B. Appendix C. Modem Data Carrier Detector Signal

One of the most intractable algorithms is one that reliably discriminates FSK signals from noise in a hard-limiter demodulator. In these demodulators, the baseband signal amplitude itself is not a reliable discriminant, since the amplitude of the noise with no signal present is nearly the same as the amplitude of the signal, when present. In typical modems, an analog signal is developed called the Data Carrier Detect (DCD) signal which reflects in some sense the signal/noise ratio. When the DCD signal exceeds some threshold, the DCD lead is raised at the modem interface.

In a digital modem, it should be possible using crafted algorithms to reliably develop a DCD signal. A number of schemes were tried in order to develop an algorithm to reliably discriminate legitimate FSK signals from hard-limited noise. All of these were based on the assumption that the carrier energy is concentrated in either the mark or space channels (but not both) and the noise is equal in both channels. If it is not known a-priori which channel the carrier is transmitted in, a straightforward algorithm would be to add the signals in the mark and space channels and employ a OOK demodulator to determine if the signal is present. The performance of this scheme would be equivalent to noncoherent OOK with a penalty of 3 dB.

There are two problems with this scheme. First, following a hard limiter and narrowband channel filters, the channel amplitudes with carrier present are only a couple of decibels greater than the amplitudes with only noise, even when the carrier amplitudes are large. Second, even this difference is reduced when FSK modulation is present. What is needed is an algorithm that is sensitive to the nature of the FSK modulation and independent of the particular data modulation sequence.

The most straightforward scheme to detect a FSK signal is simply to measure the relative amplitudes of the mark and space channels. The channel with the largest amplitude must contain the carrier plus noise, while the other channel must contain only the noise. While this works well if the signal is not modulated, it does not work well if the signal is modulated, since in this case the carrier switches rapidly between the mark and space channels and the signal energy is not completely confined to either channel.

Assuming the modulation data rate is known, it is possible to discriminate FSK signals from noise in the following way. First, assume that both channels have been processed by a matched filter, where the length of the filter is chosen to match the bit interval of the modulating data signal. As the carrier frequency swings from mark to space, for example, the amplitude of the differential (mark minus space) detector signal decreases from the positive carrier level through zero to the negative carrier level. Thus, the absolute value of this signal will reach maximum at least once every bit interval, regardless of the instantaneous value of the modulating data signal.

This observation suggests a carrier detector design based on a sample-and-hold circuit, where the hold time is at least equal to the bit interval. Since the differential detector signal is sampled eight times per bit interval, this can be done using an eight-sample shift register, where the DCD signal amplitude is taken as the maximum sample in the register. With this design, the DCD signal amplitude is equal to the carrier amplitude as long as the carrier power is sufficiently larger than the noise power.

A DCD circuit based only on the above scheme compares the DCD signal to an operator-adjustable threshold, in order to adjust for varying reception conditions and transmission characteristics. However, this scheme works only over a narrow range and does not automatically adjust for varying receiver gain. A better scheme responds to the signal/noise ratio and not only the absolute amplitude.

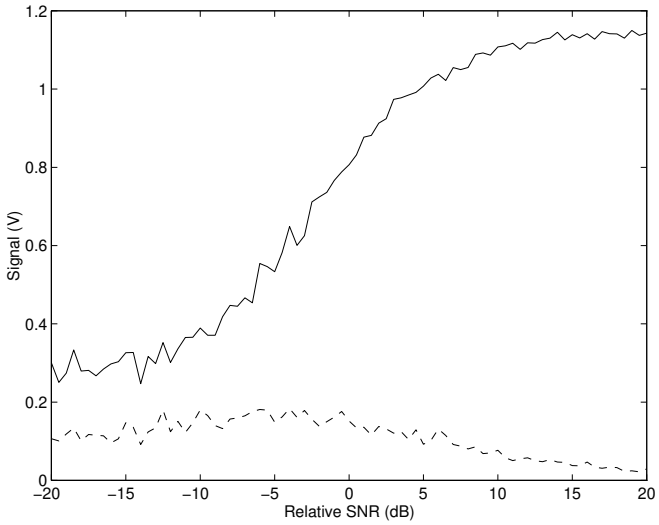

Figure C1. Simulated SITOR Decoder

In order to do this, an estimate of the noise is required. A number of schemes to provide a reliable estimate of the noise were tried with varying success. The most obvious one is to find the signal sample with maximum energy in either channel, then select the signal sample in the other channel as the noise component.

This turned out to give a reliable estimate of the noise due to all factors, but the noise sample turned out to be dominated by various modulation products produced by the matched filter and hard-limiter demodulator. Therefore, the estimator did not reliably reflect the actual random noise present at the demodulator input.

Another way to estimate the noise is to measure the differences in carrier samples produced by the sample-and-hold circuit. The most straightforward estimator of this is the variance or standard deviation. This scheme in fact turned out to work best of the various schemes tried. The ratio of the carrier amplitude to the standard deviation is thus a reliable estimator of FSK signal/noise ratio and thus represents a good DCD signal. The signal can be compared to an operator-adjustable threshold in order to function as an autostart signal which works over a large variation in signal and noise amplitudes.

In the DSP modem, the RF sample rate is 8000 Hz, while the decimated demodulator sample rate is 800 Hz, so that eight samples are produced for each baseband)it of the modulating data signal. The differential demodulator (baseband) signal is processed by the DCD algorithm. The sample-and-hold shift register has eight stages, which matches the bit interval of the baseband signal. At each sample shift, the absolute value of the baseband signal is shifted into this register. Then, the maximum sample in the register is shifted into a 256-sample shift register used to compute the mean square and variance. At each shift the sum of the samples and the sum of the squared samples are used to compute the mean square, variance and ratio of the two. As the ratio of the squares is a monotonic increasing function of the underlying ratio, the ratio of the squares can be compared to a fixed threshold in order to determine whether the signal is present or not.

The simulated performance with the DCD algorithm is shown in Figure 1. This figure shows the mean (solid line) and standard deviation (dotted line) of the processed baseband signal, as described

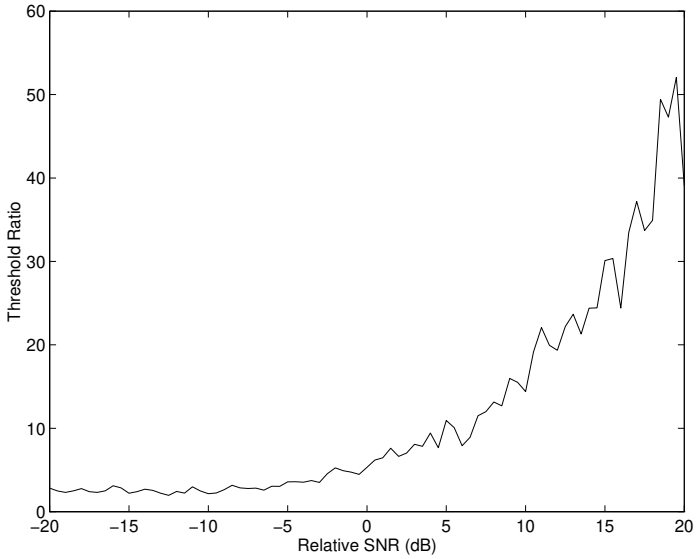

Figure C2. Simulated RTTY Decoder

above, over the range of SNR from -20 dB to +20 dB. The radio of these two quantities is shown in Figure 2 over the same SNR range. Depending on the acceptable hit and false-alarm rates, a threshold corresponding to a SNR of 0-5 dB would seem appropriate, or a few dB above a threshold BER of 10^{-3}. An even better discriminant would be possible by averaging over a longer interval; however, if the interval became too long, the DCD response may be too sluggish for rapid transmit/receive switching.