

Bell System

TECHNICAL REFERENCE

**1.544 Mbps Digital Service-
Channel Interface Specifications
(Including 1.344 Mbps Service
Option)**

MAY 1977



Bell System Data Communications

TECHNICAL REFERENCE



**1.544 Mbps Digital Service-Channel
Interface Specifications (Including
1.344 Mbps Service Option)**



MAY 1977

Engineering Manager-Data Network Services



NOTICE

This Technical Reference is published by American Telephone and Telegraph Company as a guide for the designers, manufacturers, and consultants of customer-provided systems and equipment which connect with Bell System communications systems or equipment. American Telephone and Telegraph Company reserves the right to revise this Technical Reference for any reason, including, but not limited to, conformity with standards promulgated by ANSI, EIA, CCITT, or similar agencies; utilization of new advances in the state of the technical arts; or to reflect changes in the design of equipment or services described therein. The limits of responsibility and liability of the Bell System with respect to the use of customer-provided equipment or systems are set forth in the appropriate tariff regulations.

If further information is required, please contact:

Engineering Manager —
Data Network Services
American Telephone and
Telegraph Company
295 North Maple Avenue
Basking Ridge, New Jersey 07920

TABLE OF CONTENTS

	Page
1. 1.344 MBPS, 1.544 MBPS DIGITAL SERVICE	
CHANNEL — GENERAL	1
1.1 Service Description	1
1.2 Channel Description	1
1.2.1 551A Channel Service Unit	1
1.2.2 306-Type Data Set	2
1.3 Service Objectives	2
1.3.1 Objectives	3
1.3.2 Discussion of Objectives	3
2. INTERFACE DESIGN CONSIDERATIONS	3
2.1 Local Digital Facility Transmission Plan	3
2.2 Signal Constraints for 1.544 Mbps Service	3
2.2.1 Constraints	3
2.2.2 Pulse Density Constraints	4
2.2.3 Average Density Monitor	4
2.2.4 Dotting Constraint	4
2.3 Interface Specifications for 1.544 Mbps Service	4
2.3.1 Customer Interface Specifications	4
2.3.2 Customer Interface Connector	5
2.3.3 Customer Connector Pin Assignments	5
2.3.4 1.544 Mbps Digital Channel Jitter	5
2.3.4.1 Definition	5
2.3.4.2 Discussion	5
2.3.4.3 Specification of Timing Recovery	6
2.3.4.4 Jitter Specification	6
2.4 551A CSU Physical Description	6
2.5 Testing and Maintenance	6
2.5.1 Signal Monitor Indications	7
2.5.2 Telephone Company Testing & Maintenance	7
 Appendix	 12

LIST OF FIGURES

Figure 1a — 1.544 Mbps Digital Channel	8
Figure 1b — 1.344 Mbps Digital Channel	8
Figure 2 — 551A Channel Service Unit Block Diagram	9
Figure 3 — Bipolar Pulse Pattern	10
Figure 4 — 551A Channel Service Unit	11
Figure A — Timing Distortion	14
Figure B — Effect Of Fixed Pattern Transitions On Received Clock Phase	15

1. 1.344 MBPS, 1.544 MBPS DIGITAL SERVICE CHANNEL — GENERAL

This document consists of two sections which cover the following:

- Section 1 — Service Description, Channel Description and Service Objectives.
- Section 2 — Transmission Plan, Signal Constraints, Interface Specifications, and Testing and Maintenance.

1.1 Service Description

The service provides for point-to-point, full-duplex transmission of serial bipolar isochronous pulses at a rate of 1.544 Mbps with constraints on signal format or, with a customer option, for point-to-point transmission of serial, binary, synchronous pulses at a rate of 1.344 Mbps with no constraints on signal format. A voice coordination channel is not included in the service offering.

1.2 Channel Description

The channel is implemented with a 1.544 Mbps digital facility. The 1.544 Mbps service is terminated in 551A Channel Service Units at customer locations. The 1.344 Mbps service is terminated in 306-type Data Sets* at customer locations. The digital facility will be routed through Telephone Company Central Offices and should be ordered at the earliest point in system planning. A typical digital channel arrangement for 1.544 Mbps service is shown in Figure 1a, and a typical digital channel arrangement for 1.344 Mbps service is shown in Figure 1b.

For 1.544 Mbps service, the 551A Channel Service Unit is connected at the customer's premises to a local digital facility which connects to a Bell Central Office. The digital channel is carried between central offices on interoffice digital facilities such as T1, T4, or Data Under Voice (DUV).

For 1.344 Mbps service, the 1.544 Mbps facility is terminated at the customer's premises in a 551A Channel Service Unit. In addition, a 306-type Data Set is provided to properly terminate the 1.344 Mbps service. As in 1.544 Mbps service, the equipment located at the customer's premises is connected to a local digital facility which in turn connects to a Bell Central Office. The digital channel is carried between central offices at 1.544 Mbps in a manner identical to that for 1.544 Mbps service.

1.2.1 551A Channel Service Unit

For 1.544 Mbps service, the 551A Channel Service Unit is located on the customer's premises and provides the interface between the data terminal equipment and the 1.544 Mbps digital facility that is extended to the customer location. To ensure satisfactory operation of the regenerative digital facility, the customer's transmit signal must conform to the alternating format of bipolar pulse trains and meet the following signal format constraints*:

1. At least three pulses in any 24 bit intervals;
2. Not more than 15 consecutive zeroes;
3. Not more than 250 consecutive bit intervals of dotting (alternating ones and zeroes).

The Channel Service Unit contains circuitry that monitors the customer's transmit signal and when insufficient pulses (ones) are present, adds pulses (ones) to maintain the timing integrity of the digital facility. The monitor circuitry will allow the above pulse constraints to be violated to some extent, depending on the average pulse density prior to the violation, before pulses are added. Of course, whenever the pulse constraints are violated the system performance may be degraded. Also each pulse inserted by the monitor circuitry introduces an error into the customer's data stream.

A block diagram of the 551A Channel Service

*The 306-type Data Set (included as part of the Data Service Unit) is described in PUB 41304, "Wideband Data Set 306-Type Interface Specifications."

*The bipolar format and Data Rate Accuracy Requirements are listed in Section 2.3.1.

Unit is shown in Figure 2. The signal monitor interfaces with the customer's equipment and contains the circuitry necessary to monitor and regenerate the customer's transmit data signal. A regenerative repeater interfaces with the 1.544 Mbps local digital facility and contains a regenerator on the receive side (from the local digital facility). A brief description of the 551A Channel Service Unit circuitry is presented in the following paragraphs.

The signal monitor contains a voltage controlled crystal oscillator that is phase-locked to the customer's transmit data signal. The recovered clock is used to regenerate the binary transmit data stream. The regenerated data is then converted to bipolar and applied to the local digital facility through the transmit portion of the repeater.

The 551A Channel Service Unit regeneration process removes any bipolar violations that might be present in the customer's input signal to the 551A CSU and provides the local digital facility with pulses that have proper amplitude and shape independent of the customer's input pulse characteristics (provided that they are in conformance with the specifications of Section 2.3).

Bridged onto the regenerated data line are two monitor circuits, the 16 zero monitor and the average density monitor. The 16 zero monitor activates an indicator whenever 16 or more consecutive zeroes are present but does not alter the bit stream. The average density monitor determines a weighted average of the pulses present in the customer's transmit data signal and, if this weighted average falls below a satisfactory level, causes ones to be transmitted instead of the customer's data stream. The average density indicator is activated whenever pulses are being inserted into the transmitted signal. Hence, the 16 zero monitor acts in a passive role, in the sense that its activation results only in an indication, while the average density monitor performs an active role, in the sense that its activation results not only in an indication but also in an alteration of the customer's data stream. The 16 zero indicator and average density indicator are provided primarily for Bell

System use to aid in maintenance by providing an indication of the characteristics of the customer's Send Data signal.

The receive signal from the local digital facility is regenerated in the repeater and provided to the customer through an isolation transformer in the signal monitor.

The remaining portions of the circuitry are provided to aid in maintenance (Testing and Maintenance are discussed in Section 2.5). The 551A Channel Service Unit is provided with a Remote Test (RT) feature that may be remotely activated from a Bell System Office. Note that this looping is unidirectional; that is, the loop is only towards the Bell System Office, the customer's SD and RD pairs being open during this time. When the RT is activated, the customer's RD and SD pairs are opened and the service unit is looped at the customer interface. Three leads (RTM, RTB, RTC) are available to the customer to indicate the status of the RT relay.

1.2.2 306-Type Data Set

For 1.344 Mbps service, the 306-Type Data Set is located on the customer's premises and provides the interface between the data terminal equipment and the 1.544 Mbps digital facility that is extended to the customer location. To ensure satisfactory operation of the regenerative digital facility, approximately 200 Kb/s of the 1.544 Mbps capability is required by the 306-Type Data Set, resulting in a 1.344 Mbps digital channel to the customer which is without constraints on signal format. A complete description of the 306-Type Data Set is found in PUB 41304, "Wideband Data Set 306-Type Interface Specification."

1.3 Service Objectives

The following are preliminary design objectives and are not to be construed as minimum performance guarantees. They apply to either 1.344 Mbps service or to 1.544 Mbps service.

1.3.1 Objectives

- Quality — The objective is to provide an average performance exceeding 95 percent error-free seconds.
- Availability — The objective is to provide at least 99.7 percent Availability; i.e., average annual downtime less than 0.3 percent. It should be noted that this value is the average which would be observed over a period of several years. Some of the causes of downtime are failures which occur infrequently but which may have long outages associated with them when they do occur. While these infrequent long outages represent small contributions to the long term average, they may significantly affect the downtime seen in a shorter period of time (even as long as a year).

1.3.2 Discussion of Objectives

It is important to recognize the differences between Quality, as discussed in the previous section, and Availability. For a communication system, Quality is a measure of the error performance to be expected while the system is in use. Availability is a measure of the fraction of time the channel is operative.

Quality degradations are transient in nature, and are normally separated by many error-free seconds. Quality degradations may be caused by many different transient error sources, each one of which has a very small probability of occurring at any given time. Many Quality degradations require no repair action. The concept of Availability, however, deals mainly with permanent degradations that always require some type of repair action (either automatic or manual) before the system can be restored to operation. The following equation is often given as a definition of Availability, where MTTR is the

mean time to repair and the MTBF is the mean time between failures:

$$\text{Availability} = \frac{\text{MTBF} - \text{MTTR}}{\text{MTBF}} \times 100\%$$

Thus, during the time that a communication channel between two stations is "unavailable", any Quality measurement made would indicate 0 percent error-free seconds. Even a period of extremely low Quality would include some error-free seconds. Thus, the 0 level of Quality may be used to distinguish between "unavailable" and "available at some level of Quality greater than 0".

2. INTERFACE DESIGN CONSIDERATIONS

2.1 Local Digital Facility Transmission Plan

Baseband, bipolar return-to-zero pulses are used for transmission over the local digital facility. The signal format is a sequence of digital "ones" and "zeroes," the zeroes of the sequence are at the zero volt level, and the "ones" are alternately positive and negative with respect to the "zero" level. An oscilloscope photograph of a typical bipolar pulse pattern is shown in Figure 3. The pulse transmission rate is 1.544 Mbps, nominal amplitude of "ones" is 3.0 volts and the nominal width of each pulse is 325 ns at half amplitude.

The fundamental advantage gained by this type transmission is that the pulse train can be regenerated with little or no accumulation of noise and distortion from one repeater section to another. The repeater has only to respond to the presence of a pulse in a particular bit interval and if a pulse is present, regenerate a new pulse. In this way, a completely new pulse train is generated which is essentially free of noise and distortion.

2.2 Signal Constraints for 1.544 MB/s Service*

2.2.1 Constraints

The customer's data signal applied to the

*The 306-Type Data Set terminates a 1.344 Mbps Service Option that is without signal format constraints.

551A Channel Service Unit should conform to the bipolar format specified in Section 2.3.1, the Data Rate Accuracy detailed in Section 2.3.1, and meet the following pulse density constraints:

1. At least three pulses in any 24 bit intervals;
2. Not more than 15 consecutive zeroes;
3. Not more than 250 consecutive bit intervals of dotting (alternating ones and zeroes).

2.2.2 Pulse Density Constraints

In order to ensure adequate timing recovery of the regenerative digital facility, two requirements in the form of pulse density constraints, are placed upon the customer's transmit data. The first constraint, at least three pulses in any 24 bit intervals, ensures the average density of ones. The second constraint, not more than 15 consecutive zeroes, ensures that there will exist no long time interval during which there are no pulses.

Data signals that do not meet the stated pulse density constraints will be transmitted without alteration if the average pulse density is above the monitor threshold. Under these conditions, however, it may be expected that the system performance will be progressively degraded as the constraints are violated even before the monitor threshold is reached.

2.2.3 Average Density Monitor

The average density monitor determines an exponentially weighted average, with a 32 bit interval time constant, of the pulse density. The monitor threshold is set to allow periodic signals meeting the stated pulse density constraints to be transmitted unaltered, and to insert pulses for input sequences whose weighted average pulse density is less than satisfactory.

When continuous pulses are transmitted for at least 100 bit intervals prior to starting transmission of continuous zeroes, the monitor time constant results in allowing 70 zeroes to be transmitted before the monitor threshold is reached. With 50 percent

weighted average pulse density prior to sending no pulses, the monitor responds after 50 bit intervals.

2.2.4 Dotting Constraint

Under certain conditions, a long sequence of dotting (alternating ones and zeroes) can be translated in the network to a signal which may produce unwanted crosstalk (intersystem coupling) into other services. In addition, under certain conditions, long sequences of dotting can cause degraded performance to the customer. Thus, long sequences of dotting must be avoided. Therefore, a constraint is placed upon the customer's data signals such that no sequence of dotting longer than 250 bit intervals be transmitted.

2.3 Interface Specifications for 1.544 Mbps Service*

This section describes the electrical characteristics at the customer interface connector of the 551A Channel Service Unit. It also provides mechanical information on the interface connector and pin assignment.

2.3.1 Customer Interface Specifications

a. Cable Type	Shielded Twisted Pair
Impedance	100 ohms nominal
Length	500 feet maximum
b. SD or RD Signal Format	
Format	Bipolar Return-to-Zero
Balance	Balanced to ground with no dc component
c. Pulse Amplitude**	
SD (positive or negative)	3±1.5 volts peak into a 100 ohm termination
RD (positive or negative)	2.75±.25 volts peak into a 100 ohm termination

*Interface specifications for 1.344 Mbps service can be found in PUB 41304, "Wideband Data Set 306-Type Interface Specification".

**As measured at the 551A Channel Service Unit.

- d. SD or RD Pulse* 325±50 ns
Width (half amplitude)
- e. Data Rate SD or RD 1.544 Mbps±100 bps
Absolute Accuracy
- f. SD Pulse Constraints
 - Pulse Density 3 pulses in any 24 bit intervals
 - Zero Sequences Maximum of 15 consecutive zeroes
- g. Remote Test Indication
 - No Remote Test RTB — Connected to RTC
RTM — Open
 - Remote Test RTM — Connected to RTC
RTB — Open

- Sliding Lock Retainer:
DA51220-1 Cannon Electric
- Right Angle Hood:
DA51211-1* (plastic) Cannon Electric
DA19977-1 (steel)
- DA19977-1 (steel) Cinch Electronics

2.3.2 Customer Interface Connector

The 551A Channel Service Unit is equipped with a subminiature 15-pin female connector**, number DA-15S, which may be supplied by either of two manufacturers:

Cannon Electric
666 E. Dyer Road
Santa Ana, California 92702

Cinch Electronic Group
1501 Morse Avenue
Elk Grove Village, Illinois 60007

The customer's interface cable should be terminated in a 15-pin subminiature connector equipped with a right angle hood and sliding back assembly that will mate and lock with the connector on the 551A Channel Service Unit.

The following mating connectors, sliding lock assemblies and hoods are available commercially:

- 15-Pin Connectors (male):
- DA - 15P (solder cup) Cannon Electric
 - DAC - 15P (crimp)
 - DA - 15P (solder cup) Cinch Electronics
 - DA - 15P - F179 (3/8" wire wrap)
 - DA - 15P - F179 (1/2" wire wrap)

*As measured at the 551A Channel Service Unit.
**The connector for the 306-Type Data Set is described in PUB 41304 Section 3.1.3.

2.3.3 Customer Connector Pin Assignments

Pin	
1, 9	SEND DATA 1 = SEND DATA (A) 9 = SEND DATA (B)
3, 11	RECEIVED DATA 3 = RECEIVED DATA (A) 11 = RECEIVED DATA (B)
2, 4	FRAME GROUND
5	REMOTE TEST MAKE (RTM)
6	REMOTE TEST BREAK (RTB)
13	REMOTE TEST COMMON (RTC)

2.3.4 1.544 Mbps Digital Channel Jitter**

2.3.4.1 Definition

See Appendix

2.3.4.2 Discussion

Jitter can be produced by a variety of sources. Each source may produce jitter whose characteristics (e.g., amplitude, frequencies) are highly dependent upon such factors as the reference timing source against which the jittered signal is compared and the method used in measurement. Sources of jitter for a 1.544 Mbps Digital Channel include, but are not restricted to, atmospheric variations, switches to protection channels, and mistuning of timing recovering circuits in the regenerative repeaters.

Since jitter may be measured by the customer at the output of a timing recovery circuit, one

*Discard the 4-40 self-tapping screws and use the 4-40 machine screws supplied with DA51220-1 to mount the connector and the sliding lock retainer to the hood.

**Jitter for the 1.344 Mbps Digital Channel is discussed in Section 3 of PUB 41304, "Wideband Data Set 306-Type Interface Specification".

must be hypothesized in order to provide a meaningful jitter specification. The specification of one such timing recovery circuit is given in Section 2.3.4.3.

The jitter specification given in Section 2.3.4.4 is divided into two parts, high frequency jitter and low frequency jitter. The low frequency component is further subdivided into that portion which is data pattern dependent and that portion which is not.

2.3.4.3 Specification of Timing Recovery Circuit

A timing recovery circuit designed to operate with the 551A CSU may be characterized as follows. In response to an input phase change, $\Delta\Phi$ in degrees, the phase of the recovered signal is changed at a rate (in Hz) not less than

$$S \left(\frac{\Delta\Phi}{17} \right)$$

where $S = 2500$ Hz and is a measure of system bandwidth, and $\Delta\Phi$ is any phase shift less than or equal to 17 degrees.

2.3.4.4 Jitter Specification

High Frequency Component

Specification —The isochronous distortion with respect to the reference timing source described below is expected to be no greater than 40 percent (20 percent peak individual distortion).

Reference for Specification —The reference timing source for the specification of isochronous distortion is such that it is expected to track very low frequency jitter (e.g., below 10 Hz).

Low Frequency Components

Pattern Sensitive Component

The peak-peak distortion should be less than 2.4 bits for frequencies less than 300 Hz, and 4.8 bits for frequencies less than 60 Hz.

Non-Pattern Sensitive Component

The peak-peak distortion for periods of less

than one day should be no greater than 25 bit intervals. The peak-peak distortion for periods of less than one year should be no greater than 80 bit intervals.

2.4 551A CSU Physical Description*

A photograph of the 551A Channel Service Unit is shown in Figure 4. The 551A Channel Service Unit consists of a chassis 1.96" (5.0 cm) high, 21" (53.3 cm) wide, and 12" (30.5 cm) deep. The weight of the unit is approximately 7.5 pounds (3.4 kg). The 551A is designed to mount in a 23" relay rack or in a cabinet. The customer interface connections are made at the rear of the Channel Service Unit by the 15-pin connector specified in Section 2.3.2.

2.5 Testing and Maintenance

In any system, outages will occasionally occur, and it is important for the customer and the Telephone Company that prompt and efficient corrective actions be taken in all such situations. A telephone number will be provided at the time of service installation for customer use in reporting troubles in his service. Telephone Company testing and repair can be accomplished most efficiently if a complete and accurate description of the difficulty is provided by the customer.

When operating difficulties are encountered by a customer, it is expected that he will check his terminal equipment for proper operation prior to reporting trouble to the Telephone Company. Considerable time and expense can be saved by making a careful initial evaluation of a trouble condition. Such things as unplugged power cords, tripped circuit breakers and loose interface connectors can completely disable a customer's system, but may be corrected by customer personnel with little delay. Diagnostic indications which are often included as part of customer provided equipment can also be useful in trouble isolation. For these reasons, it is

*A physical description of the 306-Type Data Set can be found in PUB 41304, "Wideband Data Set 306-Type Interface Specification".

recommended that customer personnel be acquainted with the basic equipment layout and instructed in fundamental maintenance techniques.

2.5.1 Signal Monitor Indications

As discussed in Section 2.2.2 there are two pulse density constraints, the violation of either of which will cause indicator lamps located on the 551A Channel Service Unit to become active. While these indicators are primarily for Bell System use to aid in maintenance, they can give an indication of the characteristics of the customer's Send Data signal, and may be used by the customer in evaluating potential difficulties requiring maintenance action.

As discussed in Sections 2.2.2 and 2.2.3, the pulse density monitor threshold is designed to allow signals meeting the pulse density constraints to be transmitted unaltered, and to insert pulses for input sequences whose weighted average pulse density is less than satisfactory. When the monitor threshold is not exceeded (i.e., insufficient pulse density) pulses are introduced and the AVG DENS (average density) indicator lamp on the 551A Channel Service Unit is activated. Thus, an excessive error rate in conjunction with the AVG DENS indicator lamp being ON may indicate that the customer's Send Data signal has been altered (i.e., pulses added by the 551A) due to insufficient pulse density.

As discussed in Section 2.2.2, no deliberate alteration of the customer's Send Data signal

is performed by the 551A Channel Service Unit as long as the average pulse density is above the monitor threshold. However, when the customer's Send Data signal violates the 15 consecutive zero constraint, the 16 ZEROS indicator lamp on the 551A becomes active. Hence an excessive error rate in conjunction with the 16 ZEROS (but not the AVG DENS) indicator lamp being ON may indicate errors in the 1.544 Mbps digital channel due to violations in the 15 consecutive zeroes constraint. If both the AVG DENS and the 16 ZEROS indicator lamps are ON, it may be inferred that the customer's data stream has been altered (i.e., pulses have been added) and that the 15 consecutive zeroes constraint has been violated.

2.5.2 Telephone Company Testing and Maintenance

The Telephone Company will be aware of many trouble conditions that may occur, and repair will be undertaken prior to reports from customers. If the customer suspects an undetected trouble condition and has checked his station equipment, he should call the number for trouble reporting that is furnished when the service is installed.

Repair procedures by the Telephone Company may require remote testing. Indication of remote testing is given to the customer over the RTM, RTB, and RTC leads. Under normal conditions, no remote test, continuity is provided between RTB and RTC, RTM is open. During remote test, continuity is provided between RTM and RTC, RTB is open.

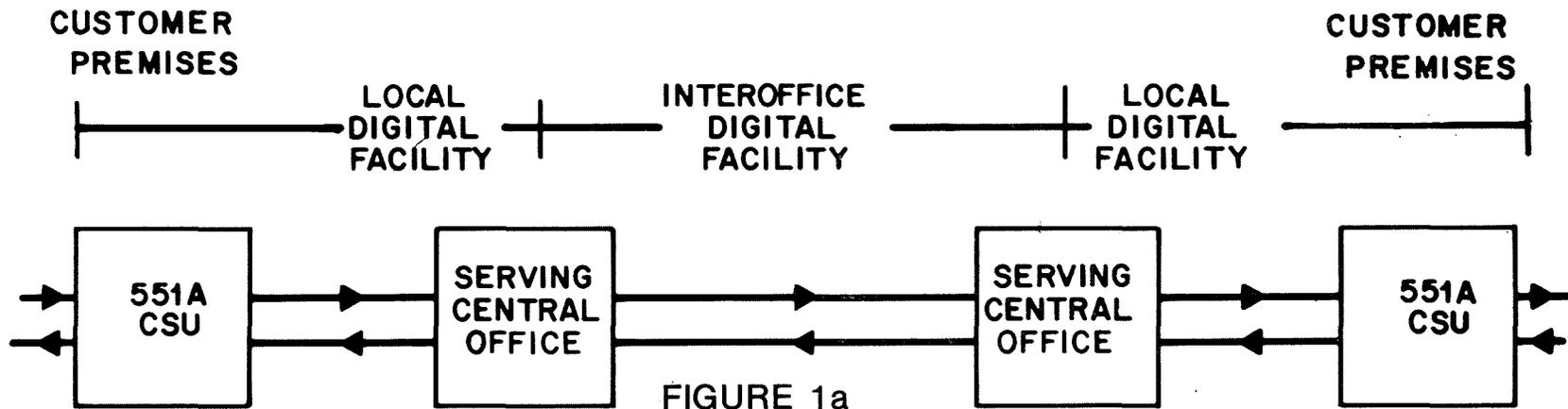


FIGURE 1a

1.544 Mbps DIGITAL CHANNEL

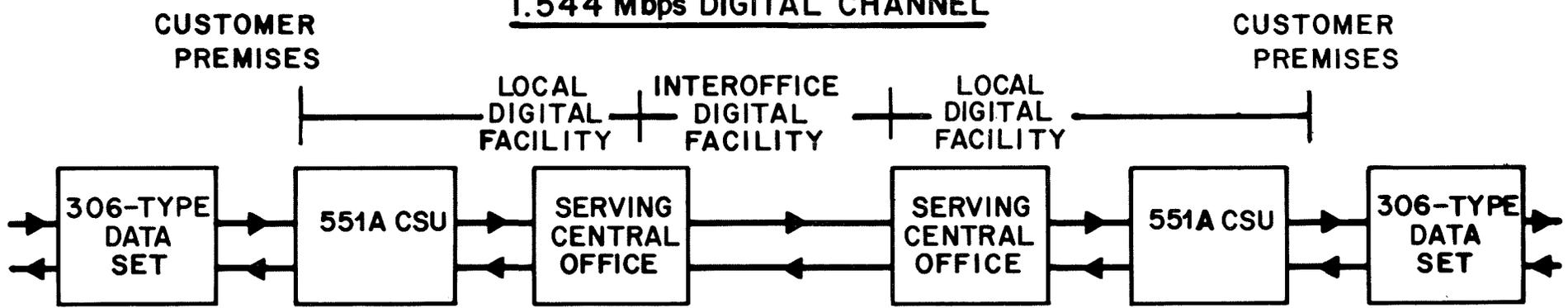


FIGURE 1b

1.344 Mbps DIGITAL CHANNEL

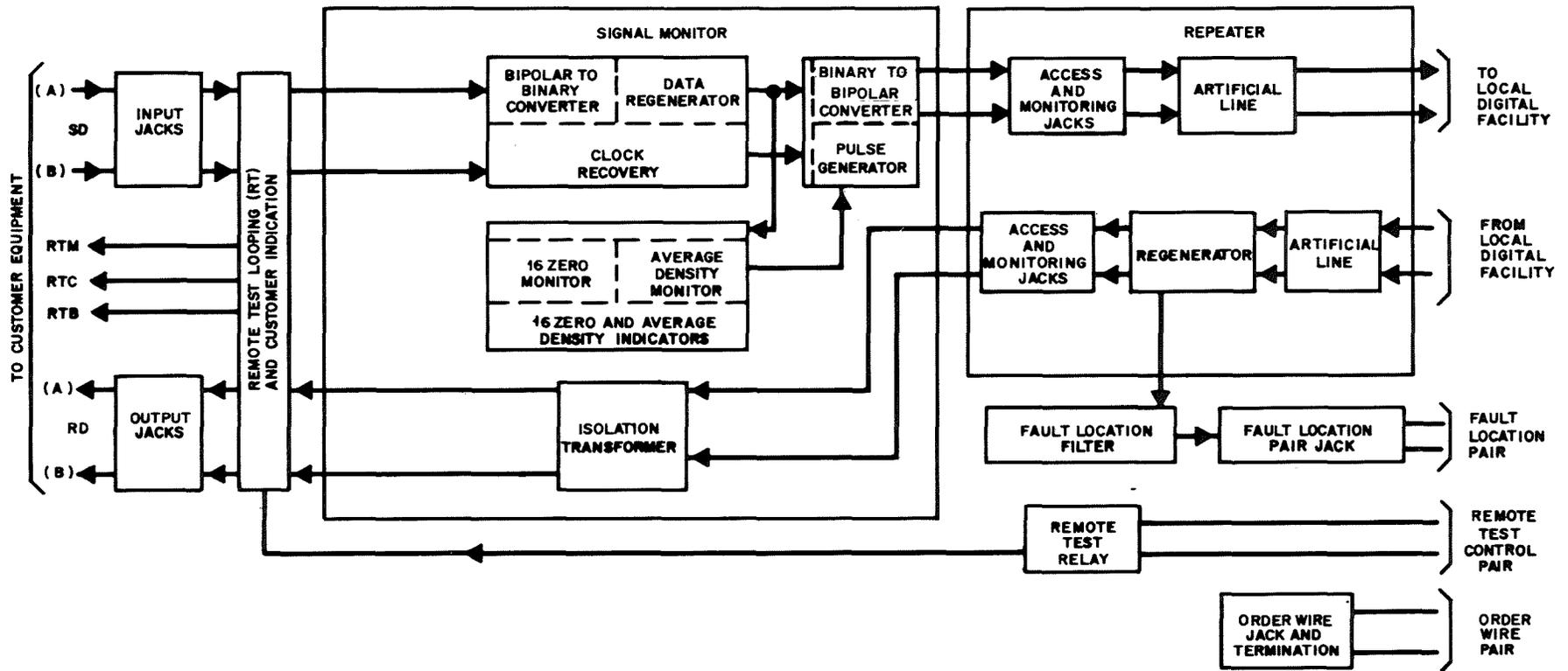
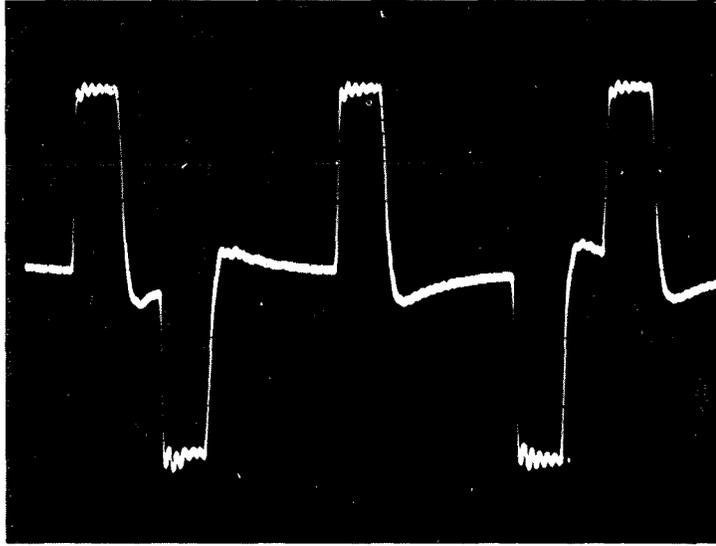


FIGURE 2

551A CHANNEL SERVICE UNIT
BLOCK DIAGRAM



BIPOLAR PULSE PATTERN

FIGURE 3

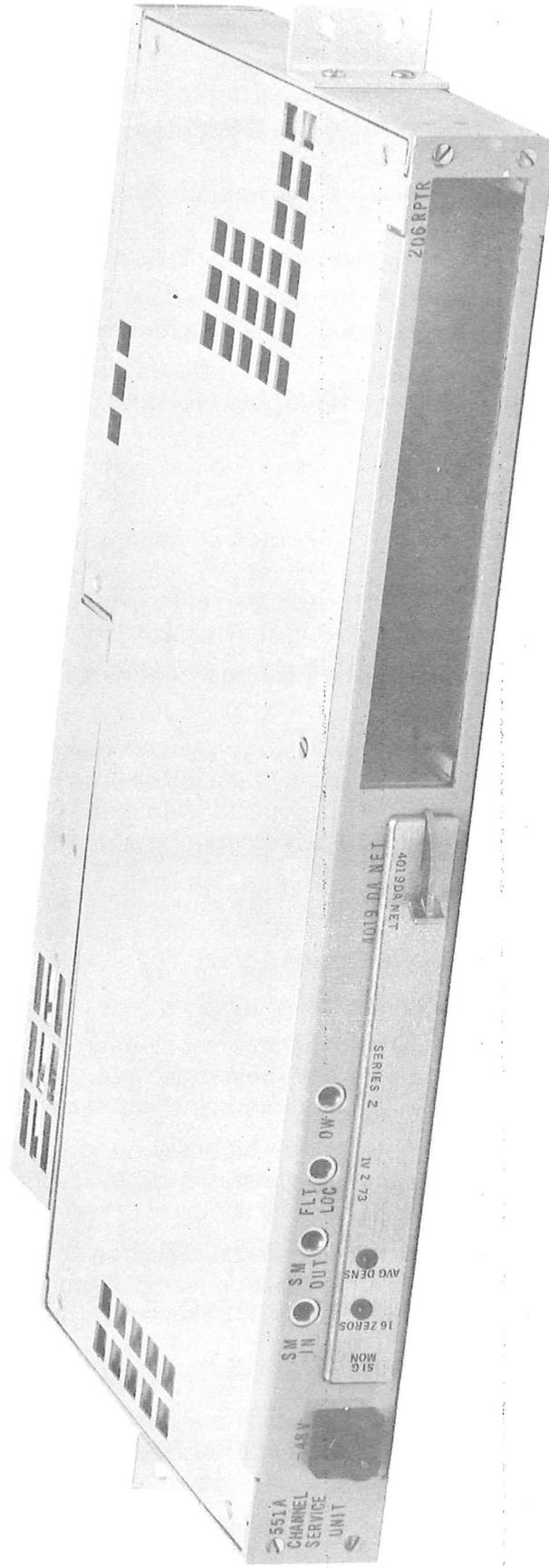


FIGURE 4
551A CHANNEL SERVICE UNIT

APPENDIX

Timing Recovery Definitions

This appendix is included to provide a convenient reference for the definition of isochronous and peak individual distortion of data signal transitions. And although not directly applicable, these terms are also used and discussed in two publications:

EIA Standard RS-334, "Signal Quality at Interface Between Data Processing Terminal Equipment and Synchronous Data Communication Equipment for Serial Data Transmission."

EIA Industrial Electronics Bulletin No. 5, March, 1956, "Tutorial Paper on Signal Quality at a Digital Interface."

Definitions

In the following discussion, the term "unit interval" means the reciprocal of the data rate. The term "significant instant of modulation" with reference to a bipolar data signal, means the instant the signal crosses a preset threshold level. In the case of the CSU interface, the levels are as specified in Section 2.3.1.

Degree of Individual Distortion of a Particular Significant Instant (from Bulletin No. 5):

"The ratio to the unit interval of the displacement, expressed algebraically, of this significant instant from an ideal instant. This displacement is considered positive when the significant instant occurs after the ideal instant. The degree of individual distortion is usually expressed as a percentage."

Degree of Peak Individual Distortion (from RS-334):

"The maximum individual distortion, irrespective of sign, of all significant instants occurring during a particular measuring period."

Degree of Isochronous Distortion (from RS-334):

1. "Ratio to the unit interval of the maximum measured difference, irrespective of sign, between the actual and the theoretical intervals separating any two significant instants . . . , these instants being not necessarily consecutive.
2. "Algebraical difference between the highest and lowest value of individual distortion affecting the significant instants of an isochronous modulation. ("This difference is independent of the choice of the reference ideal instant.")"

In the case of both isochronous and peak individual distortion, the length of observation is also important. In the case of a prolonged observation, it is appropriate to consider the probability that a given degree of distortion will be exceeded.

Applications

To apply these definitions to the CSU interface, the expected nature of the data signals must be considered. The receive data (RD) signal delivered to the customer is expected to be synchronous, relatively noise-free and well-controlled in width (see Section 2.3.1).

The measurement of peak individual distortion (or isochronous distortion) proceeds as illustrated in Figure A. Since the signals on the RD are relatively noise-free, fairly large measuring intervals may be used.

Timing Recovery

Timing recovery in data transmission commonly involves applying the received signal, or a processed version thereof, to a high-selectivity circuit, such as an LC tank or a phase-locked loop, to extract the fundamental bit frequency. The equivalent circuit for these schemes usually reduces to a low-pass filter acting on the input jitter of the received data transitions.

The data signal is then sampled at clock transitions in phase with the nominal center of the received pulses.

Since the low-pass character of the timing circuit attenuates high frequency jitter, attention is focused on the low-frequency input and output jitter. An empirically verified theory, discussed below, leads to a useful figure of merit for the quality of the received signal transitions in the presence of data pattern dependent jitter and establishes performance limits for the synchronous sampling circuits described above.*

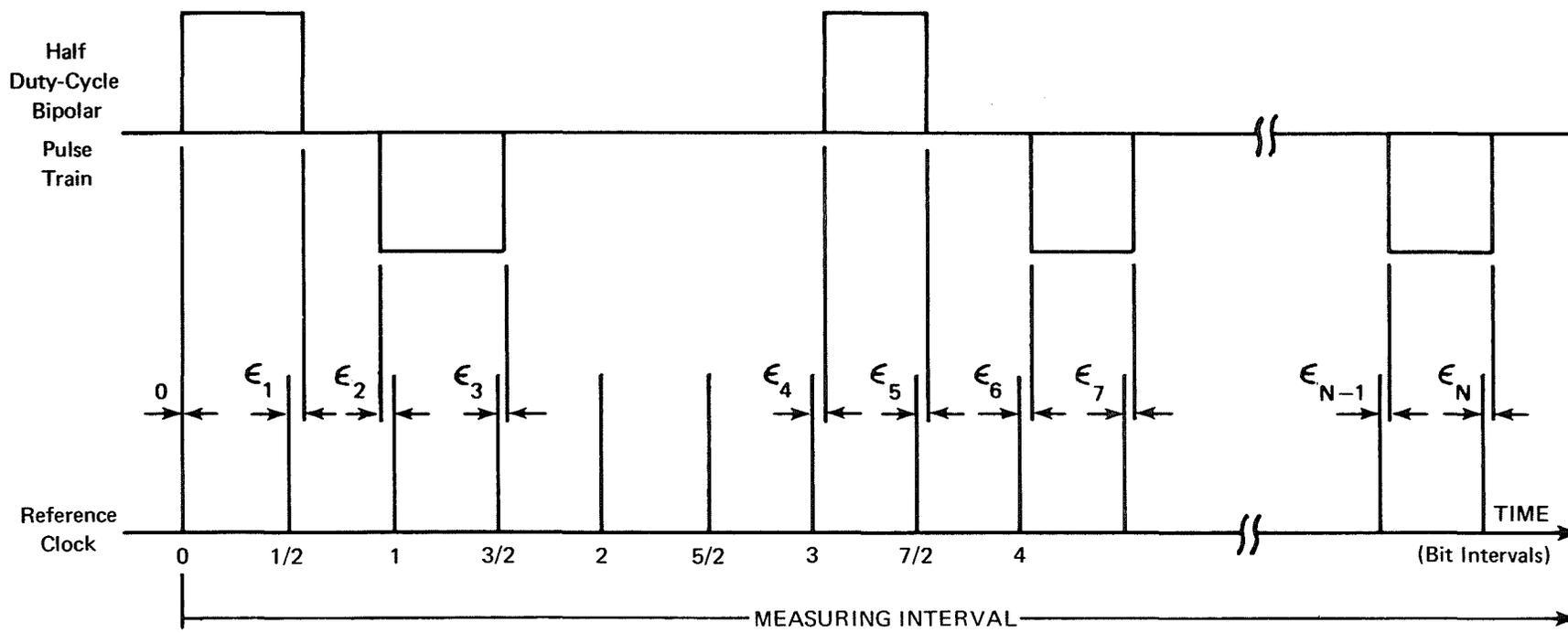
We suppose that the input jitter depends only on the last few bits transmitted, and consider a repetitive pattern with period much less than the reciprocal of the bandwidth, B . Associated with this periodic pattern is an average or dc phase shift, θ^1 , corresponding to the location of the average of the pulse centers; the phase is measured with respect to the transitions of an appropriate ideal clock signal. Now suppose the pattern is suddenly switched to one with average phase, θ^2 . The data transitions adjust their phase to θ^2 in a few bit's time, the assumed memory span of the jitter mechanism. The recovered clock phase, however, changes at a rate $B(\theta^2 - \theta^1)$, and thus requires a time $1/B$ to adjust to the new phase (see Figure B).

Evidently, the recovered timing signal has an irreducible phase jitter of $\theta^1 - \theta^2$; moreover, the data sampling instant is offset from the nominal pulse center by $\theta^2 - \theta^1$ immediately following the change in pattern.

Thus, the worst-case peak-to-peak dc phase shift between any two repetitive patterns represents a figure of merit for the quality of the received data transitions.

It is independent of the particular realization in this class of timing and sampling circuits.

*Byrne, C. J., Karafin, B. J., and Robinson, D. B., Jr., "Systematic Jitter in a Chain of Digital Regenerators," *Bell System Technical Journal*, November, 1963, pp. 2679-2714.



LEGEND:

$100.0 \times \epsilon_i$ = Individual Distortion Of i^{th} Significant Instant (%) ($i = 1, 2, \dots, N$)

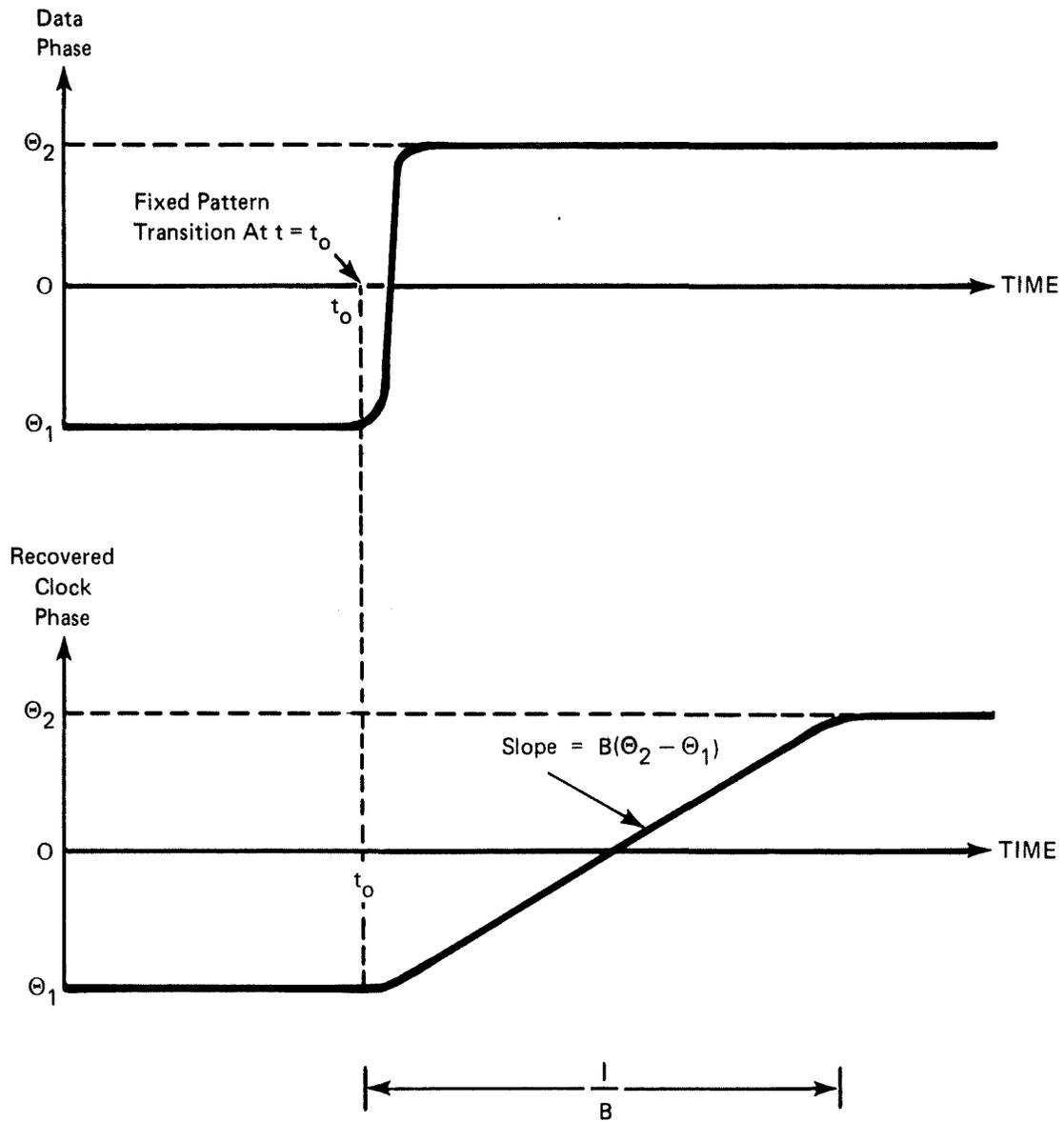
ϵ_{max} = Maximum $|\epsilon_i|$ Observed In Measuring Interval ($i = 1, 2, \dots, N$)

$100.0 \times \epsilon_{\text{max}}$ = Peak Individual Distortion

δ_{max} = Maximum $|\epsilon_i - \epsilon_j|$ Between Any Two Individual Distortions Observed In Measuring Interval, ($i, j = 1, 2, \dots, N$) Not Necessarily Consecutive Pulses.

$100.0 \times \delta_{\text{max}}$ = Isochronous Distortion (%)

Timing Distortion
Figure A



$B =$ Timing Circuit Bandwidth

**Effect Of Fixed Pattern Transitions
On Received Clock Phase
Figure B**