TUNABLE FSK/AM SIGNAL DETECTOR ON A 6U-VME CARD

Theodore J. Hordeski, Jr.
GDP Space Systems

ABSTRACT

The telemetry and aerospace communities require communications equipment providing various modulation and demodulation formats. One format, with application in Space Ground Link Subsystems (SGLS), utilizes a Ternary (tri-tone) Frequency Shift-Keyed (FSK) signal Amplitude Modulated (AM) by a triangle waveform. Historically, SGLS equipment has operated with a fixed tri-tone frequency set (e.g., 65 kHz, 76 kHz and 95 kHz). The need for additional transmission channels and increased bandwidth efficiency creates the requirement for equipment with the flexibility to generate and receive varied and higher frequency tone sets.

Combining analog and digital techniques, GDP Space Systems has developed the FDT001. It is an FSK/AM detector which recovers a bit rate clock at one of four selectable bit rates and reproduces ternary FSK modulation data over a widely tunable range of tone frequencies. The tuning range is expanded by using two methods of digital frequency discrimination. The following paper describes the design of the FDT001.

KEY WORDS

FSK/AM, Ternary FSK, SGLS, Clock Recovery, Demodulation, Digital Frequency Detection

INTRODUCTION

GDP Space Systems has implemented a tunable FSK/AM frequency detector on a single 6U-VME card. Using analog design techniques, the FDT001 recovers a coherent bit rate clock from the AM envelope at one of four selectable bit rates. Digital frequency discrimination is used to reproduce ternary (S, 0 and 1) FSK modulation data. The range of detectable frequencies is greatly expanded by using two different methods of detection. A traditional analog approach would generally limit the design to receive a single tone set.

HISTORY

First generation analog SGLS demodulators used minimal hardware and offered minimal noise performance. They used three bandpass filters as the principle noise filters with envelope detectors at IF for data and clock recovery. In theory, the bandpass filters could be made close to optimal for best noise performance; however, optimal filtering at IF requires complex hardware and a labor-intensive alignment. In practice, the bandpass filters were usually wider than optimal, i.e., just good enough to eliminate grossly out-of-band noise. Filter bandwidths were typically two to four times bit rate. These demodulators started off with about a five dB disadvantage (from optimal) due to wide bandwidth filters and the resultant excess noise in the bit detection/decision process.

Second generation analog SGLS demodulators first down convert the incoming signal and then filter it at baseband. They use non-linear devices (typically full or half wave rectifiers) for down conversion. The output of each rectifier is a baseband signal which is then lowpass filtered. These low pass filters serve as the principal noise filters. While this approach allows better filtering with less hardware complexity than an optimal bandpass filtered demodulator, it does have a significant short coming. The rectifiers, like all non-linear devices, exhibit threshold. Threshold occurs when, for a given decrease in SNR at the input of a device, the SNR at the output decreases by a significantly larger amount. Threshold in rectifiers occurs at an SNR of approximately five dB[1] and in a noisy environment, this demodulator would have poor performance.

GDP Space Systems developed the FDM001; an improved analog SGLS demodulator. It uses multipliers, instead of rectifiers, for non-coherent down conversion and does not suffer from threshold. Primary noise filtering is done at baseband which yields filtering closer to optimal and with less hardware than filtering done at IF. The 0-Hz-IF demodulator, as well as the first and second generation demodulators use similar clock recovery circuits and data bit decision circuits. Like its predecessors, the 0-Hz-IF demodulator utilizes fixed bandpass and lowpass filters limiting operation to a single tone set.

DIGITAL FSK/AM DETECTOR THEORY OF OPERATION

Refer to the block diagram in Figure 1. The front end circuitry of the FDT001 accepts a single FSK/AM input signal and normalizes its amplitude using automatic gain control (AGC). Filtering is done at IF and consists of a lowpass filter cascaded with a highpass filter. Both filters are tunable and second-order. They are tuned to bracket the upper and lower tone frequencies and limit out-of-band noise or interference. This normalized and filtered FSK/AM signal is processed to recover timing and data.

Clock recovery is accomplished with analog techniques. The FSK modulation data timing is embedded in the AM triangle wave envelope on the FSK signal. See Figure 2 for a graphical representation of the SGLS FSK/AM waveform. The frequency of the triangle wave is one-half the bit rate. The FDT001 can recover a clock at one of four selectable bit rates: 1 kbps, 2 kbps, 5 kbps and 10 kbps. The bit rate clock is recovered by squaring and filtering the FSK/AM signal. When a sinusoid (f_s) amplitude modulated by a periodic signal (f_m) is squared, a spectral term at $2f_m$ is generated (see figure 3 for the math). A selective bandpass filter isolates this term to recover the bit rate clock. The clock phase is adjusted to position the rising edge of the recovered clock over the frequency transition for use by the data detection circuit. This adjustment is needed as a result of the fixed time offset or sync delay (T_d) between the FSK tone transition and the zero-crossing of the AM envelope.

The task of a ternary FSK demodulator is to differentiate three separate tone frequencies (f_S, f_0, and f_1) corresponding to three data streams; S, 0 and 1. The FDT001 uses two techniques of digital frequency detection to reproduce the modulation data. In one method of frequency detection, the number of tone cycles per bit period are counted. In the second method, the number of cycles of a free-running 120 MHz clock are counted during each tone cycle. In either method, the three FSK tone frequencies will result in three count values (n_S, n_0 and n_1). To discriminate three frequencies, two threshold values; one between n_S and n_0 and one between n_0 and n_1, are calculated and stored. Each count is compared with both thresholds for a bit decision.

In the first method of digital frequency detection, a digitized version of the FSK tone signal is used to clock a counter. The counter is run for known gate period, T_g. The counter value, n, at the end of the gate period is the number of positive transitions of the measured signal within that fixed time. The period of the measured tone signal, T_m, is the gate time divided by n. The optimal gate time for this measurement is one bit period since it is the maximum period the tone frequency is guaranteed to persist.

The FSK sinusoid is not coherent with the AM envelope; therefore, it 'walks' by the recovered clock at a finite rate. This leads to an uncertainty in the count value of at least plus or minus one. Because of this uncertainty and the fact that the counter value and thresholds are integers, two frequencies, whose associated count values differ by no more than two, can not reliably be discriminated with the first method of detection. Accuracy may also be affected by clock alignment and noise. As an absolute minimum, with a perfectly aligned clock and no noise, the nominal count values, n_{low} and n_{high} of two adjacent frequencies should differ by three so that the threshold value can lie between (n_{low}+1) and (n_{high}-1).

Using the bit period as the counter gate time, the count magnitude, and thus the difference between count values, is limited as the bit rate increases. Consider the traditional SGLS tone frequencies of 65 kHz (f_s), 76 kHz (f_0) and 95 kHz (f_1). At a bit rate of 1 kbps, the nominal counter values are 65 (n_s), 76 (n_0) and 95 (n_1), respectively, giving a difference of eleven between S and 0, and a difference of nineteen between 0 and 1. However, at 10 kbps, the counts are reduced to 6.5 (n_s), 7.6 (n_0) and 9.5 (n_1), respectively. The difference between counts is not sufficient to accurately discriminate these frequencies. Because a twelve-bit counter is used, the maximum counter value is 4095 allowing for a maximum detectable tone frequency of approximately 4 MHz at a 1 kbps bit rate.

To expand the range of usable tone frequencies the FDT001 incorporates a second digital technique in which frequency detection is independent of the bit rate. A free-running 120 MHz clock is used to drive a counter while using the tone period as the gate time. The period of the tone being measured is equal to the counter value, n, multiplied by 8.33 ns (the period of the 120 MHz clock). The counter outputs a value for each tone cycle, whereas only one frequency decision is made per bit period using the first method. The use of this technique is limited by the size of the counter and the tone frequencies being received. A twelve-bit counter enables a maximum count of 4095. This corresponds to a minimum detectable tone frequency of approximately 29 kHz. As the tones increase in frequency, the counter values will decrease, limiting the resolution or minimum spacing between frequencies.

The two methods of digital frequency detection are complimentary in their effectiveness. Lower frequency tone sets tend to be spaced more closely than higher frequency tone sets. Using the first detection mode with lower tone frequencies, the number to tone cycles per bit period and the difference between counts decreases as bit rate increases, eventually rendering the first method unusable. The second method, which is bit rate independent, is optimized for lower tone frequencies since the counter achieves larger count values, and even relatively closely spaced tones result in significant count differences. Conversely, higher tone frequencies result in low count values when using the second method. Here the first method is optimized because the counter achieves sufficiently high count values over the entire range of bit rates.

CONCLUSION

The GDP Space Systems FDT001 presents a FSK/AM signal detector with greater flexibility than traditional approaches to SGLS demodulation. It provides, on a single VME circuit board, a complete SGLS FSK/AM signal recovery system which can reproduce ternary (S, 0 and 1) data over a wide range of continuously tunable FSK tone frequencies. It can also recover a bit rate clock at one of four selectable bit rates. This flexibility is a result of the use of integrated circuits with complex functionality, the use of two different digital frequency detection techniques and to the fact that no fixed IF bandpass filters are used. As a trade-off for flexibility, performance is impacted as the circuit operates only on relatively low-noise signals. Noise within the band occupied by the FSK tri-tones is not filtered. Because the digital method of frequency detection uses transitions in the FSK signal, the circuit is noise sensitive.

REFERENCE

1. Taub, Herbert and Schilling, Donald, "SQUARE-LAW DEMODULATOR," Principles of Communication Systems, Magraw-Hill, 1971, p.287.

The proof in this reference is for a squaring device. A squaring device can be thought of as a rectifier working with only the fundamental term as its inputs. The threshold level of a rectifier is within one dB of the value given for a squaring device.

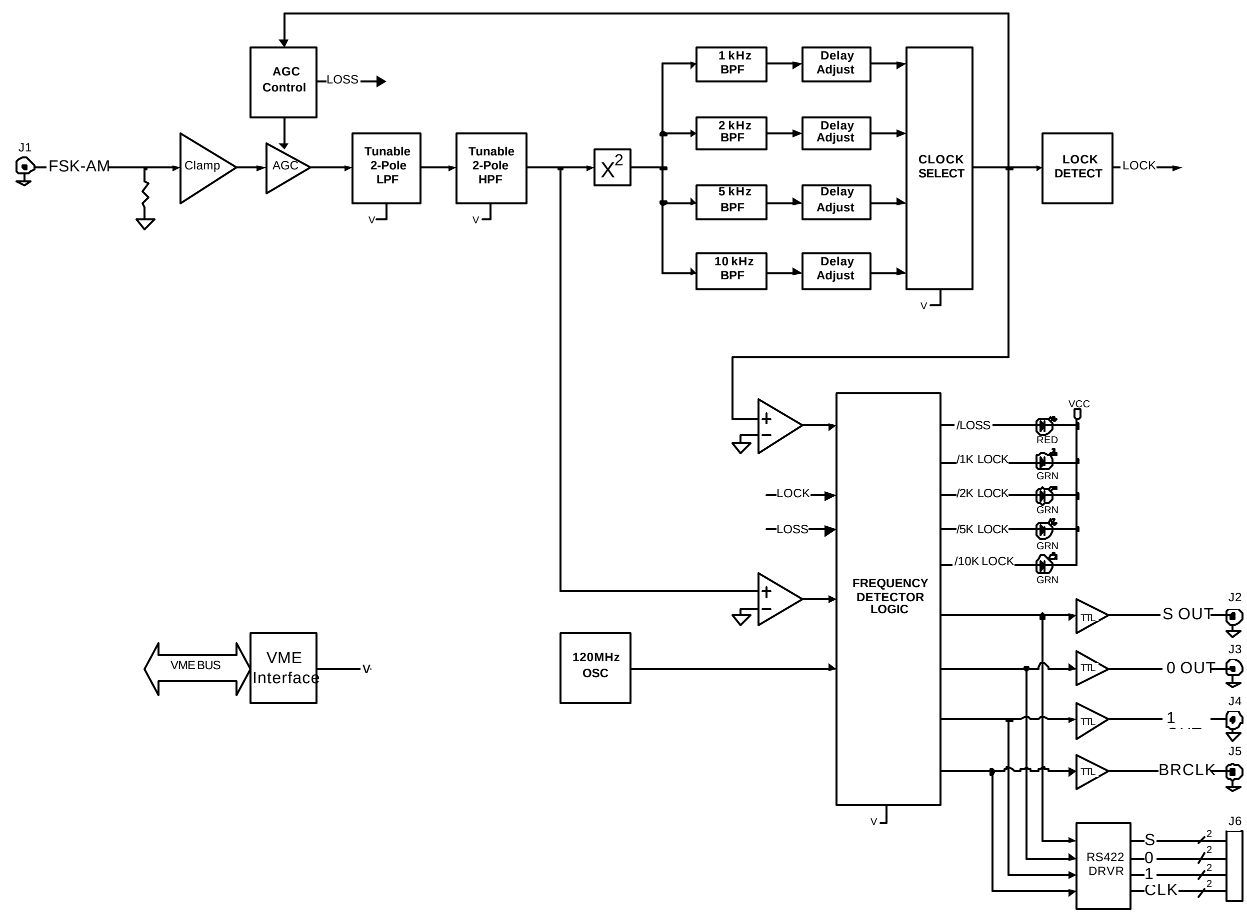


Figure 1 - FDT001 Functional Block Diagram

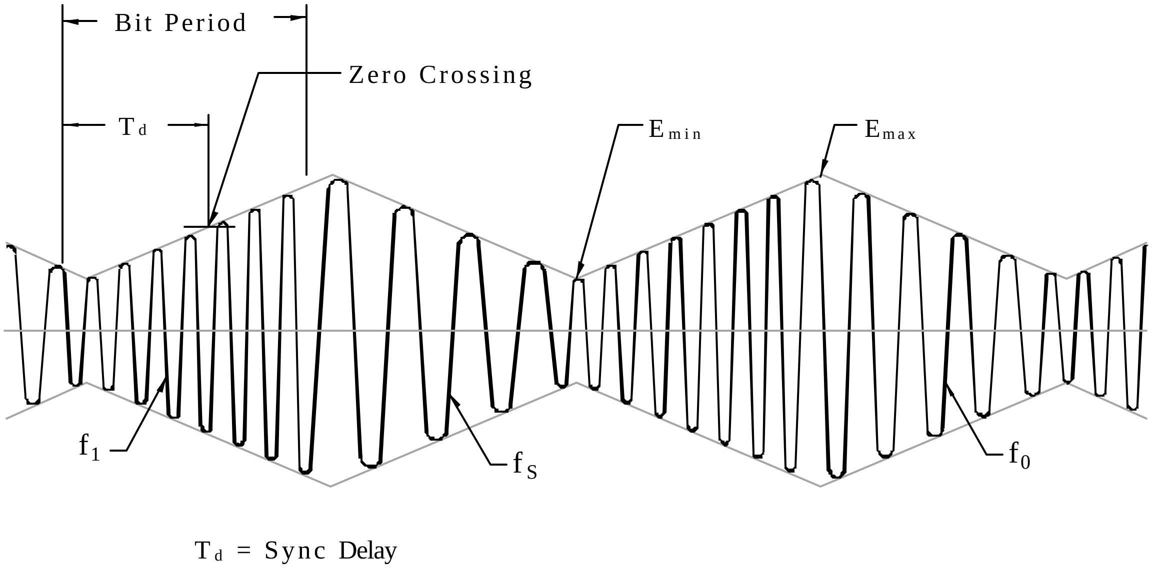
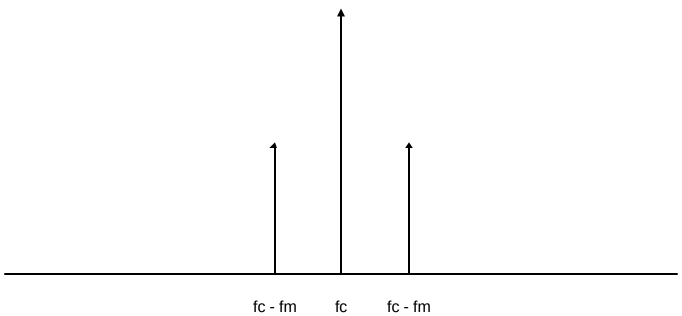


Figure 2 - SGLS FSK/AM Signal Waveform

For a sinusoidal modulation input to an amplitude modulator, i.e., $m(t) = \cos \omega_m t$, the complex envelope of the AM signal is given as: $g(t) = A_c * (1 + m(t)) = A_c * (1 + \cos \omega_m t)$.
For $A_c = 1$, the output of the modulator is:

$$
\begin{aligned}
s(t) &= (1 + \cos \omega_m t) * \cos \omega_c t \\
&= \cos \omega_c t + \cos \omega_m t * \cos \omega_c t \\
&= \cos \omega_c t + \tfrac{1}{2}[\cos(\omega_c t - \omega_m t) + \cos(\omega_c t + \omega_m t)]
\end{aligned}
$$



At the receiver, the signal, s(t), is squared:

$$
\begin{aligned}
s^2(t) &= [\cos \omega_c t + \tfrac{1}{2}[\cos(\omega_c t - \omega_m t) + \cos(\omega_c t + \omega_m t)]]^2 \\
&= \cos^2\omega_c t + \cos \omega_c t * \tfrac{1}{2} \cos(\omega_c t - \omega_m t) + \cos \omega_c t * \tfrac{1}{2}\cos(\omega_c t + \omega_m t) + \tfrac{1}{2}\cos(\omega_c t - \omega_m t) * \tfrac{1}{2}\cos(\omega_c t + \omega_m t) + \tfrac{1}{4}\cos^2(\omega_c t - \omega_m t) + \tfrac{1}{4}\cos^2(\omega_c t + \omega_m t) \\
&= \tfrac{1}{2}[1 + \cos 2\omega_c t] + \tfrac{1}{4}[\cos(\omega_m t) + \cos(2\omega_c t - \omega_m t)] + \tfrac{1}{4}[\cos(\omega_m t) + \cos(2\omega_c t + \omega_m t)] + \tfrac{1}{8}[\cos(2\omega_m t) + \cos(2\omega_c t)] + \tfrac{1}{8}[1 + \cos(2\omega_c t - 2\omega_m t)] + \tfrac{1}{8}[1 + \cos(2\omega_c t + 2\omega_m t)] \\
&= \tfrac{3}{4} + \tfrac{1}{2}\cos(\omega_m t) + \tfrac{1}{8}\cos(2\omega_m t) + \tfrac{1}{8}\cos(2\omega_c t - 2\omega_m t) + \tfrac{1}{4}\cos(2\omega_c t - \omega_m t) + \tfrac{5}{8}\cos(2\omega_c t) + \tfrac{1}{4}\cos(2\omega_c t + \omega_m t) + \tfrac{1}{8}\cos(2\omega_c t + 2\omega_m t)
\end{aligned}
$$

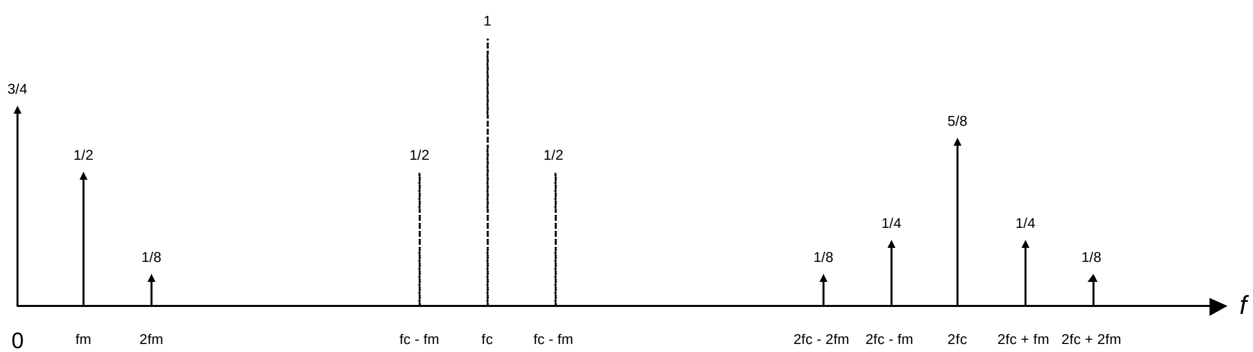


Figure 3 - Spectrum of Squared AM Signal