Sideband Criticism

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Abstract:

Amplitude Modulation using missing cycles (MCM) can be transmitted and received without sidebands. The method can involve a long period in which the carrier is ON, with a few cycles removed, or it can have the carrier ON for a very short period, with long missing cycle OFF periods. Filling in the missing cycles with pulses having different carrier phases makes it possible to transmit digital data without sidebands.

The range of RF pulse modulation systems such as RADAR, IFF, TACAN and DME can be greatly improved by reducing the bandwidth required for echo signal reception. SNR improvements greater than 40 dB can be demonstrated, along with improved resolution and reduced jamming effects. The method involves the use of ultra narrow bandpass filters having near zero envelop group delay and rise time instead of the normal Nyquist criteria IF filters. These filters also preserve the modulation waveform.

The zero group delay filters have a 3 dB noise bandwidth of approximately 500 Hz instead of the normally required B = 1/T bandwidth. (Ref. 2). A pulse width of 250 nanoseconds normally requires a filter 4 MHz wide at baseband, or 8 MHz at RF. Since noise is directly related to bandwidth, the bandwidth reduction, hence noise reduction, is 8,000,000/500 = 16,000/1, or 42 dB. The method removes the sidebands, which account for ½ of the signal power, so there is a loss of 6 dB. The total SNR improvement in this case is 36 dB.

Sidebands vs. Carrier:

It is well known that an AM signal contains a carrier plus sidebands. The carrier contains ½ the peak voltage and the summed sidebands add to double or cancel the peak voltage for 100% modulation. It can be shown by the simple means of removing the carrier from a pulsed signal that the sidebands contribute only 50% of the energy. Similarly, using the near zero group delay filters, reducing or removing the sidebands causes a detected voltage loss of 50%. All of the necessary information to detect an AM pulse is present in the carrier alone. This has also been proven since 2001 in the case of 'Ultra Narrow Band' digital data modulation (Ref. 1).

The Fourier expansion for the sinx/x AM waveform of Fig. 1 is:

$F(t) = A_{peak}\,(t/T_p)\,[\,½ + (2/\pi)\cos\pi(t/2T_p) - (2/2\pi)\cos 2\pi(t/2T_p) + (2/3\pi)\cos 3\pi(t/2T_p)$

- $(2/4\pi)\cos 4\pi(t/2T_p) + (2/5\,\pi)\cos 5\pi(t/2T_p)$ ---]
- Which nulls when $n(t/2T_p) = 1.0$ t = pulse width, T_p is repetition period.

Eq. 1

This is the carrier plus the sideband modulating signal F in equation 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 need be considered. A sideband frequency spike is created for each value of 'n'.   For all amplitude modulation methods:

$$\mathbf{V_t} = \mathbf{V}_m(\cos \omega_c t) + 0.5K(\cos\omega_c + F)t + 0.5K(\cos \omega_c - F)t \qquad \text{Eq. 2}$$

Although there are many sideband frequency spikes seen in Figure 1, they alternately + - cancel part of the power of the adjoining sideband frequency spike and the total added power contributed by the level difference between all of the sidebands is only 6 dB**.** Reducing the repetition rate increases the number of sidebands, but does not change the carrier to sideband energy ratio, which remains at 6 dB. When the sidebands are reduced 40 dB after two stages of filtering as seen in Fig. 5, it is equivalent to reducing K in equation 2 to 0.005.

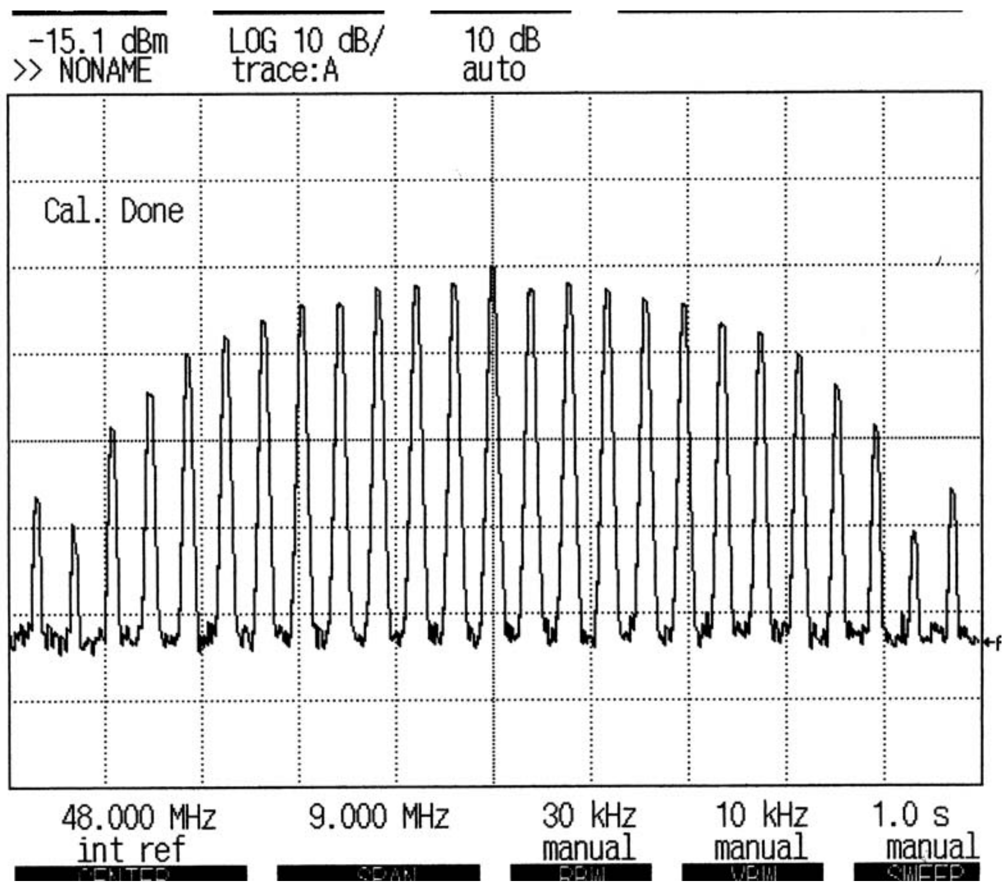

Figure 1. The Simulated RADAR (short time ON) Pulse Spectrum for a 250 ns pulse. There are many sideband frequency islands, but the total energy contributed by the vector sum of all of the sidebands is the same as that of the carrier alone. (Eq. 2). Eliminating the sidebands results in a 6 dB power loss. The number of these sidebands is immaterial to the detected signal. The carrier frequency spike is seen at the center. All other spikes are sinx/x Fourier sideband spikes which can be removed.

Figure 1 shows the spectrum of a 250 nanosecond pulse repeated at a 350 kHz rate. This is a Fourier sinx/x spectrum as represented by Equation 1. The Nyquist bandwidth is 4 MHz. The RF bandwidth is 8 MHz as seen in Figure 1.

Note: While the spectrum analyzer shows the average spectral component level rising and falling with a change in pulse width, the voltage peak V_p as seen at the filter output (Fig. 7) does not change as pulse width is varied. $F(t) = A_{peak} (t/2T_p)$ changes with $t/2T_{p,}$ but this has no effect on carrier voltage level A_{peak}, or the detected output level.

Zero Group Delay Filters:

There are several known filters that can exhibit near zero group delay while having a very narrow noise bandwidth to remove or reduce the sidebands.. These filters have an envelop group delay of 1 IF cycle. If the IF is high enough, the filters eventually reach zero group delay. Group delay and envelop rise time are related. The filter shown in Figure 2 is a very effective filter for use with AM pulses, such as those employed with RADAR, IFF, DME, TACAN etc., and with UNB data. Negative group delay filters are also known to exist. The filter shown in Figure 2 will display a negative group delay on a network amalyzer.

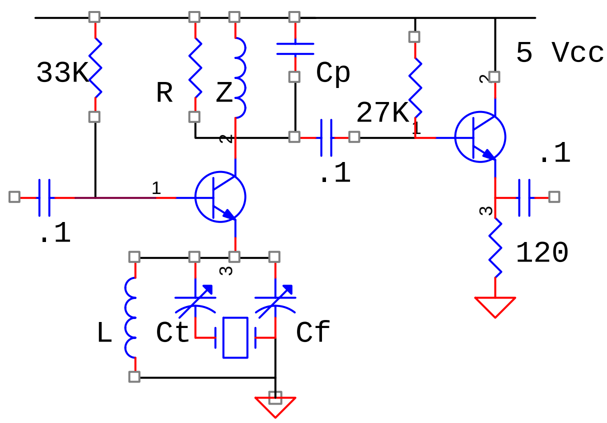

Figure 2. Schematic of the series emitter near zero group delay filter. The gain is determined by the load resistor R. This filter circuit is rich in harmonics when overdriven. The inductor Z and the capacitor Cp are a low Q resonator to reduce 2nd and 3rd harmonics. At 48 MHz, 0.47 uH and 22 pf were used with R of 47 to 68 Ohms.

The gain of the circuit is determined by the ratio between the emitter impedance of the series resonant crystal and the collector load impedance. At crystal resonance, the emitter impedance is very low, being approximately 25 Ohms. Off resonance, the impedance is much higher. These stages can be cascaded to further reduce the sideband levels, thereby reducing the out of band noise as well to extremely low levels.

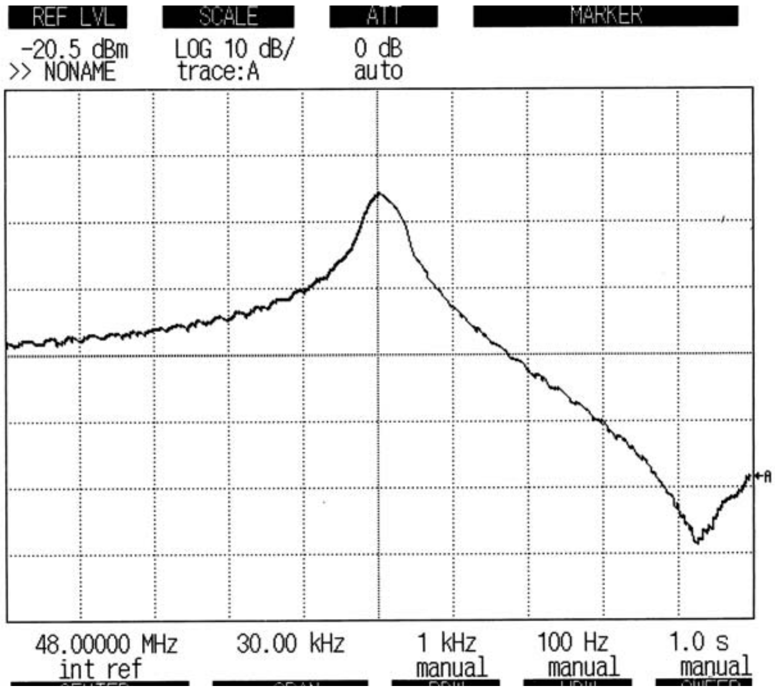

Figure 3 shows the swept response for one stage of the series emitter filter of Figure 2. The measured 3dB noise bandwidth is approximately 500 Hz.

Simulating a RADAR pulse:

A very narrow pulse equivalent to a RADAR pulse can be obtained from the circuit shown in Figure 4. The width of the pulse can be adjusted as desired. The waveform of the pulse is seen in the upper trace of Figure 8. This is also the waveform seen at the IF filter input.

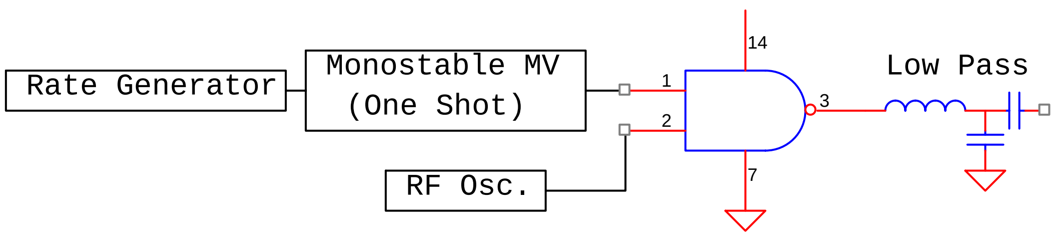

Figure 4. RF Pulse generating circuit.

The lower trace of Figure 8 shows the waveform after two stages of the filter shown in Figure 2. Note that the rise time is one IF cycle. There is little or no integration, or rise time to reach the cycle peaks, as would be occur after a conventional Nyquist filter. This waveform remains essentially unchanged after several cascaded stages of the filter.

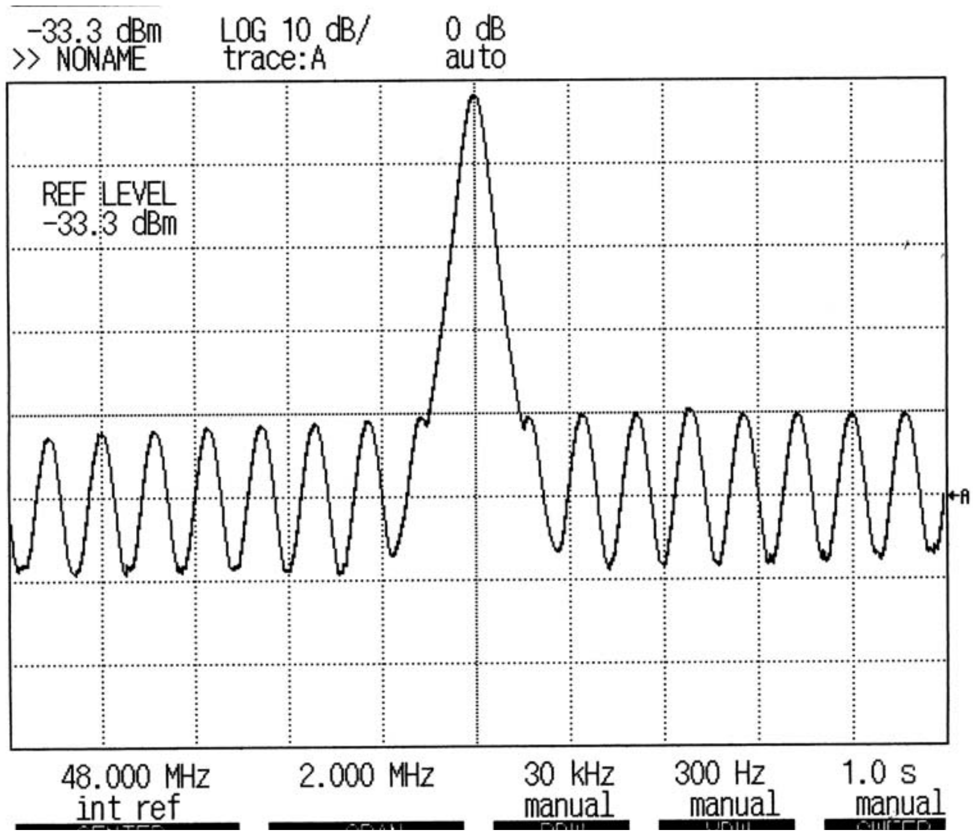

Figure 5 shows the spectrum within a narrower bandspread on the spectrum analyzer after 2 stages of the filter shown in Figure 2. The sidebands have been reduced by 40 dB relative to the carrier and no longer contribute any significant amount of energy to the signal. This also indicates that any interference, or noise on either side of the carrier, is reduced by a similar amount. The signal to noise ratio is now totally dependent upon the signal plus noise that passes through the narrow band filter, which has a 500 Hz noise bandwidth.

Similar results are obtained when the carrier is ON most of the time and only a few cycles are removed.

The above discussion assumes there are missing cycles. Digital data can be transmitted by filling in the missing cycles with carrier pulses of a different phases so that carrier phase one represents a digital one and carrier phase two represents a digital zero.. This becomes end to end AM pulse width modulation. It is necessary that the baseband waveform be a rectangular waveform, or FM will occur. There will be a missing cycle, or distorted cycle at the transition between switched phases. The modulation method must use “switched” phases and not ordinary PM. With switched phases the spectrum is a Fourier sinx/x spectrum, while ordinary PM creates a Bessel spectrum.

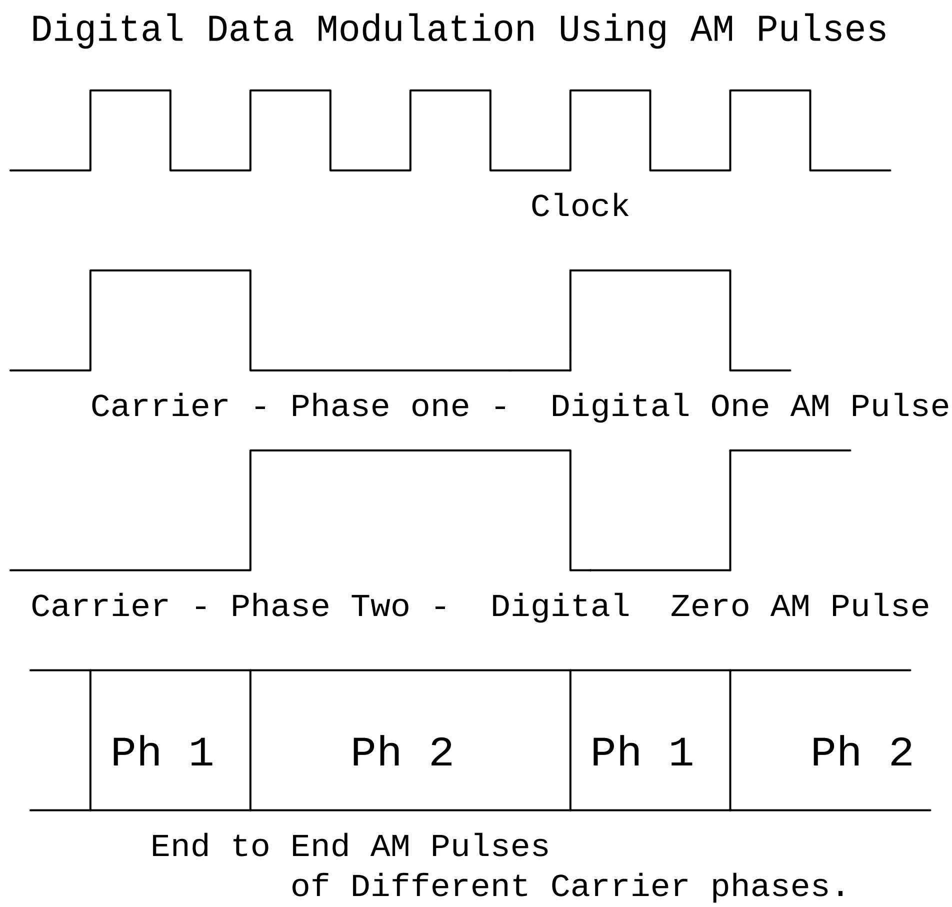

Figure 6.

Zero group delay filters used with AM pulse modulation make it possible to transmit digital data without sidebands as seen in Figure 6. The 1 IF cycle rise time of the filters makes it possible for the data pulses to be detected with a synchronous phase detector.

Detection:

Any detecting means can be used for MCM pulses, but the optimum choice is one which does not introduce group delay and thus preserves the waveform. A synchronous detector that does not introduce any RC rise/fall time is desired. When two phases are used, the detector must be a phase detector, usually preceded by a limiter.

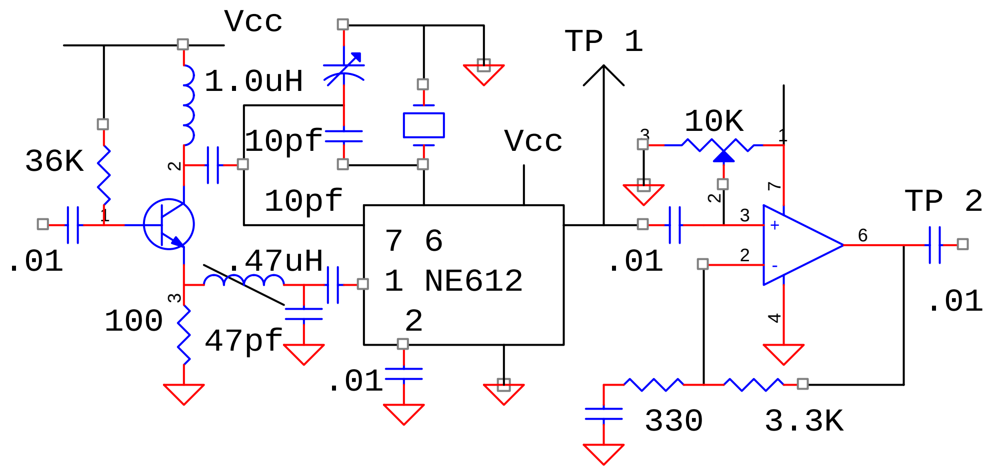

Figure 7. A synchronous detector that responds to individual cycles. It has a linear, not a square law response. This detector is also a phase detector.

MCM Pulses:

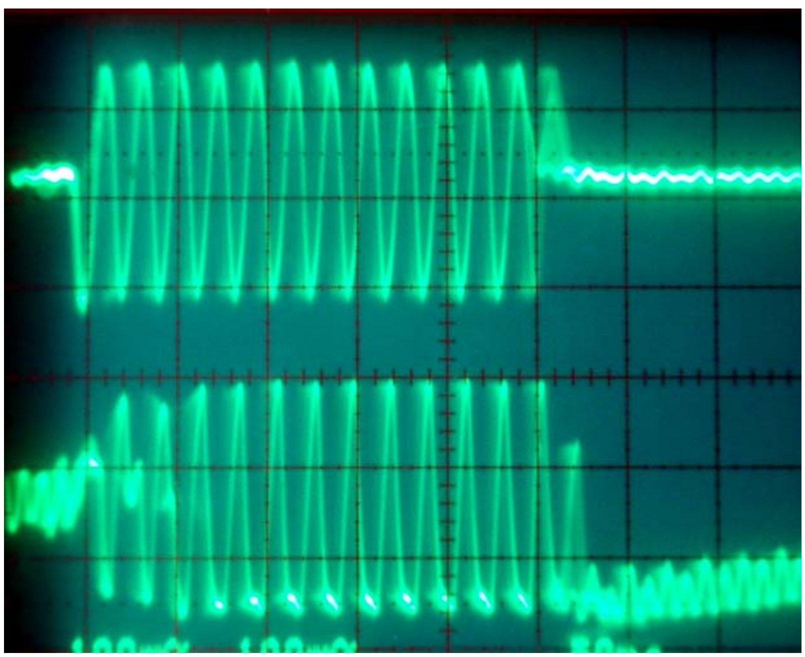

Figure 8. The upper trace is the signal showing the IF cycles of the pulse at the filter input. The lower trace shows the RF pulse after the zero group delay filter. The pulse width as shown is 250 nanoseconds, or 12 IF cycles at 48 MHz. According to the relationship BT = 1, a rise time of 1 IF cycle implies a Nyquist bandwidth B equal to the intermediate frequency, or 48 MHz, not the measured 500 Hz. Shannon's channel capacity equation is not violated if this bandwidth is used.

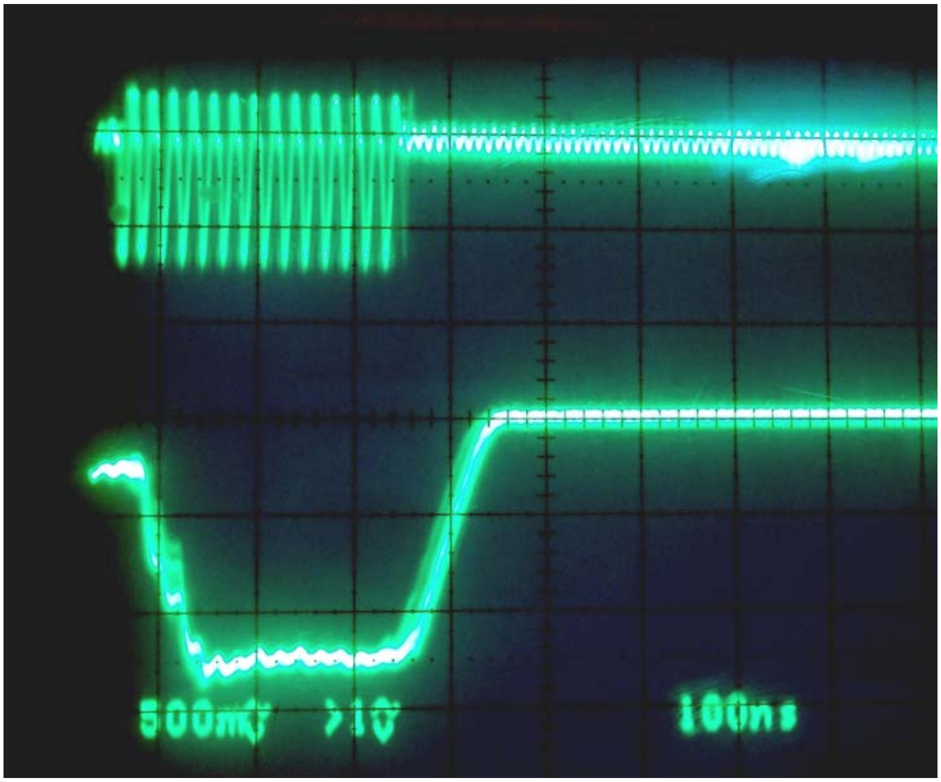

Figure 9 shows the signal after RF removal at TP2 of Figure 7.

Resolution:

There is some waveform edge loss (+ - 1 cycle) seen in Figure 8 due to RC time constants and waveform cycle uncertainty. This edge uncertainty is present with or without the ultra narrow band zero group delay filter. Allowing for repeated pulses, the edge timing will average with a 1 IF cycle uncertainty. The RADAR resolution accuracy is therefore 1 IF cycle, or in this case 20 nanoseconds.

Using normal Nyquist criteria filters, which have a rise time that is integrated over the period 't' and then differentiating the detected signal, the edge uncertainty would be spread over many IF cycles, depending on signal level. These Nyquist criteria filters also have a loss of energy in the detected pulse. Resolution properties are dependent upon the pulse waveform after filtering as discussed in Ref. (5), Table 25.5. The best results are obtained with a filter that retains the rectangular wave shape. The present method retains the approximate rectangular baseband pulse wave shape as seen in Figure 8, while conventional filtering and detection does not. A conventional matched filter at 48 MHz IF with a 250 nanosecond pulse would have a range uncertainty of about 35 meters, while the rectangular wave shape obtained with the present filter would have an uncertainty of 3-6 meters.

Two Phase Data Pulses:

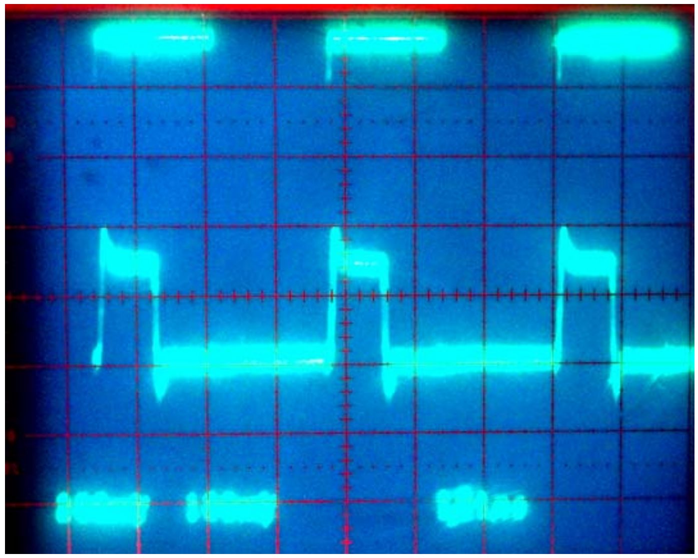

Figure 10. Two phase data pulses using end to end pulse modulation as seen in Fig. 6. The data pattern is 1010101010-- using 3 PSK modulation (90 degree phase difference). The pulse width for a digital 1 is ½ the bit period. The detector of Fig. 7 was used. A detected pulse appears for digital ones, while there is no amplitude change for digital zeros.

Two Ways to Produce UNB:

UNB modulation can be produced by using end to end AM pulses, as described here, or by using switched phases with a rectangular baseband waveform according to the Howe concept. In both cases the essential sinx/x spectrum is produced. AM pulses could also have amplitude shaped baseband waveforms, while the switched phase Howe concept is absolutely dependent upon a rectangular waveform. The basic difference is in the modulator used. In the AM pulse case, there is a transition spike at the data bit edges due to uncertainty of the phase at the bit edge. Using the Howe concept there is a spike due to a momentary FM burst at bit edges that is filtered off.

Improvements in SNR:

When sidebands are removed, the noise bandwidth used by the receiver is greatly reduced. Normal sideband spread according to Nyquist requires a bandwidth equal to the bit or symbol rate. A 1 MHz rate requires a bandwidth of 1 MHz. Similarly, according to BT = 1, a pulse 1 microsecond wide requires a 1 MHz BW at baseband. Using double sideband RF, this is doubled so that a 2 MHz bandspread is required. Using UNB filters which have a 500 Hz to 1 kHz 3 dB noise bandwidths, any and all UNB methods improve the SNR by the ratio of the normal Nyquist BW to the UNB filter noise BW. Assume a 10 Mb/s data rate, then 10,000,000/500 is a bandwidth - and consequently a noise power reduction of 20,000/1, or 43 dB. Needless to say this should greatly increase range.

Problems:

The crystals used in the filter will have a temperature drift problem and RADAR returns are usually subject to Doppler Effects, which can cause the returned signal to fall outside the narrow frequency bandpass of the UNB filter. Both of these problems can be solved by using a Doppler correcting circuit described in References (1) (5), which provides a stable IF that ignores the Doppler.

Summary:

Sidebands have been shown to be removable and only the carrier need be transmitted.

Pulse transmitting and receiving circuits have been described that improve the received signal to noise ratio by a factor greater than 30 dB for short pulses, which indicates that a much greater range is possible for RADAR and other pulse systems. Since the transmitted waveform is retained, the target resolution for distance measurement is greatly improved. The very narrow bandwidth of the filter will also reject or reduce the effects of 'Jamming' signals. The method may also be applicable to UWB and under water sound systems.

When broad carrier pulses with different carrier phases are used end to end, the AM pulse method can be used to transmit digital data without sidebands.

References:

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(2) Merrill Sokolnik, "Introduction to RADAR Systems", McGraw Hill. 1962, pp 21.
(3) August W. Rehaczek, " Principles of High Resolution RADAR", Mc Graw Hill, 1969.
(4) Povejsil, Raven and Waterman, "Airborne RADAR", Boston Technical Publishers (D. Van Nostrand) 1965.
(5) Donald G. Fink and Donald Christiansen, "Electronic Engineers Handbook", McGraw Hill, 1989. Chapter 25.