TECHNICAL FEATURE

MCM Receiver Performs Well in Noisy EW Environments

Compressive by nature, multiplier-convolution-multiplier receivers borrow spectrum analyzer techniques for EW applications.

Fast threat detection, low cost and easy portability are important attributes of an electronic warfare (EW) receiver. All of these properties are found in multiplier-convolution-multiplier (MCM) receivers.

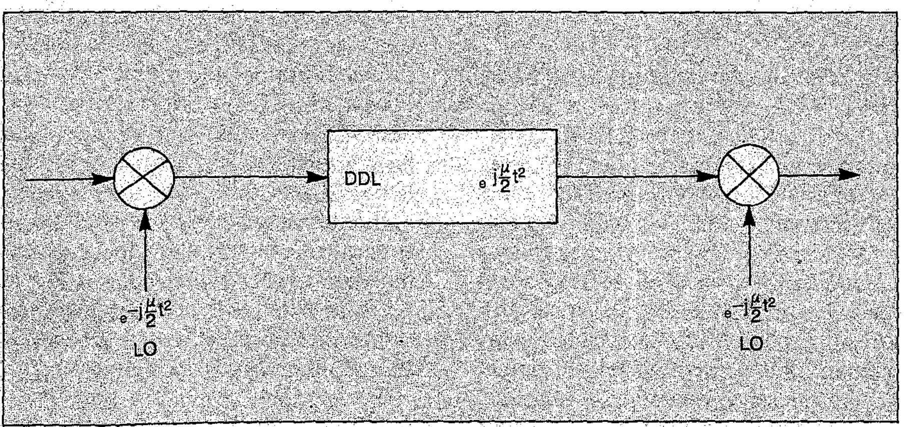
An MCM system is, in essence, a real-time spectrum analyzer based on frequency-time conversion. Surface acoustic wave (SAW) dispersive delay lines are the heart of the conversion circuitry.

MCM receivers are useful in radar systems as electronic support measures (ESM) receivers used to detect and analyze electronic counter measures (ECM) signals—before these signals can jeopardize the radar. The receiver can deliver key spectral parameters of an ECM signal (frequency, bandwidth, power spectral density) to the radar system control so that electronic counter counter measures (ECCM) activities can be initiated.

Since EW receivers must operate in noisy environments, it is important that they perform well under these circumstances. Computer simulation is the easiest and least expensive method of evaluating this kind of performance and is also useful in showing the performance trade-offs of bandwidth, S/N and discrimination of closely-spaced signals.

Compression Improves S/N

Compressive receivers are those in which a dispersive delay line (DDL) is used to compress the input RF signal into a narrow pulse. In MCM configuration, a fast sweeping local oscillator is used to convert the input signal to a frequency-modulated signal, and another sweeping oscillator is used to adjust the phase of the output signal (Fig. 1).



1. Basic MCM receiver configuration uses fast-sweeping LOs and a dispersive delay line to perform a frequency-time conversion of the input RF signal. Frequency of the detected signal is determined by relative position in the compressed time-domain pulse.

If the impulse response of the DDL is a chirp signal, and the sweeping local oscillators have the same frequency-time slope as the DDL (but with opposite sign), then it can be shown that the output is the Fourier transform of the input.[1,2] In this way, the MCM receiver behaves as a frequency-time converter, with fine frequency resolution.

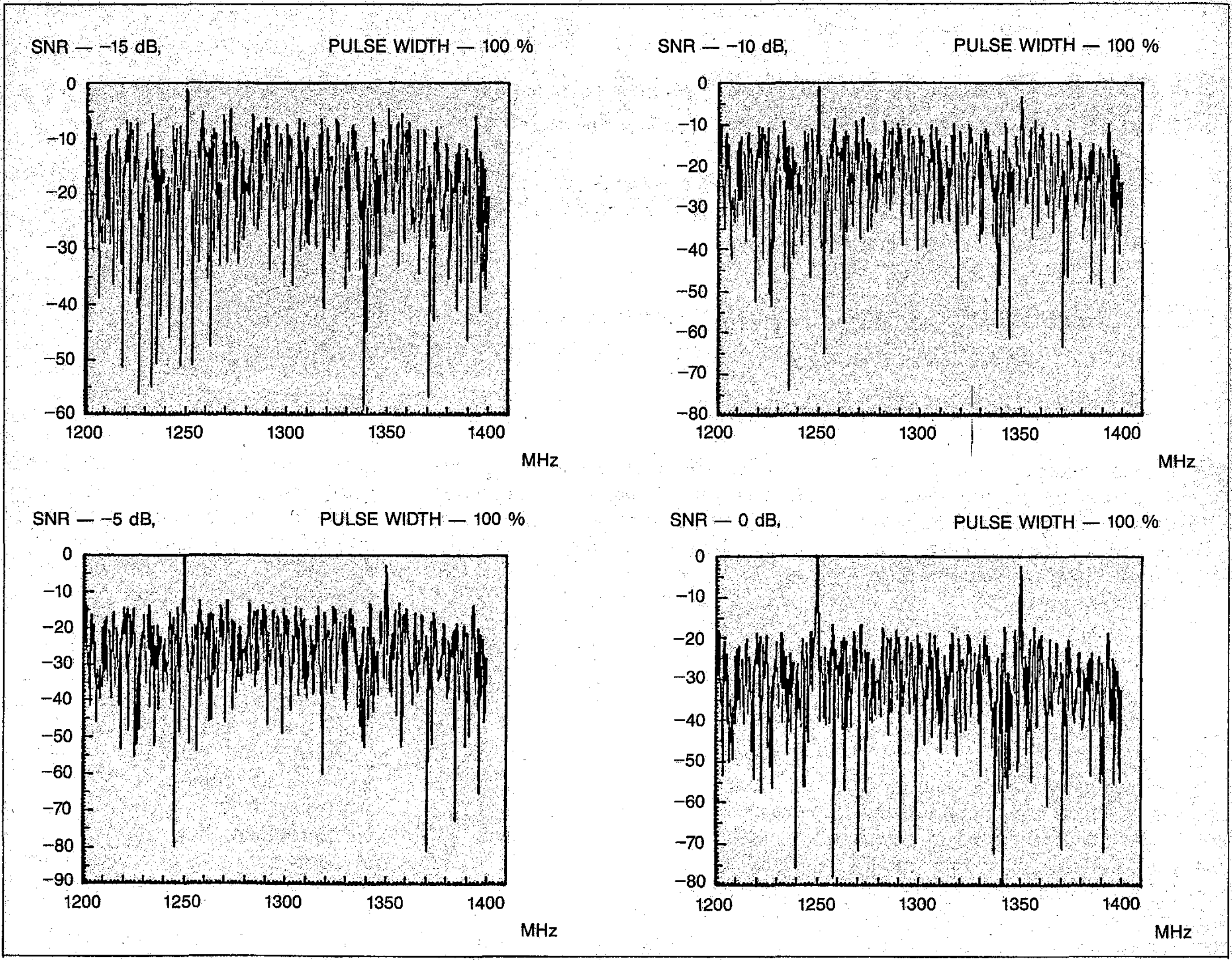
It thus has the capability to process simultaneous ECM signals; the detected outputs are narrow time domain pulses arriving in series. By measuring the positions of signals within these compressed pulses the frequency of the original signals can be determined. Also, the pulse compression results in S/N improvement that is equal to the pulse compression ratio.

In experimental designs, the chirp signals are time-windowed and an optimum relationship between their bandwidths can be derived.[2] If the bandwidth of the DDL line is B_1, and the dispersive delay of the DDL is T_1, then the sweeping local oscillators must scan at a rate matching the frequency versus time slope of the DDL.

$$\text{Scan Rate} = B_m/T_m = B_1/T_1 = \mu/(2\pi)$$

where B_m is the frequency range of the LO, and T_m is the scanning time. If the input bandwidth of the receiver is B_i, then the bandwidth processed by the DDL is

By **J.M. Rius**, and **A. Elias**, *associate professors at Universitat Politecnica de Catalunya, Grupo AMR, Dep. Teoria de la Senal y comunicaciones, E.T.S.I. Telecomunicacion, Ap. Correos 30.002, 08080 Barcelona, Spain. Tel.: 34 3 204 65 51.*



2. Signals become apparent as S/N increases in this simulated output of the MCM receiver for two CW input signals at 1250 and 1350 MHz (pulse width equal to 100 percent of time-windowing).

$$B_l = B_m B_i$$

For a given DDL, B_l and T_l are fixed and optimum performance is achieved when the processed input bandwidth, B_i, and the time-windowing, T_m, are maximum. Maximization of the ratio

$$(B_i \times T_m)/(B_l \times T_l) \text{ is achieved when}$$

$$B_l = 2 \times B_m$$

which implies that B_i must equal B_m.

Because the MCM receiver is a real-time Fourier transformer, the frequency resolution at the output is equal to the inverse of the time-windowing of the input,

$$\Delta f = 1/T_m$$

and the compression factor is

$$B_m/\Delta f = B_m \times T_m$$

Thus, S/N at the input is improved by the factor $B_m \times T_m$.

Computer Simulation

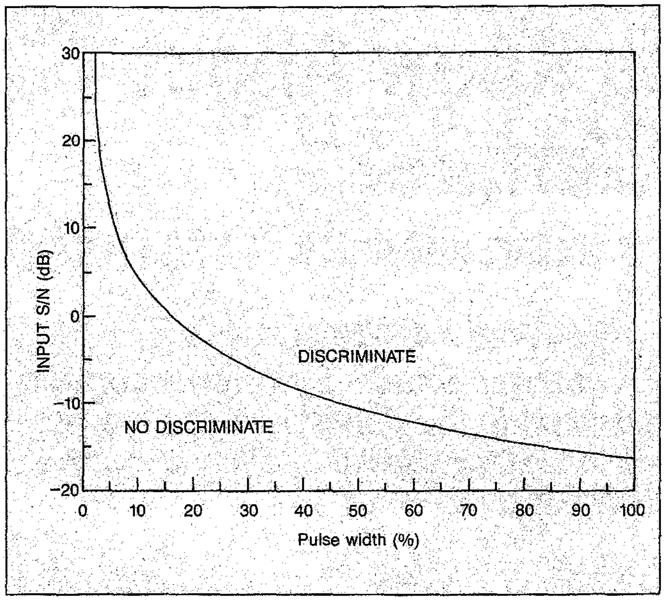
Analog convolution in a DDL must be computer simulated with discrete time signals. Highly efficient algorithms (FFT) are available for computing the discrete Fourier transform of a finite-duration sequence. For this reason, it is computationally efficient to consider implementing a convolution of two sequences by computing their discrete Fourier transforms, multiplying the results and computing the inverse discrete Fourier transform.[3]

As the Nyquist theorem states, a continuous-time signal must be sampled at a rate equal to or greater than the bandwidth of the signal. If T is the time-duration of the signal, B is the bandwidth of the signal, then the number of sampling points, N, will be at least

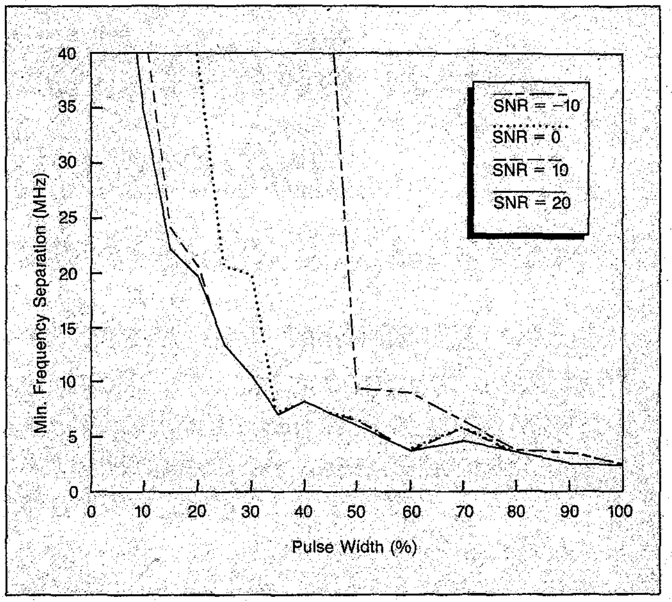
$$N = T/\Delta t = T \times B$$

When simulating the MCM receiver, the number of sampling points must be equal to the highest T x B product of the different signals to be sampled. This condition is reached at the output of the DDL, where

$$B = B_l = 2 \times B_i$$
$$T = T_l + T_m = 3 \times T_m$$



3. *It is important to predict the minimum required S/N at the input to guarantee proper detection of an ECM signal. Valid detection is defined here as producing an output S/N greater than 8 dB. An input S/N of at least -17 dB is needed to obtain an output S/N of 8 dB resulting in an S/N improvement of 25 dB for this CW signal.*



4. *The minimum frequency separation (vs. pulse width) required for successful discrimination of two ECM signals is shown here for four different input S/Ns. Larger pulse widths are required for a smaller input S/N with equivalent frequency separations.*

and, multiplying these two equations by each other results in

$$T \times B = 6 \times B_i \times T_m$$

where B_i is the processed input signal bandwidth and T_m is the duration of time-domain windowing.

The ECM signal is not always a continuous wave signal, and may be composed of finite duration modulated pulses. We have simulated the detection of ECM signals made of different pulse widths, T_i. As time-windowing, T_m, at the mixer using chirp signal LO reduces values of T_i greater than T_m to T_m, only values of T_i that are less than T_m will be considered. These will be expressed as a percentage of T_m.

To predict the performance of the MCM receiver in noisy environments, white Gaussian random noise has been added at the simulated input of the receiver, and S/N is calculated for a single CW input signal. When the input signal is pulse-modulated, the input signal energy decreases with narrowing pulse width. Because the noise level is unaffected by pulse width, S/N decreases under such conditions. For that reason, the performance of the system degrades if the input pulse width is reduced.

The following parameters were used to simulate a typical ESM receiver:

Proc. bandwidth (B_i=B_m) = 200 MHz

Center frequency = 1300 MHz

Sample rate ($B_1 = 2 \times B_i$) = 400 MHz

Sample pts. (N) = 2048 (= $6 \times T_m \times B_m$)

Resulting in:

$$\text{S/N improvement} = 10\log\,(T_m \times B_m) = 25.3\text{ dB}$$

Graphical presentations of other performance parameters for this simulated MCM receiver are given in Figures 2, 3 and 4.

Conclusion

- Because an MCM receiver is compressive, S/N is improved by a factor equal to the product of the processed input bandwidth and the input time-windowing. In our simulation, the improvement factor is 25 dB.
- As expected, the minimum required S/N needed to detect an ECM pulse increases with the inverse of pulse width.
- An MCM receiver simulated using 2048 sampling points is not able to detect pulses shorter than 1 percent of multiplier chirp windowing, even in the absence of noise.
- If fine frequency resolution is required, the following pulse width and S/N guidelines are useful:

50% min pulse width @ S/N = −10 dB

34% min pulse width @ S/N = 0 dB

30% min pulse width @ S/N = 10 dB

- Frequency resolution for an input S/N greater than 0 dB is similar to that for noiseless signals.
- Continuous-wave resolution is about 1.8 MHz in the absence of noise. ☐

References

1. James Bao-Yen Tsui, *Microwave Receivers with Electronic Warfare Applications*, John Wiley & Sons, 1986.
2. J.B.G. Roberts, G.L. Moule and G. Parry, "Design and Application of Real-Time Spectrum Analyzer Systems," *IEEE Proceedings*, April, 1980.
3. A.V. Oppenheim, R.W. Schaffer, *Digital Signal Processing*, Prentice-Hall, 1975.