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ADAPTIVE SPREAD SPECTRUM RECEIVER USING SAW TECHNOLOGY.(U)

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ADAPTIVE SPREAD SPECTRUM RECEIVER USING SAW TECHNOLOGY

Technical Report MA-ARO-1

by

P. Das, D. R. Arsenault and L. B. Milstein

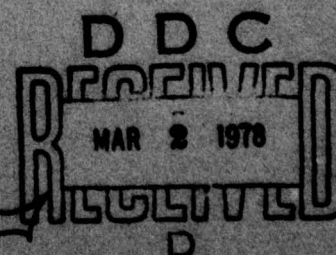
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Summary

A spread spectrum receiver implemented with surface acoustic wave (SAW) technology is discussed, and experimental results for the detection of a signal embedded in narrowband interference are presented. An adaptive version of that receiver is also discussed for the case of detecting a signal in the presence of a wideband Gaussian (out not necessarily white) interferer whereby an attempt is made to estimate the unknown noise spectral density.

1. Introduction

In [1], a spread spectrum receiver using surface acoustic wave (SAW) technology was described and experimental results showing its ability to remove a narrowband interferer were presented. In this paper, those results will be further elaborated upon and a method of making that scheme adaptive will be discussed. In particular, it will be shown that if one is receiving a spread spectrum signal in the presence of an interferer that can be modeled as a non-white Gaussian process with a covariance function which is changing slowly as a function of time, the receiver described in [1] can be made adaptive by estimating the spectral density of the interference and then slowly adjusting a prewhitening filter according to that estimate.

2. SAW Receiver

The general form of the receiver is shown in Figure 1. It consists of a Fourier transformer, a multiplier, an inverse Fourier transformer, and a matched filter. As described in detail in [1], the rationale for the above receiver is the ease with which it is possible to perform a real-time Fourier transformation using SAW technology. In essence, the filtering by the transfer function $H(w)$ is done by multiplication followed by inverse transformation rather than by convolution. This multiplication, while ostensibly being performed in the "frequency domain," is of course accomplished by the SAW device in real-time.

Alternately, the receiver may be implemented as shown in Figure 1(b) ([2][4]) wherein the matched filtering is performed by inverse transforming the product of the transforms of the filtered input waveform and the impulse response of the matched filter.

To illustrate the above ideas, Figures 2 and 3 show results of narrowband interference removal when $s(t)$ is a 13-bit Barker code and a 255 bit PN sequence respectively. (Actually, both codes were composed of ONE's and ZERO's rather than $\pm$ ONE's.) The interference in both cases was a sine wave, and in Figure 2 it was filtered out by multiplication in frequency by a rectangular pulse (i.e. a low-pass filter) while in Figure 3 it was filtered out by effectively multiplying by a notch filter.

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It can be seen from both figures that the interference has been effectively eliminated. The distortion seen in the final trace of each figure is due in large part to the bandwidth of the final video filter. As an incidental result, if traces 1 and 3 are compared with each other (also traces 4 and 6) one can see the fidelity with which the Fourier transforms can be taken.

Figure 4 shows the actual implementation used to generate the above results, and corresponds to the block diagram of Figure 1(a). The Fourier transforms were implemented using SAW delay times with a chirp (i.e. linear FM) impulse response built into the tap weights. However, the final matched filtering operation was performed using a silicon-on-lithium niobate convolver ([1],[5]).

To demonstrate the feasibility of Figure 1(b), the receiver shown in Figure 5 was built and results are shown in Figures 6 and 7. Figure 6 shows the output of a filter matched to a 255-bit PN code (again implemented with ONE's and ZERO's) when the input was that same code under interference-free conditions. When a narrowband interferer (specifically a periodic triangular waveform) was added, the filter output is shown in Figure 7.

If instead of being a sine wave the interference $I(t)$ was a wideband Gaussian process with some given covariance function, then $H(w)$ might have been chosen to be a prewhitening filter ([6]). However, some knowledge of the noise spectral density $S(w)$ of the interference must be available at the receiver. A possible technique to acquire this information is presented in the next section.

3. Spectral Estimation Using SAW Devices

It is well known that one cannot obtain unbiased and consistent estimates of the spectral density of a stochastic process with a single finite time realization of that process ([6]-[8]). This is because the most obvious estimate of the power spectrum of some process $x(t)$, namely

$$\hat{S}(w) = \frac{1}{T} \left| \int_0^T x(t) e^{-j\omega t} dt \right|^2, \quad (1)$$

has a variance which does not approach zero as T approaches infinity. This particular function is sometimes known as a periodogram. However, if one convolves $\hat{S}(w)$ with an appropriate "spectral window" ([8]) one will end up with an estimate whose variance does approach zero as the time over which the spectral estimate is computed approaches infinity. This new estimate is no longer unbiased, but for appropriate spectral windows the bias can be kept within tolerable limits.

There are many spectral windows that one can use ([8]). The one that is most easily implemented using SAW devices is one whose impulse response is of the form $(\sin u)/2$ so that its transfer function is just that of an ideal lowpass filter. Because of the simplicity of both Fourier transforming and convolving

using SAW devices, convolving the periodogram with a rectangular pulse (in the frequency domain) is easily accomplished if one can isolate the process $x(t)$ from which the periodogram is computed.

4. Adaptive Receiver

For the problem at hand, $x(t)$ is the sum of the additive noise $n(t)$ plus interference $I(t)$. If it is assumed that $n(t)$ is a stationary additive white Gaussian process and that $I(t)$ is a Gaussian process whose covariance function changes very slowly relative to the duration of one information bit, and if further it is assumed that the form of the desired signal $s(t)$ is known at the receiver (i.e. any distortion on $s(t)$ from what it was at the transmitter is known and can be reproduced at the receiver), then a possible implementation of an adaptive version of Figure 1 is shown in Figure 8. The idea in Figure 8 is to subtract from the received waveform an estimate of the transmitted signal $s(t)$. This (ideally) would leave just $I(t) + n(t)$ whose power spectrum could then be estimated. The second input to the convolver $P_{\delta}/2$ ($\omega = \delta/2$), is just a rectangular window of height unity, width δ , and centered at $\omega = \delta/2$. The inverter is a blackbox whose output is $1/X$ when its input is X . Finally, the Fourier transform in the estimation branch of the diagram operates over MT seconds for some integer M , where T is the duration of one information bit. The parameters M and δ have to be optimized for each given situation. Also, implicit in all of the above is the assumption of a low bit error rate, since only then can the decision-directed operations be expected to perform well.

5. Conclusion

Experimental results for a spread spectrum receiver implemented using acoustic surface wave technology has been presented for the case of a narrowband interferer. The same basic receiver was shown to be applicable to detecting a signal in wideband Gaussian noise, and a potential implementation of an adaptive version of that receiver was discussed. At present, this adaptive receiver is being implemented, but experimental results are not currently available.

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Fig. 1 Receiver block diagrams.

Fig. 2 Filtering of Barker code signal (hor. scale - 5 μ sec/div):

- Trace 1 - Barker code input
- Trace 2 - Fourier transform of Trace 1
- Trace 3 - Inverse Fourier transform of Trace 2
- Trace 4 - Barker code plus interference
- Trace 5 - Fourier transform of Trace 4
- Trace 6 - Inverse transform of Trace 5
- Trace 7 - $H(w)$ - gating signal
- Trace 8 - Filtered signal

Fig. 3 Filtering of 255 bit PN code signal (hor. scale 5 μ sec/div):

- Trace 1 - PN code input
- Trace 2 - Fourier transform of Trace 1
- Trace 3 - Inverse Fourier transform of Trace 2
- Trace 4 - PN code plus interference
- Trace 5 - Fourier transform of Trace 4
- Trace 6 - Inverse transform of Trace 5
- Trace 7 - $H(w)$ - gating signal
- Trace 8 - Filtered signal

Fig. 4 Implementation of SAW receiver where the matched filter part is implemented using a Si-on-LiNbO₃ convolver.

Fig. 5 Implementation of SAW receiver using up-chirp SAW delay lines only.

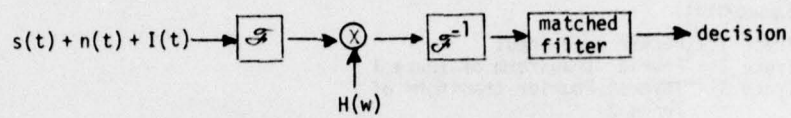
Fig. 6 255-bit PN code-matched filtering:

- (a) Hor. scale - 5 μ sec/div
 - Traces 1 and 2 - Code and its time reversal
 - Traces 3 and 4 - Respective Fourier transforms
 - Trace 5 - Product of Traces 3 and 4
 - Trace 6 - Matched-filtered output
- (b) Magnified and expanded view of Trace 6 (hor. scale 2 μ sec/div)

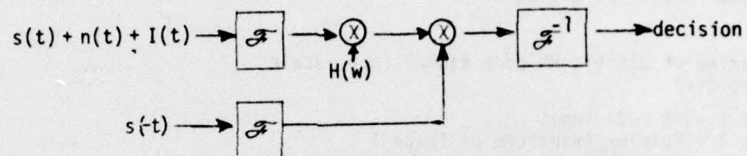
Fig. 7 255-bit PN code-matched filtering in the presence of triangular interferer. (hor. scale - 5 μ sec/div):

- Trace 1 - Time reversed signal
- Trace 2 - Signal plus interferer
- Traces 3 & 4 - Fourier transforms of 1 and 2 respectively
- Trace 5 - Multiplication of Traces 3 and 4
- Trace 6 - Matched-filtered output

Fig. 8 Adaptive receiver block diagram.



(a)



(b)

Figure 1. Receiver Block Diagrams

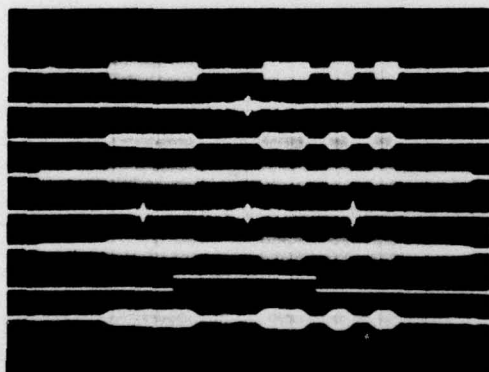


FIGURE 2

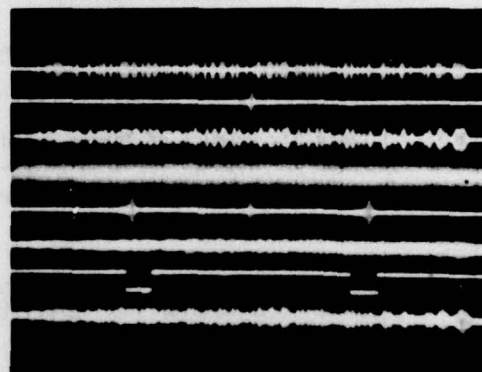


FIGURE 3

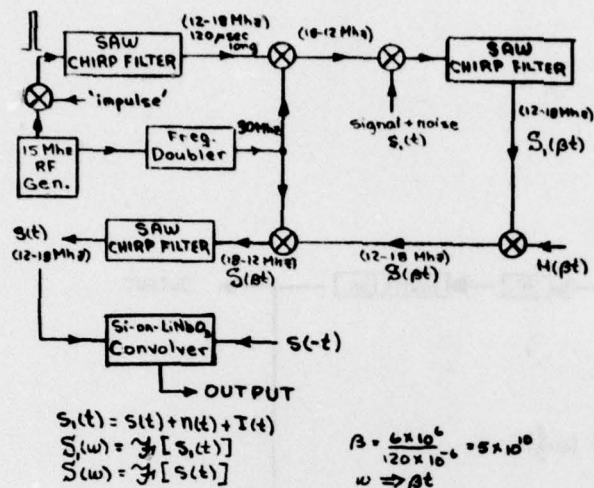


Figure 4

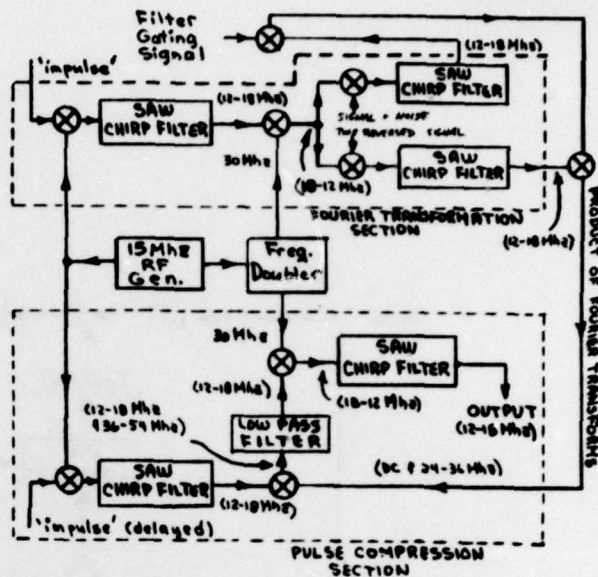


Figure 5

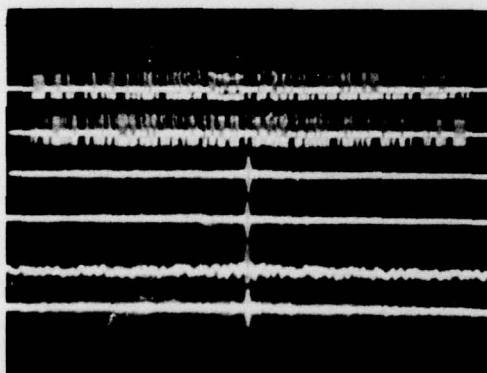


Figure 6A



Figure 6B

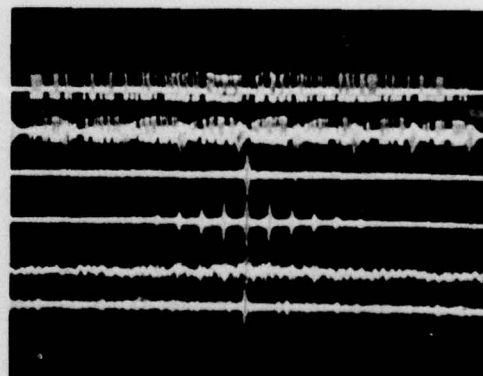


Figure 7

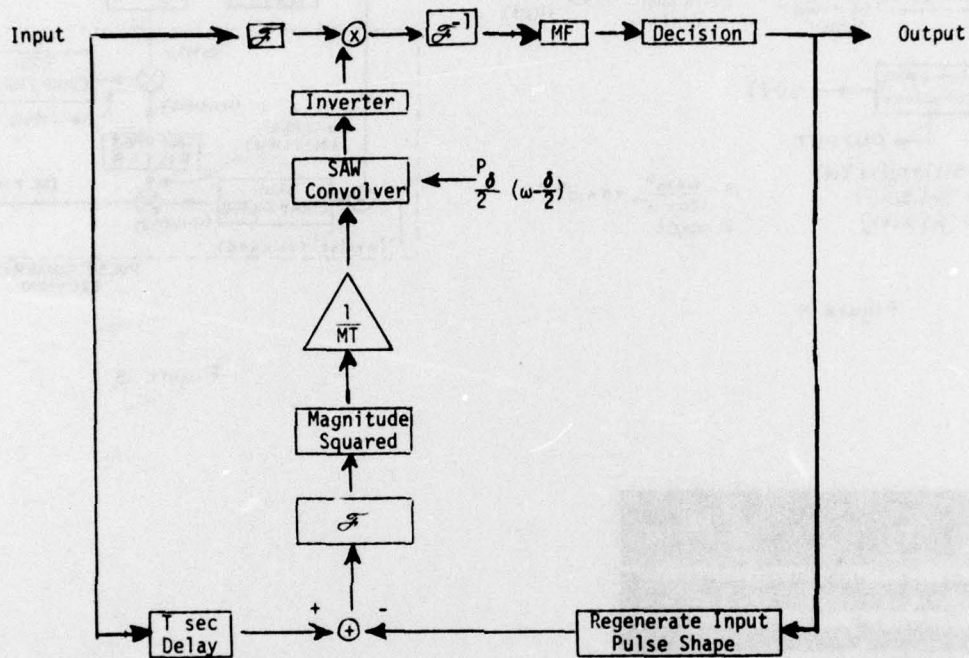


Figure 8. Adaptive Receiver