# SAW TRANSFORM SIGNAL PROCESSING

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Abstract

Many new signal processing functions can be achieved through the availability of real-time transforms. One implementation of such transforms uses surface acoustic wave (SAW) linear FM filters. Not only may these SAW devices be employed to produce a real-time signal that is proportional to the Fourier transform of the input, but several of these "chirp transforms" can also be configured to provide continuously tunable bandpass/bandstop filtering* and versatile programmable matched filtering. Moreover, transform processing permits prewhitening to suppress narrowband interference in some systems. These topics, their limitations, and prototype results are described in the presentation although this text focuses primarily on the continuously variable bandpass/bandstop filtering.

## INTRODUCTION

The SAW chirp transform[1-9] produces a time response that is proportional to the Fourier transform of successive intervals of the input signal. Figure 1 shows a configuration of SAW linear FM (chirp) filters and mixers which perform this transformation. A mathematical description which shows that the output signal has the form of the Fourier transform is given in reference 1. Figure 2 is a diagram which shows heuristically the operation of this system step-by-step through the time to frequency conversion. The chirp signals $C_1$ and $C_2$ are generated repeatedly to transform each successive interval of the input signal. A second chirp transform synchronized with the first can then reconvert the frequency information back into the original time signal.

## PROTOTYPE CHIRP TRANSFORM

That the block diagram of Figure 1 does serially order in time the frequency components of an incoming signal is demonstrated in Figure 3. Seven CW signals from 120 MHz to 180 MHz in 10 MHz steps are each successively applied to the input of the prototype. Since the prototype is designed to process 60 MHz every 1.9 usec as shown in the schematic, the output signal is shifted linearly by 0.32 usec for each 10 MHz increment of the CW signal input. The accuracy with which the transform is performed is indicated by comparing the chirp transform of a 0.4 usec, 150 MHz pulse with the result obtained with a conventional spectrum analyzer. Figures 4 and 5 show that comparison on a linear scale to correspond with the oscilloscope trace.

This spectrum information can easily be inverse transformed to recreate the original signal. Figure 6 shows the transform-inverse transform process for multiple input signals. Two sets of pulses at 140 MHz and 160 MHz with 0.5 usec and 0.2 usec widths respectively are applied to the input of the chirp transform. That the second trace, the output of the prototype, shows correctly the transform of the input can be quickly verified. The final trace is the inverse transform of that spectrum data. Further confirmation of the successful successive transform operations is shown in the spectrum analyzer data of Figures 7 and 8 comparing the spectra of the input and output signals respectively.

The performance of systems employing these transform-inverse transform processors is dramatically related to the time-bandwidth product (BT) of the SAW filters.[1] The prototype described here is theoretically capable of average errors nominally 40 dB below the signal level. Simulations comparing the output waveform with the input after two transformations reveal that the average error decreases approximately as -20 log(BT) suggesting the desirability of longer chirps. The most serious distortion in these processors, however, is due to timing considerations which require very accurate control to avoid serious phase errors in the output.

## CONTINUOUSLY VARIABLE BANDPASS/BANDSTOP FILTERING

Since the frequency components of a signal are separated and ordered linearly in time after the chirp transform, adaptable filtering in the simplest sense can be achieved by time gating the waveform with a switch whose position and width can be changed to realize many combinations of bandpass and/or bandstop responses.[1,6,9] The gated signal is then inverse transformed to produce the filtered signal.

The realizability of this adaptable filtering approach is demonstrated by the performance of the prototype system. An example of bandpass operation is shown in Figure 9. The two sets of pulses at 140 MHz and 160 MHz already described are shown in the top trace. The second trace is the transform of that input. To pass the 0.5 usec, 140 MHz pulses, a switch follows the chirp transform and is turned off except during the time period which corresponds to the frequency content of the broad pulses. This modulated transform data in the third trace is then inverse transformed. The fourth trace shows the prototype output which contains only the wide pulses at 140 MHz as desired. The short pulses at 160 MHz are clearly rejected by more than 30 dB. The spectrum analyzer photographs of Figures 7 and 10, showing the input and output spectra respectively, further confirm the bandpass performance of this system.

The realization of bandstop filtering is demonstrated in Figure 11 in which the switch now is turned off only during the time corresponding to the undesired frequencies: in this case a band centered at 140 MHz. The inverse transform of the remaining frequencies yields the 160 MHz pulses which had been in the rejection region of the preceding bandpass example. The spectrum of the fourth trace of Figure 11 is shown in Figure 12 which shows the frequencies rejected and those passed in comparison to the input spectrum of Figure 7. Hence, the prototype has clearly demonstrated its capability to perform adaptable bandpass/bandstop filtering.

These results reflect a significant consideration in the operation of transform adaptable filtering. Described in considerably more detail in the presentation, the effects of filtering CW signals requires the use of parallel transform-inverse transform pairs[6,7] which alternately provide the filtered output signal. Operation with only a single channel attenuates the filtered CW term at the edge of each time segment as much as 6 dB. Two channel operation avoids this degradation and simultaneously permits the elimination of most of the spurious responses which degrade performance. Therefore, one channel performs a transform every 3.8 μsec instead of every 1.9 μsec for the single channel system. The results in this paper are indicative of dual channel operation.

## TRANSFORM PROGRAMMABLE MATCHED FILTERING AND PREWHITENING

Since one can show that a product in the frequency domain corresponds to a convolution in the time domain,



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a matched filter can be implemented by transforming a signal and its reference to the frequency domain, mixing the signals to obtain a product, and transforming back to the time domain.[1,5,9] (Figure 13) Not only can versatile programmable matched filtering be achieved through transform processing, but an important additional advantage is the potential for prewhitening to suppress narrowband interference, a common problem in many systems. Spectrum analysis could permit identification of the offending frequencies to tune notch filters, transform processors might provide adaptable bandstop filtering, or a simple clipping operation shown in Figure 13 could suppress the interference sufficiently well to permit continued system operation. Results of work in these areas are presented, but readers are referred to the references[1,9] for elaboration since inclusion of the material presented is precluded here by text length.

## CONCLUSION

SAW chirp transforms permit several novel signal processing functions including continuously variable bandpass/bandstop filtering, versatile programmable matched filtering, and prewhitening capability. Simply implemented with SAW linear FM filters, mixers, amplifiers, and timing circuitry, transform adaptable processing has been clearly demonstrated by the prototype system currently under development.

## References


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9. R. M. Hays and C. S. Hartmann, "Surface Acoustic Wave Devices for Communications," Proc. IEEE, May 1976.

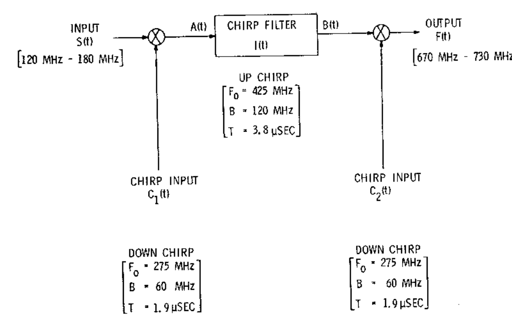




Figure 1. SAW Chirp Transform Prototype

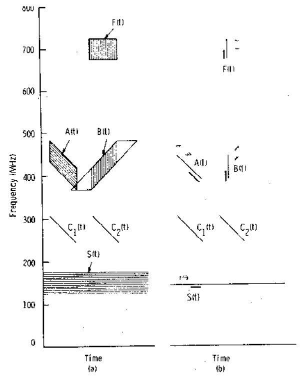
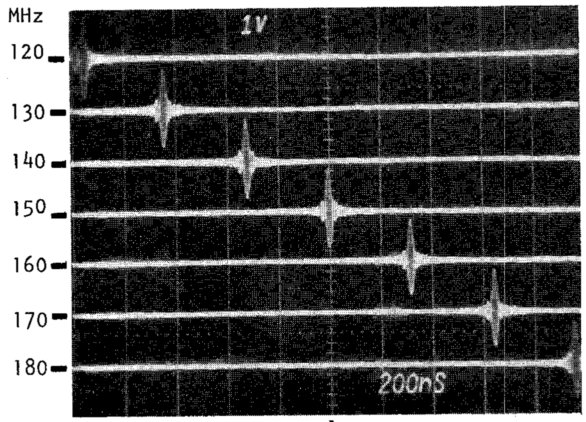
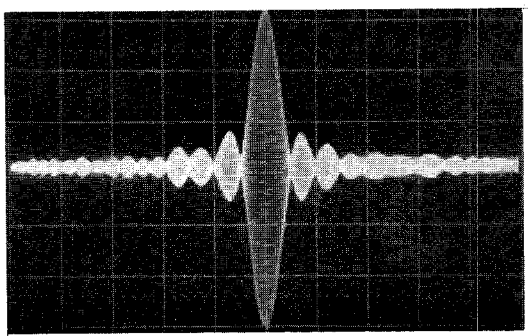



Figure 2. Frequency-Time Diagram for the Chirp Transform



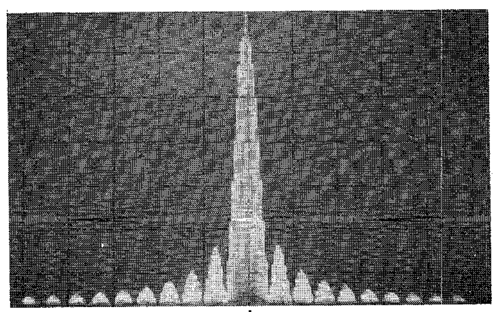

150 MHz
200 μsec/Div
31.5 MHz/μsec

Figure 3. Chirp Transform of Seven Successive CW Input Signals



150 MHz
0.16 μsec/Div

Figure 4. Chirp Transform of a 0.4 μsec Pulse at 150 MHz



150 MHz
5 MHz/Div

Figure 5. Spectrum of the 0.4 μsec Pulse at 150 MHz

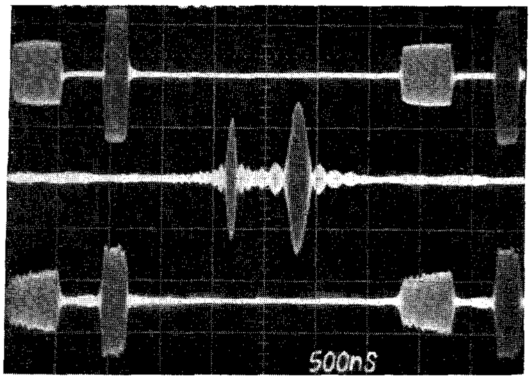



Figure 6. Chirp Transform-Inverse Transform of 140 and 160 MHz Pulses with 0.5 and 0.2 μsec Widths Respectively

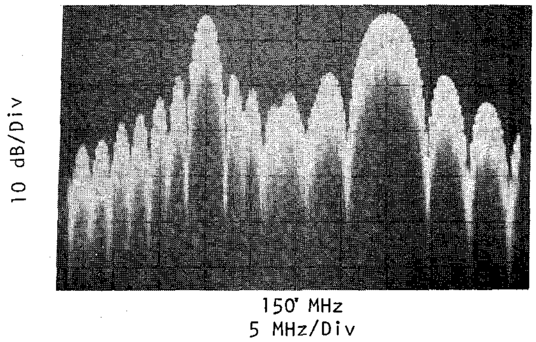



Figure 7. Input Signal Spectrum for the Two Sets of Pulses of Figure 6

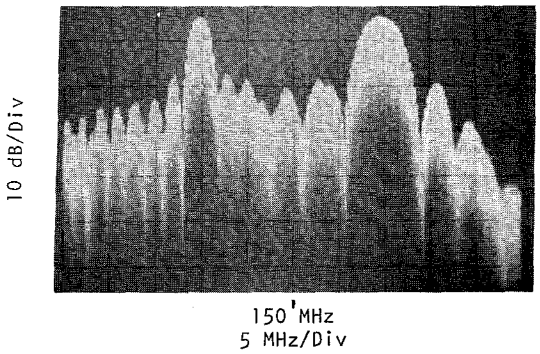



Figure 8. Prototype Output Signal Spectrum Following the Transform and Inverse Transform

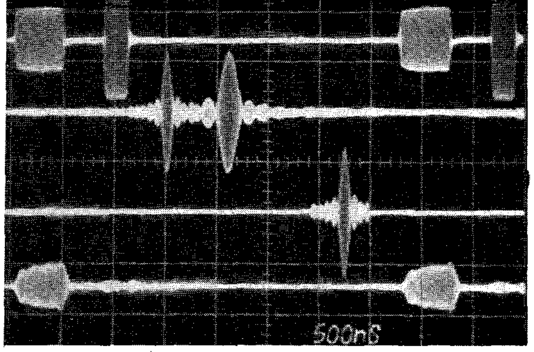



Figure 9. Demonstration of Adaptable Bandpass Filtering to Pass the 0.5 μsec wide, 140 MHz Pulses

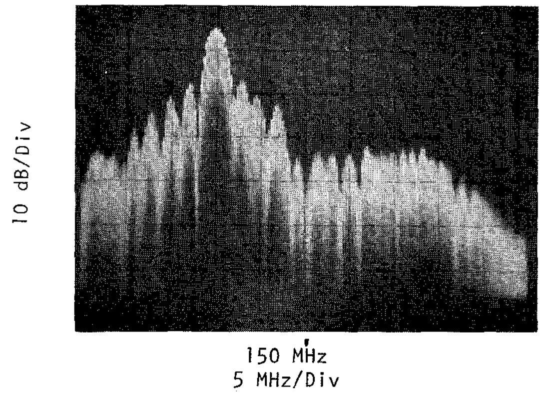



Figure 10. Bandpass Filtered Signal Spectrum of Fig. 9

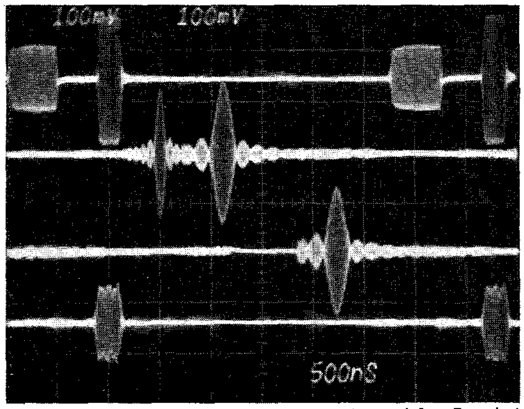



Figure 11. Demonstration of Adaptable Bandstop Filtering to Reject the 0.5 μsec, 140 MHz Pulses

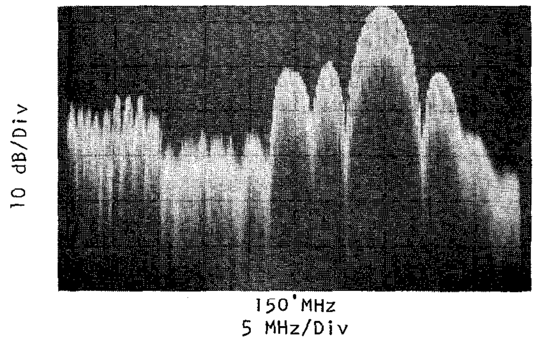



Figure 12. Bandstop Filtered Signal Spectrum of Fig. 11

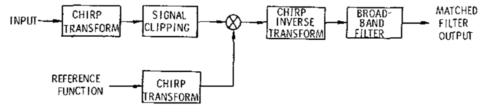



Figure 13. Transform Programmable Matched Filter with Transform Clipping to Approximate Spectral Pre-whitening for Suppression of Narrowband Interference