DATA COMMUNICATIONS SERVICE
GENERAL ENGINEERING CONSIDERATIONS
DATA SERVICE ON THE SWITCHED NETWORK

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1. GENERAL

1.01 This section outlines transmission engineering considerations for data communications service on the switched network. The detailed engineering information on the derivation and significance of transmission parameters and factors previously given in Section 880-440-101 has been incorporated in this section. Test procedures and requirements are covered in Sections 314-205-500 and 314-205-501. The information contained in this section and referenced sections is applicable to wide area telecommunications service (WATS). The engineering guidelines provided in this section apply to data communications service, which is defined above.

1.02 This section is reissued for the following reasons:

(a) To change the title of the section

(b) To eliminate the term DATAPHONE® throughout this section.

Revision arrows are used to emphasize significant changes.

1.03 Some of the information contained in this section is also applicable to private line services. Private line services are specifically covered in the 880-420-ZZZ series of sections.

1.04 Registration is the Federal Communications Commission's (FCC) program for terminal equipment establishing protection requirements to minimize potential harms to the network from terminal equipment directly accessing the message network. To qualify for registered status, terminal equipment must meet requirements which are concerned with the following:

Longitudinal balance

Hazardous voltage protection

Signal power level

Network control signaling

Call charge protection.

1.05 Certain unregistered equipment lawfully connected to the network prior to May 1, 1976, is considered to be "grandfathered" equipment and will continue to use connecting arrangements. More detailed information on the Registration Program and details on grandfathered equipment are given in Section 880-440-103.

1.06 Descriptive information common to the transmission of data on the switched network, private line (PL) services, and Switched Service Networks (SSN) is covered in the following sections:

- Data General—Analog Transmission Parameters—Description (Section 314-010-100)
- Data General—Data Testing Principles (Section 314-010-101)
- Data General—Data Services Support (Section 314-010-102)
- Data General—Interconnection/Interpositioning (Section 314-010-103).

A basic understanding of the Data General sections is recommended prior to the use of this section.

2. SERVICE CONCEPTS

2.01 Initially, only telephone company provided data sets were connected to the network and the service was called DATAPHONE service. However, with the advent of interconnection, customer provided equipment (CPE) was permitted to be directly connected using some means of network protection. With the Registration Program, network protection is achieved by having equipment registered and connections made using voice jacks and data jacks.

2.02 Acoustical and inductive coupling is permitted; but data performance is not specified. Facilities provided for use with such devices are treated as voice circuits.

3. TRANSMISSION CONCEPTS

3.01 The switched message network evolved through the years as a system to handle voice communication. The design criteria and network characteristics were based largely upon transmission of the human voice. Speech and hearing characteristics were used to advantage to provide better and more economical transmission systems. Compandors and echo suppressors are typical examples of equipment designed to these characteristics. Such aids to voice transmission can become obstacles to data transmission.

3.02 In voice communication, the talker and the listener usually have a high degree of tolerance to transmission impairments. Redundancy in speech often allows the listener to supply syllables or even words missed or garbled because of noise, excess loss, or other transmission difficulties. Data sets are sensitive to some of the same transmission imperfections as voice, but they are also sensitive to other transmission parameters.

3.03 Some important transmission impairments (parameters) which can affect data transmission are as follows:

- C-notched noise

- Impulse noise
- Phase jitter
- Attenuation distortion
- Intermodulation distortion
- Gain hits, phase hits, and dropouts
- Frequency offset
- Envelope delay distortion (EDD).

The parameters listed above are those measured during a minimum acceptable performance (MAP) investigation as described in Section 314-205-503. Other parameters which may affect data transmission are as follows:

- C-message noise
- Return loss and echo
- Long-term loss variation
- Round trip delay.

These parameters and their effects on voiceband data transmission are discussed in Part 6.

3.04 Some connections established through the switched network show variations in the characteristics important in data transmission. The total number of switched links (trunks) in a connection can vary from none, in a local connection, to a maximum of nine, when the entire final routing chain is used on a long-distance call. Also, several different types of transmission systems are used to provide message facilities, ranging from open-wire pairs to microwave radio to satellite. Carrier systems are used extensively with many different types of channelizing arrangements. Variations in transmission characteristics, due to the trunking pattern and the different types of facilities, cannot usually be avoided. Proper engineering and maintenance can control variations within a particular facility or trunk and thus minimize the variations encountered in the network.

3.05 For a particular switched data service installation, the same subscriber loop is used in all connections. For a given subscriber, this part of the connection is not subject to the variations described in paragraph 3.04. For this reason, loops (subscriber lines) may require engineering. Detailed design of local loops is covered in Section 880-440-103. When engineering is required, it is important that the guidelines given in this section be followed carefully. Loops should have low net loss, noise, and distortion (attenuation and envelope delay) and high return loss consistent with engineering economy.

3.06 The foreign exchange (FX), remote exchange (RX), and/or remote exchange WATS are always engineered using the guidelines in Section 851-300-100. Where the above lines are used for switched data service, the additional guidelines specified in Section 880-440-105 also apply.

4. PERFORMANCE OBJECTIVES

4.01 The MAP program has been established to help in identifying those connections on which frequent or consistent substandard performance may be experienced. The parameter requirements given in Section 314-205-503 should not be considered as objectives for the facilities investigated; they are, rather, the ***minimum acceptable requirements*** for the parameters measured that can be expected to provide a satisfactory grade of service.

4.02 The service objective for the network is to achieve acceptable performance on 85 percent of the calls. To ensure that this objective is met, sufficient requirements for switched data service transmission are needed at the trunk and facility level. End-to-end requirements have been known for some time and are given in Section 880-440-105. Trunk requirements are also given in Section 880-440-105.

4.03 There are four basic types of access lines:

Subscriber loop

FX

WATS (both remote and local)

PBX.

All FX and remote WATS orders are designed services, but other orders are installed on a normal service order. However, if problems are encountered at installation or troubles are reported, the loop, local WATS, or PBX service will be sent to engineering for design. If any of the above service arrangements do not perform after engineering design, then MAP tests should be made to determine if end-to-end requirements are met. The PBX lines terminated in voice jacks are not designed; and MAP requirements do not apply. Further details on access lines are given in Section 880-440-103.

5. TRANSMISSION CONSIDERATIONS

5.01 This part discusses briefly some of the parameters which must be considered in the transmission of data over the switched network and states current requirements for these parameters. In the establishment of objectives, there must be a constant trade-off. This trade-off exists between parameter values needed to provide reasonable transmission of data and the current capabilities of transmission facilities. Since the requirements on trunks are statistical by nature, there will always be cases where all requirements are not met. If all requirements are met for all trunks, there is no guarantee that the connection will be satisfactory for all data transmission. The primary goal is to keep existing facilities performing as well as possible. Better quality data transmission and higher bit rates can only be achieved through the introduction of new facilities, designed to higher standards.

A. Standard Jacks

5.02 The FCC registration program requires that all terminal equipment be registered and connected to the switched network by means of a jack and plug. One of the two jacks used is the ***voice jack***. One type of registered data equipment for use on voice loops using a standard miniature voice jack may transmit at a nonadjustable level not to exceed −9 dBm maximum (no tolerance). The other jack used is the ***data jack***. ➧Normally, a 97A-type connecting block is used with the fixed loss line or adjustable type equipment and is called the "universal data jack." A 97B-type connecting block may be used with the programmed type of data equipment only and is called the "programmed data jack" in this case.➧ Additional information on the voice jacks is given in the appropriate sections in the 463-400-ZZZ layer. Additional information on data jacks is given in Section 590-101-103.

> ***Note:*** Grandfathered equipment may continue to be connected as in the past. Data couplers and data access arrangements may continue to be used for existing services and that equipment which is "grandfathered."

B. Transmission Levels

5.03 Control of the signal power is the responsibility of the network forces. This necessitates a basic change in the way a data modem is arranged for signal power control. Three methods are available, and two of them allow the modem designer to optimize performance. These methods continue the basic idea of past practice, which is power at the serving central office set as close to −12 dBm as practicable.

Voice Jack

5.04 One method allows modem designers to provide a nonadjustable signal power (output level) not to exceed −9 dBm. Such a modem can be connected to either a voice or data jack. (This procedure has resulted in some confusion. A data modem or protective circuitry using this method of controlling signal power will be equipped with a 6-position plug. Such a plug can be inserted into a 6-position voice jack or the 8-position keyed data jack. Pin assignments and mechanical alignment are such that direct connection to tip and ring results in either case.) Major motivation for this option comes from a desire for electrically-connected, portable data modems. Such an option is also available for data protective circuitry. It is expected that the basic data access line will be satisfactory for such applications.

Data Jacks

5.05 ➧Control of output level (signal to noise advantage) is the most important transmission parameter. Since data sets with −9 dBm output level cannot optimize signal level, data transmission quality cannot be assured. However, since the telephone company has no control over what is connected to the jack, only lines terminated in data jacks will be supported for data communications. Voice jacks are supported for voice services only.➧

5.06 Another option allows the transmitted signal power to be set at −4 dBm at the time of manufacture (or it can be adjustable, provided the highest level is no more than −4 dBm nominal). The telephone company will pad out the loop when the data jack is installed to a loss between 8 and 9 dB.

5.07 The third option continues the idea of signal power adjustment within the modem. The installer equips a data jack with a resistor, the value of which is determined by a measurement of loop loss. The modem is designed to respond to that value of resistance to produce a transmitted signal power which will result in power at the serving central office between −12 and −13 dBm. Modems of either of the latter two types will connect to a data jack via a keyed, 8-position plug furnished as part of the registered data modem.

5.08 When transmitting into toll facilities, the serving central office is connected to the toll office by a toll-connecting trunk designed to via net loss (VNL) + 2.5 dB, which will average 3 dB at 1004 Hz. Since the toll switch is a −2 transmission level point (TLP), the serving central office appears to be a +1 TLP in relation to the toll facilities, which accounts for the −12 dBm level specified for the serving central office. The losses of toll connecting trunks will vary, but the combination of loop loss and data transmit level should not permit the data signal to exceed the specified maximum level at the serving central office by any appreciable amount.

5.09 At various types of jacks, the transmit level is adjusted as follows:

- Voice jack—use −9 dBm as transmit level
- Universal jack—use a fixed resistor
- Programmed jack—select a resistor value.

In data sets transmitting F1 and F2 frequencies, the maximum levels specified apply to the F2 frequency. These data sets will use voice jacks and a maximum −9 dBm output. Since maximum data set loop loss is stated at 8 dB, the maximum permissible transmit level for a programmable data jack will be −4 dBm. The transmit levels of some data sets are adjustable in steps which vary with different data sets. When data jacks are used, the data transmit levels should be adjustable to obtain −12 dBm, as nearly as possible, at the serving central office. Where the desired level cannot be obtained exactly, use the next lower setting.

C. Overall Loss

5.10 The overall 600-ohm transducer loss is the loss, expressed in dB, experienced by a 1004-Hz tone propogating along the circuit from a 600-ohm signal source to a 600-ohm transmission measuring set (TMS). The power is measured at the receiving end using a TMS which is calibrated in dBm. Where compandored facilities are involved, mistracking may cause the measured loss to vary as much as 1 dB with changes in the level of the transmitted tone. Normally, the tone is transmitted at the data signal level, ie, at −13 dBm0. That is, at any zero transmission level point (0 TLP) in the system, the signal should measure −13 dBm. At any other point, the signal power will differ from −13 dBm by the gain or loss from the point in question to a 0 TLP. The loss limits stated for lines and trunks are normally in terms of 1004 Hz. The losses at other frequencies differ, depending on the facility used. In some cases, the loss of the facility at some other frequency may be controlling; this requirement will be stated in the requirements for that application. For instance, a loss limit at 2804 Hz may be stated and this may be the controlling loss.

6. ANALYSIS OF ANALOG PARAMETERS ON DATA TRANSMISSION

6.01 Different parameters have different levels of importance to data transmission in general, and a particular parameter may have different levels of importance, depending upon the type of data signal and the speed at which the data is transmitted. The discussion of parameters in this section is intended to provide an understanding of the parameters which affect data transmmission, but no attempt is made to assign relative degrees of importance to the parameters. This information is generally provided in Section 314-205-500 covering particular data sets and data systems.

A. Attenuation Distortion (Slope)

6.02 The term attenuation distortion (slope) refers to the departure in dB referenced to the response at 1004 Hz within the "flat" or used portion of the frequency characteristic of the channel. It is also defined as the difference in loss referenced to the loss at 1004 Hz. The "flat" portion is generally from about 404 to 2804 Hz for most long-haul trunks. The voiceband usually extends from about 304 to 3204 Hz.

6.03 As with overall attenuation, the attenuation-frequency characteristic of connections on the PSN varies from connection to connection. On a built-up connection, it includes facility effects as well as the effect of "creeping distortion" at the higher frequencies due to office wiring, capacitance building out, etc. Slope between 1004 and 2804 Hz should not exceed 8 dB on any end-office to end-office connection. When designed for data the maximum permissible slope in a local loop is 3 dB.

B. Return Loss and Echo

6.04 Impedance mismatches in a circuit cause signal energy reflections called echoes. If a transmitted signal is reflected once, energy is returned to the transmitter and is called (first) talker echo. Talker echo is not normally a problem to data transmission since the data set does not transmit and receive on the same frequency at the same time.

> ***Note:*** Talker echo could be a problem on half-duplex transmission with long delay time, such as would be experienced on a satellite connection. If delay time is large, the receiver would be opened too quickly and the echo interpreted as data from the far end. The use of the newly developed echo canceler chip will greatly reduce this transmission impairment.

If a second impedance mismatch exists in a circuit and echo is returned toward the receiver, it is called (first) listener echo. Listener echoes arrive at the receiving data set after the direct data signal and can be a serious problem since they interfere with the received data signal. Listener echo should be at least 20 dB below the received signal level.

6.05 Echoes are generally not a problem on 4-wire channels because there is virtually no echo path since each direction of transmission is electrically separate. On 2-wire and combination 2-wire/4-wire channels, however, echo control is an important consideration. Echoes are controlled by matching impedances and by controlling loss in the echo path. The impedance of the balancing network is ideally the same as the impedance into the 2-wire section. Under this condition, signal power from the station receive side of the 4-wire facility would divide evenly between the balancing network and the 2-wire facility, and no signal power would "return" on the transmit side. In practice, the match is never perfect and is different at different frequencies. Some portion of the signal power is always transferred into the transmit side of the 4-wire facility.

Return Loss

6.06 Return loss is the ratio in dB of power of a ***single-frequency*** signal placed on the station receive side of the 4-wire facility to the resulting power ***at the frequency*** "returned" on the transmit side. Return losses at each 2- to 4-wire transition point in the transmission path affect echo. At 2-wire switching points, the return losses are affected in turn by office balance.

Echo Return Loss

6.07 Echo return loss is the same as single-frequency return loss except that a weighted average of returned power, expressed in dB, over the frequency band between 504 and 2504 Hz is used.

Singing Return Loss

6.08 Singing return loss is a weighting average of returned power, expressed in dB, at all frequencies in a frequency band. There is a low-frequency test covering the 204- to 504-Hz band and a high-frequency test covering the 2504- to 3204-Hz band.

Singing Point

6.09 A singing point test is made by placing a variable-gain amplifier ***between*** the two directions of a 4-wire facility and increasing the gain until self-sustained oscillations ("singing") occur at some frequency. The singing condition is detected by audio monitoring of the circuit. The amount of gain in dB required to cause singing is called the singing point. Measuring techniques are covered in Section 103-106-105.

Singing Margin

6.10 This test is similar to the singing point test. For this test the channel is terminated in its normal impedance. A variable-gain amplifier is inserted ***on one side*** of the 4-wire facility and the gain increased until singing occurs. The amount of gain in dB required to cause singing is called the singing margin.

Testing 2-Wire Voice Facilities

6.11 The return loss, echo return loss, singing return loss, and singing point tests can be made on a 2-wire facility by incorporating the hybrid in the test set and making measurements as described in paragraphs 6.06 through 6.10.

C. C-Notched Noise

6.12 C-notched noise is message-circuit noise on a channel in the presence of a signal. It is important because of quantizing noise produced in digital carrier systems and because of the effects of compandors in both digital and analog carrier systems. C-notched noise is measured by transmitting a 1004-Hz holding tone (at −13 dBm0), filtering out the tone at the receiving end using a notch filter, and measuring the noise through a C-message weighting network. The ratio of the received level of 1004-Hz tone to received noise is the approximate data signal-to-noise ratio on the channel under operating conditions.

D. Impulse Noise

6.13 Impulse noise is a serious consideration in data communications service. Error-rate performance deteriorates rapidly once the specified overall requirements are exceeded. Impulse noise is difficult to measure because it occurs intermittently with relatively long periods between bursts. To determine the true mean level within a high degree of confidence where a given number of counts per minute occurs, measuring periods of 5 to 15 minutes may be specified. Impulse noise measurements can be made at any time in the day, but if measurements are made during trouble investigations, they should be made during the time period when the customer experiences trouble. Likely sources of impulse noise are short-haul carrier systems—such as N, ON, and O, poorly designed and/or maintained step-by-step switching offices, and electromechanical PBXs. Panel offices are not recommended for data communications services.

6.14 When making measurements on syllabic compandored facilities, a 1004-Hz holding tone is transmitted at −13 dBm0, fixing the expandor loss at 9 dB. Measuring techniques are covered in Section 314-010-101.

6.15 Impulse noise requirements for data communications access lines are given in Section 880-440-105.

E. Peak-to-Average Ratio (P/AR)

6.16 It is difficult to evaluate the resultant intersymbol interference from an envelope delay measurement. It is, therefore, difficult to establish requirements in the delay domain which satisfactorily characterize the channel quality. A technique to measure signal dispersion in a channel (lessening in amplitude and lengthening in duration) has been developed to help overcome this problem. The technique is as follows: a pulse train is generated with spectral content shaped to be representative of a data-modulated voiceband signal with spectral components chosen at the generator to give rise to high peak-to-average ratio (peak signal to full-wave rectified average) in the output. The dispersion of the signal in time, caused by the characteristic of the channel, results in a deterioration of the P/AR. By measuring the ratio at the receiving end, an indication of the amount of signal dispersion is obtained. The 27F or 27G P/AR instruments are susceptable only to intersymbol interference caused by EDD, poor frequency response, and echoes. These sets are essentially immune to all other impairments if the others are within limits. The use of the earlier versions of P/AR sets should be discontinued since these sets are seriously affected by noise and intermodulation distortion.

6.17 The P/AR signal transmitted is designed so that degradation of the signal by envelope delay distortion is similar to that usually experienced by data signals. As a result, the correlation between P/AR readings on transmission facilities containing delay distortion and the quality of data transmission over these facilities is excellent. The results of experiments to investigate this correlation are shown in Fig. 1. It should be observed that the uncertainty in degradation, as determined by the P/AR reading, increases with decreasing P/AR values. For readings in excess of 55, the maximum uncertainty is about 2 dB. The degree of uncertainty increases as the threshold of complete failure is approached. The P/AR readings for the threshold of complete failure vary through the range of about 35 to 70, depending upon the particular data set. The data points which lie farthest from the curve (each identified by an o) originate from over-equalized delay characteristics, ie, the characteristics had maximum relative delay near the center of the frequency band instead of at the edges. This is not the usual case on long built-up connections.

6.18 The points discussed in paragraph 6.17 are indicative of a qualification that must be kept in mind in using P/AR values; the best correlation with data performance is obtained when the envelope delay characteristic in all bandpass filters that have not been delay-corrected in some fashion is generally parabolic. Therefore, P/AR readings obtained over carrier systems should be reliable measures of the quality of data transmission with regard to envelope delay distortion. The correlation of P/AR with data transmission performance deteriorates as the envelope delay characteristic becomes extremely asymmetrical. Long runs of loaded cable may yield erroneous P/AR readings because of the asymmetrical envelope delay.

6.19 In specifying envelope delay distortion in terms of maximum differential envelope delay, the problems of correlation with differential delay statements, and therefore data transmission, are indicated in Fig. 2. Several envelope delay characteristics which meet a given differential delay (envelope delay distortion) requirement produce oscillograph eye openings ranging from 0.45 to 0.85, corresponding to P/AR readings of 45 and 85, respectively.

6.20 Although the P/AR meter evaluation of delay distortion correlates well with the impairment to data transmission in real systems, the use of P/AR as an engineering tool has shortcomings. For example, P/AR readings taken on individual trunks are not additive. Two trunks composed of different types of carrier facilities may yield a P/AR value of 90, but when measured in tandem, the P/AR value may be greater or less than 90 (usually less). In addition, the P/AR meter is sensitive to impairments other than envelope delay distortion in varying degrees, as previously stated. The P/AR requirements for trunks are based upon the channel bank and/or cable characteristics of the facilities which make up the trunk and the average end-office equipment such as office cabling, coils, single-frequency signaling units, etc.

F. Envelope Delay Distortion

6.21 This parameter is not normally measured unless P/AR requirements are not met. The characteristic called envelope delay (dF/df), a derivative of phase, is used because it is difficult to measure the phase characteristic of a transmission facility since a phase reference is difficult to establish at the receiving end of the circuit. Also the channel may have a varying zero frequency phase intercept. In practice the true derivative cannot be measured either, but can be approximated by measuring the difference in shift (DF) experienced by the sidebands of a narrowband AM signal and displaying the approximate derivative (DF/Df) on an instrument. The quantity Df is twice the modulation frequency and is referred to as the aperture of the instrument. The difference between the quantity DF/Df measured at some frequency and that measured at a reference frequency is referred to as envelope delay distortion.

6.22 Several different apertures have been used in practice, two of which are discussed here. One is the telephone company standard of 166 2/3 Hz and the other is the international standard (CCITT) of 83 1/3 Hz. Figure 3 shows how each of these apertures modifies the true derivative of the phase characteristic by the factor sin x/x. The factor sin x/x is plotted as a function of f_0 for each of the two apertures. Echoes are usually of importance where part or all of the transmission path consists of 2-wire facilities. The plots have been truncated at $f_0 = 20$ Hz, because echo suppressors are installed on 2-wire connections where the round-trip delay exceeds 45 milliseconds and f is reciprocal of the round-trip delay or echo time. Therefore, components finer than 20 Hz should be of no interest. One exception to this supposition occurs when echo suppressors are disabled to permit simultaneous 2-way operation over a single 2-wire connection. Echoes having a delay time of 45 milliseconds or more are usually not a problem in practice because of the extra loss they encounter in traversing the relatively long echo path.

6.23 Echoes having long delay paths tend to cause very large envelope delay distortion even though they may cause very little difficulty to data transmission. This is shown in Fig. 4. An echo of −12 dB with respect to the transmitted signal, ie, one-fourth the power of the signal, is shown to cause large excursions in peak-to-peak envelope delay when delayed more than a few milliseconds. If such an echo were delayed by 10 to 20 milliseconds, it would completely obscure a plot of envelope delay distortion, even though it would not be significantly interfering. The aperture error, determined by the modulation frequency of the delay measuring set, tends to offset this effect. The response to a −12 dB echo by a delay measuring set having an aperature of 166 3/4 Hz is shown to have peaks of about 1000 microseconds, but peak-to-peak response will generally be in the area of 500 microseconds.

6.24 Data transmission, particularly at higher speeds, can be seriously degraded by envelope delay distortion. This distortion results from variation of the phase characteristics of a facility from perfect linearity. Since frequency is expressed in Hertz and phase shift in degrees, envelope delay, which is the ratio of phase shift variation in a small frequency band, is expressed in units of time, usually milliseconds or microseconds. A plot of the delay distortion at various frequencies across the voice band produces the envelope delay characteristic for a facility.

6.25 Like other transmission parameters on the PSN, the amount of envelope delay distortion varies from connection to connection, depending primarily upon the number and type of carrier links and the length and type of voice-frequency links in the connection. Compromise or automatically adaptive equalization is provided in higher-speed data sets to provide satisfactory operation on the PSN.

6.26 When proper equipment such as the 25B gain and delay set is available at each end of a connection, envelope delay distortion can be measured. The envelope delay distortion measured should be compared to the requirement for the data sets to be used.

6.27 Measures taken to improve the attenuation-frequency characteristic on local loops do not significantly change the delay-frequency characteristics. The EDD requirements for loops, RX/WATS lines, and FX lines are given in Section 880-440-103. If RX lines are used, they must meet the requirement specified for WATS lines. Additional conditioning of facilities may be required in some cases. Grades of conditioning for voiceband private line or switched trunk circuits are covered in Section 880-420-101.

G. Frequency Offset

6.28 The PSN may contain some single-sideband carrier transmission facilities. Because the carrier frequency is not transmitted with the signal in these systems, the signal is demodulated with a locally generated carrier that may differ slightly from the modulating frequency. This introduces a fixed frequency offset for all signal frequencies by an amount equal to the difference between the modulating and demodulating frequencies. In some older carrier systems, frequency offsets of greater than 5 Hz due to relatively poor control of the difference between the modulating and demodulating frequencies have been observed. These channels account for less than 1 percent of all the carrier-derived channels; however, in newer systems, frequency offset is held to less than 1 Hz per section. The measurement of frequency offset requires a tone source near 1004 Hz stable to at least 1 Hz in 1 million. Both the transmitted and the received zero crossings of the waveform must be observed for at least 10 seconds with frequency counters accurate to within ±0.01 percent. The difference in zero crossing counts is frequency offset to the nearest 0.1 Hz. Frequency counters are generally not balanced to ground; they may be sensitive to extraneous noise picked up on the test leads or from longitudinal currents on the line under test. It is desirable to place a filter with a 200- to 300-Hz bandpass, centered at 1020 Hz, just ahead of the counter to avoid disturbances and ensure repeatability of frequency measurements.

6.29 Frequency offset experienced over the PSN has little effect on voice transmission, but for data service it presents more serious problems. Modulation in data set transmitters results in tones of various frequencies on the transmission facilities. These tones are demodulated at the data set receiver to recover the data. If the frequencies of the transmitted tones are changed as they traverse the network, the frequency-sensitive circuits in the receivers will not be receiving the tones at the optimum points, resulting in distortion in the received data. Deviations of more than ±10 Hz may cause distortion of a data signal.

6.30 There is no frequency error problem with cable facilities or carrier systems in which the carrier used for modulation is transmitted to the receiving end and used for demodulation. Likewise, there is no problem in systems which suppress the carrier at the transmitting end and resupply it at the receiving terminal from a generator held in synchronism with the generator at the transmitting end. If there is no provision for synchronizing carrier supplies, frequency error problems can exist in suppressed-carrier systems. Actual frequency offset performance of any system should be determined prior to the start of service.

6.31 The overall frequency offset should be kept to within ±5 Hz; individual carrier facility sections should show errors no greater than ±2 Hz. Newer systems normally hold the error to less than ±1 Hz per facility section.

H. Phase Jitter

6.32 Phase jitter is the variation of the instantaneous phase or zero crossings of a signal which is advanced and retarded at cyclic rates, normally less than 300 Hz. In long-haul carrier systems, phase jitter is typically caused by ripple in the dc power supply appearing in the master oscillator and being multiplied through many stages. Some phase jitter also occurs in short-haul carrier systems caused by incomplete filtering of image sidebands. Some common jitter frequencies are 20 Hz (ringing current) and 60 Hz (commercial power) and the second-through-fifth harmonics of these frequencies. An overall requirement for phase jitter is difficult to specify. Phase jitter in excess of ±10 degrees, peak-to-peak, may impair data transmission. Facility requirements are given in Section 880-440-106. A discussion of the measurement of phase jitter is given in Section 314-010-101.

6.33 The term phase jitter includes all ac components of PM which cause the zero crossings of a voiceband signal to be advanced and retarded, ie, "jitter." To be precise, phase jitter must also include the phase-disturbing effect of uncorrelated interference and quantizing noise. In fact, phase jitter measurements should be accompanied by a signal-to-noise ratio measurement to ascertain what portion of the phase jitter measurement is due to incidental PM and what portion is due to noise. Figure 5 illustrates jitter readings produced by quantizing noise on a time-division multiplex system, while Fig. 6 illustrates the effects of uncorrelated white noise on a typical phase jitter measuring set.

6.34 Since the peak phase deviation caused by ac components of PM rarely exceeds 0.2 radians (low-index phase modulation), only one pair of significant sidebands is produced for each sinusoidal component. Consequently, a bandwidth of about 600 Hz, centered about a carrier at or near 1020 Hz, suffices to recover the major suspected sinusoidal PM without incurring large amounts of uncorrelated interference.

6.35 Instruments designed to measure phase jitter generally process a received voice-frequency tone in this mannner: (a) band limits around carrier frequency, nominally 1020 ±300 Hz, (b) amplifiers and amplitude limiters strip off AM, (c) detects zero crossings jitter from the error voltage of a phase-locked loop, and (d) displays filtered jitter, up to about 300 Hz, on a peak-to-peak indicating meter.

6.36 The accuracy of phase jitter measuring sets is typically ±5 percent or 0.2 degrees, whichever is larger. The newer measuring instruments can measure jitter to about 4 Hz. Low-frequency jitter is rarely bothersome to nonvoice signals but may be a greater impairment to some data signals than jitter at higher frequencies. Since very low-frequency jitter appears as time-varying phase intercept, it may produce appreciable deviation of P/AR readings when instruments not compensated for this effect are used. The 27F and 27G P/AR meters are not affected.

6.37 To accurately assess the transmission impairment to data signals or to isolate specific equipment troubles, it may be necessary to know more than the total peak-to-peak phase jitter in a 600 Hz (±300 Hz) band. In these cases, either of two courses might be taken: (a) partition the 600 Hz (±300 Hz) bandwidth into two or three narrower bands, or (b) perform a fine-grain frequency analysis with a spectrum analyzer. In a vast majority of cases where peak-to-peak excursions are less than 7 to 10 degrees in the 600 Hz (±300 Hz) band, fine-grain frequency analysis is not required.

I. Intermodulation Distortion

6.38 Intermodulation (amplitude) distortion occurs when not all amplitudes of the signal are amplified to the same extent. This results in the generation of other frequencies on the channel which add to the transmitted signal, usually in a harmful manner. Electronic devices and other components used in the voiceband channel are sources of this impairment. Intermodulation distortion is usually measured and identified by the effect it has at certain frequencies, ie, nonlinear distortion appears as harmonics of the transmitted signal.

6.39 The method of measuring intermodulation distortion, in which four frequencies are transmitted and the intermodulation products of the frequencies (intermodulation distortion) are measured, is now used. The four frequencies used are: 856 Hz (A), 863 Hz (A), 1374 Hz (B), and 1385 (B); they represent two narrow bands of noise. The four frequencies are transmitted at a composite level of −13 dBm0 (data level). The intermodulation products are measured at the receiver through 50-Hz wide filters centered at B−A (520 Hz), B+A (2240 Hz), and 2B−A (1900 Hz), where A is the center frequency between A and A and B is the center frequency between B and B . Second-order distortion is represented by B−A and B+A, while third-order distortion is represented by 2B-A. The requirements given in Section 880-440-

106 are based upon using the 4-tone technique. Other methods will yield different results and are not recommended. Facility and trunk requirements are given in Section 880-440-106.

J. Gain Hits, Phase Hits, and Dropouts

6.40 The rapid changes in gain and phase called gain and phase hits are transient phenomena that can be thought of as components of incidental AM and PM. These phenomena can and usually do occur in coincidence. Some of the more common causes of these impairments are automatic switching to standby facilities or carrier supplies, patching out working facilities to perform routine maintenance, fades and path changes in microwave facilities, and noise transients coupled into carrier-frequency sources. The channel gain and phase (or frequency) shift (offset) may return to its original value in a short time or remain at new values indefinitely.

6.41 Changes in gain are usually detected by changes in an AGC circuit; phase changes are detected by means of a phase-locked loop. In order to provide protection against false operation of the detectors on peaks of uncorrelated (impulse) noise, a guard interval of 4 milliseconds is designed into the peak-indicating instrument. Unfortunately, the guard interval also masks true phase impulses shorter than 4 milliseconds that are not accompanied by a peak-amplitude excursion large enough to be detected by threshold devices described in paragraph 6.14. The risk is considered to be justified when the known relative frequencies of phase jumps are compared to those for impulse noise. Recovery rates or loop stiffness also impose an upper limit on how slowly gain or phase may change and still fall into the "rapid" category. Currently this upper bound is defined as about 100 milliseconds.

6.42 Gain and phase hits are measured by monitoring the magnitude and phase of a sinusoidal tone. Hits are accumulated and recorded on electromechanical or electronic counters with adjustable threshold levels. Gain hit counters typically accumulate events exceeding thresholds of 1, 2, 3, and 6 dB, although they do not distinguish between an increase or a decrease in magnitude.

6.43 Phase hit counters accumulate changes at thresholds of 5 to 45 degrees in 5-degree steps. They respond to hits equal to or in excess of the selected thresholds. When impulsive phase hit activity is suspected, a switch is provided to remove the impulse noise blanking feature. The measuring set should have a similar dead time (150 milliseconds) to that of counters discussed in paragraph 6.14 to obtain consistent readings between sets of different manufacturers. One serious problem with gain and phase counters occurs when a signal dropout on the order of 20 to 30 dB is experienced with a simultaneous rise in background noise to place the signal level near the original level. The phase-locked loop still recognizes the desired signal, but erroneous gain and phase hits are recorded due to the influence of the noise. At the present, there is no solution to this problem.

6.44 A dropout is a sudden, short-duration, large drop in the power of a transmitted signal. In the past, dropouts have been defined as any drop in signal power below a threshold 18 dB below the normal signal power and remaining so for at least 300 milliseconds. A dropout is presently defined as any drop in signal power below a threshold 12 dB below the normal signal power and remaining for at least 10 milliseconds. The requirements for these parameters are given in Sections 880-440-105 and 880-440-106.

7. REFERENCES

7.01 The following sections, to which references have been made, contain information which is supplemental to that contained in this section.

SECTION	DESCRIPTION
311-100-500	Circuit Order and Trunk Order Transmission Tests, PBX Central Office Trunks, Off-Premises Station Lines and Tie Trunks Having Access to Direct Distance Dialing Network
314-010-100	Data General, Analog Transmission Parameters, Description
314-010-101	Data General, Data Testing Principles
314-010-102	Data General, Data Services Support
314-010-103	Data General, Interconnection/Interpositioning
314-205-500	Data Communications Service, Overall Data Transmission Test

SECTION	DESCRIPTION
	Requirements on the Public Switched Network
314-205-501	Data Communications Service, Test Requirements for Subscriber, Foreign Exchange, Remote Exchange and WATS Lines On the Public Switched Network
314-205-503	Data Communications Service, Minimum Acceptable Performance (MAP) Criteria Data Systems on the Public Switched Network
331-850-501	Noise Measurements on Two-Wire Subscriber Loops, Methods and Requirements at Stations
851-300-100	Transmission Design Considerations and Objectives, Special Services Circuits and PBX Services
856-100-100	Universal Cable Circuit Analysis Program (UNICCAP), Description and Use
880-100-100	Envelope Delay Characteristics of Telephone Facilities, General Information
880-100-111	Data Circuits, Delay Equalization
880-440-103	Station Loops, Remote Exchange Lines, Foreign Exchange Lines, and Wide Area Telecommunications Lines, Engineering Design Guidelines
880-440-105	Data Communications Service, Access Line Design Limits, Data Systems on the Public Switched Network

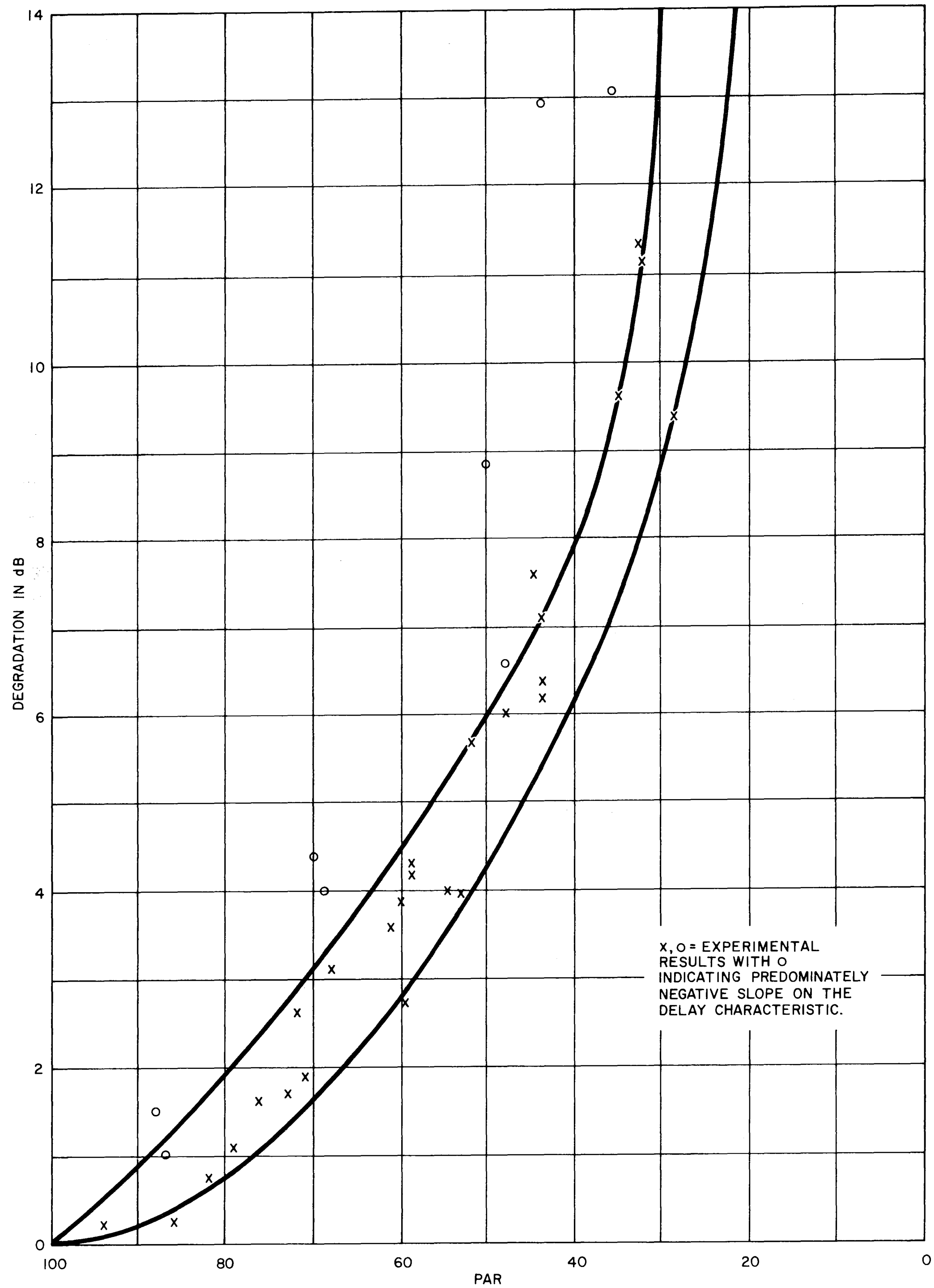

Fig. 1—Signal-to-Noise Performance as a Function of P/AR

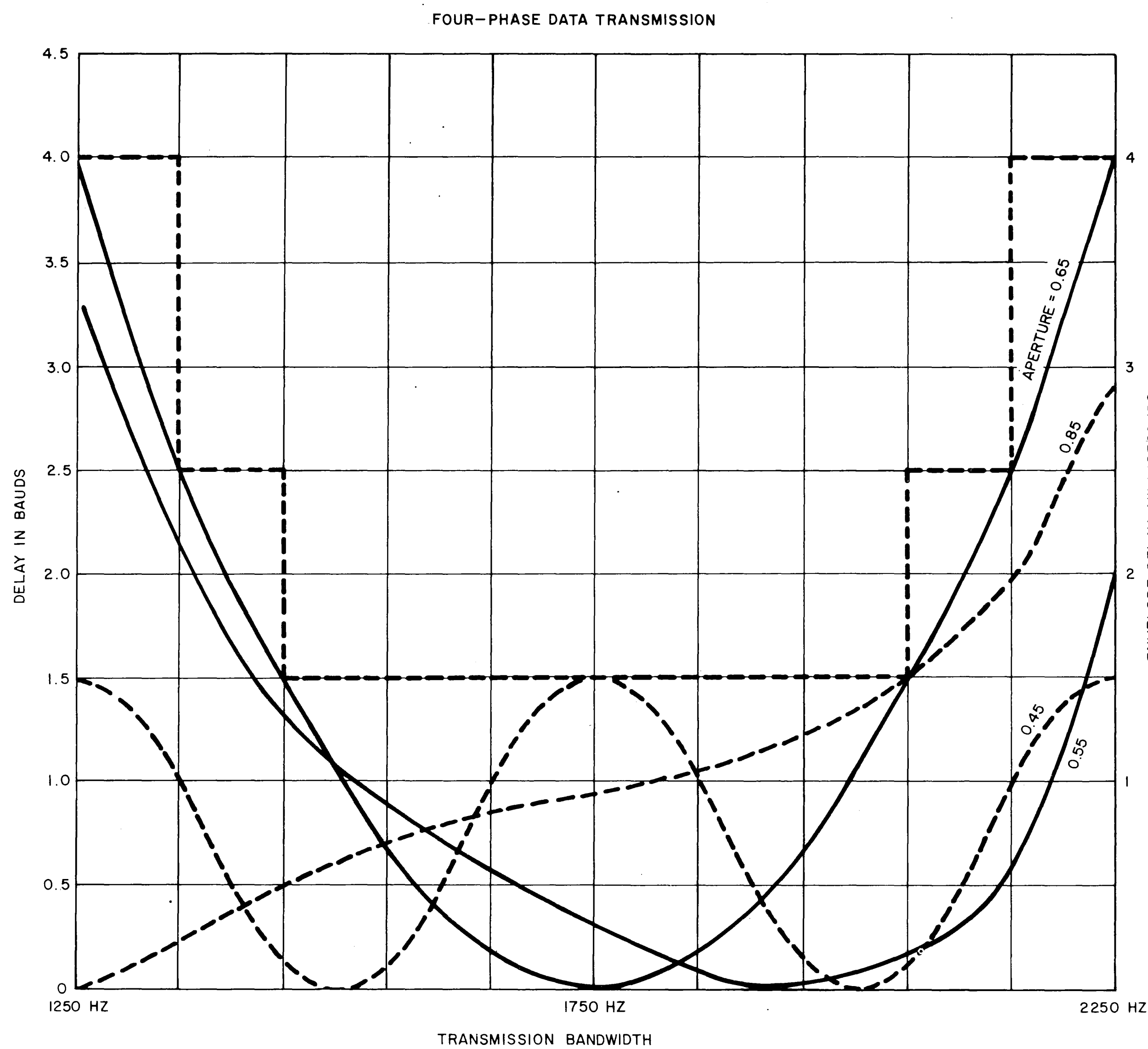

Fig. 2—Examples of Performance Range Meeting Classified Delay Requirements, Frequency in Multiples of Bit Rates from Carrier

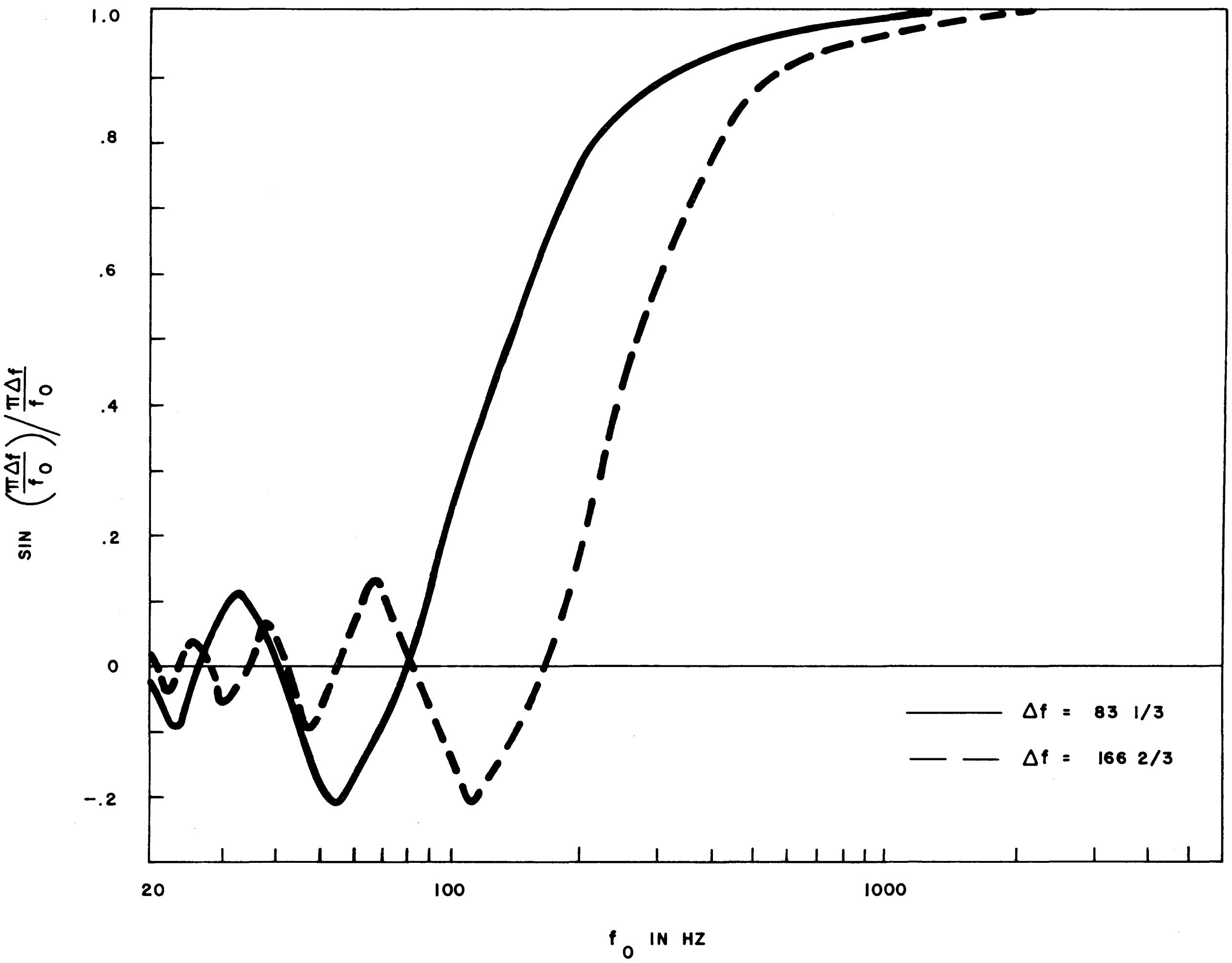

Fig. 3—Response of Two Envelope Delay Test Sets to Ripples in the Phase Characteristics of a Transmission Line

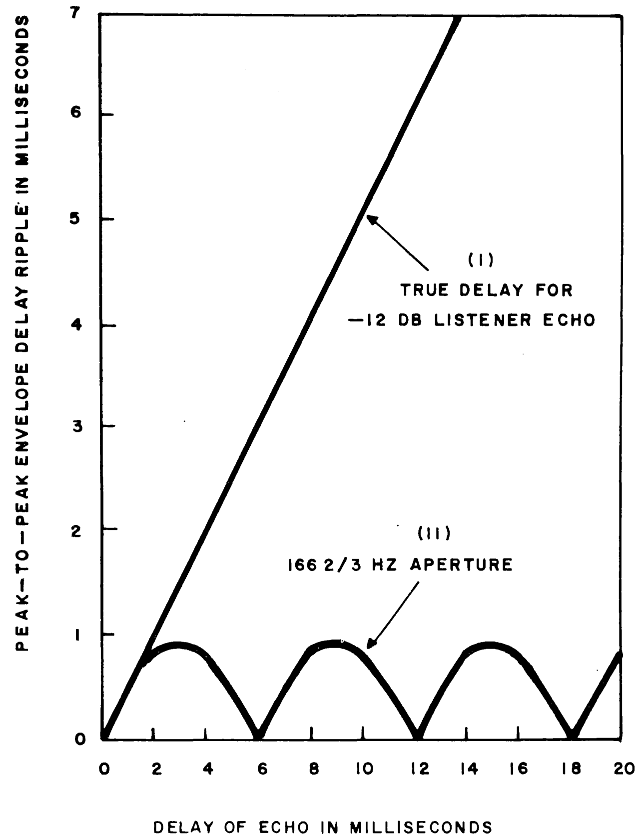

Fig. 4 — Response of Envelope Delay Test Sets to Echoes as Compared to True Delay

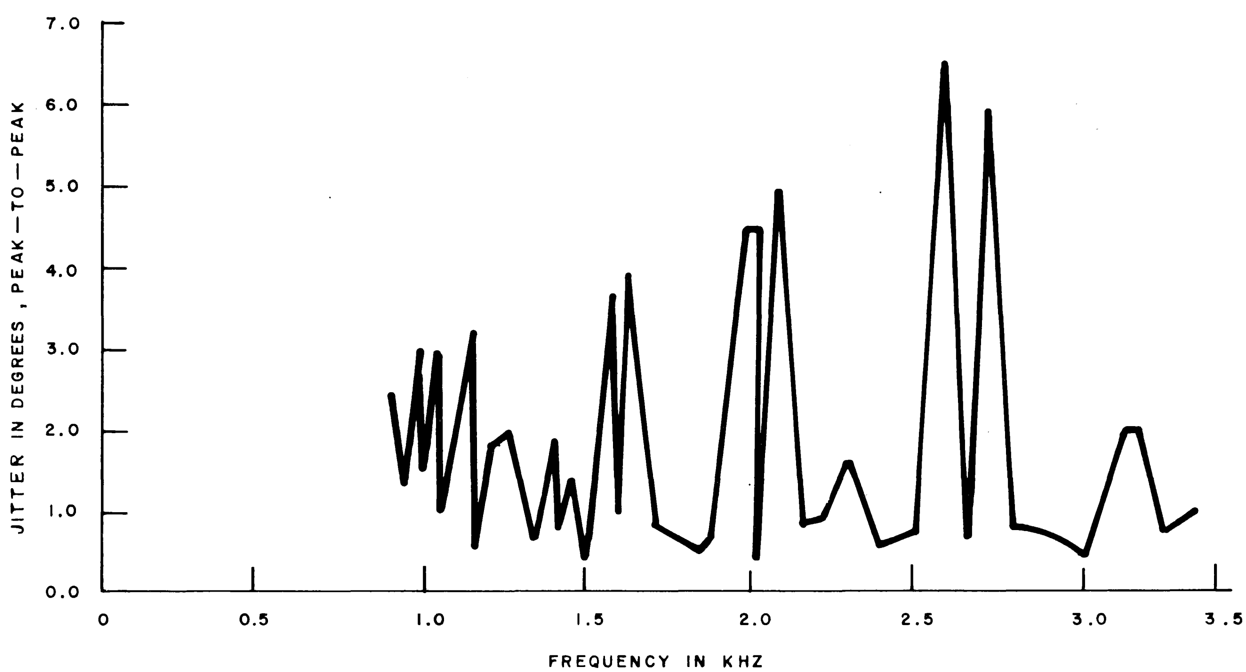

Fig. 5—Typical Phase Jitter on a PCM System as a Function of Carrier Frequency (110-Hz Bandwidth)

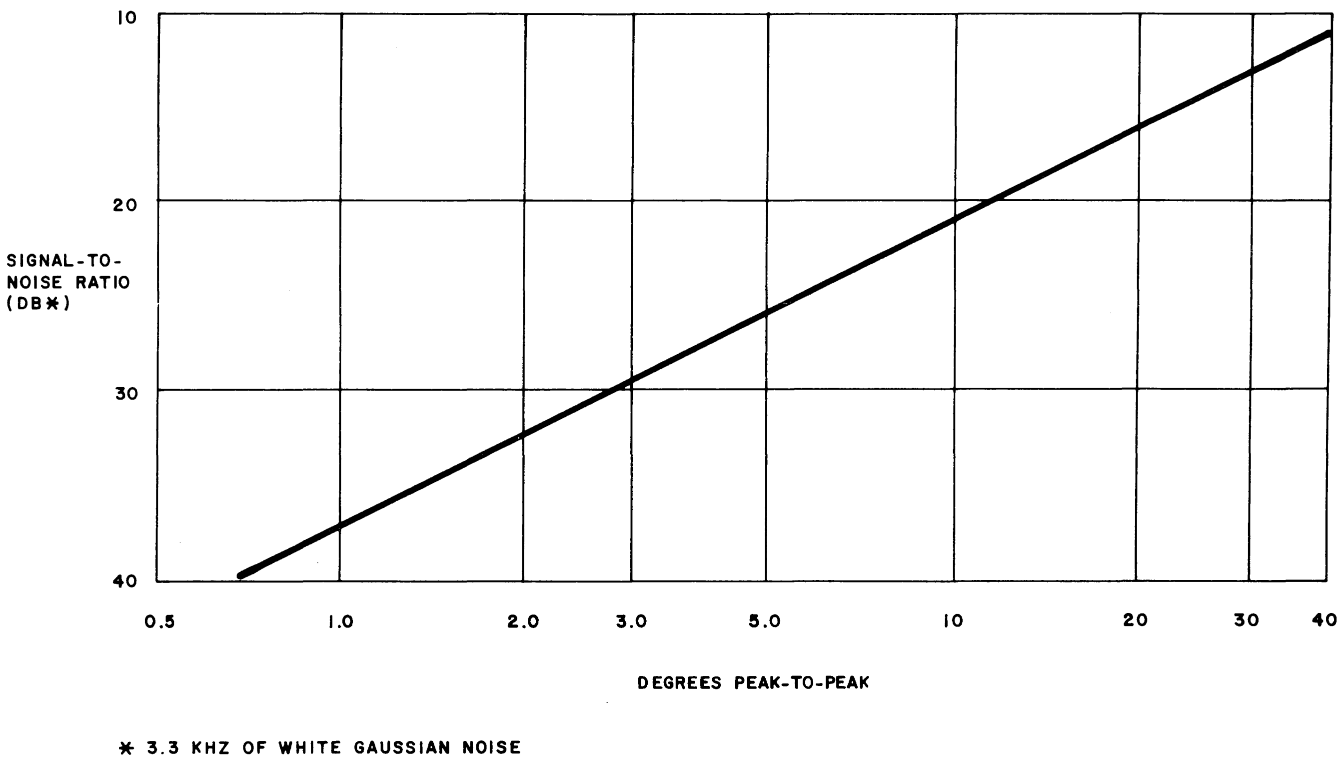

Fig. 6—Typical Response of a Jitter Test Set to Noise