BITS AND POTS TOGETHER

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BITS and POTS Together

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ABSTRACT

The generic telephone system is known as POTS, Plain Old Telephone Service. The system includes an analogue instrument at the subscribers location, a twisted pair of wires connecting this instrument to the central office, and equipment in the central office that transmits and receives analogue signals to and from the subscribers instrument. All the POTS functions are performed in the frequency band from 0 Hertz to 4000 Hertz.

An inexpensive encoding and decoding scheme for binary data (BITS) is described which allows the BITS to be transmitted over the same twisted pair of wires that are used for POTS without affecting the POTS performance, and without being affected by the POTS signals.

• BITS NOT INTERFERING WITH POTS

POTS places voltages on the twisted pair of wires connecting the subscribers to the central office which have amplitudes in the tens of volts, e.g. the battery voltage and the ring voltage, and voice signals in the tens to hundreds of millivolts. All the voltages are within the 0 Hertz to 4000 Hertz frequency band [1, 2].

The twisted pair of wires can transmit frequencies much greater than 4000 Hertz provided the distance is not too great. The measurements in this report were all done at 500,000 bits/second over a 12,000 foot length of 24 gage copper wire, BELDEN 1227A, terminated in 100 ohms. Most Internet users would probably find 500,000 bits/second more than adequate, and while 12,000 feet is not adequate for all subscribers, it is adequate for a substantial portion of the subscribers. A tradeoff can be made between bit rate and subscriber loop length, i.e.

$(\text{bit rate})^{1/2}$ times (subscriber loop length) is constant.

The measurements made in this study should be representative of the following bit rate and line length combinations

250 kilobits per second	17,000 feet
500 kilobits per second	12,000 feet
1.5 Megabits per second	7,000 feet
10 Megabits per second	2,700 feet
25 Megabits per second	1,700 feet
50 Megabits per second	1,200 feet
150 Megabits per second	700 feet

Since POTS is well-defined and ubiquitous, the encoding of the binary data should produce no signals on the twisted pair which would affect the POTS. Since the ear responds to low sound levels, the encoding should produce very low levels in the POTS sound band. The signals in this sound band are those which pass through a C-message filter.

A common encoding of binary data is Alternate Mark Inversion Return to Zero (AMI-RZ), with 50% duty cycle. An alternate encoding not described in the literature is Alternate Mark Inversion Biphase (AMI-Biphase) [3, 4]. The input to the 12,000 foot loop and the output of the 12,000 foot loop are shown in Figures 1, 2 and 3 for different bit patterns. The AMI-RZ is on the top, and the AMI-Biphase is on the bottom for each bit pattern. It is obvious that the AMI-Biphase has less distortion and less intersymbol interference than the AMI-RZ. If the data is a pseudo-random sequence of $2^{15} - 1$ bits, the measured values of the output of a C-message filter for the transmitted waveform are

2 µsec AMI-RZ	21 dBrn
2 µsec AMI-Biphase	19 dBrn
4 µsec 4 level	74 dBrn

No additional filtering is necessary for the AMI-RZ and the AMI-Biphase encoding to prevent interference with the POTS.

- ## POTS NOT INTERFERING WITH BITS

The binary data is usually recovered from the received waveform by observing the amplitude at appropriate evenly spaced time intervals. This requires deriving a receive clock signal, and establishing cut or decision levels to determine the received bit. An alternate method for AMI-Biphase is to determine the time interval between successive peaks, which alternate in polarity. If the time interval is one bit interval, the bit is a one. If the bit interval is N bit intervals ($N > 1$), then the bits are $N - 1$ zeros followed by a one.

The time the peak occurs is determined by the derivative passing through zero. This is independent of the amplitude of the waveform. Errors caused by noise are proportional to the derivative of the noise, which is proportional to the amplitude and frequency of the noise. For 500 Kilobits/second, the signal frequency is 250 kilohertz. This is over 60 times the POTS signal band of 4 kilohertz, and gives the time interval decoding more than 35 dB noise advantage over the usual amplitude decoding in the BITS and POTS TOGETHER application.

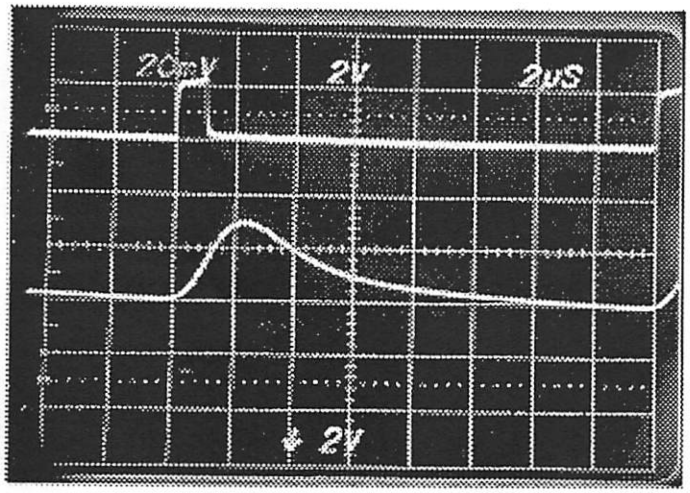
A sequence of N zeros can be transmitted as a sequence of $N - 1$ MARKS using a clock delayed one-half bit interval from the normal clock. This is called stuffing. It makes the interval between peaks 1 or 1.5 or 2 bit intervals and simplifies the clock recovery. Figure 4 illustrates this enhancement.

• SUMMARY

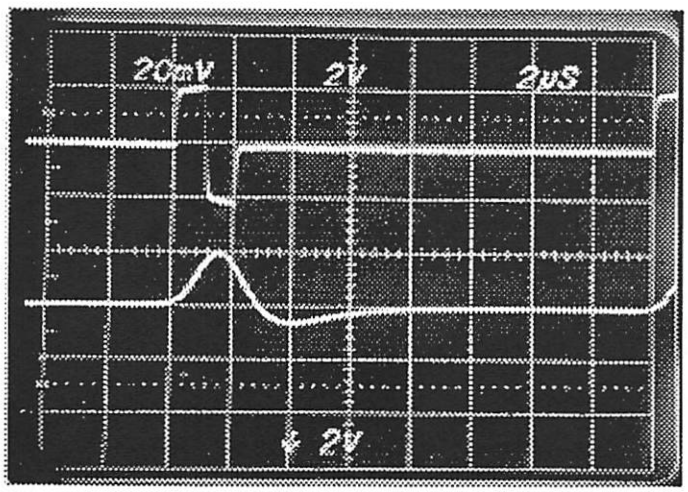
Three techniques useful for implementing BITS and POTS together are:

1. Alternate Mark Inversion - Biphase encoding of the data.
2. Decoding the data from the timing of the peaks of the received waveform.
3. Stuffing marks into the transmitted data with a delayed clock for sequences of zeros.

The combination of these techniques makes the design, implementation, and installation of binary data links on existing POTS installations simple and inexpensive.



RZ

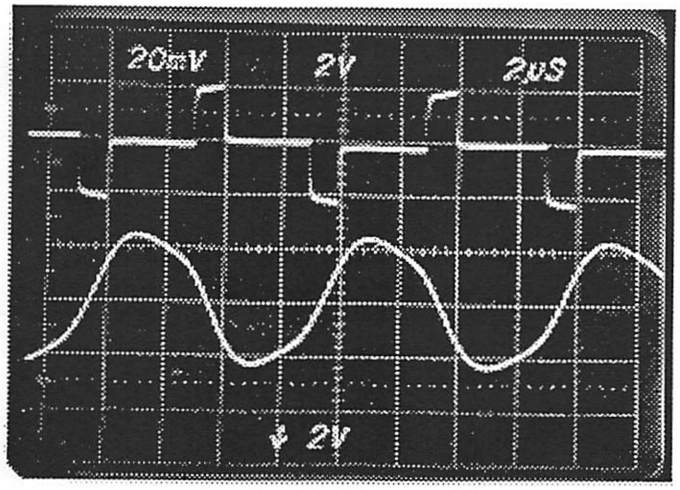


Biphase

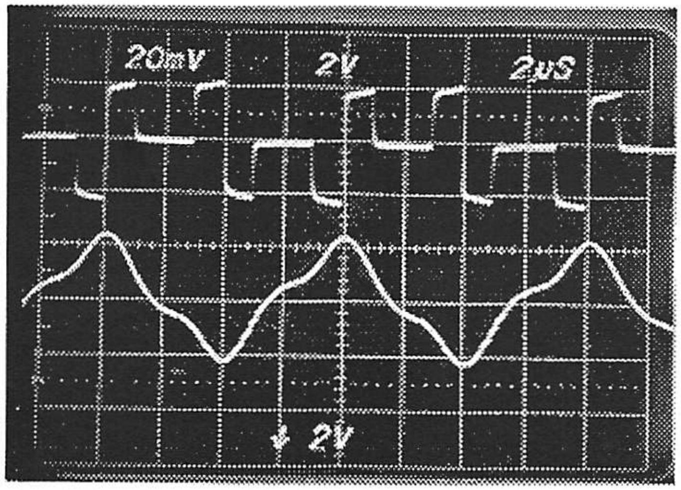
Single ONE

Top trace	Differential input to line	2 Volts/div
Bottom trace	Differential output of line	20 mVolts/div
Horizontal	2 microseconds/div	

FIGURE 1



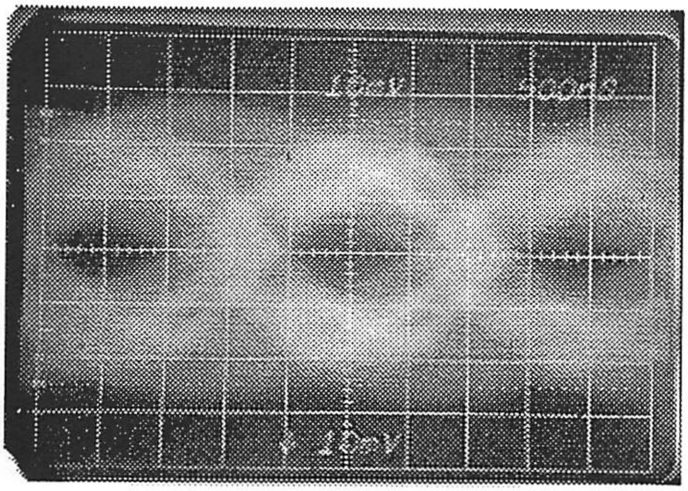
RZ



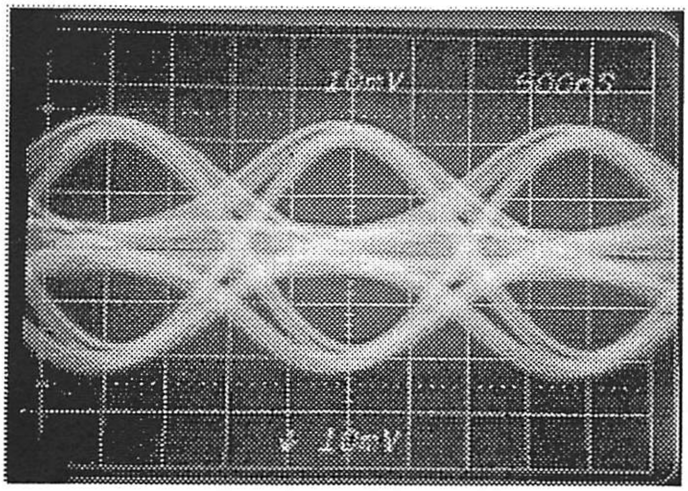
Biphase

Alternating	ONE-ZERO	
Top trace	Differential input to line	2 Volts/div
Bottom trace	Differential output of line	20 mVolts/div
Horizontal	2 microseconds/div	

FIGURE 2



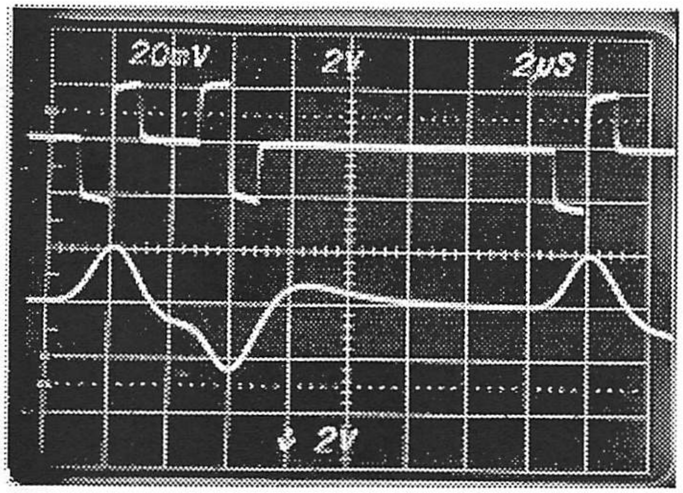
AMI-RZ



AMI-Biphase

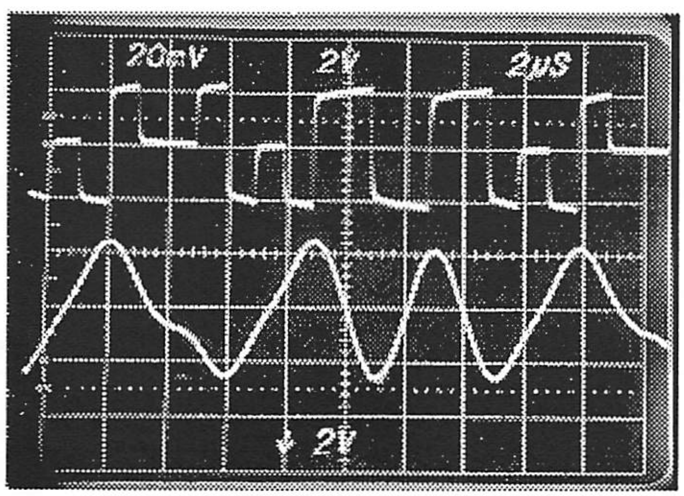
EYE Patterns for $2^{15} - 1$ Pseudo Random Sequence
10 mVolt/div   vertical
500 nanosecond/div horizontal

FIGURE 3



AMI-Biphase

Not Stuffed



AMI-Biphase

Stuffed

Data Bit Pattern	1 0 1 0 0 0 0 0 repeated	
Top trace	Differential input to line	2 Volts/div
Bottom trace	Differential output of line	20 mVolts/div
Horizontal	2 microseconds/div	

FIGURE 4

• REFERENCES

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[3] A. Lee and D. G. Messerchmitt, *Digital Communication*, Chap. 12, "Spectrum Control," Kluwer Academic Publishers, 1994.

[4] D. R. Smith, *Digital Transmission Systems*, Chap. 5, "Baseband Transmission," Van Nostrand Reinhold Co., NY, 1985