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November 21, 1967

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Berkeley, California

### Abstract

A technique is described for transmitting computer data over twisted-pair telephone lines at a rate limited only by the round-trip propagation delay.

The LINK method of signal generation and detection is presented along with a discussion of the effects of telephone line distortion, attenuation, and noise.

### Introduction

The Data Link system has been developed to transmit data from building to building at LRL Berkeley over telephone lines on the order of 1 mile long. The Data Link should not be confused with systems that use telephone lines to transmit data over long distances. Long telephone lines have a bandwidth of about 3kHz, which limits the rate of transmission to about  $1.2 \times 10^3$  bits per second. The noise on long telephone lines causes about one error per  $10^5$  bits.

The Data Link will transmit data between any of the several experimental areas at LRL and the computer center in Building 50B. The first line to be used runs from the 184-inch cyclotron to Building 50B, a distance of 4,000 feet. I will hereafter refer to this line as the cyclotron line. On the cyclotron line the rate of transmission is  $8 \times 10^4$  words per second or about  $10^6$  bits per second. The present raw error rate is about one error per  $10^7$  words, but even this low rate should be reduced several orders of magnitude by the Data Link error-detection and correction system described by Sypko W. Andraea and Robert W. Lafore in previous papers.<sup>1</sup>

The Data Link at present is a full-duplex system using 34 "voice quality" twisted-pair telephone lines. Twenty-six lines are used for transmission of 13-bit words<sup>2</sup> and eight lines are used for transmission of control signals. At this writing, the hardware for the system has been built and debugging is just beginning. The first experiment to use the Data Link is scheduled to receive beam in the 184-inch cyclotron in January 1968.

### Transmission

Data are transmitted in the form of bipolar pulses. The arrival of a pulse indicates a logic "1" and the absence of a pulse indicates a logic "0." Since the Data Link uses complete handshaking, the period between pulses is equal to the round-trip propagation time. The 4,000-foot cyclotron line has a period of 12.5 microseconds.<sup>3</sup> A 3- $\mu$ sec bipolar pulse is used on this line. The attenuation factor of 4 allows the use of a simple integrated circuit transmitter. The 9.5  $\mu$ sec between the end of one pulse and the start of another is just long enough to allow base-line recovery at the receiver. A preliminary study of telephone lines both longer and shorter than the cyclotron line indicates that a bipolar pulse can always be found which is wide enough to keep the attenuation factor near 4 and yet narrow enough to allow base-line recovery between pulses. The correct ratio between pulse width and period between pulses appears to be approximately  $1/4$ .

Two monostable multivibrators control the width of the positive and negative areas of the bipolar pulses for all the 13 transmitters. Each transmitter consists of two power nand integrated circuit gates which drive two transistors connected in a push-pull configuration to produce a bipolar pulse in the secondary of the output transformer. An oscilloscope picture of a transmitter output pulse is shown in Figure 1.

The signal is filtered as it travels along the phone line. The high-frequency components are reduced more than the low-frequency components. The resultant waveform at the receiver is made up of only the

lowest-frequency components and closely resembles one period of a sine wave. See Figure 2.

Detection

Our telephone lines lie in underground ducts paralleling other lines for thousands of feet. These other lines are constantly producing noise. Most of the noise is of low frequency and is of no particular concern; but some high-frequency noise (e. g., switching transients) is produced. The cyclotron line, after entering the cyclotron building, runs in a wire-trough several hundred feet to the experimental area. Here the line is subjected to noise produced by spark chambers and other apparatus as well as the rf field of the cyclotron itself.

The noise on the cyclotron line occurs rarely enough, however, to make direct observation and photography of oscilloscope displays of the errors extremely difficult. No reliable photographs of telephone line noise were taken before the signal detection system had been designed. As a result we were overcautious. With the impression that the background might include noise of about the same frequency and amplitude as the data pulses, we at first envisioned using detectors with multiple height and time windows.

For purposes of testing and gathering data on noise, we designed several simpler detectors, one of which required the positive-going portion of the bipolar pulse to pass through a height window much like a single-channel analyzer. A detector of this type was constructed. The first hour it was connected to one of the cyclotron lines, it detected 300 counts due to noise. After a few days of tuning and debugging, the noise count was down to less than 100 per hour.

This low error rate encouraged us to make a full-scale test of the transmitter-receiver system using the height-window method on the cyclotron phone lines. The technique used for testing required all 26 transmitters and 26 receivers of the actual system. It is shown schematically in Figure 3, and is described more fully in the Test Program section.

This test demonstrated that many more error words were caused by the failure to detect the desired signals than by the detection of unwanted noise. Even with our already weakened detection requirements, we were still being too strict. The present system, which requires only that the positive amplitude be greater than a given threshold,

was then designed. The round-trip error rate when this system is used on the cyclotron line is about one error per  $10^7$  words.

Control Signals

In a previous paper by Robert W. Lafore, control or "fuzzy"<sup>4</sup> signals were mentioned in connection with conversation format, general reset, and the error detection and correction system. In all, eight fuzzy signals are used--five by the Device Synchronizer and three by the Channel Synchronizer.

The failure of any of the many control signals sent in each conversation would cause a system abort. The control signals must therefore never fail. This is, perhaps surprisingly, not difficult to approach in practice. Our technique at present is to send a train of square waves 16 cycles long. (The same types of transmitters and receivers are used for both the data and control signals.) The output of each control signal receiver goes to an analog device which essentially counts the number of cycles. Approximately 5 out of the 16 cycles must arrive for the control signal to be detected.

More than  $10^{11}$  control signals have been transmitted without failure (i. e., both without failing to detect a signal and without triggering on noise). Since this figure is several orders of magnitude larger than the total number of control signals likely to be sent during the lifetime of the Data Link, the possibility of even one failure appears remote.

Test Program

A block diagram of the test system is shown in Figure 3. A 12-bit word is generated by the computer, sent to the test rig, and transmitted over phone lines to the cyclotron. There the word is detected and retransmitted back to the test rig in Building 50B. After detection, the word received is sent to the computer for comparison with the original word. Words may be chosen by the PDP-5 on any basis: random numbers, all sevens, all zeros, all but one bit up, all but one bit down, etc.

The test rig was very effective in locating problems during development. The transmitters, receivers, and associated registers and logic went through considerable evolution before the present design was adopted. Each change was dictated by test results and then checked for effect. The PDP-5 had one drawback, however; it was not fast enough to send words at the maximum rate the Data Link could sustain (12.5  $\mu$ sec). The fastest PDP-5 program we used

sent words every 150  $\mu$ sec.

In order to investigate the behavior of the Data Link at the maximum rate, the PDP-5 was replaced with a hardware device. The word to be sent was chosen by a switch register. The word returning after a round trip was stored in a register and compared with the switch register with exclusive-or gates. Regardless of the outcome of the comparison, the switch register word was immediately retransmitted, thus maintaining the 12.5- $\mu$ sec rate. Each time the comparison failed, a count was stored in a scaler. At a fixed period of time after an error was detected, the contents of the scaler were printed out on a typewriter and the scaler was reset. By varying the time from error detection to scaler readout, a crude idea of the noise pattern could be obtained.

#### Error Rate

The following is a summary of the findings of the test program:

(a) The errors usually occur in bursts with a particular time pattern (i. e. , one or two errors followed by eight to ten correct transmissions followed by one or two errors, etc. ).

(b) As might be expected, errors are more probable during the day than at night, and are more probable during the week than on weekends.

(c) During an 8-hour working day, the raw error rate averages about one error in  $10^7$  words.

It should be emphasized that the above describes the error rate of the transmission system only. The error rate of the entire Data Link system (after automatic error correction) is expected to be reduced several

orders of magnitude below one error per  $10^7$  words.

#### Footnotes and References

\* Work done under the auspices of the U. S. Atomic Energy Commission.

1. Sypko W. Andreae, A Computer Data Link for High-Energy Physics Experiments, this Symposium;

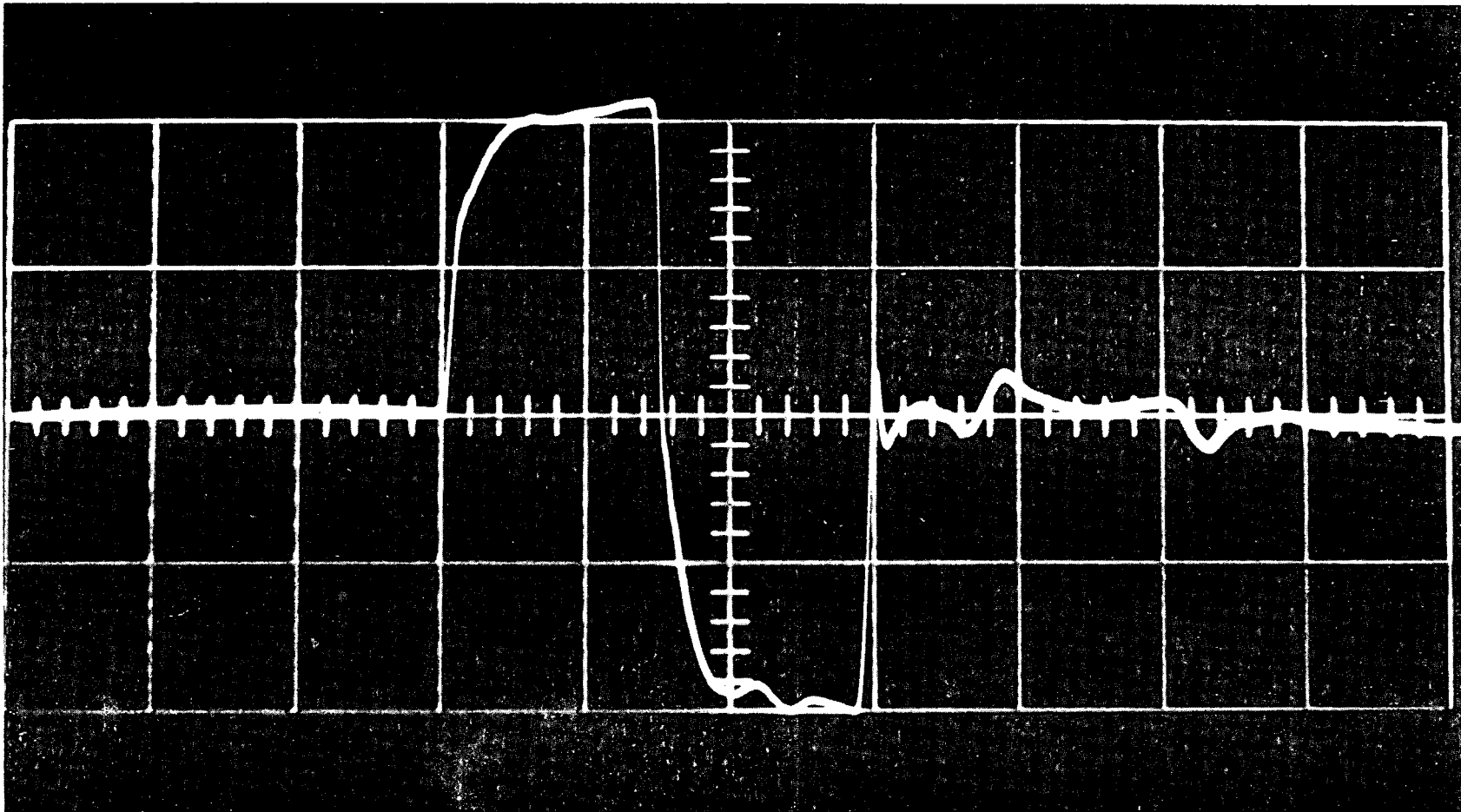
Robert W. Lafore, Error Checking and Other Aspects of Data-Link Organization, this Symposium.

2. Data Link accepts and delivers 12-bit words, but within the system a 13th bit is transmitted with data words to distinguish them from status and function words.

Status and function words are described in a previous paper by Robert W. Lafore.

3. Because the telephone lines twist not only on themselves but also about other wires in the cable to form double helixes, more than one foot of line is contained in a linear foot of cable. We find the propagation velocity to be nearly 1.6 nsec per linear foot of cable, or about 12.5  $\mu$ sec for the cyclotron line.

4. Many of the bugs of the Data Link system were discovered and ironed out by using a large "gameboard"--a block diagram representation of the buffers and their interconnections drawn on a piece of cardboard. Data, function, and status words were represented by small cards and were moved from register to register to simulate the action of the actual system. When control signals first made their appearance on the gameboard, they were represented by ordinary signals. In our haste to see how the system would work with control signals, the wave trains were drawn on the cards before the background was completely dry. The black ink leached into the yellow. The wave train looked fuzzy. The name stuck.

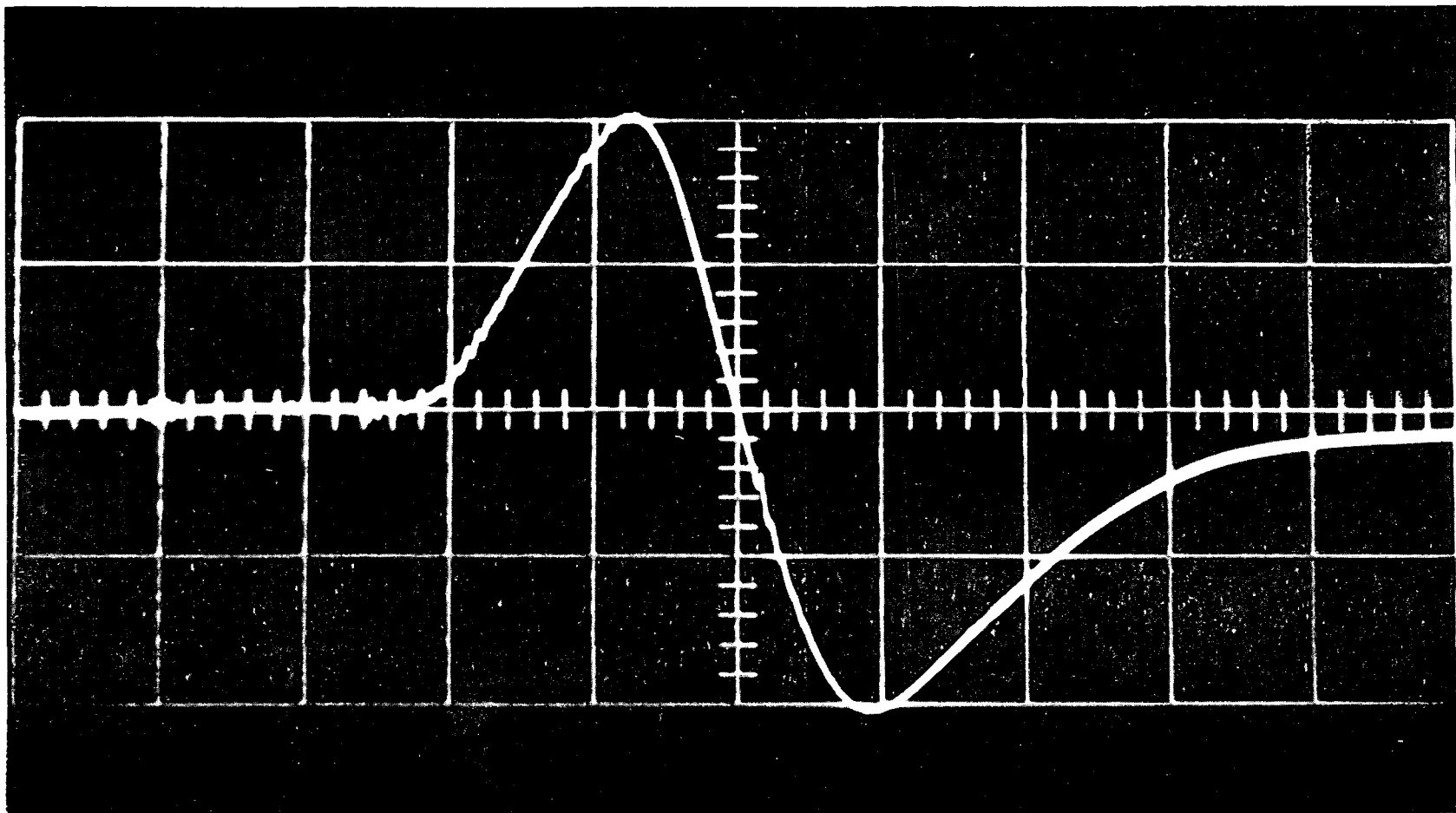


Transmitted Pulse  
4 V/cm      1 microsec/cm

XBB 6710-6191

Fig. 1. Transmitted pulse.





**Received Pulse**  
**500 mV/cm      1 microsec/cm**

XBB 6710-6192

Fig. 2. Received pulse.

# TEST RIG LRL DATA LINK

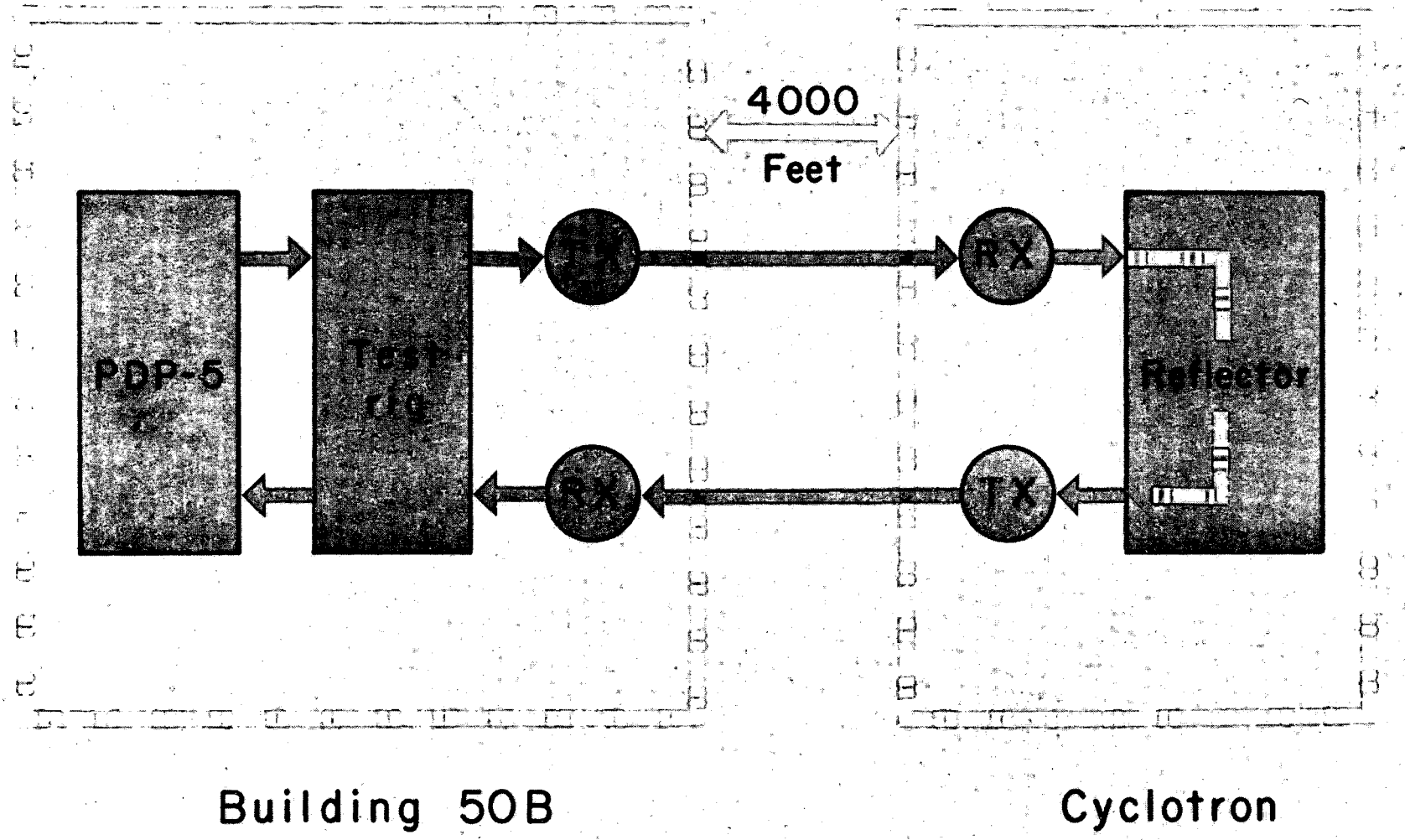


Fig. 3. Test rig.

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