IEEE 802.11
802 LAN Access Method for Wireless Physical Medium

DATE: December 27, 1990

TITLE: **CORRELATIVE MINIMUM SHIFT KEYING (CMSK) LINE SIGNAL WITH MEASURED VIDEO AND RF SPECTRUM SHAPES**

AUTHOR: Chandos A. Rypinski,
Chief Technical Officer
LACE, Inc.
921 Transport Way
Petaluma, California 94954 USA

Telephone: 707 765 9627
Facsimile: 707 762 5328

OVERVIEW

CMSK is the modulation that results if the starting point is Manchester, and the changes are introduced so that it will go through a medium with delay and amplitude distortion, noise and crosstalk, and then emerging with small jitter and intersymbol interference. Further refinements have been added for burst transmissions. This modulation is now described as a possible technical element of the 802.11 Standard.

The CMSK technology has evolved from efforts to develop an unshielded telephone twisted pair (UTTP) line signal combining rate, reach, flexibility and cost in the right mix. Much of the work was initially motivated by competing solutions to 10BaseT and by competition with PR4 and 4-CAP within the 802.9 IVD Standard Committee. More recently, CMSK has been developed for consideration as a long reach telephone subscriber lines at the 1.544 MB/s rate (HDSL), and for the ISA/NEMA SP50 "Fieldbus" at a 1 Mb/s rate.

The CMSK concept and the analytical and experimental work reported are from the efforts of Mr. G. L. Somer.

CORRELATIVE MINIMUM SHIFT KEYING (CMSK) LINE SIGNAL WITH MEASURED VIDEO AND RF SPECTRUM SHAPES

Table of Contents **Page**

Figures

CORRELATIVE MINIMUM SHIFT KEYING (CMSK) LINE SIGNAL WITH MEASURED VIDEO AND RF SPECTRUM SHAPES

OVERVIEW

CMSK is the modulation that results if the starting point is Manchester, and the changes are introduced so that it will go through a medium with delay and amplitude distortion, noise and crosstalk, an then emerging with small jitter and intersymbol interference. Further refinements have been added for burst transmissions. This modulation is now described as a possible technical element of the 802.11 Standard.

The CMSK technology has evolved from efforts to develop an unshielded telephone twisted pair (UTTP) line signal combining rate, reach, flexibility and cost in the right mix. Much of the work was initially motivated by competing solutions to 10BaseT and by competition with PR4 and 4-CAP within the 802.9 IVD Standard Committee. More recently, CMSK has been developed for consideration as a long reach telephone subscriber lines at the 1.544 MB/s rate (HDSL), and for the ISA/NEMA SP50 "Fieldbus" at a 1 Mb/s rate.

The CMSK concept and the analytical and experimental work reported are from the efforts of Mr. G. L. Somer.

HIGHLIGHTS OF CMSK

- Carrier type modulation with ac waveform equally suitable for unshielded telephone twisted pairs, data grade cable or radio subcarrier modulation.

- <u>Characteristics</u>

Spectrum energy-density peak:	0.75 × bit rate
Spectrum energy-density zero's:	dc and 1.5 × bit-rate
95% energy bandwidth:	1.8 bits/Hz
95% energy bandwidth frequency limits:	0.5 and 1.0 × bit-rate
Reach-rate product for NEXT limited multi-pair 24 gauge plastic-insulated horizontal cable (estimate):	8 kilofeet × megabits/sec valid 1-16 megabits/sec

- CMSK does not have spectral lobes beyond the high side zero.

- Pure binary at sampling points at receiver input terminals.

- "Eye" width is one-half bit period and (constant envelope) amplitude equal to signal peak value.

- The transmitted line signal will be defined by ROM including necessary predistortion, if required.

- Fast bit-clock acquisition within two octets of signal present state with predefined preamble bit pattern.

- The technology used is suitable for volume production as ASICs.

DESCRIPTION OF CMSK TECHNOLOGY

This line signal is an adaptation of minimum-shift keying to generation by linear methods which include overlapping pulses (partial response) and which has advantage against other 2-level and multi-level possibilities.

This modulation is a 1.8 bit per Hz binary carrier type now called **Correlative Minimum Shift Keying (CMSK).**

The energy peak is at 0.75 times bit-rate and that 95% of the signal power is contained between frequencies corresponding to 0.5 and 1.0 times bit-rate (approximation). Further, the reach is increased by 1st order compensation at the transmitter for the time and amplitude dispersion of the transmission line for specified reach limit.

The analogy to minimum shift frequency keying is approximate, and it is based on a similarity in the appearance of the waveform to MSK with 0.5/1.0 times bit-rate frequencies. After filtering, a phase reversal keyed carrier at the bit-rate also has a similar appearance. Compared with either of these waveforms, CMSK has a materially narrower energy density spectrum and it does not have spectral lobes beyond the high side zero.

Advantages of CMSK Modulation

- it is a two level signal with no intersymbol distortion at the sample point.
- it is readily detected with threshold, matched filter or coherent detectors.
- the power bandwidth is only about 10% greater than that of PR4 (a 3-level modulation with 2 bit/Hz bandwidth efficiency).
- the pulse shape has good truncation characteristics making it ideally suited to digital filter technology.
- using a predefined bit pattern for a preamble, fast bit-clock acquisition is possible.

LINE SIGNAL DESCRIPTION

The following Figures 1-4 are calculated and scaled for a data rate of 1.5 Mbs. Idealized waveforms shown are without line compensation at the transmitter, and they are valid at the receiver input with line compensation and after going through the transmission path for which the compensation was designed.

Wave Source

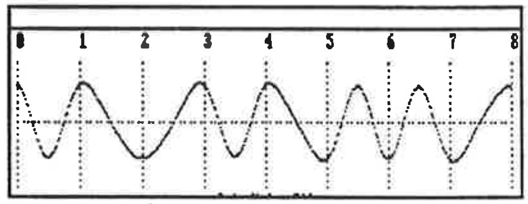

Figure 1 CMSK Line Signal Amplitude vs. Time in Bit Periods for Data Pattern 10010110

A time plot of the line signal is shown in Figure 1 above where the sampling instant is marked by the vertical grid. At the sampling instant, the waveform has two possible values: +1 or -1.

The data value is differentially coded (for threshold detection). If the polarity of the present sample is the same as for the previous sample, that is defined as data 1; if the polarity is different, then it is data 0. This precoding might be differently defined for coherent detection.

The "eye pattern" for this signal is shown in Figure 2 below where the eye width is half the period of one bit. The detection process is described in terms of sampling, however this does not mean that other more elegant methods would not be equally usable.

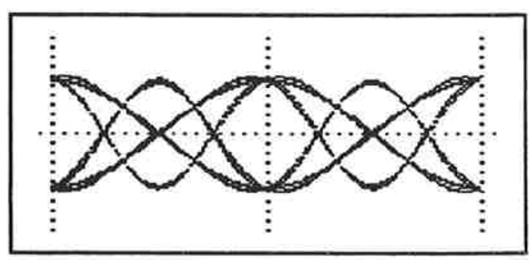

Figure 2 Eye Pattern for CMSK Line Signal with Sample Time at Vertical Grid Lines

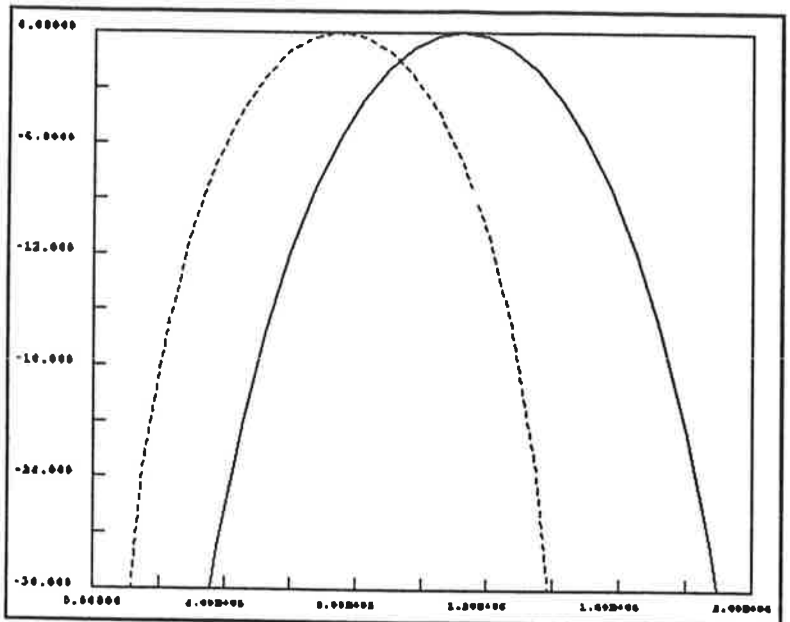

Figure 3 Power Density Spectrum for CMSK (solid line) and 3-level PR4 (dashed line)

Energy Density Spectrum

The calculated power spectrum density vs. frequency shown in Figure 3 above, compares PR4 and CMSK both operating at 1.5 Mbs. The dashed line is PR4 and the spectrum is centered at 0.75 Mhz (0.5 times the bit-rate). The solid line is CMSK centered at 1.125 MHz (0.75 times the bit-rate). About 95% of the transmitted power is contained between the 6 dB down points as marked slightly wider than 0.75 and 1.5 MHz for a 1.5 Mbs data rate.

The horizontal scale is 0.0 to 2.0 MHz and 0.2 MHz/division. The vertical scale is 0.0 to 30.0 dB and 6 dB/division.

Digital Synthesis of the Line Signal

The line signal is formed from a succession of overlapping pulses each of which may be either one of two polarities. The pulse shape, shown in Figure 4, is chosen considering a number of factors. In this case, there is no dc content. The finite width of the pulse actually synthesized in the FIR filter is two bits defined by the limits of the four central zero crossings. The shape is derived from a sine-squared spectrum to providing the desirable shape shown.

The pulse shape actually used is a modification of the shape shown to offset the time and amplitude distortion of the maximum defined reach transmission line.

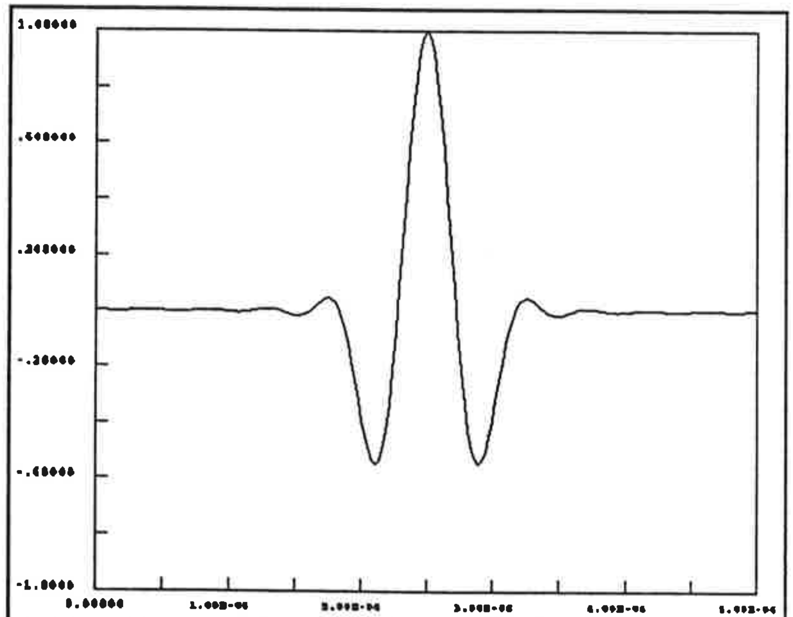

Figure 4 Generating Pulse Shape for CMSK

The horizontal time scale of the Figure is 0 to 5 microseconds.

IMPLEMENTATION

A number of models of modems using the principles described have been built and tested at 4 and 16 Mbs on lengths of 24 gauge DIW. More recently, the CMSK modulation has been tested as an FM modulation to observe the net RF spectrum. With random data, the shape was smooth and confined. Far out sidelobes were not observed.

On the following pages, measured data is shown.

Baseband Signal Waveforms

The "eye" Pattern form of the CMSK signal, shown in Figure 5, resembles conventional MSK except that amplitude peaks are not exactly aligned with bit interval boundaries.

The data rate in this and following Figures is 1 Mb/s with a horizontal scale of 200 nanoseconds/division. The results are probably scalable to any higher rate.

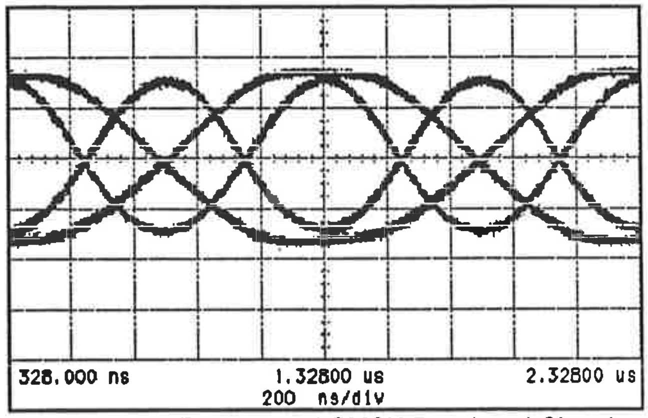

Figure 5 EYE Pattern of CMSK Baseband Signal

The spectrum is shown in Figure 6 at a horizontal scale of 0.2 MHz/division.

The nose is about 0.4 MHz wide at −6 dB down. The peak is about 0.7 MHz, and the first high side null is 1.5 MHz. The display near zero frequency contains artifacts of the spectrum analyzer used.

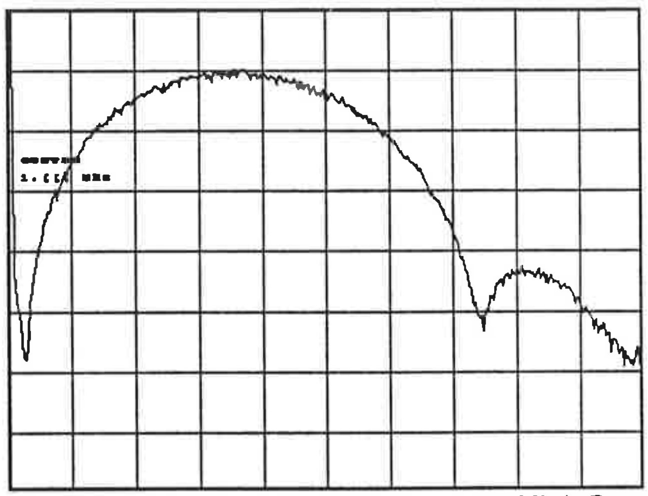

Figure 6 CMSK Baseband Spectrum at 1 Mb/s Data Rate. Display center = 1 MHz, X = 0.2 MHz/division, Y = 10 dB/division

The spectrum is displayed in Figure 7 on a longer scale so that the sidelobes are bettered defined. The first sidelobe is about −35 dB. Most of the rest is somewhat further attenuated. There has been no attempt to clean the signal with more than simple filtering. Given that the signal is generated from a stair-case digital structure, this is considered fairly clean.

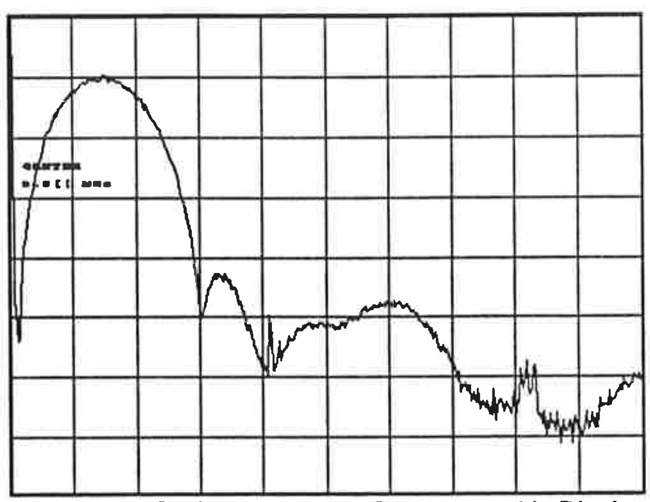

Figure 7 CMSK Baseband Spectrum with Display Sweeping Up To 5 MHz. X = 0.5 MHz/division

RF Frequency Modulated Spectrum

The CMSK Signal was frequency modulated onto an 833 MHz carrier using a linear voltage-controlled oscillator. A pseudo random data pattern obtained from a 9-bit scrambler was used. The resulting RF spectrum was observed with the results shown in the adjoining Figures.

The pictures do not resemble those that result from sine wave modulation. Line sideband frequencies are present which relate to the bit-rate clock frequency. There is also significant carrier frequency present.

The Carson Rule for FM bandwidth is:

$$BW = 2B + 2D$$

where B is the highest modulating frequency and D is the deviation.

The 6 dB down bandwidth points are not clearly defined, but with some subjective approximation the bandwidth at 16 dB down from the preponderant energy peaks appears to be as follows:

Deviation:	1.5	3	4 MHz
-16 dB bandwidth:	4	8	11 MHz
Carson Rule:	5	8	10 MHz

Integrate-Sample-Dump Data Detection

The data detection process, in the LACE implementation of the CMSK demodulator function, has two major parts: 1) clock acquisition, and 2) data detection. The first step is clock acquisition, after which the timing of the beginning and ending of each symbol/bit interval is known. With that information it is possible to integrate the energy received over the bit interval to determine whether it better matches one of two or more known patterns. The binary decision is made near the end of the bit interval, and the energy stored in the integrator is dumped.

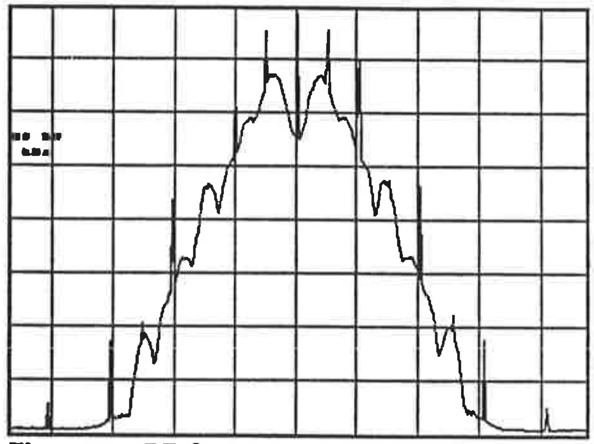

Figure 8 RF Spectrum of 833 MHz Frequency Modulated Signal with 1 Mb/s CMSK Data at ±1.5 MHz Peak Deviation.
X = 2 MHz/Division Y = 10 dB/Division

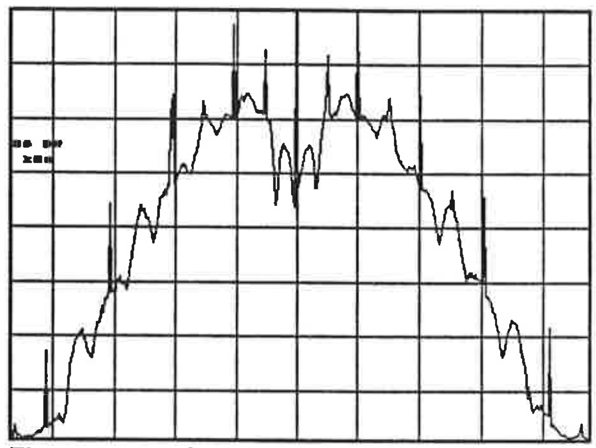

Figure 9 RF Spectrum at ±3 MHz Deviation.

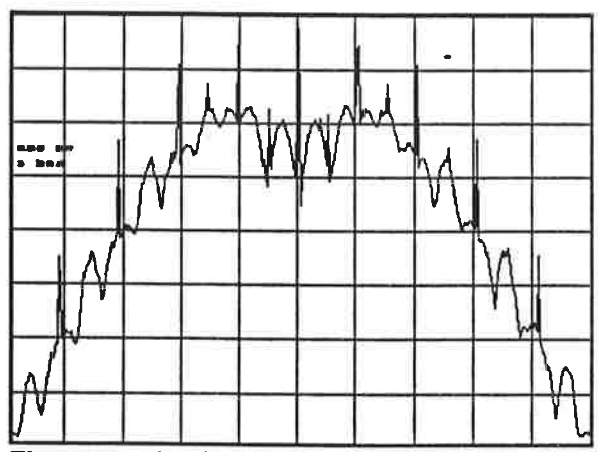

Figure 10 RF Spectrum at ±4 MHz Deviation.

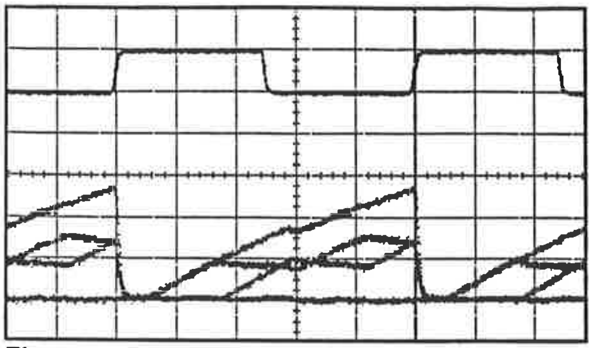

Figure 11 Baseband CMSK Eye Pattern with Integrate-Sample-Dump Detection, and Clock Pulse with Sampling on the Rising Edge.

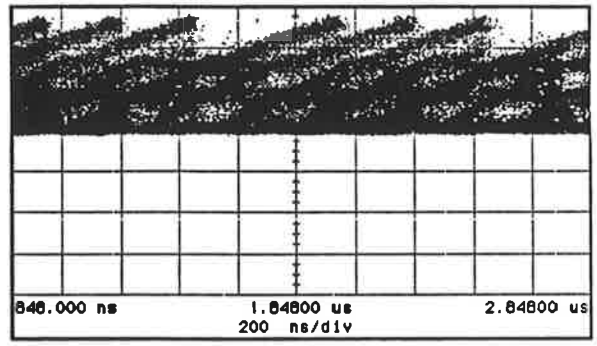

Figure 12 Detector Eye Pattern with Poor Carrier-to-noise Ratio (18.5 dB) Sufficient to Cause Loss of Clock.

This process is often called matched filter demodulation. Figure 11, above shows the observed waveform across the integrating capacitor in a detector of this type.

Ideally, there are three possible values of charge possible at the end of the interval now called 0, 1 and 2. The path by which the value is reached may differ from bit to bit, and it can be contaminated with noise shown at increasing progressive levels in Figures 11, 13, 14, 15 and 12.

Errors will be made if a dot occurs on the wrong side of the two midpoints between the three levels at the instant just before the wave form peaks at the end of the bit interval. **If there is clear white band in that area, no mistakes are being made.**

The display shown is made on a "digital storage oscilloscope" over a 20 second interval. A pixel will be displayed if it is "hit" once. Figure 15 looks "clean" on an ordinary oscilloscope. The detectable error probability is 1-in-2 x 10^7. The necessary test duration is the period for sufficient Mbits to be transmitted.

In the data shown, the CMSK is linearly frequency modulated on an 833 MHz RF carrier, demodulated after a soft limiting IF with a quadrature discriminator. The C/N is that in the receiver IF amplifier. All work is on first iteration laboratory breadboards.

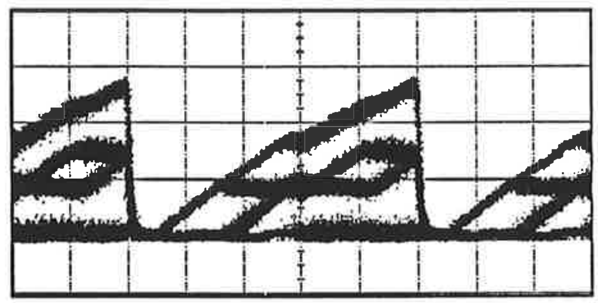

Figure 13 Detector Eye Pattern for Adequate Near-threshold C/N. (21.5 dB)

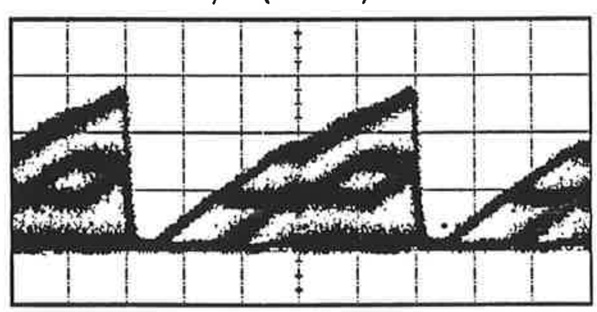

Figure 14 Detector Eye Pattern for Near Inadequate C/N. (20.5 dB)

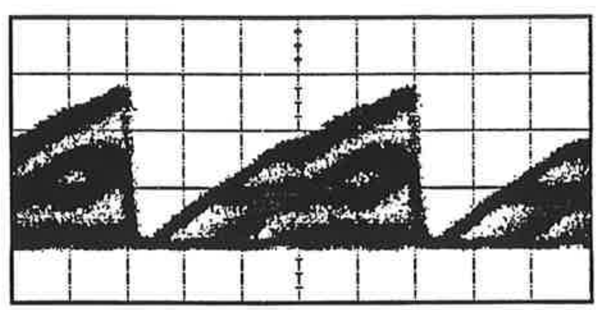

Figure 15 Detector Eye Pattern with Unusable C/N but Clock Lock Retained. (19.5 dB)