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SAW CONVOLVERS AND SIGNAL PROCESSING IN A PACKET RADIO*

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Abstract

Surface-acoustic-wave convolvers have been combined with digital circuits to create a signal processor for a packet-radio data-communications network. The multifunction radio supports data rates of 44 bps to 1.45 Mbps and signal processing gains from 18 dB to 61 dB for robust communication and ranging in a multipath environment.

Introduction

Surface-acoustic-wave (SAW) convolvers have been previously developed to provide 30 dB of processing gain for 100-MHz bandwidth signals(1-3). This paper describes the application of convolvers as programmable matched filters for direct-sequence spread-spectrum communications with continuously changing codes. The convolvers, which provide the equivalent of 10^{11} arithmetic operations per second, form the core of a hybrid analog and digital multifunction signal processor for a packet radio data link. Specific processor functions include detection, rapid synchronization, demodulation, adaptation to multipath and measurements of the communication channel.

Signal Processing

The analog SAW device consists of a 22-μs-long lithium-niobate piezoelectric delay line with ultrasonic transducers at each end and a metal overlay waveguide between them. The received signal and a locally generated, time-reversed reference waveform are counter-propagated along the crystal under the waveguide. The nonlinear wave interaction creates the instantaneous product of the signal and reference along the crystal. The metal waveguide collects and sums the resulting product fields to create the convolution output. The convolution function allows completely asynchronous detection of waveforms with time-bandwidth (TB) product of 1000 for 30 dB of processing gain. Because of the counterpropagation, the convolver output has 200-MHz bandwidth centered at 600 MHz for the 100-MHz bandwidth inputs centered at 300 MHz; thus the postprocessing circuits must operate at 200 MHz.

The spread-spectrum carrier used in this system consists of a nonrepeated pseudonoise minimumshift-key (MSK) modulated waveform to provide the 100-MHz instantaneous bandwidth(4). Among the advantages of the wide instantaneous bandwidth achieved with direct-sequence spreading, as opposed to the more conventional frequency-hopped techniques, are the resolving and processing of multipath echoes, the measurement of the range between radios, the immunity to deep fading of multipath, the increased suppression of interference, and the reduced probability of detection by unintended recievers. Changing codes continuously for each convolution output provides immunity against intersymbol interference and rejection of repeat jamming.

Packet-radio architecture is that of a distributed-control, shared-resource communication network(5,6). Messages are partitioned into packets of the order of 1000 data bits long and are routed to the destination through various parts of the network in an attempt to share traffic requirements among the radios. Packets are transmitted at somewhat arbitrary times and the time of arrival at a receiving radio is further modified by varying path delays and clock drift. The receiver detects and quickly synchronizes to the incoming signal, and data demodulation proceeds.

Differential phase shift keying (DPSK) is used for data demodulation. Two series-connected 11-μs halves of a long convolver create a 22-μs device for 90-kbps data rate and 30-dB signal-processing gain(7). The outputs are combined coherently in a sum-difference RF hybrid. If there is a carrier-phase transition on the signal between the two convolvers, then the output will appear at the difference port (data logic 1). If there is no phase transition, the output will appear at the sum port (logic 0). The port that does not contain the convolution output has uncorrelated noise of equal power to the noise in the port that does. This noise reference is used within the radio to set a constant-false-alarm-rate (CFAR) threshold for detection(3). The long convolver is used for packet synchronization and, as outlined below, the hybrid analog-digital correlator operation which permits signal-processing gain to 61 dB. Additional, shorter convolvers

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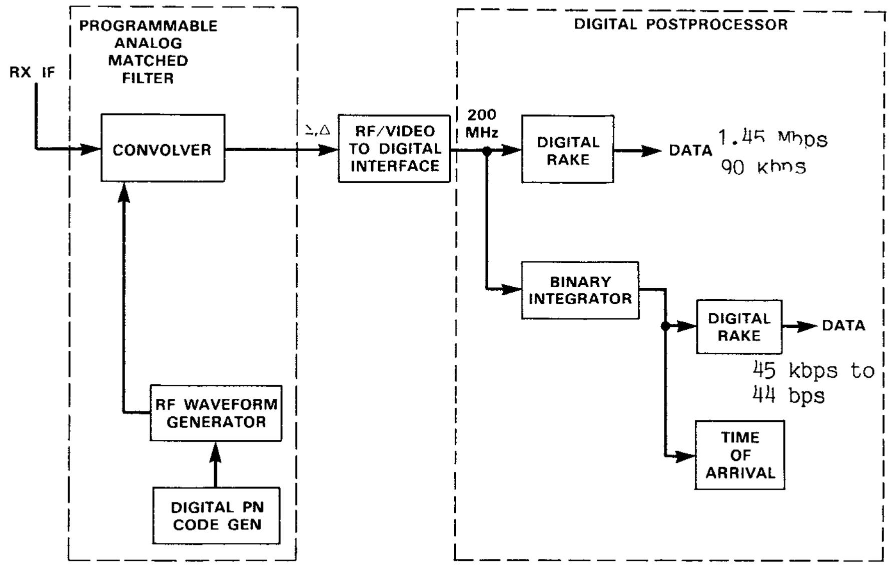

Fig.1 The hybrid analog/digital signal processor located in the modem. On the left is the SAW-based analog matched filter with waveform generators. On the right is the binary-digital post processor for detection, data demodulation and time-of-arrival annotation.

operating on orthogonal-keyed waveforms are used for a 1.45-Mbps data rate with 18-dB signal-processing gain(7).

The hybrid signal processor block diagram is shown in Fig. 1. Processing within the convolver permits the use of binary quantized rather than multilevel digital postprocessing of the 200-MHz output bandwidth(8). The hybrid approach overcomes the limitations encountered when using either analog or digital technology alone(3). The convolver handles very wideband signals with arbitrary interference but with short waveform durations and modest dynamic range. The lower-bandwidth digital integrator can sum consecutive convolver outputs to remove the restrictions of waveform duration and dynamic range, but used alone would be particularly susceptible to non-Gaussian interference. The postprocessing consists of data demodulation using RAKE and binary integration for correlation(3). The RAKE process accumulates the energy received in the individual multipath echoes for an improved data decision. The binary integrator stores consecutive output frames from the convolver matched filter and accumulates them on a sample-by-sample basis, forming parallel correlations. The processor described creates 256 parallel correlations, each with as much as 61 dB of processing gain. At the highest gain, the data rate is 44 bps. The flexible trade of increased processing gain for reduced data rate permits graduated compensation for poor channel conditions.

The synchronization and binary integration circuits can be reconfigured to facilitate range measurements. Synchronization to the signal determines the time of arrival (TOA) of the packet(9). The time of transmit of the packet is placed in its data; thus the propagation delay and hence the range between radios is determined after demodulating the packet. The 100-MHzs convolver bandwidth allows a 3-meter resolution in range. The receiver will synchronize to the earliest multipath signal that corsses the detection threshold. However, this path may not represent line of sight (e.g. a mountain may block the shortest path). The binary integrator is used in a background process with an additional 30-dB of correlation gain to identify the precursor path and thereby improve the TOA estimate.

Summary

SAW convolvers and associated digital processing circuits support a multifunction advanced packet radio data link. The complete radio is shown in Fig. 2. The convolver matched filter allows rapid synchronization with over 30 dB of processing gain and determines the multipath profile with high resolution to be used in demodulation. Analog processing simplifies RAKE demodulation and binary integration is made possible. The combination of analog and digital processing enables robust communications in a hostile multipath environment and supports important network functions such as range and channel measurements.

The views expressed are those of the author and do not reflect the official policy or position of the U.S. Government.

References

(1) S. A. Reible, J. H. Cafarella, R. W. Ralston, and E. Stern,"Convolvers for DPSK Demodulation of Spread-Spectrum Signals," IEEE Ultrasonics Symposium Proceedings. New York: IEEE, 1976, pp. 451-455.

(2) J. H. Cafarella, "Wideband Signal Processing for Communication and Radar," NTC'83 IEEE National Telesystems Conference Proceedings. New York: IEEE, November 1983.

(3) I. Yao and J. H. Cafarella, "Applications of SAW Convolvers to Spread-Spectrum Communication and Wideband RADAR," IEEE Trans. Sonics Ultrason. Special Issue on SAW Convolvers and Correlators, Vol. SU-32 No. 5, pp. 760, Sept. 1985.

(4) F. Amoroso and J. A. Kivett,"Simplified MSK Signaling Technique," IEEE Trans. Commun., vol. Com-25, April 1977, pp. 433-441.

(5) V. G. Cerf, "Packet Communication Technology," in Protocols & Techniques for Data Communication Networks. F. F. Kuo, ed. Englewood Cliffs, NJ: Prentice-Hall, 1981.

(6) R. E. Kahn, S. A. Gronemeyer, J. Burchfiel and R. C. Kunzelman, "Advances in Packet Radio Technology," Proc. IEEE, vol. 66, pp. 1468-1496, Nov. 1978.

(7) V. S. Dolat and G. T. Flynn, "Integration of Multiple Elastic Convolvers into a Communication Signal Processor," 1984 Ultrasonics Symposium Proceedings. New York: IEEE, 1984,

(8) J. V. Harrington,"An Analysis of the Detection of Repeated Signals in Noise by Binary Integration," IRE Trans. Inform. Theory, Vol. IT-1:(1), March 1955.

(9) J. H. Fischer, "Autocalibrating Circuitry for Processing SAW Convolver Outputs," 1985 Ultrasonics Symposium Proceedings. New York: IEEE, October 1985.

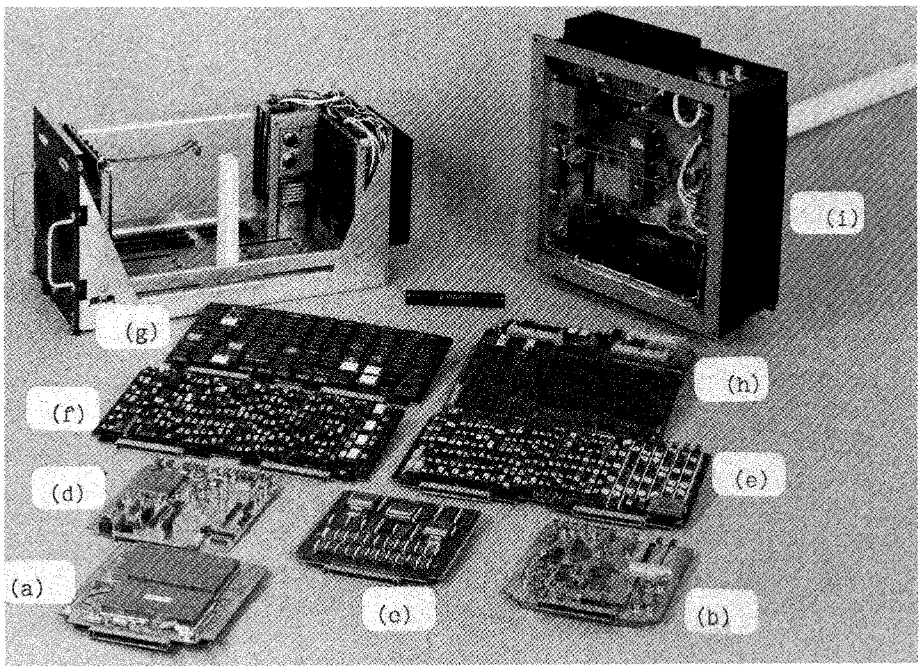

Fig.2 The complete packet radio which includes the (a) convolver circuit board with long and short convolvers, (b) MSK waveform generator, (c) pn code generator, (d) video interface, (e) digital postprocessing board, (f) control logic, (g) error detection and control board, (h) microcomputer, and (i) L-band RF unit.