HIGH-SPEED DATA TRANSMISSION ON TELEPHONE WIRES

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Memorandum No. UCB/ERL M89/24

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COVER PAGE

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ABSTRACT

The transmission properties of copper wire are very stable. System design for local baseband data communications can exploit that stability to reduce complexity and cost and improve performance. A non-return-to-zero coding scheme is proposed for data transmission over twisted pair copper. Two low-cost detection methods are proposed and results are discussed.

I. CURRENT ENCODING METHODS

Manchester encoding is used pervasively in data transmission systems today. Manchester encoding uses a voltage change on each bit to produce a signal that carries timing and provides carrier sense on each bit, and has no DC component.

The inclusion of timing and carrier presence on each bit had its origins in the use of media whose speed varied with time, such as magnetic tape, for data storage and transmission. Because of the variation in the speed of the tape drive, timing was a critical element of the encoding. The equipment used to transmit data recorded in magnetic tape form also could not transmit DC.

In contrast to some other media, the transmission characteristics of wire are highly stable and known. With a wire-based transmission system, clock need not be included on each bit. There is also no inherent reason why a DC component should not be included in a wire-based coding method for data transmission.

II. DISADVANTAGES OF CURRENT ENCODING METHODS

While Manchester encoding is appropriate for communication applications that may have a variable timing element, such as magnetic tape or radio links, it has serious drawbacks for wire-based local data communications.

The primary disadvantage is its bandwidth inefficiency. Half the bandwidth is used for timing information, which is not necessary in a stable system. Only half the Nyquist rate is attained. The higher frequency requirement needlessly increases the cost and complexity of local data transport.

III. PROPOSAL

This paper proposes the use of a non-return-to-zero (NRZ) coding scheme for local data transmission over twisted copper pairs. One bit per N bits is used as needed for carrier sense and clock. This could be 1 bit/8 bits for a byte-oriented system, or 2 bits/8 bits in the usual asynchronous transmission (one start bit and one stop bit). In either case, the efficiency gain over Manchester's high overhead ratio is significant.

Rather than looking for discrete signal levels on each bit, the proposed coding system looks for the presence or absence of a change in the derivative of the voltage. This is accomplished using one of two techniques.

A. Secant Method

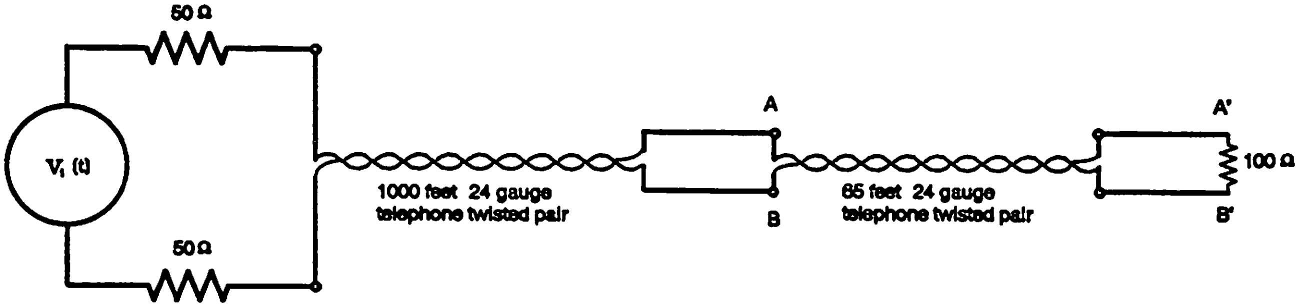
The secant method gives the best possible noise immunity. It looks for a change from + to - or - to + using a linear circuit to determine a finite time (one bit interval) approximation of the derivative.

This is an old technique, used in nuclear instrumentation as far back as the 1940's and referred to as "delay line differentiation." If the signal used is:

$$V_t - kV_{t-t_b}$$

the k can be chosen to remove the effect of an exponential decay in the waveform.

The waveform shown in Figure A is a received signal with no differentiation. The waveform shown in Figure B uses the following secant differentiation circuit:



$$V_o = V_{AB} - \frac{1}{2} V_{A'B'}$$

Circuit 1: Secant Differentiation

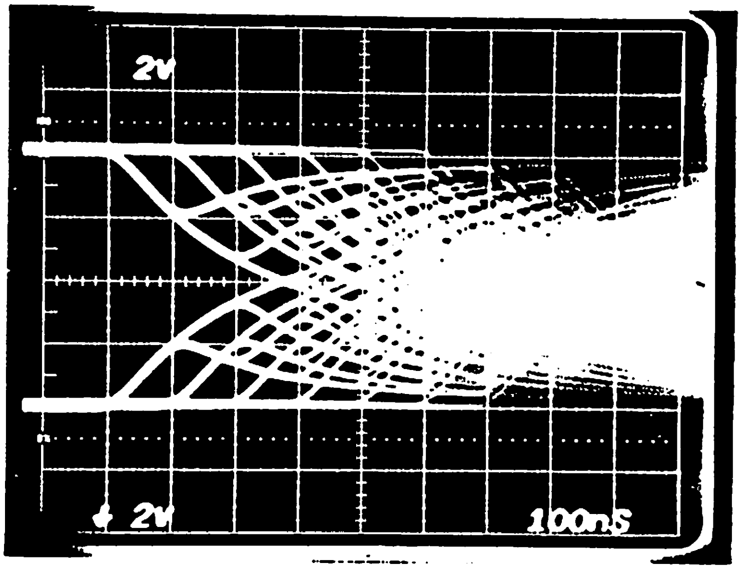


Figure A: Received Signal--No Differentiation

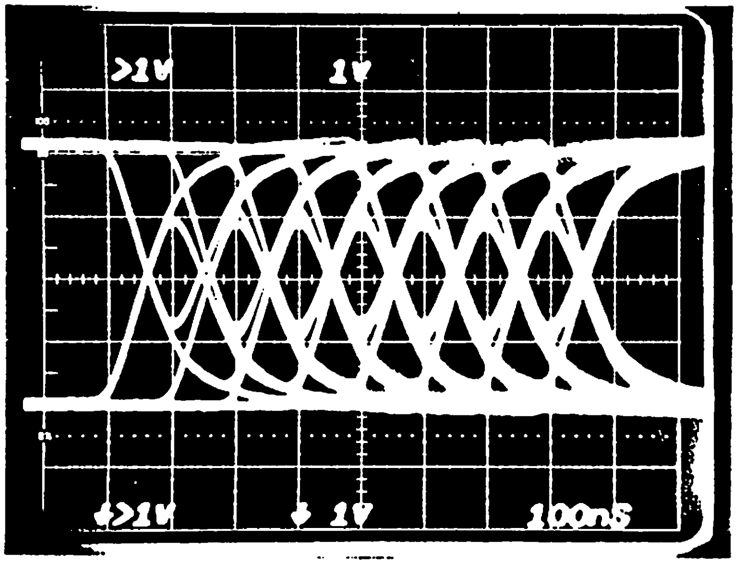
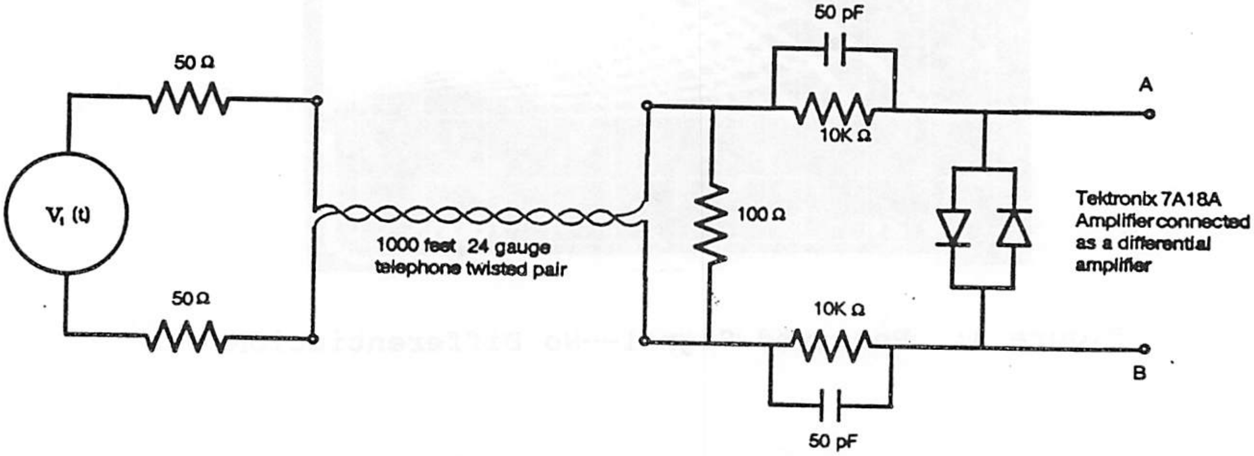


Figure B: Secant Differentiation

B. Nonlinear Derivative Method

The second method measures the occurrence of maxima and minima by looking for a change in the nonlinear derivative of the received waveform obtained with a capacitor diode circuit. If the nonlinear derivative is positive or zero, the circuit looks for the onset of a decrease greater than some threshold, and vice versa. The occurrence of a maximum or minimum indicates a shift in the direction of the output. This method works at any distance, so long as the signal is large enough for the diodes to operate in a nonlinear mode.

The waveform shown in Figure C is a received signal using the following capacitor diode circuit. The diodes are Schottky diodes:



Circuit 2: Nonlinear Differentiation

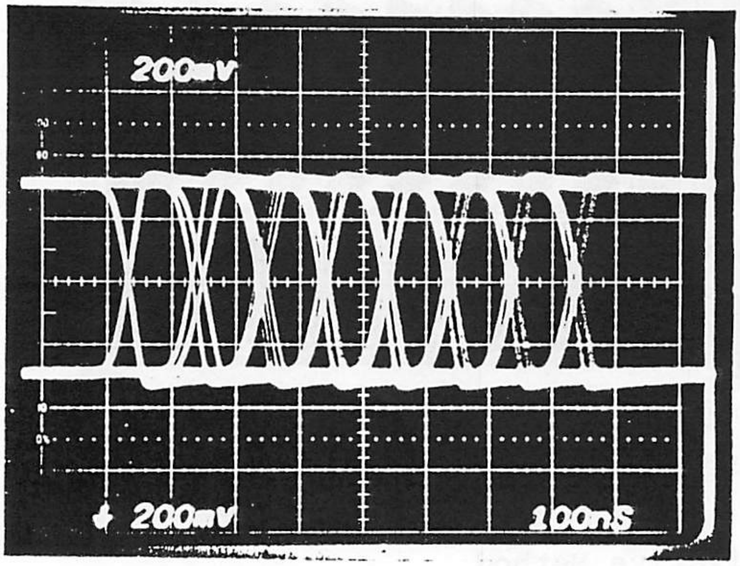


Figure C: Nonlinear Differentiation

IV. RESULTS

The normal eye pattern is a superposition of all possible waveforms over one bit interval, with the time axis the same for all the waveforms. It is usually observed by using random or pseudorandom bit sequences as inputs, and synchronizing the time base to the bit clock.

The eye patterns shown here are somewhat different. They show the seven one-bit intervals between eight bits of data. The eight bits are all possible eight-bit combinations, and they begin following a string of zeros or ones long enough for the steady state condition to be reached. The seventh eye is thus essentially the same as would be observed for a 2^8-1 pseudorandom bit sequence.

It is interesting to observe that the opening of the first eye is the same as the opening of the seventh eye, and is displayed in a much clearer way. This will be true if the following conditions are met:

1. It is a two-level system.
2. It is a linear system.
3. The response to a step input, $V_i(t)$

   has $\frac{d[V_o(t)]}{dt} > 0$,

   and $\frac{d^2[V_o(t)]}{dt^2} < 0$

   after the first bit interval.

This is shown in Figure D for the received signal of 5 MHz NRZ transmitted through 500 feet of 24 gauge telephone twisted pair. The received signal has an open eye without any differentiation.

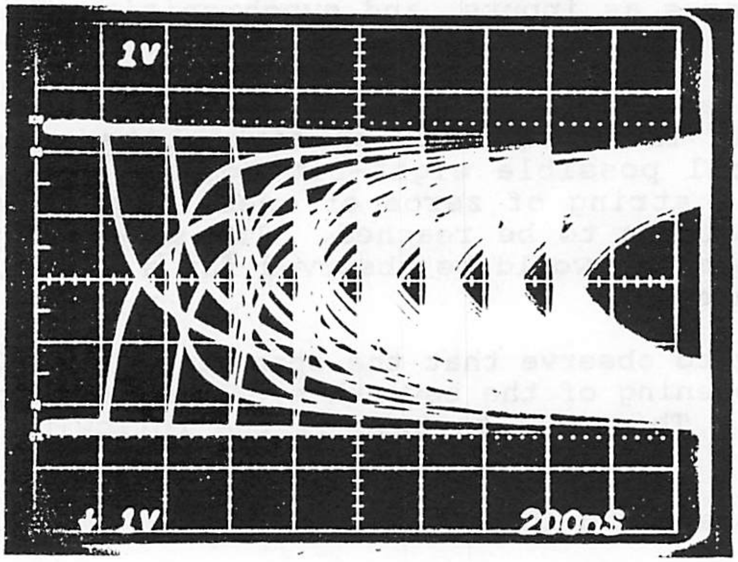


Figure D: 5 MHz NRZ Over 500' 24 Gauge Telephone Wire

The circuit design is straightforward for both detection methods. In the secant method, the time interval is one bit interval. The major cost of the secant design is in achieving this analog time delay. In the nonlinear derivative method, the design parameters are the amplitude of the signal compared to the forward conduction voltage of the diode, and the ratio of the time constant of the coupling capacitance and the line impedance to the bit interval. The circuit cost is very low, involving little more than the two diodes and single capacitor, and the circuit need not be tailored for a specific distance. This flexibility is highly advantageous given the dynamic nature of many local data communications installations.

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