

The Trap
11/30/02(Reviewed (9/2/07)

Abstract:

The critics of Ultra Narrow Band Modulation methods (those who say "you cannot do that") have all taken a fast look at the waveform, or spectrum, and said immediately that this is impossible. The critics are so numerous that a few of the Ultra Narrow Band investigators will not even answer their complaining E-Mail any more. UNB methods do work, and in some cases work extremely well.

THE CRITICS ARE CAUGHT IN THE FILTER TRAP.

Without the filters described below, and in other papers, the Ultra Narrow Band methods do not work. With these filters, they work very well. Understand these filters before you comment, or analyze. These filters have Nyquist bandwidths that are very broad and very narrow noise bandwidths – this is a necessary condition.

Using various code differences, filter differences, detector differences and 'R' effect correction methods, **there appears to be a dozen or so usable combinations that produce a single frequency Ultra Narrow Band spectrum.**

HOWEVER: Until recently, **VMSK/2 in its original version was the only one of these methods known to have been satisfactorily demonstrated over the air.** More recently, 3PRK and NRZ-MSB have been added to the tested over the air tested list, with excellent results.

Dr. Wm. C.Y. Lee, formerly with Vodaphone, witnessed an over the air demonstration held at Vodaphone's facility. He has this to say in his recent book (1). "VMSK technology (2) can also be used. It can send 48 kb/s data through a 2 kHz filter and receives with good quality "----. He also refers to the 1 Hz transmitted bandwidth. 48 kHz was used as a comparison with IS136, which presently uses 48 kb/s data in a 30 kHz channel. The demonstration he witnessed was transmitting 270 kb/s through a 2 kHz receiver filter.

To paraphrase Dr. Lee further, "The idea is to find ways to slightly mark the carrier wave with the modulation so that the least distortion of the carrier wave is achieved."

All of the successful ultra narrow band methods end up doing just that. That is, they modify 1 or more cycles of the transmitted carrier single frequency at bit period intervals to mark the presence of a one or zero. If properly implemented, they can do so without an unnecessary frequency

spread that does not contain any useful information. The baseband encoding of VPSK and VMSK is not what comes out of the modulator.
Let's start with VMSK/2b.

The Coded BPSK baseband signal, which is a pulse width modulation signal, does not come out of the modulator and sideband filters as such. There is a conversion in the modulation and filtering to phase modulation. Instead, a single sideband frequency J_1 is all that comes out of the filters. This signal has a constant RF frequency that is interrupted at boundary intervals by a short burst of 1-3 cycles involving a phase rotation (un -synchronized), or a halving of the RF frequency (synchronized) for that short period. The Phase Detector sees this as a 180 degree phase rotation and outputs a rail to rail pulse. The result is that a narrow band filter, with almost zero group delay, passes the change, but outputs either a blank period, or missing cycle, or a phase shifted signal, depending upon the phase of the synchronizing circuit. The detected output is the same for MCM (3PRK), or VMSK/2b. It is a spike lasting about 2-3 RF cycles. (Feher keying has several similar variations)(VMSK/2a is different).

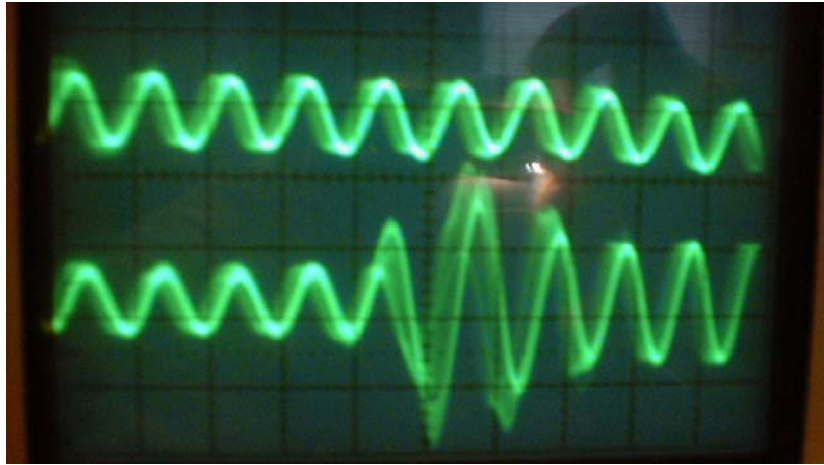


Figure 1. Waveform of the unsynchronized VMSK/2b Single Sideband ahead of narrow bandpass filtering. The early / late transitions of the VMSK modulation are seen as abrupt phase changes lasting 2-3 cycles. The remainder of the time, the signal is almost constant in frequency and phase. The modulation is in the form of phase change pulses.



Figure 2. The abrupt phase changes can appear as a missing cycle after a narrow band filter and synchronizing the RF change with the data coding edges. Changing the synchronizing phase will show a phase shift instead of a blank out as seen in Fig. 15. After one stage of special narrow band filtering and optimum carrier phasing, the waveform of the single sideband VMSK/2b signal appears as shown in Fig.2, or 15. The modulation appears as a missing cycle, or phase distorted cycle, which when detected appears as shown in Fig. 4.

Filtering and detection is the same for all methods. The hole, or phase distortion, in the RF waveforms, must be passed by the filter, and the detector (a phase detector) must see it as a phase change. Usually, the filters phase distort the gap in a brief RF burst change.

3PRK/MCM merely creates this missing pulse in the carrier (as a baseband equivalent) at the start, without going through the VMSK Aperture Coding, modulation and SSB filtering.

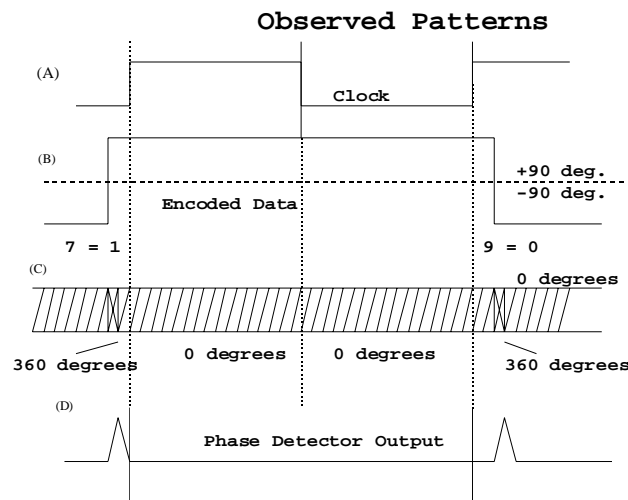


Fig. 3. Encoding and SSB modulation produce phase modulation pulses.



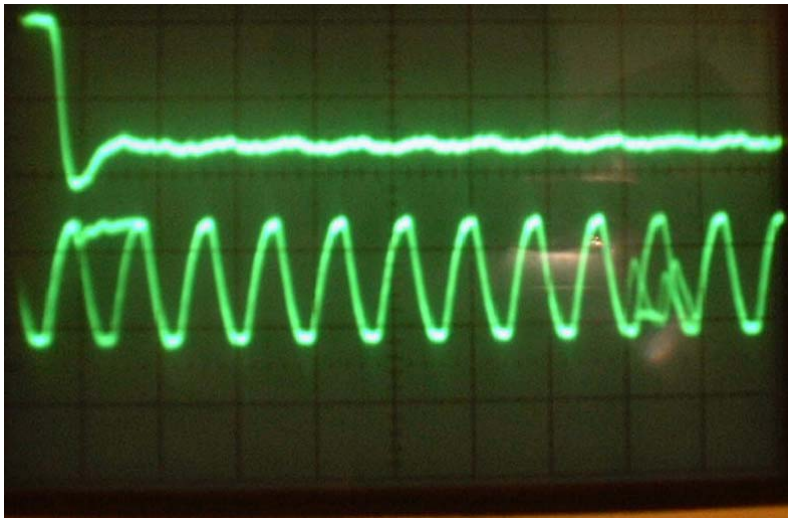


Fig. 4. The phase detector output for VMSK/2b, MCM/3PRK and some FK variations.

Fig. 5. Missing Cycle Modulation.

This form of modulation bypasses the pulse width modulation and conversion to PM in VMSK by altering a carrier to appear the same as the synchronized sideband waveform. The unfiltered output of the modulator main lobe (MCM) is shown above. The mono-crystal filter stages must preserve this waveform with a minimum of phase distortion loss. A digital one is seen at the left, where one cycle is robbed from the 90 cycles in the bit period. A digital zero is at the right. There is an overlay that shows both the digital one and the zero in the right and left traces. Robbing the carrier of this single cycle, causes the pulses that are seen as a sinc/x envelope in Fig. 6. Each of the sinc/x pulses in this envelope has an RMS level less than -60 dB below the main lobe. (The RMS level is not the peak level shown). No further filtering of the transmitted signal is required to meet many FCC regulations. Wideband filtering is often used to further reduce the spread.

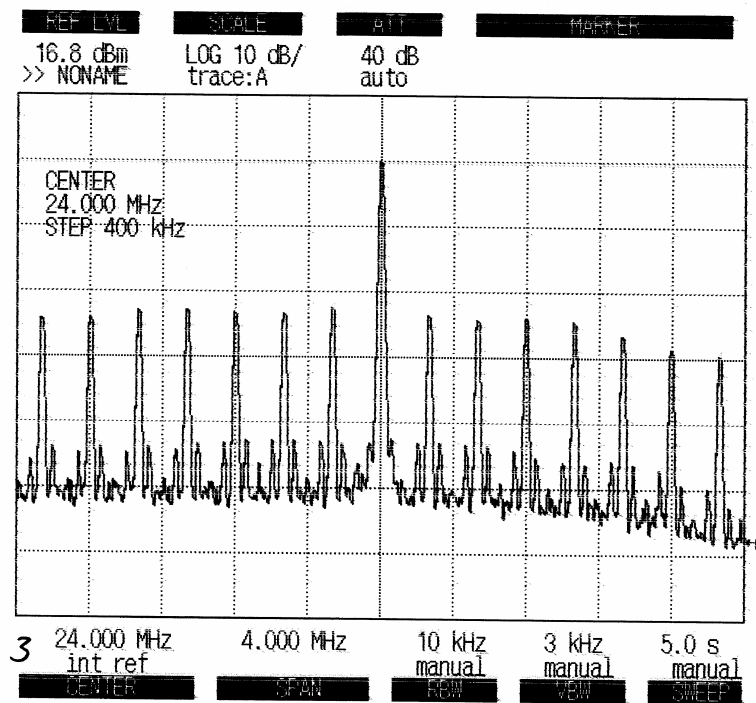


Figure 6, Showing how Pulse Modulation with long time on and short time off gives a strong central spike at the RF frequency (Lower J_1 for VMSK/2b) and Carrier for MCM and FK. The sinc/x pulse spread has multiple lower pulses with very short time duration, each with very little RMS power. These are AM pulses, which convert to PM pulses after several stages of filtering when some small amount of group delay is retained.

Power In Spread Pulses:

The peak level of the spread sinc/x pulses is shown in Fig. 6 to be $A(t/T)$. This is plotted on the left of Fig. 7. If the peak level of the spread spikes is at -40 dB with respect to a peak level where t/T approaches .01, then its average (Mean) power is reduced by a like amount as shown at the right. The average (Mean) power is down an additional -40 dB, for a total mean power reduction in each sinc/x spike to -80 dB.

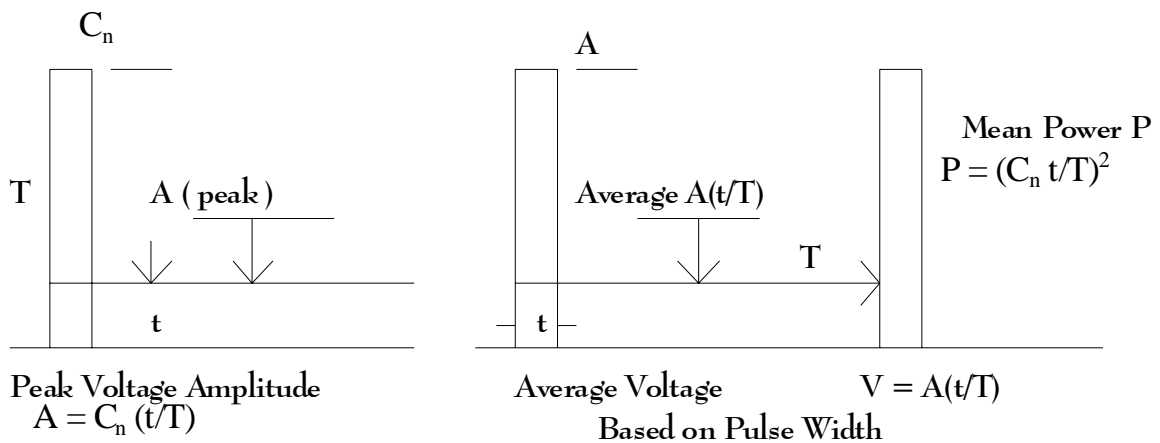


Fig. 7.

If the peak power of the minor spikes is further reduced with a narrow band filter to -50 dB, then the peak power is at -90 dB and the RMS (average, Mean) is at -140dB.

Mean Power Measurement of sinc/x lobes in MCM.

Figure 8 shows the RMS measuring capability of the AD8306.

The RMS voltage measured from the AD8306 Log Amplifier with RMS output shows the RMS voltage for the spike output in -Figure 9 - after the special filter, on one of the sinc/x lobes at 23.468 MHz. The main lobe at 24.000 MHz has been largely suppressed to prevent overload of the sidelobe in the filter. The sidelobe shows -40 dB below the carrier on the peak reading spectrum analyzer.

Point B is for the measured RMS value. Point A is the reading when a CW signal is inserted having the same peak to peak value. The meter readings are 1.94 Volts for the CW signal and 1.512 Volts for the pulses. The difference is 428 mv. The AD8603 has a slope equal to 20 mv/dB. The measured difference is 21.4 dB. This represents $40 + 21.4 = 61.4$ dB RMS below the un-modulated carrier.

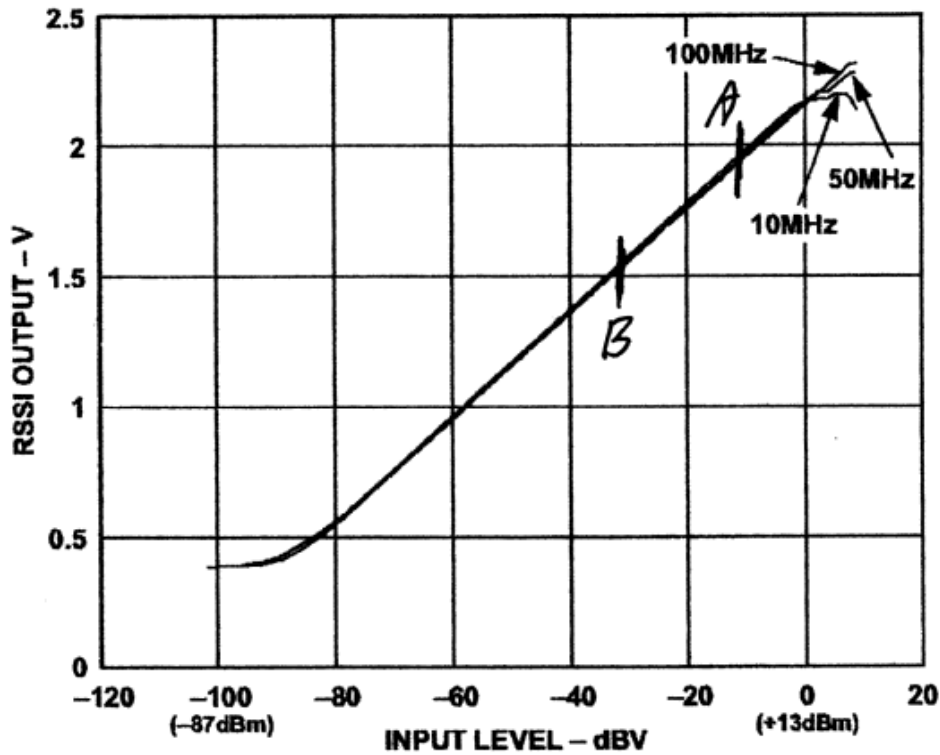


Figure 8. RSSI Output vs. Input Level, at $T_A = +25^\circ\text{C}$, Frequencies of 10 MHz, 50 MHz and 100 MHz

Poor shielding and layout of the test boards, plus less than optimum filter shoulders, causes some bleed through of the main carrier and other board noises, which causes the readings to be somewhat poorer than calculated. The readings nevertheless indicate the method complies with the FCC regulations for out of band radiation with no transmitter filtering. This is evident from the oscilloscope photo taken at the filter output. (Fig. 9). There should be no signal in the space between the pulses. Even when there are no pulses (no modulation), there is some signal bleed through which is readable 532 kHz away from the un-modulated carrier. This results in a meter reading floor.

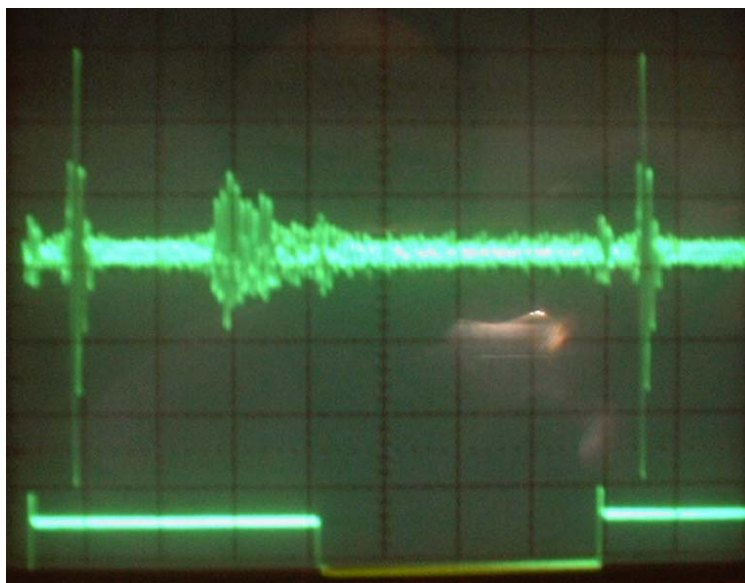


Fig. 9.

The output of the filter, tuned to a minor lobe, as seen on the oscilloscope, shows primarily the pulses. There should be no signal in between. The in between signal is

from poor test set up construction. Note also that the filter has a decay time of about 3-4 cycles, which detracts from the RMS level measured. If the filter had a normal group delay, (for example 26 microseconds for a 30kHz filter), it would tend to fill in and the reading would be the same as for a peak reading spectrum analyzer. For this reason it is necessary to use a filter with almost zero group delay- both to measure the pulse RMS level and to detect the signal at the carrier with the missing or phase altered pulse. Ordinary crystal filters have too much group delay to be used. They will not see the missing or phase altered cycle in the main lobe, or the sinx/x pulses in Fig. 9.

The power (RMS) in these sinx/x spikes is so low that minimal filtering is needed at the transmitter to comply with FCC regulations.

3 Pole receiver filters are in use with -50 dB shoulders and 1.5 kHz noise bandwidth.

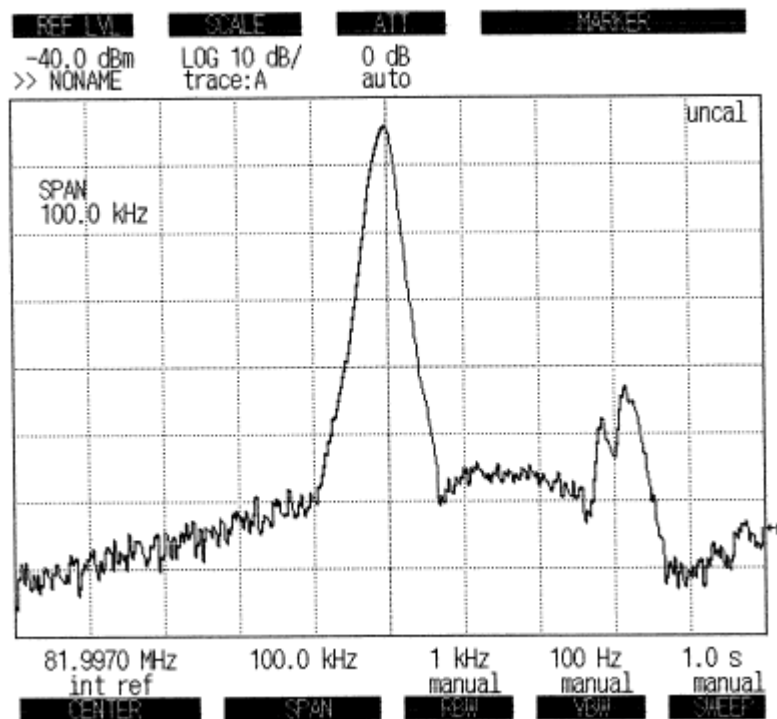


Fig. 10. Bandpass characteristic of 3 Pole Ultra Narrow Band Filter.

Ultra Narrow Band filtering does not reduce the detected output level as might be expected. The sinx/x spread, the result of an AM pulse signal, has very little power, is absolutely removable after conversion to PM. See Appendix 3 of the UNB Textbook. All of the necessary information in a UNB method is carrier in the single transmitted frequency.

- Believe it or not. The same is true for the grass in VMSK.

See Radar and UWB notes. Then note the description of these very unique filters.

FK and MCM differ from VMSK/2b, in that for VMSK the transmitted signal is a sideband. It is common wisdom that all modulation energy is in the sidebands.

Therefore, MCM and FK must have all their usable energy the $\sin x/x$ spread. --- But is this so? Actually it can be shown that the altered carrier after filtering takes on the characteristics of a sideband, when an artificial carrier is added.

Take as an example, narrow band FM or PM. The signal consists of a large J_0 signal and 2- J_1 signals at either side. If interference is added that exceeds the level of either of the J_1 sidebands, the signal becomes useless. With MCM or FK, the addition of a strong interfering signal at the side of the central spike has no such effect.

How does this filtering and detection stand up under white noise?

Better than BPSK. The $\sin x/x$ spikes, or the grass in VMSK, can be smothered with AWGN by more than 40 dB. BER measurements come in at or better than for BPSK.

Radar and UltraWideBand Notes:

Reference: "Electronic Engineers Handbook". Fink and Christiansen, McGraw Hill.

With a matched filter: $S/N = E_b/n$ (Where the bit rate and bandwidth are the same.)

The bandwidth required for a matched filter is $B = 1/\tau$, where τ = pulse width.

Thus for a 24 MHz carrier, a one cycle pulse = $1/24,000,000 = 41$ nanoseconds = pulse width.

The required matched filter BW is 24 MHz. If the filter is 2.4 MHz wide, the signal energy in the pulses is reduced to 1/10 the full energy level = E_b/n . **A very narrow filter with large group delay will not pass any useful energy.**

The Ultra Narrow Band methods all use a narrow band filter with near zero group delay that can have a noise bandwidth less than 1 kHz.

This cannot be done with UWB, or Radar, because there is no coherent reference. The narrow band methods establish a detector phase reference that is coherent to the signal, which is on most of the time, and then look for very brief irregularities in the signal. Pulse Amplitude methods such as UWB and radar must look for an irregularity in the noise, or a signal that stands out above the noise.

Near Zero Group Delay Filters:

The group delay for conventional filters is traditionally calculated to be:

$$T_g = [\Delta\Phi / (2\pi \Delta f)] \quad \text{Eq. 1.}$$

For LC or Gaussian filters, this is:

$T_g = [1/(4\Delta f)]$ Obviously, a very narrow $[\Delta f]$ bandwidth filter has a very large group delay.

There is an associated equation for the rise time of the conventional filter: $T_r = 0.7/B$, where B is the 3 dB bandwidth $[\Delta f]$ of the filter. This is the time from 10% to 90% on the RC curve. Bandwidth, rise time and sampling rate are mathematically linked using conventional filters.

The bandwidth required for a matched filter is $B = 1/ \tau$, where τ = pulse width, which is also the approximate rise time of the filter.

A conventional filter 2 kHz wide has a rise time of 350 microseconds. If the group delay is too large, that is the bandwidth is too narrow, UNarrowBAND modulation bursts will not pass through the filter. **The object of the burst tests of VMSK filters is to find filters that do not obey this rule. They must have a very narrow noise bandwidth and a very fast rise time. The shunt filters and bridge filter do not obey this conventional rise time rule as seen from Fig. 11. They have rise times equal to 1 IF cycle.**

A slew rate can be calculated from the rise time. A 180 degree shift in the ideal filter is considered to be 100% of rise time. A change from 10-90% is 80% of the 180 degree change, so there is a slew rate of 144 degrees/time interval. A slew rate $\Delta\Phi/\Delta t$ of $0.8\pi/\Delta t$. This slew rate is very important in filters for ultra narrow bandwidth methods which must recognize a change in amplitude or phase lasting only 1-2 cycles, hence must have a very rapid slew rate, or fast rise time, or near zero group delay.

A filter with a normal Q, ie for a narrow BW in $T_r = 0.7/BW$, has a long rise time and loses the modulation.

$$3dB BW = (Freq. /Q), \text{ so } T_r = .7/[(Freq.)/Q], \text{ or } (Freq)T_r = .7Q \text{ or } .7Q/(Freq) = T_r$$

$$T_g = [\Delta\Phi/ (2\pi \Delta f)] = [\Delta\Phi/ (2\pi Freq./Q)]$$

$$T_g = [Q\Delta\Phi/ \omega] \tag{Eq 2.}$$

A burst of a number of cycles at a given frequency will show a rise time according to Q. With a high Q there is a long rise time and large group delay. The missing cycle, or a phase changed single cycle as seen in Figs. 1 and 2 will not pass a conventional filter with a large Q. See Fig. 14.

You have fallen into the filter trap, if you use Eqs. 1 and 2, with a conventional filter (Rise time = Bit period) --- Your analysis will fail.

You must use a zero group delay filter responsive to a single frequency as discussed in the filter papers, and in Fig. 12 below. Such a filter would have a very low Q in terms of rise time (applying the formula in reverse). With $Q = 1$, the rise time can approach one cycle. However, a near zero group delay filter has rise time of 1 IF cycle and a Q of 10 to 30,000.

Figure 11 shows the burst response of a near zero group delay, very fast rise time, filter. The rise time is approximately 1 to 2 cycles.

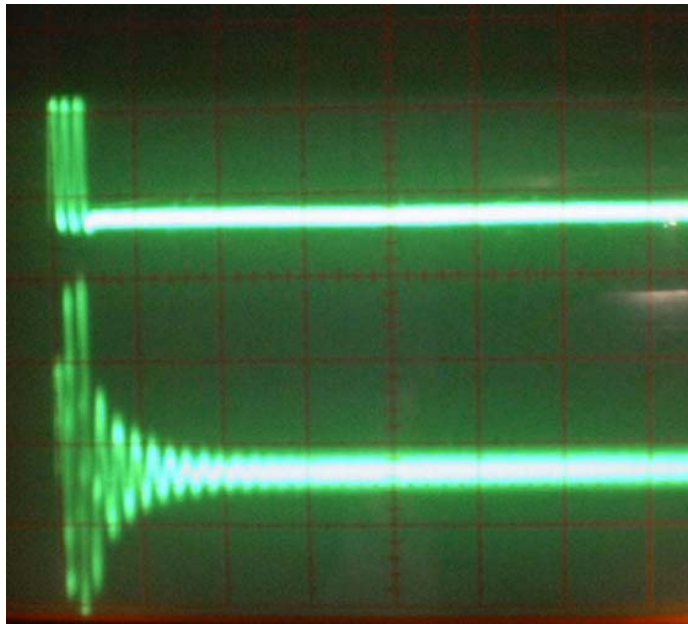


Fig. 11.

Burst Response of Near Zero Group Delay Filter.

How do these filters work? Simple, they just do not pass the signal through the crystal, but use the filter crystal as a reference to the single frequency of the ultra narrow band signal. At parallel resonance, the crystal is very large pure resistance.

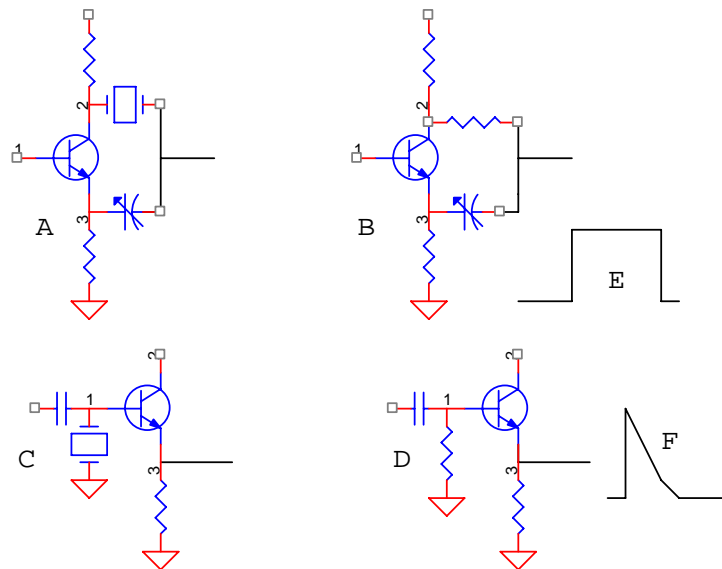
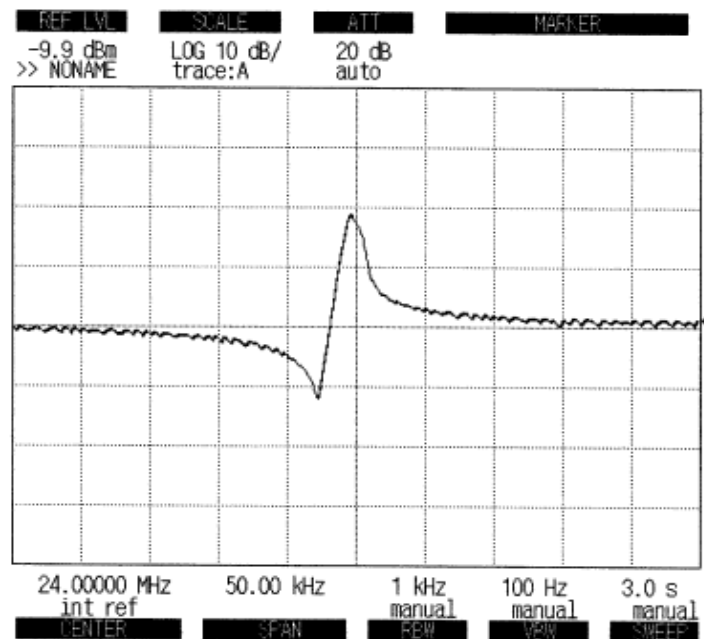


Fig. 12. Fast Rise Time and Zero Group Delay Filters.

Fig. 12 shows two filters that use the crystal in the parallel mode as a pure **resistance for a single frequency**. The equivalent circuit is shown in C and D. The impulse response in E and F. These circuits have a rise time determined by other parts of the circuit, not the crystal and coupling capacitor. **See the file “Filter summary” for better circuit descriptions.**

The circuit simply does not see the crystal as a bandpass device, but passes the burst input in the same way an RC differentiator would pass the burst, via the capacitor. For frequencies other than the single frequency of resonance, the circuit has the bandpass response shown in Fig. 13. The crystal acts as a capacitor in a capacitor voltage divider circuit. Other impedances in the circuit cause the circuit to integrate. **Fig. 13. Bandpass**



Response of Zero Group Delay filter.

This filter does have a very good rise time at a single frequency, but also has a very high Q in terms of 3dB bandwidth, according to the formulas above. A 2 kHz wide filter at 24 MHz has a Q of 12,000. Obviously having much too much rise time. The group delay calculated from Q can be from 25-60 microseconds. These units can be cascaded as in Fig. 10.

The TRS and other half lattice derived crystal filters have a near zero group delay, which means they have a very broad Nyquist bandwidth = the Intermediate frequency, but they have a very narrow noise bandwidth. This is the secret of ‘Ultra Narrow Band Modulation’. See the file “FilterS”, or Filter Summary.

The simulation on page 12 (Fig. 14) was submitted by Dr. Saso Tomazic. It shows more clearly than any amount of text and formulas, why conventional filters cannot be used at baseband, or RF, for Ultra Narrow Bandwidth methods. This analysis is for the missing cycle seen in Figs. 2 and 5.

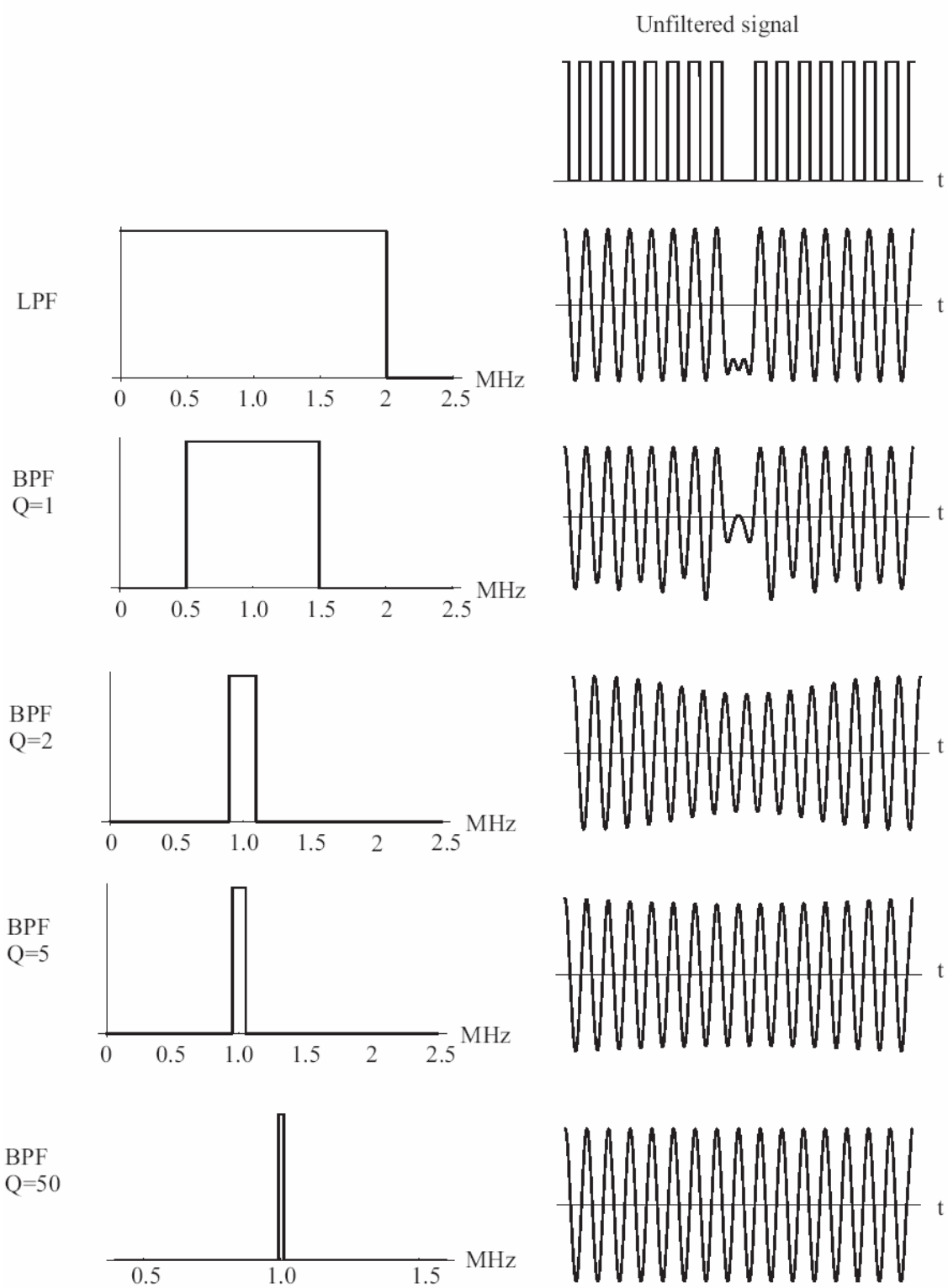


Fig. 14. Simulation of Missing Cycle Modulation after conventional filtering. All data is lost when the 'conventional' (integrating) filter has a high Q.

This is a display of the waveform according to the formula: $T_g = [Q\Delta\Phi / \omega]$. The higher the Q, the more modulation it destroys. A filter with near zero group delay, as in Fig. 12, and a burst response as in Fig. 11, is required. This simulation is for an integrator, or correlator, which is the representation of the conventional filter. (see end note). As seen in Figs. 12 and 13, the filter for VMSK, VPSK, 3PRK and MCM must be a differentiator with a very fast rise time. It must also offer 'processing gain', as defined by (Bit Rate/Bandwidth). (Fig. 13).

There is no known equivalent of the zero group delay RF filters (Fig. 12) that can be used at baseband with VMSK. At RF, if $\Delta\Phi = 0$, then neither the Q of the filter, or its bandwidth matter.

Any filter for a baseband method such as VPSK and VMSK, must have a $Q = 1$. For this reason, simulation programs fail. They cannot reduce the noise bandwidth, because all conventional filters to reduce the noise bandwidth have a high Q and long rise time.

The Ultra Narrow Bandwidth filters have a low Q response to pulses and a high Q response to AWGN off the resonant peak.

Phase Change vs Amplitude Change:

Figures 1 and 2 may create the impression that the desired result is always the missing cycle effect. By changing the synchronization phase of the RF with the data pulse edge, a phase change rather than a missing cycle is created after ultra narrow band filters with less than perfect rise time. A missing cycle will disappear after filtering and limiting.

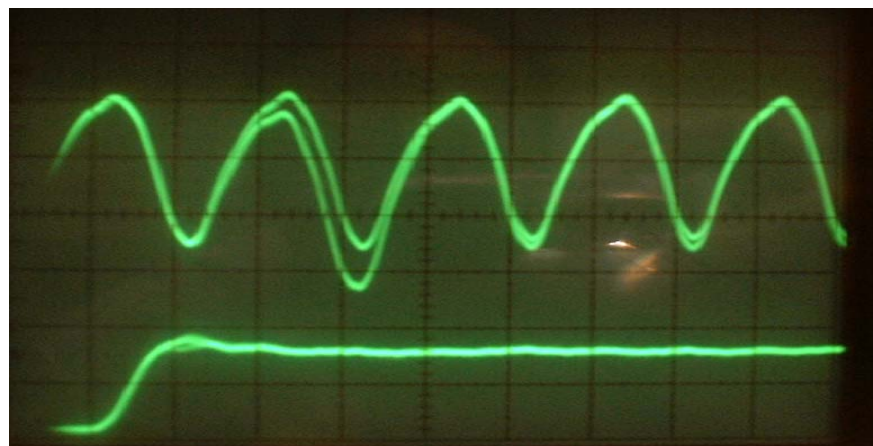


Figure 15. Phase Change instead of Missing Cycle or Phase Reversal, after multiple stages of Ultra Narrow Band filtering and limiting. All AM is lost.

The phase detector used with all ultra narrow band methods locks to the continuous signal at the right and left of the single cycle change to obtain a phase reference. The abrupt phase change at the missing cycle or phase reversal point seen in Figs 1, 2 and 5 then appears as a detected pulse seen in Fig. 4.

The filter response shown in Fig. 14 would eliminate this phase shift. The zero group delay filters in Fig. 12 seek to preserve it.

The $\sin x/x$ pulses seen in Fig. 6 (AM) are largely removed after such filtering. After a cascaded filter as seen in Fig 10, they would be reduced approximately 60 dB, yet the phase change is easily detectable. Amplitude change has been exchanged for phase change.

This paper should be used together with the paper entitled "A Filter Summary".

Definitions:

Conventional Filters:

All *conventional* digital communication takes place in the form of pulses, usually square wave pulses. As seen with a correlator, which is considered an optimum filter, each pulse has a rise time when using conventional filters, having a duration ' τ ', and an associated repetition rate, optimized at $= 1/\tau$. Conventional filters are integrators. It is also associated with a fixed filter bandwidth $= 1/\tau$, which is optimized at 1 bit period

Ultra Narrow Band Filters:

Filters, which do not have a rise time equal to the data bit period, but instead have a rise time as close to one RF cycle as possible, are a special class. Sometimes referred to in these papers as zero group delay filters. A true zero group delay filter with a bandpass response to limit the noise bandwidth has not been achieved in practice, but filters that approach this are in use.

Ultra Narrow Band methods in use to date (11/30/02) all have very brief changes in signal marking bit boundaries instead of changes over a full bit period.