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Bell System TECHNICAL REFERENCE

DATA COMMUNICATIONS USING VOICEBAND PRIVATE LINE CHANNELS

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ENGINEERING MANAGER - ENGINEERING METHODS, OBJECTIVES AND STUDIES

NOTICE

If further information is required, please contact:

Engineering Manager — Engineering Methods, Objectives and Studies
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PREFACE

This Technical Reference supersedes and replaces the "Transmission Specifications for Voice Grade Private Line Data Channels" issued in March, 1969. It attempts to more clearly state Bell System policy regarding transmission parameter limits which are supported, to introduce new parameter limits, to clarify statements found confusing in the original, to indicate policy with respect to interconnection of customer-provided modems, and to provide a general technical revision. Comments from users for improvements in this Technical Reference are invited. They may be addressed to the Engineering Manager — Engineering Methods, Objectives and Studies, A.T.& T. Company, 195 Broadway, New York, N.Y. 10007.

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DATA COMMUNICATIONS USING VOICEBAND PRIVATE LINE CHANNELS

1. GENERAL DESCRIPTION

1.1 Purpose

The purpose of this Technical Reference is to provide information to designers and manufacturers of data terminal equipment, and to users of such terminal equipment and of voiceband private line channels offered under interstate Tariff F.C.C. No. 260 and similar intrastate tariffs. Various offerings and channel arrangements are described, and transmission performance is specified in terms of parameter limits. System design and maintenance are also discussed and the interface requirements for customer-provided equipment are given.

1.2 Scope

The voiceband private line arrangements and parameters discussed apply to Tariff F.C.C. No. 260 offerings, specifically to 2001, 3001 and 3002 channels, and similar channels derived from series 5000 and 8000 wideband channels. The stated use of the 2001 channel is for voice transmission. Data transmission is a permitted use. The 3001 channel is used for remote metering, supervisory control, and miscellaneous signaling. The 3002 channel is used for the transmission of voiceband data and facsimile signals. Alternate voice use of 3002 channels is permitted. Most local Telephone Companies have similar intrastate interexchange offerings. Where intrastate arrangements are anticipated, the local Telephone Company should be contacted to determine what arrangements are available. In addition to the interstate and intrastate interexchange offerings, there are intraexchange (local) tariffs which may be very different from Tariff F.C.C. No. 260. Again the local Telephone Company should be contacted to determine available arrangements. Questions on individual case applications of Tariff F.C.C. No. 260 should be referred to Long Lines Sales representatives.

This Technical Reference covers channels which normally contain amplifiers or carrier-derived sections. The usable frequencies in these channels are nominally 300 to 3000 Hz (300 to 3200 Hz with C4 conditioning). The usable frequencies on voiceband data channels do not normally extend below 300 Hz. Where signaling below 300 Hz is contemplated, the local Telephone Company should be consulted to determine what operation is permissible or possible.

A separate Technical Reference (Reference 1) covers operation with metallic channels and discusses restrictions on their general availability.

1.3 Bell System Voiceband Data Offerings

There are two types of connections of customer-provided data devices with Bell System services. The first involves customer-provided equipment connected to Bell System modems; the second involves customer-provided equipment (including modems) connected to Bell System transmission channels. There are also two types of Bell System data transmission arrangements offered: Private Line and the Switched Telecommunications Network.

The most common voiceband data arrangement offered by the Bell System is DATA-PHONE® service, using a Bell System modem connected to the Switched Telecommunications Network. The customer also may choose to provide his own data modem and use the Switched Telecommunications Network. Under this arrangement, the customer-provided equipment is connected through a network protection device known as a Data Access Arrangement (DAA). The DAA is furnished, installed, and maintained by the Bell System.

Voiceband private line data channels may be preferred over the Switched Telecommunications Network for a number of reasons, including:

1. Above some threshold of message

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traffic volume to a restricted number of terminals, private line service will be more economical.

2. A private line network (switched or nonswitched) can be "conditioned" (attenuation distortion and envelope delay distortion controlled) to meet the needs of the services carried.
3. Nonswitched private line channels do not have the performance variability of the transmission parameters encountered between connections in the Switched Telecommunications Network.
4. Since no other user is competing for his private line network facilities, the user can choose the probability of calls being blocked in his network to differ from that found in the Switched Telecommunications Network.
5. A nonswitched private line channel provides essentially zero call set up time. This eliminates the time required in the Switched Telecommunications Network for addressing (dialing), switching (call routing), alerting (ringing), and obtaining billing information. This may be a dominant consideration in certain data communication applications.

Voiceband channels offered under Tariff F.C.C. No. 260, and many intrastate tariffs, are intended for both voice and data applications. For the purpose of this Technical Reference, all nonvoice applications, including telephoto* and facsimile, will be defined as data applications. The tariff also specifies grades of conditioning which may be applied to certain of these channels. Section 2 of this Technical Reference describes the characteristics of each channel, and the conditioning available.

* The Type 4002 channel is a special channel for telephoto usage; it is also referred to as a facsimile channel in the Tariff. It is intended that all facsimile equipment, and eventually all telephoto equipment, will use a 3002-type channel, with conditioning if necessary.

The arrangements which can be ordered include two-point, multipoint, or switched channels. These channels can be ordered for half-duplex or duplex service. (See Section 2.6 for a discussion of simplex, half-duplex, and duplex operation, and 2-wire and 4-wire channels.) Section 2 of this Technical Reference will describe some of the various arrangements possible.

The Bell System offers a wide range of modems capable of operating on the various private line basic or conditioned channels. The 100 series modems provide bit serial asynchronous operation at speeds of 300 bits per second and below. The 200 series modems on private line channels provide for bit serial asynchronous operation up to 1800 bits per second and synchronous operation at certain speeds from 2000 bits per second up to 10,800 bits per second. The 400 series modems accept parallel digital inputs for transmission at speeds up to 75 characters per second. The 600 series modems accept analog inputs rather than digital, and are used for medical (electrocardiogram) and facsimile data transmission. The Technical Reference on each type of modem may be useful in planning a data communications system. A recommended channel is specified for each modem. Several grades of channels are recommended in some cases, based on the bit rate to be transmitted.

Bell System modems on private line networks can be connected to similar Bell System modems on the Switched Telecommunications Network. Some forms of connection are permissive only, i.e., no specified error performance will be supported but the connection is permitted; on others a specified error performance is supported.

1.4 Performance Specifications

1.4.1 Digital Performance with Certain Bell System Offerings

When Bell System digital modems are used with recommended grades of channel conditioning and specified network configurations, data transmission performance may be specified at the digital interfaces with the customer. The

specification is given in terms of the overall block or bit error rate of the received data as compared to the transmitted data.

The specified network configurations are those where the transmission parameters of the connections are supported within certain limits. No configuration which includes other than Bell System facilities is covered by this provision.

Some examples follow:

- Two-point channels.
- Multipoint channels meeting certain design criteria as specified in Section 6.2.
- Up to four two-point channels in tandem when arranged for central office switching (see Section 2.3).
- CCSA Networks.
- Foreign Exchange (FX) channels used to dial a Switched Telecommunications Network connection to a point within 200 airline miles of the FX central office.
- Tandem tie trunk connections between on-premises PBX stations. For Bell System 201-type and 202-type modems, up to two tie trunks can be in the connection, provided the length of the overall connection does not exceed 4000 miles, and the tie trunks are appropriately C-conditioned. For Bell System 203-type and 208-type modems, performance will be supported over a single tie trunk. No data performance will be supported from modems attached to off-premises stations or between modems connected together by an off-network call.

When the other restrictions described above are met, performance is specified for all transmissions on the first three configurations above. For the last three, performance is specified for some percentage of the possible connections established. Where two or more channels are to be switched together, the combined channels must meet the recommended conditioning for the modem used. Connecting together a series of channels, each having the recommended conditioning, will usually result in the overall channel having less than the recommended grade of conditioning. Where switching arrangements are desired, the channel conditioning must be ordered as switched under Tariff F.C.C. No. 260 or similar intrastate tariff. If customer-provided switching arrangements or transmission facilities are employed, the Bell System cannot assure satisfactory end-to-end conditioning of combined circuits.

On two-point, multipoint, and central office switched (not CCSA) service using Bell System modems, performance is supported as indicated in Table 1.

On CCSA networks (see Section 2.5) ordered without conditioning, and on calls over FX lines to points within 200 miles of the foreign exchange central office, performance using Bell System modems will be approximately the same as similar operation on the Switched Telecommunications Network; this performance is described in Reference 2. On CCSA networks which are ordered with C3 conditioning, approximately 90% of the connections established will meet C2 conditioning. Since impairments other than gain and phase distortion (impulse noise, harmonic distortion, etc.) may be limiting on some of the connections, the performance statements of Table 1 for C2 conditioning may apply to between 80 and 90% of the CCSA connections.

On calls over the number of tie trunks specified for the type of modem used, and with the conditioning and distance specifications met, at least 80 percent of the calls should meet the performance statements of Table 1.

The use of block error rate specifications in Table 1 for higher speed modem operation is a departure from the bit error specification used in the past. It is a measure of considerably more interest for systems using block retransmission error control (most systems operating at these speeds). Block error rate is more closely related to the overall measure of system performance than is bit error rate because it is not as sensitive to error bursts encountered in transmission. References 2 and 7 discuss the relationships between bit error rate, block error rate, and throughput in detail. The block error performance specified in Table 1 is in terms of a 1000 bit block error rate, that is, the number of 1000 bit blocks which contain one or more bit

TABLE 1

ERROR PERFORMANCE SUPPORTED USING BELL SYSTEM 200-SERIES MODEMS ON TWO-POINT, MULTIPOINT*, AND CENTRAL OFFICE SWITCHED CHANNELS

Data Set	Speed	Channel Conditioning	Minimum Performance Supported
201A	2000 bps	Basic	1 1000-bit block error per 100 blocks transmitted (Note 1)
201C	2400 bps	Basic	1 1000-bit block error per 100 blocks transmitted (Note 1)
202C, D, E, R	Up to 1200 bps Up to 1400 bps Up to 1800 bps	Basic C1 C2	1 bit error per 100,000 bits transmitted (Note 3)
203 4-level	3600, 4800 bps	C2	1 1000-bit block error per 100 blocks transmitted (Note 2)
4-level	6400, 7200 bps	C2	(Note 4)
8-level	5400, 7200, 9600, 10,800 bps	C2	None supported
208A	4800	Basic	1 1000-bit block error per 100 blocks transmitted

NOTE 1: Approximately equivalent to 1 bit error per 100,000 bits transmitted.

NOTE 2: Approximately equivalent to 1 bit error per 10,000 bits transmitted.

NOTE 3: Bit error rate specifications are used because these data sets are typically used for asynchronous transmission of characters and other very short blocks.

NOTE 4: Limit not established.

* See Section 6 for restrictions on multipoint channels.

errors divided by the number of 1000 bit blocks transmitted. A system which encounters, on the average, one block error per 100 blocks transmitted has a block error rate of 10^{-2} and a maximum efficiency or throughput of 99 percent [$100(1-10^{-2})$]. The 1000 bit block size at which performance is specified is a convenient reference block size in the range of block sizes used by many data systems in operation today. It is not necessarily the recommended block size for any particular data system. Block error rate performance for systems using block sizes in the range of 500 to 10,000 bits may be estimated with good accuracy from the 1000 bit block error rate. As discussed in References 2 and 7 the relationship between block error rate and block size is linear to a good approximation over this range of block sizes. For example, if a system has an average 1000 bit block error rate of one block error per 100 blocks transmitted, the block error rate for 3000 bit blocks is estimated to be three block errors per 100 blocks transmitted.

The minimum performance specification given in Table 1 is meant to represent the "long term average" error performance of the channel. At times, performance which is poorer than this specification may be encountered. To verify that the performance experienced is as specified, the customer may make error measurements. A 30 minute measurement time is suggested. This will usually be a reliable indication of channel performance if the channel meets the specifications easily or fails by a wide margin (worse than one 1000 bit block in error per 10 blocks transmitted, or one bit error per 1000 bits transmitted). If the channel is marginal, the customer should observe the performance for at least several hours to determine if average error performance specifications are met.

When Bell System modems are not used with the recommended grade of conditioning or a specified network configuration, or customer-provided modems, switching equipment, or transmission facilities are used, the Bell System will not specify the overall error performance. When customer-provided equipment is used, the Bell System does not have responsibility for all the components of the data transmission assembly and thus cannot assume responsibility for either the component parts not under its control or for the overall assembly. Component parts for which the Bell System has responsibility will be maintained to their individual specifications.

On any given private line service all data modems at all premises must be provided either entirely by the Telephone Company or entirely by the customer.

1.4.2 Analog Channel Performance (Voiceband Data Channel)

Where customer-provided modems are used, the Bell System supports the channel transmission characteristics as ordered if the channel is entirely provided by the Bell System. The parameter limits supported are those in the appropriate tariff and those in this Technical Reference. It is Bell System policy to follow the same transmission facility selection and channel maintenance procedures regardless of whether customer-provided or Bell System-provided modems terminate the channel. Channels meeting the supported transmission limits will not be improved, with the exception that a higher grade of C-conditioning will be provided, if requested, for an appropriate charge.

Where customer-provided modems are used, the customer must specify the channel conditioning required. This will generally be based on the recommendations of the manufacturer, appropriate to the type of service desired. **The Bell System does not make such recommendations, verify recommendations made by manufacturers, or make known any test results for, or experience with, non-Bell System modems.** The Bell System is not responsible for any incompatibility between customer-provided equipment and Telephone Company equipment. If a problem arises due to parameters not specified in either the Tariff or this Technical Reference an effort to correct the problem will be made provided the condition, in the judgment of the Telephone Company, is the result of defective operation of Telephone Company equipment or facilities, or improper channel design.

1.5 Trouble Conditions with Channel-Only Service

If a customer chooses to provide the modems and orders a channel-only service from the Bell System, and problems arise, Bell System representatives will meet jointly with the customer, the manufacturer of the customer's modems and/or others designated by the customer to help resolve technical problems involving the channel provided. Each of the Bell Telephone Companies has Data Technical Support (DATEC) groups available to assist in troubleshooting. These groups exist to help meet the Bell System commitment to service by providing highly trained people to assist in resolving difficult technical problems involving data services. This commitment to service holds whether the Bell System provides a data system, including the modems, or a channel-only service.

If the Telephone Company is called regarding a trouble which, upon investigation by the Telephone Company, is found to be caused by customer-provided equipment, then a service charge will be made if a repairman has been dispatched to the customer's premises, and if the applicable Tariff provides for this service charge.

1.6 Requests for Channel Facilities Used

The Telephone Companies occasionally receive requests from customers for information regarding the facilities on which their channel is provided. As part of a continual effort to more efficiently use its transmission facilities, the Telephone Companies may route the channel over different facilities and types of facilities from time to time. The resulting channels will still meet transmission requirements as specified, but the facilities used may be quite different from those used at the time of installation or at any other particular time. Customer equipment which is not compatible with all facilities meeting the stated specifications would possibly be subjected to outages when such facility changes occur. As discussed in Section 8.3, the facilities or types of facilities to be used or avoided in providing any service will be determined entirely by the Telephone Company except where facilities provided by others are used. Thus the Telephone Companies do not provide the customer with the facility layout of the channel provided, and the customer or others acting for him should not request such information.

1.7 Interconnection with Customer-Provided Modems

Customer-provided modems connected to voiceband private lines which have access to the Switched Telecommunications Network are permissible if they conform to the signal power restrictions of Section 4.1, and the connection to the Switched Telecommunications Network is through a Telephone Company-provided Data Access Arrangement. For private lines which do **not** have access to the Switched Telecommunications Network, the limitations on signal power, balance, and applied voltages and currents, as given in Section 4.1, must be met. The specific procedures for the enforcement of compliance with these limits are, at the time of this writing, being negotiated with the appropriate regulatory bodies.

1.8 Special Assemblies and Development Inquiries

The services commonly provided by the Bell System cover a wide range of applications. If the standard services do not meet customer requirements, modification of the standard service arrangements can often be made to provide what is needed, usually at additional cost. These modifications are initiated by the customer specifying his requirements to his Telephone Company Sales or Marketing contact. If the requirements cannot be met with standard offerings, a "special assembly" may be requested by the Telephone Company Marketing Department or a "development inquiry" initiated by the AT&T Long Lines Marketing Department. These special arrangements require a long lead time in most instances because of the special engineering, costing and rate development required.

2. TYPES OF ARRANGEMENTS PROVIDED

F.C.C. Tariff No. 260 provides for a basic voiceband channel and five types of C-conditioning. These are summarized in Table 2. Note that C-conditioning on multipoint channels applies to the complete channel; a mixture of C-conditioned and basic segments, or different grades of conditioning on the same channel, is not permitted.

The basic channel and channels with C1 and C2 conditioning may be ordered in two-point, multipoint, and switched configurations.

C3 conditioning applies only to private switched networks and is specified in terms of access lines and trunks. The intent of C3 conditioning is to provide C2 conditioning end-to-end on most switched connections involving a maximum of four trunks and two access lines in tandem. C3 conditioning is used on Common Control Switching Arrangements (CCSA) or Switched Circuit Automatic Networks (SCAN). (See Section 2.5.)

C4 conditioning can be ordered for two-, three-, or four-point operation only. (See Section 2.2.)

C5 conditioning can be ordered two-point only. The intent of C5 conditioning is similar to that of C3 conditioning, i.e., achieving C2 conditioning end-to-end on multiple link connections. Its principal use is for two-point private lines between customer control points in networks which extend overseas. It is recommended that customers not order C5 conditioning for other than this application. Technically satisfactory alternatives in most other cases are more economically obtained using a lower grade of conditioning.

The following discussion applies to both the 2001 and 3002 channels when used for data applications with or without C-type conditioning, which can be applied to either.

TABLE 2

TYPES OF VOICEBAND CHANNEL CONDITIONING*

	Present Designation	Previous Designation
Basic Channel	2001, 3002, 3001	Schedule 4, Type 4
Conditioning	C1	Schedule 4, Type 4A
	C2	Schedule 4, Type 4B
	C3	–
	C4	Schedule 4, Type 4C
	C5	

* C-conditioning applies only to the attenuation and envelope delay characteristics of series 2000, 3000, 5000 and 8000 voiceband channels.

The basic use of the 2001 channel is as a point-to-point voice private line, including PBX tie trunks, and off-premises PBX stations. However, there are tariff provisions for data communications using the 2001 channel so it has been included. Due to its application, the 2001 channel 1004 Hz loss is generally different from that of the 3002 channel.

With this exception, in the text when the 3002 channel is specified, the 2001 channel will be included as well. The 2001, 3002, and similar intrastate offerings are the most commonly used channels covered; Section 1.2 lists other channels to which this Technical Reference applies.

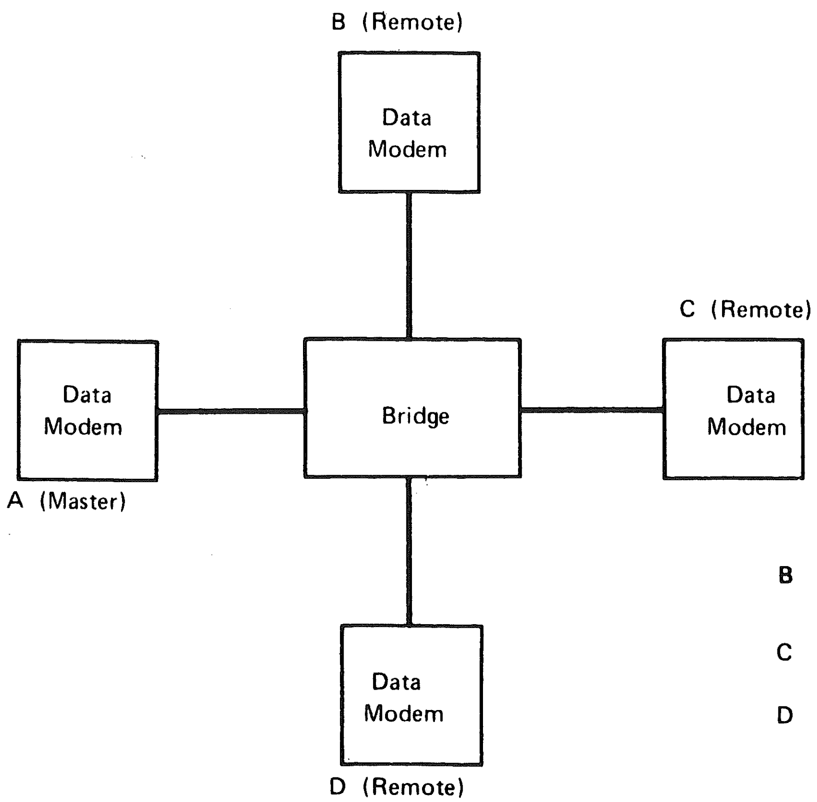
2.1 Point-To-Point

The 3002 channel, and C1, C2, C4, or C5 conditioning can all be ordered between two locations.

2.2 Multipoint

The 3002 channel and C1 and C2 conditioning may be ordered on channels interconnecting more than two locations (multipoint). Section 6 will describe some of the various multipoint arrangements possible. It is important to note here that multipoint C4 conditioning is provided 2-, 3-, or 4-point only. Four-point operation with C4 conditioning is an arrangement where Station A (see Figure 1) can transmit to B, C, and D, and B, C, and D can transmit to A. Transmissions between B and C, B and D, and C and D may be possible, but the conditioning is not specified between these points. Three-point operation with C4 conditioning is similar, but Station D is not present.

The restriction is required because the transmission requirements for C4 conditioning are such that a proration into segments is not practicable. Channels between Station A and each of the other three stations are equalized



	A	B	C
B	C4		
C	C4	Unspecified	
D	C4	Unspecified	Unspecified

Table for Conditioning Specified Between Points

Fig. 1 — Four-Point Arrangement with C4 Conditioning

overall, not in segments. Thus, there is no specified equalization between the bridge location and any of the stations.

2.3 Central Office Relay Switching

It is possible to connect two or more point-to-point private line data channels through the use of switching keys and relays. Tariff F.C.C. No. 260 provides for a maximum of three such switches in tandem. Figure 2 shows such an arrangement. Normally, four point-to-point circuits exist: A-B, B-C, C-D and D-E. If key 1 is operated, circuits A-B and B-C are broken and a new circuit, A-C, is set up. If key 2 is then operated, circuits A-C and C-D are broken and a new circuit, A-D, is established. If all three keys are operated, circuit A-E is established and all others are broken.

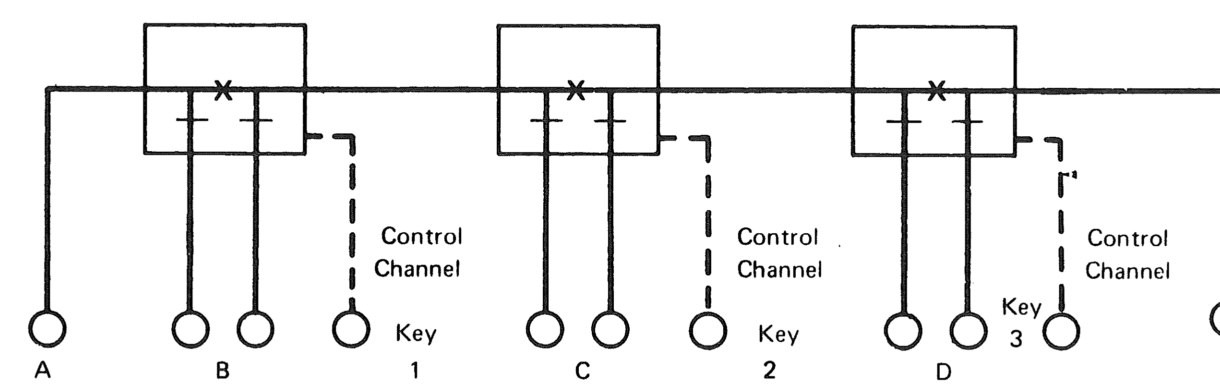
This arrangement provides great flexibility in design, but usually requires manual control of the keys using control channels from the central office to the customer station. No design requiring Telephone Company central office personnel to operate the central office switches is permitted.

Central office relay switching is generally preferred, from a transmission viewpoint, to the customer's premises switching arrangements described in the following paragraphs. Central office relay switching may be provided on the basic 3002 channel and with C1 or C2 conditioning. It is not provided with C4 or C5 conditioning.

2.4 Customer's Premises Switching

Connecting together two-point data channels can be accomplished on the customer's premises (see Figure 3) but both the transmission characteristics and the conditioning may be adversely affected. Customer's premises switching may cause local and short haul facilities to appear in both intermediate switched legs. These facilities often affect signal-to-noise ratio, attenuation distortion and envelope delay distortion more than do the long-haul intercity facilities. Therefore, greater amounts of equalization are required and higher noise levels may result as more of these facilities appear in any connection. For this reason, it is desirable to avoid this form of switching for data operation whenever possible. End-to-end conditioning is not specified with this type of operation, although the individual two-point channels may have C-type conditioning.

A customer connecting two channels together should provide amplifiers to raise the received signal power from one channel to the specified



X Open Contact with Relay Released
I Closed Contact with Relay Released
O Customer Station
☐ Central Office

Fig. 2 — Central Office Relay Switching Example

transmitted signal power of the other. For standard channels this is nominally 16 dB at 1004 Hz (−16 dBm received signal power raised to 0 dBm transmitted signal power). Channel loss at a later time may vary ± 4 dB from the nominal 16 dB loss at installation, however, so great care should be taken that the gain added does not cause the transmitted signal power to exceed 0 dBm if the received signal power is greater than −16 dBm.

2.5 Common Control Switching Arrangements (Central Office Switching)

Customers generating large volumes of traffic to selected locations in a large geographical area may find it advantageous to use a switched private line network similar to the Switched Telecommunications Network. Common control switching machines are used to interconnect trunks and access lines. Trunks are circuits between switching machines; access lines are circuits between customer locations and switching machines (similar to customer loops in the Switched Telecommunications Network). As indicated by the examples of Figure 4, these networks (called CCSA networks) can be connected to other CCSA networks or to the Switched Telecommunications Network. Data transmission from one network to another (involving off-net access lines), or to tributary or satellite PBXs, is permitted but no error performance is specified. Data transmission at less than 300 bps may be successful on such off-net connections, but higher speed operation is much less likely to be successful and is not recommended.

The only C-type conditioning available for CCSA networks is C3. With C3 conditioning, most connections consisting of two access lines and up to four trunks will have C2 conditioning overall.

2.6 Modes of Operation and Types of Channels

There are three modes of operation possible: simplex, half-duplex, and duplex. There are two types of transmission facilities used: 2-wire

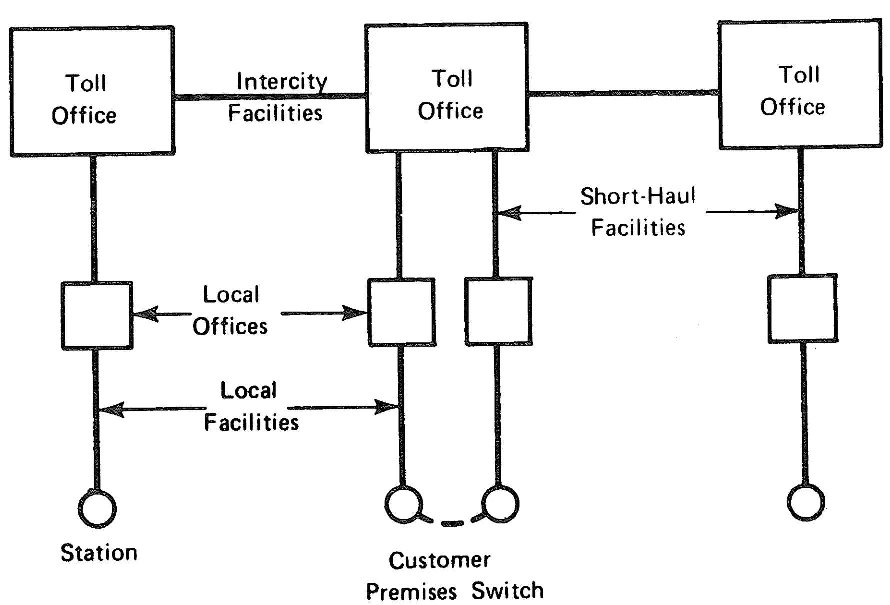


Fig. 3 — Customer's Premises Switching Example

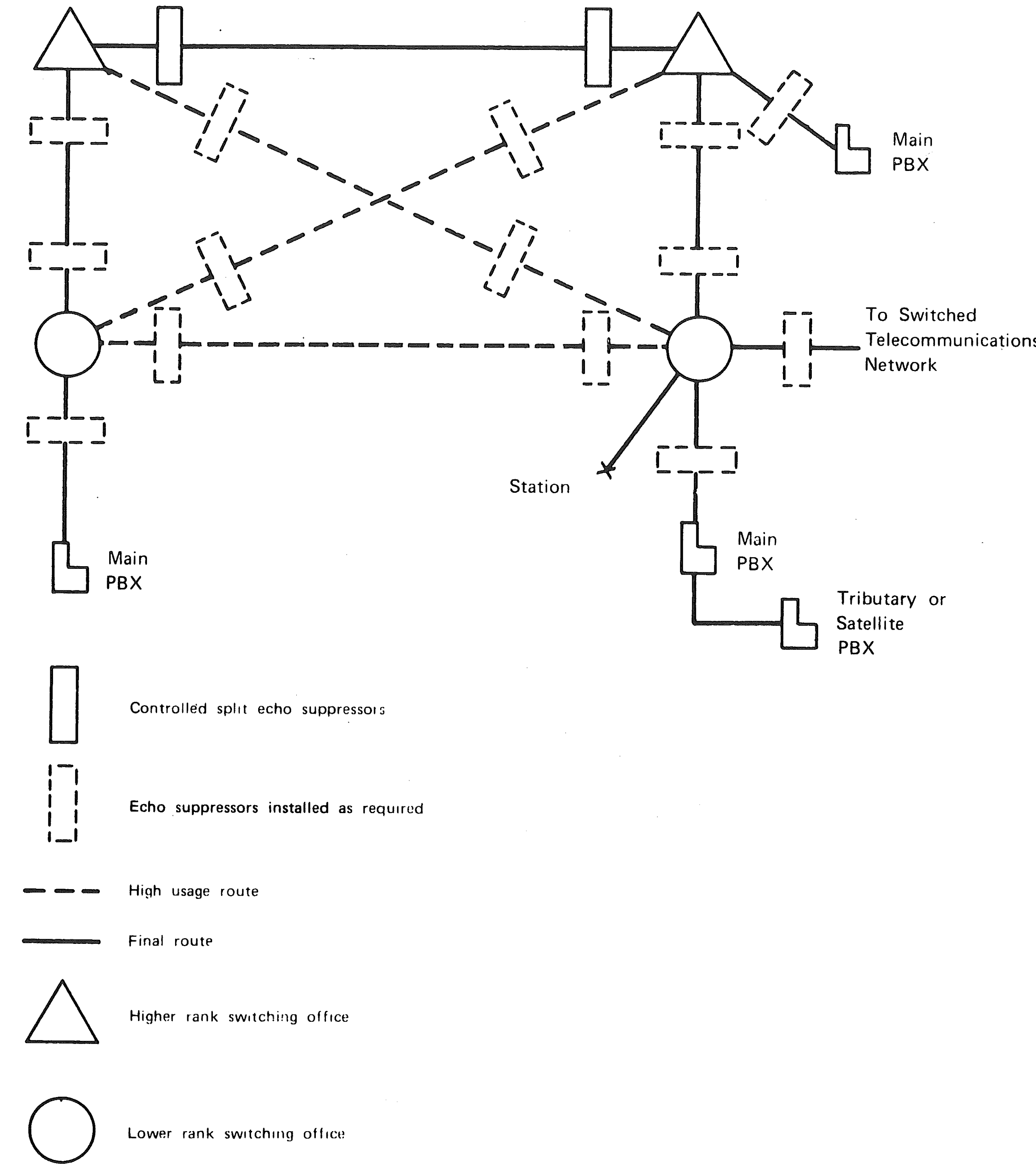


Fig. 4 — Common Control Switching Arrangement (CCSA) Example

and 4-wire. These facilities are used to make up 2-wire and 4-wire channels. A 2-wire channel is made up either partly or completely of 2-wire facilities, i.e., one pair of wires may carry both directions of transmission. A 4-wire channel is made up entirely of 4-wire facilities, i.e., a separate pair of wires or equivalent is used for each direction of transmission.

Simplex operation is the use of a channel in one direction only. An example of this is broadcast operation where a master station transmits data to one or more remote stations, with no signals required in the reverse direction.

Half-duplex operation is the use of the voiceband frequencies in either direction on an alternate (not simultaneous) basis. An example of half-duplex operation is data being transmitted in one direction and the modems "turned around" (transmitting modem becomes the receiving modem and vice versa) to reverse the direction of transmission.

Duplex operation is the transmission of signals in both directions simultaneously.

It is possible to operate simplex, half-duplex, or duplex over either 2-wire or 4-wire channels. On 2-wire channels, simplex operation is achieved with the channel equipped with unidirectional amplifiers if amplification is required. Half-duplex operation is achieved with the channel equipped with bidirectional amplifiers in 2-wire sections or separate unidirectional amplifiers in 4-wire sections. Duplex operation is achieved by dividing the channel frequency spectrum into bands used for transmission in different directions. On 4-wire channels the full voiceband is available for use in both directions simultaneously. The customer may choose to use one direction only (simplex operation), both directions alternately (half-duplex operation), or both directions simultaneously (duplex operation).

Most tariffs do not refer to either channel type or mode of operation, but rather to half-duplex and duplex **services.** Significant differences exist between these services in interstate, intrastate interexchange, and intraexchange tariffs.

Since the transmission characteristics of 2-wire and 4-wire channels place physical constraints on the channel arrangements possible (particularly for the multipoint channels discussed in Section 6), and on the end-to-end analog characteristics of the channel, this Technical Reference will refer to 2-wire and 4-wire channels rather than half-duplex or duplex services. **Customers should contact their Bell System Communications Consultants to determine how to order the arrangements discussed for their particular application.**

All the arrangements described in Section 2 may be provided with 2-wire or 4-wire channels except those with 2-wire switching arrangements (PBXs and CCSAs).

3. SUMMARY OF SPECIFICATIONS

Tables 3 and 4 contain applications, interface parameter requirements, and transmission facility parameter limits summarized for easy reference. The transmission facility parameters and the interface parameters are discussed further in Section 4 and Section 5, respectively.

In Table 3, those limits marked with an asterisk are requirements contained in Tariff F.C.C. No. 260. Most Telephone Companies offer similar intrastate arrangements. The remaining limits are current administrative instructions of the AT&T Engineering Department. If these limits are not met, and data performance is affected, the Telephone Company should be contacted for corrective action. Some of the parameters are not normally measured at installation because they usually meet the specified limits or are not service affecting. See Section 4 for details.

IMPORTANT NOTE:

> The interface parameter requirements and transmission facility limits given in Table 4 assume a standard 16 dB loss channel at 1004 Hz. Channels provided for voice service where data transmission is permitted, such as the 2001 channel, are usually designed for other than 16 dB loss. (See Reference 8 for details.) The received C-message noise limits are a function of the channel design on the 2001 channel and on nonstandard design data channels.

TABLE 3

BANDWIDTH PARAMETER LIMITS # ≠

Channel Conditioning	Attenuation Distortion (Frequency Response) Relative to 1004 Hz: Frequency Range (Hz)	Attenuation Distortion: Variation (dB) **	Envelope Delay Distortion: Frequency Range (Hz)	Envelope Delay Distortion: Variation (microseconds)
Basic	500-2500	−2 to +8	800-2600	1750
	300-3000	−3 to +12		
C1	*1000-2400	−1 to +3	*1000-2400	1000
	* 300-2700	−2 to +6	800-2600	1750
	300-3000	−3 to +12		
C2	* 500-2800	−1 to +3	*1000-2600	500
	* 300-3000	−2 to +6	* 600-2600	1500
			* 500-2800	3000
C3 (access line)	* 500-2800	−0.5 to +1.5	*1000-2600	110
	* 300-3000	−0.8 to +3	* 600-2600	300
			* 500-2800	650
C3 (trunk)	* 500-2800	−0.5 to +1	*1000-2600	80
	* 300-3000	−0.8 to +2	* 600-2600	260
			* 500-2800	500
C4	* 500-3000	−2 to +3	*1000-2600	300
	* 300-3200	−2 to +6	* 800-2800	500
			* 600-3000	1500
			* 500-3000	3000
C5	* 500-2800	−0.5 to +1.5	*1000-2600	100
	* 300-3000	−1 to +3	* 600-2600	300
			* 500-2800	600

C-conditioning applies only to the attenuation and envelope delay characteristics.

≠ Measurement frequencies will be 4 Hz above those shown. For example, the basic channel will have −2 to +8 dB loss, with respect to the 1004 Hz loss, between 504 and 2504 Hz.

*These specifications are tariffed items.

**(+) means loss with respect to 1004 Hz.
(−) means gain with respect to 1004 Hz.

TABLE 4
SPECIFICATIONS COMMON TO STANDARD DESIGN VOICEBAND DATA CHANNELS

APPLICATION

1. Alternate voice/data or data only.
2. Two-point or multipoint layout (Note 1).
3. Two-wire or four-wire termination.
4. One-way, two-way simultaneous, or two-way nonsimultaneous transmission.

INTERFACE PARAMETERS FOR TERMINAL EQUIPMENT

1.	Recommended impedance of terminal equipment:	600 ohms ± 10% resistive over the voiceband and balanced. (Note 2)
2.	Recommended isolation to ground of terminal equipment:	At least 20 megohms dc At least 50 kilohms ac (300-3000 Hz) At least 1500 volts rms breakdown voltage at 60 Hz
3.	Data signal power (above 300 Hz): Maximum transmitted:	0 dBm (3-second average) + 13 dBm (instantaneous) (Note 3)
	Received power of 1004 Hz test tone (at installation):	−16 dBm ± 1 dB (Note 4)

4. Maximum test signal power: same as data signal power (Note 4)
5. In-band transmitted signal power: signal power in 2450 to 2750 Hz band should not exceed signal power in 800 to 2450 Hz band if Bell System SF signaling is used, or if the signal can have access to the Switched Telecommunications Network.
6. Out-of-band transmitted signal power

   Above the Voiceband:

   (a) Power in band from 3995 to 4005 Hz at least 18 dB below maximum allowed in-band signal power.

   (b) Power in band from 4 to 10 kHz less than -16 dBm.

   (c) Power in band from 10 to 25 kHz less than -24 dBm.

   (d) Power in band from 25 to 40 kHz less than -36 dBm.

   (e) Power in band above 40 kHz less than -50 dBm.

   Below the Voiceband:

   Where signal components below 300 Hz, excluding ringing, are applied, the rms currents and voltages (including harmonics and spurious signals) at the interface shall not exceed the following.

   (f) rms current per conductor as specified by the Telephone Company, but never to exceed 0.35 ampere.

   (g) Magnitude of peak conductor to ground voltage not to exceed 70 volts.

   (h) Conductor to conductor voltage shall be such that conductor to ground voltage is not exceeded. For ungrounded signal source, conductor to conductor limit is the same as conductor to ground limit.

   (i) Total weighted rms voltage in band from 50 to 300 Hz not to exceed 100 volts. Weighting factors for each frequency component f are $f^2/10^4$ for f between 50 and 100 Hz, and $f^{3.3}/10^{6.6}$ for f between 100 and 300 Hz.

TRANSMISSION CHANNEL PARAMETER LIMITS COMMON TO ALL BASIC AND C-CONDITIONED STANDARD-DESIGN CHANNELS

1. 1004 Hz loss variation: no more than ±4 dB long term (12 dB to 20dB) and no more than ±3 dB short term (Note 5).
2. C-message noise: (Note 6)

Facility miles	Maximum noise at modem receiver (assumes standard design channel)
0-50	28 dBrnc
51-100	31
101-400	34
401-1000	38
1001-1500	40
1501-2500	42
2501-4000	44
4001-8000	47
8001-16000	50

3. C-message notched noise: at least 24 dB below received 1004 Hz test tone power (Notes 4, 7)
4. Impulse noise:

Threshold with respect to received 1004 Hz test tone power	Maximum counts above threshold allowed in 15 minutes
6 dB	15
2 dB	9
+2 dB	5

5. Single frequency interference: at least 3 dB below C-message noise limits
6. Frequency shift: no more than ±5 Hz
7. Phase intercept distortion: not controlled
8. Phase jitter: no more than 10° peak-to-peak
9. Nonlinear distortion (harmonic distortion):
   fundamental-to-second harmonic 25 dB minimum
   fundamental-to-third harmonic 30 dB minimum
10. Peak-to-Average Ratio (P/AR): not specified
11. Echo: first listener echo at least 12 dB below signal (Note 8)
12. Phase hits: not specified (Note 9)
13. Gain hits: not specified (Note 9)
14. Dropouts: not specified (Note 9)

TABLE 4 (Cont'd)

Note 1: C4 conditioning 2-, 3-, or 4-point only
C5 conditioning 2-point only
Duplex multipoint with 3002 channel only (not available with 2001 channel).

Note 2: Balanced operation is required (e.g., do not ground either side of the facility) but the degree of balance and method of measurement are not presently specified.

Note 3: Signals having instantaneous power more than 13 dB above the allowed 3-second average power may be distorted and may also interfere with services on other channels. The composite instantaneous signal power for signal components between 300 and 3995 Hz at a 0 dBm transmit point must not exceed + 13 dBm (3.46 volts peak) across a 600 ohm resistive load.

Note 4: The Bell System test signal at the input to a standard 16 dB loss channel is a 1004 Hz tone at 0 dBm.

Note 5: The short term variation specification will eventually be replaced by a gain hit specification. "Short term" refers to periods of several seconds, but not to hours or days. "Long term" refers to periods of days, weeks, or a few months.

Note 6: C-message noise limits apply at the modem receiver in the absence of a received signal. For voice operation with Bell System equipment in alternate voice/data operation, the C-message noise at the telephone receiver differs from the data limits given, and depends upon channel design. The limits are given in dBrnc. The "c" refers to C-message weighting. "dBrn" is dB above reference noise, where reference noise is -90 dBm. Note the mileage bands are facility miles, not airline miles.

Note 7: C-message notched noise provides an indication of the signal-to-noise ratio. This measurement simulates normal operation of compandors and other channel equipment.

Note 8: Although included under transmission parameters, echo is also affected by a terminal impedance other than 600 ohms resistive.

Note 9: Limits under consideration.

4. TRANSMISSION PARAMETERS

The transmission parameters discussed in this section are divided into three broad categories: interface parameters, bandwidth parameters, and facility parameters. These categories are indicated in Table 5.

These are the parameters of major importance to data transmission. In the case of the facility parameters there is a continuing effort to learn more about the nature of the impairments they cause, how they should be measured, and their sources. (Reference 3 is a Bell System Technical Reference devoted to definition and discussion of analog transmission parameters which affect data transmission. Reference 4 is a companion Technical Reference on measuring these parameters.)

There are additional areas such as the time-variation of parameters or ripple in the bandwidth parameters, which may have an adverse effect on data transmission, particularly at bit rates above 2400 bits per second. These are areas requiring further engineering study. Should these or other peculiar effects cause problems, they should be discussed with Telephone Company engineers. The Telephone Company will only attempt to correct conditions causing impairments if they are due to defective operation of telephone plant or improper channel design (see Section 1.4.2.). However, if difficulty occurs because of a design incompatibility between customer-provided equipment and typical Bell System plant, the Telephone Company will not change channels, facilities, or other equipment to eliminate the problem. This is necessary because of the administrative and technical problems which would result if the customers were allowed to specify facility and equipment mixes suitable for their terminal equipment.

4.1 Interface Parameters

The interface parameter specifications are influenced by two considerations: electrical protection of the telephone network and its operating personnel, and standardization of private line design arrangements.

4.1.1 Terminal Impedance and Balance

The recommended impedance of data terminal equipment is 600 ohms ±10% resistive over the voiceband and balanced. The designer of customer-provided equipment should be aware that it is in the best interest of the user that this impedance be realized. The impedance of the Bell System test equipment used for installation tests and trouble tests is 600 ohms resistive. Channels lined up using 600-ohm terminations should be used with 600-ohm terminations to assure transmitted and received signal power is as specified.

It should be noted that the foregoing does not necessarily imply that the Bell System facilities will of themselves present an impedance of 600 ohms to customer-provided equipment. The actual impedance may vary significantly with frequency, and also depend upon the length and type of facility used in the local loop plant. It is also affected by the nature of the Bell System interface equipment used. However, these factors do not prevent the published parameters from being realized, as long as the customer-provided equipment meets the 600-ohm recommendation expressed above.

If there is a substantial mismatch of the terminating impedance with 600 ohms, echoes interfering with the data signal may result, particularly on 2-wire channels (see Section 4.3.11).

If the termination is poorly balanced and there is high noise exposure, e.g., long cable runs or high ambient noise, the noise experienced at the modem may be considerably higher than the noise on the transmission facilities alone. This is due to longitudinally induced noise voltages being converted to metallic noise currents. These noise currents may affect the overall channel performance. In addition, an unbalanced terminal may cause interference in other users' channels. Thus, it is in the customer's and other users' interests to use longitudinally balanced terminal equipment. At present the Bell System has no requirement on the degree of longitudinal balance of customer-provided terminal equipment. The effect of longitudinal imbalance in Bell System facilities is covered by C-message noise measurements.

TABLE 5

CLASSIFICATION OF PARAMETERS

Interface Parameters

1. Terminal Impedance and Balance
2. Isolation from Ground
3. In-Band Data Signal Powers
4. Test Signal Power
5. Distribution of In-Band Transmitted Signal Power (300 to 3000 Hz Nominal)
6. Out-of-Band Transmitted Signal Power
   (a) Above the Voiceband (3995 Hz and above)
   (b) Below the Voiceband (Below 300 Hz)

Bandwidth Parameters

1. Attenuation Distortion (Loss vs. Frequency)
2. Envelope Delay Distortion

Transmission Facility Parameters

1. 1004 Hz Loss Variation
2. C-Message Noise
3. C-Notched Noise
4. Impulse Noise
5. Single Frequency Interference
6. Frequency Shift
7. Phase Intercept Distortion
8. Phase Jitter
9. Nonlinear Distortion (Harmonic Distortion)
10. Peak-to-Average Ratio (P/AR)
11. Echo
12. Phase Hits
13. Gain Hits
14. Dropouts

4.1.2 Isolation from Ground

Interface leads may be connected to exposed cable facilities which are subject to lightning hits and accidental power crosses. Although carbon block protectors are installed on the customer's premises to limit the effect of such occurrences, residual voltages may appear on the interface leads. A common test waveform for lightning surges appearing across the tip and ring leads is a 1000 volt peak surge having a 10 microsecond rise time to crest and a 1000 microsecond decay time to half crest. A common test waveform for lightning surges appearing between the interface leads and ground is a 5000 volt peak surge having a 1.2 microsecond rise time to crest and a 50 microsecond decay time to half crest. Voltages resulting from crosses to power lines will be limited by the carbon block protectors to less than 800 volts peak to ground.

It is recommended that customer-provided terminal equipment be isolated from ground. The dc isolation should be greater than 20 megohms, and the ac isolation should be greater than 50 kilohms for voiceband frequencies. The insulation between the equipment and ground should be able to withstand a test voltage of 1500 volts rms at 60 Hz.

The isolation from ground will eliminate a number of potential electrolysis problems and will tend to reduce noise caused by small imbalances in cables or terminating equipment converting longitudinal currents to metallic noise voltages. In addition, certain tests made to sectionalize troubles may erroneously indicate a failed transmission path if these limits are not met. This may result in an increased outage time when the trouble is not in the local facility but appears to be.

The suggested insulation requirements will protect other customer-provided equipment circuitry from longitudinal line transients.

4.1.3 In-Band Data Signal Powers

The maximum allowable transmitted signal power is as specified by the Telephone Company. The specification applies to all frequencies above 300 Hz. However, the requirements for the spectrum from 3995 Hz and above [see Section 4.1.6(a)] are such that, if they are met, the total power at 3995 Hz and above can be ignored for practical purposes and the total power specification applies to the 300 to 3995 Hz region. In addition, since the voiceband channel is not specified to transmit signals above 3000 Hz (3200 Hz with C4 – conditioning) the in-band data signal power is usually restricted by modem design to the 300 to 3000 Hz region (300 to 3200 Hz with C4 – conditioning.) However, any power between 3000 and 3995 Hz, spurious or otherwise, must be included when determining if the transmitted power specification is met.

The standard transmitted signal power for a voiceband data signal, measured over any 3-second interval, is 0 dBm, rms. (See Section 6.2.5 (d) for an additional restriction on multipoint channels.) In meeting the 3-second average power, it is permissible for the instantaneous signal power to exceed the average power by as much as 13 dB. For the standard channel, at the 0 dBm transmit point the instantaneous signal power must not exceed +13 dBm (3.46 volts peak across 600 ohms resistive). If a nonstandard channel is ordered to interface with a 3-second average transmitted signal power of less than 0 dBm, it is still permissible for the transmitted signal to instantaneously exceed the maximum permitted 3-second average power specified by as much as 13 dB.

The standard 1004 Hz channel loss at the time of installation is 16 dB ± 1 dB. This assumes a 1004 Hz signal transmitted at 0 dBm. Hence, the standard received data signal power is nominally – 16 dBm. On 2000-series channels where data is a permitted use, the channel loss is a function of the channel length and application, and the received signal power is thus also a function of the channel length and application.

Certain older data terminal equipment was designed for different interface signal powers, for example, a –8 dBm transmitted signal and a –16 dBm received signal. Additions to networks using such equipment will be engineered to be compatible with the existing equipment. New data terminal equipment should be capable of transmitting at 0 dBm.

If other than standard transmitting and receiving signal powers are required, (for example, where equipment was designed for different signal powers and will not operate with the present standard), negotiation with the Telephone Company is required. Furthermore, it will be the responsibility of the customer to renew the request on all service additions and channel rearrangements. Additional charges may be applied where nonstandard transmitted or received signal power is specified by the customer. Use of standard transmitting and receiving powers results in standard design and maintenance rules being applied. This benefits the customer directly by avoiding problems, primarily maintenance, associated with unusual designs.

4.1.4 Test Signal Power

Test signals applied by the customer must not exceed the maximum power specified for the data signal. The standard Bell System test signal, applied to a standard design channel, is a 1004 Hz tone at 0 dBm. Higher customer test signal power is a violation of the Tariff. A test signal with power well below the maximum data signal power specified may give erroneous results because of nonlinear channel response with changes in signal power (see Reference 2, pp. 1338-1339).

4.1.5 Distribution of In-Band Transmitted Signal Power (300 to 3000 Hz Nominal)

The signal power limitations given in Section 4.1.3 apply to the total spectrum above 300 Hz. An additional restriction is imposed on the power distribution within the spectrum if the customer requires control signaling which is implemented by the Telephone Company using SF signaling units (see Section 6.8), or uses a modem which accesses the Switched Telecommunications Network. In these cases the modem must not apply signal power in the 2450 to 2750 Hz band which exceeds the power in the 800 to 2450 Hz band. Failure to observe this requirement can cause erroneous signaling information to be transmitted, may adversely affect the data signal on private line channels, or cause disconnection of the call on the Switched Telecommunications Network.

Because tones near 1000 Hz, 2800 Hz and 2713 Hz are frequently applied to private lines for loss and noise measurements, and for control of certain station loopback arrangements, it is preferable to avoid using these frequencies for control purposes. This will help prevent Telephone Company and customer tones from interfering with each other.

4.1.6 Out-of-Band Transmitted Signal Power

Out-of-Band signals are defined to be in either of two regions: above the voiceband (3995 Hz and above) and below the voiceband (below 300 Hz). The limits on out-of-band signal power are applicable to all connections of customer-provided voiceband equipment to Telephone Company facilities. The limits apply to the transmitted signal power at the interface with the Telephone Company.

The out-of-band signal power limits are required to protect Telephone Company personnel from hazardous currents and voltages, and to prevent interference with other services carried on Telephone Company facilities.

(a) **Above the Voiceband (above 3995 Hz)**

The criteria for short duration rms powers are:

(1) The power in the band from 3995 to 4005 Hertz shall not exceed 18 dB below the specified maximum in-band signal power.

(2) The power in the band from 4 to 10 kHz shall not exceed –16 dBm.

(3) The power in the band from 10 to 25 kHz shall not exceed –24 dBm.

(4) The power in the band from 25 to 40 kHz shall not exceed –36 dBm.

(5) The power in the band above 40 kHz shall not exceed –50 dBm.

(b) **Below the Voiceband (Below 300 Hz)**

Where customer-provided equipment applies signals having components in the frequency spectrum below 300 Hz, excluding ringing signals, the currents and voltages (including all harmonics and spurious signals) at the interface shall not exceed the limits indicated in (1) through (4) following:

(1) The maximum rms (root-mean-square) value, including dc and ac components, of the current per conductor will be specified by the Telephone Company but in no case will the specified value exceed 0.35 ampere.

(2) The magnitude of the peak of the conductor to ground voltage shall not exceed 70 volts.

(3) The conductor to conductor voltage shall be such that the conductor to ground voltage limit in (2) above is not exceeded. If the signal source is not grounded, the voltage limit in (2) above applies to the conductor to conductor voltage.

(4) The total weighted rms voltage within the band from 50 to 300 Hz shall not exceed 100 volts. The total weighted rms voltage is the square root of the sum of the products of the weighting factors for the individual frequency components times the square of the rms voltage of the individual frequency components. The weighting factors are as indicated:

For frequencies between	Weighting factor
50 and 100 Hz	$f^2/10^4$
100 and 300 Hz	$f^{3.3}/10^{6.6}$

where f is the numerical value of the frequency, in Hertz, of the frequency component being weighted.

4.2 Bandwidth Parameters

The bandwidth parameters (attenuation and envelope delay are the only transmission parameters with limits specified in F.C.C. Tariff No. 260. They provide an indication of the usable bandwidth of a channel. A summary of these limits is provided in Table 3; intrastate tariffs may differ somewhat in the limits specified.

4.2.1 Attenuation Distortion (Loss vs. Frequency)

One requirement for a channel to provide distortionless transmission is that all signal frequencies experience the same loss in traversing the channel. Typical data channels, however, have variation in loss with frequency. To control the magnitude of this variation, attenuation distortion limits are specified.

Attenuation distortion is a difference in loss at one frequency with respect to the loss at another frequency. It is specified by placing a limit on the maximum loss at any frequency, in a specified band of frequencies, with respect to the loss at a reference frequency. The reference frequency established in this country is 1004 Hz. Table 3 indicates the limits on attenuation distortion for the basic channel and for various grades of C-conditioning.

4.2.2 Envelope Delay Distortion

Another channel requirement for distortionless transmission is a linear phase vs. frequency characteristic. Typical 3002-type channels will only approximate such linearity over the 300 to 3000 Hz nominal voiceband. Measuring the phase vs. frequency channel characteristic directly is difficult because of problems in establishing a phase reference. However, a usable approximation to the derivative of phase with respect to frequency, called envelope

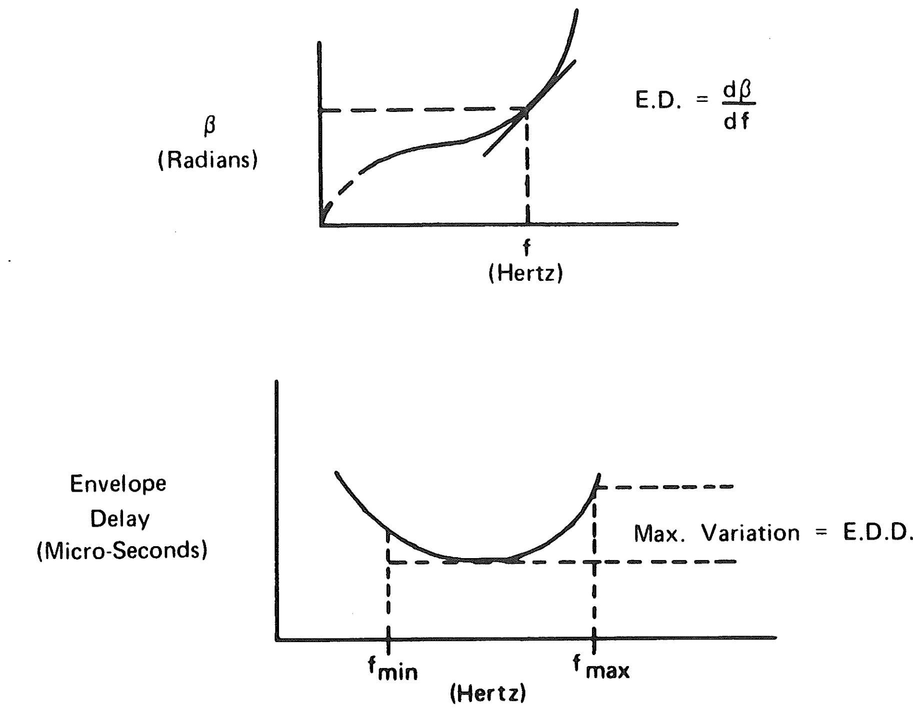


Fig. 5 — Illustration of Envelope Delay Distortion

delay, can be more easily measured. As indicated in Figure 5, the maximum variation in envelope delay over a band of frequencies is called envelope delay distortion. The quality of the channel with respect to its phase characteristic is controlled by limiting the amount of envelope delay distortion allowed (see also P/AR, Section 4.3.10). Table 3 indicates the limits on envelope delay distortion for the basic channel and for various grades of C-conditioning. It assumes the use of an 83-1/3 Hz modulating frequency for the measurement.

The definitions, derivations, and interpretations of envelope delay and envelope delay distortion have caused confusion. The Appendix provides a detailed discussion of these parameters. (See also Reference 3.) The Appendix is for illustrative purposes only. Actual channels may have envelope delay shapes very different from the examples in the Appendix. For example, Figure 6 shows some possible envelope delay curves which meet C2 envelope delay requirements. The shapes of the envelope delay and attenuation characteristics may change with changes in channel routing. After such routing changes, readjustment of manually-equalized modems may be required.

To obtain envelope delay vs. frequency curves meeting C-conditioning requirements, it is usually necessary to insert gain and delay equalizers in the channel. These equalizers tend to place bumps or ripples in the usually smooth unequalized channels. Generally the more heavily equalized channels have more bumps and ripples than lightly equalized or unequalized channels. There are no separate requirements on the number or size of bumps or ripples for either envelope delay or attenuation characteristics, except for the overall limits of Table 3. It should be noted that automatically-equalized modems may be sensitive to delay bumps and ripples. These modems may give better performance on a particular channel with the recommended conditioning than with higher grades of conditioning.

4.3 Facility Parameters

The facility parameters covered in this section represent potential impairments to a data signal that can be caused by typical telephone transmission equipment in conjunction with the environment in which it operates. The limits specified are common to all voiceband data circuits regardless of the conditioning specified.

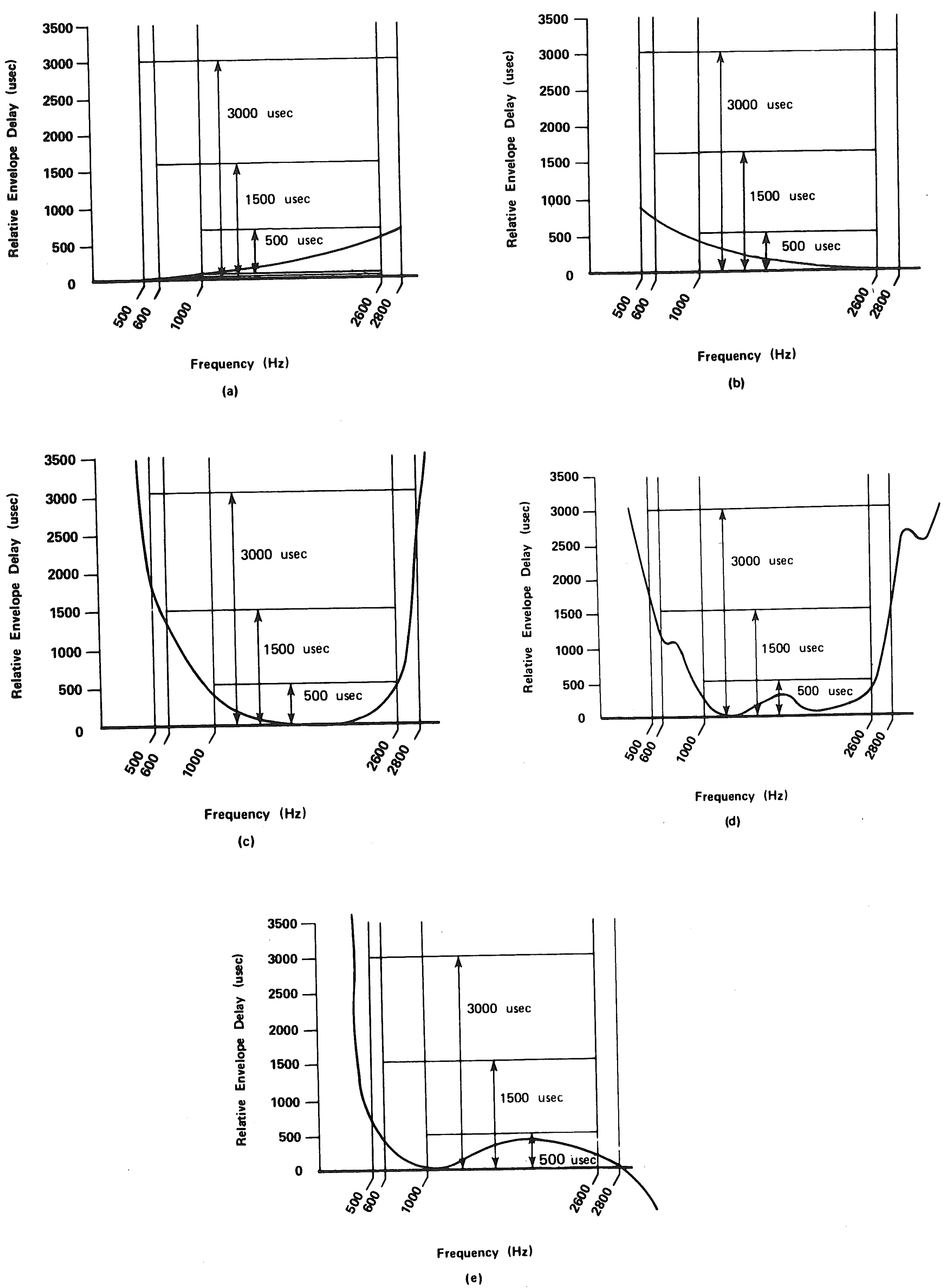


Fig. 6 — Some Examples of Envelope Delay Shapes with C2 Conditioning

In all cases the facility parameters exhibit some variation over a period of time. There is little information on the amount of time variability of these parameters. The parameter limits, unless otherwise stated, apply to measurements of steady-state phenomena and the measurements generally last less than one minute.

Transient phenomena (impulse noise, phase hits, gain hits, dropouts) are measured over longer periods and events meeting certain criteria are counted. The results of either steady-state or transient measurements may vary by time of day, day of week, season of year, or according to some other time dependency. In the face of this uncertainty, the attempt made is to determine the conditions representative of the channel during normal operation.

Limits for parameter values which will be maintained by the Telephone Company are explicity stated as limits. Any other data provided are for informative purposes only. In some cases the information is based on limited studies, and substantial changes may result as new information becomes available.

4.3.1 1004 Hz Loss Variation

As discussed in Section 4.1.3 the standard 1004 Hz loss at channel installation is 16 dB ± 1 dB. However, variations can be expected. Short term loss variation may be caused by dynamic regulation of carrier system amplifiers, switching to standby facilities, and some maintenance activities. "Short term" is meant to be a few seconds or less. Short term variations eventually will be covered by gain hit and dropout limits (Sections 4.3.13 and 4.3.14). The limit on short term variations is ±3 dB.

Long-term variations are primarily caused by temperature changes affecting local plant; component aging, amplifier drift, and other phenomena also contribute. "Long term" is meant to be periods of days, weeks, or even longer. Long-term variations are corrected during periodic routine measurements. They should not exceed ± 4 dB with respect to the nominal 16 dB channel loss, i.e., the 1004 Hz loss must be between limits of 12 and 20 dB.

4.3.2 C-Message Noise

C-message noise is a weighted measurement of the background noise on a channel in the absence of a signal. It is measured with an rms-responding noise measuring set such as the Western Electric 3C Noise Measuring Set. The weighting used is provided by a C-message filter (see Figure 7). Although originally developed for

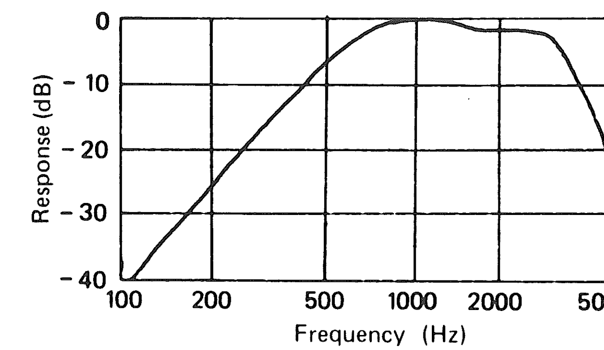


Fig. 7 — C-Message Frequency Weighting

voice applications, C-message weighting has been found to be quite useful for data applications as well. It offers less than 5 dB attenuation in the 600-3000 Hz band of interest for most voiceband data transmission, and sharply attenuates low frequency components, such as 60 Hz and its low harmonics, and high frequency components above 3200 Hz. Substantial low frequency noise components may be masked in measuring message noise by the attenuation of the C-message filter below approximately 500 Hz. In particular, 60 Hz and its harmonics up to 300 Hz may be present at relatively high levels. Use of the spectrum below 300 Hz is not recommended because of the frequent presence of these interfering tones; protection against low and high frequency noise should be provided by filtering or other suitable means. It is estimated that the flat-weighted noise below 300 Hz will average approximately 40 dBrn* (−50 dBm) and that infrequently it will be below 25 dBrn (−65 dBm) or above 55 dBrn (−35 dBm).

* 0 dBrn = −90 dBm by definition.

The C-message noise limits at the modem receiver are given in Table 4. These limits assume a standard −16 dBm received signal power design. They are particularly important for modems operating without continuously present received signals since they apply to the channel in the idle condition. In the voice mode, with Bell System-provided telephone sets and alternate voice/data operation, the noise measured at the telephone set will differ from that measured at the modem. The differences, which are dependent upon the type of Bell System-provided telephone set used (2- or 4-wire), are due to channel designs which improve the quality of speech transmission as measured by subjective tests. The noise limits of Table 4 are the only limits which apply to alternate voice/data service.

4.3.3 C-Notched Noise

The C-message noise described in Section 4.3.2 often is not the principal noise experienced when a signal is present. Quantizing noise in digital carrier systems and the effect of compandors in both digital and some analog systems result in signal dependent noise. Thus, the ratio of the received power of a 1004 Hz test tone to the received C-message noise power is not a reliable indication of the signal-to-noise ratio.

C-notched noise is a measure of the amount of noise on a channel when a signal is present. In making this measurement, a single frequency 0 dBm "holding tone", currently 2804 Hz,* is applied at the transmitting end of the channel to act as a signal. This tone operates compandors and other signal-dependent devices, and thus simulates a data signal. At the receiving end, the tone is removed by a narrow band elimination filter (notch filter) and the noise is then measured through a C-message filter. The ratio of the received 1004 Hz test tone power to the C-notched noise power is indicative of the signal-to-noise ratio on the channel. The limit for the received 1004 Hz power to C-notched noise power ratio is a minimum of 24 dB. Since the nominal standard receiving power is −16 dBm (74 dBrn), the nominal C-notched noise limit is 50 dBrnc at the receiver on standard-design channels.

4.3.4 Impulse Noise

Impulse noise is characterized by large peaks, or impulses, in the total noise waveform. It is measured with an instrument which counts impulses greater than a selected threshold value, using a counter having a maximum counting rate of approximately seven counts per second. Measurements are made through a C-message filter. A 0 dBm 2804 Hz** holding tone is transmitted and notched out at the receiver to activate any compandored facilities in the channel.

The usual impulse noise measurement at installation for 3002-type channels involves counting the number of noise peaks exceeding a threshold numerically 6 dB below the received 1004 Hz test tone power. For a standard 16 dB loss channel, the threshold is −22 dBm or 68 dBrnc, and the limit is 15 counts in 15 minutes. In addition, there are limits of 9 counts in 15 minutes at a threshold 2 dB below the received 1004 Hz test tone power, and 5 counts in 15 minutes at a threshold 2 dB higher than the received 1004 Hz test tone power. These additional limits are designed to cover cases where impulses of relatively high power would interfere substantially with data transmission but the channel would pass the single threshold test.

Note that the measuring instrument has a maximum counting rate of approximately 7 counts per second. This results from having a "dead time" of approximately 150 milliseconds after registration of an impulse exceeding the threshold. Any other impulses occurring during this dead time will not be counted. A high-speed counter with no dead time will read as many counts as, and usually more than, the standard measuring set. To illustrate this point, Figure 8

* A 1004 Hz holding tone will be used in the near future.

** A 1004 Hz holding tone will be used in the near future.

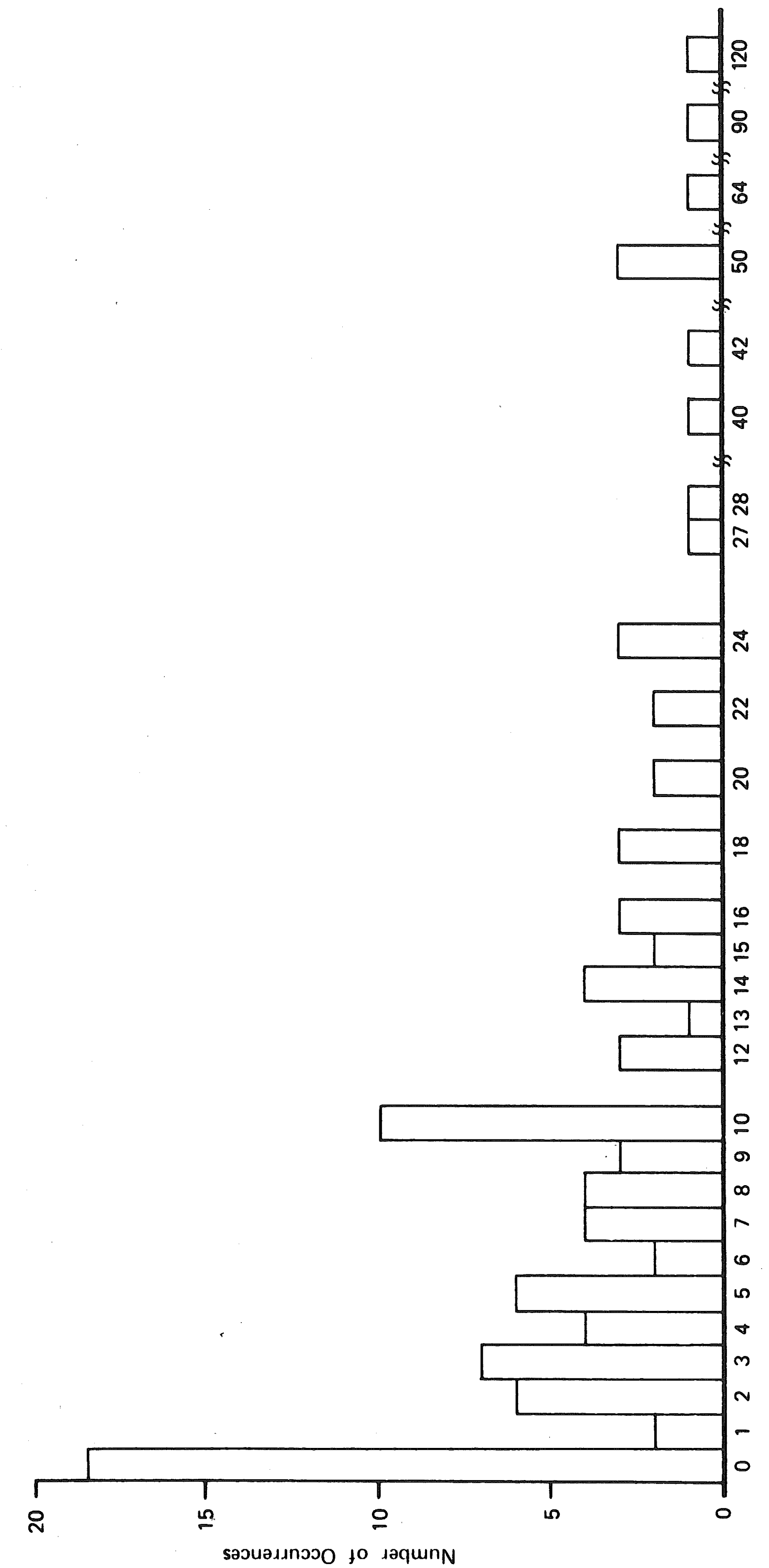


Fig. 8 — Example of the Number of Impulses Not Counted in a 30 Minute Period by an Electromechanical Counter. (Threshold of Counter Adjusted to Produce Exactly 30 Counts in 30 Minutes.)

shows the results of approximately 100 channel measurements. In these measurements, the threshold on an electro-mechanical counter was adjusted to produce 30 counts in 30 minutes. A high-speed counter set for the same threshold simultaneously recorded the number of impulses, including those occurring in the dead time of the electro-mechanical counter. Generally, the higher number of counts registered by a high-speed counter does not correlate well with data transmission performance where block retransmission error control is used since the "additional" impulses are quite likely to occur in blocks in which another impulse has already occurred. An adjustment for the average number of "missed" impulses is made when impulse noise limits are established.

The distribution of impulse noise peaks on telephone facilities is such that for each 7 dB increase in the threshold, the expected number of counts decreases by an average factor of 10. A channel just meeting the limit of 15 counts in 15 minutes at a threshold 6 dB below the received 1004Hz data test tone power would have an estimated 1.5 counts in 15 minutes exceeding a threshold 1 dB above this power. (Note that the impulse noise limits allow as many as 5 counts in 15 minutes exceeding a threshold 2 dB above the received data test tone power.)

4.3.5 Single Frequency Interference

Spurious single-frequency tones may interfere with certain data signals, particularly narrowband signals which are frequency-division multiplexed onto a voiceband channel. Message circuit noise will be distributed across the voiceband, so the noise power in each narrowband channel will be less than the total noise power, and the signal-to-noise ratio per channel may be quite adequate. If, however, a single-frequency tone of substantial power is present, it may interfere with one of the narrowband channels. The limit for single-frequency interference is that the noise contribution at any frequency should, when measured with C-message weighting, be at least 3 dB below the C-message noise power limit at the modem receiver as given in Table 4.

4.3.6 Frequency Shift

Most long haul carrier systems operate in a single sideband suppressed carrier mode. Because the carrier is not transmitted and must be reinserted, there may be a slight difference in frequency between the modulating and demodulating carriers. The resulting frequency shift contributes a constant change at all frequencies in the voiceband. Substantial frequency shift can degrade some data demodulation processes and can cause high distortion in narrowband frequency division multiplex systems.

The limit on frequency shift for the overall channel is ±5 Hz.

4.3.7 Phase Intercept Distortion

When single sideband suppressed carrier transmission systems are used in the Bell System, the phase of the reinserted carrier with respect to the phase of the modulating carrier is not controlled. The result is phase intercept distortion, which contributes a constant phase shift to all frequencies present in the voiceband signal. It appears as the phase intercept at zero frequency on a graph of phase vs. frequency for carrier-derived channels. Phase intercept distortion will affect any signal in which preservation of the phase relationships in the transmitted waveshape is important. A modem designed to operate over a channel having frequency shift should not experience difficulties due to phase intercept distortion. Since data sets can be designed to circumvent phase intercept distortion by frequency translation of baseband signals and local demodulation of carrier from the received waveform, no limit on phase intercept distortion exists and none is contemplated.

4.3.8 Phase Jitter

Various sources cause the instantaneous phase, or zero crossings, of a signal to "jitter" at rates normally less than 300 Hz. This phase jitter is typically caused by ripple in the dc power supply appearing in the master oscillator of long haul carriers and then passing through many stages of frequency multipliers. Some phase jitter

occurs in short haul systems from incomplete filtering of image sidebands. Digital carrier systems also will exhibit phase jitter at certain input frequencies. The most common jitter frequencies are 20 Hz (ringing current) and 60 Hz (commercial power), and the second through fifth harmonics of each of these.

Measurement of phase jitter is made with an instrument sensitive to frequencies within 300 Hz of an approximately 1004 Hz carrier (see Reference 3 for more detail). Noise may strongly influence this measurement, so phase jitter should be measured with a test tone at data level. The overall channel limit for phase jitter is 10° peak-to-peak.

4.3.9 Nonlinear Distortion (Harmonic Distortion)

Nonlinear distortion is that portion of a channel output which is a nonlinear function of the channel input. It is presently measured by transmitting a 0 dBm 704 Hz tone and observing the received 1408 Hz power (second harmonic) and 2112 Hz power (third harmonic). The fundamental-to-second harmonic ratio limit is 25 dB and the fundamental-to-third harmonic ratio limit is 30 dB.

Although the present measuring method provides an adequate indication of the degree of nonlinear distortion for many transmission facilities, it has some drawbacks, particularly where digital (PCM) transmission systems are involved. For this reason, a new measurement technique is being implemented. With this technique two pairs of closely-spaced tones centered at frequencies A and B will be transmitted. Distortion products will be measured through narrowband filters centered at 2B-A, B-A, and A + B. (Frequencies A and B are 860 Hz and 1380 Hz, respectively; the limits for the distortion products are not yet specified.) The new method will provide less variable measurements for PCM systems than does the present method.

4.3.10 Peak-to-Average Ratio (P/AR)

As indicated in Section 4.2.2, envelope delay is measured because of difficulties in measuring the true phase characteristic. Reference 3 discusses some of the approximations made in designing envelope delay test sets. These approximations, and the time consuming procedure required to first measure envelope delay and then determine if envelope delay distortion limits are met, led to the development of the peak-to-average (P/AR) test set.

The transmitted P/AR signal is a train of shaped pulses with a high peak-to-average ratio (hence the name). As the signal traverses a channel the pulses tend to spread in time as the different frequency components experience different delays. This spreading decreases the peak-to-average ratio. The received peak-to-average ratio is converted into a P/AR rating on a scale from 0 to 100. P/AR provides a single measurement which is strongly affected by phase distortion, thus overcoming some of the problems with envelope delay distortion tests. P/AR is sensitive to a lesser extent to attenuation distortion and C-notched noise.

A further advantage of P/AR measurements is that they can be made on 2-wire channels, whereas most methods of measuring envelope delay require a 4-wire channel.

P/AR limits for the 3002 channel with various C-type conditionings have been established on a trial basis, but P/AR at present is not normally measured.

4.3.11 Echo

Impedance mismatches in a channel cause echoes to be returned to the transmitter (talker echo) or the receiver (listener echo). The impedance mismatches may occur at numerous locations in the channel, but the major contributors to echo problems occur at the interface between 2-wire and 4-wire operation (hybrid transformers). Figure 9 indicates some typical echo paths.

Channels designed for half-duplex operation will have a listener echo at least 12 dB below the received signal, provided the terminating impedances are reasonably close to 600 ohms resistive across the voiceband. An impedance of 600 ohms ± 10% will satisfy this condition.

Channels designed for duplex operation have separate paths for each direction of

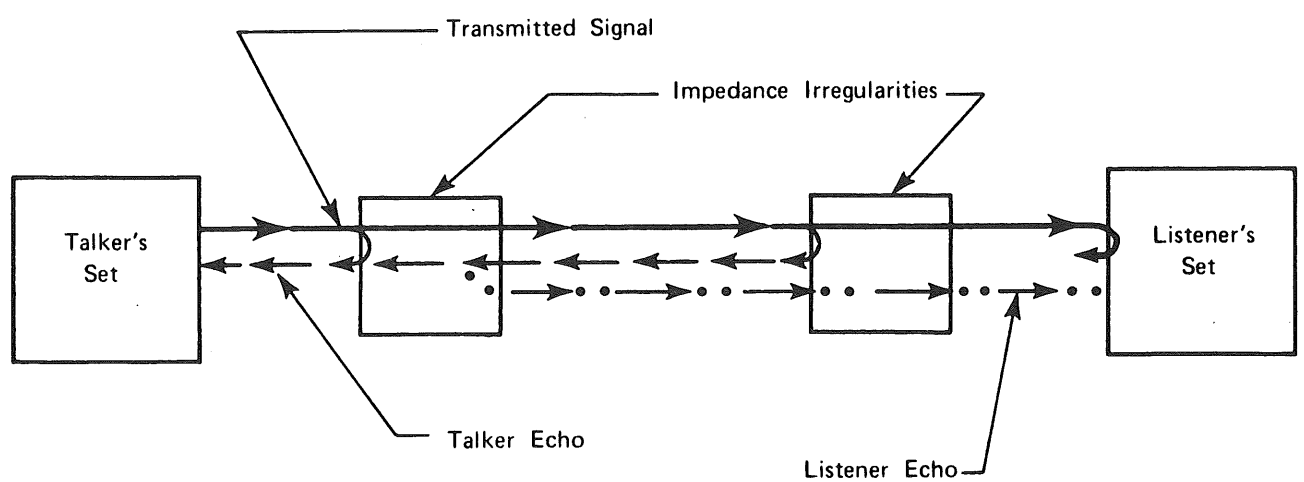


Fig. 9 — Echo Paths on a Two-Wire Transmission Line

transmission. The talker echo in this case will be at least 35 dB below the standard received signal.

For half-duplex operation with 2-wire data sets, particularly in multipoint and polling applications, turn-around times on the order of 200 milliseconds are required to assure that echoes have decayed, and the new transmission signal path stabilized, before data transmission can begin to a new pair of stations.

Absolute delay (propagation time) is discussed in Section 6.10.

4.3.12 Phase Hits

Phase hits are sudden uncontrolled changes in phase of the transmitted signal. Phase hit activity on Bell System transmission facilities is being characterized. Characterization of this parameter includes determining the distribution of hit magnitudes in degrees, the duration of the hits, the number of occurrences in a fixed period of time, and their time variability. Limits are under consideration to determine their feasibility.

The threshold at which phase hit activity is specified will be at least 20°, i.e., no limits are contemplated for phase hits under 20° . A recent limited study of phase hit activity on long channels indicated an **average** of 2.9 phase hits per hour, where the phase hit was at least 22.5° in magnitude and 2 milliseconds in duration. Approximately one-third of these lasted more than 20 milliseconds. Observed phase hits have included cases where:

1. The signal jumps to a new phase and then returns within a few milliseconds.
2. The signal jumps to a new phase and then returns after approximately 25 milliseconds.
3. The signal jumps to a new phase and remains there.
4. The signal continually changes phase over a period which may exceed one second.

The last of these can be viewed as a short duration frequency shift rather than a phase hit.

Measurement of phase hits is complicated by the effect impulse noise spikes have on most phase hit detectors. Various methods for preventing impulse noise from being counted by a phase hit counter are under investigation. Customers making their own measurements of phase hits should be aware that many apparent

phase hits are actually caused by impulse noise, and that there are separate limits on impulse noise (see Section 4.3.4).

At the present time there are no limits for phase hits on Bell System services.

4.3.13 Gain Hits

Gain hit activity, like phase hit activity, is being characterized for Bell System transmission facilities. Gain hits are sudden uncontrolled changes in the gain (or loss) of the channel. They are not impulse noise spikes, which rarely last more than 4 milliseconds. and almost never longer than 10 milliseconds. Gain hits usually last longer than impulse noise spikes, and occasionally considerably longer. They can be characterized by the distribution of hit magnitudes in dB, duration of the hits, the number of occurrences in a fixed period of time and their time variability. Limits are under consideration to determine their feasibility. At present there are no limits for gain hits on Bell System services.

In order to avoid possibly frequent errors due to transient gain changes, modems should be able to withstand gain changes of at least ±3 dB, where these changes may occur at a rate of up to ±1 dB per 0.15 milliseconds. A recent limited study on long channels indicated an **average** of 3.4 gain hits per hour, where the gain hit was at least 3 dB in magnitude and 2 milliseconds in duration. An average of 2.7 such hits per hour lasted more than 5 milliseconds, and 2.0 lasted more than 20 milliseconds.

4.3.14 Dropouts

Dropouts are large reductions in channel gain. An extreme example occurs when channel continuity is interrupted, resulting in an open circuit. Deep fading of radio facilities, and defective components can cause dropouts. As with phase hits and gain hits, droupout activity is being characterized for Bell System transmission facilities. Dropouts are characterized by the length of time channel gain goes below some threshold (currently 18 dB below the standard test signal) and remains below the threshold, the number of occurrences in a fixed period of time, and their time variability. Limits are under consideration to determine their feasibility. At present there are no limits for dropouts on Bell System services.

A recent limited study of dropouts on long channels indicated an **average** of 0.7 dropouts per hour, where the dropout had an increase in loss of at least 10 dB and a duration of at least 20 milliseconds. There were very few dropouts which lasted less than 20 milliseconds. Current dropout measuring equipment registers a dropout when the loss increases by at least 18 dB for at least 300 milliseconds.

5. INTERFACE ARRANGEMENTS

The interface between Bell System facilities and customer terminal equipment depends upon the service desired and who provides the modems, telephone sets, and other terminal equipment.

5.1 Bell System-Provided Modems

Where Bell System data service is ordered, the interface with customer terminal equipment is as specified in the Bell System Technical Reference describing the modem used. If alternate voice/data operation is ordered, the Bell System will provide the telephone set and the means for switching between modes. Arrangements for backup service using the Switched Telecommunications Network may also be available. (See Section 8.2.)

5.2 Customer-Provided Modems

Where the customer chooses to provide his own modems, the Bell System interface with the customer will usually consist of standard terminal blocks or terminal strips, although 549A jacks or other similar simple termination devices are available. Figure 10 shows the standard 549A arrangement. More elaborate arrangements (such as keys, cabinets, and patching panels) can be negotiated with the Telephone Company. Where 4-wire terminations are provided, the red and green wires are the transmit pair and the yellow and black wires are the receive pair. (An exception to this rule may occur on an intrabuilding channel using only "house cable.")

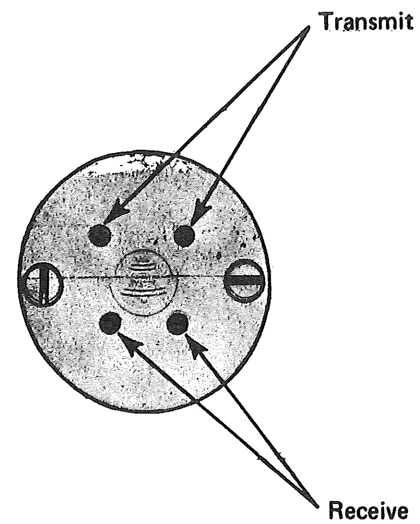


Fig. 10 — Wiring Arrangement for a 549A Jack

If alternate voice/data service is required with customer-provided modems, the telephone set may be provided by either the customer or the Telephone Company. A customer choosing to provide the telephone set is responsible for switching between data and voice modes, end-to-end mode signaling, and amplifying and/or attenuating the voice signal to the proper level. Network protection criteria must be met for both the data and voice transmitted signals. A customer providing the modem and desiring backup service using the Switched Telecommunications Network must provide the arrangement to transfer between the private line channel and the switched network. Access to the switched network must be through a Telephone Company-provided Data Access Arrangement.

6. DESIGN CONSIDERATIONS

The following sections discuss engineering considerations which affect the design and operation of data communication systems. These are of importance regardless of whether Bell System or customer-provided modems are used.

6.1 2-Wire and 4-Wire Channels

As indicated in Section 2.6, 2-wire channels may consist partly or entirely of 2-wire transmission facilities. As a result, the two directions of transmission are not physically separated, and echo (signal energy reflected from impedance mismatches) may be an important consideration in system operation. Echoes on 2-wire channels may cause intersymbol interference or false start-up unless they are considered in modem design and system operation. (See Section 4.3.11.)

Four-wire channels are required for data systems that simultaneously utilize the same portion of the bandwidth in both directions of transmission, or do not permit sufficient turnaround time for the decay of echoes. On large multipoint channels (more than 6 points) 4-wire channels are normally required to prevent "singing" and high level echoes. Four-wire channels offer significant advantages on multipoint polling systems where remote stations need not communicate directly with each other. The advantages include more points, faster turnaround time, and simpler safeguards for preventing false remote station start-up.

6.2 Multipoint Channels

Multipoint channels are used to communicate among more than two customer locations. There are three basic types of multipoint channel which will be discussed here. They are the **broadcast multipoint**, the **conference multipoint**, and the **broadcast polling multipoint.** There are also combinations of these arrangements, as well as additional configurations to meet special customer requirements. The physical constraints applicable to the three types discussed are generally applicable to other configurations as well.

Broadcast Multipoint

The broadcast multipoint consists of a single master station which transmits to two or more remote stations. Figure 11 illustrates a simple 6-point multipoint with five remote stations served from two bridging locations. There is no return path from the remote stations back to the master station, and the remote stations cannot communicate with each other. The broadcast multipoint uses a 2-wire channel arranged for simplex operation.

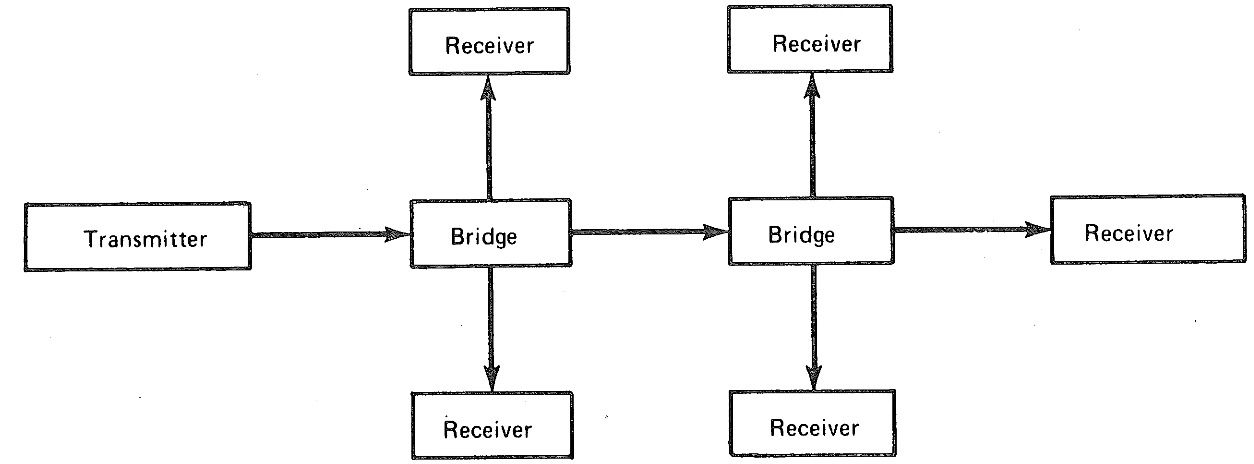


Fig. 11 — Broadcast Multipoint Example

Conference Multipoint

The conference multipoint consists of a number of stations connected together so that transmissions from any station are received by all other stations. Only one station at a time may transmit on a given frequency. Figure 12 illustrates a 7-point conference multipoint.

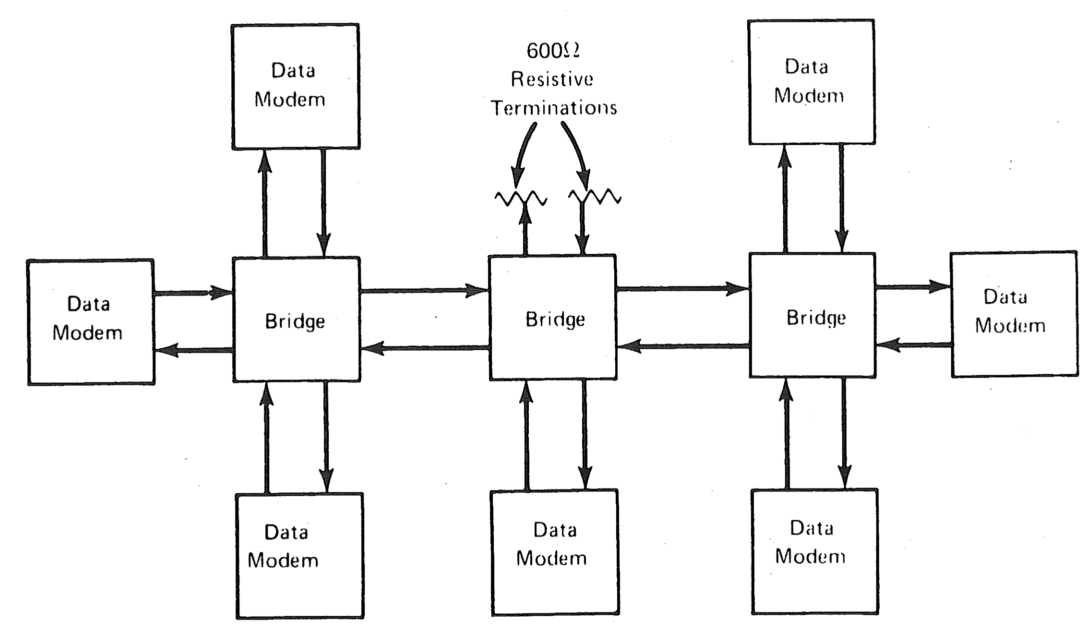


Fig. 12 — Conference Multipoint Example

Since more than six points are involved, it is shown using a 4-wire channel.

Broadcast Polling Multipoint

The broadcast polling multipoint consists of a single master station and two or more remote stations (sometimes called "slaves"). Transmissions from the master station are received by all remote stations. Transmissions from the remote stations are received only by the master station. Figure 13 illustrates a broadcast polling multipoint. A 4-wire channel is required. This is the most commonly ordered multipoint for data applications. In a typical operation, requiring 4-wire channels, the master station is transmitting carrier continuously to all remote stations. The master station polls a remote station by sending a discrete address code which will be recognized by the particular remote station polled. (All remote stations received the poll but only one is activated by the address information in the poll.) If the remote station has no business to transact with the master, a negative response is made and the master polls another remote station. If the remote station has business to transact with the master, a positive response is made and the transaction is completed before the next poll is made. Any transactions between remote stations must be made through the master, since no direct communication is possible between the remote stations.

6.2.1 Traffic Considerations

With broadcast multipoints there is no contention for the channel, and the network is limited only by the rate at which the master can transmit (consistent with the analog transmission characteristics of the channel).

With conference multipoints one station seizes the entire network for the duration of its transmission. If another station transmits simultaneously on the same frequency, the messages will interfere. Operational procedures to avoid simultaneous seizures and simultaneous transmissions are required for orderly network operation. With many active stations, an individual station may encounter long delays before it can seize the network. Thus, traffic considerations usually limit the number of stations on conference multipoints.

With broadcast polling multipoints the master station completely controls the network. Since there is no contention for the network, the master station can perform the polling quite rapidly. If the remote stations are likely to respond negatively to the poll, and to send short messages with a positive response, or if long times are allowed between successive polls of the same station, it is possible from a traffic standpoint to have a very large number of remote stations on this type of multipoint. Transmission impairments or network availability may be more limiting on the size of the network or the number of points than traffic considerations.

6.2.2 Number of Points

The variety of transmission facilities involved in implementing channels, the variability of the analog parameters on these facilities, variations in modem impedances, the type of channel provided (2-wire or 4-wire), and a number of other physical factors make it difficult to establish precise rules for the maximum number of points on a multipoint network. The following should be considered as guidelines: (Section 6.2.3 should be consulted for mileage limitations.) The complexity of networks consisting of more than approximately 20 points is such that the time required to restore service following outages, and the increased number of outages as the number of points increases, cause channel availability to be less than can be tolerated by many data systems. This is the origin of the recommendation that careful consideration to channel availability be given if systems requiring more than 20 points are contemplated.

Broadcast Multipoints (Simplex)

Broadcast multipoints can be considered as a collection of 2-point networks in terms of analog transmission performance and channel

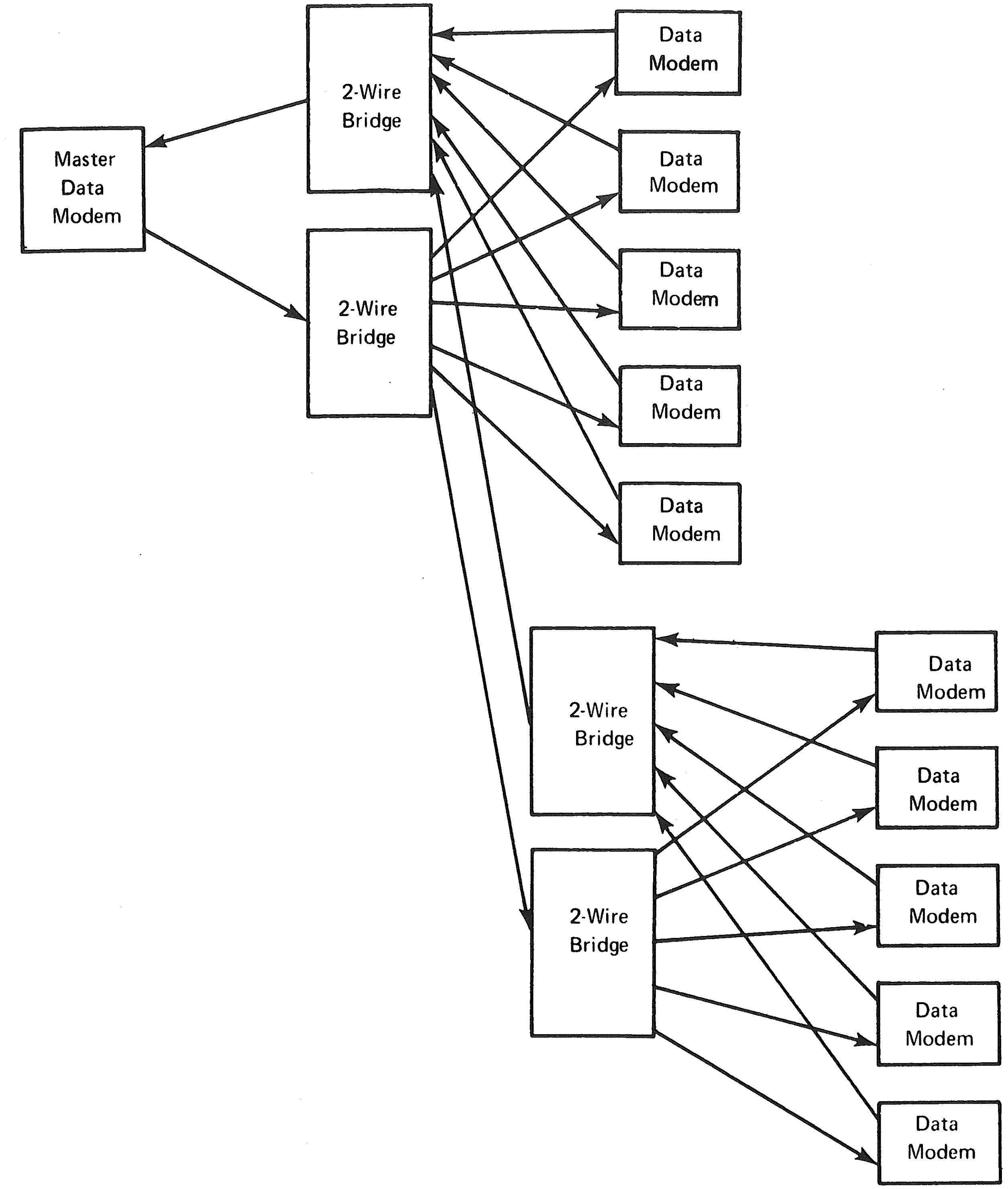


Figure 13 — Broadcast Polling Multipoint Example

availability. In general the availability of the channel will decrease as the number of points increases, assuming that all points must be operable or the channel is considered unavailable. If more than 20 stations are on the channel, availability of the entire channel at any given time may become a problem. There are some systems of this type having hundreds of stations, but care must be taken in planning such systems to allow for the fact that at any given time one or more stations may not be available due to channel or station outages.

2-Wire Conference Multipoints

Customers may find it economically advantageous to order conference multipoints provided on 2-wire channels, particularly where intraexchange services are involved. The inherent stability problems on large 2-wire conference multipoints will usually restrict the network to a maximum of six points.

4-Wire Conference Multipoints

The availability of 4-wire conference multipoint channels will usually be satisfactory for up to 20 stations. If 2-wire stations are used on such networks it may not be possible to provide an electrically stable network for much in excess of 20 points, and fewer if there is an impedance problem with the modem, even if the 4-wire to 2-wire conversion is done at the interface of the analog channel with the modem. If 4-wire stations having electrically independent transmit and receive sides are used, channels having large numbers of points are physically possible. Usually, however, traffic considerations will be limiting before the 20 point availability guideline is reached.

Broadcast Polling Multipoints

Networks designed for broadcast multipoint polling must be 4-wire (2-wire multipoints could be used for broadcast polling operation, but every remote station would receive all messages generated anywhere in the network, and some of the advantages of the broadcast polling design would be lost.) Although 2-wire stations could be used on small networks (fewer than six points), 4-wire stations having electrically independent transmit and receive sides may be required to eliminate echo and stability problems on large networks. The comments on the number of points for 4-wire conference multipoints apply to this case as well, with the exception that traffic considerations frequently do not limit the number of stations to as few as 20.

6.2.3 Mileage Limitations

In addition to stability and availability considerations which affect the number of stations on multipoint networks, there is an additional constraint required to assure transmission parameter limits are met. The constraint is that a receiving station cannot be directly connected to more than 4000 miles of transmission facilities or else the transmission parameter limits given in Section 4 will not be supported. Transmission facilities "directly connected" are those which are carrying the transmitted signal or those which can feed noise into the signal path. The three types of multipoint networks described above will be used to illustrate this principle.

Broadcast Multipoints

The only facility miles directly connected to a particular receiver in a broadcast multipoint are those actually carrying the signal to that receiver. This is illustrated in Figure 14 where Transmitter A is transmitting to Receiver B over the facilities marked by the heavy lines. Any noise generated on facilities shown as lighter lines would not be fed into the signal path, since there are normally amplifiers in these facilities or at the bridges which would prevent noise being fed back into the signal path. Hence, the analog parameter limits of Section 4 will be supported

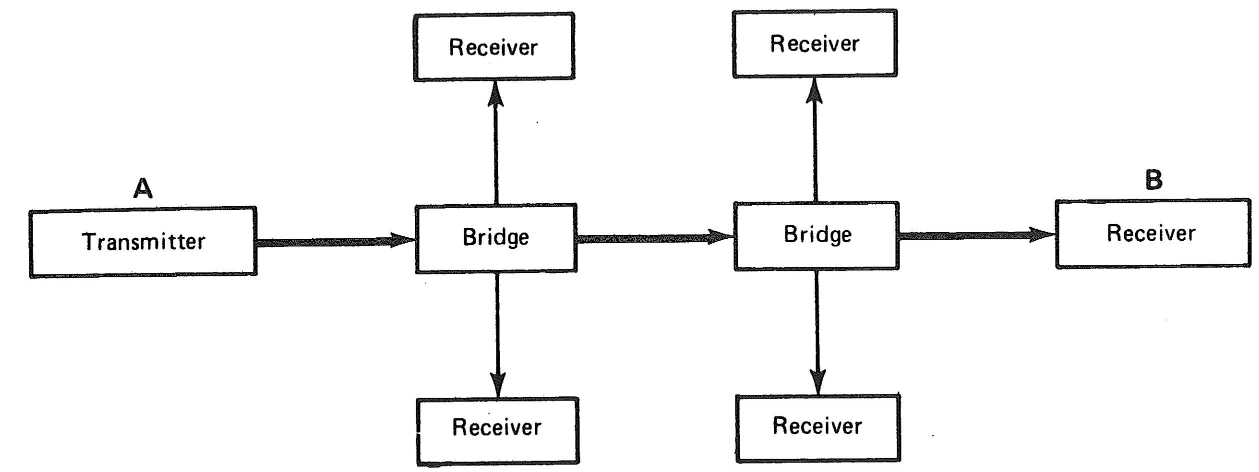


Fig. 14 – Directly Connected Facility Miles – Broadcast Multipoint Example

between the transmitter and any receiver not more than 4000 facility miles distant (see Section 6.2.4 for computation of approximate facility mileage).

Conference Multipoints

The facility miles directly connected to a particular receiver in a conference multipoint include all the facility miles between the transmitters of all the other modems on the channel and the particular receiver. As illustrated in Figure 15 where Modem A is transmitting to Modem B, the facility miles shown as heavy solid lines are carrying the signal and the facility miles shown as heavy dotted lines act as "noise antennas" feeding noise into the path of the signal. Hence, the

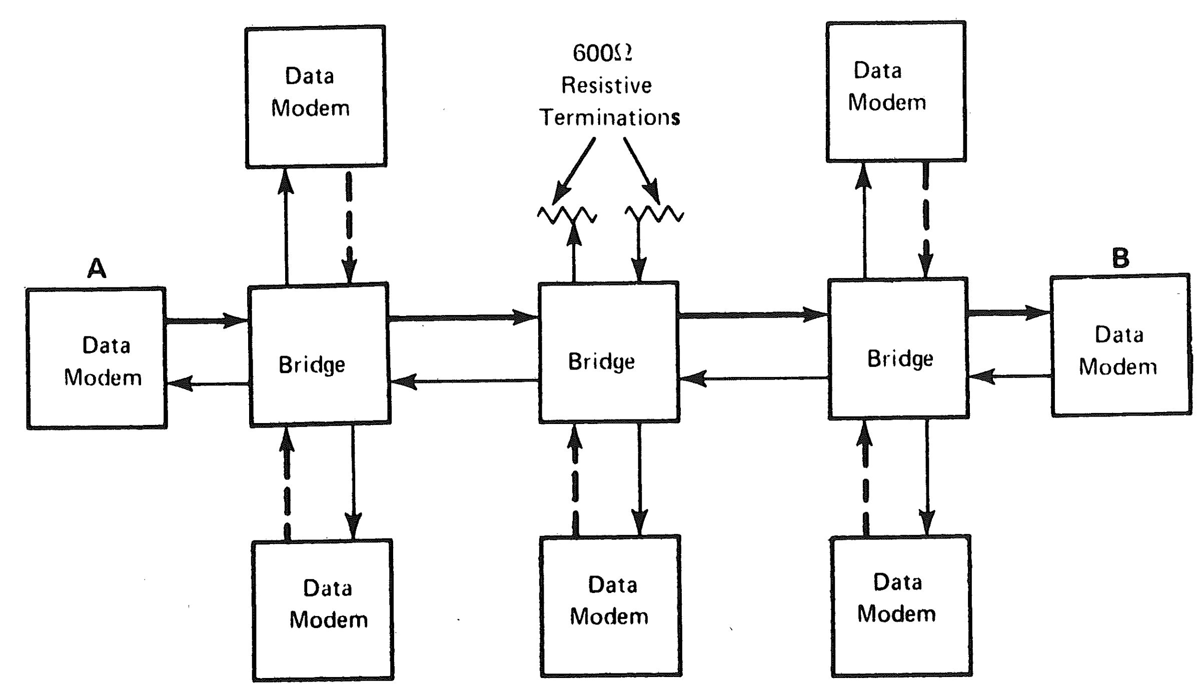


Fig. 15 – Directly Connected Facility Miles – Conference Multipoint Example

analog parameter limits of Section 4 will be supported on a conference multipoint as long as the total number of facility miles in the multipoint does not exceed 4000. Note that the computation of facility miles involves only one direction of transmission, e.g., in Figure 15 it is the sum of the facility miles shown as heavy solid and heavy dotted lines, and excludes the return paths shown as lighter lines. Note also that regardless of the receiver picked the facility mileage does not change.

Broadcast Polling Multipoints

The broadcast polling multipoint can be considered as a broadcast multipoint for transmissions from the master station, and as similar to a conference multipoint for transmissions to the master station. As illustrated in Figure 16, the controlling condition is the number of facility miles directly connected to the receiver of the master station. Transmission from Modem A to Modem B is

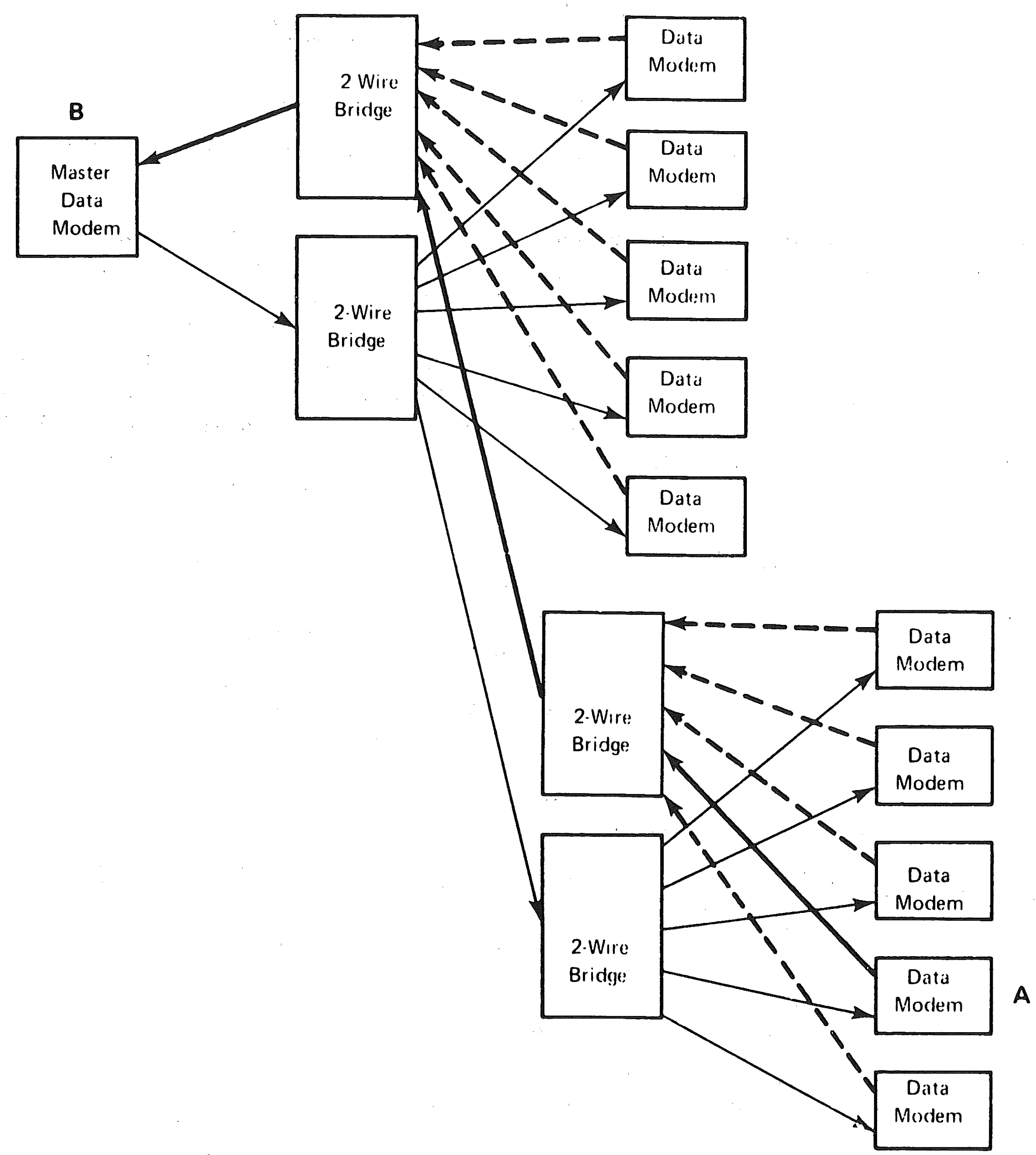


Fig. 16 – Directly Connected Facility Miles – Broadcast Polling Multipoint Example

over the path shown as a heavy solid line, but all the paths shown as heavy dotted lines may feed noise into the transmission path. As with the conference multipoint, the analog parameter limits of Section 4 will be supported if the total facility mileage (heavy solid and dotted lines) in the multipoint does not exceed 4000 as determined by the Telephone Company's actual channel design.

6.2.4 Computation of Facility Mileage

To approximate the facility mileage in a multipoint channel, the following procedure is suggested as a guideline to aid the customer in determining the size of his proposed network. Interconnect all the proposed points by means of bridges (see previous examples). For the purpose of estimation, placement of the bridges can be arbitrary. The bridge placement by the Telephone Company, and even the number of bridges used, may be quite different on the actual channel. No acceptable configuration may have more than five bridges between any transmitter and an allowed receiver. (In Telephone Company terminology, the facilities connecting stations with bridges or switches are known as "end links" and the facilities connecting two bridges, two switches, or a bridge and a switch are known as "middle links." An acceptable configuration does not allow a transmitted signal to traverse more than four middle links.) If two stations on a 4-wire channel are less than 1500 cable feet apart, one may be considered as an extension of the other and together they will constitute a single point for engineering purposes. If they are more than 1500 cable feet apart, or if they are on 2-wire channels, they are considered as separate points for engineering purposes and served over separate end links from a bridge.

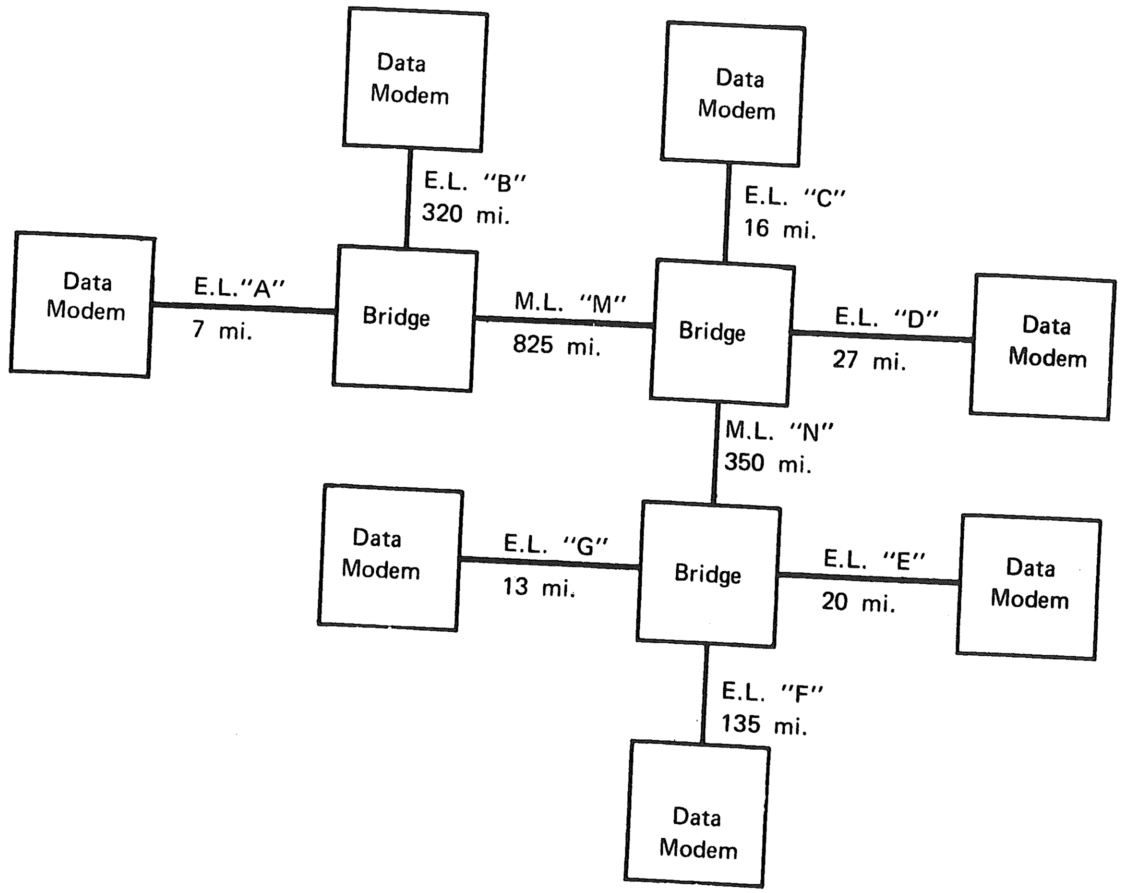
Once the multipoint has been configured, the airline mileage for each end link and middle link should be determined. Table 6 can be used to convert airline miles to approximate facility miles. The facility miles can then be summed as indicated in Section 6.2.3 to determine whether the 4000 facility mile guideline has been met or exceeded.

As an example, assume a channel as shown on Figure 17. It is assumed that this channel is the result of laying out a multipoint according to the bridging rules given above. Figure 17 illustrates how to convert the airline miles to approximate facility miles using Table 6. For example, in the mileage band 0-200 miles there are 6 links

TABLE 6

MULTIPLICATION FACTORS FOR CONVERTING
AIRLINE MILEAGE TO APPROXIMATE FACILITY MILEAGE

Airline Mileage Bands	Number of Links in Mileage Band 1 – 4	5 – 9	10 or more
0-200	3.0	2.5	2.2
201-750	2.5	2.1	1.8
751-2000	2.0	1.7	1.5
2001-3000	1.5	1.4	–
3001-4000	1.3	–	–
Over 4000	1.2	–	–



Mileage Band	Link	Airline Miles	Airline Miles in Band		Conversion Factor*		Approx. Facility Miles
0-200	A	7					
	C	16					
	D	27					
	E	20					
	F	135					
	G	13					
201-750	B	320	218	x	2.5	=	545 Miles
	N	350					
751-2000	M	825	670	x	2.5	=	1675
			825	x	2.0	=	1650
					Total		3870 Miles

* From Table 7

Figure 17 – Multipoint Facility Mileage Computation Example

totaling 218 airline miles. From Table 6, for the 0-200 mile band and five to nine links, the conversion factor is found to be 2.5. Thus, approximately (2.5) (218) = 545 facility miles are contributed by these six links. The computations indicate that there are approximately 3870 facility miles in this channel giving it nearly the maximum mileage for which the analog parameter limits will be supported. The actual number, however, must be determined by the serving Telephone Company.

6.2.5 Additional Considerations on Multipoint Channels

(a) Multipoints Exceeding Guidelines

The Telephone Companies, at the request of the customer, will attempt to design and build multipoint channels which exceed the number of points given in 6.2.2 or the mileage limitations given in 6.2.3, provided the customer acknowledges that he understands increased outages may result or the analog parameter limits may be exceeded. On channels exceeding 4000 facility miles, individual transmission facility limits will be met, but end-to-end analog or digital (with Bell System-provided modems) transmission performance will not be supported. The Telephone Companies reserve the right to refuse to provide a channel which cannot be made stable, since high level signals may be generated which would interfere with other services.

Three basic types of multipoint channels have been described. Additional configurations are possible and the guidelines may still be applied. For example, if receive-only station equipment is used, the end-link provided for serving that station may be designed for one-way transmission and there will be negligible noise contributed by that end-link to the remainder of the channel. The guideline regarding the number of facility miles can still be applied. It is also possible for service to be supported between some stations and not between others. A simple example is a broadcast multipoint where only a single receiver is more than 4000 miles from the transmitter and all other receivers are less than 4000 miles from the transmitter.

(b) Four-Wire Terminations

Where 4-wire terminations are indicated, the two directions of transmission must be electrically independent within the modem. Otherwise severe impedance mismatches with 600 ohms may result and the assumptions under which the maximum number of points was derived may not be met.

(c) Impedance of Two-Wire Modems

The guidelines on the number of points where 2-wire modems are used assume the modems are 600 ohms ±10%, balanced and resistive, across the band from 300 to 3000 Hz.

(d) Signal Power on Multipoint Channels

The restriction on the 3-second average power transmitted into the channel applies to all signals into the channel collectively. On frequency division multiplexed channels, the combined transmitted signal power (averaged over 3 seconds) from all modems on a standard design channel should not exceed 0 dBm. Thus each narrowband signal must be transmitted below 0 dBm. If there are N narrowband channels transmitting equal signal powers, that power must not exceed $-10 \log_{10} N$ dBm if the combined power is not to exceed 0 dBm. Coherent frequencies should not be used. Table 7 provides the maximum per channel rms signal power for this case. On standard design channels where time division techniques are used, polling of modems having short duration, high signal power responses should not be done sufficiently rapidly to cause the 3-second average combined input signal power from all modems to exceed 0 dBm.

(e) Signal Regeneration Between Multipoint Channels

If the number of facility miles limits the size of a single multipoint channel, it may be possible to separate a single channel into two or more multipoint channels with signal regeneration between them. Careful consideration must be given to timing problems. The Bell System does not provide voiceband service having digital regeneration between multipoint channels.

(f) Advance Planning

It is suggested that the Telephone Company be contacted early in the planning stages if multipoint channels will be required. Large installations require long lead times, to insure that facilities and equipment are available to meet service dates. The Telephone Company can also offer suggestions on layouts, maintenance procedures, and installation schedules. Telephone Company knowledge of the purpose of the data system, and of its requirements, can help assure a smooth cutover and a reliable system.

6.3 Signal Power Restrictions with Multiple Channels

The restrictions on transmitted signal power given in Section 4 apply to individual channels. Occasionally there are applications where multiple channels are used, and additional restrictions on transmitted signal power apply as follows:

6.3.1 Subdivision of Groupband Channels

Where tariff offerings permit, a customer may lease 48 kilohertz bandwidth groupband channels and have the Telephone Company subdivide them into as many as 12 voiceband channels. In this case the total 3-second average power transmitted into the groupband channel must not exceed +8 dBm where the derived voiceband channels are designed for 0 dBm transmitted signals. For example, if all 12 channels are used for simultaneous two-way data transmission, the individual channels should transmit signals at −3 dBm instead of 0 dBm. As an alternative, 6 of the 12 channels could be used for simultaneous two-way data transmission at 0 dBm, and the remaining 6 channels could then not be used.

6.3.2 Coherent Signals

In some systems multiple voiceband channels are used to simultaneously transmit identical signals. With such operation, crosstalk between channels is much more likely to be service-affecting than when the signals are statistically independent. To prevent such interfering crosstalk, the signal power in each of N voiceband channels simultaneously transmitting identical signals should be reduced by a factor of 1/N. Thus, if there were 2 such channels each should transmit at 1/2 the normal 0 dBm power, or −3 dBm; if there were N such channels, each should transmit at $-10 \log_{10} N$ dBm. (The signal powers in Table 7 apply to this case also, although they were derived for uncorrelated narrowband signals on a single voiceband channel, since Table 7 tabulates $-10 \log_{10} N$ dBm.) The transmitting signal sources must be balanced. To reduce the number of signals being transmitted simultaneously it is recommended that the signals be staggered over a time equal to a nominal signal element. For example, the signals could be divided into four groups and a delay of one-fourth of a signal element provided between successive groups.

TABLE 7

MAXIMUM TRANSMITTED SIGNAL POWER FOR EACH OF N CHANNELS SUCH THAT THE COMBINED POWER FROM ALL N CHANNELS IS 0 dBm (ASSUMES UNCORRELATED SIGNALS ON CHANNELS).

No. of Channels	Per Channel Maximum rms Power — (dBm)	No. of Channels	Per Channel Maximum rms Power — (dBm)
1	0	11	−10.4
2	−3.0	12	−10.8
3	−4.8	13	−11.1
4	−6.0	14	−11.5
5	−7.0	15	−11.8
6	−7.8	16	−12.0
7	−8.5	17	−12.3
8	−9.0	18	−12.6
9	−9.5	19	−12.8
10	−10	20	−13.0

6.4 Derivation of Additional Channels

Voiceband data channels can be subdivided into additional channels either by frequency division or time division multiplexing. It should be noted that channels may be derived only to the extent of the transmission characteristics of the bandwidth of the channel as ordered. Performance of channels above or below the specified frequencies will not be supported.

6.5 Noise Protection in Data Modems

In systems where continuous energy is not present on the channel ("switched carrier" operation instead of "continuous carrier" operation) a data modem may attempt to demodulate impulse noise and peaks of background noise. This is particularly true if the modem has been designed to operate with greatly attenuated signals. Precautions should be taken to preclude false data reception due to noise. These precautions include synchronization schemes, start of message characters, and decrease of the sensitivity of the modem. Rarely will peaks of C-message noise exceed 13 dB above the rms noise. Hence with rms noise at the limit of 24 dB below the signal power it is rare that C-message peaks will be closer than 11 dB to the average data signal power. Impulse noise, however, may be considerably higher in power and may even exceed the average data signal power for a few milliseconds (usually less than 4 milliseconds and rarely more than 10 milliseconds). See Section 4.3.4 for a discussion of impulse noise characteristics and limits.

Refer also to Section 4.3.2 for the need to protect modems against noise below 300 Hz, particularly 60 Hz and its low order harmonics.

6.6 Compandors in Carrier Systems

6.6.1 Analog Carrier Systems

Certain analog carrier systems use "compandors" (compressor + expandor) to improve voice transmission by reducing noise in the quiet intervals between bursts of speech energy. As the action of these compandors may affect certain aspects of data transmission, their operation should be understood by data modem designers and users of voiceband data channels.

Compandor circuitry consists of a compressor circuit at the transmitting end of a carrier system and an expandor circuit at the receiving end. In the compressor, low power signals are amplified and very high power signals are attenuated, thus compressing the power range of the input signals and usually increasing its average value. The expandor performs the complementary function. Figure 18 is a level diagram illustrating the compression and expansion functions and the resulting improvement in performance with respect to the noise of the carrier system. These compandors are syllabic compandors, i.e., they operate rapidly enough to respond to syllables of speech.

Ideally, the compressor and expandor actions should precisely match, or track, i.e., a change in the input signal power should result in an exact complementary change in the output signal power. Practically, however, there is always a small tracking error which may be of two types, "dynamic" or "static."

When the input signal power to a compandored analog carrier is changed slowly, the output signal power also changes slowly. There is usually some "static tracking error" in that the steady-state output signal power does not change exactly as much as the input signal power. Further, this static tracking error may have some frequency dependency, i.e., the tracking error for a given change in signal power may be greater at some frequencies than at others. Table XII, p. 1339 of Reference 2 provides pertinent data, as does Reference 6.

When the input signal power to a compandored analog carrier is changed suddenly, there is a transient effect while compressor gain and expandor loss adjust to the new signal power.

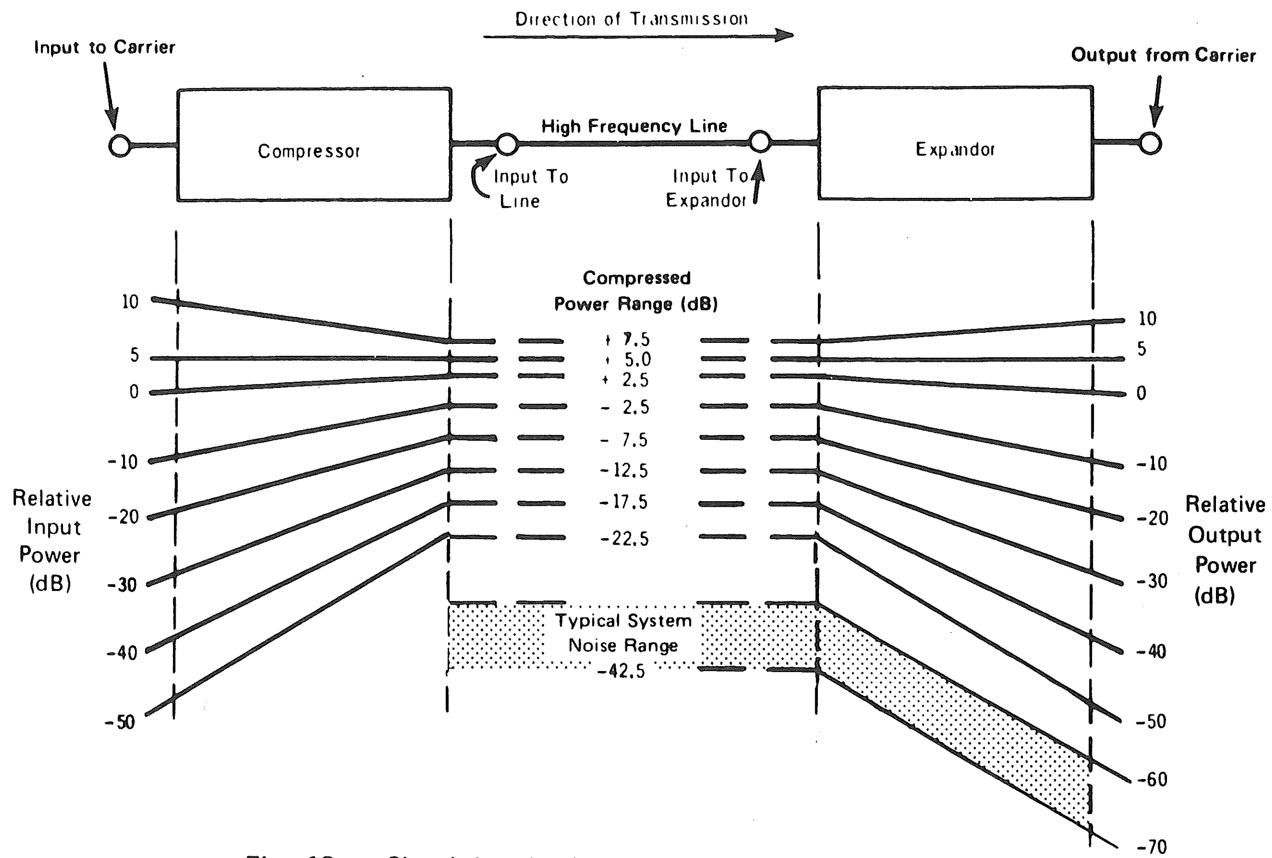


Fig. 18 — Signal Level Diagram of Syllabic Compandored Carrier System

This "dynamic tracking error" can affect data modems designed for fast startup applications (polled stations on broadcast multipoint polling channels, for example).

The oscilloscope photographs of Figures 19 through 22 illustrate the dynamic response of Bell System syllabic compandors. In all four figures the input signal is a 2000 Hz sine wave, and the horizontal scale is 5 milliseconds per vertical grid line.

In Figure 19, the response of a syllabic compandor to an "infinite step" input is shown. The step is from no signal to 64 cycles of the 2000 Hz sine wave at the maximum 3-second rms data signal power, followed by no signal. Figure 20 is a similar illustration, for the same carrier system, where the input signal is stepped 12 dB to the maximum 3 second average data signal power for 64 cycles, and then decreased 12 dB to the original signal power. In Figures 19 and 20 the top trace is the input signal to the compressor, the second trace is the output signal from the compressor, the third trace is the input signal to the expandor, and the bottom trace is the output signal from the expandor. (Refer to Figure 18 for the location of these points.) Note that although the dynamic signal changes within the compandor (middle two traces) the input signal is reproduced with reasonable fidelity at the compandor output. Also, the signal to noise ratio within the compandor, (on the high frequency line of Figure 18) may vary for several milliseconds following a sudden increase in signal power.

Figure 21 illustrates the response of the compressor of the same carrier system to an input signal suddenly increased 12 dB for 32 cycles and then decreased 12 dB to its original power. The top trace is the input signal to the compressor and the bottom trace the output signal from the compressor. This figure more clearly illustrates the response to a sudden

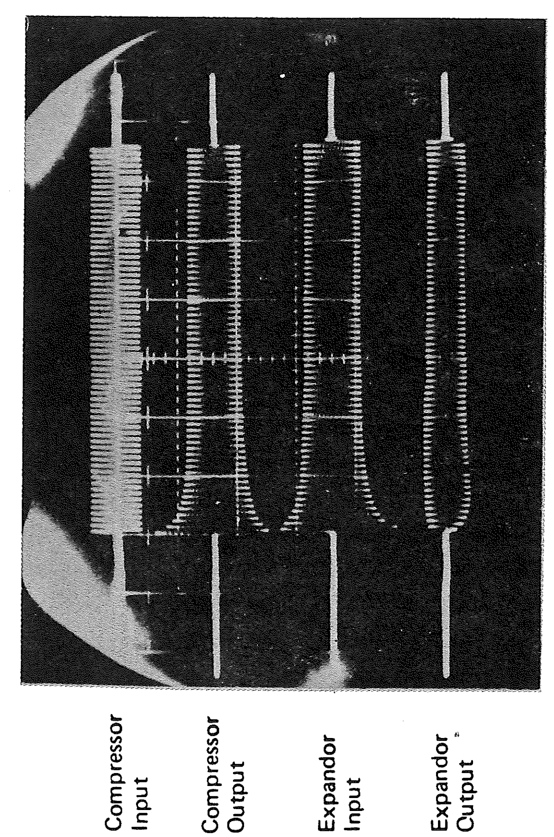


Fig. 19: Dynamic Response of a Syllabic Compandor to an Infinite Step Input Signal

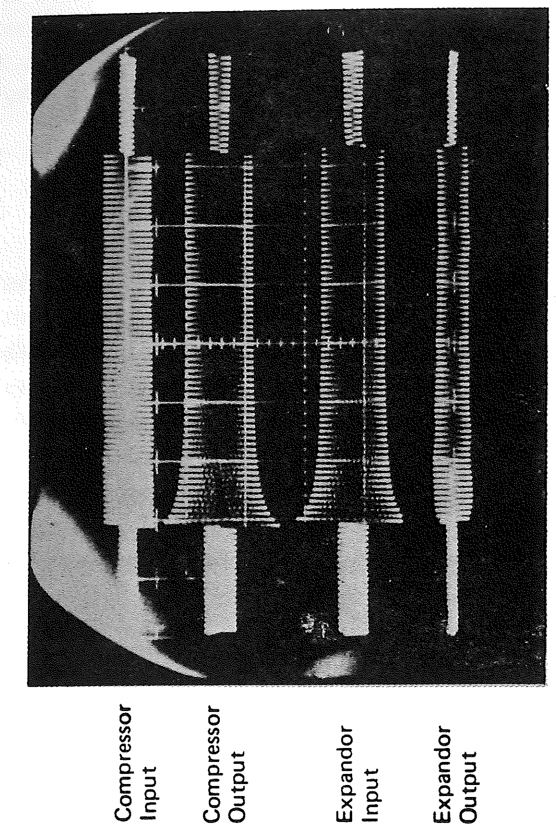


Fig. 20: Dynamic Response of a Syllabic Compandor to a 12dB Step Input Signal

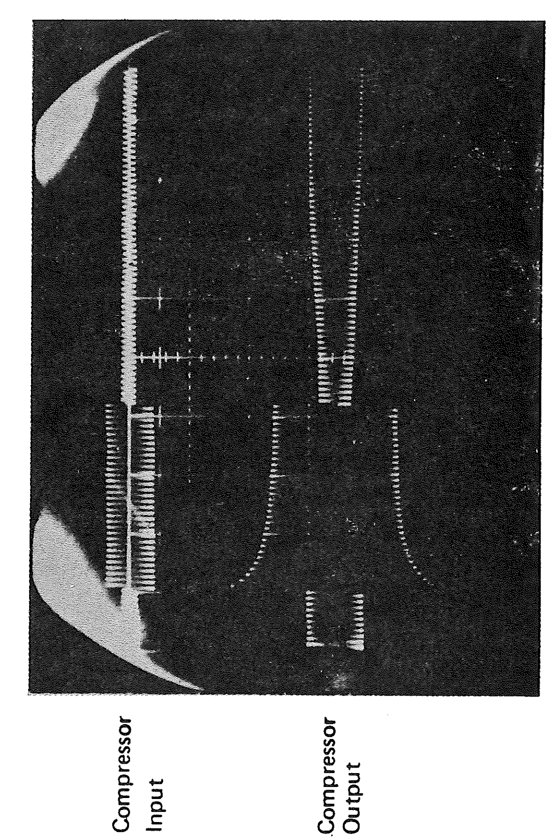


Fig. 21: Dynamic Response of a Compressor to a 12 dB Step Input Signal

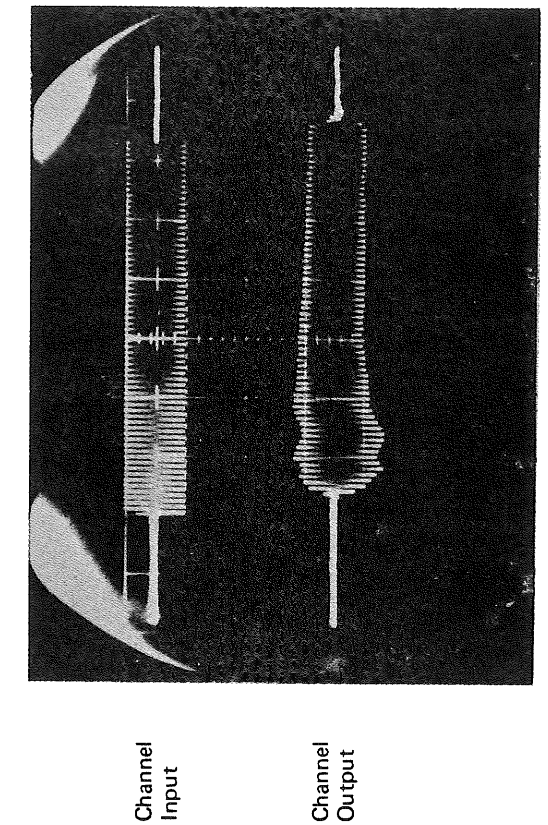


Fig. 22: Dynamic Response of a Channel Consisting of Three Syllabic Compandors to an Infinite Step Input Signal

decrease in the input signal power. The signal to noise ratio on the high frequency line is varying for approximately 20 milliseconds following the negative step in input power.

Several syllabic compandors may be encountered by a data signal on a data channel. Figure 22 illustrates the dynamic response of a channel consisting of three different kinds of Bell System carrier facilities, each equipped with syllabic compandors, to an infinite step input. (It would be unusual for a data signal to encounter more than three syllabic compandors.) The top trace is the input signal to the first compressor, an infinite step to the maximum 3-second rms data signal power for 64 cycles followed by removal of the signal. The second trace is the corresponding output of the third expandor. The output signal is observed to have been delayed slightly (the propagation time of the three high-frequency lines is not included) and there is some distortion of the leading edge of the wavefront which subsides in less than 10 milliseconds.

Reference 6 provides additional information on the dynamic response of a specific carrier system with syllabic compandors.

Non-Bell System compandors may have dynamic responses different from those illustrated by Figures 19 through 21. Also, in some situations the Bell System may provide the compressor and expandor at one end of the high frequency line, and non-Bell System equipment may be at the other end. Where these combinations, in the judgment of the Telephone Company, deviate markedly from satisfactory compandor performance, the Telephone Company may, at its option, modify the compandor or remove it entirely.

If a customer requests removal of a syllabic compandor from a data channel, the Telephone Company may treat this request as a special assembly as discussed in Section 1.8. If compandors are removed on a multipoint channel, the C-message noise limits will not be supported. If alternate voice/data service is involved, syllabic compandor removal may result in subjectively annoying noise in the voice mode, even on two-point channels.

On broadcast polling and conference multipoint channels, compandors in channel end links or middle links not carrying signals will reduce the overall noise in the channel. This is due to the fact that the expandor in the idle condition attenuates the noise from the carrier facility itself.

6.6.2 Digital Carrier Systems

Bell System short-haul digital carrier systems use "instantaneous" compandors rather than syllabic compandors, or else nonlinear encoders having the same companding effect. These compandors provide a nearly constant signal-to-noise ratio over the wide range of input power typical of speech signals. Tracking errors in these instantaneous compandors produce nonlinear distortion, as discussed in the next section. (Instantaneous compandors are an integral part of digital carrier system terminals, and cannot be removed or disabled on a per-channel basis.)

6.7 Nonlinear Distortion in PCM Systems

Bell System short-haul digital carrier systems use pulse code modulation (PCM). In these systems a band limited analog voiceband signal is sampled 8000 times per second. The resulting pulse amplitude modulated (PAM) signals are interleaved with others on a time-division basis. Finally, each PAM sample is encoded into a discrete binary PCM signal to be transmitted over a digital line.

Representing the message by a discrete and therefore limited number of signal amplitudes is called quantizing. Quantizing inherently introduces an initial error in the amplitude and phase of the samples, giving rise to quantizing noise. The signal is then compressed and encoded. At the far end the signal is decoded and expanded. Once it has been encoded it can be transmitted over a line using regenerative repeaters with little or no additional degradation.

Signal processing in PCM systems can give rise to a unique form of nonlinear distortion which has no direct counterpart in analog systems. The PCM processes involved in producing this distortion are sampling, quantizing, and mistracking of the instantaneous compandors.

The sampling process produces upper and lower sidebands (sometimes called aliases) about the sampling frequency and its harmonics. If the input signal is not sufficiently band limited (to half the sampling frequency or less), the lower sideband about the sampling frequency will overlap the baseband spectrum. That portion of the lower sideband which extends down into the baseband is known as foldover distortion (see Reference 5). As an example of this phenomenon, consider an input signal with significant out-of-band power, say at 6000 Hz. The 6000 Hz component will appear in the lower sideband about the 8000 Hz sampling frequency at 2000 Hz (8000-6000), which is near the middle of the baseband spectrum. Thus it is to the modem designer's advantage to limit out-of-band power to an acceptable level (this is also required to meet the network protection criteria discussed in Section 4).

In addition to foldover distortion, any nonlinearities encountered after sampling will create intermodulation products from the baseband signal and its aliases and the sampling frequency and its harmonics. The primary sources of nonlinearities after sampling are quantizing and companding. Some of the intermodulation products created by these nonlinearities may appear as tones or noise at baseband frequencies. For example, suppose a 2700 Hz input tone is transmitted. Then an alias of this input occurs at 5300 Hz (8000-2700). A nonlinear process may then produce distortion at the difference frequency of 2600 Hz (5300-2700). Notice that the 2600 Hz output is close to the 2700 Hz input; when the input frequency is a rational fraction of the sampling frequency, many of the resulting inband tones may coincide. For the fraction 1/3 (2666-2/3 Hz), all the products in the baseband occur at 2666-2/3 Hz.

Other input frequencies for which many tones build up at relatively few inband frequencies are listed in Table 8, along with the corresponding distortion output frequencies.

Table 8 assumes the input frequencies are rational fractions of the 8000 Hz sampling rate. If the input frequencies drift with respect to the sampling rate, sudden rising or falling of energy at the output frequencies may be observed as the rational fraction relationship appears and disappears. Since the sampling rate will vary slightly, this phenomenon may occur within a very narrow band (less than ±1 Hz) around the input frequencies listed in Table 8.

Input frequencies which are very close to those listed in Table 8, but not an exact rational fraction of the sampling frequency, will produce sidebands close to the output frequencies listed. The result is a beating effect about the output frequencies (which include the input frequency).

To reduce the probability of encountering significant distortion, it is suggested that modem designers avoid designs which generate high signal levels (such as carriers) within a few Hertz of the input frequencies of Table 8.

6.8 Signaling

Signaling is divided into two general categories: address signaling and control signaling. Address signaling is used to direct switching equipment to establish connections through a switched network to a specific destination. Address signaling is accomplished using either rotary dial equipment or tone signaling devices such as used in the Bell System's TOUCH-TONE® service. The CCSA networks discussed in Section 2.5 are examples of private line networks which require address signaling. Nonswitched private line services do not generally require address signaling since the destination is predetermined. (In multipoint networks a form of address signaling is often embedded in the transmitted signal to identify the destination desired.)

Control signaling is used to indicate the mode in which the channel is operating (e.g., busy vs. idle, or voice vs. data) or to alert personnel or equipment at either end of the channel to take some action. The most commonly used method of transmitting control signals over Bell System broadband carrier facilities is by means of single frequency (SF) signaling, which uses the presence or absence of 2600 Hz tone to indicate mode information. See Section 4.1.5 for details

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TABLE 8

Input Frequencies Having Inband Distortion Building Up at Relatively Few Output Frequencies (PCM Systems)

Input Frequency (Hz)	Distortion Output Frequencies (Hz)*
800	800, 1600, 2400, 3200
888 8/9	888 8/9, 1777 7/9, 2666 2/3
1000	1000, 2000, 3000
1142 6/7	1142 6/7, 2285 5/7, 3428 4/7
1333 1/3	1333 1/3, 2666 2/3
1600	1600, 3200
1777 7/9	888 8/9, 1777 7/9, 2666 2/3
2000	2000
2285 5/7	1142 6/7, 2285 5/7, 3428 4/7
2400	800, 1600, 2400, 3200
2666 2/3	2666 2/3
3000	1000, 2000, 3000
3200	1600, 3200
3428 4/7	1142 6/7, 2285 5/7, 3428 4/7

* 0 Hz and above 3500 Hz excluded.

regarding input signal characteristics required for proper operation of channels having Bell System-provided SF units.

There are many possible control signal devices; they may be Bell System-provided or customer-provided. If signaling is required in a private line data system, the Telephone Company should be consulted for assistance in determining which signaling systems are suitable for the proposed application.

6.9 Echo Suppressors

Long half-duplex alternate voice/data channels may include echo suppressors for the voice mode transmission. Echo suppressors are used in the 4-wire portion of 2-wire terminated channels, or in 4-wire channels which may be connected to 2-wire terminated channels. They function by increasing the loss in the transmission path opposite in direction to the path being used. Echo suppressors have two characteristics which affect data transmission.

The first characteristic is hangover time, i.e., the time it takes for the echo suppressor to release. This is usually less than 100 milliseconds, except on satellite channels. Hangover time limits the speed with which data transmission can be "turned around" (stopped in one direction and started in the other).

The second characteristic is the high loss inserted into the return path while data is being transmitted. This blocks simultaneous return transmission, which might otherwise be accomplished on frequencies different from those used for the primary data transmission.

For some applications, simultaneous return transmission is desirable for circuit assurance, answerback, retransmittal requests, etc. An echo suppressor disabling feature has been provided which eliminates echo suppressor loss for services designed to utilize this feature. The disabler will operate upon receipt of a tone in the 2010-2240 Hz band with no significant signal energy simultaneously present outside this band. This disabling tone must be sent from the station at a power between the maximum specified rms data signal power and 16 dB lower for this feature to function, and the tone must be present for at least 400 milliseconds. After the disabler has operated, signal energy in the 300-3000 Hz band, in either direction of transmission, applied at the station at a level between 0 and −12 dB with respect to the specified transmitting signal power will hold the echo suppressor disabled, provided that this energy is not interrupted for periods of 100 milliseconds or more.

6.10 Absolute Delay

As indicated in Sections 3 and 4, the absolute delay (or change in absolute delay) of the transmission path is not specified. Normal network reconfigurations and system tolerances make such a specification impractical. Normally, the absolute delay of a channel is not limiting for most data applications. If satellite facilities are used for a portion of the transmission medium, however, one-way delays of approximately 300 milliseconds will occur, and these could be limiting for block retransmission error control systems. On terrestrial channels using Bell System facilities the absolute delay will usually not exceed 50 milliseconds, one way. If a system has a requirement for control of the absolute delay of the channel, a review with a Bell System engineering representative is in order.

7. MAINTENANCE CONSIDERATIONS

Proper maintenance of the telephone plant requires performance of preventive maintenance on the portions of the system which are the Telephone Companies' responsibility. Tariff F.C.C. No. 260 specifies that service must be released at a mutually agreeable time for maintenance purposes. The release of the service is requested during normal business hours, if possible, because more meaningful measurements can be accomplished during that time. At present, it is expected that two or three release periods each year will be sufficient to maintain the service adequately.

The Telephone Company uses the terminology "data system" to refer to the case where the channel (with any recommended C-conditioning), modems, and switching equipment are all provided by the Telephone Company, and the channel configuration is one specified. If any portion of the service is provided by the customer, or if other than the recommended channel conditioning or configuration is ordered, the result is called a "data assembly" If a data system is involved, the Telephone Company will assume responsibility for finding and clearing the trouble condition for the overall data service. If a data assembly is involved, Telephone Company action following a trouble report on the channel is limited to testing and, if necessary, restoring the channel to meet the prescribed analog transmission parameters. Component parts provided by the Telephone Company will be maintained to their individual specifications. The overall system error performance is the responsibility of the customer. The Telephone Company will test the transmission characteristics of the channel, but will not assume responsibility for overall trouble location. The Telephone Company will not demodulate a customer's signal or provide a compatible terminal to test with customer-provided equipment. The Telephone Company will not endorse the recommendations of an outside supplier of terminal equipment or give advice as to whether the terminal equipment can perform satisfactorily with the channel.

If the Telephone Company is called regarding a trouble which, upon investigation by the Telephone Company, is found to be caused by customer-provided equipment, then a service charge will be made if a repairman has been dispatched to the customer's premises and the applicable tariff includes provision for this charge.

8. SYSTEM CONSIDERATIONS

8.1 Reliability and Availability

Availability of data communications is a matter of particular concern to the user and to the provider of communications service. The degree of availability needed is related to the consequences of communications failure in terms of the expected frequency of occurrence and the duration of service outage if it should occur. A reasonable balance must be struck between the value to be gained from reduction in communications down time and the cost of attaining that improvement. Availability is generally defined to be the percentage of a long period of time that a channel is operating within its transmission parameter limits. While it would be advantageous for every channel to have 100% availability, factors such as channel installation and maintenance activity, equipment failures, changes in ambient conditions, automobile accidents, malicious destruction and excavation activities not under Bell System control do cause less than 100% availability to be achieved in practice. Channel availability can be, and is, increased by prudent design and protection of equipment and rapid restoral of failed channels, including automatic switching to backup channels in some cases. Although the Bell System has taken these steps, outages are to be expected on all channels. Due to the variation in exposure to adverse conditions, wide variation in the availability of channels can be expected.

The Telephone Companies do not continuously monitor the transmission quality of in-service private line channels, and relatively little is known regarding the availability of such channels. However, customer-reported outages provide a source of relevant information. Figures 23 and 24 illustrate the results of analysis of reported outages on interstate data service. Additional information is given in Table 9.

There are a number of comments regarding Figures 23 and 24 and Table 9.

1. If an outage was reported on any part of a channel, the entire channel was assumed to be out of service. On multipoint channels, service to only a single point may have been affected, and communication with all other points may have remained satisfactory.
2. Outages were computed from the time the customer report was received to the time service was restored. No determination of the length of the outage prior to the report could be made.

TABLE 9

CHANNEL OUTAGE APPROXIMATIONS FOR TWO-POINT INTERSTATE DATA SERVICE (FROM CUSTOMER-REPORTED OUTAGES)

Percent/month with no reported outage	72%
Average number of reported outages/channel/month	0.56
Average number of reported outages/channel/month, given at least one outage	2.0
Average outage time/ channel/month	68 minutes
Average outage time/ channel/month, given at least one outage	241 minutes
Percent of outages exceeding 2.0 hours	23%

3. Customer usage of the channels varies from infrequent to 24 hours per day, seven days per week. Detailed usage information is not available, and no correlation of reported outage with customer usage could be made. Channel outages occurring outside periods of customer use are likely to have been unreported. It is not possible to compute channel availability from this outage information because of the unknown period of channel usage.
4. Short outages are less likely to be reported than long outages. The data base used provided no information on unreported outages.
5. Intrastate and local services are likely to have different outage characteristics than those of interstate services.
6. The outage reported for multipoint service is heavily influenced by the number of points served. The data points on Figures 23 and 24 represent fewer channels as the number of service points increases. As an indication of the sample sizes, there were an average of approximately 6500 2-point channels, 120 10-point channels, and 20 channels between 80 and 100 points.
7. The data presented are averages. Although service restoral is completed as soon as practicable, extended outages of many hours duration can, and do, occur.
8. Increased outage can be expected with higher bit rates. The data presented include a mixture of bit rates.

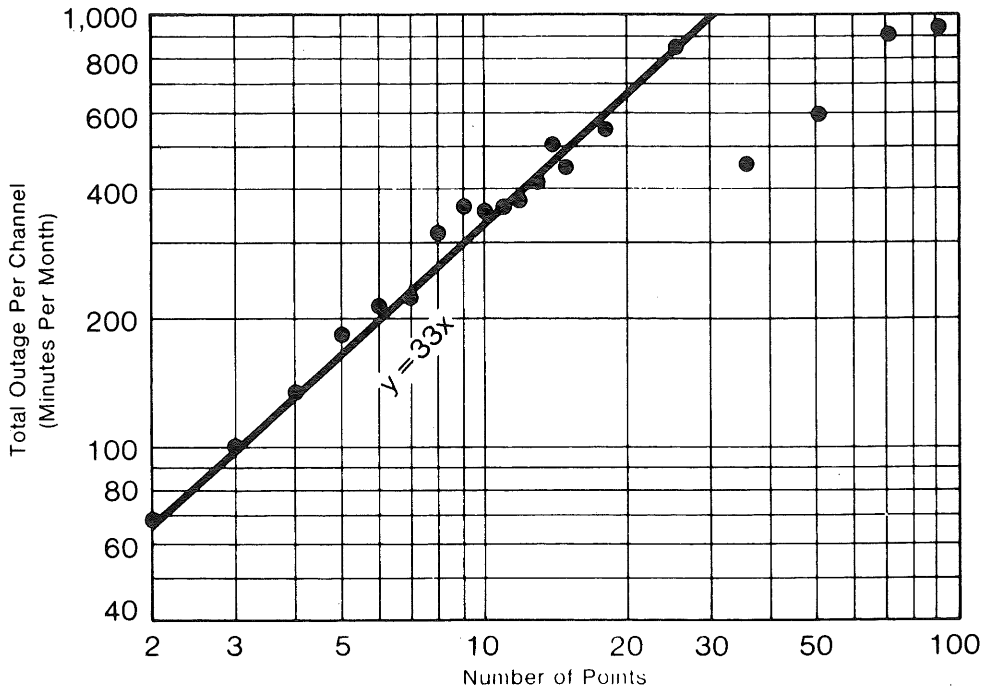

Fig. 23 - Total Reported Monthly Channel Outage as a Function of the Number of Points on Interstate Data Channels

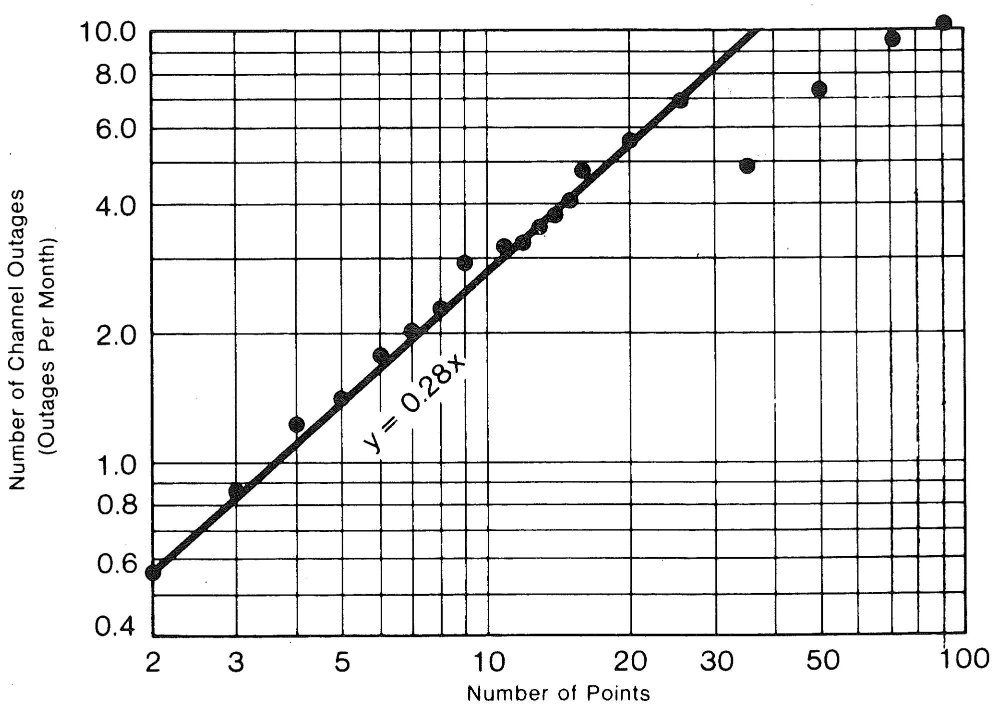

Fig. 24 - Number of Reported Channel Outages as a Function of the Number of Points on Interstate Data Channels

8.2 Alternatives for Improved Availability

It is often possible to provide a private line data system with the ability to use the Switched Telecommunications Network during periods when the private line channel is unavailable. Where 4-wire channels are required, two connections must be established through the switched network. The two connections may be routed quite differently, and their transmission characteristics may be quite different from each other and from the private line channel. The article by Duffy and Thatcher in Reference 2 (pp. 1311-1347) describes the analog transmission performance to be expected on such dialed connections.

Where transmission over the Switched Telecommunications Network is not likely to be satisfactory (stringent amplitude and delay conditioning required, for example) and channel availability is very important, a backup private line channel can be ordered. If availability is of paramount importance, backup channels with diversity routing can be ordered when facilities are available. This reduces the probability that a given failure will affect the channel and its backup simultaneously. When backup arrangements are being considered, a review of the requirements by a Bell System Communications Consultant or Data Communications Specialist is suggested. This is mandatory for route diversity. In particular, diverse routing in local facilities is frequently not available, and special construction may be necessary if it is absolutely required.

8.3 Facility Selection

Bell System policy is to provide transmission facilities which meet the parameter limits specified in this Technical Reference. If the limits are not met, corrective action, short of special construction, will be taken. This corrective action may include adjusting a carrier system or even, at the option of the Telephone Company, routing the channel over other transmission facilities in certain situations. (Rerouting may be done by the Telephone Company for two basic reasons. The first is to more efficiently use transmission facilities. The second is to restore service where a transmission facility has failed or is not meeting maintenance limits, and an extended time is required to repair or adjust the facility.) Obtaining a channel under Tariff F.C.C. No. 260, or similar intrastate tariffs, does not give the customer the right to specify the facilities to be used. Requests to exclude a type of carrier, or to include only a certain type of carrier, will not be honored. Hence a designer should be aware that he should not design terminal equipment which requires control of parameters beyond the specified limits (no frequency shift, for example) even though many, or even most, facilities might meet the special criteria.

The reason for the policy of not allowing facility selection is that very significant administrative costs would be involved to keep track of channels with better than standard limits, and in certain cases it would not be possible to meet special criteria. An example of the latter situation would be one where the only facility available for initial service or to effect failed channel restoral did not meet the special criteria, but did meet standard limits.

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APPENDIX

The objective of this Appendix is to define the terminology used in the description of delay distortion. The definitions are established through the use of examples which show the cause of delay distortion and its effect on typical data signals. The Glossary provided in Section 7 contains a useful list of terms and definitions.

1. DELAY DISTORTION

1.1 Introduction

Data communications are particularly sensitive to phase irregularities in the transmission path. This differs from voice communications because the human ear is relatively insensitive to phase irregularities.

To introduce the problem of delay distortion, certain aspects of network theory pertaining to phase should be considered. The networks frequently encountered in telephone circuits are transmission lines, filters, and equalizers. The phase-shift characteristics of these networks can affect data transmission.

For example, a loaded telephone cable may be considered as a 2-terminal pair network. Since cable pairs are packed together tightly, they have a large amount of distributed shunt capacitance. Lumped series inductances called loading coils are inserted at regular intervals to reduce attenuation in the region of interest. If all of the distributed constants are

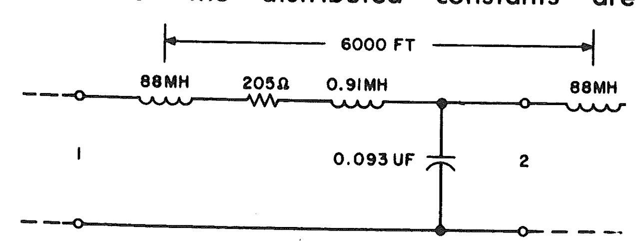


Fig. 1 – Two-Terminal Pair Representation of 6000 Feet of 22H88 Loaded Cable

considered "lumped" in each loading section, the loaded cable circuit can be represented as shown in Fig. 1. The values shown are for 22-gauge exchange grade cable loaded with 88 millihenries series inductance every 6000 feet. This is referred to as 22H88 cable and is very common in the exchange telephone plant.

The network shown in Fig. 1 can be approximated by the T-section filter shown in Fig. 2. In order to simplify calculations, the resistance has been omitted.

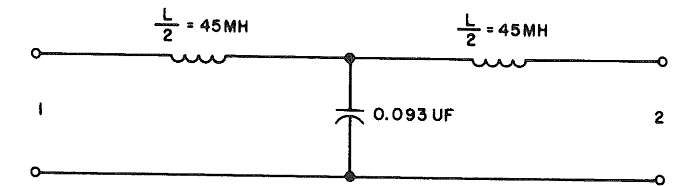


Fig. 2 – Lossless Form of Fig. 1 Redrawn as a T–Section Filter

The filter shown in Fig. 2 is a low-pass filter with a passband that extends from zero frequency to a cutoff frequency, when the filter is terminated in its image impedance.

$$f_0 = \frac{1}{\pi\sqrt{LC}} = \frac{1}{\pi\sqrt{90 \text{ mh} \quad 0.093\ \mu f}}$$

$$f_0 = 3480 \text{ Hz}$$

The electrical characteristics of filters of the form shown in Fig. 2 are well known and are given in any standard network text.* The purpose of this Appendix is to discuss those characteristics leading to the concepts of phase shift and delay.

The variation of attenuation (α) and phase shift (β) for the network in Fig. 2 are of importance and are plotted in Fig. 3. The parameters plotted in Fig. 3 deal only with lossless networks, whereas actual loaded cable does have a resistance component which is its major contributor to loss. If the loss is

* For example, M.E. Van Valkenburg, "Network Analysis," Prentice-Hall, Inc.

substantially constant across the passband, it is not a major factor in waveform distortion. The phase-shift parameter, however, is another matter. It may introduce different delays at various frequencies which will cause waveform distortion.

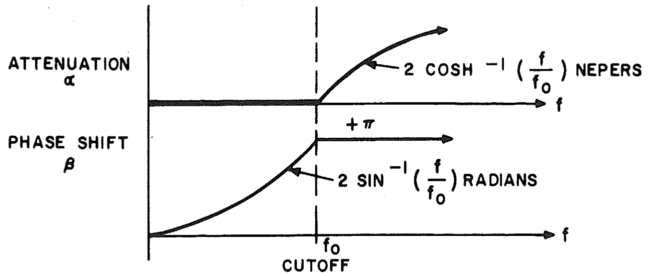


Fig. 3 – Attenuation and Phase Shift of Low-Pass Filter

1.2 Phase Delay

The 2-terminal pair network transfer function G (jω) is defined in terms of a current ratio I_1/I_2 as shown in Fig. 4. G (jω) is a complex number made up of magnitude (attenuation) and angle (phase shift). This can be expressed as

$$G(j\omega) = e^{\alpha} \angle +\beta$$

and

$$I_2 = \frac{I_1}{e^{\alpha} \angle +\beta} = \frac{I_1}{e^{\alpha}} \angle -\beta$$

Because of the sense used in its definition, a positive β (phase shift) in the transfer function causes a negative phase shift in the output current. This can lead to confusion unless recognized. For example, suppose a waveform $e_1 = \sin 2\pi f_1 t$ is applied to the input of an ideal lossless network representing 6000 feet of 22H88 loaded cable, whose phase-shift characteristic was plotted in Fig. 3. If $f_1 \leq f_0$ (the cutoff frequency), the output waveform will be $e_2 = (2\pi f_1 t - \beta_1)$. This is illustrated in Fig. 5.

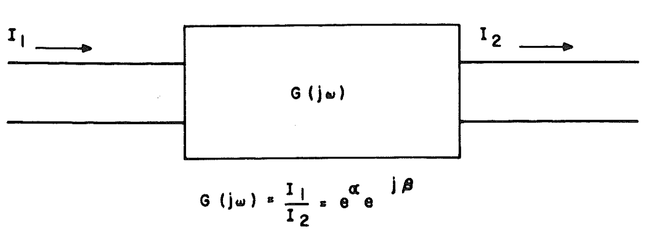


Fig. 4 – Definition of Network Transfer Function

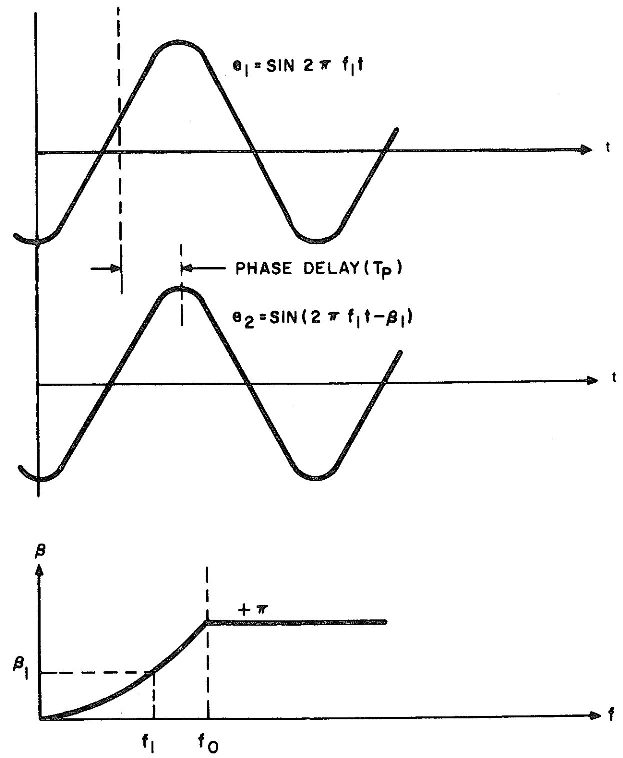


Fig. 5 – Relationship of Phase Delay to Phase Shift

The time delay between the input and output waveform is called phase-delay or propagation time. It is the characteristic of any network or transmission medium to introduce phase-delay to all frequencies. If the phase-shift characteristic β is known, the phase delay (T_p) at any frequency ω_1 can be computed as:

$$T_P = \frac{\beta_1 \text{ radians}}{\omega_1 \text{ radians/second}}$$

As can be seen from this expression, if β and ω do not change in direct proportion, the phase-delay will change with frequency. Therefore, a complex waveform made up of many differing frequencies could be severely distorted during transmission because of the difference in arrival time of each component at the output. The difference between the phase-delays at two frequencies is called the Delay Distortion (T_d) between those two frequencies.

1.3 Determination of Delay Distortion From the Phase-Shift Characteristic

Assume it is desired to determine the maximum delay distortion experienced by frequencies in the 1000- to 3000-Hz band passing through 10 miles of 22H88 loaded cable. In effect, it is desired to know the maximum difference in arrival time of frequency components in the 1000- to 3000-Hz range. This may be determined from the phase-shift characteristic. As can be seen in Fig. 6, the phase-shift at 3000-Hz is greater than three times the phase-shift at 1000-Hz, resulting in delay distortion. This delay distortion may be expressed as:

$$T_d = \frac{\beta_2}{\omega_2} - \frac{\beta_1}{\omega_1}$$

$$= \frac{18.084}{2\pi\, 3000} - \frac{5.185}{2\pi\, 1000}$$

$$= 134 \text{ microseconds}$$

where β_2/ω_2 and β_1/ω_1 are the phase delays at ω_2 and ω_1 ($T_{P_{\omega_1}}$) ($T_{P_{\omega_2}}$) as previously defined.

As a result, a 3000-Hz component will be delayed 134 μsec relative to a 1000-Hz component. This is the maximum difference in phase delay ($T_{P_{\omega_2}} - T_{P_{\omega_1}}$) in the 1000- to 3000-Hz band in this example.

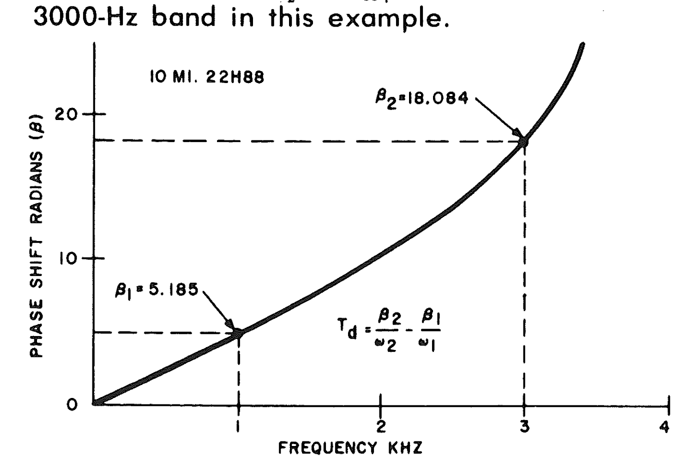


Fig. 6 – Variation in Phase Delay in the 1000- to 3000-Hz Band for 10 Miles of 22H88 Loaded Cable

1.4 Envelope Delay

It is normally not practical to send a single frequency over a circuit and measure the phase delay. This is due to the difficulty of establishing a phase reference and the slight frequency translation (frequency error) that occurs in suppressed carrier systems. It is practical, however, to send a narrowband AM modulated sine wave at various frequencies in the channel passband and evaluate the slope of the phase-shift curve at each point selected. For voiceband measurements, for example, points in the 350- to 3500-Hz range would be selected, and the resulting measurements, would be the envelope delay at each point. A detailed discussion of this measurement is given in Section 6. A typical measurement signal is shown in Fig. 7. The line bounding the outer edges of the AM signal is called the envelope of the signal and is shaped, top and bottom, like the modulating waveform. The

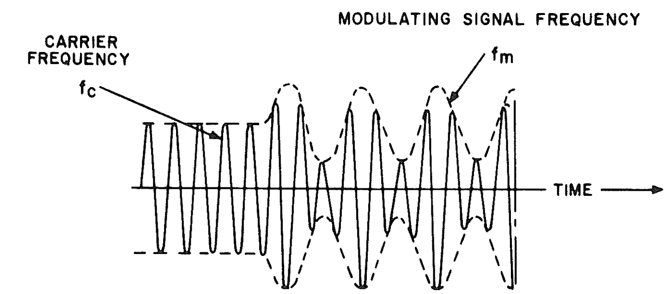


Fig. 7 – Single Sinusoidal AM Signal

transmission of an AM signal through a 2-terminal pair network with a phase-shift characteristic (β) will cause the envelope of the signal to be delayed differently than the carrier. The AM signal for a single sinusoidal modulating frequency consists of a carrier frequency f_c and an upper and lower set of sidebands f_u and f_L. These three frequencies will fall at different points on the phase-shift characteristic as shown in Fig. 8.

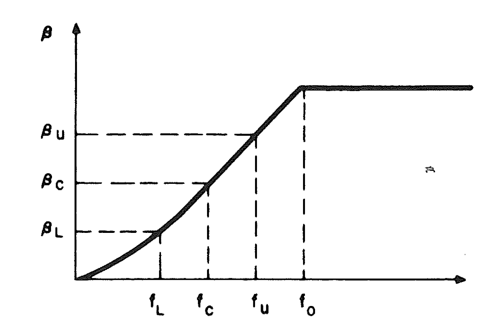


Fig. 8 – Frequencies of Interest for AM Signal

The difference between the carrier frequency and the two sideband frequencies can be made small enough that

$$\beta_u - \beta_c = \beta_c - \beta_L$$

as shown in Figure 9.

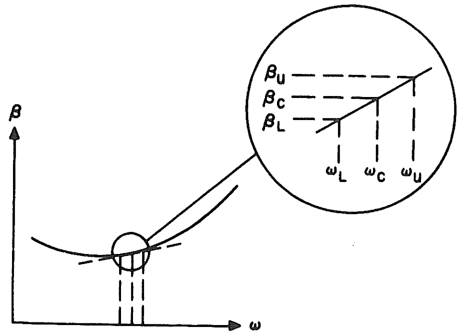


Fig. 9 – Phase Delay for Two AM Envelope Components

The approximation of envelope delay ($T_e = d\beta/d\omega$) by the difference relation $\frac{\beta_u - \beta_L}{\omega_u - \omega_L}$ does not depend upon the overall phase characteristic being linear. The linearity assumption applies only over the measurement interval. Thus the sidebands of any measuring device must be confined to a narrow enough signal spectrum so the linearity assumption is valid. Bell System measuring sets have a measurement interval of 166-2/3 Hz (twice the modulating frequency of 83-1/3 Hz).

The measurement of envelope delay is useful in television and telephoto transmission and is used in data transmission to determine the phase-shift characteristic which is used to compute the intersymbol interference or pulse distortion.

The envelope delay characteristic is the variation in instantaneous slope of the phase-shift characteristic, i.e.,

$$T_e = \frac{d\beta}{d\omega},\ f_m << f_c$$

It follows that the phase-shift characteristic (β) is related to the area under the envelope delay curve (Fig. 10). Then, for a frequency (ω_j), the phase-shift at that frequency is:

$$\beta_j = \int_0^{\omega_j} (T_e)\, d\omega$$

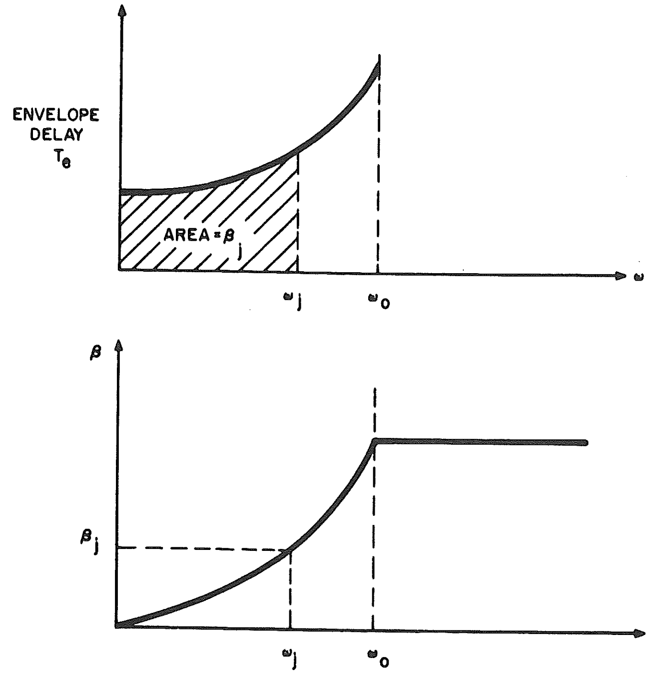


Fig. 10 – Determining the Phase-Shift Characteristic from the Envelope Delay Characteristic

1.5 Absolute Envelope Delay and Relative Envelope Delay

Absolute envelope delay is the amount of delay encountered by the modulating energy in a signal between the sending end and receiving end of any circuit. Since frequencies are affected differently by the phase-shift causing delay, each frequency will have its own particular absolute delay. Relative envelope delay is this difference in delay at various frequencies but with a specific frequency selected as a reference point for all other frequencies. The absolute envelope delay curve is merely shifted downward so that it is normalized (set equal to zero) at some selected frequency. A frequency of, at, or near minimum absolute delay is usually chosen and the envelope delay at this point is considered to be zero. For most voice circuits this will be in the 1500- to 2000- Hz range. All other frequencies will either have more (positive) or less (negative) envelope delay than the envelope delay at the reference frequency. Integration of the relative envelope delay characteristic will not yield the true phase-shift but will provide a picture of its relative variation over the frequencies of

interest. This is shown in Fig. 11. The relative envelope delay characteristic provides all the information necessary to determine delay distortion. Absolute envelope delay values are of no importance except in special cases such as where two or more data channels operate in parallel in a synchronous mode.

1.6 Confusion of Delay Distortion with Envelope Delay Distortion

A frequent error is to confuse true delay distortion, as determined from the phase characteristic, with envelope delay distortion, which is obtained from the envelope delay characteristic. Part of this confusion is the result of nomenclature adopted years ago for telephotograph and television transmission. As then defined, envelope delay distortion (EDD) was the maximum deviation in envelope delay across a certain band of frequencies. As shall be seen, the delay distortion is related to, but is not the same as, envelope delay distortion. Fig. 12 illustrates the envelope delay characteristic of 10 miles of 22H88 loaded cable. Based on this definition, the value of envelope delay distortion is approximately 770 microseconds in the 1000- to 3000-Hz band. This is designated EDD in Fig. 12.

The delay distortion of this length and type of cable has previously been computed to be 134 microseconds, based on Fig. 6.

Obviously, 770 microseconds is not the difference in phase delay of a set of 1000- and 3000-Hz discrete frequencies. Neither is it the delay distortion in the 1000- to 3000-Hz band. The value of 770 microseconds has no significance except to compare it with other values determined in a similar manner for other facilities. Of course this value is also the difference in slope on the phase-shift curve measured at 3000-Hz and 1000-Hz. As stated before, the real advantage of the envelope delay distortion parameter is that it is readily measurable and correctable.

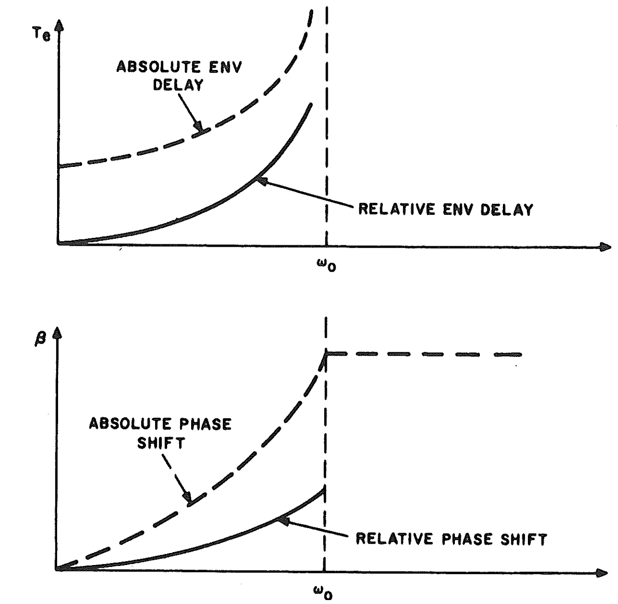


Fig. 11 – Relative Envelope Delay and Phase Shift

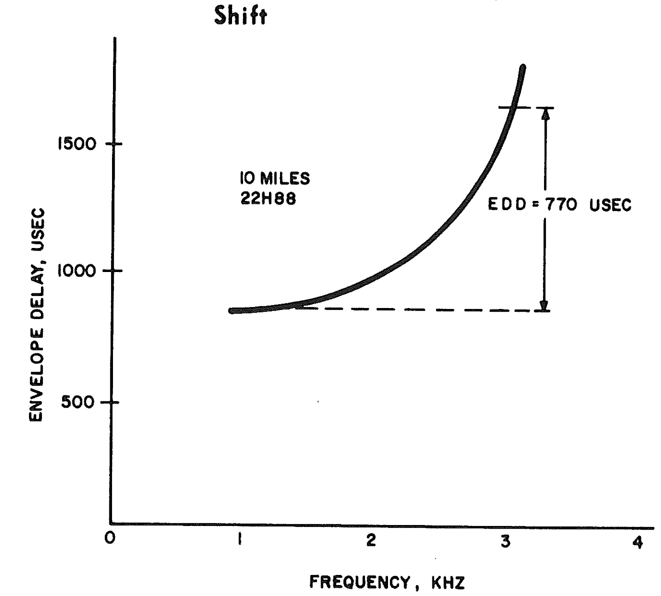


Fig. 12 – Envelope Delay Characteristic of 10 Miles of 22H88 Loaded Cable

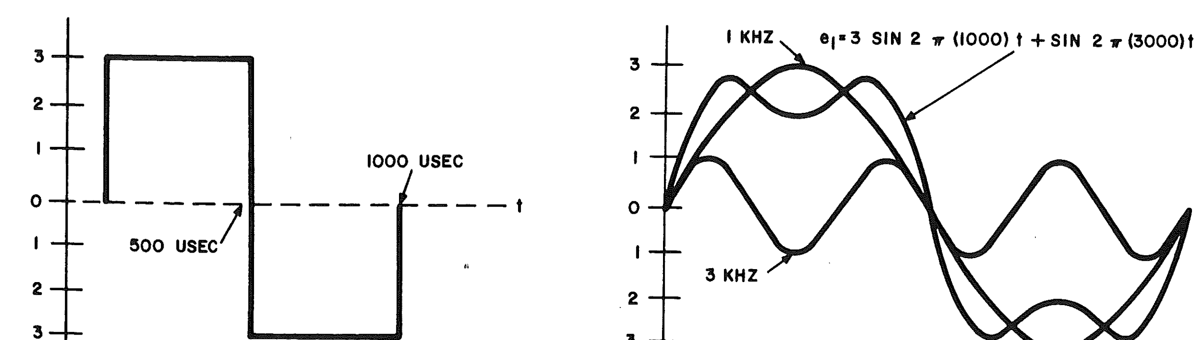


Fig. 13 – Input Square Wave and Effective Waveform

2. DELAY DISTORTION OF PERIODIC BASEBAND SIGNALS

If the 1000-Hz square wave shown in Fig. 13 were applied through a section of 22H88 loaded cable, the fundamental and third harmonic would arrive at the output but the other frequency components would be severely attenuated. This is because the loaded cable acts as a low-pass filter with a 3480-Hz cutoff frequency. In addition, the square wave would be further distorted by phase-shift changes that are not proportional to frequency changes.

Fig. 13 shows the fundamental and third harmonic components of the input waveform which form the effective input signal.

The phase-shift characteristic of 1 mile of 22H88 loaded cable is shown in Fig. 14. The frequencies of 1000-Hz and 3000-Hz are indicated by arrows. The phase-shift at 1000-Hz is 0.5185 radian/mile and at 3000-Hz is 1.8084 radians/mile.

As shown on Fig. 6, if the cable circuit is 10 miles long, the 1000-Hz component will be shifted 5.185 radians and the 3000-Hz component will be shifted 18.084 radians. The output voltage, neglecting attenuation, will be

$$e_2 = 3 \sin (2\pi 1000t - 5.185) + \sin (2\pi 3000t - 18.084)$$

Since the phase-shift at 3000-Hz is not three times the shift at 1000-Hz, the third harmonic component is delayed, relative to the fundamental, by 134 microseconds, as discussed earlier.

This value corresponds to the difference in velocity of propagation at the two discrete frequencies for 10 miles of 22H88 loaded cable. The waveforms in and out of 10 miles of 22H88 loaded cable are drawn to scale in Fig. 15. The waveform distortion is apparent. Attenuation has been neglected to emphasize the effect of the delay distortion. Fig. 16 is an oscillogram illustrating actual waveforms in and out of 10 miles of 22H88 artificial line.

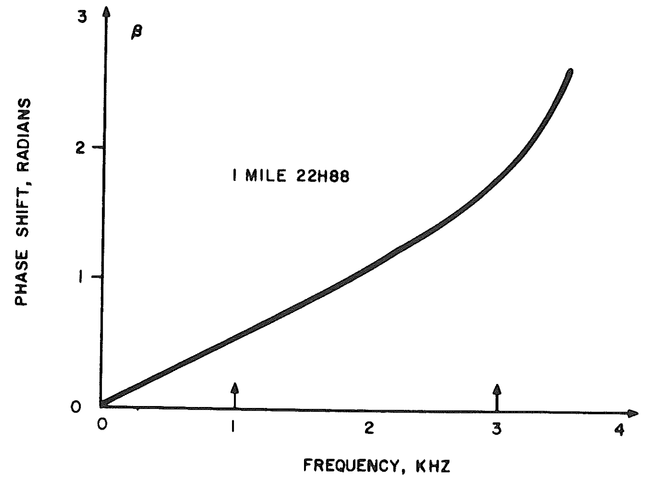


Fig. 14 – Phase-Shift Characteristic of One Mile of 22H88 Loaded Cable

3. DELAY DISTORTION IN PULSE TRANSMISSION

In the previous parts of this Appendix, only the effects of phase or delay distortion on periodic waveforms have been considered. Data signals are, in general, nonperiodic. They are frequently characterized and simulated as random combinations of unit length pulses. One limiting condition is the "isolated" pulse, e.g., a single binary 0 in a field of binary 1's. The energy in such a pulse is distributed over a wide (theoretically infinite) band of frequencies. The relationship between the pulse shape and duration in the time domain and its energy distribution in the frequency domain is defined by the Fourier integral or transform. An example of a transform pair is shown in Fig. 17 for the case of one "bit" of a 2000-bps binary unipolar data signal.

The effect of transmission parameters on such a pulse can be calculated by use of the Fourier transform, or more directly, in the time domain, by means of convolution integral. Since the frequency domain parameters of telephone circuits are more commonly known than their impulse responses, the Fourier transform is more commonly used. The effects of attenuation and delay interact and, in general, are not easily written in closed form for actual data circuits. Calculations become very cumbersome and are usually performed with the aid of computers.

By assuming that the attenuation is constant out to a certain frequency, the effect of phase variations within the passband can be estimated. Fig. 18 shows the effect of various departures from linear phase over a limited passband.

The oscillogram in Fig. 19 was obtained by transmitting an isolated 500-microsecond pulse through 10 miles of 22H88 artificial line. The output pulse has a pronounced oscillatory "tail" due to the combination of attenuation and phase-shift distortion. These oscillations have a frequency of about 0.8 of the cutoff frequency. They persist longer than the main part of the output pulse and are a major cause of intersymbol distortion.

If a random succession of binary ones and zeros are transmitted over such a circuit, the pulse distortions will overlap into the next signal element, causing intersymbol interference. When displayed on an oscilloscope, the long-time average display forms a distorted "eye pattern" as shown in Fig. 20. The effect of delay distortion on the eye pattern is evidenced by lack of symmetry about the vertical axis and a spread in the crossover point. This latter effect causes timing distortion or "jitter." The eye opening or aperture is reduced by increased distortions.

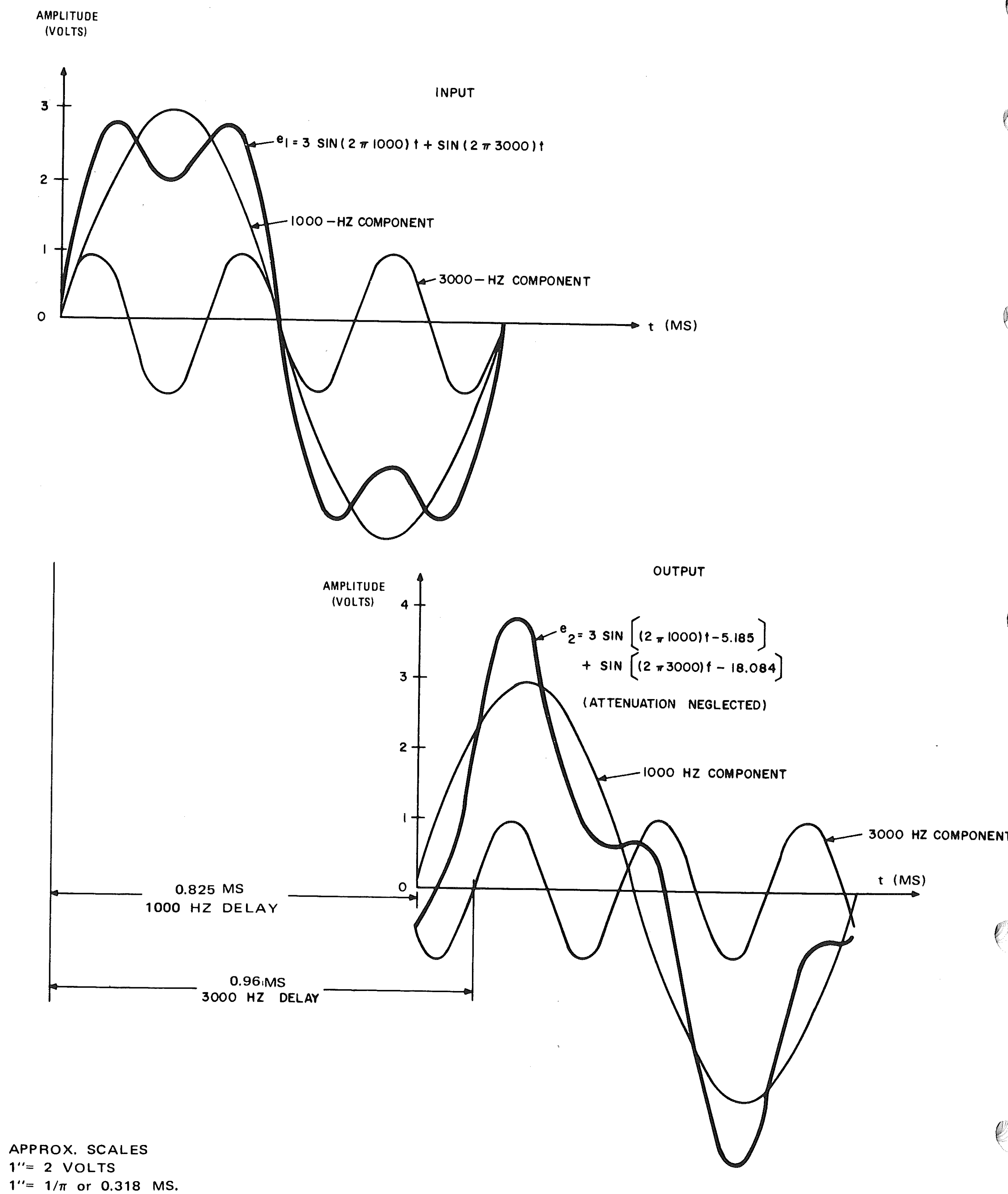


Fig. 15 – Waveforms In and Out of 10 Miles of 22H88 Cable

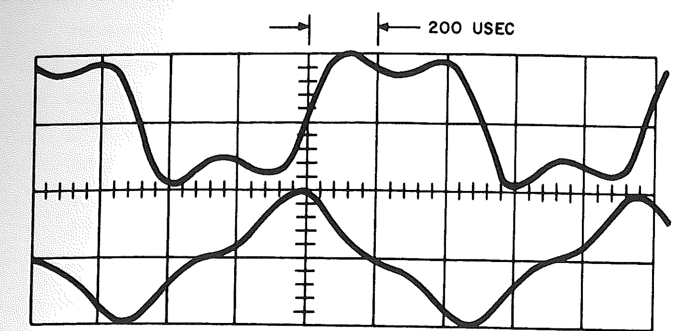


Fig. 16 – Simultaneous Waveforms In and Out of 10 Miles of 22H88 Artificial Line

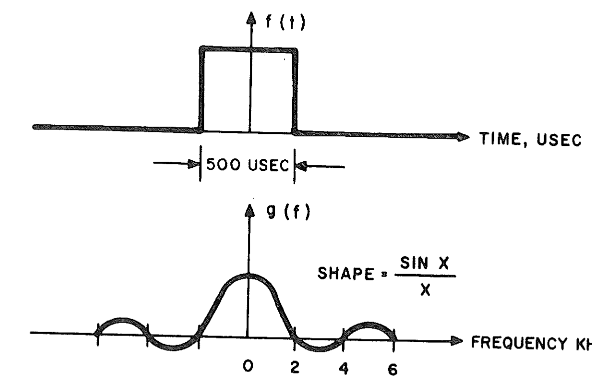


Fig. 17 – Example of a Fourier Transform Pair Illustrating an "Isolated" 500-Microsecond Pulse

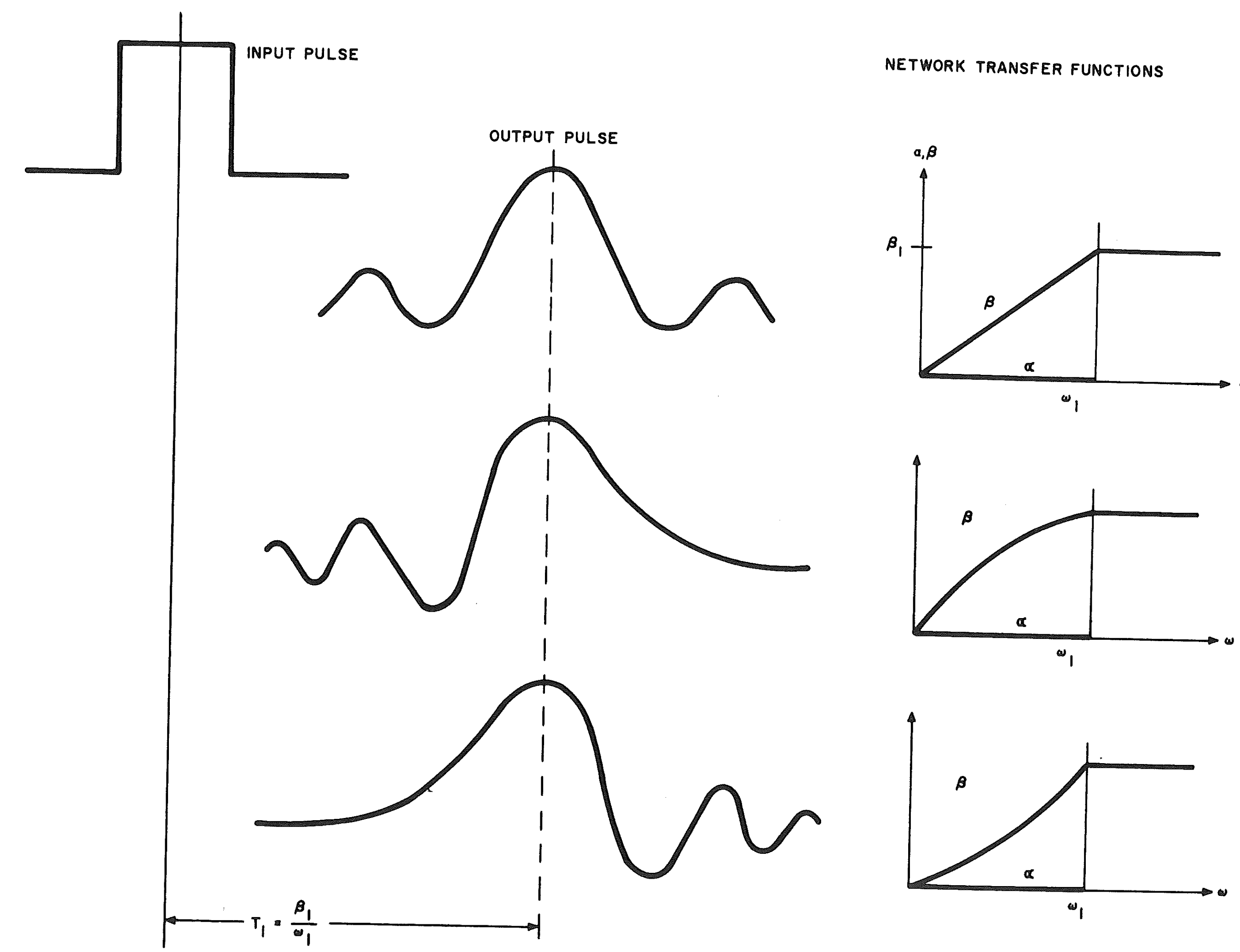


Fig. 18 – Pulse Transmission Through Low-Pass Filter with Phase Distortion

4. DELAY DISTORTION ON CARRIER FACILITIES

Thus far, 10 miles of 22H88 loaded cable has been used as an example of a 2-terminal pair network for quantitative calculations of delay distortion. A typical long-distance telephone

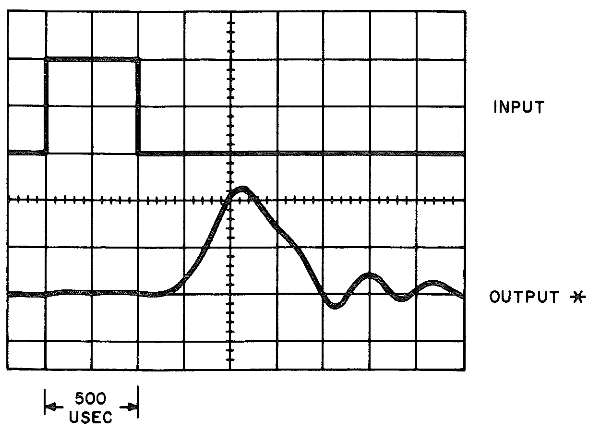


Fig. 19 – Oscillogram Showing Response of 10 miles of 22H88 Loaded Cable to a 500-μsec Pulse

circuit will likely utilize some type of multiplex equipment to provide a number of channels on the same physical facility. A typical example, and one which will be used for illustrative purposes, is the Western Electric type L carrier equipment. This equipment is similar to carrier equipment manufactured by others that meet CCITT standards. It can be used to provide up to 600 voice channels in the 60- to 2788-kHz band using frequency division multiplex and single-side-band (SSB) modulation. Each voice channel provides a frequency band from 175 to 3250 Hz. Twelve individual voice channels make up a channel bank. The A-type channel banks use highly selective full-lattice crystal filters in the 60- to 108-kHz range to select the lower sideband in the(SSB) system. Since these filters must have very sharp cutoffs, their phase-shift characteristic is quite nonlinear at the lower and upper end of the voiceband. This phase nonlinearity is the major contributor to delay distortion when using L carrier channels for data transmission.

It is usually impractical to measure the phase-shift characteristic of(SSB) suppressed carrier systems because of the lack of phase lock on the reinserted carrier at the product demodulator. This is true even if frequency lock is achieved by baseband transmission of a carrier synchronizing signal. In general,(SSB) suppressed-carrier systems exhibit a phase drift between input and output corresponding to the slight frequency offset in the demodulating carrier supply. Even primary frequency supplies which allow virtually no frequency shift over a measuring interval (for instance,

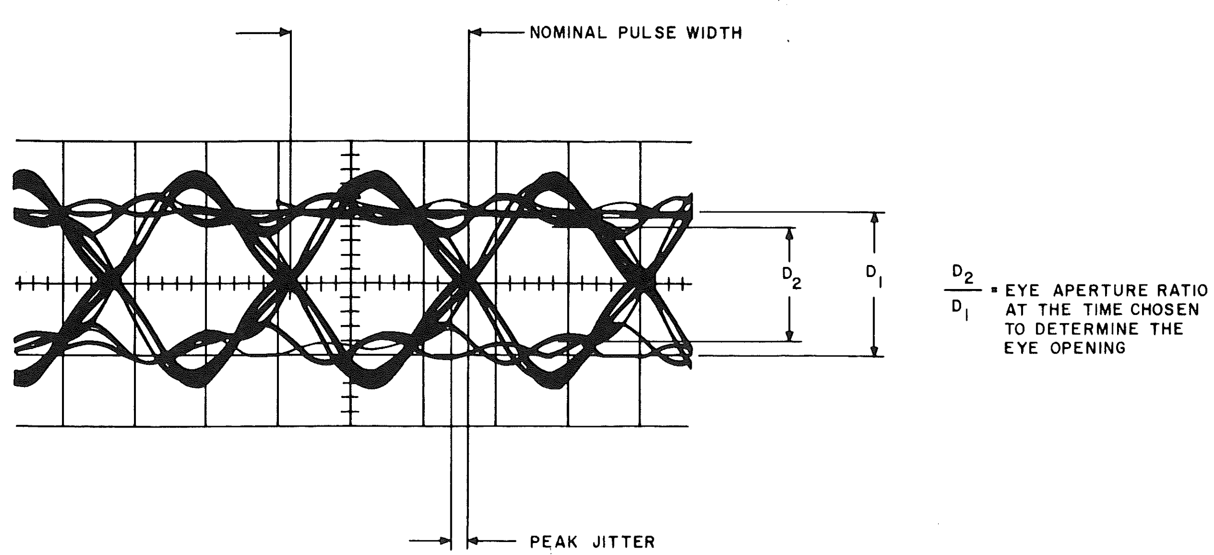


Fig. 20 – Eye Pattern for 2000-BPS Random Data on 10 Miles of 22H88 Loaded Cable Artificial Line – DC Continuity at Both Ends

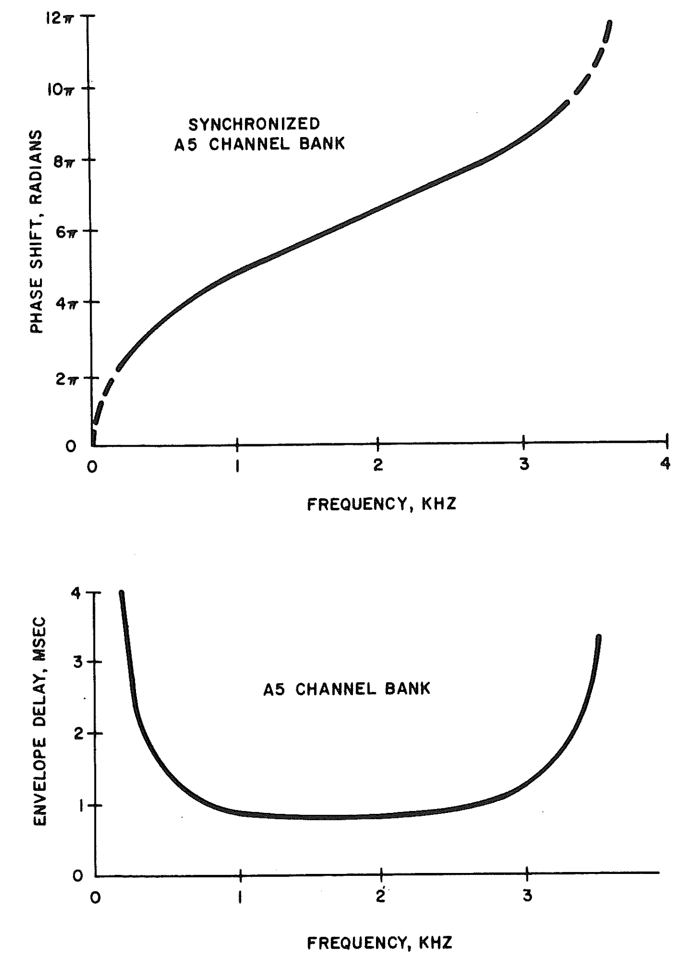


Fig. 21 – Phase Shift and Envelope Delay Characteristic of an L Carrier Channel

one second) may exhibit instantaneous phase excursions during the period and may be locked at arbitrary phase angles. By using the same carrier for modulation and demodulation it is possible to measure the actual phase-shift characteristic of an L carrier channel. This is plotted in Fig. 21 along with the corresponding envelope delay characteristic for one channel of an A5 channel bank. For a working system, the phase-shift scale will be moving up or down at 2 radians per Hertz of carrier frequency offset. The shape of the phase-shift characteristic is not affected, however.

The phase-shift characteristic can be determined by integration of the envelope delay curve. Envelope delay will be independent of carrier offset. The resulting phase-shift characteristic can be examined to determine delay distortion relative to some reference point on the curve, usually the data set carrier frequency. The phase delay at a given frequency cannot be determined in this manner unless the actual propagation time is known at the lowest frequency which the channel will transmit. The channel will normally have to be looped back for this test. Phase delay on an SSB carrier channel is sometimes confused with absolute envelope (or "group") delay, which is readily measurable even in the presence of carrier offset. Fig. 22 illustrates phase-delay and absolute envelope delay. Based on this figure it may be seen that at 1000 Hz:

$$\text{phase delay} = \frac{\beta}{\omega} = \frac{4.63\pi}{2\pi\ 1000} = 2310\ \mu\text{sec}$$

while the absolute envelope delay is equal to 900 μsec. Thus, there is no relationship between the two types of delay. Also, since a phase-shift of η (2π radians, where η = 1, 2, 3, etc. at a discrete frequency is not detectable, the output waveform would appear as if it had encountered a delay of only:

$$\text{apparent phase delay} = \frac{(4.63-4)\pi}{2\pi\ 1000} = 315\ \mu\text{sec}$$

This is also shown graphically in Fig. 22.

If carrier offset were encountered, the apparent phase delay would be continually drifting at the cyclic rate of the offset. Phase-shift effects such as this are not usually of importance in data transmission since some type of modulation is used which will provide phase reference for data recovery. It is the phase-shift irregularities relative to this reference carrier frequency which are generally of interest.

For example, consider the delay distortion for envelope components of an AM data signal with a carrier frequency of 2200-Hz (f_c) and a maximum upper sideband component at 3400-Hz (f_u) when transmitted over an L carrier circuit using A5 channel banks. For simplicity, assume the lower sideband is not used. The lowest AM modulating components will be very near the carrier frequency. The difference in delay for the envelope components near the

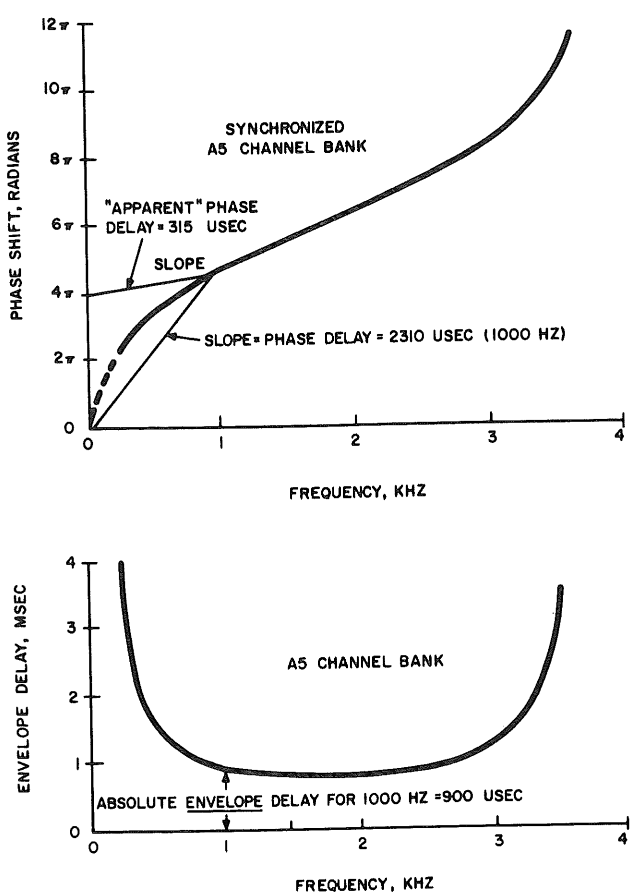


Fig. 22 – Phase Delay, Apparent Phase Delay, and Absolute Envelope Delay for an L Carrier Channel

carrier and those at 3400-Hz is the delay distortion in the detected signal. For the case of one link of A5 channels, the distortion can be computed directly from the phase-shift characteristic or indirectly by integrating the envelope delay characteristic.

Referring to Fig. 23, the area obtained by integrating the envelope delay curve from f_c to f_u (neglecting the actual absolute envelope delay near the carrier) is designated β_d and corresponds to the phase-shift of the 3400-Hz envelope component relative to the components near the carrier. The shape of the phase-shift characteristic thus determined agrees with the actual phase-shift curve "twisted" so that its slope is zero at the carrier frequency. This is shown in Fig. 23 as relative phase-shift. This, in effect, arbitrarily makes the delay of the envelope components near the carrier frequency equal to zero seconds. The detected 3400-Hz component will have a baseband frequency of 1200 Hz after detection, and the detected 2200 Hz component will have a baseband frequency of 0 Hz after detection.

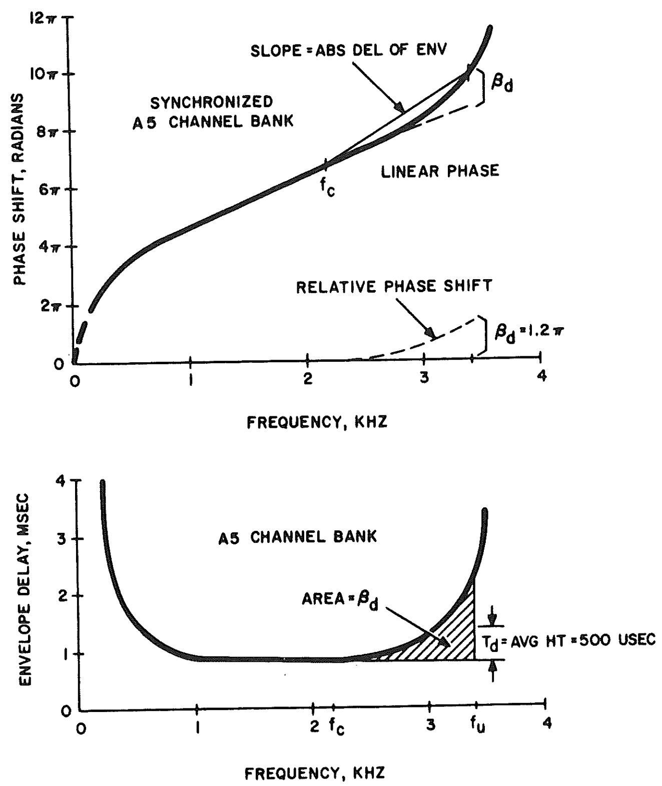


Fig. 23 – Method for Determining Delay Distortion for Envelope Components in an AM Signal

Therefore, the delay distortion between 0 Hz and 1200-Hz will be:

$$T_d = \frac{\beta_d}{\omega_m} = \frac{1.2\pi \text{ radians}}{2\pi\ 1200 \text{ radians/second}} = 500\ \mu\text{sec}$$

Since each signal element is only 1/2400 = 417 μsec in width, the detected signal is severely distorted.

It must be emphasized that the results of this example do not take into account the vector addition of two sidebands in a product demodulator, the effects of envelope detectors, and unequal sideband attenuation. The numerical results of this example are not directly applicable to FM, FSK, PM, PSK, differential phase detection (4-phase systems), etc.

4.1 Intercept Distortion

If an SSB carrier system, such as type L with A5 channel banks is used to transmit a baseband data signal, the difference in phase delay for the various frequency components causes delay distortion in the output waveform. If the significant frequency components of the complex waveform fall along the linear portion of the phase-shift curve, (e.g., 1000-to 2500-Hz for an A5 channel), the output waveform can still be distorted unless an extension of the linear phase has a zero frequency intercept of $\eta(2\pi)$ where η = 1, 2, 3, etc. This is illustrated in Fig. 24. In effect, the "apparent" phase delay in the useful frequency band is the same at all frequencies. At the present "state-of-the-art," no attempt is made to stabilize the frequency and phase of the reinserted carrier to achieve satisfactory baseband transmission over telephone grade circuits. On nonsynchronized SSB carrier systems, the carrier offset will cause a drift in the zero frequency intercept over a $\pm\ \pi$ radian range. Some channels are synchronized to prevent this drift for special services, but even in these cases no attempt is made to correct the actual intercept to $\eta(2\pi)$.

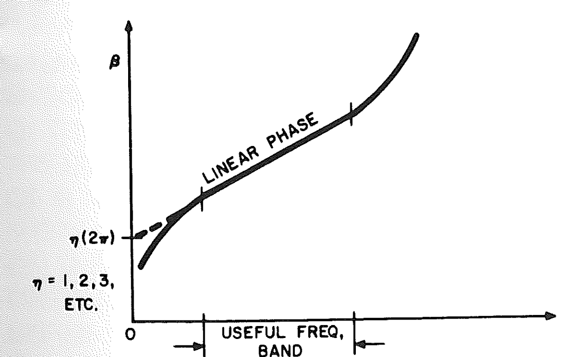


Fig. 24 – Requirements for Zero Intercept Distortion

5. SUMMARY

In general, actual calculation of the envelope delay characteristic of a particular telephone circuit requires adding the individual envelope delays contributed by the wire line, the terminal apparatus, and all intermediate equipment for each selected frequency in the frequency band of interest. At frequencies above 1000-Hz, the amount of envelope delay contributed by transformers, signaling equipment, and most repeaters is negligible compared to the delay contributed by the loaded wire line or channel bank filters. Below 1000-Hz this same equipment is a major contributor to delay and each item must be considered.

Where an accurate determination of envelope delay for a particular transmission system is required, it is desirable to check the amount of envelope delay by actual measurement. This is especially necessary when an appreciable mismatch exists between sections of the line, or between the line and office apparatus. Reflections sometimes cause an overall envelope delay characteristic that is much different from that which is deduced by adding the envelope delays of the component parts. This is particularly noticeable at low frequencies where the return loss may be low and in the case of short lengths of line where the loss is relatively low. In the case of long-loaded cable circuits, the envelope delay should be checked by measurement because manufacturing and loading tolerances and subsequent cable rearrangements can cause appreciable variations from the envelope delay. The envelope delay of various multiplex systems is not as susceptible to such variations. However, where extreme accuracy is required, actual measurements are recommended.

6. MATHEMATICAL DERIVATION OF ENVELOPE DELAY

Envelope delay is the delay that the envelope of a "narrowband" amplitude-modulated signal experiences in being transmitted through a circuit. This delay can reasonably be defined as the first derivative of phase with respect to radian frequency.

Let the input voltage to a circuit, e_i, be expressed as:

$$e_i = \cos \omega_c t + m \cos \Omega t \cos \omega_c t \qquad (1)$$

where

ω_c = radian carrier frequency
m = amplitude modulation index $(0<m\leq 1)$
Ω = radian modulating frequency = $\Delta\omega$

A trigonometric expansion of Eq. (1) gives this expression for e_i.

$$e_i = \cos \omega_c t + \frac{m}{2} \cos (\omega_c + \Omega) t \qquad (2)$$

$$+ \frac{m}{2} \cos (\omega_c - \Omega) t$$

where ω_c is the carrier frequency, $\omega_c + \Omega$ is the upper sideband frequency, and $\omega_c - \Omega$ is the lower sideband frequency. When e_i passes through a circuit, each of these frequencies will, in general, experience a different amount of phase shift. An example of this phase-shift is shown in Fig. 25 for ω_c, $\omega_c + \Omega$, and $\omega_c - \Omega$

Assuming that the total system under consideration has only the characteristic of Fig. 25 the expression for the output signal is simply Eq. (2) with the appropriate phase-shift term added. This results in:

$$e_o = \cos (\omega_c t - \beta_c) + \frac{m}{2} \cos (\omega_c t + \Omega t - \beta_u)$$

$$+ \frac{m}{2} \cos (\omega_c t - \Omega t - \beta_L) \qquad (3)$$

If the frequency difference between $\omega_c - \Omega$ and $\omega_c + \Omega$, i.e., 2Ω, is small enough, then the phase characteristic will be nearly linear over the bandwidth of the test signal. Fig. 25 is drawn to make this evident. If this is true, then β_L and β_u can be expressed in terms of β_c, the phase-shift at the carrier.

$$\beta_L = \beta_c - \Omega T_e$$

and

$$\beta_u = \beta_c + \Omega T_e \qquad (4)$$

where T_e is a constant equal to the slope of the straight line segment shown in Fig. 25 (see derivation of T_e on sketch) T_e is also the envelope delay. Substituting the expressions in Eq. (4) into Eq. (3) gives

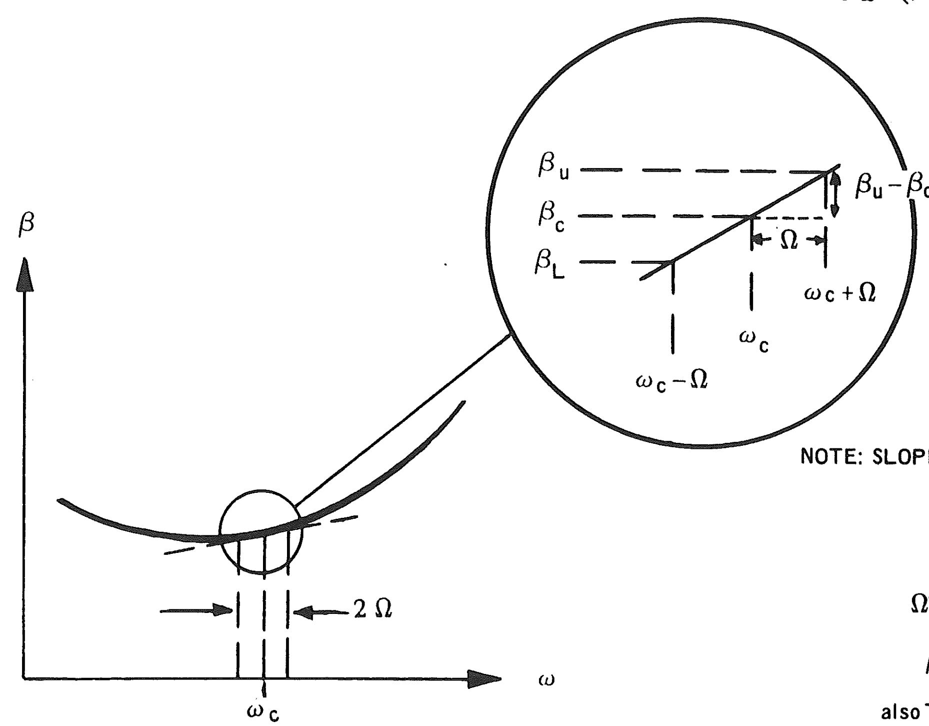
$$e_o = \cos (\omega_c t - \beta_c) + \frac{m}{2} \cos (\omega_c t + \Omega t - \beta_c - \Omega T_e)$$

$$+ \frac{m}{2} \cos (\omega_c t - \Omega t - \beta_c + \Omega T_e) \qquad (5)$$

Writing Eq. (5) in the closed form of Eq. (1) gives

$$e_o = \cos \omega_c \left(t - \frac{\beta_c}{\omega_c} + m \cos \Omega (t - T_e)\right)$$

$$\cos \omega_c \left(t - \frac{\beta_c}{\omega_c}\right) \qquad (6)$$



NOTE: SLOPE
$T_e = \frac{\beta_u - \beta_c}{\Omega}$

SOLVING FOR β_c

$\Omega T_e = \beta_u - \beta_c$

$\beta_c = \beta_u - \Omega T_e$

also $T_e = \frac{\beta_c - \beta_L}{\Omega}$

and $\beta_c = \beta_L + \Omega T_e$

Fig. 25 – Measurement of Envelope Delay

Equation (6) is identical to the equation of the input signal, Eq. (1), except that the carrier has been delayed by β_c/ω_c and the envelope has been delayed by T_e; i.e., the delay of the carrier is the slope of a straight line drawn from the origin through the phase curve at the radian frequency ω_c, and the delay of the envelope is given by the slope of the straight-line approximation of the phase curve at ω_c.

Because the approximation is over a narrow portion of the phase curve, the slope approaches, for all practical purposes, the derivative of the phase-shift characteristic at the frequency of measurement. Then envelope delay is defined as

$$T_e = \frac{d\beta}{d\omega}$$

where β is the phase-shift function in radians and ω, is the angular frequency $(2\pi f)$ in radians per second. T_e is normally plotted vs f for data channel measurements.

NOTE THAT T_e IS NOT THE DELAY OF A SINE WAVE SIGNAL OF FREQUENCY ω_c OR EVEN Ω RADIANS/SEC. THIS IS THE MOST OFTEN ENCOUNTERED CONFUSION ABOUT THE USE OF THE ENVELOPE DELAY CHARACTERISTIC OR THE USE OF THE TERM "DELAY." THE "DELAY" OF A SINGLE FREQUENCY SINE WAVE IS THE SLOPE OF A STRAIGHT LINE FROM THAT POINT ON THE PHASE-SHIFT CHARACTERISTIC TO THE ORIGIN. IT IS IMPRACTICAL OR IMPOSSIBLE TO DEFINE THE ORIGIN ON CARRIER DERIVED CHANNELS.

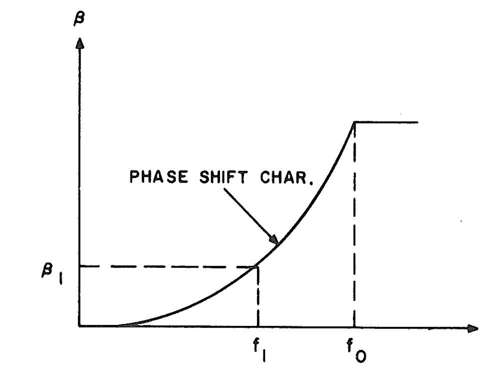
7. GLOSSARY

As an additional aid to understanding the material presented in this appendix, the following glossary briefly reiterates the meaning of several of the more important terms used in the area of delay distortion.

Phase-Delay (T_p)

The time-delay between an input sinusoidal waveform to a circuit or network, and the output waveform is called phase-delay or propagation time. For example, if the formula for the input waveform (e_1) were e_1 = sin $2\pi f_1 t$ the output waveform e_2 would be e_2 = sin $2\pi f_1 t - \beta_1$. β_1 is the amount of phase-shift obtained from the phase-shift characteristic at a particular frequency f_1.

Example:



If the phase-shift characteristic is known, the phase delay at any frequency (ω_1) can be computed as:

$$T_p = \frac{\beta_1 \text{ radians}}{\omega_1 \text{ radians/second}}, \quad \text{where } \omega = 2\pi f$$

Delay Distortion (Td)

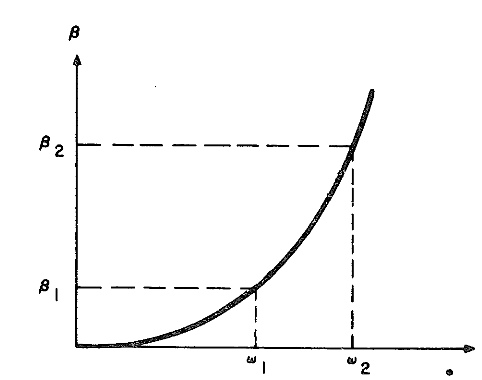
The delay distortion between two frequencies is defined as the difference in arrival time between signals at the two frequencies. It is the direct result of a nonlinear phase-shift characteristic in the transmission medium. Delay distortion may be defined as:

$$T_d = \frac{\beta_2}{\omega_2} - \frac{\beta_1}{\omega_1} \qquad T_d = \frac{\beta_{max}}{\omega_{max}} - \frac{\beta_c}{\omega_c}$$

Base Band — Subcarrier

which is the difference in phase-delays at the two frequencies of interest.

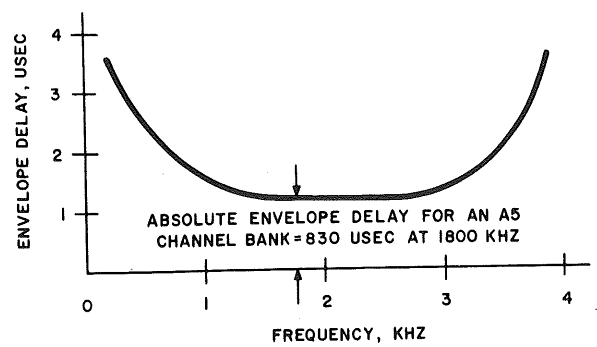
Example:



Absolute Envelope Delay (Envelope Delay)

Absolute envelope delay (envelope delay) is the derivative of the phase-shift characteristic with respect to frequency. It is measured by transmitting a narrowband signal at the frequency(s) of interest and using the same reference at the receiver.

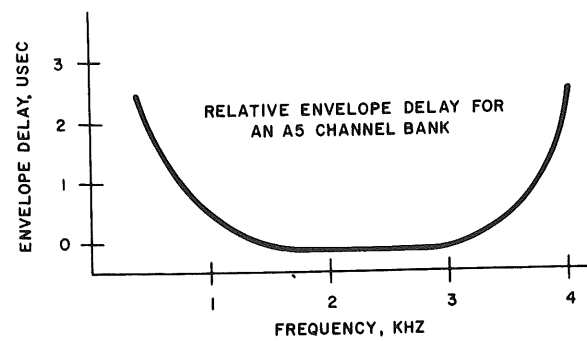
Example:



Relative Envelope Delay

Relative envelope delay is the difference in envelope delay at various frequencies, but with a specific frequency selected as a reference point for all other frequencies. The envelope delay at the reference frequency is considered to be 0 microseconds, and all other frequencies will either have more (positive) or less (negative) envelope delay than the reference frequency.

Example:



Envelope Delay Distortion

True delay distortion as determined from the phase characteristic is often confused with envelope delay distortion as determined from the envelope delay characteristic. Envelope delay distortion is the maximum difference, in microseconds, of the envelope delay characteristic between any two specified frequencies. It is not directly related to delay distortion (T_d).

Example: