Experiments in Pulse Communication With Filtered Sidebands

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This article describes the author's study of a method for increasing receiver sensitivity through narrow-band filtering, removing sidebands but retaining the pulse information

Any RF communications system that uses carrier on/off pulses can be designed to have better receiver sensitivity by using negative or zero group delay narrow band filters in the receiver. These filters greatly reduce the bandwidth normally required by removing the sidebands, while retaining the necessary information in the pulsed on/off carrier. SNR improvements greater than 40 dB are being obtained by means of bandwidth reduction alone (Processing Gain). The method is applicable to RADAR, TACAN, IFF, DME, PAM, PWM, UWB and UNB data methods. The information presented here enables any experimenter to duplicate the displayed results. There are no tricks or secrets, but readers should remember that this method only applies to on/off pulse communications, where the sidebands do not contain modulation information.

Analyzing the Sin*x*/*x* Spectrum

Figure 1 shows the spectrum of a pulsed signal applicable to RADAR and other pulse methods.

For all amplitude modulation methods:

$$I_t = I_m(\cos \omega_c t) + 0.5K(\cos\omega_c + F)t + 0.5K(\cos \omega_c - F) \quad (1)$$

Where ω_c is the carrier and F is the Fourier transform of the modulating signal. K is the modulation index, which is presumed to be 1.0 for pulse modulation. This is an AM sequence for which all components are required to initially produce amplitude modulation. The carrier is continuous for audio modulation, but is keyed on/off for pulse modulation.

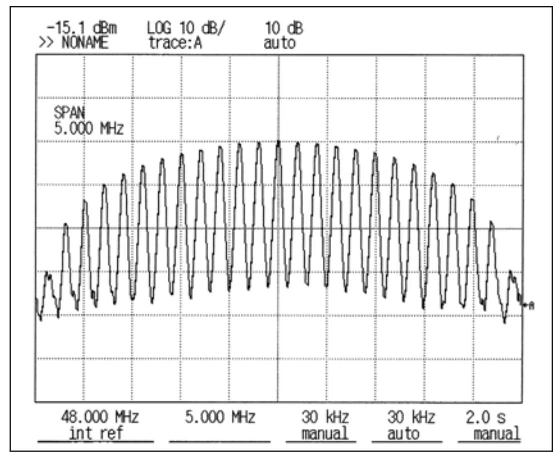

Figure 1 · Sin*x*/*x* Pulse spectrum for a pulse width of 400 nanoseconds with a repetition rate of 200 kHz. Most pulse systems would not use a rate this high.

The Fourier spectrum for a pulse using rectangular pulse modulation is:

$$F(t) = A_{peak}\,(t/2T_p)\ [\ 1/2 + (2/\pi)\cos\pi(nt/2T_p) - (2/2\pi)\cos 2\pi(nt/2T_p) + (2/3\pi)\cos 3\pi(nt/2T_p) - (2/4\pi)\cos 4\pi(nt/2T_p) + (2/5\pi)\cos 5\pi(nt/2T_p)\ \ldots\ ] \quad (2)$$

which nulls when nt = 1.0, thus the DC component can be ignored. $(1/T_p)$ is the repetition rate and "t" is the pulse width. Only the fundamental is of interest because all harmonics are removed by the filters. This is a sin*x*/*x* waveform; all portions of equation (2) have a common form: $(Y)\cos \pi(nt/2T_p)$.

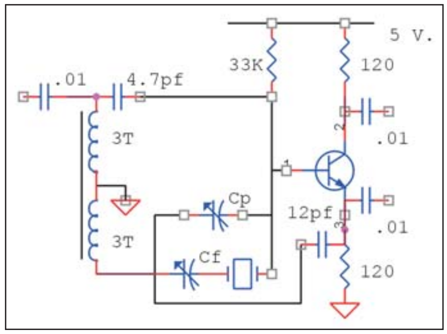

Figure 2 · Schematic of the "half lattice" or "bridge derived" narrow band filter. This filter has near zero group delay and a very narrow noise bandwidth. The capacitor Cp must be very small (1- 2 pF). Cf determines the frequency of the filter. It may require as much as 40-50 pF to tune the filter to the nominal center frequency. Tune Cp first to obtain the swept spectrum seen in Figure 3, then adjust the frequency with Cf.

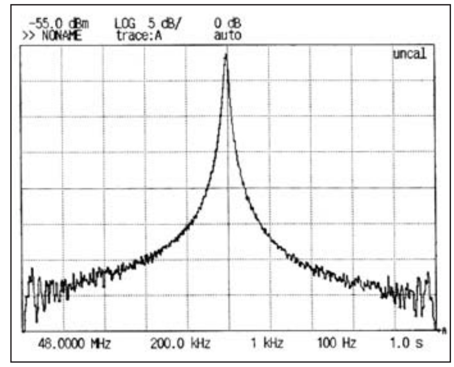

Figure 3 · Swept bandpass of one stage of the half lattice or bridge filter at 48 MHz. The filter is balance tuned with equal slopes on both sides for pulse systems. These filters can be cascaded to increase the shoulder reduction. In the following examples, two or more stages are cascaded with a total sideband reduction of 40 dB. The 3 dB noise bandwidth of this filter at 48 MHz is approximately 500 Hz.

A difference is to be noted in eq. (1) in that, unlike audio, the carrier is being turned on and off. Sidebands cannot be removed for ordinary audio modulation, or for FM/PM, where the carrier must be continuous.

The baseband signal equivalent to the modulating signal F in equation 1 is given in eq. (2). This signal results in hundreds of sideband frequency spikes, which are seen in Figure 1. n has values from 1 to infinity, but only those up to nt = 1, which are within the Nyquist bandwidth, need be considered. A frequency spike is created for each value of n (Figure 1).

Alternate $\pm n$ frequency spikes seen in Figure 1 cancel in phase so that only the difference between them in level adds to the total sideband amplitude. The total contribution of all of the sideband spikes to the total signal power is only 6 dB according to eq. (1). This can be verified by measuring the signal power when the carrier is notched out with a notch filter, or by means of detecting the carrier after the sidebands are removed.

Note: While the spectrum analyzer shows the spectral component level rising and falling with a change in pulse width, the voltage peak as seen on an oscilloscope at the filter output does not change as the pulse width is varied. $F(t) = A_{peak}\ (t/2T_p)$ changes with $t/2T_p$, but this has no effect on carrier voltage levels, or the detected output level.

Zero Group Delay Filters

Figure 2 is a schematic of one version of a filter having near zero group delay. Actually, this filter will indicate negative group delay when tested on a network analyzer. Negative group delay implies that an event could be predicted in advance, which is not possible. The filter can exhibit near zero group delay with a causal response. There are other filters with this characteristic [1, 8].

The nominal Nyquist bandwidth (baseband) for the signal shown in Figure 1 is 2.5 MHz ($B = 1/t$). The RF bandwidth is 5 MHz. Reducing the filter noise bandwidth from 5 MHz to 500 Hz results in a SNR improvement due to processing gain of 5,000,000/500 = 10,000/1 = 40 dB. There is a power loss of 6 dB, due to the loss of the sidebands (eq. 1), so the net SNR improvement is 34 dB, which would extend the range of the system by almost 50/1, or in the case of RADAR, enable the detection of much smaller targets.

There is little or no rise time integration as would be present using a conventional Nyquist criteria filter having the necessary Nyquist bandwidth of 5 MHz. Some energy will be stored in the filter crystals between pulses, but at the normal radar pulse rates this is negligible. This filter has a rise time T of one IF cycle. From the relationship BT = 1, the Nyquist bandwidth (5) of this filter is 48 MHz, not the 500 Hz seen in Figure 3. Because of this Nyquist bandwidth, the method does not violate Shannon's channel capacity equation.

If the repetition rate is too high, there will be ringing energy stored in the crystal between pulses. This is not a factor at RADAR and other distance measuring pulse rates.

Equation (1) is the general equa-

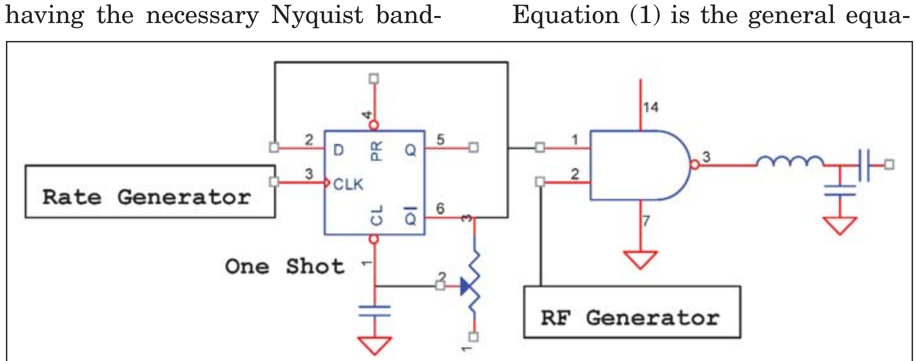

Figure 4 · RF Pulse generator used for these experimentals.

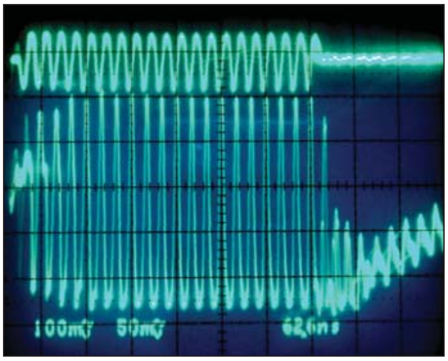

Figure 5 · 400 ns pulsed output waveform of the generator in Fig. 4 (upper trace), and the waveform after one stage of the zero group delay filter (lower trace).

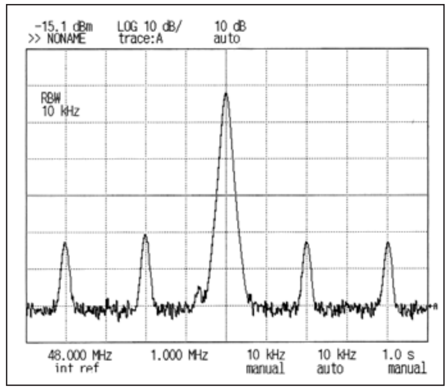

Figure 6 · The spectrum after two stages of the near zero group delay filter, showing the sidebands reduced by 40 dB. These sidebands are too weak to have an effect on the detected pulse signal.

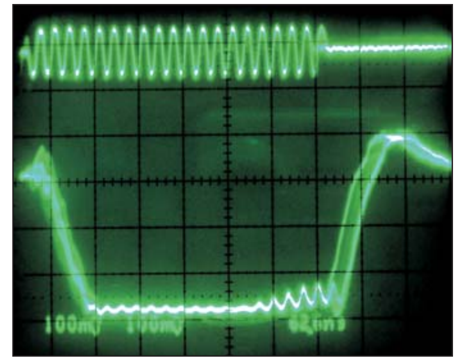

Figure 7 · The detected waveform of the 400 ns pulse using a synchronous detector. The rectangular waveform of the baseband pulse has been preserved.

tion for all AM modulation methods, including pulse modulation. Each full sideband contributes 0.5*K* to the signal, where *K* is the modulation index ($K = 1$). When the sidebands are reduced 40 dB as shown in Figures 5 and 6, it is the equivalent of reducing the sideband 0.5*K* to 0.005. 40 dB reduction implies that only 1/10,000 of the remaining signal power is in the sidebands.

The synchronous detector detects and outputs each IF cycle of the pulse. The pulse start/stop in the pulse generator is not synchronized with the RF sine waves, hence there is a ±1 IF cycle uncertainty in the leading edge. The detected output is the same with or without the filter, indicating the filter has little or no envelop (group) delay, or rise time.

Normally used pulse methods employ a Nyquist criteria filter that has a rise time *T* (the same as group delay) as close as possible to the pulse width. This is explained in all of the references as a filter having $BT = 1$, Ref [5]. These filters do not preserve the baseband waveform. The detected signal must then be differentiated to obtain the best rising edge for range resolution. This is not necessary with the zero group delay filters described here and in Ref. [1], since the rise time and range determining edge is ±1 IF cycle. The bandwidth *B* becomes the same as the pulse frequency.

When pulses are used between vehicles, the velocity of the vehicles creates a Doppler effect that must be taken into consideration. The Doppler frequency change could cause the return signal to be outside the very narrow filter bandwidth. Means to correct for this are found in references [1] and [4].

Data transmission using AM pulses employs switched carrier phase AM pulses which are one or more bit widths wide, placed end to end so that there is no empty signal space between the pulses. A digital one has a carrier phase at nominal zero degrees and a digital zero has the carrier phase shifted 90 -120degrees. The pulse widths vary according to the data pattern [1]. All sidebands can be reduced to comply with FCC regulations. A synchronous phase detector detects the ones and zeros. The same hardware as described here is applicable.

Author Information

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References

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7, 8, 9. Internet searches on “Wavelet RF Filters,” Negative Group Delay,” and “Fourier Spectral Separation,” respectively.

Editor’s note—Mr. Walker recognizes that some of his past work in narrowband communications has been controversial. In that light, he encourages others to duplicate these experiments and investigate other analog and digital filtering options.