

LOW GROUP DELAY LC FILTERS

10/5/09

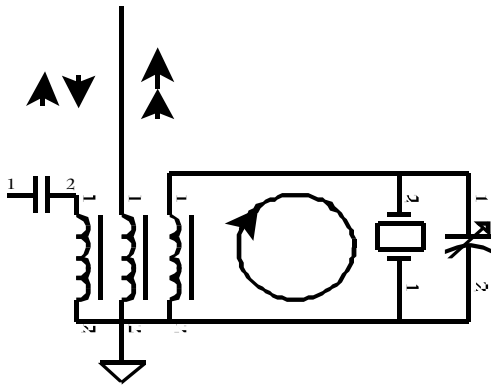


Figure 1. Transformer Reflected Shunt filter.

Figure 1 illustrates the transformer coupled (Transformer Reflected Shunt) principle. At the parallel resonance point of the crystal, which is the point of maximum phase change, the crystal has near infinite impedance. At all other frequencies there is a large shunt load that reduces the amplitude response, since the circuit is normally driven by a high impedance source. In this circuit the impedance of the resonant circuit is merely reflected as a shunt load to the following amplifier input. The effective shunt impedance is altered by the transformer turns ratio and the coupling coefficient. It is not necessary to use a crystal, since any resonant circuit with a high Q can be used.

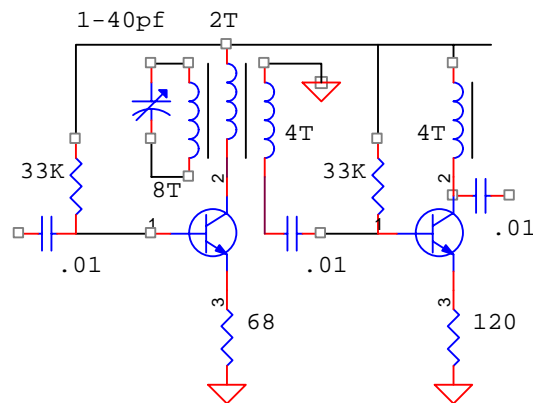


Figure 2. LC –TRS filter.

In Figure 2 the shunting load of the LC circuit is used to change the transistor amplifier gain. The coupling coefficient is adjusted by the transformer turns ratio to obtain the best shoulder reduction 'off' resonance. The coil used was an 8 turn Toko 10 mm adjustable coil (.5 uH). The 2 T primary and 4 T secondary are wound over the plastic frame. The first stage is extremely load sensitive. An emitter follower second stage , which feeds some of the load back to the source cannot be used, hence the output load is driven from the collector.

Figure 3 shows the response of the filter when the input is a broadband noise source. The scale is 5 dB per division. This indicates the rejection of adjacent channels.

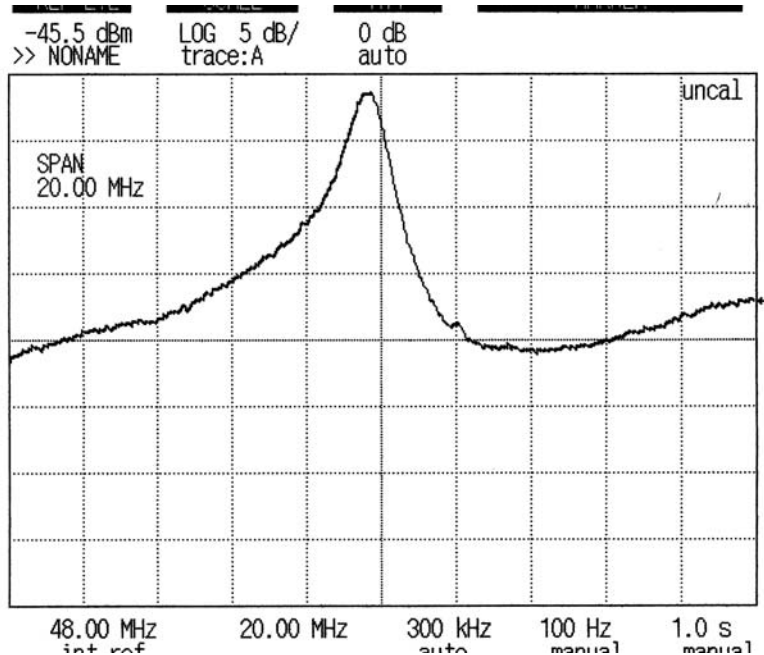


Figure 3. The response to broadband noise at 48 MHz.

The operating point for least group delay is slightly to the right of the peak, indicating the energy stored in the resonant circuit is vector adding to the signal

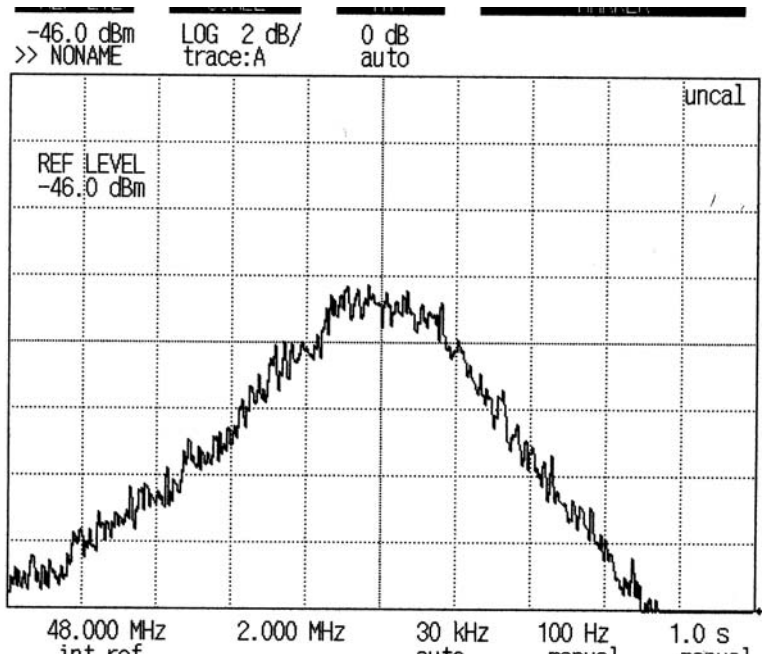


Figure 4. The response when the scale is changed to 2 dB per division and 2 MHz span.

The 3 dB bandwidth of the filter is 0.6 MHz, indicating a Q of 80.

From the relationship: $T_g = Q/[4IF]$, derived from $T_g = [\Delta\Phi / (2\pi \Delta f)]$, the group delay at peak resonance should be 400 nanoseconds. This would mean a phase slew rate of 180 degrees in 400 nanoseconds if the filter were not vector adding. The total time to slew the phase 180 degrees would be 20 IF cycles. The maximum conventionally tolerated bit rate would be 2.5 Mb/s. The maximum data rate would be much lower for 3PRK and 3PSK.

See the UNB Textbook - Chapters 6 and 7. Chapter 4 of the Textbook discusses filters that do not vector add and have group delay. Additional information is in Appendix 5.

UNB modulation consists of AM pulse switched carriers in sequence, using a rectangular waveform where $\Delta\Phi/\Delta t$ is usually zero. The carrier pulse for phase one has a different relative phase than that for a phase zero pulse. The resonant circuit of the filter stores slow changing reference energy from the incoming signal, which is then vector added to the phase shifting carrier pulses.

Figure 5 shows the UNB signal for NRZ-MSB, which has 90 degrees of phase difference between the switched phase carrier pulse for the digital one and the pulse for the digital zero, as shown by the dotted vectors. If the reference phase of the energy stored in the resonator, as the filter is tuned, is between phase 1 and phase 2, and is relatively strong, as it is when overcoupled, the vector summed result can have a serious resultant loss of phase at the phase detector.

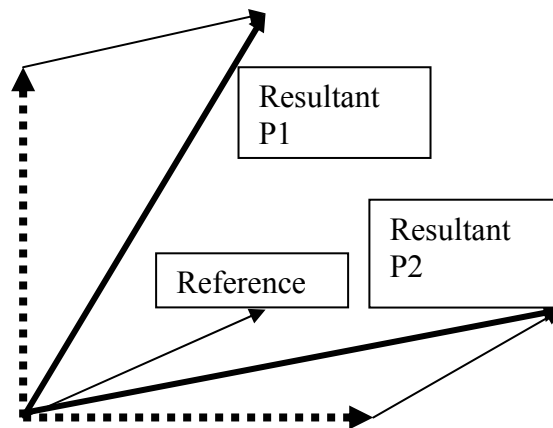


Figure 5. This example would apply to a near peak tuned filter. Cascading these filters would result in considerable phase loss in a system. For example: $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2} = \frac{1}{8}$. Only 1/8 the original phase difference would remain.

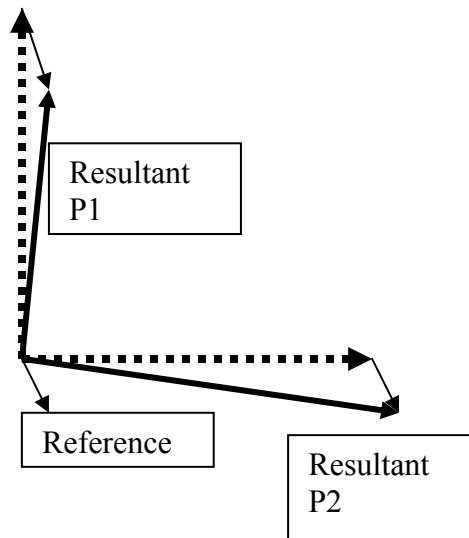


Figure 6. An extreme case where the reference energy level is very small and the resultant vectors suffer very little phase loss. The filter of Figure 2 is off tuned to have as little phase loss as possible. This means the filter peak will be to the right or left of the operating frequency and the signal will be 3-5 dB below the filter peak response level.

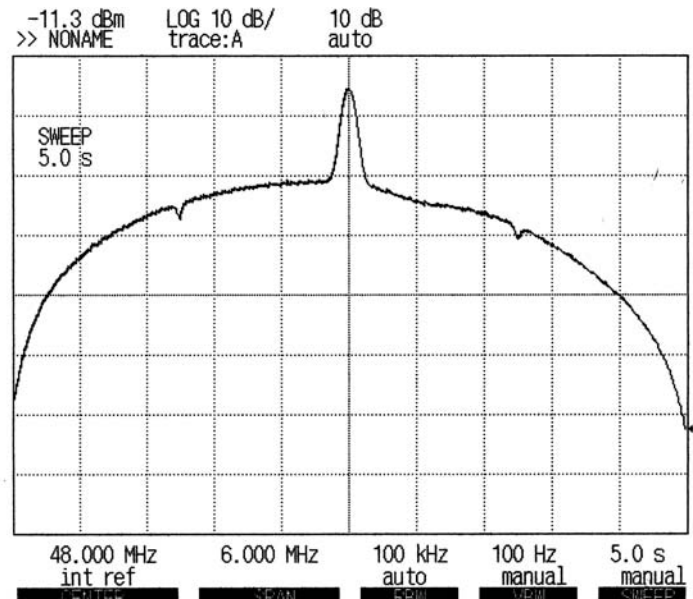


Figure 7. Spectrum for NRZ-MSB data using a random data pattern.

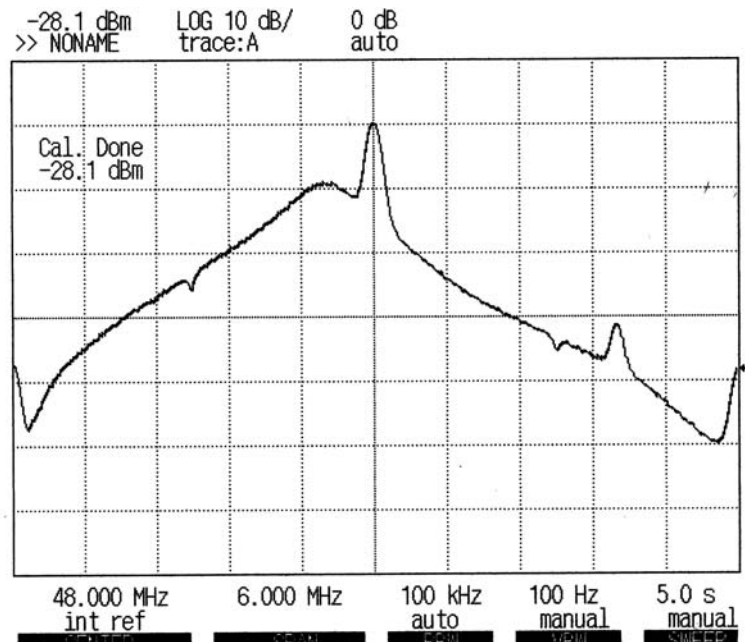


Figure 8. The spectrum at the filter output. The signal is approximately 5 dB below the filter peak. There is an indicated phase shift for the reference energy of approximately 55 - 60 degrees away from the signal average. This is 10-15 degrees below the digital zero -90 degrees.

This filter would be used as a pre-filter in receivers – equivalent to the RF filter ahead of the mixer in a superheterodyne receiver. Crystal TRS filters following this filter would reduce the sideband hump by 15 dB per cascaded stage.

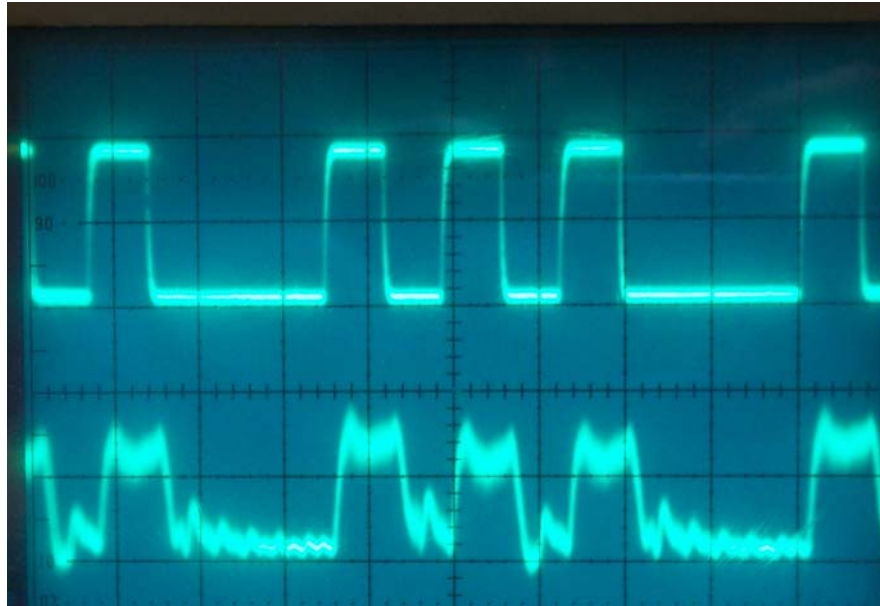


Figure 9. NRZ-MSB Data at 3 Mb/s. The data pattern is 10101000. The top trace is the pattern generator output. The lower trace is the detected output from an SA602 used as a phase detector. Digital 1 is 0 degrees. Digital zero is 90 degrees.

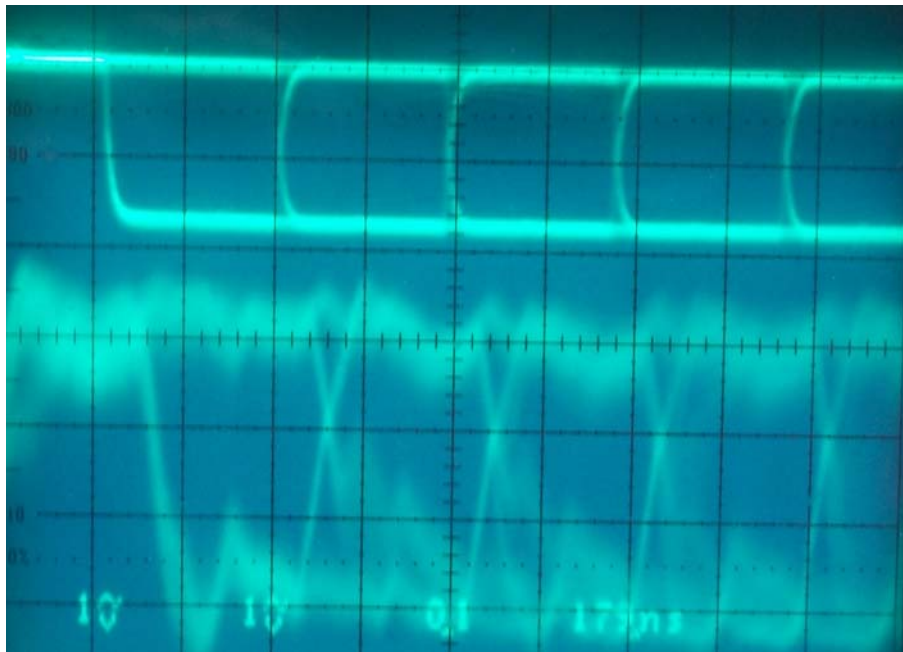


Figure 10. EYE Pattern for Random Data. 3 Mb/s. This pattern was made with no filter to be used for calibration purposes. If there is a phase loss, it will show as a reduction in level after the filter. The scale is fixed at 1 Volt per division. Dip and recover at bottom is also an indication of the group delay



Figure 11. The EYE pattern after the filter. The scale is 1 Volt per division. There is a slight increase in output voltage level indication no phase loss. The rise and fall slope is slightly longer in time. The spectrum is that shown in figure 8 where the filter peak is to the left of the signal and approximately 4-5 dB higher. This indicates a reference phase approximately 60 degrees off signal average, similar to that seen in Figure 6.

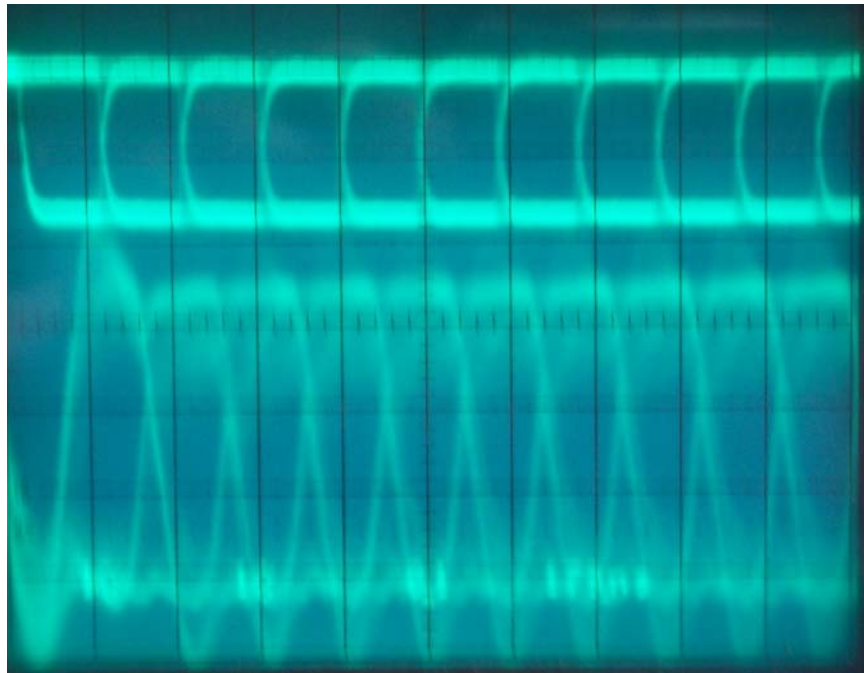


Figure 12. The EYE pattern for 6 Mb/s data.

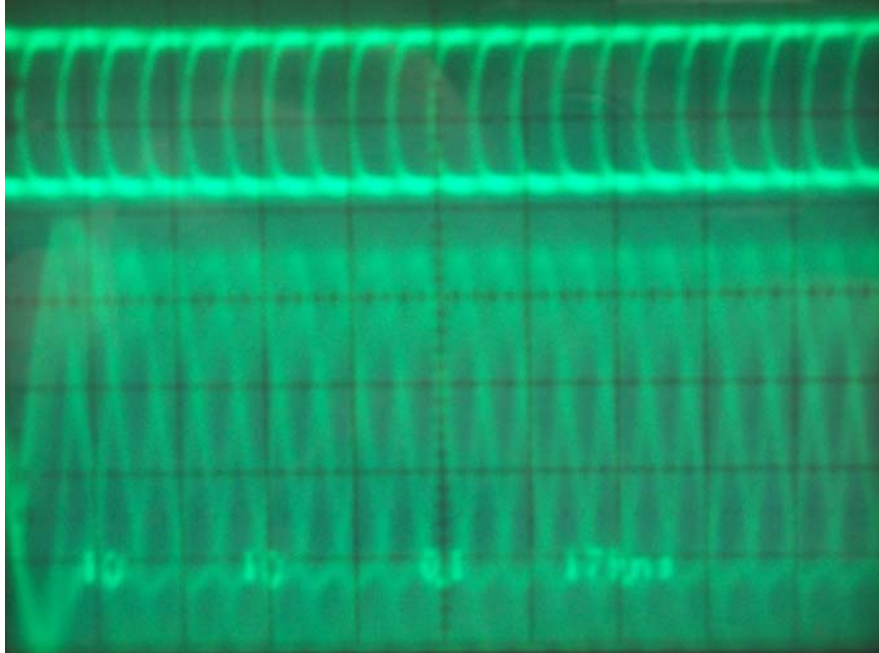


Figure 13. The EYE Pattern for 12 Mb/s data. At this data rate there are 4 IF cycles per data bit. The envelope group delay as evidenced by the rise time is less than 4 cycles (80) nanoseconds. There is no phase loss.

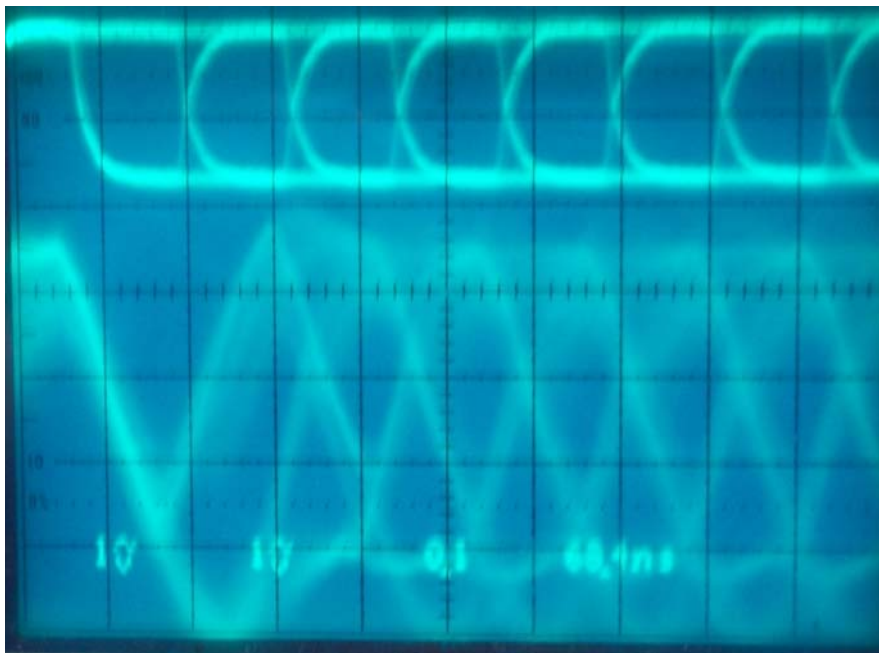


Figure 14. The EYE Pattern for 12 Mb/s expanded. As seen from the rise time slope, the delay time is slightly less than the 80 nanosecond period.

The circuit shown has a rise time of approximately 3 IF cycles instead of the 20 cycles that would be expected when using a conventional filter. Data rates up to 12 Mb/s were passed and detected without difficulty using NRZ-MSB, with a 600 kHz BW filter; indicating a rise time and group delay of 3 IF cycles (60 nanoseconds), instead of the predicted 400 nanoseconds. The phase is stable after 3 cycles. No 'Network Analyzer' was available for plotting.

Nyquist's bandwidth theorem, which relies on the $BT=1$ relationship, indicates that a bandwidth of 12 MHz is required for double sideband transmission, and 6 MHz for SSB, if that is possible. This is bandwidth efficiencies of 1 b/s/Hz and 2 b/s/Hz. A 600 kHz BW indicates $12/.6= 20$ b/s/Hz.

UNB methods cannot be analyzed at baseband. The transmission bandwidth is 1 Hz after filtering, the receiver 3dB noise BW using crystal vector adding filters is 500 Hz, and the Nyquist BW based on IF cycle by cycle detection is equal to the IF. The IF in this case is 4 times the bit rate (48/12). These values do not apply at baseband, or when using conventional filters. Shannon's limit is calculated using the 48 MHz bandwidth, or the energy per cycle.

These tests also confirm the fact that the sidebands are not related to the phase loss using UNB modulation. If the sidebands were directly related to phase loss, as is the case with Bessel sidebands, a 20 dB reduction in sidebands would reduce the detected phase 20 dB. This loss does not occur. UNB sidebands are Fourier sidebands which do not contribute to the detected phase. Phase loss is directly related to the vector addition as seen in Figs. 5 and 6.

The test circuit used is not an optimized circuit. It was found the results could vary considerably with the output load coupling method. The coupling coefficient in the transformer could not be varied.

Reference Angle vs Amplitude Reduction due to offset:

3dB	45 degrees
4	50
5	55
6	60

Level depends on coupling coefficient..

*** See the files "Analyzing Ultra Narrow Band Modulation" and "Ultra Narrow Band IF Filters", which discuss the crystal equivalent of this LC - TRS filter..