Digital Signal Processing Techniques Used to Demodulate Multiple Types of Telemetry Data

Frank A. Ziegler

Microdyne Corporation
491 Oak Road
Ocala, Florida 32672

ABSTRACT

Telemetry systems today are required to receive a variety of modulation formats. Typically, to change the format required changing the demodulator unit or large switching systems. Using some common digital building blocks and multiplexers, the user can change demodulation mode by pressing a button. This paper describes a system that demodulates PM, FM, BPSK, QPSK and DSB AM.

INTRODUCTION

As seen in Figure 1, the 20Mhz IF signal is passed thru a wide band 90 degree phase shifter and digitized. This generates a set of quadrature signals at baseband which can be mathematically processed using various algorithms to generate a reconstructed video output and the control voltage to phase lock the IF to the 20Mhz reference.

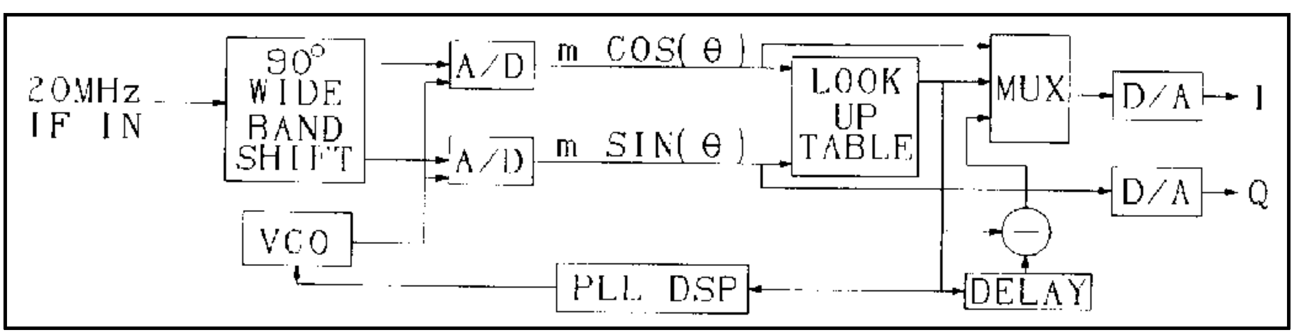


Figure 1

PHASE MODULATION

Principals of PM

To demodulate a signal requires an understanding of how the signal is generated. A PM signal is generated by making the video signal vary the phase of the output signal relative to the reference carrier. Assuming a sinusoidal modulation signal F(m), the modulated phase will be symmetrical about the reference and have constant magnitude. If the CW carrier is said to be at 0°, then from a vector standpoint, the carrier has a large cosine component and no sine component. As the vector is phase modulated about the 0° point, the sine and cosine components of the vector are obviously modulated also.

If the modulation is great enough that the vector is greater than ±90°, then the cosine component will be negative at the peaks of F(m). If the modulation is further increased, the average value of the cosine component will approach and drop below zero. The point where the cosine component goes to zero is the first Bessel null. If observed on a spectrum analyzer, the carrier component would be gone.

Note that since the modulation was symmetrical, the sine component was modulating positive and negative in equal amounts and never generated a DC value.

PM Demodulation

To demodulate the PM, the original carrier is reconstructed with a phase lock loop, and the phase angle difference is calculated. To do this with the block diagram in Figure 1, the look up table is loaded with the equation

$$1 = \arctan(m \sin(1) / m \cos(1) \qquad \text{EQ 1.1}$$

where 1 is the phase angle difference of the reference to the incoming IF.

Since the average phase angle in the modulator was originally zero, the video output is used as the error signal to drive the phase lock loop.

Notice in the equation that the m term cancels itself, thus giving a limiting action to the system. This proves to be slightly detrimental at low C/N because the phase angle of a small error has the same effect as the phase angle of a large signal and thus tends to perturb the loop more. To compensate for this the magnitude is added to EQ 1.1

$$1 = m \arctan(m \sin(1) / m \cos(1)) \qquad \text{EQ 1.2}$$

Lock detection is achieved by filtering the cosine component and checking for a DC value greater than the noise floor and offsets. During sweep acquisition, the PLL is open loop and the cosine term is a sine wave beat note or noise and will have no DC term. As mentioned earlier, as the Bessel null approaches, the DC component goes to zero and the system will lose lock. If the modulation angle continues to increase, the cosine term will go negative. Therefore, the absolute value of the low passed cosine term is used, which provides only a small window of cosine term that will not generate a lock.

Due to the uncorrelated nature of the phase samples, the demodulator can only track signals up to ±180° because +190° appears the same as -170°. If the video bandwidth is known, the large step from large positive phase to large negative phase could be discerned as a positive phase greater than 180° and thus extend the range. To do this would require more hardware and prior knowledge of the signal.

AMPLITUDE MODULATION

Standard double side band AM is comprised of a carrier which is varied in amplitude but constant in phase. If the signal is phase locked with a PM demod the phase output will be a constant 0°, but the cosine term will be representative of the modulation with a DC offset. The DC term is the lock detect signal and discounting the noise terms should remain constant due to the AGC action in the radio. since the AM demodulation is synchronous in nature, the noise floor will have less effect than a typical RMS type detector extending the dynamic range to -15dB C/N.

FREQUENCY MODULATION

By varying the relative frequency of the carrier, the modulating waveform generates an FM signal. The waveform can be received by tracking the difference in frequency of the incoming signal and the center frequency of the receiver. The beat note caused by the frequency difference can be viewed as a difference in phase per unit time. As the beat note increases, the d1/dt will increase. Likewise if the d1/dt goes negative, the beat note becomes a negative frequency. Therefore, knowing the relative phase over a period of time, the frequency offset can be determined. At a 20MHz sampling frequency, which is a 50nS period, a +90° phase differential would relate to a 25MHz input signal. Likewise, a -90° differential would be from a 15MHZ signal.

Since the difference in phase rather than the absolute phase is used in the FM mode, EQ 1.2 above can not be used due to the effective reduction in maximum phase angle during signal fades. This is compensated by using EQ 1.1 and a limiter action on the signal followed by a low pass filter to regenerate the sinusoid needed for phase angle measurements.

As in the PM case, the maximum ±180° differential relates to a maximum ±½ of the sampling frequency or ±10MHz at 20Mhz center. Using a bits of phase resolution provides for 256 steps over the ±10MHz range, or 78.13Khz per step. To increase the resolution of the demod, a divide by N counter can be inserted in the A/D sampling clock which increases the dt per cycle. This in effect allows for more phase difference to accumulate per cycle thus decreasing the step size. Two consequences of lowering the sampling rate are: 1. a decrease in the maximum deviation and 2. the output reconstruction filter must be reduced to match. The decrease in maximum deviation is not typically a problem because the deviation is typically proportional to the video bandwidth. By installing a variable length FIFO in the delay circuit, the sampling frequency can be maintained while effectively increasing the time between samples.

As can be seen in Figure 2, the calculated outputs of the phase shift network are 90° apart over the entire bandwidth of the demodulator. But the propagation delay from one frequency to another will induce a distortion in the output as the carrier steps between the two frequencies. This problem is more obvious at the higher deviation rates and modulation bandwidths due to the larger frequency steps incurred.

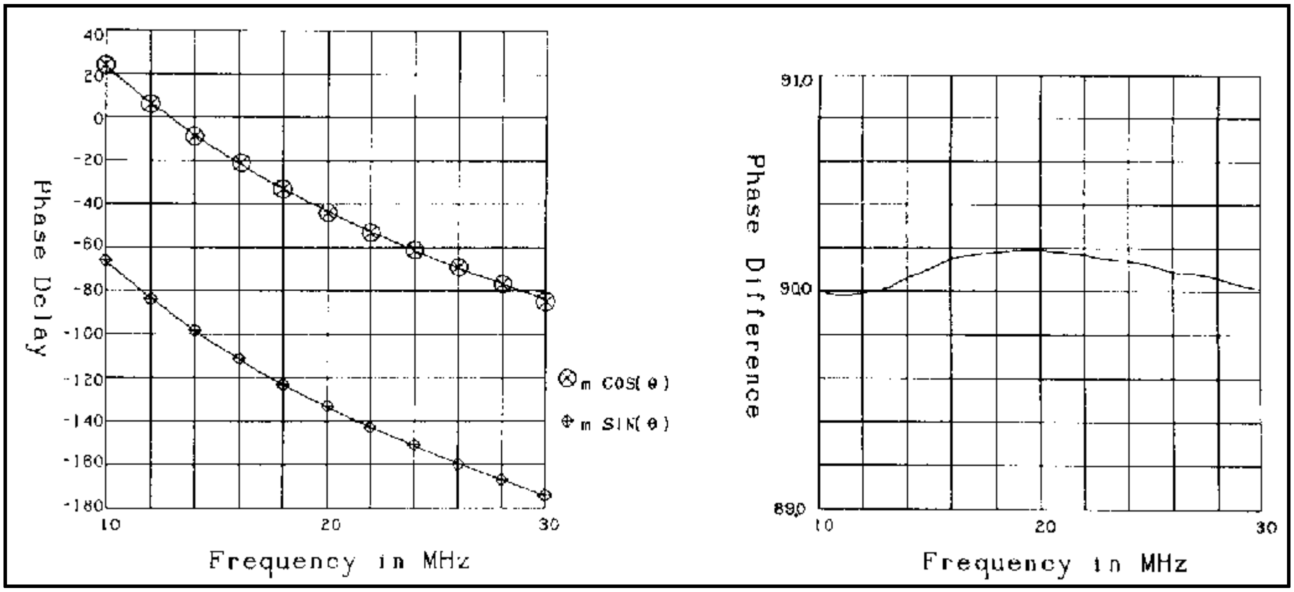


Figure 2

BI-PHASE SHIFT KEYING

BPSK signals are a way of transmitting a single data channel over a carrier. The data pattern is used to invert the phase of the carrier by 180°. Therefore a 1 is sent as 0° and a 0 as 180°. If the modulated carrier is mixed with the original carrier frequency and low pass filtered, the output will be the original data pattern. The demodulator accomplishes this task by phase locking the sampling clock to the incoming carrier. As seen in Figure 3, the carrier is phase locked such that the phase vectors land on one of the two poles along the cosine axis. The look up table is loaded with the sine term or the negated sine term as determined by the cosine term. This is equivalent to a standard Costa’s loop. Since the poles are located on the cosine axis, the cosine term is the reconstructed data.

The two poles are equal in magnitude, but opposite in phase. Therefore, to generate a lock signal, the absolute value of the cosine term is used as a relative carrier amplitude. This process has the effect of generating the RMS value of the noise floor which is no longer zero except at very high C/N rates. To distinguish between the noise floor power and

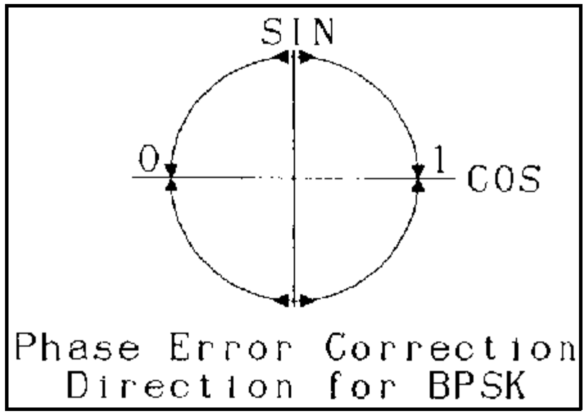


Figure 3

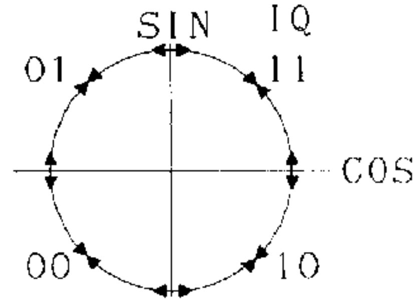
the carrier power, the sine term is also RMS detected. When locked, the sine term of the carrier is zero, but, the RMS noise in the sine term is equal to the RMS noise in the cosine term. Therefore subtracting the sine term from the cosine term leaves only the signal power.

QUADRATURE PHASE SHIFT KEYING

QPSK is a stereo form of BPSK. It is generated by splitting a carrier into two carriers that are 90° apart. These two carriers are then modulated the same as the BPSK above. The resultants are then summed to generate one carrier with two quadrature modulations. Essentially the output switches between one of four 90° phases.

To demodulate the signal, the incoming carrier is phase locked to the reference at a 45° offset as shown in Figure 4. This forces the decision points to land on the axis. This allows the sine and cosine terms to be used as the data outputs but degrades their amplitudes by .707.

To detect a lock is not as straight forward as the BPSK due to the fact that the sine and cosine terms have equal RMS carrier power and RMS noise power. The synchronous sine and cosine power will be stronger than the noise power but a reference can not be defined since the total carrier power may vary with AGC drift.



Phase Error Correction
Direction for QPSK

Figure 4

However, as mentioned above, the signal is phase locked to an average 45° angle. If the absolute values of both sine and cosine terms are generated, the carrier vectors are all confined to quadrant one. If the phase angle is then calculated, and all values greater than 45° are subtracted from 90° the vectors are then in the first half of the quadrant. The average value of noise vectors in this area will equal 22.5°, while the carrier vectors should equal 45°. Therefore, if the average vector angle approaches 45°, a lock is detected. This is summarized in the program below.

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Angle = ARCTAN( ABS( sin(1) ) / ABS (cos(1) ) )
If Angle > 45 then Angle = 90 - Angle
LockDetect = LOWPass(Angle)
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Conclusions

Microdyne has developed a series of multi-mode demodulators using this concept and has shown comparable results to their standard analog units. The 1458-D is used in the 1400MR receivers, and the 1258-D is used in the 1200 MR receivers. Several of the advantages of the single unit over the individuals are:

1. No need to switch nodules depending on modulation format.
2. Requires half the power, lowering cooling problems.
3. Fewer adjustments. No field adjustments are necessary at all and only a dozen internal controls allow for faster alignment at test.
4. Less expensive than multiple analog units.
5. Flexibility. Other forms of demodulation may be implemented as defined later.
6. Totally remote controllable.