Systems Involving Group Delay

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MSB modulation has several forms. 3PRK and 3PSK use very short phase pulse changes to obtain the best spectrum with the least amount of transmitter filtering. 3PSK offers little advantage, so it is probably not a method that will see much use. 3PRK and 3PSK require filters in a system that has no group delay. This may not be practical in the real world where signals are passed through cascaded bandpass filters, or where very narrow band pre-filters are used with high data rates. Very little group delay can make high data rate 3PRK impractical. For example, long haul microwaves, or satellites.

It was noted with the old VmaxSK, that one form - VMSK/2a - could tolerate a group delay of close to one bit width. This experience carries over to MSB when using the NRZ code directly with a 90 degree phase shift. The solution is to use a phase correlator as the detector.

Figure 1 shows the effects of group delay in a pre-filter using phase reversal keying.

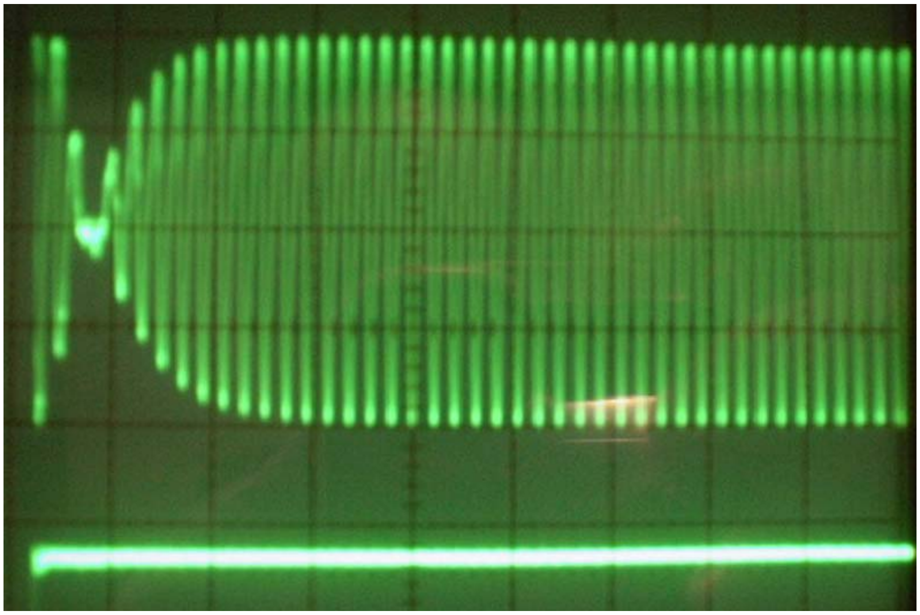


Figure 1.

The phase reversal is subject to a rise time, which can be calculated from:

$T_g = [\Delta\Phi / (2\pi\,\Delta f)]$ [1]

For LC or Gaussian filters, this is:

$T_g = [\,1/(4\Delta f)]$ **and** $T_g = [Q\Delta\Phi/\,\omega]$ [2]

Obviously, a very narrow [Δf] 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 [Δf] of the filter. This is the time from 10% to 90% on the RC curve. Bandwidth, rise time and optimum sampling rate are mathematically linked. In practice, the relationship $BT_r = 1.0$ is used. (Bandwidth)(Rise Time) =1.0. Bandwidth is the Nyquist bandwidth = symbol rate = sampling rate, which is based on Δf.

There is also a phase slew rate $\delta\Phi/\delta\tau$, which is approximately 160 degrees in the rise time **T_r**, or .8π radians, with the frequency fixed. In practice, π radians per bit period is used.

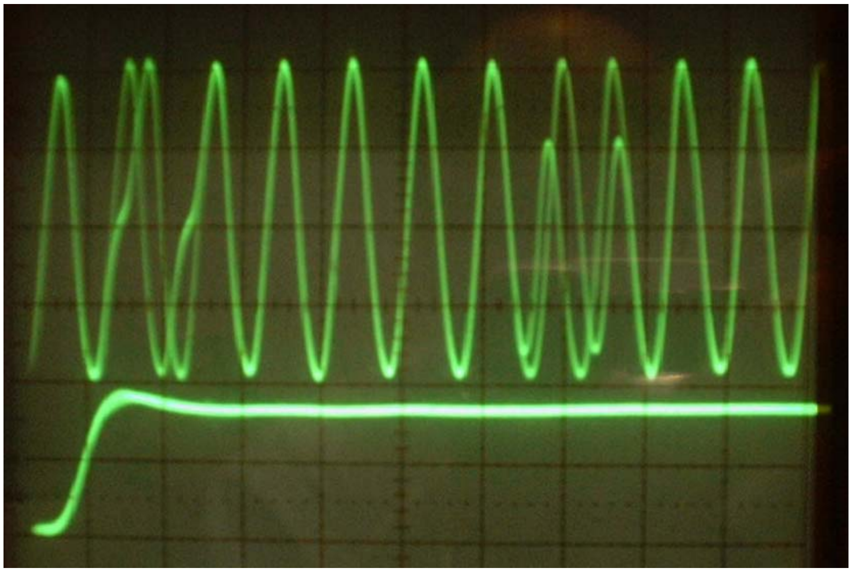


Figure 2. 90 degree abrupt phase modulation.

90 degree abrupt phase change modulation is used with the NRZ data input because it is easy to obtain an unambiguous phase reference from the single frequency that is transmitted. The phase change is seen above with no group delay. When group delay is involved, there is a phase slew rate $\delta\Phi/\delta\tau$ that determines how long it will take to complete the phase shift from phase one to phase two. If this phase change is equal to, or less than a bit period, the signal is detectable.

In most analyses, the rise time is considered to be **$T_r = 1/B$ and the slew rate is π/T.**

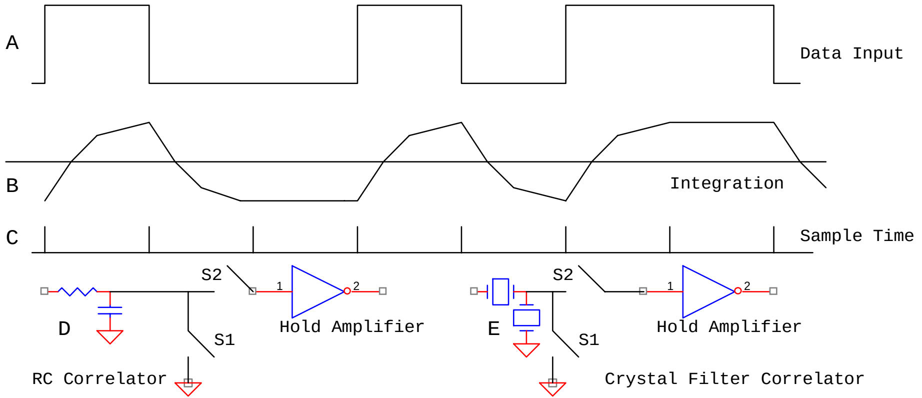


Figure 3. The amplitude or phase modulation correlator.

The correlator is shown in Fig. 3. The correlator consists of a sample and hold circuit following an RC integrator. In this case(left side), the integrator RC is optimized for the delay rise time = sample period. A conventional crystal filter is also a correlating device.

Using the data pattern at (A) as a sample, the integrator charges positively as shown in (B) until it is sampled by S2 at its peak (C). The peak output is shown in (B.) The capacitor is then discharged by S1 to be recharged anew by the input signal. The original waveform appears at the sample and hold device output.

The correlator itself is considered to be an "optimum filter" in the presence of white noise. The maximum signal power is obtained by optimally integrating the incoming phase change pulses. The noise is white and has a long term integrated output level at 0 volts. The short term signal information will have a positive or negative integrated value.

The input pulse here is considered to be rectangular, but other pulse shapes apply as well if the sample time is properly chosen.

The example above is for amplitude modulation. A similar model using the PLL can made using the loop filter as the correlating integrator. The limiter, after all filtering, eliminates the AM, leaving only signal and noise phase changes for the PLL.

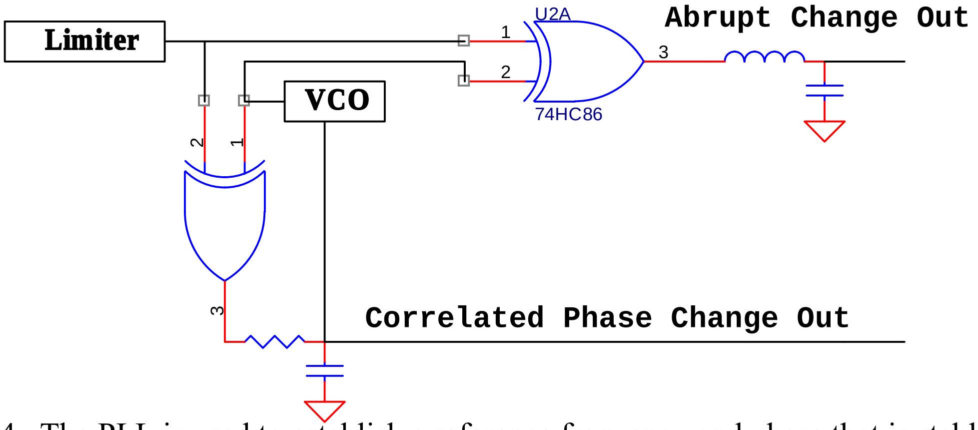
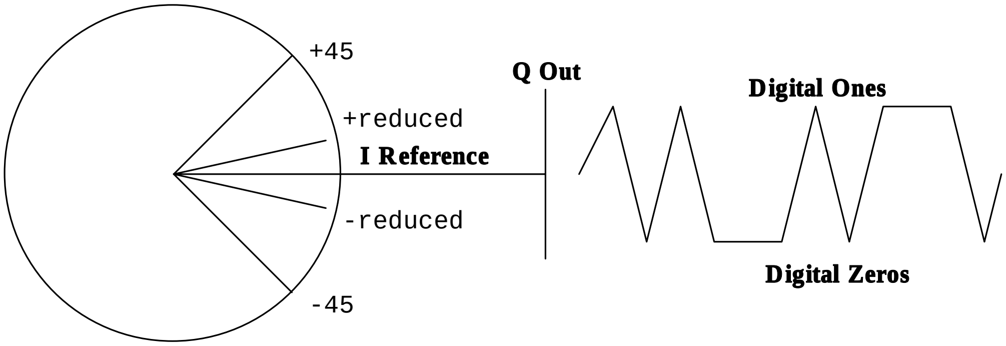


Figure 4. The PLL is used to establish a reference frequency and phase that is stable near the 'I' reference phase shown in Fig. 5. The abrupt phase change output can be used for 3PRK and 3PSK. The PLLoop filter output is a phase correlator that rejects low frequency noise in the reference frequency to yield a steadier EYE pattern.

Fig. 5.



MSB modulation with a 90 phase shift (Fig. 5) will have an output from the phase detector (EYE Pattern) that shifts phase with the incoming signal. The tracked output is shown at the right. There will be phase losses resulting in a reduced output level from optimum. The data is sampled at the phase change peaks as in the amplitude correlator.

This circuit takes advantage of the phase noise at the input being changed to low frequency noise depending on the summed filter bandwidth. The PLL can track the low frequency noise and reject it, but the data shifts at a much higher frequency will be detected. The signal at the PLL input is a low frequency noise with the data riding on top of it. The PLL reduces the low frequency noise effect on each sample.

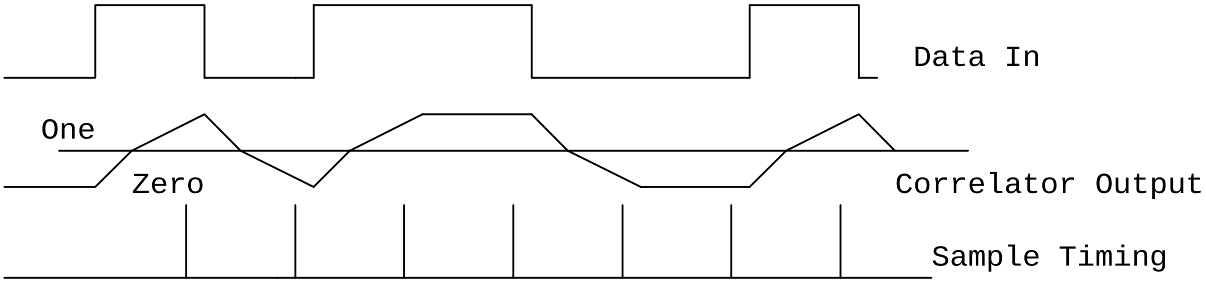


Figure 6. Phase Change Correlator. The output is ones and zeros depending on the level above or below the center line, resulting in the EYE pattern seen in Figs. 5 and 7.

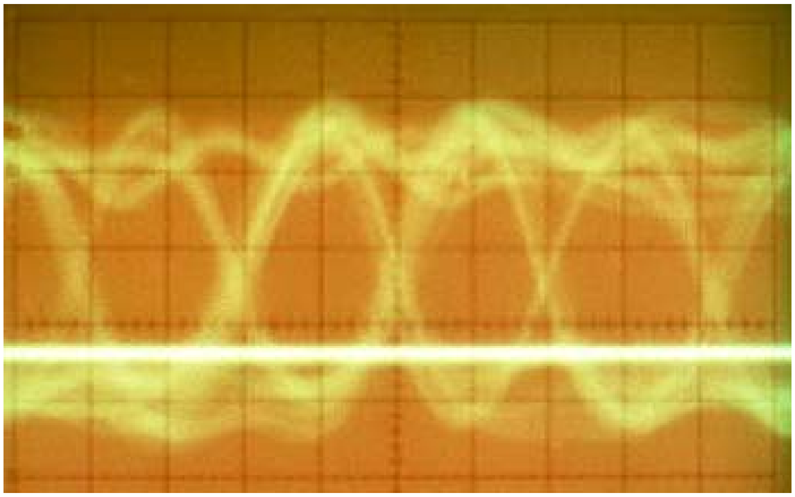


Figure 7. The detected EYE pattern when the total system group delay, or rise time, equals the bit period.

Figure 8. When broadband noise passes through a narrow bandpass filter, the noise that is seen at the output is a low frequency signal that varies in amplitude and phase at a maximum frequency equal to 1/2 the filter BW. High frequency noise is removed.

Pre-filters will limit the upper noise frequency, enabling the PLL to reject a large amount of noise. This is the R effect, which is well known in PLL work.

The total group delay in the system will determine the slew rate. This in turn will determine the output level available from the loop filter (Figs 5-7). The combination results in an improved SNR.

Best's equation [1] for SNR using a PLL is:

$$SNR = \beta^2 \left(\frac{BitRate}{2LoopBW} \right) \left(\frac{BitRate}{IFFilterBW} \right) \left(\frac{E_b}{\eta} \right)$$

[3]

and

$$P_e = \frac{1}{2} erfc[\beta^2 \left(\frac{BitRate}{2LoopBW} \right) \left(\frac{BitRate}{IFFilterBW} \right) \left(\frac{E_b}{\eta} \right)]^{\frac{1}{2}}$$

[4]

The bit error rate is obtained from the square root of the SNR.
This is an improvement of as much as 6 dB over BPSK, or QPSK modulation, where:

$$P = \frac{1}{2} erfc \left[\frac{E_b}{\eta} \beta^2 \left(\frac{BitRate}{IFFilterBW} \right) \right]^{\frac{1}{2}}$$

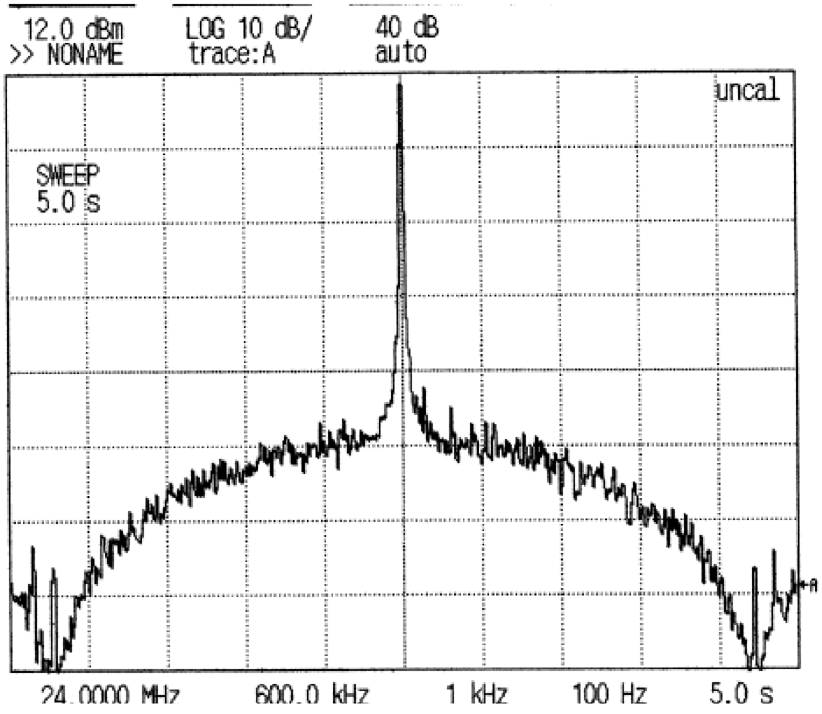


Figure 9. Spectrum of NRZMSB signal showing single frequency transmitted and low level Fourier products that can be removed with additional filtering. The RMS level is below FCCrequirements.

Summary:

Some group delay can be tolerated in MSB systems. (up to 1 bit period) as t/T approaches 1.

The use of near zero group delay filters makes it possible to obtain much higher data rates than with ordinary filters, since the rise time is extremely fast and there is less accumulated loss due to rise time.

References.

[1] Best, R.E., *"Phase Locked Loops"*, McGraw Hill.
Additional phase noise improvement (in SNR) is possible. See sect. 3.
[2] Taub and Schilling, "*Principles of Communications Systems*" McGraw Hill.
On broadband noise being reduced to low frequency noise in a narrow band filter. Sect. 7.5.
[3] β has been added to allow for different phase modulation levels (angles).
K. Feher, " *Wireless Digital Communications*", Prentice Hall.