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IBM 2790 Digital Transmission Loop*

Abstract: A tandem connection of terminals for a data collection system has certain desirable advantages over the more common radial configuration. To make use of these advantages, high-speed transmission links are required. This paper describes the transmission capability necessary for a high-speed digital data repeater when it is restricted to an in-house environment. The transmission techniques discussed are implemented in the IBM 2790 Data Communication System.

Introduction

The pulse-transmission approach used in the IBM 2790 Data Communication System evolved from a need for a data collection system that could service a large number of in-house locations. This could best be done by arranging all terminals in a series connection, the major control function being performed at one central location.[1] The transmission loop to be described is unique because it is designed specifically for high-speed pulse transmission in an in-house environment.

The major transmission objectives for the IBM 2790 Data Communication System were:

1) Use of two-wire transmission lines to connect all terminals.
2) Data rates up to 500 kbit/sec.
3) Maximum terminal spacing of 1000 ft.
4) Use of up to 100 tandem terminals per system.
5) Low cost repeaters having no sophisticated components.
6) A digital interface located at each repeater location.
7) Provision of redundant powering along the transmission line.
8) A system error rate lower than 10^{-7} error/bit.
9) No field adjustment required during installation or operation.

With these objectives in view a search was made for an existing technology that could be used. The Bell System's T1 Carrier System[2-4] uses pulse-code modulation techniques to span up to 6000 feet between repeaters with a bit rate of 1.544 M bit/sec. A similar IBM La Gaude design is presently used to transmit digital data between two Paris bank locations. Although these designs meet most of the objectives, they are more sophisticated than would be required for an in-house system. The objective of this paper is to describe the design that was implemented in the IBM 2790 system.

Figure 1 shows the system configuration. Note that the serial chain of terminals has been divided into four segments so that a "fail-soft" capability is provided in the event of a wire or repeater failure. The transmission links shown are twisted pairs that can be provided by the common carrier or installed by electrical contractors at a reasonable cost. The following sections will describe signal specifications and repeater features.

Signal specifications

• *Bit rate*

In order to provide the necessary system throughput and to provide for future system expansion, a transmission rate of approximately 500 kbit/sec is required. Since crossing public lines is usually an important consideration in any data transmission system, 514.67 kbits/sec was chosen for the data rate. Because this is one-third the T1 carrier data rate, the possibility for a compatible system does exist.

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* Based on a paper presented at the IEEE International Conference on Communications, San Francisco, California, June 8–10, 1970.

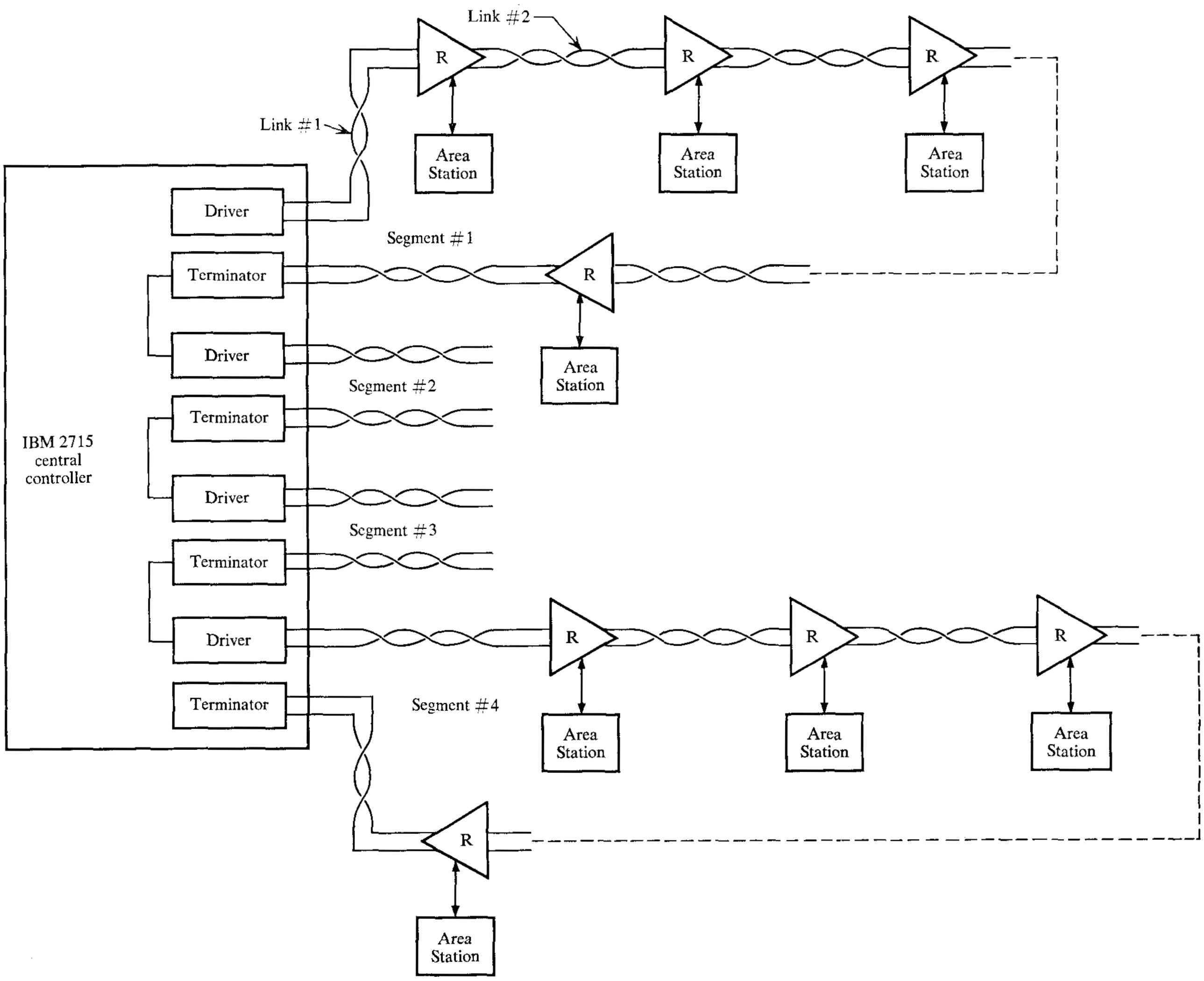


Figure 1 Configuration of the transmission loop system.

• *Line signal coding*

The signal coding scheme selected is shown in Fig. 2. A convenient feature of this coding method is that it does not suffer from phase ambiguity. The rise and fall times for each pulse are equal to or less than 100 nsec, so that both pulses occupy approximately one-half of a bit interval. Transitions occur on the transmission line during every bit interval. This feature provides the distinct advantage of making clock recovery relatively easy, since long strings of ONES and ZEROS without transitions are never present. The requirement for a high-Q tank circuit, with its associated disadvantages, is thus eliminated.

The second pulse in each bit cell is used to remove the dc component from the signal. This arrangement suffers the disadvantage of requiring additional logic in the terminator to remove the second pulse. This disadvantage is outweighed by the simplified detection permitted by utilizing the second pulse of each bit time.

The pulse amplitude of ± 3 V peak was again chosen for T1 compatibility; however, a small departure from compatibility was made when the transmission coding and pulse widths were selected, as required by the simplified detection and clock recovery methods. The departure from T1 compatibility was so small that a subsequent minor modification to the IBM 2790 Repeater allows full compatibility.

Repeater features

• *Transmission cable*

Transmission between Area Stations and from the IBM 2715 Central Controller to Area Stations is via 100 ohm, twisted pair cable balanced to ground. The design of the

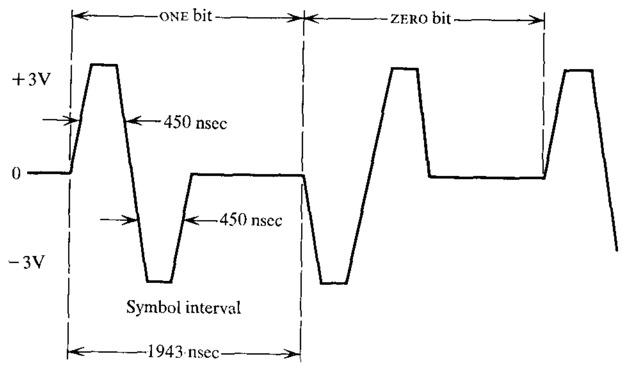


Figure 2 Transmission coding scheme.

repeater is based on the worst-case attenuation of 1000 ft of AWG #22 polyethylene twisted pair cable.[5] Many different types of cables can be used provided the attenuation at 1.0 mHz does not exceed 8.0 dB. For low-loss cable such as RG-130, the distance between repeaters can be extended up to 4500 ft.

• *Line terminator*

The terminator portion of the repeater serves a number of functions, including provision of a balanced input; impedance matching that terminates the transmission line in its characteristic impedance; common-mode noise rejection; and recovery of the line signal to a useful logic level. The basic terminator, along with key signals, is shown in Fig. 3.

The resistors R_{T0} and R_{T1} are selected to match the characteristic impedance of the transmission line, and the diodes D1 and D2 are disconnect diodes used to prevent loading of the transformer secondary by the detectors. The nominal threshold of the terminator [see Fig. 3(b)] is adjusted to 0.75 V, referenced to the line side of the receiving transformer. Since the 3-V peak line signal is attenuated approximately 6 dB by 1000 ft of AWG #22, there remains, at the terminator input, a 1.5-V peak signal to be detected. The noise margin on the line side of the RECEIVE transformer for zero signal is approximately 400 mV peak. The worst-case RECEIVE signal and the corresponding detector outputs are shown in Fig. 3. Both positive and negative portions of the line signal are recovered, and the terminator outputs are restored logic levels.

In order to reduce the high-frequency noise susceptibility of the line terminator, it is necessary to limit the detectors to a bandwidth of approximately 1.5 mHz. The receiving transformer should have a high common-mode rejection ratio over the bandwidth of the terminator. The high ratio insures that the detectors do not respond to signals that are coupled by the primary-to-secondary capacitance of the RECEIVE transformer.

Additional common-mode noise rejection is obtained by using ferrite cores on the transmission cable where it enters the repeater. Since the receiving transformer has a total turns ratio of 1:4, the line signal is doubled in half of the secondary. The 1:4 transformer was selected to provide signal-voltage amplification and also to reduce the dynamic range of the terminator threshold.

The ONE-ZERO decision is made by using two latches that are cross-coupled so that the setting of either latch inhibits the setting of the other until reset occurs. An *RC* time constant is used to bridge the gap shown in Fig. 3 that occurs between the first and second pulse of any bit interval. Because the clock used in the terminator portion of the repeater has no inertia, the difference in path delays through the logic for a ONE and a ZERO bit must be considered. This problem is addressed in the next section.

• *Repeater clock*

The clock can be derived from the OR of the ONE-ZERO latch outputs and is sufficient for a small number of series repeaters. However, this clock contains jitter that accumulates in proportion to the number of series repeaters. In order to link 100 terminals it was necessary to provide a more stable clock-recovery method. Because of the low Q required to recover the clock, a conventional flywheel clock was used. It is interesting to note that since pulses are present at every bit interval, the tank circuit Q is determined by the amount of jitter reduction required and not by the number of bit times to be spanned.

The amount of jitter accumulated through any one link can be attributed to any or all of the following three sources:

1) Difference in path delays through the logic,
2) failure of the transmission line to recover between bit times, and
3) noise.

The first item can be explained by referring to Fig. 3(a). The times t_1 and t_2 are the path delays incurred by a RECEIVE ONE and a RECEIVE ZERO bit, respectively. Since inertial clocking has not been used to recover the data, the difference in path delays through the terminator logic is a prime source of jitter. The failure of the transmission line to recover is shown in Fig. 3(b). This is a source of jitter because of the early pulse detection when polarities are changed. This jitter source could have been improved by increasing the bit time or decreasing the pulse widths. However, the T1 compatible bit rate and the simplified detectors prevented this. White noise levels of -30 dBm contribute only about ± 5 nsec of jitter to any link.

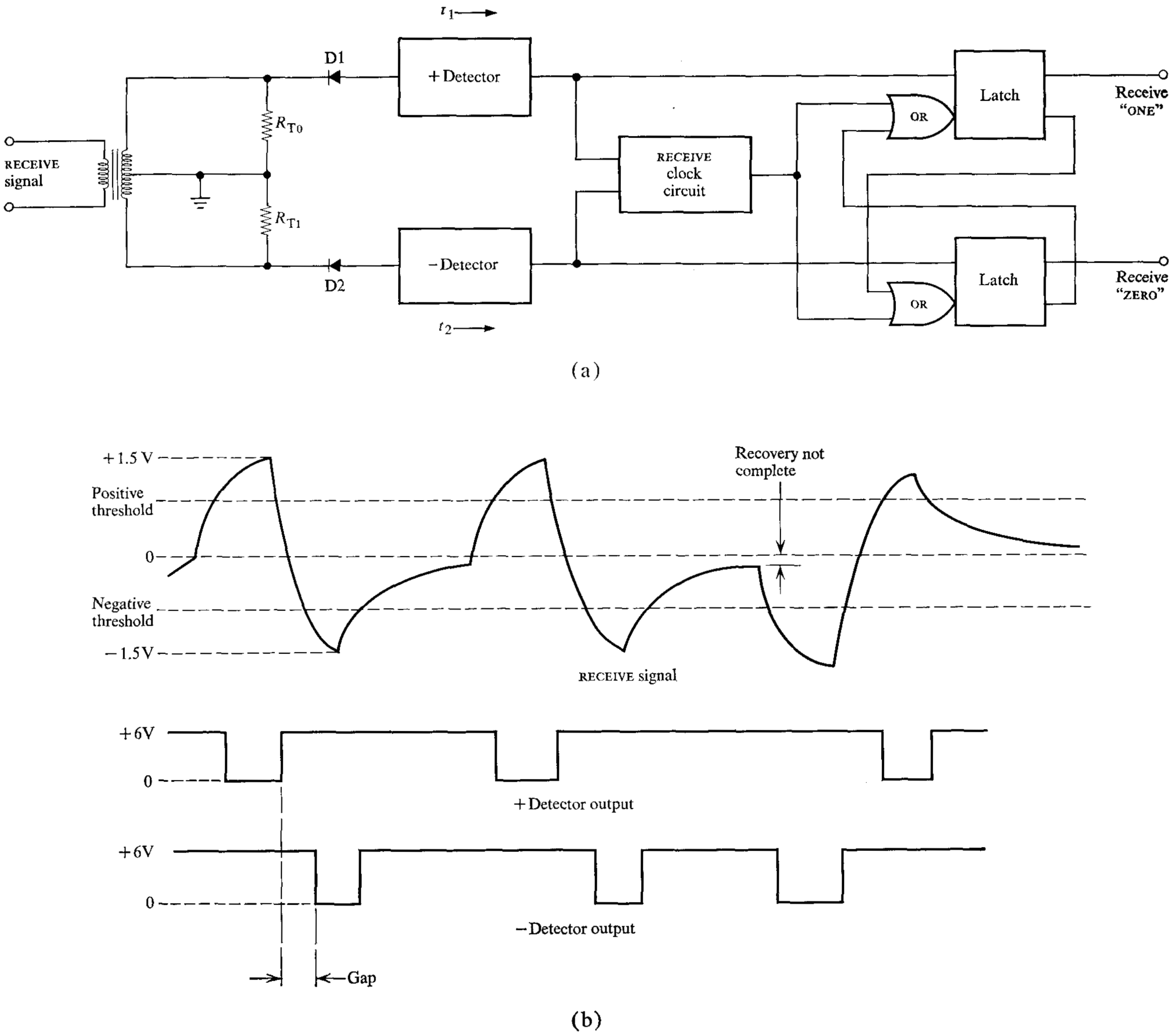


Figure 3 (a) The basic line terminator. (b) Key signals.

This jitter is negligible compared to the contributions of the other sources, which can amount to ±95 nsec.

In order for jitter for each link to be noncumulative, the expression $r = (r + J_a)/F$ must be satisfied. Solving for F,

$$F = 1 + (J_a)/r,$$

where

J_a is the maximum systematic jitter accumulated through the line driver, transmission line and terminator, assuming an initial jitter of r,
r is the residual jitter allowed after clocking, and
F is the jitter reduction factor.

Plots of the jitter reduction factor vs the accumulated jitter for a constant residual jitter are shown in Fig. 4(a). Measurements indicate that the maximum accumulated jitter (J_a) is 100 nsec for any one link in the system. Thus, allowing 40 nsec of residual jitter requires a minimum F of 3.5 to insure that jitter does not accumulate through the system. Tests were performed to relate the tank circuit Q to the jitter reduction and the results are shown in Fig. 4(b).

It can be seen from Fig. 4(b) that the value of the tank circuit Q must be approximately 7 to obtain the desired jitter reduction of 3.5. Although the tank-circuit phase shift is an important consideration, the low Q requirement and the use of 1% components in the tank circuit limited the phase shift to an acceptable level.

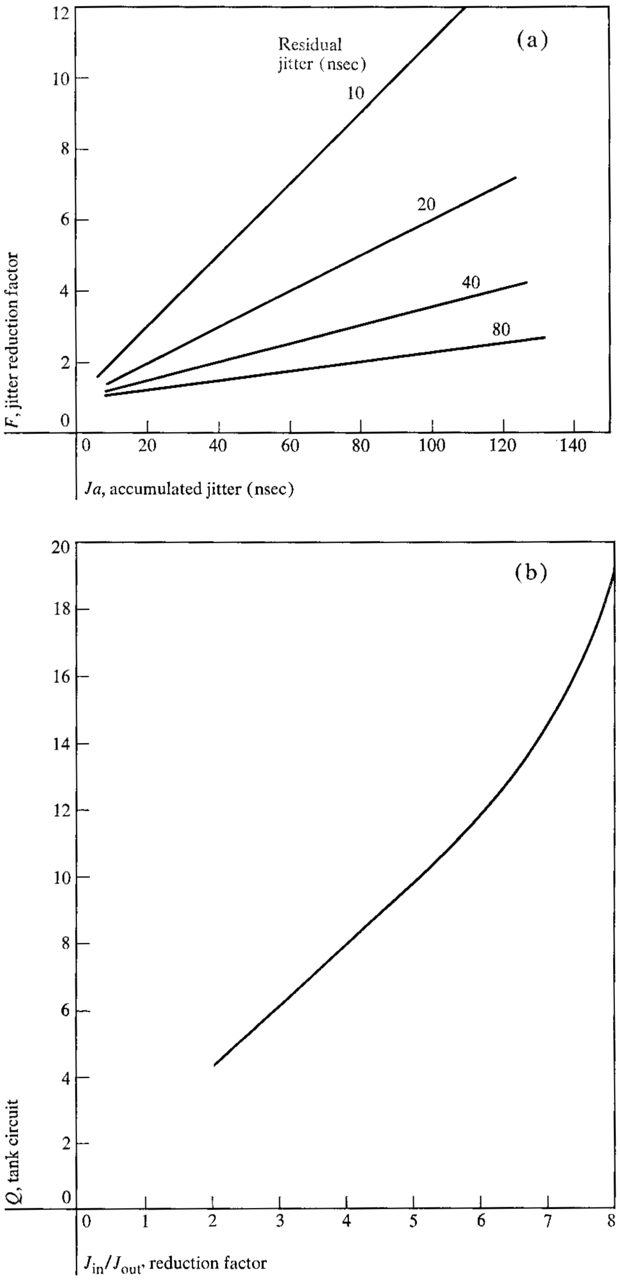


Figure 4 (a) Relation between jitter reduction factor and accumulated jitter for several values of constant residual jitter. (b) Relation between tank circuit Q and jitter reduction.

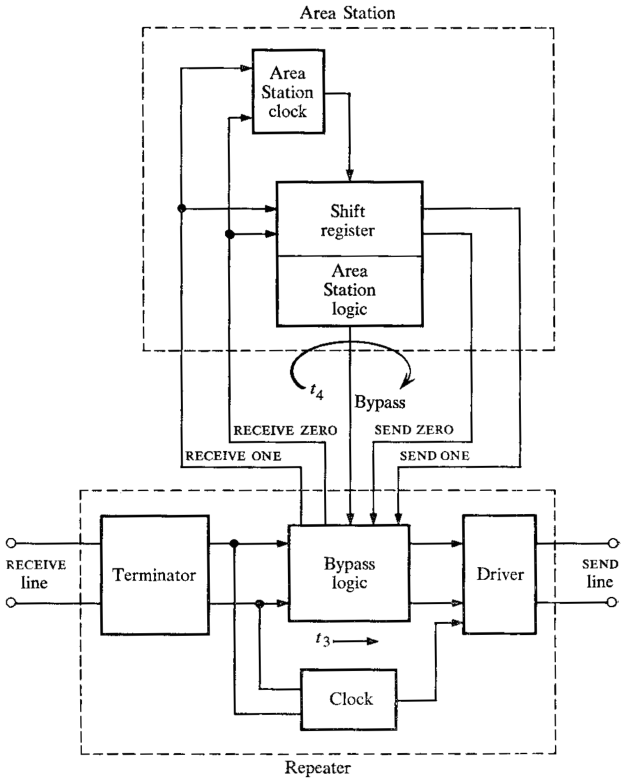
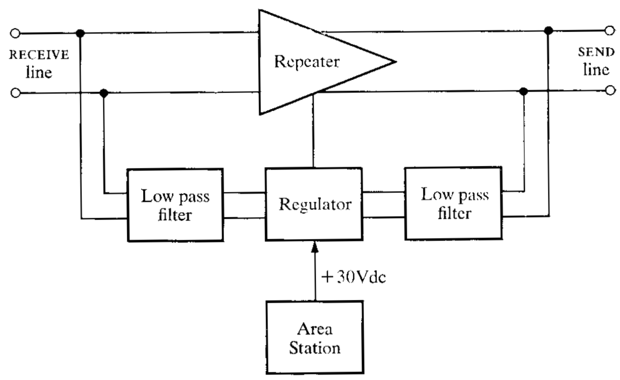


Figure 5 Block diagram for the interface provided by the repeater between Area Station and SEND-RECEIVE line.

Figure 6 Parallel connections between voltage regulator and SEND-RECEIVE transmission lines.



• *Interface to Area Station*

The repeater must function as a stand-alone unit but must also provide data and accept data for transmission from the Area Station. The basic block diagram for this interface is shown in Fig. 5. With the Area Station bypassed, the data flow is from the terminator through the bypass logic to the line driver and a delay of t_3 is accumulated, but when the Area Station is not bypassed, a different path delay t_4 is accumulated between the terminator and driver. It is necessary that the two different delays t_3 and t_4 be made as nearly equal as possible so that the Area Station can be bypassed and restored to the loop without making a transmission error.

The Area Station derived its clock by OR'ing the RECEIVE ONE and the RECEIVE ZERO lines obtained from the repeater. Note that the SEND CLOCK is the same for both bypassed and unbypassed operation. The logical attachment of the Area Station to the repeater is under control of the BYPASS line, so that if a power failure occurs in the Area Station the repeater will automatically bypass the station.

- *Line driver*

The logic contained in the line driver accepts positive pulses and does the necessary shaping and sequencing to form the proper bipolar pulse. A 1:1:1 transformer is used to provide a balanced output to the transmission line and the inductance is adjusted so that less than 10% droop is present on the pulses.

- *Powering*

During normal operation each Area Station provides +30 V dc to a regulator contained in the repeater and also to the RECEIVE and SEND transmission lines. The connections to the transmission lines are through low-pass filters connected in parallel with the lines as shown in Fig. 6. The parallel powering was necessary to provide a return path for the current and is a departure from the more common series powering methods.

If an Area Station has a power interruption or if off-line maintenance is necessary, the affected repeater regulator uses the line voltage supplied by adjacent Area Stations to provide the voltage needed by the repeater circuits. The remote powering is designed so that two adjacent Area Stations or alternating Area Stations can be powered down and the loop will remain operational.

Performance

Laboratory tests have shown that the error rate is less than 10^{-10} errors/bit/link. Since errors in a tandem system are cumulative, the total system error rate for 100 repeaters is less than 10^{-8} errors/bit. The error rates were established using a wide variety of transmission lines with a white noise level of −30 dBm. The impulse noise characteristics are not well defined but, because of the high terminator threshold, no impact on system performance is expected.

Pertinent repeater specifications are shown in Table 1.

Conclusion

The digital transmission system described meets all of the original objectives that were outlined for an in-house system. The design approach permits the use of low cost repeaters with no critical circuits or sophisticated components. Although in some instances extended distance capability is required, most of the in-house requirement[6] for digital transmission can be met.

Table 1 Repeater specifications.

Transmission type	Balanced bipolar
Coding	ONE bit: positive pulse, negative pulse and space ZERO bit: negative pulse, positive pulse and space
Pulse amplitude	3 V peak for each pulse. 6 V peak-to-peak for total line signal
Risetimes	100 nsec
Pulse width	450 nsec @ 50% point for both positive and negative pulses
Bit rate	514.67 kbit/sec
Cable type	Balanced twisted pair
Impedance	100 ohms nominal
Terminator threshold	0.75 V nominal
White noise level	−30 dBm maximum
Jitter	±300 nsec maximum for 100 links
Impulse amplitude	0.35 V isolated impulse will not cause error
Error rate	10^{-10} per link
Input signal	The 3.0 V peak SEND pulse must not be attenuated more than 6 dB
Logic interface	0 to +6 V
Power	+30 V @ 150 mA for each repeater
Environment	Temperature: 40 to 158F. Relative humidity: 8 to 95%

Acknowledgments

The author wishes to thank G. C. Georgallis, under whose guidance the work was performed. Thanks are due also to Alain Croisier of the IBM La Gaude, France, Laboratory for many valuable discussions and to W. B. Nunnery for his design efforts.

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Received May 7, 1970