Ultra Narrow Band IF Filters

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All bandpass filters are subject to envelop group delay, which limits the upper bit rate that can be passed within a given bandwidth. There is a phase shift in the filter that determines the envelop group delay.

Derived from $\omega t = \Phi$:

$T_g = \Delta\phi / 2\pi\Delta f$

$\Delta f = \Delta\phi / 2\pi T_g$ Eq. 1.

$T_g = 1/4\Delta f$

T_g = Q/[4IF] IF is the filter freq. - where Δf is the 3 dB bandpass. Eq. 2.
For the ideal filter or raised cosine filter, **T_g = [1/(2Δf)]**
Obviously, a very narrow [Δf] bandwidth filter has a very large group delay *unless $\Delta\Phi = 0$.*

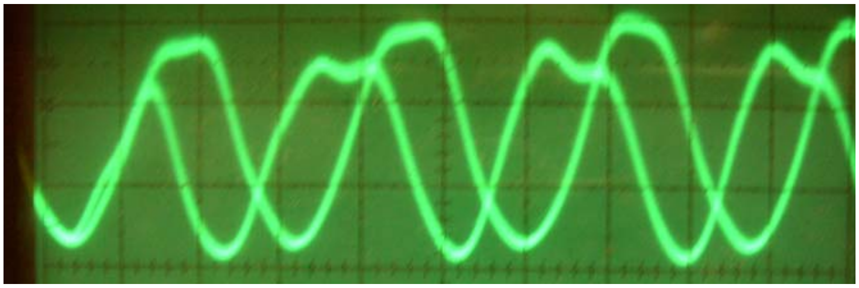

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Figure 1. Abrupt Change 90 Degree Phase Modulation, at modulator output. This is applicable to 3PSK and NRZ-MSB modulation. These are modulation methods in which the carrier phase is shifted abruptly 90 degrees to distinguish between ones and zeros.
(1 = 0 degrees, 0 = 90 degrees). The input is a rectangular waveform where $\Delta\Phi/\Delta t$ is usually zero.

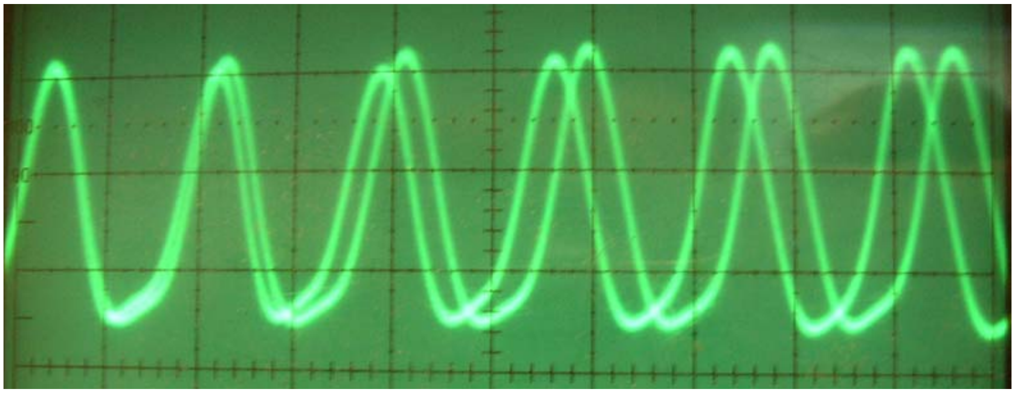

Figure 2. Phase changes with time using ordinary filters. The phase will slew 180 degrees in the calculated period T_g. (A slew rate = $\Delta\Phi/\Delta t$ is involved). From Eq. 1, FM is produced. The abrupt change of Figure 1 is lost. A different filter is required.

The data rate for a given ***conventional filter bandwidth*** can never be greater than 1/ T_g. A 1 megabit per second data rate requires a filter 1 MHz wide. This is also a quote from Nyquist's bandwidth theorem.[10]. **The following simulation was made by** Dr. Saso Tomazic, University of Ljubljana, Slovenia, Faculty of Electrical Engineering.

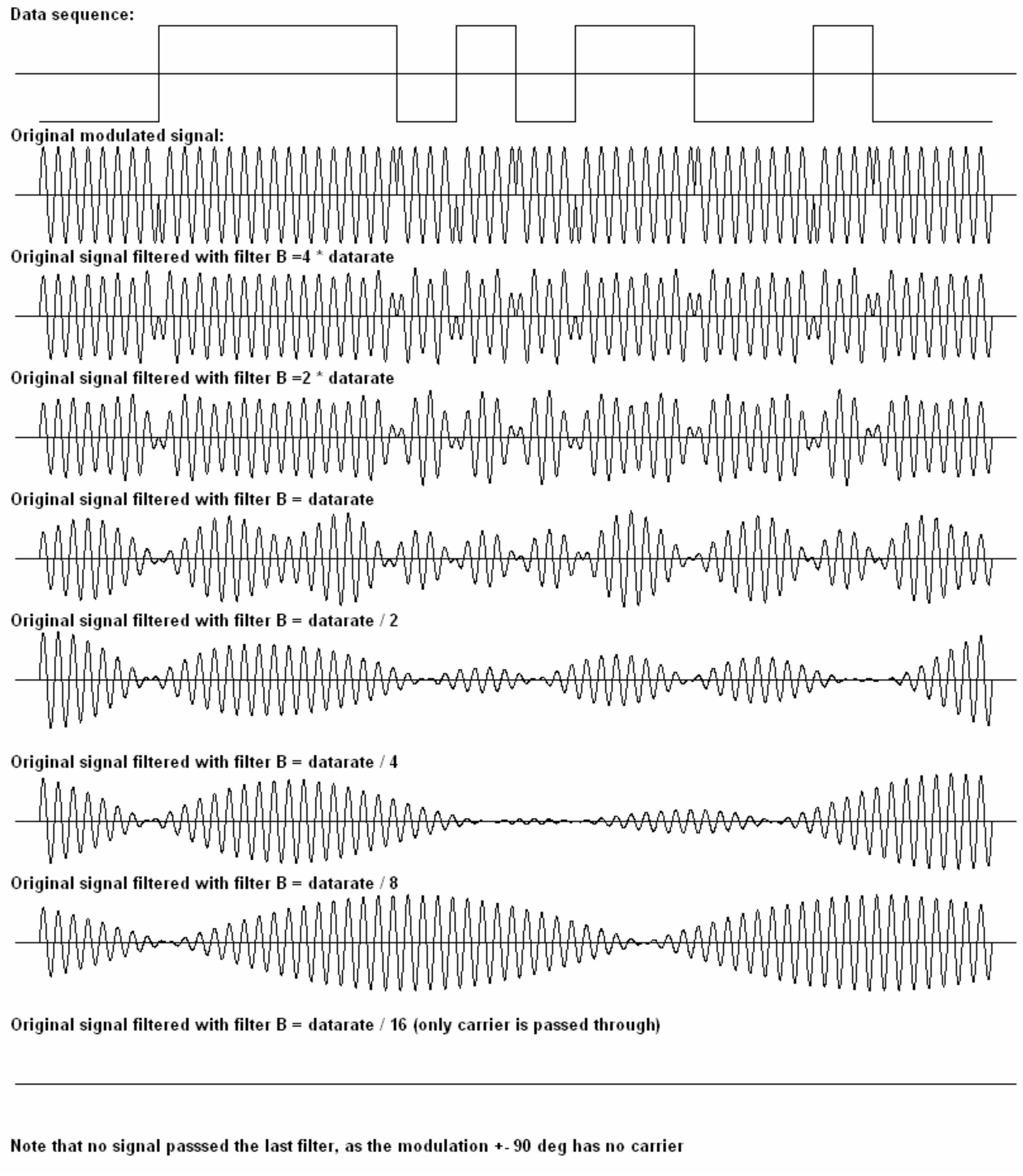

Figure 3.

Any conventional filter with T_g = rise time = bit period is a form of integrating filter. Normally, the signals are sampled at the minimum Nyquist sampling rate, which is equal to two samples per bit at the baseband frequency f_m, which is ½ of the bit rate f_b. Thus the minimum sampling rate 'W', and the minimum bandwidth B with conventional filters, are equal to the bit rate = $1/\tau$, and both are tied to the rise time τ, or **T_r.** *Ultra Narrow band methods sample at the IF rate (cycle by cycle) and not at the bit rate.*

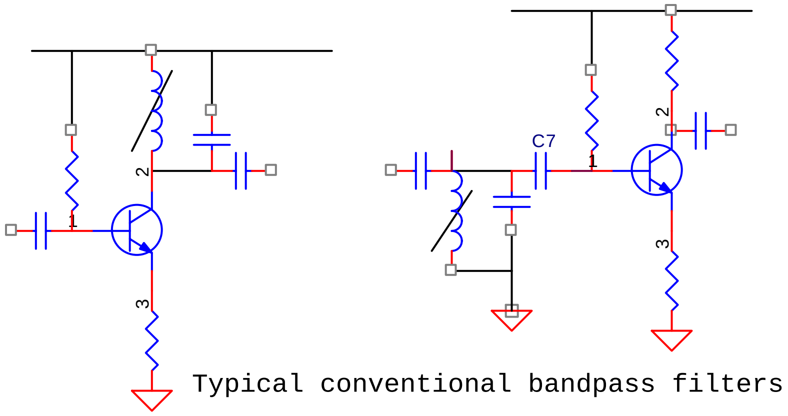

Figure 4. Typical conventional bandpass filters that are subject to the **T_g = Q/[4IF]** rule.

There are special filters that rely upon vector addition that do not conform to this rule.

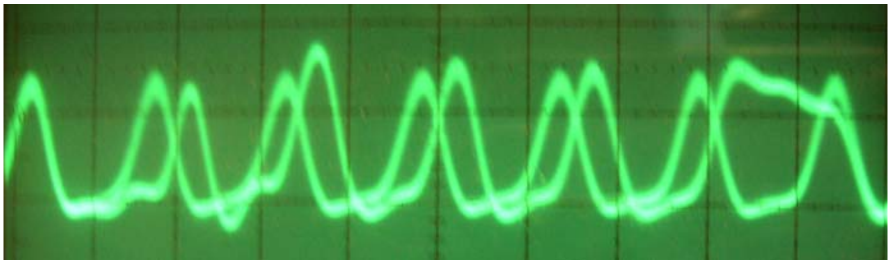

Figure 5 shows the preservation of the abrupt phase changes **after a zero group delay (zero rise time) filter**. The filter has active components, which in this case have been over driven, resulting in some harmonic distortion. Note that the abrupt phase changes are preserved and that at the phase return point at the right a cycle inversion (missing cycle) has been created.

Ultra Narrow Band Modulation requires a filter having near zero group delay to transient phase changes so that Figure 5, and not Figure 2, applies. The envelop group delay and the transient group delay are separable in the special UNB filter group, so that a transient change in 1 IF cycle can be detected as seen in Figure 5. The filters have an extremely narrow noise bandwidth and need not have any phase loss with cascaded sections.

Ultra Narrow Band modulation utilizes AM pulses with switched carrier phases to indicate a one or zero. These pulses must be passed as close to their original form as possible. That is, without amplitude rise time T_g , or phase loss between pulses. This is shown in Figure 15 below.

The group delay of the filter is determined from **$T_g = [\Delta\Phi / (2\pi\,\Delta f)]$.** A **zero group delay narrow band filt**er having ($T_g = 0$) requires $\Delta\Phi = 0$, *which can be obained if a rectagular modulation waveform at the input is used.* There is a group of filters based on the 'half lattice filter' that have a large $T_{g,}$, but which can exhibit the desired near zero group delay characteristic for pulses.

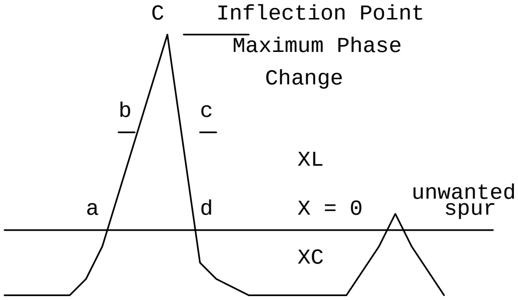

Figure 6. Characteristics of the Crystal Resonator. The phase change with frequency $\Delta\Phi/\Delta\mathbf{f}$ depends upon the change of impedance (reactance) with frequency.

There are several circuits that can be used in this manner. Some particularly useful embodiments are the 'Bridge' variations of the half lattice filter. Derivatives of the simple bridge are the 'Walker Shunt', 'Sideband Nulling' and 'TRS' filters.

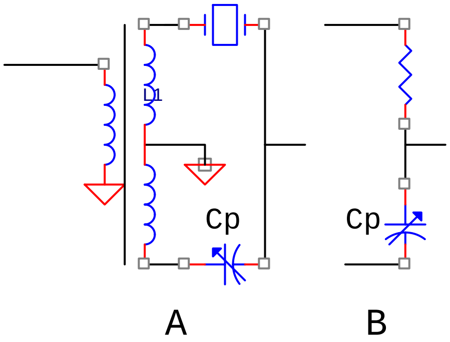

Figure 7. Half Lattice, or Bridge Circuit A. At peak resonance the circuit becomes the RC differentiator B.

Figure 7 Shows the well known bridge, or **half lattice filter**. In Figure 7A, the filter is used in a bridge circuit that permits the crystal to be used in regions 'b', 'c' or 'd' of Fig. 1. The trimming capacitor Cp adjusts the phase of the circuit while canceling or adding to the crystal shunt impedance. Point 'c' is an inflection point where **ΔΦ and envelop group delay are maximum.** This frequency varies with tuning reactances added in parallel or series with the crystal.

The crystal forms a shunt load as indicated in Figure 5 to a high impedance input. The shunt load is minimum at the impedance peak and becomes a capacitive load above and below the pass band. The bridge circuit is not necessary, since the shunting effect is available from a simple drive as in Figure 8.

There are newer and better circuits than that shown in Figure 8. The Transformer Refleceted Shunt (TRS) filter provides a better match between the crystal and the coupled circuit. ***Using overtone crytals improves the shoulder reduction and reduces stored energy in the crystal. Fundamental or overtone crystals can be used.***

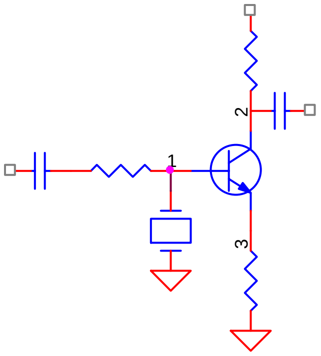

Fig. 8. Walker Shunt Filter

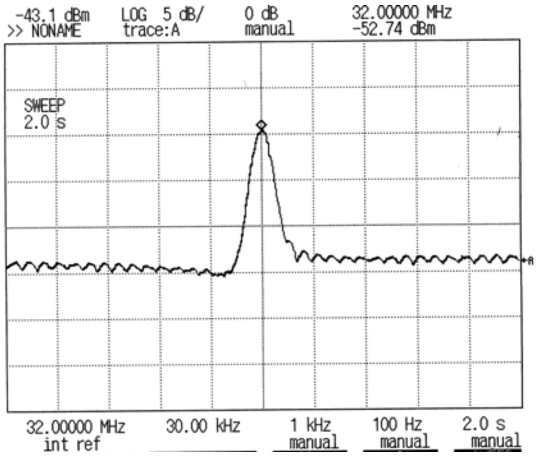

Figure 9. Swept response of 3rd overtone Walker Shunt filter. (5 dB per division). The shoulder reduction is 13-14 dB per stage. Three cascaded stages can have more than 30 dB shoulder reduction with near zero phase loss.

In the TRS filter, the auto transformer provides a better impedance match between the crystal and the transistor input to optimize the crystal filter shoulder reduction. The result is approximately a 5 dB improvement compared to Figure 9. The trimming capacitors and the series inductance enable the 3rd overtone crystal frequency to be varied enough to tune it to the desired frequency.

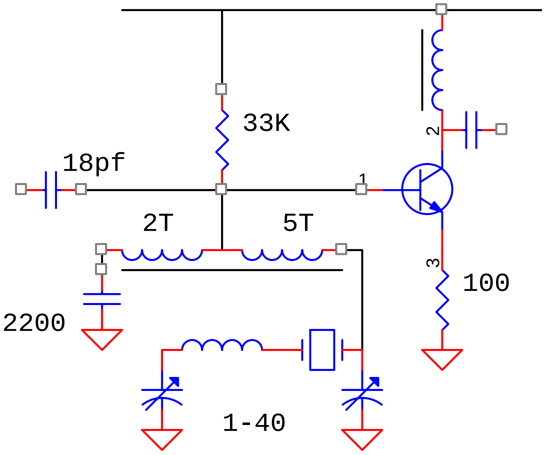

Fig. 10. Transformer Reflected Shunt (TRS) Filter with 3rd overtone crystal.

Overtone crystals have approximately 1/10 the tuning range of the fundamental mode crystals. (Ref. 1). Adding an inductance in series with the crystal lowers the frequency and extends the tuning range. *In none of the usable UNB filters is the signal allowed to pass through the resonator.*

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 crystal in the filter stores reference energy from the incoming signal, which is vector added to the phase shifting carrier pulses. Overtone crystals store much less energy than fundamental crystals, therefore may be the preferred crystals to use.

Figure 11 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, as the filter is tuned, is between phase 1 and phase 2, and is relatively strong, as it is with a fundamental crystal, the vector summed result can be a 50% resultant loss of phase at the phase detector.

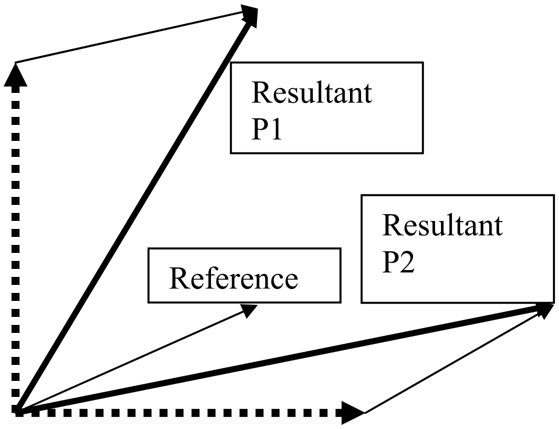

Figure 11. This example would apply to an off tuned filter with fundamental crystals. Cascading these filters would result in considerable phase loss in a system. For example: ½ x ½ x ½ = 1/8. Only 1/8 the original phase difference would remain.

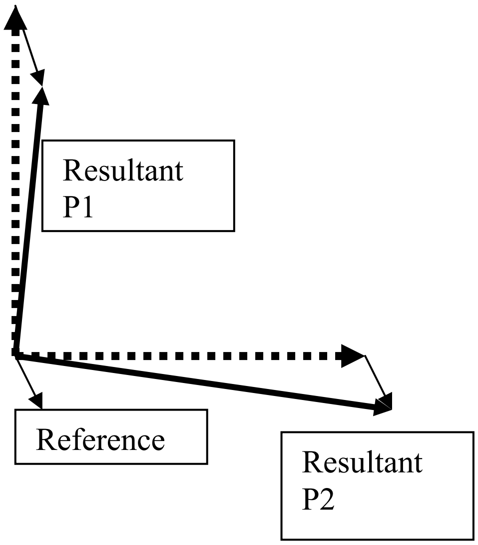

Figure 12.

Figure 12 shows the vector sum possible with a 3rd overtone crystal which is optimum tuned to shift the reference away from phase 2 to obtain the least phase loss in the vector sum. The reference energy stored in the crystal is phased to vector add with the least phase loss. It is possible to actually increase the vector sum so that the detected phase is increased. There need be no phase loss with cascaded sections, so that any sideband reduction in the filters will have no effect on the detected signal.

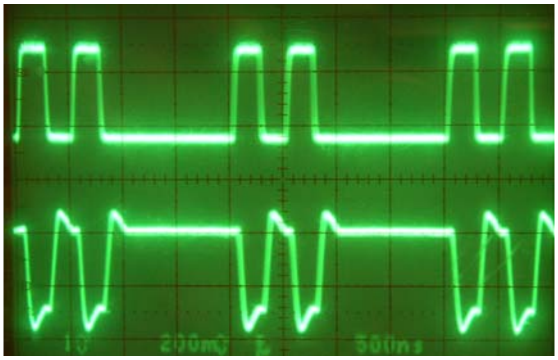

Figure 13. Detected signal prior to any filtering.

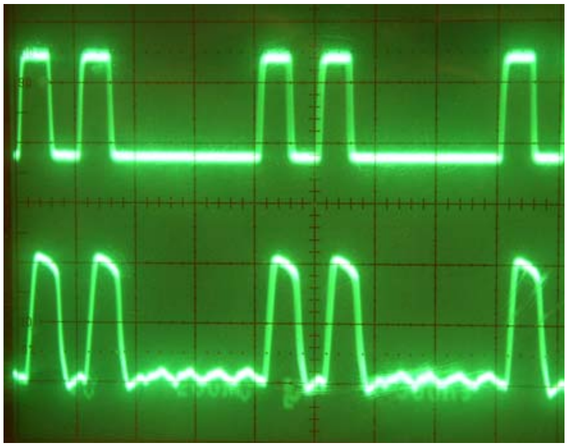

Figure 14.

Figure 14 is the detected output <u>after one stage of TRS filter</u> with a 3rd overtone crystal. It actually appears here that there is a slight gain in detected phase as indicated by Figure 12, not a loss. This has been noted before with TRS filters and is due to the skew tuning of the reference in the filter away from point ‘c’ to point ‘b’ or ‘d’ in Fig. 6. For multiple stages this apparent gain may not be sustainable.

There is little evidence of any stored reference energy. The reference energy remaining is phase added to avoid any vector summing loss. The 200 mv per division scale on the scope has not been changed. A 10/1 probe is used.

The TRS vector adding filter has a typical 3 dB bandwidth of 500 Hz and a transient group delay = 1/IF (one IF cycle) - to be able to detect a phase change in one IF cycle as shown in Figure 5. For a 48 MHz IF, this is a transient group delay of approximately 20 nanoseconds. The Q is 96,000. From T_g = Q/[4IF], ***the calculated group delay is 490 microseconds. This has been verified/measured on a network analyzer.***

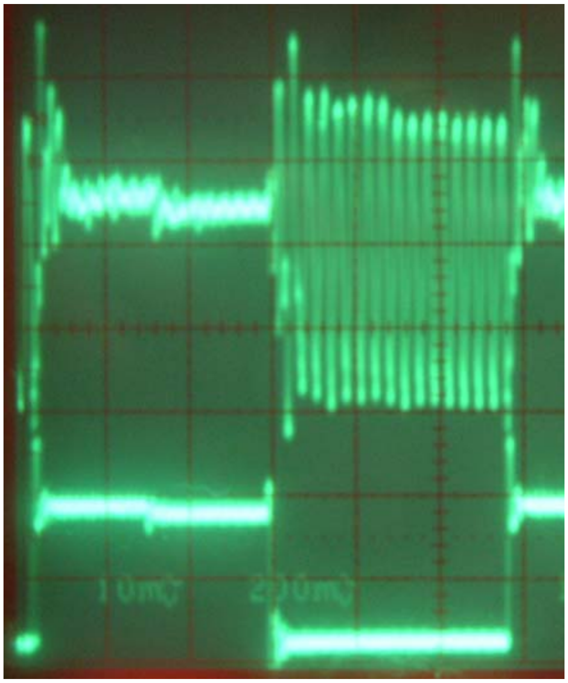

Figure 15. The amplitude response after the TRS filter when the pulses are for the zeros only. Note how this differs from Figure 3. With one and zero switched phase pulses, the pulses are end to end of different phase. The data rate in this example is 3.2 Mb/s, 1010101 pattern, 32 MHz IF. (16 cycles per pulse) The transient rise time is approximately one IF cycle, so the transient group delay is 1/(IF)sec. = 30 nanoseconds. The phase response shows almost no slew time for the IF cycles to be exactly in phase with the data pulse as transmitted to arrive at a steady state in amplitude and phase. A filter with normal envelop group delay T_g of approximately 500 microseconds cannot have this response, but would be as in Figures 2 and 3. (Also References 2, 3).

Figures 13 and 14 show a slight amplitude rise time due to the RC time constants and the slew rate of the operational amplifier used after the phase detector.

Figures 9,10 and 11 show the filter has near zero group delay to the transient phase changes. *The filters do have envelop group delay, which applies to the reference only.*

As stated above, the group delay of the filter is determined from:
$T_g = [\Delta\Phi / (2\pi\ \Delta f)]$. A zero group delay narrow band filter having(**$T_g = 0$)** requires **$\Delta\Phi = 0$.** The TRS filters described here have a large T_g in the reference, but they can exhibit the desired near zero group delay characteristic for pulses due to *vector adding* as in Figure 11 and 12.

The envelop group delay at the resonant peak is between 300 and 500 microseconds, whereas the transient group delay is approximately equal to 1/IF, or as in the example of Figure 15, approximately 30 nanoseconds. A group delay of 300 microseconds implies the phase can change 180 degrees in 300 microseconds. Also, the filter output will rise in 300 microseconds to full amplitude when subjected to a pulse as shown in Figures 3 and 15. Vector adding filters show little amplitude rise or decay times.

The sidebands created using UNB modulation methods are Fourier sidebands, characteristic of AM, and do not have any effect on the phase changes observed at the detector. Reducing the shoulders (sidebands) infinitely would have no effect on the detected phase change.

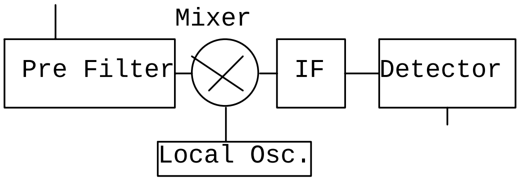

Figure 16. The total sideband reduction and noise rejection comes from both the IF and the Pre filters. See Ref. 3 (App. 5) regarding filter noise overload. Typically the prefilter has a T_g loss = 2-3 RF cycles and the IF filter has no loss.

The amount of sideband reduction necessary from the cascaded UNB filters is related to the total bandwidth effect represented by both the pre and UNB filters. Generally, 30+ dB is adequate. See Apendix 5 of Reference 3.

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