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Reinhardt

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[54] **POLAR DIGITAL BEAMFORMING METHOD AND SYSTEM**

[75] Inventor: **Victor S. Reinhardt**, Rancho Palos Verdes, Calif.

[73] Assignee: **Hughes Electronics**, Los Angeles, Calif.

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[51] **Int. Cl.^{6}** **H01Q 3/22**; H01Q 3/24; H01Q 3/26

[52] **U.S. Cl.** **342/372**; 342/157; 342/81

[58] **Field of Search** 342/372, 157, 342/81

[56] **References Cited**

U.S. PATENT DOCUMENTS

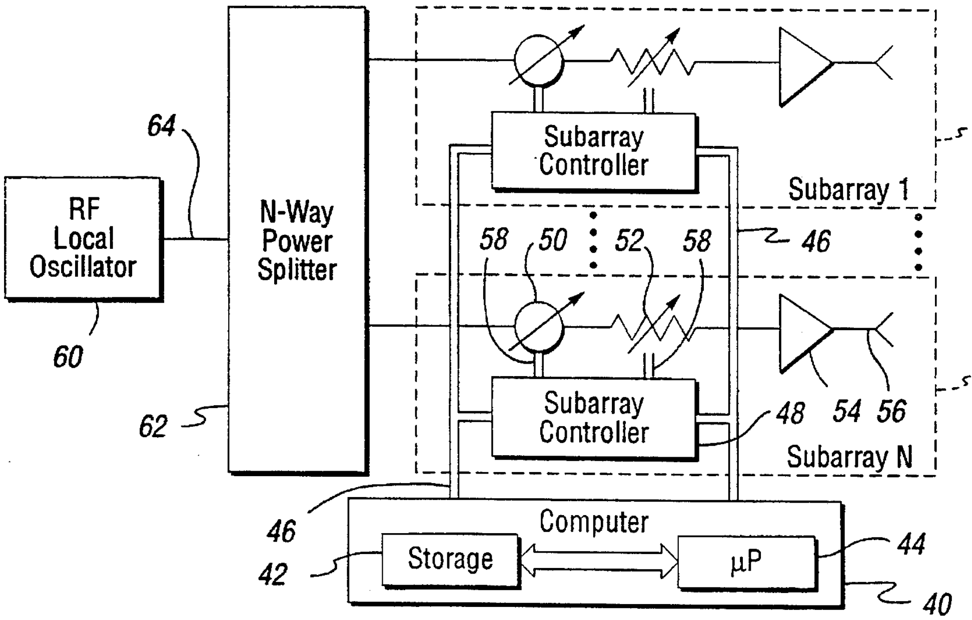
4,965,588	10/1990	Lenormand et al.	342/372
4,983,981	1/1991	Feldman	342/372
5,093,667	3/1992	Andricos	342/372

Primary Examiner—Theodore M. Blum
Attorney, Agent, or Firm—Elizabeth E. Leitereg; Terje Gudmestad; W. K. Denson-Low

[57] **ABSTRACT**

A system and method for polar digital beamforming of at least one independent transmit beam is disclosed. A computer generates a digital signal representing both pointing and modulation information which is communicated to a plurality of subarray controllers which generate the polar weighting signals corresponding to the appropriate antenna element for transmitting. The complex weighting signals may be generated by summing a sequence of complex multiplications or by simply inverting the real and imaginary components of the weighting signal for particular modulation schemes. A phasor may be used in conjunction with an attenuator to modulate a local carrier signal. Alternatively, phasors are utilized without attenuators to increase the efficiency of the power amplifiers. The antenna architecture disclosed permits a single set of phasors and attenuators to be utilized per antenna element regardless of the number of beams to be generated.

18 Claims, 3 Drawing Sheets



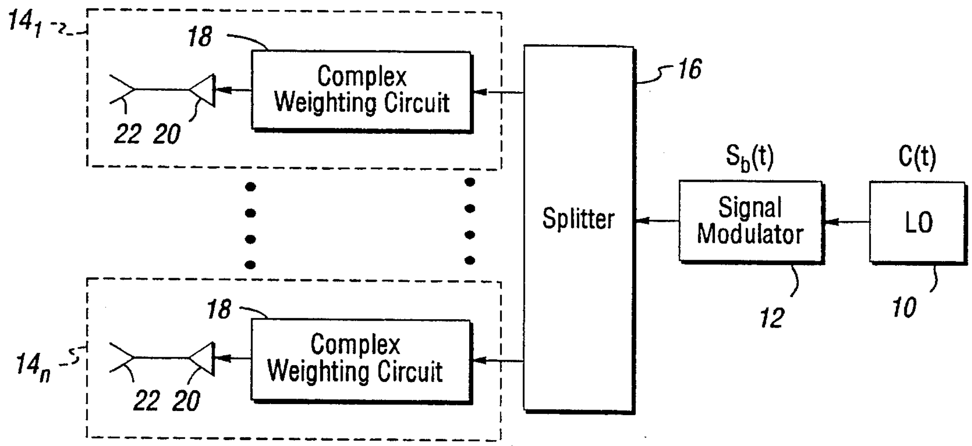


Fig. 1 (PRIOR ART)

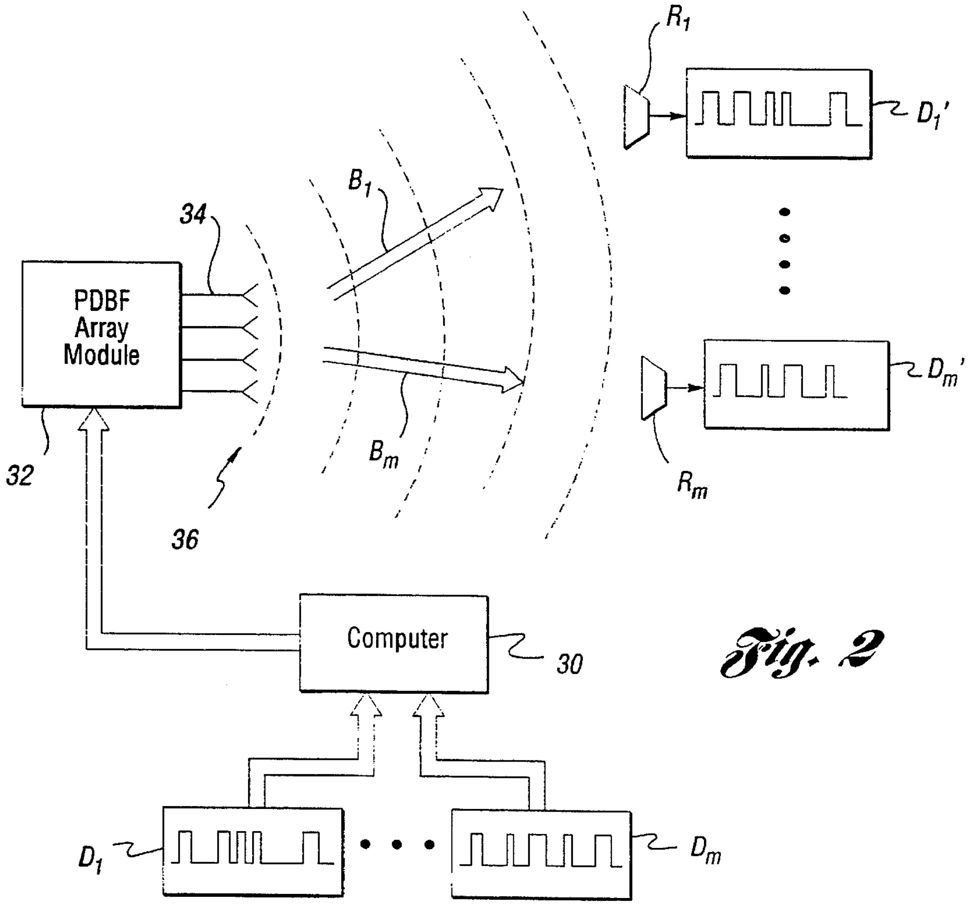


Fig. 2

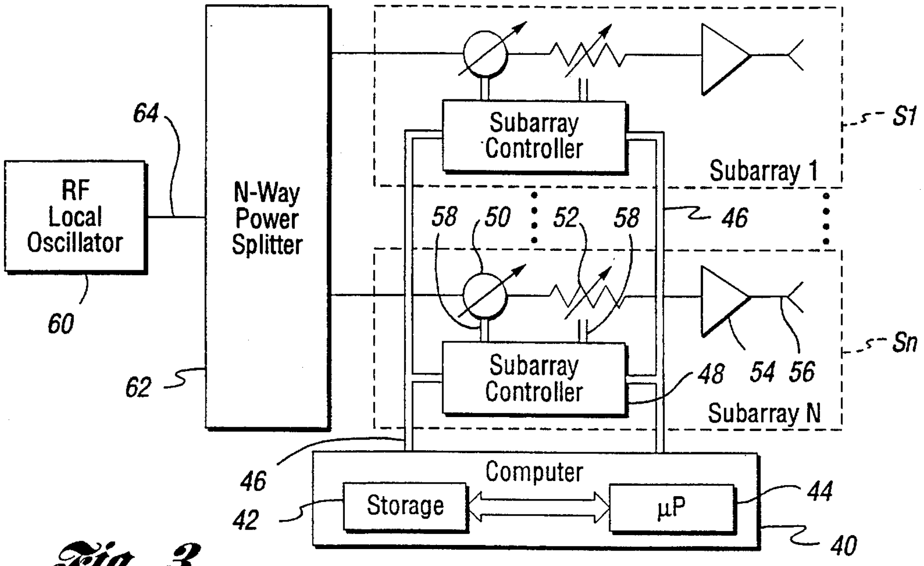

RF Local Oscillator
60
64
N-Way Power Splitter
62
Subarray Controller
Subarray 1
S1
58
50
52
58
46
Subarray Controller
48
54
56
Subarray N
Sn
46
Computer
42
Storage
μP
44
40

Fig. 3

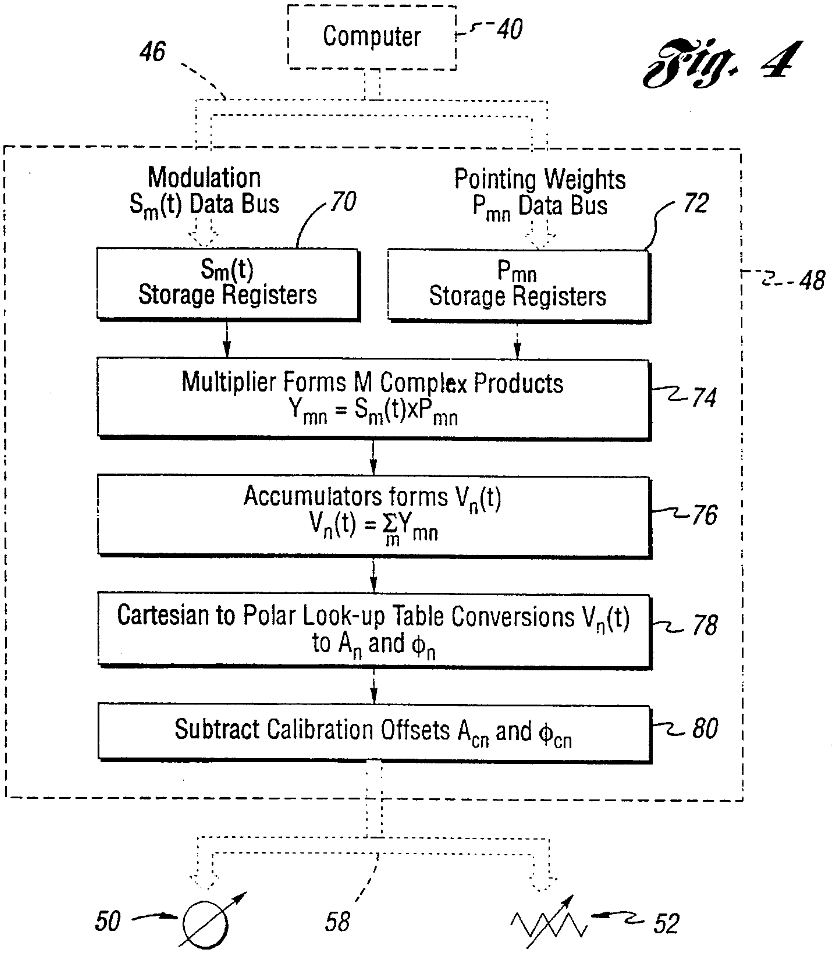

Computer
40
46
Modulation $S_m(t)$ Data Bus
70
Pointing Weights P_{mn} Data Bus
72
48
$S_m(t)$ Storage Registers
P_{mn} Storage Registers
Multiplier Forms M Complex Products $Y_{mn} = S_m(t) x P_{mn}$
74
Accumulators forms $V_n(t)$ $V_n(t) = \sum_m Y_{mn}$
76
Cartesian to Polar Look-up Table Conversions $V_n(t)$ to A_n and ϕ_n
78
Subtract Calibration Offsets A_{cn} and ϕ_{cn}
80
50
58
52

Fig. 4

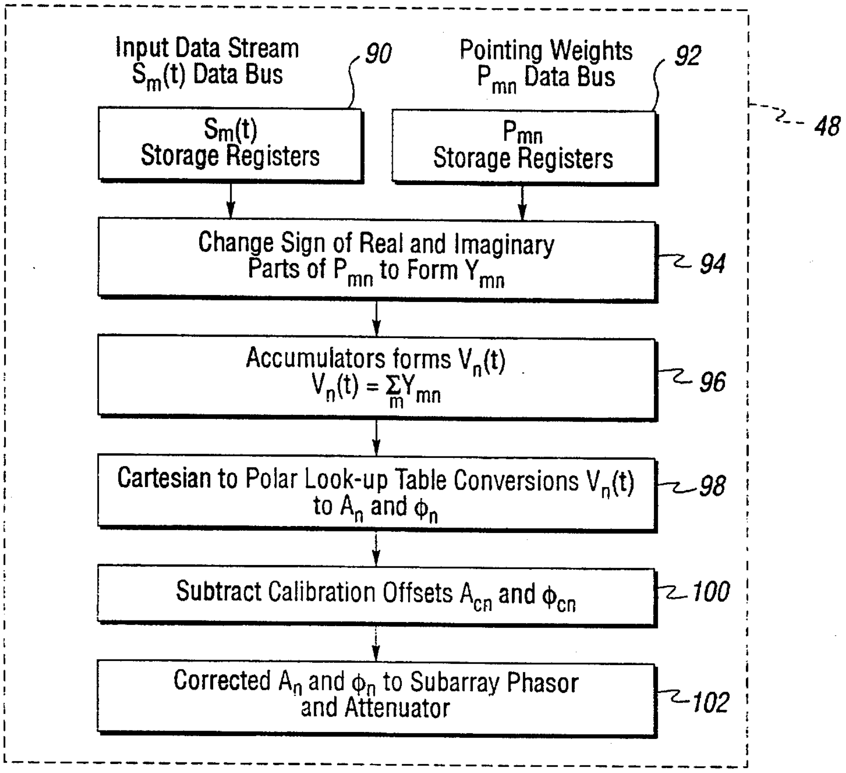

Input Data Stream
$S_m(t)$ Data Bus
90
Pointing Weights
P_{mn} Data Bus
92
48
$S_m(t)$
Storage Registers
P_{mn}
Storage Registers
Change Sign of Real and Imaginary
Parts of P_{mn} to Form Y_{mn}
94
Accumulators forms $V_n(t)$
$V_n(t) = \sum_m Y_{mn}$
96
Cartesian to Polar Look-up Table Conversions $V_n(t)$
to A_n and ϕ_n
98
Subtract Calibration Offsets A_{cn} and ϕ_{cn}
100
Corrected A_n and ϕ_n to Subarray Phasor
and Attenuator
102

Fig. 5

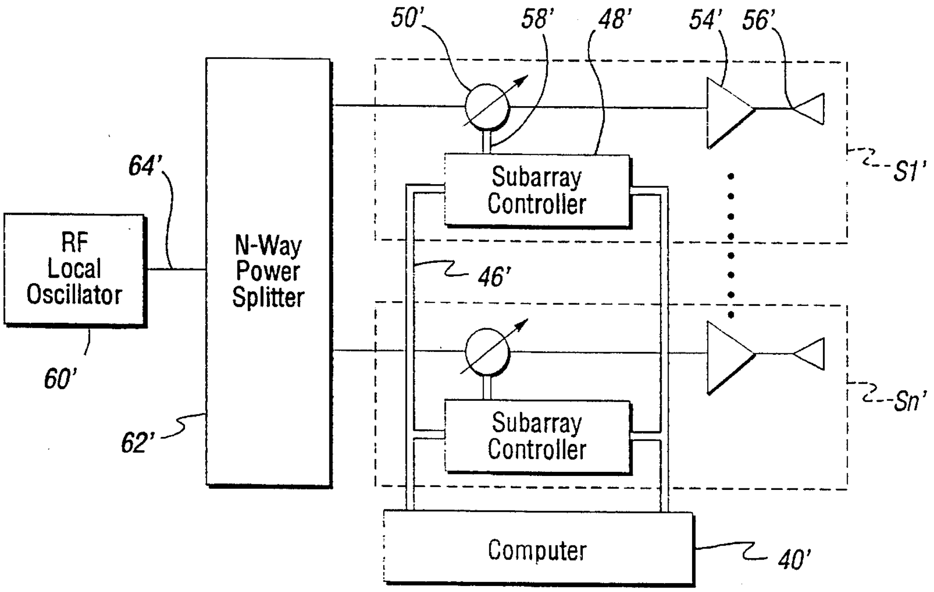

50'
58'
48'
54'
56'
S1'
64'
RF
Local
Oscillator
N-Way
Power
Splitter
Subarray
Controller
46'
60'
62'
Subarray
Controller
Sn'
Computer
40'

Fig. 6

POLAR DIGITAL BEAMFORMING METHOD AND SYSTEM

TECHNICAL FIELD

This invention relates to transmit phased array antennas and more particularly to a method and system of digital beamforming using a polar element weighting configuration.

BACKGROUND ART

A beamsteered transmit phased array antenna allows electronic steering of the antenna beam direction. This type of antenna system includes a number of individual antenna elements spaced in a regular array. The beam direction of the antenna (i.e., pointing direction) is controlled by the relative phases of the signals radiated by the individual antenna elements. As is known, phased arrays may be used to produce highly directional radiation patterns. Furthermore, performance characteristics normally associated with antennas having large areas can be achieved with a phased array antenna having a comparatively smaller area. Conventional transmit phased array antennas utilize two basic architectures: analog beamforming (ABF) and digital beamforming (DBF).

The basic analog beamforming approach found in the prior art is illustrated in FIG. **1**. This system comprises a local radio-frequency (RF) oscillator **10** and an associated signal modulator **12** to produce an RF signal expressed in complex form as:

$$S(t) - S_b(t) \cdot C(t) \tag{1}$$

where S_b(t) is the complex carrier provided by the RF oscillator and given by:

$$C(t) - A_o e^{j\omega_o t} \tag{2}$$

where S_b(t) is the complex baseband waveform generated by the signal modulator. The signal S(t) is then distributed to n subarrays **14**$_1$ to **14**$_n$ by a splitter **16**. Each subarray consists of a digitally controlled complex weighting circuit **18**, a power amplifier **20**, and an antenna element **22**. Each complex weighting circuit produces a controlled phase and amplitude shift in its corresponding subarray RF signal. The signal is then amplified by power amplifier **18** and radiated by antenna element **22**.

If each complex weight is represented by P_n, then the signals at the output of each weighting circuit may be represented by $P_n \cdot S(t)$. The far field radiation pattern will depend upon the number and type of antenna elements, the spacing of the array, and the relative phase and magnitude of the excitation currents applied to the various antenna elements. Generally, the electric field (E-field) generated by the entire phased array is of the form:

$$E(k) = F(k)S(t) \sum_n e^{-jk \cdot r_m} P_n \tag{3}$$

where k is the wave vector, r_n is the position of the nth element, and F(k) is proportional to the E-field generated by a single element. The sum in (3) is maximized in the direction of k when

$$P_n \alpha e^{jk\tau_m}$$

(assuming approximately equal magnitudes for all the P_n). Thus, the phased array can be electronically steered by manipulating the complex weights P_n.

One of the advantages of a phased array is that a number of beams m can be sent from the same aperture. However, to accomplish this, ABF requires the same number m sets of local oscillators, signal modulators, power splitters, and weighting circuits. At the input of each subarray power amplifier, the m beams are combined to produce a single radiation signal out of each antenna element. The various beam signals then combine in phase in m different directions so as to produce an m-beam output. The resultant E-field of the far field signal is given by:

$$E(k) = F(k) \sum_n e^{-jk \cdot r_n} \sum_m P_{m,n} S_m(t) \tag{5}$$

which represents m independent beams in the far field.

In digital beamforming (DBF), the beam pointing information represented by the complex weights and the modulation information are generated digitally. For one beam, the operation of the complex weighting circuit on the modulated RF signal can be represented as the multiplication of a complex modulation function by a complex weighting number. For multiple beams, these m complex products are summed to produce a single complex number for each subarray. This signal may be represented by:

$$V_n(t) = \sum_m P_{m,n} S_{r,m}(t) \tag{6}$$

where $S_{r,m}$(t) is either S_m(t) or $S_{b,m}$(t). One or more digital to analog (D/A) converters are then utilized to produce an analog representation of V_n(t) for each individual antenna element. Thus, only a single set of digitally controlled complex weighting circuits is required thereby eliminating much of the hardware required to generate a similar signal using ABF techniques. The disadvantage of DBF is that a large number of complex multiplications (m·n) and complex additions (n) must be performed at a rate equal to the modulation rate. This requires the use of a high speed processor which typically consumes a great deal of power.

Two implementations of DBF have been utilized in the prior art: baseband Cartesian DBF and intermediate frequency (IF) DBF. Cartesian DBF uses a linear in-phase and quadrature (I-Q) modulator and two (2) D/A converters for each complex weighting circuit. The IF DBF technique utilizes D/A converters to directly produce the modulated subarray signals at the intermediate frequency. Upconverters are then required to convert these signals to RF signals. Both Cartesian DBF and IF DBF are characterized by complex implementations which require a significant amount of power. These implementations are not cost effective unless a very large number of beams are required.

SUMMARY OF THE INVENTION

It is, therefore, an object of the present invention to provide a multiple-beam phased array antenna which digitally generates pointing and modulation information and utilizes a simple polar architecture.

A further object of the present invention is to provide a multiple-beam phased array antenna which utilizes a single set of phasors and attenuators per antenna element.

Another object of the present invention is to provide a multiple-beam phased array antenna which utilizes a single set of phasors without attenuators for each antenna element.

Yet another object of the present invention is to provide a multiple-beam phased array antenna which utilizes previously developed phasors, attenuators, and digital Application Specific Integrated Circuits (ASICs) to implement polar digital beamforming.

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