

- [54] ADAPTIVE, PROGRAMMABLE SIGNAL PROCESSING AND FILTERING FOR HEARING AIDS
- [75] Inventors: **Malcolm J. Williamson; Kenneth L. Cummins; Kurt E. Hecox**, all of Madison, Wis.
- [73] Assignee: **Wisconsin Alumni Research Foundation**, Madison, Wis.
- [21] Appl. No.: 269,937
- [22] Filed: Nov. 10, 1988
- [51] Int. Cl.⁵ H04R 25/00
- [52] U.S. Cl. 381/68.4; 364/724.01
- [58] Field of Search 381/68.4, 68, 68.2, 381/71, 73.1, 94, 104, 106, 107, 99; 333/166, 167, 168, 173, 14; 328/167; 364/724.01, 724.08, 724.09

Rabiner et al., "Terminology in Digital Signal Processing," IEEE Trans. Audio Electro. Acoust., vol. AV-20, pp. 322-337, Dec. 1972.
 Bader et al., "Programmgesteuertes Rauschfilter," Fernseh und Kino Technik, 1974, No. 8, pp. 231-233 (in German). Accompanying English translation (A Program Controlled Noise Filter).
 Barford, "Automatic Regulation Systems with Relevance to Hearing Aids," Scandinavian Audiology Supplement, (6/1978), pp. 335-378.
 Mangold et al., "Programmierbar Filter Hjalper Horselskade," Elteknik med Aktuell Elektronik, 1977, (List continued on next page.)

Primary Examiner—Forester W. Isen
 Attorney, Agent, or Firm—Foley & Lardner

[57] ABSTRACT

A hearing aid system utilizes digital signal processing to correct for the hearing deficit of a particular user and to maximize the intelligibility of the desired audio signal relative to noise. An analog signal from a microphone is converted to digital data which is operated on by a digital signal processor, with the output of the digital signal processor being converted back to an analog signal which is amplified and provided to the user. The digital signal processor includes a time varying spectral filter having filter coefficients which can be varied on a quasi-real time basis to spectrally shape the signal to match the hearing deficit of the user and to accommodate ambient signal and noise levels. The coefficients of the spectral filter are determined by estimating the energy in several frequency bands within the frequency range of the input signal, and using those energy estimates to calculate desired gains for the frequency bands and corresponding spectral filter coefficients. The spectral energy analysis may be carried out using pairs of high pass and low pass digital filters in cascade relation, with the output of each low pass filter being provided to the next pair of high pass and low pass filters. The rate at which output data is provided from the filters in each pair may be reduced from the sample rate of input data by one half for succeeding pairs of filters in the cascade to thereby reduce the computation time required.

[56] References Cited

U.S. PATENT DOCUMENTS

3,180,936	4/1965	Schroeder	381/94
3,403,224	9/1968	Schroeder	381/98
3,509,558	4/1970	Cancro	340/349 AD
3,571,529	3/1971	Gharib et al.	381/72
3,784,749	3/1971	Shigeyama et al.	381/106
3,803,357	4/1974	Sacks	330/279
3,855,423	12/1974	Brendzel et al.	381/68.2
3,872,290	3/1975	Crooke et al.	381/106
3,894,195	7/1975	Kryter	369/48

(List continued on next page.)

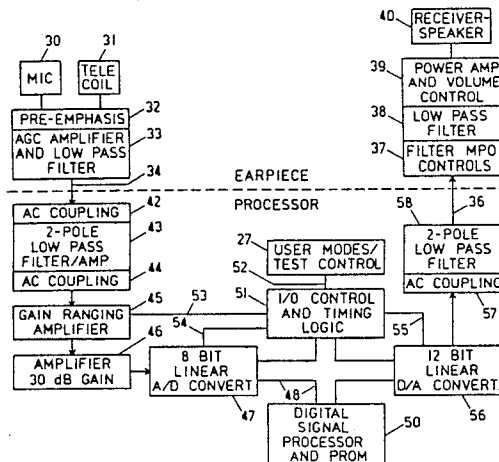
FOREIGN PATENT DOCUMENTS

67671/87	7/1987	Australia	
237203	9/1987	European Pat. Off.	
2407613	6/1979	France	364/724.19
60-21612	2/1985	Japan	381/94
2184629A	6/1987	United Kingdom	

OTHER PUBLICATIONS

Tavares, "Nature and Application of Digital Filters," The Engineering Journal (The Engineering Institute of Canada), vol. 50, No. 1, Jan. 1967, pp. 23-27.
 Brochure entitled "The Heritage" by Zenith Hearing Aid Sales Corporation, (publication date unknown).

58 Claims, 10 Drawing Sheets



U.S. PATENT DOCUMENTS

3,927,279	12/1975	Nakamura et al.	381/68
3,989,897	11/1976	Carver	381/68
3,989,904	11/1976	Rohrer et al.	381/68.4
4,025,721	5/1977	Graupe et al.	381/47
4,051,331	9/1977	Strong et al.	381/68.4
4,061,875	12/1977	Freifeld et al.	381/72
4,071,695	1/1978	Flannigan et al.	381/106
4,079,334	3/1978	Hamilton	330/279
4,099,035	7/1978	Yanick	381/68.2
4,112,254	9/1978	Blackmer	381/106
4,169,219	9/1979	Beard	369/48
4,185,168	1/1980	Graupe et al.	381/68
4,187,413	2/1980	Moser	381/68
4,188,667	2/1980	Graupe et al.	381/68.4
4,249,042	2/1981	Orban	381/106
4,297,527	10/1981	Pate	381/107
4,366,349	12/1982	Adelman	381/68.2
4,396,806	8/1983	Anderson	381/103
4,409,435	10/1983	Ono	381/68.2
4,425,481	1/1984	Mangold et al.	381/68.2
4,454,609	6/1984	Kates	381/68
4,508,940	4/1985	Steeger	381/68.2
4,548,082	10/1985	Engebretson et al.	73/585
4,622,440	11/1986	Slavin	381/68.1
4,628,529	12/1986	Borth et al.	381/94
4,630,304	12/1986	Borth et al.	381/94
4,630,305	12/1986	Borth et al.	381/94
4,661,981	4/1987	Henrickson et al.	381/31
4,696,044	9/1987	Waller, Jr.	381/98
4,700,361	10/1987	Todd et al.	381/94
4,701,953	10/1987	White	381/46
4,723,294	2/1988	Taguchi	381/94
4,731,850	3/1988	Leviitt et al.	381/68.2
4,747,143	5/1988	Kroeger et al.	381/47
4,783,818	11/1988	Graupe et al.	381/71
4,791,672	12/1988	Nunley et al.	381/68
4,792,977	12/1988	Anderson et al.	381/68.4
4,852,175	7/1989	Kates	381/68.4
4,887,299	12/1989	Cummins et al.	381/68.4

OTHER PUBLICATIONS

No. 15, pp. 64-66 (In Swedish). Accompanying English

translation Programmable Filter Helps Hearing Impaired People.

Braida et al., "Hearing Aids—A Review of Past Research," ASHA Monographs, No. 19, 1979, pp. 54-56, section entitled Characteristics of Compression Amplifiers.

Mangold et al., "Programmable Hearing Aid with Multichannel Compression," Scandinavian Audiology 8, 1979, pp. 121-126.

Mangold et al., "Multichannel Compression in a Portable Programmable Hearing Aid," Hearing Aid Journal, Apr. 1981, pp. 6, 29, 30, 32.

Walker et al., "Compression in Hearing Aids: An Analysis, A Review and Some Recommendations", National Acoustics Laboratories, NAL Report, No. 30, Jun. 1982, Australian Government Publishing Service.

McNally, "Dynamic Range Control of Digital Audio Signals," J. Audio Eng. Soc., vol. 32, No. 5, May 1984, pp. 316-326.

Williamson, "Gisting Analysis" Rome Air Development Center Final Technical Report RADC-TR-8-4-130, Jun. 1984.

Stikvoort, "Digital Dynamic Range Compressor for Audio," J. Audio Eng. Soc., vol. 34, No. 1, Jan./Feb. 1986, pp. 3-9.

White, "Compression Systems for Hearing Aids and Cochlear Protheses," Veterans Administration Journal of Rehabilitation Research and Development, vol. 23, No. 1, 1986, pp. 25-39.

Cummins et al., "Ambulatory Testing of Digital Hearing Aid Algorithms," RESNA 10th Annual Conference, San Jose, Calif., 1987, pp. 398-400.

P. J. Bloom, "High-Quality Digital Audio in the Entertainment Industry: An Overview of Achievements and Challenges," IEEE ASSP Magazine, Oct. 1985, pp. 2-25.

"TMS320 First-Generation Digital Signal Processors," brochure published by Texas Instruments, Jan. 1987.

P. O. Vaidyanathan, "Quadrature Mirror Filter Banks, M-Band Extensions and Perfect Reconstruction Techniques," IEEE ASSP Magazine, Jul. 1987, pp. 4-20.

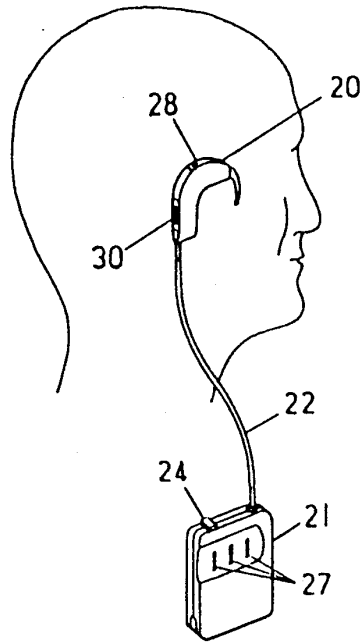


FIG. 1

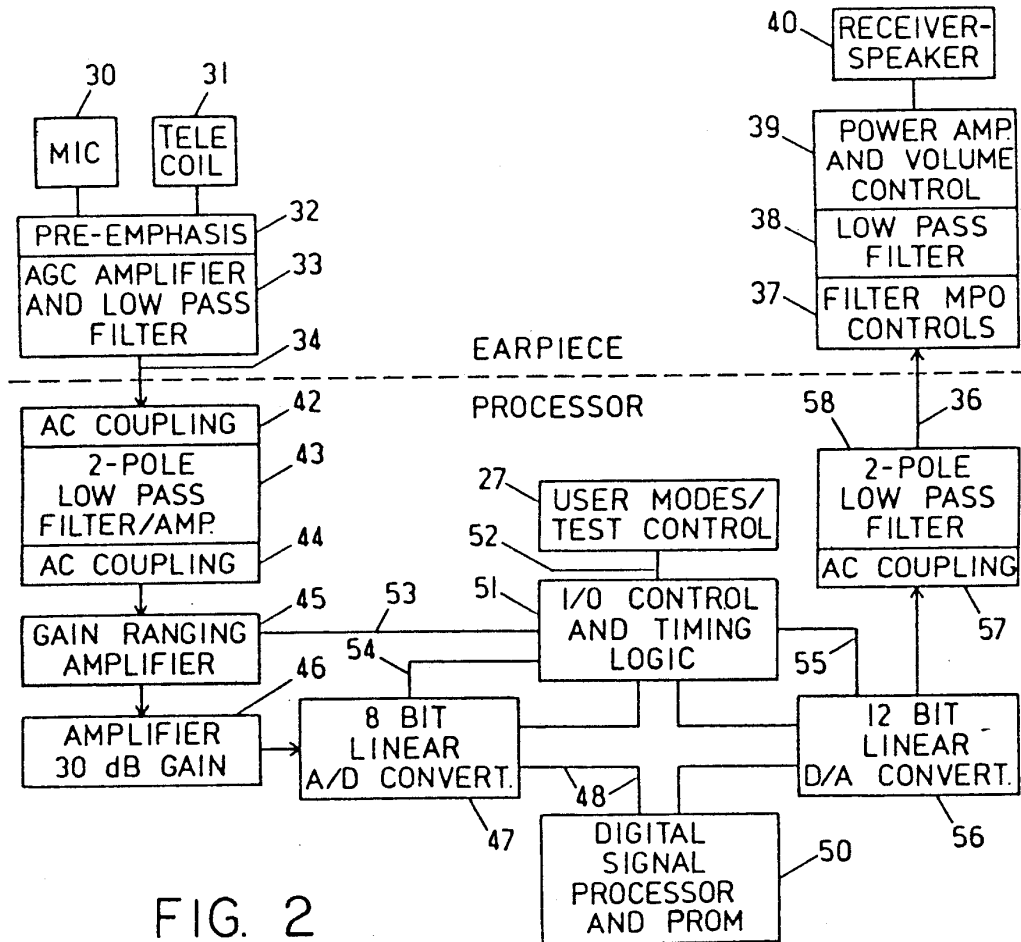


FIG. 2

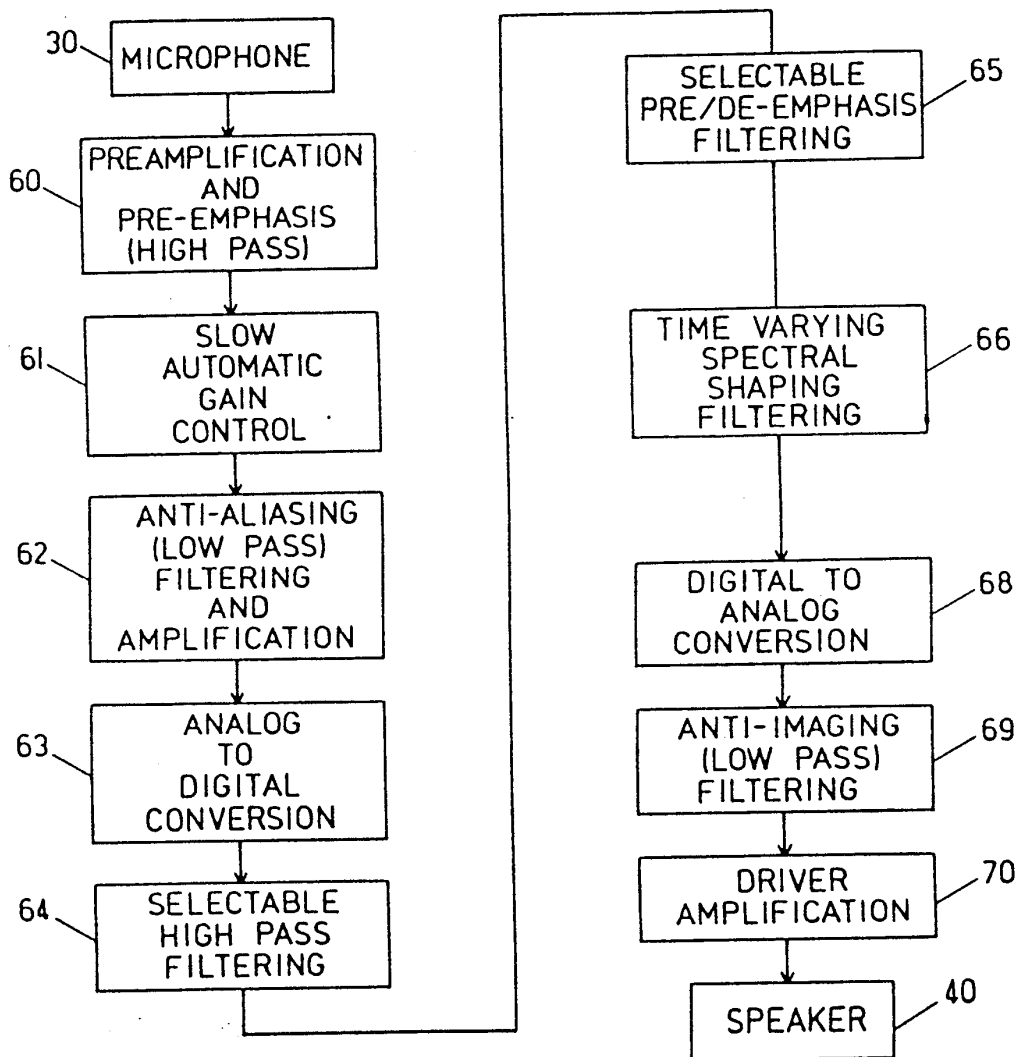


FIG. 3

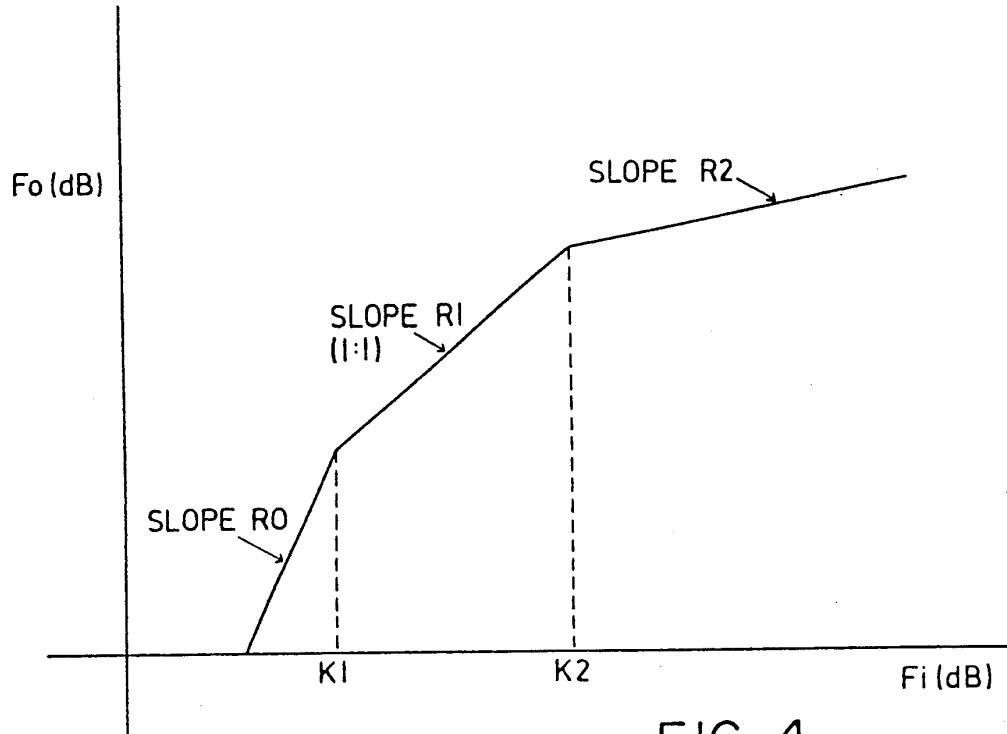


FIG. 4

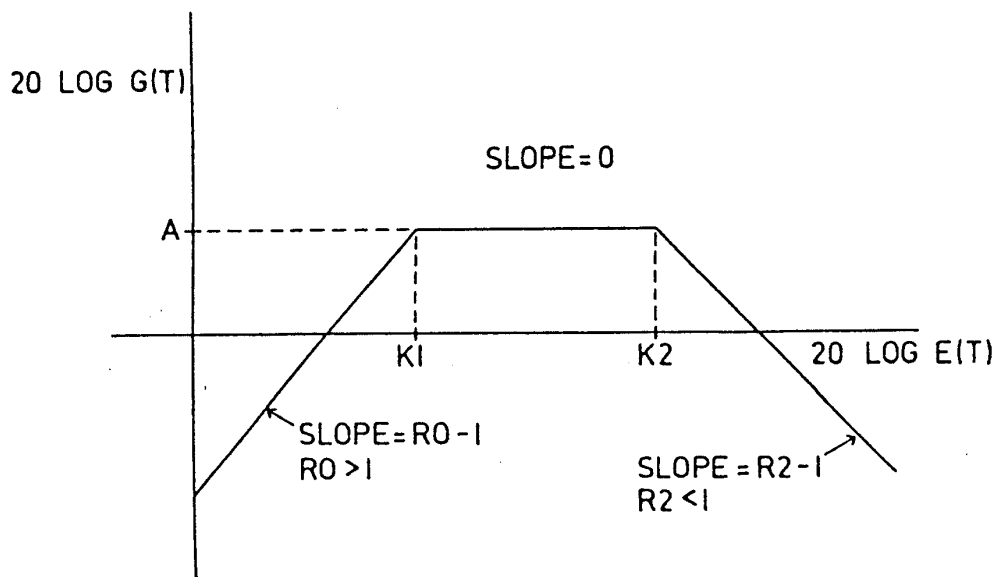


FIG. 5

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.