Proceedings of The Institute of Acoustics

THE PRINCIPLES AND APPLICATIONS OF SURFACE ACOUSTIC WAVE FOURIER TRANSFORM PROCESSORS

J H Collins and P M Grant

University of Edinburgh, Department of Electrical Engineering, Edinburgh, Scotland.

Abstract

The principles and applications of surface acoustic wave (SAW) Fourier transform processors are reported. They offer sophisticated wideband (10's of MHz) signal processing for radar sonar and communication systems. The application of individual SAW based processors to spectrum analysis, network or communication link analysis, and frequency hopped waveform generation is reviewed prior to investigating the use of two or more processors for cepstrum analysis and programmable correlation.

Introduction

This paper reviews the principles and application of a new class of fast Fourier transform processors (1) based on surface acoustic wave (SAW) (2) linear frequency modulated (FM) "chirp" filters (3,4). These processors are based upon the chirp transform algorithm (5), Figure 1. The significance of the chirp transform algorithm lies in the fact that the required convolution can be efficiently performed using a SAW analog tapped transversal (chirp) filter (3,4). These devices, initially designed for use in pulse compression radar systems, are now commercially available, permitting realization of Fourier transform processors with up to 250 MHz real time bandwidth and greater than 10^3 transform points (6). In comparison to established digital fast Fourier transform (FFT) processors (7), the analog SAW processors offer wideband, real time operation, vastly reduced power consumption (eg, 10-100 w) and size (eg, less than 1 cubic foot) at the expense of limited (approximately 1%) accuracy and dynamic range (60-70 dB).

The application of individual processors in spectrum analysis (8), network (or communication link) analysis (9) is discussed in Table 1. The application of the (inverse) chirp transform processor to waveform synthesis(10) will also be reported. Finally, signal processing applications will be discussed where two or more Fourier transform processors are combined, with other circuit elements. Figure 2 shows how two processors may be interconnected such that the output from the first processor is modified or edited, under the control of an externally programmed function, prior to processing in the second transform and Table 2 summarises the processing functions which can result.

Chirp Transform Algorithm

The basic form of the chirp transform has been derived directly from the Fourier integral. In its simplest form, the input signal is first premultiplied by a chirp waveform, designated C_1 in Figure 1, and is subsequently convolved with the second chirp, C_2, which provides a frequency versus time characteristic, which is accurately matched to C_1. This configuration outputs directly the power spectrum of the input (time domain) signal. Fourier transformation requires post-multiplication with the final chirp C_3.

Two alternative arrangements of this multiply, convolver, multiply (M-C-M) scheme must be distinguished; one in which the time duration of the multiplying chirp signal is short compared with the duration of the impulse response of the filter - the M(S) - C(L) - M scheme, and one in which the multiplying chirp duration is long, the M(L) - C(S) - [M]. It has been shown that whereas the M(L) - C(S) scheme has a role to play in spectrum analysis (8), it is the M(S) - C(L) - M scheme which is best suited to Fourier transformation (9). There are alternative schemes involving a convolve, multiply, convolve (C-M-C) arrangement of filters (9) but they are not detailed here. For the M(S) - C(L) - M scheme the processor bandwidth and resolution is governed by the premultiplier and convolver and for optimum design a premultiplier of time bandwidth product T_1B_1 is interfaced with a convolver with parameters $2T_1 \times 2B_1$ to give an overall processor with T_1B_1 transform points.

With conventional metal electrode IDT technology SAW dispersive delay lines (3) can be made with time bandwidth products up to 1000. However, for sophisticated Fourier transform processors the larger time bandwidth product RAC filters (4) are essential to achieving processor time bandwidth products of $>10^3$. To date emphasis has been placed on design and application of SAW Fourier transform processors which operate on complex IF waveforms. When used in this mode SAW chirp filters permit the design of processors whose parameters lie within the bounds of Figure 3. For a given design, the SAW filter parameters (ie, transform bandwidth and resolution) are fixed, in contrast to CCD chirp-Z-transforms where bandwidth and resolution can be continuously altered via the external clock. Recently it has been demonstrated how the SAW IF processor can be modified to accommodate baseband I+Q inputs (11) and perform 4-10 MHz bandwidth 128-256 point transforms.

Individual Processor Applications

Spectrum analysis is one of the main application areas for SAW chirp transforms. Figure 4 illustrates schematically the operation of this configuration, which is also known as the compressive receiver. The benefit of this approach is that it offers 100% probability of signal intercept and can handle simultaneous inputs at different frequencies.

We have investigated the theory, design and performance of network analyzer configurations (9) employing SAW Fourier transform processors. Our network analyzer design energizes the network under test with an accurately generated line spectrum produced by a repetitive narrow IF pulse train. This technique, which is an extension of the impulse response analysis used in time domain metrology (TDM) yields the network transfer function, S_{12}, amplitude and phase characteristics as two sampled time outputs. We effectively replace the TDM computer based FFT processor with the SAW Fourier transform processor, to permit real time operation of the TDM systems.

The existence of SAW processors also permits the synthesis of pulsed CW waveforms by inputing appropriate timed impulses into an inverse Fourier transform processor (10). This technique has been employed for the generation of coherent frequency-hopped (FH) waveforms for use in spread spectrum communications. Here, because the input (frequency domain) consists of impulse signals the pre-multiplier chirp can be dispensed with. When the output is required on a carrier, the chirp post-multiplier dispersive slope is opposite to that of the filter and the sum frequency is selected. One pair of filters is capable of generating a hopped waveform with a 50% duty cycle and hence a second pair is required for continuous output.

Application of Combined Chirp Transform Processors

In addition to the applications described earlier, for individual chirp transform processors, numerous applications employing two or more combined SAW chirp transform processors have been developed. Access to the frequency domain characteristics of a signal permits editing or conditioning to be employed with the configuration of Figure 2. The various conditioning functions which have been proposed are summarized in Table 2.

With SAW devices the spectrum and network analysis concepts can be extended into cepstrum analysis techniques, which are capable of analyzing periodic effects in the frequency domain associated with time repetitive or "echo" waveforms. Cepstrum analysis is, by definition (12), performed by a serial arrangement of two Fourier transform processors. The first processor transforms from the time domain to the frequency domain, yielding the spectrum of the input waveform. After signal amplification (in a true logarithmic amplifier), the second processor transforms from the frequency domain to a pseudo-time (quefrency) domain to yield the cepstrum of the input waveform. For certain waveforms, particularly time periodic and superimposed time coincident waveforms, spectrum analysis can yield an ambiguous display, while cepstrum analysis provides unambiguous information on the input waveform. Figure 5 shows the analysis in a SAW cepstrum analyser (13) of a pulsed signal distorted by an echo.

The convolution theorem represents one of the most important relationships in signal processing, giving complete freedom to implement the convolution of two signals either as a time domain convolution or as a multiplication of the Fourier transforms of the two signals, followed by inverse transformation. Programmable correlation or matched filtering of an input waveform can therefore be achieved using Fourier transform techniques (6). One advantage of this matched filter implementation lies in the accessibility of the frequency domain signal which permits for example narrowband "jammer" interference to be suppressed within the matched filter by spectral editing.

References

1. BRACEWELL, "The Fourier Transform and its Applications", McGraw-Hill.
2. IEE Conf Publ No 109, Sept 1973.
3. E G S PAIGE, ref 2, pp 167-180.
4. R C WILLIAMSON and H I SMITH, IEEE Trans MTT-21, pp 195-206, April 1973.
5. L R RABINER et al, Bell Syst Tech Jour, pp 1249-1292, May-June 1969.
6. H M GERARD and O W OTTO, Proc IEEE Ult Symp, 1977.
7. "Omniferous FFT Analyser", Nicolet Scientific Corp.
8. J B HARRINGTON and R B NELSON, Microwave Journal, pp 57-62, Sept 1976.
9. M A JACK et al, Proc IEEE Ult Symp, pp 376-381, 1976.
10. B J DARBY et al, Proc IEEE Ult Symp, pp 514-552, 1977.
11. M A JACK, Electronics Letters, pp 634-635, 14 Sept 1978.
12. D G CHILDERS et al, Proc IEEE, pp 1428-1443, 1977.
13. M A JACK et al, IEEE Trans AES, pp 610-618, Nov 1977

THE PRINCIPLES AND APPLICATIONS OF SURFACE ACOUSTIC WAVE FOURIER TRANSFORM PROCESSORS

PROCESSING FUNCTION	TRANSFORM	APPLICATION	SYSTEM
NETWORK ANALYSIS	TEMPORAL COMPLEX	SYSTEM AND COMPONENT ANALYSIS	COMMUNICATION LINKS (μw or tropo)
SPECTRUM ANALYSIS	TEMPORAL REAL	SIGNAL DETECTION	RADAR/ECM
SPECIAL SIGNAL GENERATION	TEMPORAL INVERSE	FREQUENCY TO TIME CONVERSION	SPREAD SPECTRUM SIGNALLING
BEAMFORM	SPATIAL COMPLEX	SURVEILLANCE	SONAR

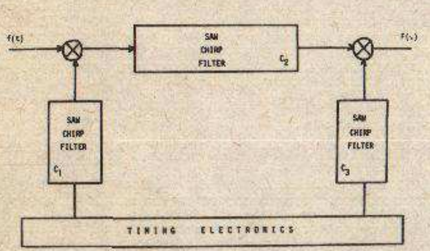
APPLICATION OF INDIVIDUAL SAW CHIRP TRANSFORM PROCESSORS

Table 1

INTERMEDIATE OPERATION	OVERALL SIGNAL PROCESSING FUNCTION	APPLICATION AREA
SWITCH ON/OFF WITH EXTERNAL PULSE	ADAPTIVE BANDPASS/BANDSTOP FILTER	SPECTRAL WEIGHTING FOR INTERFERENCE SUPPRESSION
MIX WITH SINEWAVE	VARIABLE DELAY	TARGET SIMULATION
	OR VARIABLE SLOPE CHIRP	ECM
LOGARITHM	CEPSTRUM	SIGNAL CLASSIFICATION
MULTIPLY WITH FT* OF INPUT	PROGRAMMABLE MATCHED FILTER	AUTO CORRELATE UNKNOWN INPUT
MULTIPLY WITH CHIRP	TIME EXPAND/COMPRESS OR REVERSE	MATCH SIGNAL TO EXISTING PROCESSOR

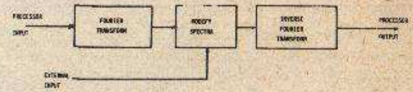
COMBINED SAW FOURIER TRANSFORM PROCESSOR APPLICATIONS

Table 2



SAW FOURIER (CHIRP) TRANSFORM PROCESSOR

Figure 1



SIGNAL PROCESSOR BASED ON COMBINED SAW FOURIER TRANSFORMS

Figure 2

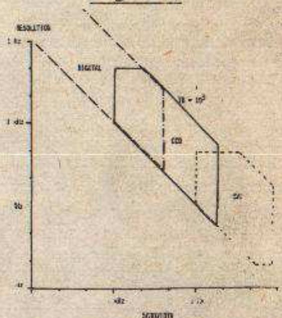


Figure 3

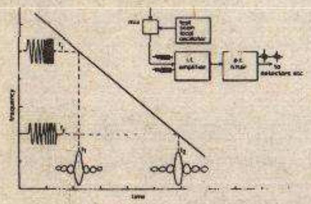
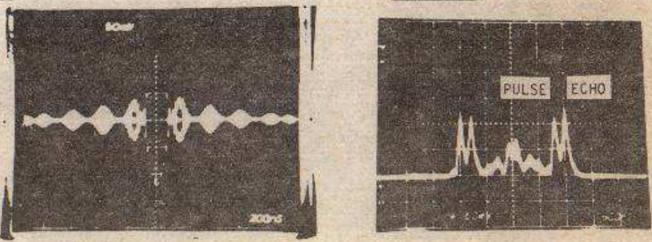


Figure 4

800 ns PULSE WITH ECHO AT 1000 ns DELAY



a SPECTRUM b. CEPSTRUM

Figure 5