4613** in FIG. **46**C and **4619** in FIG. **46**D.

The switch module **7404** can be implemented as described above with reference to FIGS. **66**A–D. The storage module **7406** can be implemented as described above with reference to FIGS. **68**A–F.

In the illustrated embodiment, the storage module **7206** includes one or more capacitors **7408**. The capacitor(s) **7408** are selected to pass higher frequency components of the EM signal **1304** through to a terminal **7410**, regardless of the state of the switch module **7404**. The capacitor **7408** stores non-negligible amounts of energy from the EM signal **1304**. Thereafter, the signal at the terminal **7410** is off-set by an amount related to the energy stored in the capacitor **7408**.

Operation of the inverted gated transfer system **7401** is illustrated in FIGS. **75**A–F. FIG. **75**A illustrates the EM signal **1304**. FIG. **75**B illustrates the EM signal **1304** after transferring energy from it. FIG. **75**C illustrates the energy transfer signal **6306**, which includes a train of energy transfer pulses having non-negligible apertures.

FIG. **75**D illustrates an example down-converted signal **1308**B. FIG. **75**E illustrates the down-converted signal **1308**B on a compressed time scale. Since the storage module **7406** is a series element, the higher frequencies (e.g., RF) of the EM signal **1304** can be seen on the down-converted signal. This can be filtered as illustrated in FIG. **75**F.

The inverted gated transfer system **7401** can be used to down-convert any type of EM signal, including modulated carrier signals and unmodulated carrier signals.

4.3 Other Implementations

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

5. OPTIONAL OPTIMIZATIONS OF ENERGY TRANSFERAL AN ALIASING RATE

The methods and systems described in sections above can be optimized with one or more of the optimization methods or systems described below.

5.1 Doubling the Aliasing Rate (F_{AR}) of the Energy Transfer Signal

In an embodiment, the optional energy transfer signal module **6902** in FIG. **69** includes a pulse generator module that generates aliasing pulses at twice the frequency of the oscillating source. The input signal **6828** may be any suitable oscillating source.

FIG. **71** illustrates a circuit **7102** that generates a doubler output signal **7104** (FIG. **72**B) that may be used as an energy transfer signal **6306**. The circuit **7102** generates pulses on both rising and falling edges of the input oscillating signal **7106** of FIG. **72**A. The circuit **7102** can be implemented as a pulse generator and aliasing rate (F_{AR}) doubler. The doubler output signal **7104** can be used as the energy transfer signal **6306**.

In the example of FIG. **71**, the aliasing rate is twice the frequency of the input oscillating signal F_{OSC} **7106**, as shown by EQ. (9) below.

$$F_{AR}=2\cdot F_{OSC} \qquad \text{EQ. (9)}$$

The aperture width of the aliasing pulses is determined by the delay through a first inverter **7108** of FIG. **71**. As the delay is increased, the aperture is increased. A second inverter **7112** is shown to maintain polarity consistency with examples described elsewhere. In an alternate embodiment inverter **7112** is omitted. Preferably, the pulses have non-negligible aperture widths that tend away from zero time. The doubler output signal **7104** may be further conditioned as appropriate to drive the switch module with non-negligible aperture pulses. The circuit **7102** may be implemented with integrated circuitry, discretely, with equivalent logic circuitry, or with any valid fabrication technology.

5.2 Differential Implementations

The invention can be implemented in a variety of differential configurations. Differential configurations are useful for reducing common mode noise. This can be very useful in receiver systems where common mode interference can be caused by intentional or unintentional radiators such as cellular phones, CB radios, electrical appliances etc. Differential configurations are also useful in reducing any common mode noise due to charge injection of the switch in the switch module or due to the design and layout of the system in which the invention is used. Any spurious signal that is induced in equal magnitude and equal phase in both input leads of the invention will be substantially reduced or eliminated. Some differential configurations, including some of the configurations below, are also useful for increasing the voltage and/or for increasing the power of the down-converted signal **1308**B. While an example of a differential energy transfer module is shown below, the example is shown for the purpose of illustration, not limitation. Alternate embodiments (including equivalents, extensions, variations, deviations etc.) of the embodiment described herein will be apparent to those skilled in the relevant art based on the teachings contained herein. The invention is intended and adapted to include such alternate embodiments.

FIG. **76**A illustrates a differential system **7602** that can be included in the energy transfer module **6304**. The differential system **7602** includes an inverted gated transfer design similar to that described with reference to FIG. **74**. The differential system **7602** includes inputs **7604** and **7606** and outputs **7608** and **7610**. The differential system **7602** includes a first inverted gated transfer module **7612**, which includes a storage module **7614** and a switch module **7616**. The differential system **7602** also includes a second inverted gated transfer module **7618**, which includes a storage module **7620** and a switch module **7616**, which it shares in common with inverted gated transfer module **7612**.

One or both of the inputs **7604** and **7606** are coupled to an EM signal source. For example, the inputs can be coupled to an EM signal source, wherein the input voltages at the inputs **7604** and **7606** are substantially equal in amplitude but 180 degrees out of phase with one another. Alternatively, where dual inputs are unavailable, one of the inputs **7604** and **7606** can be coupled to ground.

In operation, when the switch module **7616** is closed, the storage modules **7614** and **7620** are in series and, provided they have similar capacitive values, accumulate charge of equal magnitude but opposite polarities. When the switch module **7616** is open, the voltage at the output **7608** is relative to the input **7604**, and the voltage at the output **7610** is relative to the voltage at the input **7606**.

Portions of the signals at the outputs **7608** and **7610** include signals resulting from energy stored in the storage modules **7614** and **7620**, respectively, when the switch module **7616** was closed. The portions of the signals at the outputs **7608** and **7610** resulting from the stored charge are generally equal in amplitude to one another but 180 degrees out of phase.

Portions of the signals at the outputs **7608** and **7610** also include ripple voltage or noise resulting from the switching action of the switch module **7616**. But because the switch module is positioned between the two outputs **7608** and **7610**, the noise introduced by the switch module appears at the outputs as substantially equal and in-phase with one another. As a result, the ripple voltage can be substantially canceled out by inverting the signal at one of the outputs **7608** or **7610** and adding it to the other remaining output. Additionally, any noise that is impressed with equal amplitude and equal phase onto the input terminals **7604** and **7606** by any other noise sources will tend to be canceled in the same way.

The differential system **7602** is most effective when used with a differential front end (inputs) and a differential back end (outputs). It can also be utilized in the following configurations, for example:

a) A single-input front end and a differential back end; and

b) A differential front end and a single-output back end.

Examples of these system are provided below.

5.2.1 Differential Input-to-Differential Output

FIG. **76**B illustrates the differential system **7602** wherein the inputs **7604** and **7606** are coupled to equal and opposite EM signal sources, illustrated here as dipole antennas **7624** and **7626**. In this embodiment, when one of the outputs **7608** or **7610** is inverted and added to the other output, the common mode noise due to the switching module **7616** and other common mode noise present at the input terminals **7604** and **7606** tend to substantially cancel out.

5.2.2 Single Input-to-Differential Output

FIG. **76**C illustrates the differential system **7602** wherein the input **7604** is coupled to an EM signal source such as a monopole antenna **7628** and the input **7606** is coupled to ground. In this configuration, the voltages at the outputs **7608** and **7610** are approximately one half the value of the voltages at the outputs in the implementation illustrated in FIG. **76**B, given all other parameters are equal.

FIG. **76**E illustrates an example single input to differential output receiver/down-converter system **7636**. The system **7636** includes the differential system **7602** wherein the input **7606** is coupled to ground as in FIG. **76**C. The input **7604** is coupled to an EM signal source **7638** through an optional input impedance match **7642**. The EM signal source impedance can be matched with an impedance match system **7642** as described in section 5 below.

The outputs **7608** and **7610** are coupled to a differential circuit **7644** such as a filter, which preferably inverts one of the outputs **7608** or **7610** and adds it to the other output **7608** or **7610**. This substantially cancels common mode noise generated by the switch module **7616**. The differential circuit **7644** preferably filters the higher frequency components of the EM signal **1304** that pass through the storage modules **7614** and **7620**. The resultant filtered signal is output as the down-converted signal **1308**B.

5.2.3 Differential Input-to-Single Output

FIG. **76**D illustrates the differential input to single output system **7629** wherein the inputs **7604** and **7606** of the differential system **7602** are coupled to equal and opposite EM signal dipole antennas **7630** and **7632**. In system **7629**, the common mode noise voltages are not canceled as in systems shown above. The output is coupled from terminal **7608** to a load **7648**.

5.3 Smoothing the Down-Converted Signal

The down-converted signal **1308**B may be smoothed by filtering as desired. The differential circuit **7644** implemented as a filter in FIG. **76**E illustrates but one example. This may be accomplished in any of the described embodiments by hardware, firmware and software implementation as is well known by those skilled in the arts.

5.4 Impedance Matching

The energy transfer module has input and output impedances generally defined by (1) the duty cycle of the switch module, and (2) the impedance of the storage module, at the frequencies of interest (e.g. at the EM input, and intermediate/baseband frequencies).

Starting with an aperture width of approximately ½ the period of the EM signal being down-converted as a preferred embodiment, this aperture width (e.g. the "closed time") can be decreased. As the aperture width is decreased, the characteristic impedance at the input and the output of the energy transfer module increases. Alternatively, as the aperture width increases from ½ the period of the EM signal being down-converted, the impedance of the energy transfer module decreases.

One of the steps in determining the characteristic input impedance of the energy transfer module could be to measure its value. In an embodiment, the energy transfer module's characteristic input impedance is 300 ohms. An impedance matching circuit can be utilized to efficiently couple an input EM signal that has a source impedance of, for example, 50 ohms, with the energy transfer module's impedance of, for example, 300 ohms. Matching these impedances can be accomplished in various manners, including providing the necessary impedance directly or the use of an impedance match circuit as described below.

Referring to FIG. **70**, a specific embodiment using an RF signal as an input, assuming that the impedance **7012** is a relatively low impedance of approximately 50 Ohms, for example, and the input impedance **7016** is approximately 300 Ohms, an initial configuration for the input impedance match module **7006** can include an inductor **7306** and a capacitor **7308**, configured as shown in FIG. **73**. The configuration of the inductor **7306** and the capacitor **7308** is a possible configuration when going from a low impedance to a high impedance. Inductor **7306** and the capacitor **7308** constitute an L match, the calculation of the values which is well known to those skilled in the relevant arts.

The output characteristic impedance can be impedance matched to take into consideration the desired output frequencies. One of the steps in determining the characteristic output impedance of the energy transfer module could be to measure its value. Balancing the very low impedance of the storage module at the input EM frequency, the storage module should have an impedance at the desired output frequencies that is preferably greater than or equal to the load that is intended to be driven (for example, in an embodiment, storage module impedance at a desired 1 MHz output frequency is 2K ohm and the desired load to be driven is 50 ohms). An additional benefit of impedance matching is that filtering of unwanted signals can also be accomplished with the same components.

In an embodiment, the energy transfer module's characteristic output impedance is 2K ohms. An impedance matching circuit can be utilized to efficiently couple the down-converted signal with an output impedance of, for example, 2K ohms, to a load of, for example, 50 ohms. Matching these impedances can be accomplished in various manners, including providing the necessary load impedance directly or the use of an impedance match circuit as described below.

When matching from a high impedance to a low impedance, a capacitor **7314** and an inductor **7316** can be configured as shown in FIG. **73**. The capacitor **7314** and the inductor **7316** constitute an L match, the calculation of the component values being well known to those skilled in the relevant arts.

The configuration of the input impedance match module **7006** and the output impedance match module **7008** are considered to be initial starting points for impedance matching, in accordance with the present invention. In some situations, the initial designs may be suitable without further optimization. In other situations, the initial designs can be optimized in accordance with other various design criteria and considerations.

As other optional optimizing structures and/or components are utilized, their affect on the characteristic impedance of the energy transfer module should be taken into account in the match along with their own original criteria.

5.5 Tanks and Resonant Structures

Tanks and resonant circuits can be used to further optimize the energy transfer characteristics of the invention. An example embodiment is shown in FIG. **94**A. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention. This embodiment takes advantage of the properties of series and parallel (tank) resonant circuits.

A first parallel resonant or tank circuit consists of a capacitor **9438** and an inductor **9420** (tank**1**). A second tank circuit consists of a capacitor **9434** and an inductor **9436** (tank**2**). In the illustrated example, the first and second tank circuits resonate at approximately 920 Mhz. At and near resonance, the impedance of these circuits is relatively high. Therefore, in the circuit configuration shown in FIG. **94**A, both tank circuits appear as relatively high impedance to the input frequency of 950 Mhz, while simultaneously appearing as relatively low impedance to frequencies in the desired output range of 50 Mhz.

An energy transfer signal **9442** controls a switch **9414**. When the energy transfer signal **9442** controls the switch **9414** to open and close, high frequency signal components are not allowed to pass through tank**1** or tank**2**. However, the lower signal components (50 Mhz in this embodiment) generated by the system are allowed to pass through tank**1** and tank**2** with little attenuation. The effect of tank**1** and tank**2** is to further separate the input and output signals from the same node thereby producing a more stable input and output impedance. Capacitors **9418** and **9440** act to store the 50 Mhz output signal energy between energy transfer pulses.

Further energy transfer optimization is provided by placing an inductor **9410** in series with a storage capacitor **9412** as shown. In the illustrated example, the series resonant frequency of this circuit arrangement is approximately 1 GHz. This circuit increases the energy transfer characteristic of the system. The ratio of the impedance of inductor **9410** and the impedance of the storage capacitor **9412** is preferably kept relatively small so that the majority of the energy available will be transferred to storage capacitor **9412** during operation. Exemplary output signals A and B are illustrated in FIGS. **94**B and **94**C, respectively.

In FIG. **94**A, circuit components **9404** and **9406** form an input impedance match. Circuit components **9432** and **9430** form an output impedance match into a 50 ohm resistor **9428**. Circuit components **9422** and **9424** form a second output impedance match into a 50 ohm resistor **9426**. Capacitors **9408** and **9412** act as storage capacitors for the embodiment. Voltage source **9446** and resistor **9402** generate a 950 Mhz signal with a 50 ohm output impedance, which are used as the input to the circuit. Circuit element **9416** includes a 150 Mhz oscillator and a pulse generator, which are used to generate the energy transfer signal **9442**.

The example tank and resonant structures described above are for illustrative purposes and are not limiting. Alternate configurations can be utilized.

5.6 Optimizing and Adjusting the Non-Negligible Aperture Width/Duration

In an embodiment of the invention, the energy transfer signal **6306** of FIG. **63** is used to vary the input impedance seen by the EM Signal **1304** and to vary the output impedance driving a load. An example of this embodiment is described below using the gated transfer module **6404** shown in FIG. **68**G, and in FIG. **82**A. The method described below is not limited to the gated transfer module **6404**, as it can be applied to all of the embodiments of energy transfer module **6304**.

In FIG. **82**A, when switch **8206** is closed, the impedance looking into circuit **8202** is substantially the impedance of storage module illustrated as the storage capacitance **8208**, in parallel with the impedance of the load **8212**. When the switch **8206** is open, the impedance at point **8214** approaches infinity. It follows that the average impedance at point **8214** can be varied from the impedance of the storage module illustrated as the storage capacitance **8208**, in parallel with the load **8212**, to the highest obtainable impedance when switch **8206** is open, by varying the ratio of the time that switch **8206** is open to the time switch **8206** is closed. Since the switch **8206** is controlled by the energy transfer signal **8210**, the impedance at point **8214** can be varied by controlling the aperture width of the energy transfer signal, in conjunction with the aliasing rate.

An example method of altering the energy transfer signal **6306** of FIG. **63** is now described with reference to FIG. **71**, where the circuit **7102** receives the input oscillating signal **7106** and outputs a pulse train shown as doubler output signal **7104**. The circuit **7102** can be used to generate the energy transfer signal **6306**. Example waveforms of **7104** are shown on FIG. **72**B.

It can be shown that by varying the delay of the signal propagated by the inverter **7108**, the width of the pulses in the doubler output signal **7104** can be varied. Increasing the delay of the signal propagated by inverter **7108**, increases the width of the pulses. The signal propagated by inverter **7108** can be delayed by introducing a R/C low pass network in the output of inverter **7108**. Other means of altering the delay of the signal propagated by inverter **7108** will be well known to those skilled in the art.

As can now be readily seen from this disclosure, many of the aperture circuits presented, and others, can be modified in the manner described above (e.g. circuits in FIGS. **68**H–K). Modification or selection of the aperture can be done at the design level to remain a fixed value in the circuit, or in an alternative embodiment, may be dynamically adjusted to compensate for, or address, various design goals such as receiving RF signals with enhanced efficiency that are in distinctively different bands of operation, e.g. RF signals at 900 MHz and 1.8 GHz.

5.7 Adding a Bypass Network

In an embodiment of the invention, a bypass network is added to improve the efficiency of the energy transfer module. For example, referring to FIG. **95** a bypass network **9502** (shown in this instance as capacitor **9512**), is shown bypassing switch module **9504**. In this embodiment the bypass network increases the efficiency of the energy transfer module when, for example, less than optimal aperture widths were chosen for a given input frequency on the energy transfer signal **9506**. The bypass network **9502** could be of different configurations than shown in FIG. **95**. Such an alternate is illustrated in FIG. **90**.

5.8 Modifying the Energy Transfer Signal Utilizing Feedback

FIG. **69** shows an embodiment of a system **6901** which uses down-converted Signal **1308**B as feedback **6906** to control various characteristics of the energy transfer module **6304** to modify the down-converted signal **1308**B.

Generally, the amplitude of the down-onverted signal **1308**B varies as a function of the frequency and phase differences between the EM signal **1304** and the energy transfer signal **6306**. In an embodiment, the down-converted signal **1308**B is used as the feedback **6906** to control the frequency and phase relationship between the EM signal **1304** and the energy transfer signal **6306**. This can be accomplished using the example logic in FIG. **85**A. The example circuit in FIG. **85**A can be included in the energy transfer signal module **6902**. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention. In this embodiment a state-machine is used as an example.

In the example of FIG. **85**A, a state machine **8504** reads an analog to digital converter, A/D **8502**, and controls a digital to analog converter, DAC **8506**. In an embodiment, the state machine **8504** includes 2 memory locations, Previous and Current, to store and recall the results of reading A/D **8502**. In an embodiment, the state machine **8504** utilizes at least one memory flag.

The DAC **8506** controls an input to a voltage controlled oscillator, VCO **8508**. VCO **8508** controls a frequency input of a pulse generator **8510**, which, in an embodiment, is substantially similar to the pulse generator shown in FIG. **68**J. The pulse generator **8510** generates energy transfer signal **6306**.

In an embodiment, the state machine **8504** operates in accordance with a state machine flowchart **8519** in FIG. **85**B. The result of this operation is to modify the frequency and phase relationship between the energy transfer signal **6306** and the EM signal **1304**, to substantially maintain the amplitude of the down-converted signal **1308**B at an optimum level.

The amplitude of the down-converted signal **1308**B can be made to vary with the amplitude of the energy transfer signal **6306**. In an embodiment where the switch module **6502** is a FET as shown in FIG. **66**A, wherein the gate **6604** receives the energy transfer signal **6306**, the amplitude of the energy transfer signal **6306** can determine the "on" resistance of the FET, which affects the amplitude of the down-converted signal **1308**B. The energy transfer signal module **6902**, as shown in FIG. **85**C, can be an analog circuit that enables an automatic gain control function. Alternate implementations will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Alternate implementations fall within the scope and spirit of the present invention.

5.9 Other Implementations

The implementations described above are provided for purposes of illustration. These implementations are not intended to limit the invention. Alternate implementations, differing slightly or substantially from those described herein, will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Such alternate implementations fall within the scope and spirit of the present invention.

6. EXAMPLE ENERGY TRANSFER DOWNCONVERTERS

Example implementations are described below for illustrative purposes. The invention is not limited to these examples.

FIG. **86** is a schematic diagram of an exemplary circuit to down convert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock.

FIG. **87** shows example simulation waveforms for the circuit of FIG. **86**. Waveform **8602** is the input to the circuit showing the distortions caused by the switch closure. Waveform **8604** is the unfiltered output at the storage unit. Waveform **8606** is the impedance matched output of the downconverter on a different time scale.

FIG. **88** is a schematic diagram of an exemplary circuit to downconvert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock. The circuit has additional tank circuitry to improve conversion efficiency.

FIG. **89** shows example simulation waveforms for the circuit of FIG. **88**. Waveform **8802** is the input to the circuit showing the distortions caused by the switch closure. Waveform **8804** is the unfiltered output at the storage unit. Waveform **8806** is the output of the downconverter after the impedance match circuit.

FIG. **90** is a schematic diagram of an exemplary circuit to downconvert a 915 MHz signal to a 5 MHz signal using a 101.1 MHz clock. The circuit has switch bypass circuitry to improve conversion efficiency.

FIG. **91** shows example simulation waveforms for the circuit of FIG. **90**. Waveform **9002** is the input to the circuit showing the distortions caused by the switch closure. Waveform **9004** is the unfiltered output at the storage unit. Waveform **9006** is the output of the downconverter after the impedance match circuit.

FIG. **92** shows a schematic of the example circuit in FIG. **86** connected to an FSK source that alternates between 913 and 917 MHz, at a baud rate of 500 Kbaud. FIG. **93** shows the original FSK waveform **9202** and the downconverted waveform **9204** at the output of the load impedance match circuit.

IV. Additional Embodiments

Additional aspects/embodiments of the invention are considered in this section.

In one embodiment of the present invention there is provided a method of transmitting information between a transmitter and a receiver comprising the steps of transmitting a first series of signals each having a known period from the transmitter at a known first repetition rate; sampling by the receiver each signal in the first series of signals a single time and for a known time interval the sampling of the first series of signals being at a second repetition rate that is a rate different from the first repetition rate by a known amount; and generating by the receiver an output signal indicative of the signal levels sampled in step B and having a period longer than the known period of a transmitted signal.

In another embodiment of the invention there is provided a communication system comprising a transmitter means for transmitting a first series of signals of known period at a known first repetition rate, a receiver means for receiving the first series of signals, the receiver means including sampling means for sampling the signal level of each signal first series of signals for a known time interval at a known second repetition rate, the second repetition rate being different from the first repetition rate by a known amount as established by the receiver means. The receiver means includes first circuit means for generating a first receiver output signal indicative of the signal levels sampled and having a period longer than one signal of the first series of signals. The transmitter means includes an oscillator for generating an oscillator output signal at the first repetition rate, switch means for receiving the oscillator output signal and for selectively passing the oscillator output signal, waveform generating means for receiving the oscillator output signal for generating a waveform generator output signal having a time domain and frequency domain established by the waveform generating means.

The embodiment of the invention described herein involves a single or multi-user communications system that utilizes coherent signals to enhance the system performance over conventional radio frequency schemes while reducing cost and complexity. The design allows direct conversion of

radio frequencies into baseband components for processing and provides a high level of rejection for signals that are not related to a known or controlled slew rate between the transmitter and receiver timing oscillators. The system can be designed to take advantage of broadband techniques that further increase its reliability and permit a high user density within a given area. The technique employed allows the system to be configured as a separate transmitter-receiver pair or a transceiver.

The basic objectives of the present system is to provide anew communication technique that can be applied to both narrow and wide band systems. In its most robust form, all of the advantages of wide band communications are an inherent part of the system and the invention does not require complicated and costly circuitry as found in conventional wide band designs. The communications system utilizes coherent signals to send and receive information and consists of a transmitter and a receiver in its simplest form. The receiver contains circuitry to turn its radio frequency input on and off in a known relationship in time to the transmitted signal. This is accomplished by allowing the transmitter timing oscillator and the receiver timing oscillator to operate at different but known frequencies to create a known slew rate between the oscillators. If the slew rate is small compared to the timing oscillator frequencies, the transmitted waveform will appear stable in time, i.e., coherent (moving at the known slew rate) to the receiver's switched input. The transmitted waveform is the only waveform that will appear stable in time to the receiver and thus the receiver's input can be averaged to achieve the desired level filtering of unwanted signals. This methodology makes the system extremely selective without complicated filters and complex encoding and decoding schemes and allows the direct conversion of radio frequency energy from an antenna or cable to baseband frequencies with a minimum number of standard components further reducing cost and complexity. The transmitted waveform can be a constant carrier (narrowband), a controlled pulse (wideband and ultra-wideband) or a combination of both such as a dampened sinusoidal wave and or any arbitrary periodic waveform thus the system can be designed to meet virtually any bandwidth requirement. Simple standard modulation and demodulation techniques such as AM and Pulse Width Modulation can be easily applied to the system.

Depending on the system requirements such as the rate of information transfer, the process gain, and the intended use, there are multiple preferred embodiments of the invention. The embodiment discussed herein will be the amplitude and pulse width modulated system. It is one of the simplest implementations of the technology and has many common components with the subsequent systems. A amplitude modulated transmitter consists of a Transmitter Timing Oscillator, a Multiplier, a Waveform Generator, and an Optional Amplifier. The Transmitter Timing Oscillator frequency can be determined by a number of resonate circuits including an inductor and capacitor, a ceramic resonator, a SAW resonator, or a crystal. The output waveform is sinusoidal, although a squarewave oscillator would produce identical system performance.

The Multiplier component multiplies the Transmitter Timing Oscillator output signal by 0 or 1 or other constants, K1 and K2, to switch the oscillator output on and off to the Waveform Generator. In this embodiment, the information input can be digital data or analog data in the form of pulse width modulation. The Multiplier allows the Transmitter Timing Oscillator output to be present at the Waveform Generator input when the information input is above a predetermined value. In this state the transmitter will produce an output waveform. When the information input is below a predetermined value, there is no input to the Waveform Generator and thus there will be no transmitter output waveform. The output of the Waveform Generator determines the system's bandwidth in the frequency domain and consequently the number of users, process gain immunity to interference and overall reliability), the level of emissions on any given frequency, and the antenna or cable requirements. The Waveform Generator in this example creates a one cycle pulse output which produces an ultra-wideband signal in the frequency domain. An optional power Amplifier stage boosts the output of the Waveform Generator to a desired power level.

With reference now to the drawings, the amplitude and pulse width modulated transmitter in accord with the present invention is depicted at numeral **9600** in FIGS. **96** and **97**. The Transmitter Timing Oscillator **9602** is a crystal-controlled oscillator operating at a frequency of 25 MHZ. Multiplier **9604** includes a two-input NAND gate **9702** controlling the gating of oscillator **9602** output to Waveform Generator **9606**. Waveform Generator **9606** produces a pulse output as depicted at **9808** in FIGS. **98**A–D and **99**, which produces a frequency spectrum **10002** in FIG. **100**. Amplifier **9608** is optional. The transmitter **9600** output is applied to antenna or cable **9610**, which as understood in the art, may be of various designs as appropriate in the circumstances.

FIGS. **98**A–D, **99**, and **100** illustrate the various signals present in transmitter **9600**. The output of transmitter **9600** at "A" may be either a sinusoidal or squarewave signal **9802** that is provided as one input into NAND gate **9702**. Gate **9702** also receives an information signal **9804** at "B" which, in the embodiment shown, is digital in form. The output **9806** of Multiplier **9604** can be either sinusoidal or squarewave depending upon the original signal **9802**. Waveform Generator **9606** provides an output of a single cycle impulse signal **9808**. The single cycle impulse **9810** varies in voltage around a static level **9812** and is created at 40 nanoseconds intervals. In the illustrated embodiment, the frequency of transmitter timing oscillator **9602** is 25 MHZ and accordingly, one cycle pulses of 1.0 GHZ are transmitted every **40** nanoseconds during the total time interval that gate **9702** is "on" and passes the output of transmitter oscillator **9602**.

FIG. **101** shows the preferred embodiment receiver block diagram to recover the amplitude or pulse width modulated information and consists of a Receiver Timing Oscillator **10110**, Waveform Generator **10108**, RF Switch Fixed or Variable Integrator **10106**, Decode Circuit **10114**, two optional Amplifier/Filter stages **10104** and **10112**, antenna or cable input **10102**, and Information Output **10116**. The Receiver Timing Oscillator **10110** frequency can be determined by a number of resonate circuits including an inductor and capacitor, a ceramic resonator, a SAW resonator, or a crystal. As in the case of the transmitter, the oscillator **10110** shown here is a crystal oscillator. The output waveform is a squarewave, although a sinewave oscillator would produce identical system performance. The squarewave timing oscillator output **10202** is shown as A in FIG. **102**A. The Receiver Timing Oscillator **10110** is designed to operate within a range of frequencies that creates a known range of slew rates relative to the Transmitter Timing Oscillator **9602**. In this embodiment, the Transmitter Timing Oscillator **9602** frequency is 25 MHZ and the Receiver Timing Oscillator **10110** outputs between 25.0003 MHZ and 25.0012 MHZ which creates a +300 to +1200 Hz slew rate.

The Receiver Timing Oscillator **10110** is connected to the Waveform Generator **10108** which shapes the oscillator signal into the appropriate output to control the amount of the time that the RF switch **10106** is on and off. The on-time of the RF switch **10106** should be less than ½ of a cycle (1/10 of a cycle is preferred) or in the case of a single pulse, no wider than the pulse width of the transmitted waveform or the signal gain of the system will be reduced. Examples are illustrated in Table A1. Therefore the output of the Waveform Generator **10108** is a pulse of the appropriate width that occurs once per cycle of the receiver timing oscillator **10110**. The output **10204** of the Waveform Generator is shown in FIG. **102**B.

TABLE 1A

Transmitted Waveform	Gain Limit on-time	Preferred on-time
Single 1 nanosecond pulse	1 nanosecond	100 picoseconds
1 Gigahertz 1,2,3 . . . etc. cycle output	500 picoseconds	50 picoseconds
10 Gigahertz 1,2,3 . . . etc. cycle output	50 picoseconds	5 picoseconds

The RF Switch/Integrator **10106** samples the RF signal **10206** shown in FIG. **102**C when the Waveform Generator output **10204** is below a predetermined value. When the Waveform Generator output **10204** is above a predetermined value, the RF Switch **10106** becomes a high impedance node and allows the Integrator to hold the last RF signal sample **10206** until the next cycle of the Waveform Generator **10108** output. The Integrator section of **10106** is designed to charge the Integrator quickly (fast attack) and discharge the Integrator at a controlled rate (slow decay). This embodiment provides unwanted signal rejection and is a factor in determining the baseband frequency response of the system. The sense of the switch control is arbitrary depending on the actual hardware implementation.

In an embodiment of the present invention, the gating or sampling rate of the receiver **10100** is 300 Hz higher than the 25 MHZ transmission rate from the transmitter **9600**. Alternatively, the sampling rate could be less than the transmission rate. The difference in repetition rates between the transmitter **9600** and receiver **10100**, the "slew rate," is 300 Hz and results in a controlled drift of the sampling pulses over the transmitted pulse which thus appears "stable" in time to the receiver **10100**. With reference now to FIGS. **98**A–D and **102**, an example is illustrated for a simple case of an output signal **10208** (FIG. **102**D) that is constructed of four samples from four RF input pulses **10206** for ease of explanation. As can be clearly seen, by sampling the RF pulses **10206** passed when the transmitter information signal **9804** (FIG. **98**B) is above a predetermine threshold the signal **10208** is a replica of a signal **10206** but mapped into a different time base. In the case of this example, the new time base has a period four times longer than real time signal. The use of an optional amplifier/filter **10112** results in a further refinement of the signal **10208** which is present at "E" as signal **10210**.

Decode Circuitry **10114** extracts the information contained in the transmitted signal and includes a Rectifier that rectifies signal **10208** or **10210** to provide signal **10212** in FIG. **102**G. The Variable Threshold Generator circuitry in circuit **10114** provides a DC threshold signal level **10214** for signal **10210** that is used to determine a high (transmitter output on) or low (transmitter output off) and is shown at "H." The final output signal **10216** at "F" is created by an output voltage comparator in circuit **10114** that combines signals **10212** and **10214** such that when the signal **10212** is a higher voltage than signal **10214**, the information output signal goes high. Accordingly, signal **10216** represents, for example, a digital "1" that is now time-based to a 1:4 expansion of the period of an original signal **10206**. While this illustration provides a 4:1 reduction in frequency, it is id sometimes desired to provide a reduction of more than 50,000:1; in the preferred embodiment, 100,000:1 or greater is achieved. This results in a shift directly from RF input frequency to low frequency baseband without the requirement of expensive intermediate circuitry that would have to be used if only a 4:1 conversion was used as a first stage. Table A2 provides information as to the time base conversion and includes examples.

Units

$s=1$ $ps=1\cdot10^{12}$ $ns=1\cdot10^{-9}$ $us=1\cdot10^{-6}$ $MHz=1\cdot10^{6}$ $KHz=1\cdot10^{3}$

Receiver Timing Oscillator Frequency=25.0003 MHz

Transmitter Timing Oscillator Frequency=25 MHz

$$\text{period} = \frac{1}{\text{Transmitter Timing Oscillator Frequency}}$$

period=40 ns

$$\text{slew rate} = \frac{1}{\text{Receiver Timing Oscillator Frequency} - \text{Transmitter Timing Oscillator Frequency}}$$

slew rate=0.003 s

$$\text{time base multiplier} = \frac{\text{slew rate}}{\text{period}} \text{ seconds per nanosecond}$$

time base multiplier=$8.333\cdot10^{4}$

EXAMPLE 1

1 nanosecond translates into 83.33 microseconds

time base=(1 ns)·time base multiplier

time base=83.333 us

EXAMPLE 2

2 Gigahertz translates into 24 Kilohertz 2 Gigahertz=500 picosecond period

time base=(500 ps)·time base multiplier

time base=41.667 us

$$\text{frequency} = \frac{1}{\text{time base}}$$

frequency=24 KHz

Table A2

In the illustrated preferred embodiment, the signal **10216** at "F" has a period of 83.33 usec, a frequency of 12 KHz and it is produced once every 3.3 msec for a 300 Hz slew rate. Stated another way, the system is converting a 1 gigahertz transmitted signal into an 83.33 microsecond signal.

Accordingly, the series of RF pulses **9810** that are transmitted during the presence of an "on" signal at the information input gate **9702** are used to reconstruct the information input signal **9804** by sampling the series of pulses at the receiver **10100**. The system is designed to provide an adequate number of RF inputs **10206** to allow for signal reconstruction.

An optional Amplifier/Filter stage or stages **10104** and **10112** may be included to provide additional receiver sensitivity, bandwidth control or signal conditioning for the Decode Circuitry **10114**. Choosing an appropriate time base multiplier will result in a signal at the output of the Integrator **10106** that can be amplified and filtered with operational amplifiers rather than RF amplifiers with a resultant simplification of the design process. The signal **10210** at "E" illustrates the use of Amplifier/Filter **10112** (FIG. **103**). The optional RF amplifier **10104** shown as the first stage of the receiver should be included in the design when increased sensitivity and/or additional filtering is required. Example receiver schematics are shown in FIGS. **103–105**.

FIGS. **106–109** illustrate different pulse output signals **10602** and **10802** and their respective frequency domain at **10702** and **10902**. As can be seen from FIGS. **106** and **107**, the half-cycle signal **10602** generates a spectrum less subject to interference than the single cycle of FIG. **99** and the 10-cycle pulse of FIG. **108**. The various outputs determine the system's immunity to interference, the number of users in a given area, and the cable and antenna requirements. FIGS. **99** and **100** illustrate example pulse outputs.

FIGS. **110** and **111** show example differential receiver designs. The theory of operation is similar to the non-differential receiver of FIG. **101** except that the differential technique provides an increased signal to noise ratio by means of common mode rejection. Any signal impressed in phase at both inputs on the differential receiver will attenuated by the differential amplifier shown in FIGS. **110** and **111** and conversely any signal that produces a phase difference between the receiver inputs will be amplified.

FIGS. **112** and **113** illustrate the time and frequency domains of a narrow band/constant carrier signal in contrast to the ultra-wide band signals used in the illustrated embodiment.

V. Conclusions

Example embodiments of the methods, systems, and components of the present invention have been described herein. As noted elsewhere, these example embodiments have been described for illustrative purposes only, and are not limiting. Other embodiments are possible and are covered by the invention. Such other embodiments include but are not limited to hardware, software, and software/hardware implementations of the methods, systems, and components of the invention. Such other embodiments will be apparent to persons skilled in the relevant art(s) based on the teachings contained herein. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A method for down-converting a carrier signal to a baseband signal, comprising the steps of:

(1) receiving a carrier signal that includes at least one of amplitude variations, phase variations, or frequency variations at a frequency lower than a carrier frequency of the carrier signal;

(2) sampling the carrier signal over aperture periods to transfer energy from the carrier signal at an aliasing rate, the aliasing rate determined according to a frequency of the carrier signal divided by N, wherein N indicates a harmonic or sub-harmonic of the carrier signal;

(3) integrating the energy over the aperture periods; and

(4) generating the baseband signal from the integrated energy.

2. The method according to claim **1**, wherein step (2) comprises generating an energy transfer signal having a harmonic substantially equal to a frequency of the carrier signal and using the energy transfer signal to transfer the energy from the carrier signal.

3. The method according to claim **2**, wherein step (2) further comprises generating a train of pulses having non-negligible apertures that tend away from zero time in duration.

4. The method according to claim **2**, wherein step (2) further comprises optimizing a phase of the energy transfer signal.

5. The method according to claim **2**, wherein step (2) further comprises optimizing the frequency of the energy transfer signal.

6. The method according to claim **1**, wherein step (1) comprises receiving an amplitude modulated carrier signal.

7. The method according to claim **1**, wherein step (1) comprises receiving a phase modulated carrier signal.

8. The method according to claim **1**, wherein step (1) comprises receiving a carrier signal having a frequency greater than 1 giga Hertz.

9. The method according to claim **1**, wherein step (1) comprises receiving a carrier signal having a frequency between 10 mega Hertz and 10 giga Hertz.

10. The method according to claim **1**, wherein step (1) comprises receiving the carrier signal through a relatively low input impedance path.

11. The method according to claim **1**, wherein step (1) comprises receiving the carrier signal through a relatively efficient power transfer path.

12. The method according to claim **1**, wherein step (1) comprises receiving the carrier signal through a substantially impedance matched input path.

13. The method according to claim **1**, further comprising the step of:

(5) providing the baseband signal directly to a relatively low impedance load.

14. The method according to claim **1**, further comprising the step of:

(5) providing the baseband signal directly to a load through a relatively efficient power transfer path.

15. The method according to claim **1**, further comprising the step of:

(5) providing the baseband signal to a load through a substantially impedance matched path.

16. The method according to claim **1**, wherein step (2) comprises coupling the carrier signal to a reactive storage device at the rate that is substantially equal to a subharmonic of the carrier signal.

17. The method according to claim **2**, wherein step (2) comprises generating the energy transfer signal without synchronizing it with the carrier signal.

18. The method according to claim **2**, wherein step (2) comprises generating the energy transfer signal without synchronizing it to a phase of the carrier signal.

19. The method according to claim **2**, wherein step (2) comprises generating the energy transfer signal independent of the carrier signal.

20. The method according to claim **8**, wherein step (2) comprises generating an asynchronous energy transfer signal.

21. The method according to claim **20**, wherein step (1) comprises receiving the carrier signal through a relatively low input impedance path.

22. The method according to claim **20**, wherein step (1) comprises receiving the carrier signal through a relatively efficient power transfer path.

23. The method of claim **1**, wherein N is 0.5 or a positive integer.

24. The method according to claim **1**, wherein the carrier signal comprises a differential signal including first and second portions, wherein:

step (2) includes the step of sampling the first and second portions over aperture periods to transfer energy; and

step (3) includes the step of integrating the energy transferred from the first and second portions.

25. The method according to claim **24**, wherein step (1) includes the step of receiving the first and second portions.

26. The method according to claim **24**, wherein step (1) includes the step of generating the first and second portions from a non-differential signal.

27. The method according to claim **1**, further comprising the step of transferring energy to a load during an off-time.

28. The method according to claim **1**, wherein in step (3) said integrating is controlled.

29. A method of down-converting a first signal to a second signal, comprising the steps of:

(1) receiving the first signal;

(2) sampling the first signal over aperture periods to transfer energy from the first signal;

(3) integrating the energy over the aperture periods; and

(4) generating the second signal from the integrated energy.

30. The method of claim **29**, wherein N is 0.5 or a positive integer.

31. The method of claim **29**, wherein the frequency of the second signal is zero.

32. The method of claim **29**, wherein in step (2) the first signal is sub-sampled.

33. The method of claim **29**, wherein at least one of the first signal and the second signal is an optical signal.

34. The method of claim **29**, wherein the first signal is a carrier signal.

35. The method of claim **29**, herein N indicates:

a harmonic or sub-harmonic of the first signal.

36. The method of claim **29**, wherein N indicates:

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal.

37. The method of claim **29**, wherein N indicates:

a harmonic or sub-harmonic of the aliasing rate.

38. The method of claim **29**, wherein N indicates:

a harmonic or sub-harmonic of the first signal; and

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal.

39. The method of claim **29**, wherein N indicates:

a harmonic or sub-harmonic of the first signal; and

a harmonic or sub-harmonic of the aliasing rate.

40. The method of claim **39**, wherein N indicates:

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal; and

a harmonic or sub-harmonic of the aliasing rate.

41. The method of claim **39**, wherein N indicates:

a harmonic or sub-harmonic of the first signal;

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal; and

a harmonic or sub-harmonic of the aliasing rate.

42. The method according to claim **29**, wherein the first signal comprises a differential signal including first and second portions, wherein:

step (2) includes the step of sampling the first and second portions over aperture periods to transfer energy; and

step (3) includes the step of integrating the energy transferred from the first and second portions.

43. The method according to claim **26**, wherein step (1) includes the step of receiving the first and second portions.

44. The method according to claim **42**, wherein step (1) includes the step of generating the first and second portions from a non-differential signal.

45. The method according to claim **29**, further comprising the step of:

(5) impedance matching the first signal.

46. The method according to claim **29**, further comprising the step of:

(5) impedance matching the second signal.

47. The method according to claim **29**, further comprising the step of:

(5) impedance matching the first signal and the second signal.

48. The method according to claim **29**, further comprising the step of transferring energy to a load during an off-time.

49. The method according to claim **29**, wherein in step (3) said integrating is controlled.

50. An apparatus for down-converting a carrier signal to a lower frequency signal, comprising:

a universal frequency down-converter (UFD), including a switch, an integrator coupled to said switch, and a pulse generator coupled to said switch; and

a reactive structure coupled to said UFD;

wherein said pulse generator outputs pulses to said switch at an aliasing rate that is determined according to:

(a frequency of the carrier signal +/− a frequency of the lower frequency signal) divided by N;

wherein said pulses have apertures and cause said switch to close and sample said carrier signal, and wherein energy is transferred from said carrier signal and integrated using said integrator during apertures of said pulses, and wherein said lower frequency signal is generated from the transferred energy.

51. The apparatus according to claim **50**, wherein said reactive structure comprises an impedance matching network.

52. The apparatus according to claim **51**, wherein said impedance matching network comprises an input impedance matching network coupled to an input of said UFD.

53. The apparatus according to claim **51**, wherein said impedance matching network comprises an output impedance matching network coupled to an output of said UFD.

54. The apparatus according to claim **53**, wherein said integrator forms a part of said output impedance matching network.

55. The apparatus according to claim **53**, wherein said output impedance matching network has a relatively high impedance to frequencies outside of a range of frequencies that are centered about the lower frequency signal.

56. The apparatus according to claim **51**, wherein said impedance matching network comprises:

an input impedance matching network coupled to an input of said UFD; and

an output impedance matching network coupled to an output of said UFD.

57. The apparatus according to claim **50**, wherein said reactive structure comprises a resonant structure.

58. The apparatus according to claim **57**, wherein said resonant structure comprises a resonant tank structure.

59. The apparatus according to claim **58**, wherein said resonant tank structure comprises a capacitive device in parallel with an inductive device, coupled between said switch and said integrator.

60. The apparatus according to claim **58**, wherein said resonant tank structure comprises a shunt tank circuit coupled between an input of said UFD and ground.

61. The apparatus according to claim **50**, wherein said reactive structure comprises an inductive device in parallel with said integrator.

62. The apparatus according to claim **50**, wherein said pulse generator comprises a variable aperture control, wherein an impedance of said UFD varies with varying pulse apertures.

63. The apparatus according to claim **50**, wherein said reactive structure comprises a bypass circuit coupled in parallel with said UFD.

64. The apparatus according to claim **63**, wherein said bypass circuit comprises a capacitive device.

65. The apparatus according to claim **63**, wherein said bypass circuit comprises a capacitive device in series with an inductive device.

66. The apparatus according to claim **50**, wherein said UFD comprises a differential UFD.

67. The apparatus according to claim **50**, wherein energy is transferred to a load during an off-time.

68. The apparatus according to claim **50**, wherein said integration is controlled.

69. An apparatus for down-converting a carrier signal to a lower frequency signal, comprising:

a differentially configured universal frequency down-converter (UFD), including at least first and second integrators, at least one switch coupled to at least one of said at least first and second integrators, and at least one pulse generator coupled to said at least one switch; and

at least one reactive structure coupled to said UFD;

wherein said at least one pulse generator outputs pulses to said at least one switch at an aliasing rate that is determined according to:

(a frequency of the carrier signal +/− a frequency of the lower frequency signal) divided by N;

wherein said pulses have apertures and cause said at least one switch to close and sample said carrier signal, and wherein energy is transferred from said carrier signal and integrated using said at least first and second integrators during apertures of said pulses, and wherein said lower frequency signal is generated from the transferred energy.

70. The apparatus according to claim **69**, wherein said reactive structure comprises an impedance matching structure.

71. The apparatus according to claim **69**, wherein said reactive structure comprises a tank circuit.

72. The apparatus according to claim **69**, wherein said reactive structure comprises a bypass circuit.

73. The apparatus according to claim **69**, wherein said reactive structure comprises an impedance matching structure and a tank circuit.

74. The apparatus according to claim **69**, wherein energy is transferred to a load during an off-time.

75. The apparatus according to claim **69**, wherein said integration is controlled.

76. An apparatus for down-converting a carrier signal to a lower frequency signal, comprising:

a differentially configured universal frequency down-converter (UFD), including at least first and second switches, at least one integrator coupled to at least one of said at least first and second switches, and at least one pulse generator coupled to at least one of said at least first and second switches; and

at least one reactive structure coupled to said UFD;

wherein said at least one pulse generator outputs pulses to at least one of said at least first and second switches; and

wherein said pulses have apertures and cause at least one of said at least first and second switches to close and sample said carrier signal, and wherein energy is transferred from said carrier signal and integrated using said at least one integrator during apertures of said pulses, and wherein said lower frequency signal is generated from the transferred energy.

77. A method of down-converting a first signal to a second signal, comprising the steps of:

(1) sub-sampling the first signal over aperture periods to transfer energy from the first signal;

(2) integrating the transferred energy over the aperture periods;

(3) generating the second signal from the integrated energy; and

(4) impedance matching at least one of said first signal and said second signal.

78. The method of claim **77**, further comprising the step of generating an energy transfer signal that is used to control said sub-sampling, the energy transfer signal having an aliasing rate determined according to:

(a frequency of the first signal +/− a frequency of the second signal) divided by N.

79. The method of claim **78**, wherein N indicates at least one of:

a harmonic or sub-harmonic of the first signal;

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal; and

a harmonic or sub-harmonic of the aliasing rate.

80. The method of claim **77**, wherein said second signal is a baseband signal or an intermediate frequency signal.

81. The method of claim **77**, further comprising the step of establishing the aperture periods such that energy transferred in step (1) is to such an extent that accurate voltage reproduction of the first signal is prevented.

82. An apparatus for down-converting a carrier signal to a baseband signal, the carrier signal including at least one of amplitude variations, phase variations, or frequency variations at a frequency lower than a carrier frequency of the carrier signal, the apparatus comprising:

means for sampling the carrier signal over aperture periods to transfer energy from the carrier signal at an aliasing rate, the aliasing rate determined according to a frequency of the carrier signal divided by N, wherein N indicates a harmonic or sub-harmonic of the carrier signal;

means for integrating the energy over the aperture periods; and

means for generating the baseband signal from the integrated energy.

83. An apparatus for down-converting a first signal to a second signal, comprising:

means for sampling the first signal over aperture periods to transfer energy from the first signal at an aliasing rate, the aliasing rate determined according to:

(a frequency of the first signal +/− a frequency of the second signal) divided by N;

means for integrating the energy over the aperture periods; and

means for generating the second signal from the integrated energy.

84. The apparatus of claim **83**, wherein said apparatus is implemented as an integrated circuit.

85. The apparatus of claim **83**, wherein N indicates:

a harmonic or sub-harmonic of the first signal.

86. The apparatus of claim **83**, wherein N indicates:

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal.

87. The apparatus of claim **83**, wherein N indicates:

a harmonic or sub-harmonic of the aliasing rate.

88. The apparatus of claim **83**, further comprising at least one of an input impedance matching circuit and an output impedance matching circuit.

89. The apparatus of claim **83**, further comprising means for establishing the aperture periods such that energy transferred is to such an extent that accurate voltage reproduction of the first signal is prevented.

90. An apparatus for down-converting a first signal to a second signal, comprising:

means for sub-sampling the first signal over aperture periods to transfer energy from the first signal;

means for integrating the transferred energy over the aperture periods;

means for generating the second signal from the integrated energy; and

means for impedance matching at least one of said first signal and said second signal.

91. The apparatus of claim **90**, wherein said aperture periods are substantially greater than zero such that energy transferred is to such an extent that accurate voltage reproduction of the first signal is prevented.

92. The apparatus of claim **90**, wherein said second signal is a baseband signal or an intermediate frequency signal.

93. The apparatus of claim **90**, further comprising:

means for generating an energy transfer signal that is used to control said sub-sampling, the energy transfer signal having an aliasing rate determined according to:

(a frequency of the first signal +/− a frequency of the second signal) divided by N.

94. The apparatus of claim **93**, wherein N indicates:

a harmonic or sub-harmonic of the first signal.

95. The apparatus of claim **93**, wherein N indicates:

a harmonic or sub-harmonic of the frequency of the first signal +/− the frequency of the second signal.

96. The apparatus of claim **93**, wherein N indicates:

a harmonic or sub-harmonic of the aliasing rate.

97. The method of claim **29**, wherein step (2) comprises the step of:

under-sampling the first signal over aperture periods to transfer energy from the first signal.

98. The method of claim **97**, wherein said under-sampling occurs at an aliasing rate.

99. The method of claim **98**, wherein said aliasing rate is determined according to:

(a frequency of the first signal +/− a frequency of the second signal) divided by N.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,266,518 B1
DATED : July 24, 2001
INVENTOR(S) : Sorrells et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Title page,
Item [56], **References Cited**, under OTHER PUBLICATIONS, correct to read:
-- Burgueño, A. *et al.*, "Long-Term Joint Statistical Analysis of Duration and Intensity of Rainfall Rate with Application to Microwave Communications," *Antennas and Propagation (ICAP 87) Part 2: Propagation*, March 30 - April 2, 1987, pp. 198-201. --.
Peetersl, G et al. reference, please replace "Peetersl" with -- Peeters --; and please replace "*if*" with -- *of* --.
"Press Release, Parkervision, Inc., …" reference, please replace "Firest" with -- First --.

Column 22,
Line 15, equation (1), please replace "≧" with -- ≥ --.

Column 25,
Please replace lines 26-30 with -- signal, as disclosed in "Method and System for Ensuring Reception of a Communications Signal," Ser. No. 09/176,415, Attorney Docket No. 1744.0030000, now U.S. Patent No. 6,061,555, issued May 9, 2000, incorporated herein by reference in its entirety. --.

Column 49,
Line 36, please replace "PSK signal to an FSK signal" with -- FSK signal to an Ask signal --.

Column 79,
Line 59, please replace "**3607**" with -- **4607** --.

Column 86,
Line 56, please replace "**1413**" with -- **4613** --.

Column 94,
Line 45, please replace "**1602**" with -- **6302** --.

Column 95,
Line 51, please replace "FIG. **62F**" with -- In FIG. **62F** --.

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,266,518 B1
DATED : July 24, 2001
INVENTOR(S) : Sorrells et al.

Page 2 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 111,
Line 60, please delete "as A".

Column 112,
Line 15, please replace "TABLE 1A" with -- TABLE A1 --.
Line 57, please delete "at "E"".
Lines 64 and 65, please replace "shown at "H"" with -- shown in Fig. 102G. --.
Line 65, please replace "at "F"" with in -- FIG. 102F --.

Column 113,
Line 61, please replace "at "F"" with in -- FIG. 102F --.

Column 114,
Line 12, please replace "at "E"" with in -- FIG. 102E --.

Column 116,
Line 41, please replace "herein" with -- wherein --.

Column 117,
Line 5, please replace "**26**" with -- **42** --.

Signed and Sealed this

Thirtieth Day of July, 2002

Attest:

JAMES E. ROGAN

Attesting Officer

Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 6,266,518 B1
DATED : July 24, 2001
INVENTOR(S) : Sorrells et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 115,
Line 62, please replace "**8**" with -- **1** --.

Signed and Sealed this

Thirty-first Day of August, 2004

Jon W. Dudas

JON W. DUDAS
Director of the United States Patent and Trademark Office