Analyzing Ultra Narrow Band Modulation

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Abstract:

Several papers have appeared recently which incorrectly analyze UNB methods as baseband methods. This cannot be done, since the methods rely on totally different transmitted bandwidths than the actual Nyquist bandwidth and there are no Bessel products. The method does use switched carrier phases, but it is not angle modulation method as commonly understood. This paper will illustrate the correct analysis for RF modulated UNB signals and show some recent measurements as well as several new concepts.

Bellamy (Ref. 1), states: ***" Except for a relatively few uncommon frequency or phase modulated systems, digitally modulated carrier systems can be designed and analyzed with baseband-equivalent channels."***

Ultra Narrow Band Modulation is definitely one of the exceptions, since it has; 1) A very broad Nyquist bandwidth, which is greater than, and is not related to, the data rate; 2) A transmission bandwidth 1 Hz wide, which is not related to bit rate; and 3) A receiver noise bandwidth, which is not related to the 'Nyquist', or the 'Transmission' bandwith.

Figure 1 shows the frequency change resulting from a modulating input, which is $F = F_{carrier} + \Delta f$. Δf can be calculated from the basic relationship $\omega t = \Phi = 2\pi ft$, which can be rewritten in derivative form as:

$$\mathbf{\Delta f = \Delta\Phi / 2\pi\Delta t.}$$

In Figure 1 there is a slow rise in phase $\mathbf{\Delta\Phi}$ following the modulating waveform. Because the rise is linear, the resulting phase modulation and frequency modulation are predictable from the derivative $\Delta\Phi$. During the rise and fall times, there is a phase change $\Delta\Phi$, which causes a frequency change Δf, since FM is differentiated PM as the equation shows.

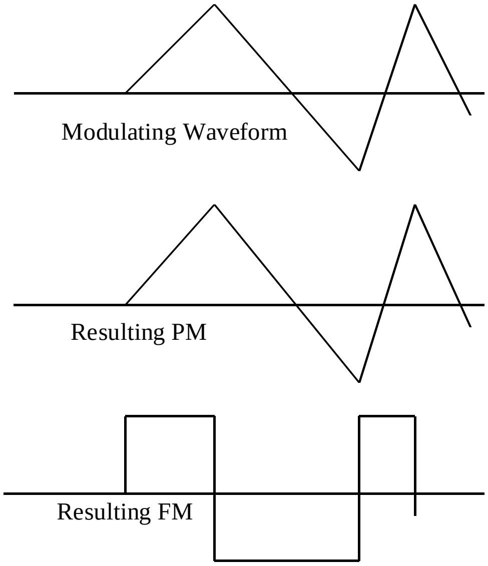

Figure 1.

The modulator is not a normal phase modulator, but a phase switching AM pulse modulator. The digital ones are an amplitude pulse lasting the duration of the data period, which is all the ones in sequence. The carrier phase is then switched and a new pulse is transmitted for the duration of the zeros. The circuitry is given in Reference 5.

The spectrum is a Fourier spectrum and not a Bessel spectrum. There is no β, as in normal angle modulation methods; therefor any formulas used with normal angle modulation methods, such as FM and PM, do not apply.

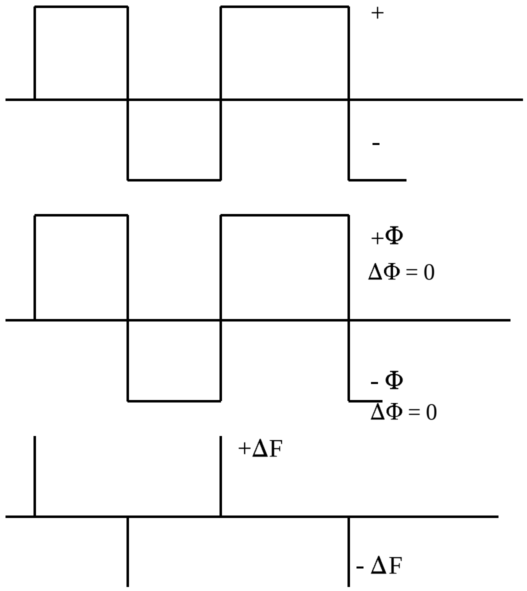

Figure 2. Abrupt changes in phase **$\Delta\Phi$** cause a totally different effect. There is a $\Delta\Phi$ only during the rise time of the rectangular input waveform. This causes a very brief FM excursion at the wavefom edges, but the remainder of the input period has no $\Delta\Phi$ and there is no Δf. Assuming the input data pattern is NRZ data, there is no Δf during the entire bit period and the frequency remains constant at the carrier frequency. Filtering will remove all of the Δf spurs and only a single frequency, the 'transmission carrier frequency', need be transmitted. There is no relationship between the 'transmission bandwidth' and the data rate.

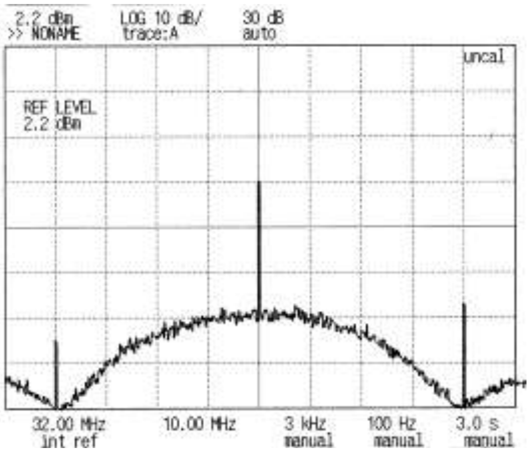

Figure 3. Pre-filter Spectrum for NRZ data.

Figure 3 shows the spectrum of the modulation with a 90 degree switched carrier phase change when using random NRZ data as the input, prior to any filtering. The data rate is 4 Mb/s with a 32 MHz IF. The lower hump is a sinx/x Fourier response that yields what is referred to as 'grass', or 'interference temperature'. This is removable by UNB filtering. The switched phase carrier is at the center. There is no useful information in this 'grass'. If the carrier is reduced by more than 3 dB relative to the grass, the signal as detected contains noise only.

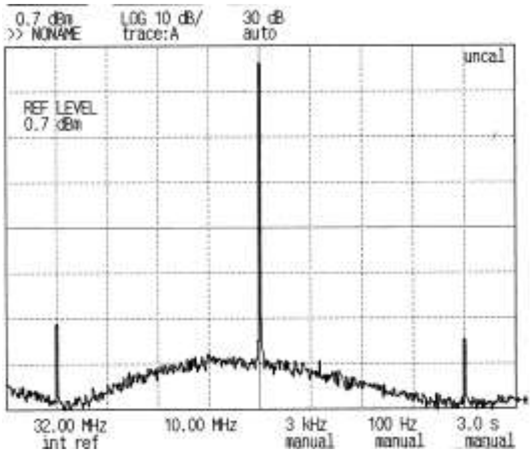

Figure 4 shows the spectrum after three stages of special ultra narrow band zero group delay filtering. (Fig. 6). If the method had a β equivalent, as in normal angle modulation methods, reducing the sidebands in the filters would reduce the β and the phase detector output would show a corresponding reduction in output level. That would be the equivalent of reducing the Bessel J_1. This does not happen. In fact, the vector adding filters used can actually increase the output level of the detected signal, as would not occur if Bessel products were involved, since there is no loss of phase change with the filters used.

The filter used must be able to respond to a single RF or IF cycle, that is, it must be a filter without envelop group delay. The group delay is **$T_g = [\Delta\Phi / (2\pi\ \Delta f)]$.** For LC or Gaussian filters, this is: **$T_g = [Q/4(IF)]$.**

Obviously, a very narrow bandwidth [Δf] filter (high Q) has a very large group delay and would not respond to a single IF or RF cycle.

The half lattice series of crystal filters store energy in the crystal, which is vector added to the incoming signal to yield a vector sum. The stored energy has a large envelop group delay T_g , which is normally 400 to 500 microseconds in the filters used. However, the transient goup delay, due to vector adding is 1 IF cycle. Assuming a 40 MHz IF, the transient group delay is 25 nanoseconds. The filters used are the series emitter filter (Fig. 5) (Preferred) and the Transformer Reflected Shunt (TRS) filter (Fig. 6). Using overtone crystals instead of fundamental crystals, less energy is stored in the crystal and there is less phase loss. The series emitter filter has the least phase loss with good shoulder reduction per cascaded stage.

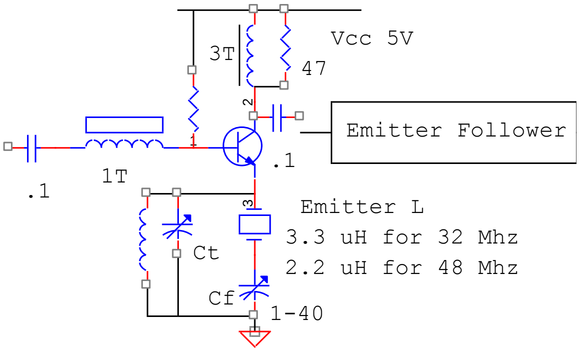

Figure 5 The Series Emitter Filter

Figure 6 shows the TRS filter with a 3rd overtone crystal. Typical sideband (shoulder) reduction is 15 dB per stage. The 3dB receiver noise bandwidth is less than 1 kHz, regardless of the data rate. Figure 7 shows the swept response of a single stage of the TRS filter. The scale is 5 dB per division. Normally, 3 or 4 stages of the TRS filter are cascaded to meet regulatory requirements for sideband reduction.

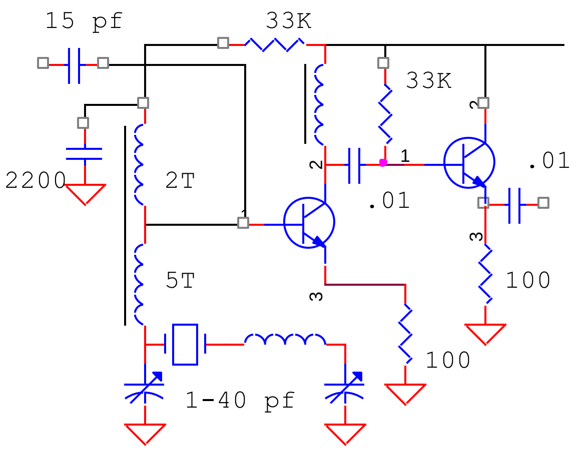

Figure 6. The TRS filter.

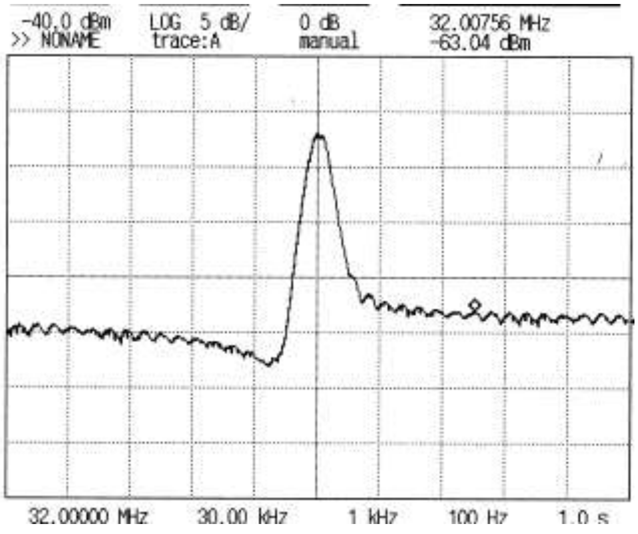

Fig. 7. Swept response of the TRS filter

Shannon's Channel Capacity:

The filters used with UNB have a transient response group delay equal to 1 IF cycle. The phase detectors used are synchronous detectors that sample at the intermediate frequency. The Sample Rate = IF. Shannon's channel capacity equation is:

$$R = W \log_2 (1 + \frac{C}{N}) = W \log_2 (1 + SNR)$$

In this equation:

R = Maximum Data rate (Symbol Rate).
W = B_w = Nyquist Bandwidth = Samples/Sec = $1/T_s$. BT= 1
C = Carrier Power
N = Noise Power

If R equals the present data rate in cycles per second and W equals the sampling rate, the equation balances when C/N and SNR = 1 = 0 dB. The Nyquist bandwidth is = IF, and not the transmission bandwidth of 1 Hz, or the receiver noise BW. Since the detector sampling is done on a cycle by cycle basis, C is the power in one IF cycle and N is the noise power in one IF cycle. (Ref. 5).

Error Probability:

$P_e = ½ \text{ erfc } [z]$ where $z = V_p/1.4E_N$ (V_p = peak signal level and **E_N** = noise RMS**)**
$(V_p/1.4E_N)^2$ = (E_b/N_o).
J.C. Bellamy (Ref. 1).

The measured BER is slightly better than that for theoretical BPSK, or any other method with two required sidebands.

Spectrum Sharing:

Since the carrier in UNB systems is a single frequency and the sidebands are not used or required for UNB, it is possible to amplitude modulate the carrier up to approximately 85% and still retain the extremely high data rates that UNB uses, thus sharing the same spectral space with two different forms of modulation. (References 6 and 7).

Analog Transmission:

Using a rectangular waveform that is frequency modulated by an analog waveform and detected by a suitable discriminating device, such as a frequency to voltage converter, a sine wave or composite analog wavefom can be transmitted using the single switched carrier frequency with no FM on the UNB signal. A sine wave of 100 kHz is easily transmitted and restored as a sine wave. (Ref. 4). The SNR is much better than with other audio methods such as AM and SSB-AM. Acceptable voice down to 2 dB SNR has been demonstrated.

Link Budget:

The 3 dB noise bandwidth of the receiving filter is approximately 500 Hz. This has no relationship to the data rate, which can be as high as 10 Mb/s with a 60 MHz IF. Comparing this with the 10 Mb/s bandwidth required for normal two level digital communications, there is a very huge saving in noise power, which translates to greatly increased range. Noise power varies directly with bandwidth. The link budget can theoretically be improved by 30 dB or more.

Summation:

UNB modulation is not an angle modulation method as commonly understood and cannot be analyzed as such. The RF characteristics, including bandwidths and filters, are totally different from those associated with the commonly used FM and PM modulation methods. UNB cannot be analyzed at baseband, since the spectrum, bandwidths, and sampling rates, are not the same as those for the commonly used angle modulation methods.

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