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1969-70 Connection Survey:

Analog Transmission Performance on the Switched Telecommunications Network

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To characterize the transmission performance of the Bell System switched telecommunications network, Bell Telephone Laboratories conducted a survey of toll connections during 1969 and 1970. Connections were established between Bell System end offices chosen by statistical sampling techniques. Both analog and data transmission tests were performed. A summary of analog transmission performance is presented in this paper. It contains estimates for noise, loss, attenuation distortion, envelope delay distortion, peak-to-average ratio, frequency offset, level tracking, nonlinear distortion, and phase jitter for toll calls within the Bell System. Accompanying papers discuss data transmission error performance at various speeds between 150 and 4800 bits per second.

I. INTRODUCTION

Information related to transmission performance of toll connections is essential to the evaluation of toll service quality, necessary for assessing the adequacy of present administrative and maintenance procedures, and important in establishing objectives for new transmission systems and equipment. Bell Telephone Laboratories has conducted a number of system-wide transmission surveys since 1959. Surveys made in 1959, 1962, and 1966[1–3] concentrated on the transmission performance of toll connections. Other surveys have examined the performance of specific equipments or portions of the telephone network.[4–6] This survey is based on a probability sample of telephone traffic. The use of probability sampling permits estimation of transmission performance parameters for the population of all toll calls and permits quantitative measure of the possible error in these estimates. The 1969–70 survey differs from previous surveys by including more measures of the transmission performance of the connection.

Frequency offset, peak-to-average ratio (P/AR), level tracking, and intermodulation and harmonic distortion for toll connections had not been measured previously on a system-wide basis.

This paper presents a statistical summary of analog transmission data. Measurements were made on toll connections from end office (local switching office) to end office over the switched telecommunications network. Due to alternate routing and diversity routing within trunk groups, connections between the same originating and terminating offices may differ. Information on the characteristics of loops, which are fixed entities connecting a subscriber to his local office, has been reported by P. A. Gresh.[7] Connection measurement results are presented on the basis of airline distance between the end offices. Results are separated into three mileage categories. The breakdown is short (0–180 airline miles), medium (180–725 airline miles), and long (725–2900 airline miles). Mileage categories are combined to provide results for the population of all toll connections. The transmission characteristics reported include noise, loss, attenuation distortion, envelope delay distortion, P/AR, frequency offset, level tracking, nonlinear distortion, and phase jitter. Accompanying papers[8,9] provide results for data transmission error performance at various speeds between 150 and 4800 bits per second (b/s).

II. SURVEY LOGISTICS

2.1 *General*

It was apparent that to achieve a valid measure of the switched telecommunications network performance, the survey would be a large-scale operation encompassing the measurement of a large number of transmission characteristics on many toll connections between many different pairs of offices. Standard test sets or equipment units used for circuit maintenance or characterization were available for making most of the measurements. The remaining test equipment was purchased, or designed and built. Considering the bulk of the test equipment required to perform both analog and data transmission measurements, the shipping involved, and the manpower required to make measurements at many different locations, several decisions were made to control the magnitude of the physical effort:

(*i*) Several measurements were made from each location to limit the amount of travel and provide opportunity for measuring alternate routes.

(*ii*) Measurements were made in one direction of transmission for most characteristics. The receiving locations for these tests required a large quantity of equipment and were designated *primary* test sites. The transmitting ends required a much smaller amount of equipment and were designated *secondary* test sites. Message circuit noise and 1000-Hz loss, however, were measured for both directions of transmission.

(*iii*) Personnel and equipment remained at a primary site for a given time while a secondary team and equipment moved from location to location.

(*iv*) With several tests to be made, and different equipment required for each test, tests were run simultaneously on several connections and then rotated rather than being made sequentially on only one connection at a time.

(*v*) Testing at each secondary site continued for at least a full day, this being judged to be an appropriate compromise between time required to travel to a site and set up the equipment, and measurement time at the site.

(*vi*) Sufficient equipped secondary teams were provided so that one could travel while another tested, thus keeping the primary team busy every working day.

2.2 *Test Equipment*

Equipment used in making *Data-Phone*® transmission performance tests is described in companion papers.[8,9] Analog transmission measuring equipment is listed in Table I.

Packed for shipping, each set of secondary test gear (analog and data), consisted of nine cases totaling about 27.5 cubic feet and weighing 550 pounds. The primary equipment was about five times larger. Figure 1 shows a primary equipment arrangement.

2.3 *Test Lines*

Access to toll connections was the same as that of telephone subscribers. Subscriber line appearances were connected directly from the main frame to the test console; the distance to the main frame ranged from 20 to 100 feet. At secondary locations five lines were used, three for simultaneous tests, one for coordination of tests (order wire), and one to provide a reference path for envelope delay measurements. At primary locations five lines were used for connections to the secondary locations and three additional lines were provided: one line for teletypewriter access to a time-shared computer for analog data management; one line for *Data-Phone* service to transfer data transmission test results from a small computer at the primary location to a similar computer at the Bell Laboratories Holmdel, N. J., location; and one line for normal telephone service, used for coordination purposes.

III. SAMPLE DESIGN

3.1 *Sampling Considerations*

In the concluding remarks of I. Näsell's report of the 1966 Connection Survey, he noted that the survey suffered from two limitations:

TABLE I—CONNECTION SURVEY ANALOG TRANSMISSION TESTING EQUIPMENT

Equipment	Function
BTL* Console. (Pri, Sec)	Terminate and connect up to 8 telephone lines to 12 test sets
WECo 3A Noise Measuring Set [10] (Pri, Sec)	Measure circuit noise
WECo 6F Voiceband Noise Measuring Set (Pri)	Count impulse noise peaks (four threshold levels)
BTL Noise Measuring Set Control Unit (Pri)	Switch control of weighting networks, notch filter, and narrow band filters for intermodulation and harmonic distortion product measurement
WECo 25B Voiceband Gain and Delay Measuring Set (Pri, Sec)	Measure loss, attenuation distortion, and envelope delay distortion
WECo KS-19260L1 Oscillator (Sec)	Resettable accurate voice-frequency source
WECo 27B P/AR Receiver[11] (Pri) WECo 27E P/AR Generator (Sec)	Measure compression of peak-to-average power ratio of test signal (P/AR)
BTL Phase Jitter Meter (Pri)	Measure peak-to-peak phase jitter
X-Y Plotter (Pri)	Associated with 25B for swept plots of gain and envelope delay distortion
Frequency Counter (Pri)	Measure frequency offset
Amplifier and BTL Attenuator (Pri)	Shift receiving sensitivity of 25B to desired range
WECo 71B Milliwatt Reference Generator (Pri, Sec)	Calibration of test set sending power and receiving sensitivity
Accessories (Pri, Sec): Power Supplies, Tools, Batteries, Interconnecting Cords, Instructions, Shipping Cases, etc.	
Teletypewriter (Pri)	Transfer analog measurement results to data management system in time-shared computer

* BTL indicates equipment designed and built for the survey.

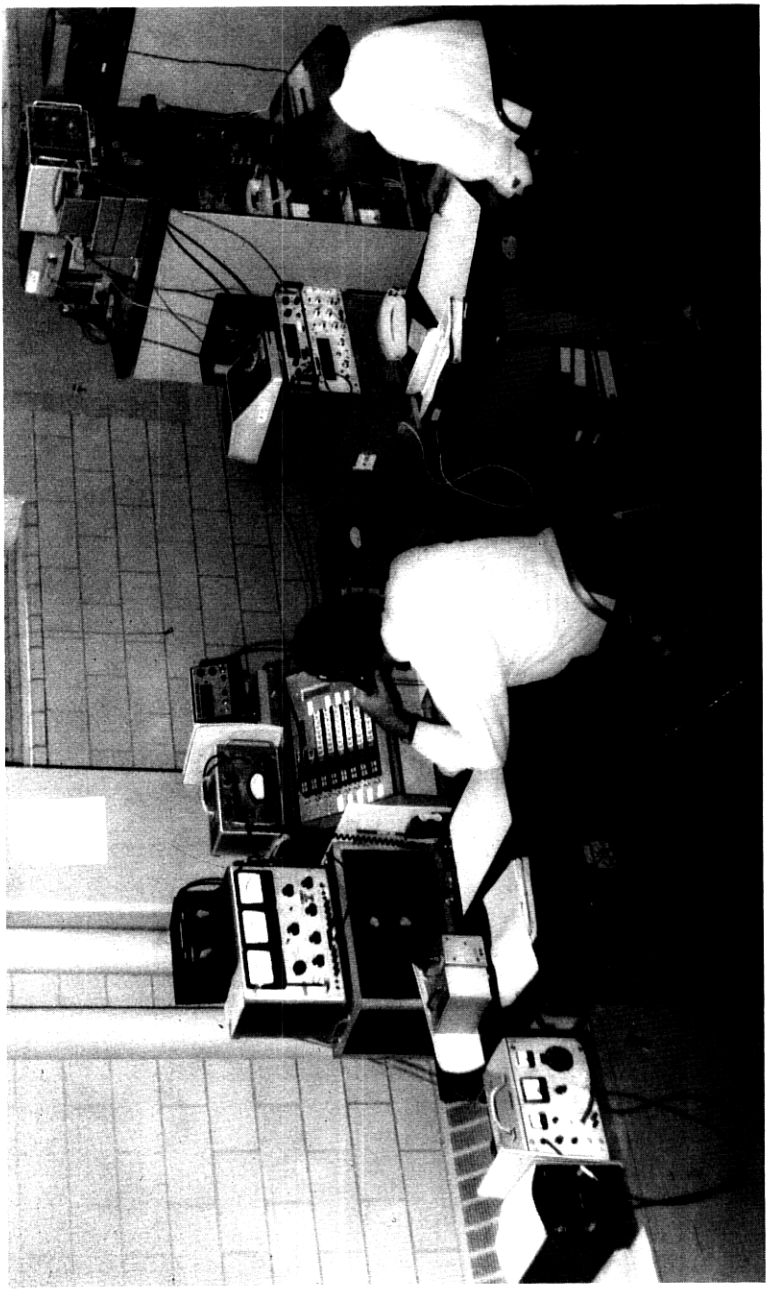

Fig. 1—Primary testing arrangement.

with test personnel only at one end of a connection, many tests could not be performed and calibration of far-end milliwatt supplies could not be verified.[3] Test personnel were assigned to both ends of the connections in the 1969–70 survey to overcome these limitations. This approach substantially increased the travel and overall time required to complete the survey. To bring these within manageable proportions, a three-stage sampling plan was adopted with 12 primary and 98 secondary test offices. Execution of this survey required at least seven persons in the field for a period of a year.

3.2 *Selection of the Samples*

A population for which information is desired must be defined prior to selecting a sample from that population. Characterization of analog transmission for toll connections was the criterion used to define a population for sampling purposes. The population was defined as all customer-dialed toll calls established between Bell System end offices via the switched telecommunications network during a normal business day. A call was classified as a toll call if the customer was detail billed, i.e., the customer incurred a specific, identified surcharge for placing the call. Calls originating or terminating in end offices not owned by the Bell System were excluded from the population. Calls originating in manual end offices also were excluded on the basis that they may not be placed without operator assistance. On January 1, 1970, 12 of the approximately 15,000 Bell System end offices were manual.

A three-stage sample with stratifications at the first and second stages of sampling was selected from the population defined above by established techniques.[12,13] First-stage sample units were selected with probabilities proportional to a measure of size. Second- and third-stage sample units were selected using stratified and simple random sampling respectively.

Prior to selecting the first-stage or primary sample units, a geographic stratification was imposed upon the population to achieve wide physical dispersion of the sample. Continental United States plus Ontario and Quebec (Bell Canada) were partitioned into twelve strata on the basis of annual outgoing toll messages (AOTM). Ideally, each stratum should have equal total AOTMs. Individual states were not subdivided in attempting to obtain equal size primary strata. This facilitated assembling the first-stage sampling frames.

One Bell System end office building was selected from each primary stratum. Selection took place independently in each primary stratum and was based upon probabilities proportional to the number of annual outgoing toll messages. The primary units selected were in the 12 cities listed in Table II.

Units of the first-stage sample were designated as primary test sites for the analog transmission characterization of the voice network, i.e., buildings from which test calls originated and which served as receiving sites for transmission tests. The suitability of each primary for serving *Data-Phone* customers was verified. At two end office buildings it was noted that a *Data-Phone* customer normally would be served from an alternate or remote building because the offices within the sampled building were unacceptable with respect to impulse noise. Accordingly, test calls were originated from the alternate buildings for these primary locations. Tests were made from the selected building and from the alternate building in one of the instances. Tests were underway at the selected building when it was discovered that a *Data-Phone* customer indeed would not be served from that building. Tests scheduled for this site were completed. Another series of tests later was made at the alternate building. In the other case, tests were conducted only at the alternate building. The improvement in precision did not justify the effort required to visit the sampled building in addition to the alternate building. The sample for analog characterization does not include data collected at alternate buildings.

When an end office building contained offices with different types of switching, tests were performed on connections established through each type of office. One building contained offices having panel and crossbar switching. In this instance, the sample for analog characterization includes connections established through the panel and the crossbar offices. The sample for *Data-Phone* characterization includes connections established through the crossbar offices only.

In the second stage of sampling, from six to twelve calls were selected from originating traffic printouts compiled at the primary test sites composing the first-stage sample. These calls were used to determine secondary test offices, i.e., offices in which the test calls termi-

Table II—Primary Test Locations

Mobile, Ala.	Omaha, Nebr.
Sacramento, Calif.	Concord, N. H.
Miami, Fla.	Rockaway, N. J.
Woodstock, Ill.	New York, N. Y.
Quincy, Mass.	Cleveland, Ohio
Trufant, Mich.	Sharon, Pa.

nated and which served as transmitting sites for most transmission tests. A substratification was imposed before selection took place. Three substrata were defined on the basis of airline distance. Connections from 0 to 180 airline miles in length were placed into one substratum. Those from 180 to 725 airline miles were placed into a second. All remaining connections were placed into the third. At least two secondary sites were selected in each of the three mileage strata for each primary site. Additional secondary sites were selected in an effort to approximate self-weighting in each substratum. With self-weighting within substrata, each data point equally represents the population for its substratum. A total of 32 secondary sites was selected in the short mileage stratum. In both the medium and long mileage strata, 33 secondary sites were selected.

The third-stage sample elements were repeated calls originating from a primary site and terminating in one of its associated secondary sites. Approximately six connections were established between each primary and each of its associated secondaries. Repetitions were desired to account for the effects of alternate routing of toll connections and to increase the amount of data gathered while at the test sites. Analog transmission tests were conducted on 188 connections belonging to the short mileage category, 227 medium length connections, and 209 long connections. The complete array of analog measurements was not obtained on all connections since 60 were prematurely disconnected. It is believed many of these disconnects were caused inadvertently by survey test personnel.

IV. TESTING PROCEDURES

4.1 *Scheduling*

Personnel from Bell Laboratories performed the tests at both ends of the connections. Separate field teams were scheduled for the tours associated with each primary site—three persons at the primary and two at each secondary. A total of 56 persons participated. Generally, two secondary teams were associated with each primary; in one case, three teams were required. All teams received training in the test procedures before going to the field. Figure 2 shows the primary and secondary locations. Schedules were planned to minimize travel distance. The testing schedule, as modified by experience at the first primary site, provided essentially two full days at the first site visited by a secondary team for them to become accustomed to and perform

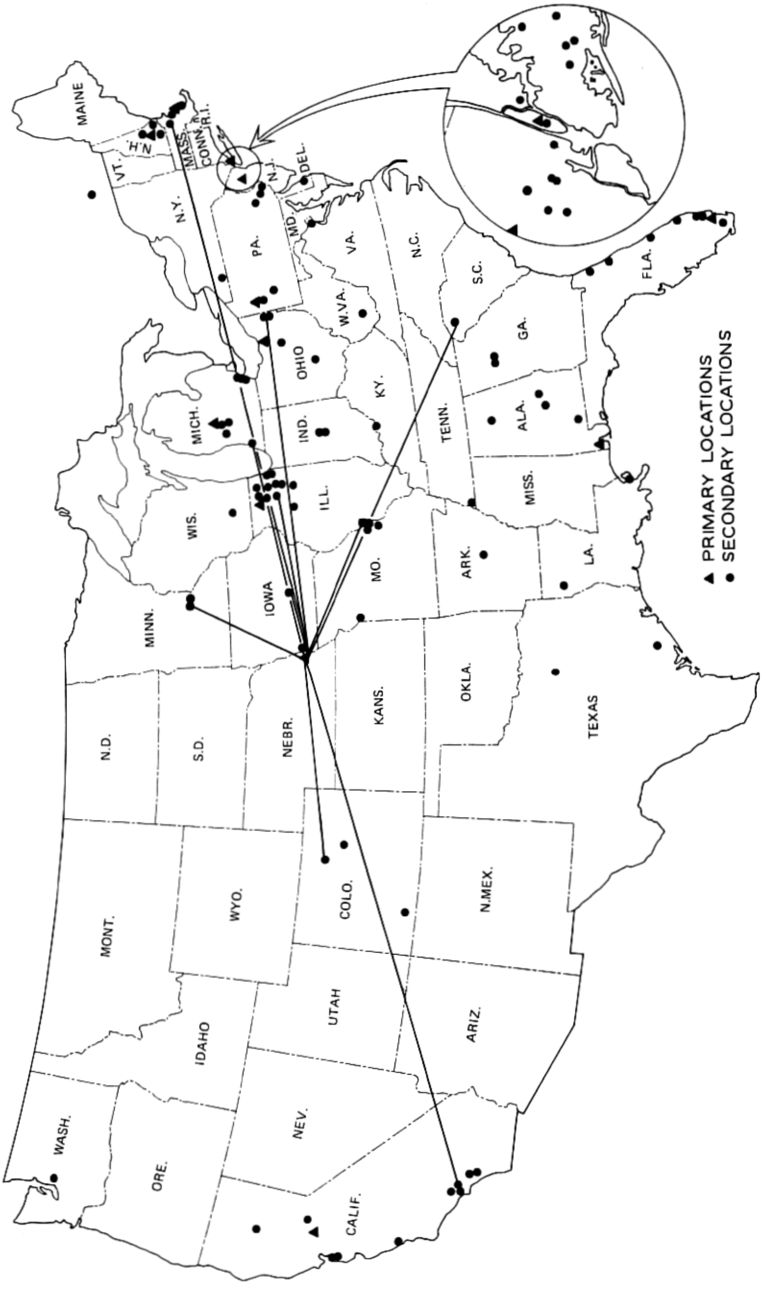

Fig. 2—Survey test locations. Lines connect Omaha and its secondaries.

the tests. Thereafter, only one day was scheduled for testing six connections.

4.2 *Placing Calls*

A testing sequence was begun in the morning by the primary team placing three test calls, one after another, from the primary to that day's secondary. As each call was answered, a few words of conversation were exchanged to assure two-way transmission to the correct number, the connection was held at both ends (push buttons on the consoles), and then the primary dialed the next test call. With three test connections established, a call was placed to serve as an "order wire" to coordinate the test activities and a call was placed to establish a data link to the Bell Laboratories Holmdel, N. J., location.

4.3 *Testing Procedures*

After the connections were established, testing was begun on all three and continued until the block of tests was completed, requiring about an hour. On one connection, a 2000-b/s data set was operated for 30 minutes, followed by a 1200-b/s data set for the next 30 minutes.[8] On a second connection, a 150-b/s data set was operated for 40 minutes, then a 3600- or 4800-b/s data set for 20 minutes.[9,8] If the secondary team was not equipped with a 3600- or 4800-b/s data set, the 150-b/s set was operated for an hour. On the third connection, the sequence of analog tests was performed. At the end of the first sequence of testing, the assignments of toll connections to the test equipments were rotated and the tests were repeated. At the end of the second hour of testing, the assignments were rotated again and testing continued until all tests had been made on each test connection. When all tests were completed, including any necessary check or verification tests, the calls were disconnected. In the afternoon, the entire sequence was repeated. When a call was inadvertently disconnected during testing, a new call was established. Testing usually continued from that point in the test sequence. An attempt normally was made to repeat the tests made on the original call but time did not always permit. Analog measurement results were read from meters and dials of the test sets. The values were recorded at the primary on a preprinted data form. At an appropriate time in the test sequence, the information was transferred to a data management system.

4.4 *Analog Data Management Procedures*

As measurements were made, results were entered into a data management system residing in a time-shared computer. Since test equipment characteristics contribute to the transmission characteristic values being measured, each data point was calibrated to subtract those contributions. It was then compared with the results calculated on the basis of previously collected data. If the data point greatly differed from previous data, information to that effect was transmitted to the test site. Field personnel verified if the measurement was correct by redoing the test since the connection was still established. Under no circumstances was a data point screened out simply because it differed greatly from other values. If the retest indicated the value was correct, then it was accepted.

Past surveys did not have immediate data processing available. Experience in this survey has clearly established the value of such a data management system providing feedback information to the test sites. Since data "laundering" was being carried out as the survey progressed, only a moderate amount remained to be done after field operations were completed. This produced two outstanding advantages. For the most part, the validity of the data was verified by people at the test site capable of investigating problems while connections were still established; secondly, analysis of data could begin immediately after field tests were completed.

4.5 *Data Analysis*

Analysis of the survey data was accomplished using computer programs based upon statistical formulas for multistage sample surveys.[12,13] Although an attempt was made to approximate self-weighting within each mileage category, it was convenient to select secondary test sites for individual primaries as the second-stage sampling frames became available. This restricted the degree to which self-weighting could be achieved. The absence of self-weighting means that some data points in a mileage category have more weight associated with them than others in translating sample measurements into population estimates. Because of this, appropriate weights were calculated and used in the analysis.

Recall that the sample design required selection of one primary unit in each primary stratum. This does not allow calculation of the variance due to the first stage of sampling when estimating a confidence interval. To solve this problem, the concept of collapsed strata was used.[14] Thus the data were analyzed as though the sample design called for six primary strata with two primary units in each. All weights were adjusted appropriately to reflect this change.

In addition to analog characterization of the voice network, an analysis to characterize analog transmission on that part of the network appropriate for data transmission was carried out. With the exception of impulse noise, only minor differences were seen when these results were compared to those for the entire voice network. Based on these findings, results for impulse noise will be presented as they relate to the entire voice network and as they relate to that part of the network serving data customers.

V. ANALOG TRANSMISSION RESULTS

Estimates of the population mean with accompanying 90-percent confidence interval and of the standard deviation are provided for most transmission characteristics. Results are presented for the population of all toll connections and for connections in three mileage categories defined on the basis of airline distance. Sampling weights reflecting the distribution of message telephone traffic were applied to the data to calculate all estimates. Generally, results for all toll calls resemble results for the short mileage category. Approximately 85 percent of all toll calls placed in the telephone network belong to the short category.[3]

When a cumulative distribution function (CDF) for a transmission characteristic indicates that the distribution has an elongated tail for large values of the characteristic, it is described as being positively skewed. If the tail of the distribution is elongated for small values of the characteristic, the distribution is described as being negatively skewed. Complete CDFs are presented to illustrate the degree of skewness for some characteristics. When a distribution of a characteristic deviates substantially from normal, the 10-, 50-, and 90-percent points are listed.

Generally, the variance of a transmission characteristic is largest in the short mileage category. Differences among the types of transmission facilities account for this large variance. A large variance along with a relatively small sample size results in a large variance for the estimator used to calculate the mean. Since the variance of that estimator is used to calculate the accompanying confidence interval, the resulting interval will be wide. As a result of this, the confidence intervals accompanying estimates for short connections are generally wider than those accompanying estimates for medium and long connections.

5.1 *Noise*

The subjective impairment due to noise in a transmission channel used for voice transmission is most directly related to the power and frequency spectrum of the noise. C-message weighted noise power is a good measure of the impairment.[10] Errors in data transmission may result from high-amplitude noise peaks; therefore, a count of the number of noise peaks exceeding a specified threshold is a better measure of the noise impairment for data transmission. This characteristic is called impulse noise.

5.1.1 *Message Circuit Noise*

Circuit noise was measured using a 3A Noise Measuring Set[10] with C-message and with 3-kHz flat weighting networks. The latter measurement includes low-frequency noise components. In addition, both measurements were recorded without and with a signal transmitted over the connection. The former indicates noise present during quiescent intervals on the telephone circuit. The latter measurements were made while a 2750-Hz tone at −12 dBm was transmitted. Since a connection may contain compandors, the tone was transmitted to provide energy to hold the compandors at a nominal gain. A band-reject filter was used to remove the tone at the receiving end of the connection before measurements were made. These measurements are an indication of the noise on a line as it would appear to a data modem. The measurements are referred to as C-message notched noise and 3-kHz flat notched noise. Results for these characteristics are listed in Table III.

C-message and 3-kHz flat noise without a tone applied to the telephone circuit were measured at both primary and secondary test offices. A comparison of C-message noise measured at the primary test offices with C-message noise measured at the secondary test offices does not indicate substantial differences. A comparison of the results for 3-kHz flat noise is not very meaningful because of the poor precision accompanying the results for measurements made at the primary offices. The precision is poor because the differences between primary test offices with respect to 3-kHz flat noise was substantial. Near-end noise contributions (60-cycle hum) accounted for these differences. Precision accompanying the results for measurements made at the secondary offices is better because there were eight times as many secondary offices. This gave a better cross-section of the near-end noise contributions.

TABLE III—RESULTS OF MESSAGE CIRCUIT NOISE TESTS ON TOLL CONNECTIONS*

Connection Length (airline miles)	C-Message Weighting		3-kHz Flat Weighting		C-Message Notched		3-kHz Flat Notched	
	Primary		Primary		Primary		Primary	
	Mean (dBrnC)	S.D.† (dB)	Mean (dBrn)	S.D. (dB)	Mean (dBrnC)	S.D. (dB)	Mean (dBrn)	S.D. (dB)
All‡	21.6 ± 3.6	9.1	42.7 ± 2.8	8.3	30.7 ± 2.9	11.4	44.8 ± 2.9	7.7
0–180	18.7 ± 3.7	8.3	42.2 ± 2.4	8.2	29.5 ± 3.6	12.6	44.5 ± 2.4	7.6
180–725	29.3 ± 0.6	3.1	43.6 ± 3.8	8.4	34.3 ± 1.4	5.2	45.1 ± 4.4	8.1
725–2900	32.7 ± 0.6	3.5	45.4 ± 5.7	8.7	34.9 ± 0.8	4.0	46.3 ± 5.6	8.1

Connection Length (airline miles)	C-Message Weighting		3-kHz Flat Weighting		1966 Connection Survey Results			
	Secondary		Secondary		C-Message Weighting		3-kHz Flat Weighting (DDD)	
	Mean (dBrnC)	S.D. (dB)	Mean (dBrn)	S.D. (dB)	Mean (dBrnC)	S.D. (dB)	Mean (dBrn)	S.D. (dB)
All	22.9 ± 3.5	8.5	43.1 ± 1.4	7.3	—	—	—	—
0–180	20.0 ± 3.7	7.6	43.1 ± 1.7	7.7	21.6 ± 0.8	6.4	42.5 ± 1.5	5.8
180–725	30.0 ± 0.5	3.7	43.3 ± 1.2	6.1	29.6 ± 0.7	4.2	43.6 ± 1.4	5.2
725–2900	33.8 ± 1.3	3.8	42.3 ± 1.9	6.2	32.5 ± 1.0	4.1	43.9 ± 1.1	4.2

* Sample weights reflecting the distribution of message telephone traffic were applied to the data to calculate all estimates in this paper.

† S.D. indicates standard deviation

‡ All indicates all connections (0–2900 airline miles)

C-message and 3-kHz flat noise have been well documented in past surveys, the most recent having been conducted in 1966.[3] A comparison of current C-message results with those of 1966, also shown in Table III, indicates substantially the same findings. In general, the mean C-message noise increases with distance while the standard deviation tends to decrease. Confidence intervals accompanying estimated means for both surveys overlap. The estimated standard deviation for short connections is greater than in 1966. The estimated standard deviations for medium and long connections are smaller than in 1966. Distributions for C-message noise are all close to normal.

Results for the 1966 survey contain 3-kHz flat noise for operator and DDD-handled calls. Since all calls in the 1969–70 survey were placed via DDD, a comparison was made with the corresponding results from 1966. The estimated means are similar for all mileage categories. Estimated standard deviations in all mileage categories are greater than in 1966. Short and long connections show approximately a 2.0-dB increase. Distributions for 3-kHz flat noise are positively skewed.

Since notched noise readings were measured only at the primary test sites, they are compared with C-message and 3-kHz flat results for the primaries. Both mean and standard deviation are larger for C-message notched noise than for C-message noise in each mileage category. The differences between the characteristics diminish with increasing distance. C-message notched noise is dependent upon the length of a connection; the means increase with distance. The standard deviation monotonically decreases with increasing distance. Distributions for C-message notched noise are close to normal in the medium and long categories. The distribution for short calls is negatively skewed.

Notched noise with 3-kHz flat weighting does not differ greatly from 3-kHz flat noise measured at primary test sites. There is a tendency for means to be slightly higher and for standard deviations to be slightly lower when a tone is present. Distributions for 3-kHz flat notched noise are positively skewed.

5.1.2 *Impulse Noise*

To measure impulse noise, a 2750-Hz signal at −12 dBm was transmitted. At the receiving end of the connection, a 6F Impulse Noise Counter was used to detect impulses of noise exceeding four different voltage levels. The levels were separated by 4-dB intervals. These levels were set so that the impulse noise counter thresholds were

5 and 1 dB below and 3 and 7 dB above the expected rms level of a received data signal. Connections were monitored for 15-minute intervals and the C-message notched weighting network was used to block the 2750-Hz tone.

Impulse noise count distributions are not normal. J. H. Fennick[15] has shown that the distribution of the logarithm of impulse noise counts is approximately normal for intertoll trunks. The logarithm of impulse noise counts is approximately normally distributed for connections as well. The mean, median, and standard deviation are listed in Table IV for the count distributions. The 10-, 50-, and 90-percent points are listed in Table V. These results characterize impulse noise on the entire voice network.

The number of counts decreases as the threshold of the impulse noise counter is raised. This is expected since the amplitude of the impulse must exceed the threshold of the counter to register. An equivalent way of phrasing the first sentence is to say that the number of impulse noise counts decreases as the signal-to-impulse-noise counter threshold gets smaller. Results in Table IV are presented for the four signal-to-impulse-noise counter thresholds used when monitoring a connection.

Impulse noise counts are dependent upon the length of a connection. The number of counts registered increases with airline distance. This is clearly illustrated in the first section of Table V where 10-, 50-, and 90-percent points are listed.

Earlier it was mentioned that results for impulse noise differed substantially when comparing the analog characterization of the voice network and the analog characterization of that part of the network providing *Data-Phone* service. The two sections of Table V permit this comparison. As discussed in Ref. 8, the sample for evaluating *Data-Phone* service excludes panel offices at either end of a connection. It also excludes originating step-by-step offices where the impulse noise level due to office equipment alone exceeded a specified limit. Reference 8 discusses this sample in detail.

5.2 *1000-Hz Loss*

A 1000-Hz 0-dBm signal was applied to the connection and the received signal power measured with a 25B Voiceband Gain and Delay Measuring Set. Loss results for measurements made at primary and secondary test sites are tabulated in Table VI. A comparison of the two sets of results does not indicate substantial differences. However, a comparison of the two measurements on a connection-by-connection

TABLE IV—IMPULSE NOISE COUNTS ON TOLL CONNECTIONS (15-MINUTE INTERVAL)

Signal-to-Impulse-Noise Counter Threshold	All			0–180 Miles			180–725 Miles			725–2900 Miles		
	Mean	Med.*	S.D.	Mean	Med.	S.D.	Mean	Med.	S.D.	Mean	Med.	S.D.
+5	39 ± 21	4	128	32 ± 15	3	105	48 ± 44	7	150	74 ± 48	15	219
+1	18 ± 11	2	68	13 ± 6	1	40	27 ± 30	2	90	44 ± 32	7	148
−3	11 ± 8	1	56	7 ± 5	0	23	24 ± 26	1	115	24 ± 20	2	87
−7	7 ± 6	0	34	5 ± 4	0	19	15 ± 18	0	72	10 ± 11	0	28

* Med. indicates median

TABLE V—IMPULSE NOISE COUNTS ON TOLL CONNECTIONS (15-MINUTE INTERVAL)
Percentage Points from Cumulative Distribution Curves

(Voice Network Characterization)

Signal-to-Impulse-Noise Counter Threshold	All			0–180 Miles			180–725 Miles			725–2900 Miles		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
+5	0	4	78	0	3	62	0	7	109	1	15	154
+1	0	2	36	0	1	29	0	2	76	0	7	95
−3	0	1	16	0	0	13	0	1	34	0	2	57
−7	0	0	7	0	0	5	0	0	19	0	0	22

(*Data-Phone* Service Characterization)

Signal-to-Impulse-Noise Counter Threshold	All			0–180 Miles			180–725 Miles			725–2900 Miles		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
+5	0	2	40	0	2	36	0	4	42	0	6	50
+1	0	1	14	0	1	12	0	1	14	0	2	28
−3	0	0	6	0	0	5	0	0	6	0	0	8
−7	0	0	3	0	0	3	0	0	3	0	0	5

TABLE VI—COMPARISON OF CONNECTION LOSSES AT 1000-Hz FROM 1966 AND 1969/70 SURVEYS

Connection Length (airline miles)	1969/70 Survey				1966 Survey	
	Primary		Secondary		(DDD)	
	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)
All	6.7 ± 0.6	2.1	6.6 ± 0.3	2.1	—	—
0–180	6.5 ± 0.7	2.0	6.4 ± 0.4	2.1	7.0 ± 0.4	2.3
180–725	7.3 ± 0.4	2.3	7.1 ± 0.6	2.1	8.5 ± 0.6	2.5
725–2900	7.7 ± 0.5	2.5	7.3 ± 0.3	2.0	8.9 ± 0.6	3.0

basis shows that a difference of 5 dB between loss measurements for the two directions of transmission is not uncommon. In one instance the difference was 20 dB.

Results from the 1966 survey are also included in Table VI.[3] Both surveys indicate that the means of the loss distributions increase with distance. However, the amount of increase with length is less than existed in 1966. Both mean loss and standard deviation are smaller in all categories when compared with the 1966 survey. On the basis of non-overlapping confidence intervals, the differences appear significant for medium and long connections. Distributions for loss are positively skewed.

5.3 *Signal to C-Notched Noise*

To obtain a measure of the effect of circuit noise upon data transmission, the ratio of received signal power to C-notched noise was calculated. Loss at 1000 Hz was used to determine the received power of a signal transmitted at -12 dBm. The distributional parameters are tabulated in Table VII.

The results from this survey clearly indicate that the ratio of signal to C-notched noise is dependent upon connection length. Both mean and standard deviation decrease with increasing distance. Note that larger ratios imply better transmission quality with respect to noise interference.

Distributions of signal to C-notched noise are negatively skewed for medium and long connections. The distribution for short connections is positively skewed. Since this characteristic is of particular interest for data transmission, the cumulative distribution functions are given in Fig. 3.

TABLE VII—RESULTS OF SIGNAL-TO-C-NOTCHED-NOISE RATIO FOR TOLL CONNECTIONS

Connection Length (airline miles)	Mean (dB)	S.D. (dB)
All	40.6 ± 3.0	11.8
0–180	42.1 ± 3.8	13.0
180–725	36.5 ± 1.3	5.3
725–2900	35.4 ± 0.9	3.8

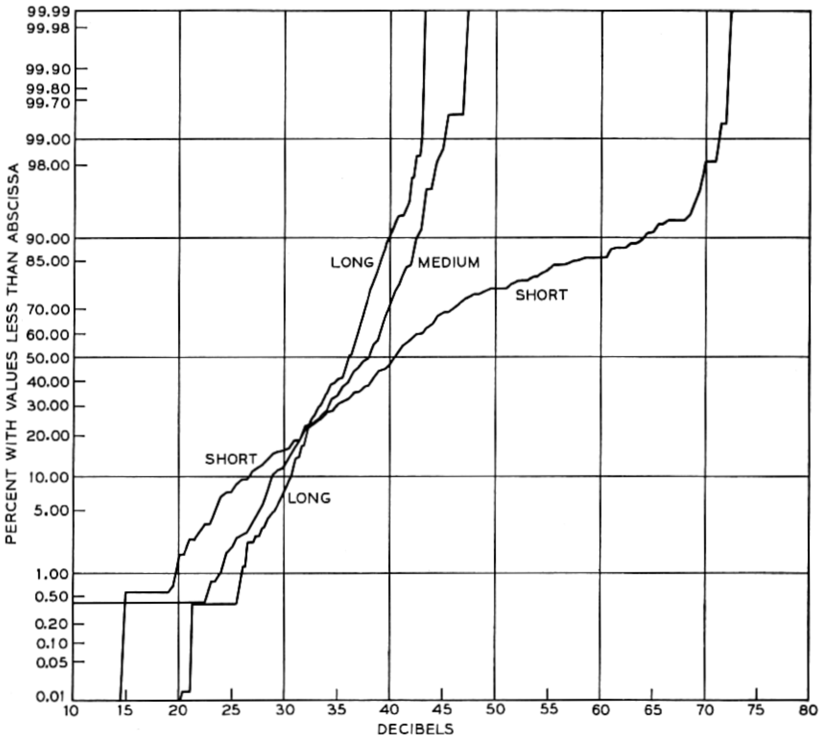

Fig. 3—Cumulative distribution curves: signal-to-notched noise with C-message weighting.

5.4 *Attenuation Distortion Relative to 1000 Hz*

Attenuation distortion is a measure of the change in loss caused by a corresponding change in the frequency of a transmitted signal.

The test was initialized by sending a 1700-Hz signal at 0 dBm and, at the receiving end of the connection, adjusting a preamplifier to obtain a high reading on a 25B Voiceband Gain and Delay Measuring Set. Once the preamplifier was set for a particular connection, the setting was not changed throughout the remainder of the test. The signal was then sent at each frequency listed in Table VIII and the received signal measured. When the power of the received signal was too low to be detected by the test equipment, the lowest detectable value was assigned. This occurred at the lower and upper edge frequencies of the voiceband (200, 3200, 3300, and 3400 Hz).

Loss is treated as a positive quantity for data analysis. Increasing positive quantities represent greater loss conditions. To obtain the attentuation distortion, the 1000-Hz loss of each connection was subtracted from the losses at all frequencies for that connection. Results for the lower and upper edge frequencies mentioned above are interpreted as indicating that the distortion is at least that great.

Attenuation distortion in all mileage categories is essentially the same between 800 and 2300 Hz. Short connections experience less distortion at both the lower and upper edges of the voiceband when compared to medium and long connections. Distortion on long connections is similar to that on short connections for the lower edge frequencies of the voiceband (200–600 Hz) and it is similar to the distortion on medium length connections at the upper edge frequencies of the voiceband (2450–3400 Hz). Attenuation distortion distributions are slightly to moderately skewed. In most cases the skewness is positive.

A graphical presentation of means listed in Table VIII is given in Fig. 4. The means for all connections combined are not plotted, since they are similar to the means for short connections. The figure provides a first-order approximation for attenuation distortion bandwidth. The 1959 survey noted an average 20-dB bandwidth of about 3000 Hz for both short (0–400 miles) and long (400–2900 miles) connections.[1] Calculating the differences in frequency between the low-end and high-end 20-dB points in Fig. 4 gives approximately 3100 Hz. Attenuation distortion curves generally are nearly linear from about 1000 Hz to 2800 Hz. The loss difference between 2750 Hz and 1000 Hz provides a measure of this slope. Accordingly, the average slopes for the curves are 3.5, 4.1, and 4.7 dB for short, medium, and long connections respectively. These results indicate a decrease in slope since 1959. When the data from the 1959 survey are adjusted to eliminate the contributions of loops, the amount of decrease is in the neighborhood of 2 to 3 dB.

TABLE VIII—ATTENUATION DISTORTION RELATIVE TO 1000-Hz ON TOLL CONNECTIONS

Frequency (Hz)	All		0–180 Miles		180–725 Miles		725–2900 Miles	
	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)
200*	11.8 ± 1.9	5.1	11.4 ± 2.4	5.1	13.7 ± 1.5	4.5	12.4 ± 2.4	5.0
250	6.6 ± 0.9	3.0	6.4 ± 1.1	2.7	8.0 ± 1.3	3.7	6.8 ± 1.6	3.1
300	4.1 ± 0.6	2.1	4.0 ± 0.7	1.9	4.8 ± 0.9	2.8	4.0 ± 0.9	2.1
400	2.3 ± 0.3	1.6	2.2 ± 0.4	1.4	2.8 ± 0.6	2.2	2.0 ± 0.3	1.4
600	1.1 ± 0.1	1.1	0.9 ± 0.1	0.9	1.6 ± 0.4	1.9	1.2 ± 0.2	0.8
800	0.5 ± 0.1	0.5	0.4 ± 0.0	0.5	0.7 ± 0.2	0.5	0.5 ± 0.1	0.4
1200	−0.1 ± 0.1	0.3	−0.1 ± 0.1	0.3	−0.3 ± 0.1	0.4	−0.3 ± 0.0	0.4
1400	−0.1 ± 0.1	0.6	0.0 ± 0.1	0.6	−0.3 ± 0.1	0.6	−0.3 ± 0.1	0.5
1700	0.3 ± 0.1	0.9	0.3 ± 0.1	0.9	0.1 ± 0.2	0.8	0.2 ± 0.2	0.8
2000	0.8 ± 0.1	1.1	0.8 ± 0.1	1.1	0.8 ± 0.2	1.1	0.7 ± 0.3	1.0
2300	1.4 ± 0.2	1.4	1.4 ± 0.3	1.3	1.4 ± 0.3	1.4	1.7 ± 0.5	1.4
2450	1.9 ± 0.4	1.6	1.8 ± 0.4	1.5	2.0 ± 0.4	1.6	2.4 ± 0.6	1.7
2750	3.7 ± 0.8	2.5	3.5 ± 1.0	2.5	4.1 ± 0.5	2.2	4.7 ± 1.0	2.3
2850	4.7 ± 1.1	3.0	4.4 ± 1.2	3.0	5.4 ± 0.6	2.6	6.1 ± 1.1	2.7
3000	6.9 ± 1.5	4.1	6.4 ± 1.6	4.1	8.1 ± 1.0	3.6	9.2 ± 1.9	4.3
3100	9.5 ± 1.7	5.7	9.0 ± 1.9	5.9	10.6 ± 1.5	4.7	11.6 ± 2.7	5.2
3200*	13.4 ± 2.1	7.8	12.9 ± 2.5	8.0	14.7 ± 2.1	6.8	15.2 ± 3.4	6.6
3300*	18.2 ± 2.7	9.5	17.6 ± 3.2	10.0	20.0 ± 3.1	8.0	19.8 ± 3.7	7.6
3400*	22.1 ± 3.0	9.2	21.2 ± 3.6	9.8	24.4 ± 2.8	6.4	25.1 ± 1.7	6.1

* Distortion values at these frequencies are at least as great as shown.

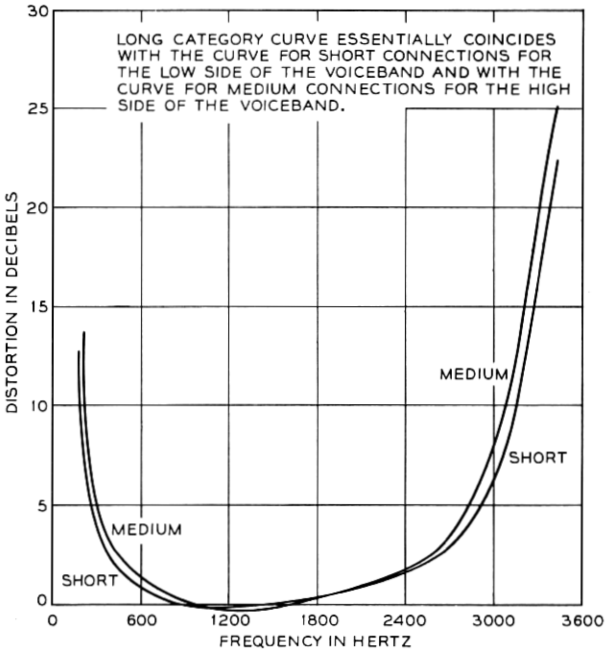

Fig. 4—Locus of means for attenuation distortion relative to 1000 Hz.

5.5 *Envelope Delay Distortion Relative to 1700 Hz*

In general, the change in phase of a signal introduced by a transmission channel depends upon the frequency of the signal. Envelope delay is the derivative of the phase characteristic with respect to frequency. Envelope delay distortion is the envelope delay minus the constant delay term.[16] Table IX presents results of envelope delay distortion relative to the delay at 1700 Hz for 19 frequencies throughout the voiceband.

Relative envelope delay distortion distributions are positively skewed. The degree of skewness varies considerably. Means and standard deviations for medium and long toll connections are very similar; generally the means are separated by less than 100 microseconds at frequencies between 800 and 2450 Hz and by less than 250 microseconds elsewhere in the voiceband. Furthermore, the means are slightly lower for long connections between the frequencies 200 and 1400 Hz. Between the frequencies 2000 and 3400 Hz, the results display slightly higher means for long connections. The standard deviation

TABLE IX—ENVELOPE DELAY DISTORTION RELATIVE TO 1700-Hz ON TOLL CONNECTIONS

Frequency (Hz)	All		0–180 Miles		180–725 Miles		725–2900 Miles	
	Mean (μsec.)	S.D. (μsec.)	Mean (μsec.)	S.D. (μsec.)	Mean (μsec.)	S.D. (μsec.)	Mean (μsec.)	S.D. (μsec.)
200*	5187 ± 566	2672	4580 ± 518	2461	7526 ± 404	1851	7505 ± 473	2422
250*	3934 ± 410	2010	3384 ± 326	1727	5866 ± 417	1595	5880 ± 314	1870
300	3290 ± 289	1660	2816 ± 209	1407	4884 ± 384	1375	4901 ± 297	1510
400	2091 ± 221	1220	1695 ± 128	930	3413 ± 341	1215	3163 ± 218	1144
600	843 ± 96	583	656 ± 43	430	1467 ± 183	628	1335 ± 127	592
800	392 ± 50	342	290 ± 20	263	737 ± 114	371	649 ± 88	350
1000	190 ± 28	206	133 ± 15	165	380 ± 73	227	335 ± 53	209
1200	80 ± 16	125	48 ± 10	103	187 ± 45	139	156 ± 32	128
1400	17 ± 5	74	3 ± 8	66	63 ± 16	83	56 ± 15	76
2000	51 ± 20	67	50 ± 18	62	36 ± 26	66	80 ± 51	95
2300	175 ± 47	136	152 ± 43	122	226 ± 54	133	273 ± 76	180
2450	284 ± 65	179	248 ± 64	159	363 ± 48	153	442 ± 89	230
2750	577 ± 120	339	485 ± 102	276	811 ± 99	273	934 ± 189	457
2850	729 ± 144	420	616 ± 120	338	1017 ± 137	348	1166 ± 263	573
3000	1041 ± 183	570	889 ± 164	456	1437 ± 144	468	1614 ± 303	816
3100	1335 ± 241	728	1128 ± 217	578	1903 ± 153	585	2071 ± 329	993
3200	1636 ± 330	956	1319 ± 279	697	2475 ± 191	750	2734 ± 414	1285
3300*	1919 ± 461	1227	1526 ± 363	917	3208 ± 343	1095	3333 ± 395	1356
3400*	2367 ± 693	1645	1935 ± 556	1277	4040 ± 553	1634	4248 ± 752	2018

* A significant percentage of connections were not measurable at these frequencies.

of the distribution of relative envelope delay distortion at each frequency for long connections is the same or moderately higher than for medium length connections.

A comparison of the results with the 1959 survey indicates less delay distortion on telephone circuits today.[1] Results for both medium and long categories compare favorably with the 1959 results for short toll connections (0–400 miles).

Except for the three lower edge frequencies, the results for short toll connections indicate that envelope delay distortion at a given frequency is about half that experienced on medium and long connections. Standard deviations for short connections are either lower or essentially the same with the exception of the three lower edge frequencies once again. Figure 5 graphically displays the means listed in Table IX. The

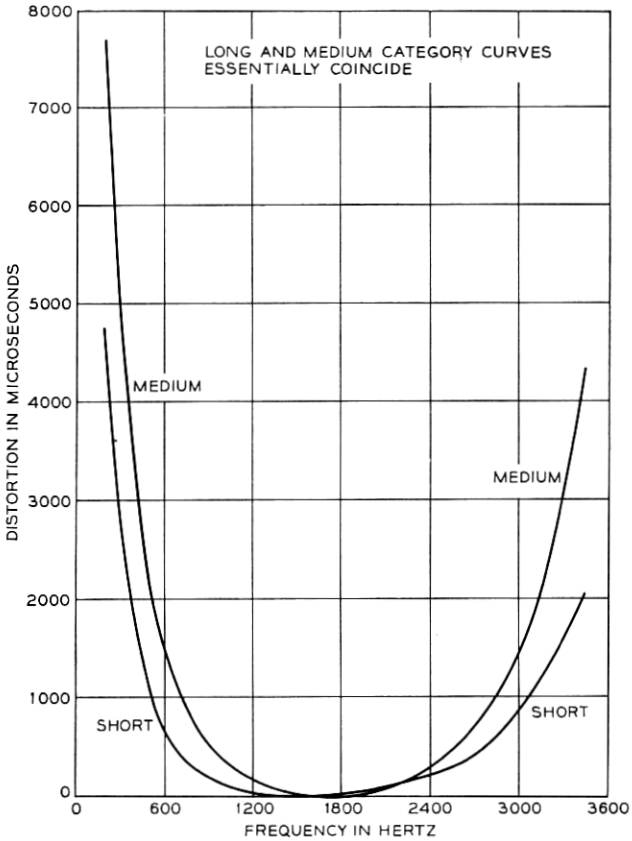

Fig. 5—Locus of means for envelope delay distortion relative to 1700 Hz.

locus of means for the population of all toll connections falls between the curves plotted for short and medium length connections. Figure 5 provides a first-order approximation for envelope delay distortion bandwidth.

At the lower and higher edge frequencies of the voice band, envelope delay distortion may not be measurable. This occurs when the circuit has a high loss at a given frequency. Since the envelope delay distortion cannot be predicted when this condition arises, the sample size diminishes at the outer edge frequencies. This reduction in sample size is as high as 27 percent at 250 and 3300 Hz. It is as high as 41 percent at 200 Hz and 54 percent at 3400 Hz.

5.6 *Peak-to-Average Ratio (P/AR)*

P/AR is a single parameter measure of the transmission quality of a connection.[11] A 27E P/AR generator was used to introduce a continuous pulse train into the telephone channel. The reading on a 27B P/AR Receiver measures the dispersion introduced by that channel. Since amplitude distortion, phase distortion, nonlinear distortion, and noise influence the dispersion that will be introduced, P/AR measurements are related to measures of each of these impairments. High values of P/AR represent favorable transmission conditions.

Results for P/AR appear in Table X. Although the mean does not show a monotonic trend with length of connection, it is dependent upon mileage. The standard deviation increases with connection length. All P/AR distributions are negatively skewed. To illustrate the low end tails of the distributions, the CDFs for short, medium, and long toll connections are given in Fig. 6.

5.7 *Absolute Frequency Offset*

The frequency of a signal may shift when transmitted over a carrier telephone channel. This will occur when modulating and demodulating

TABLE X—RESULTS FOR PEAK-TO-AVERAGE RATIO (P/AR) ON TOLL CONNECTIONS

Connection Length (airline miles)	Mean	S.D.
All	79.5 ± 3.0	9.9
0–180	81.7 ± 3.3	8.6
180–725	72.5 ± 3.3	10.5
725–2900	74.2 ± 2.0	11.0

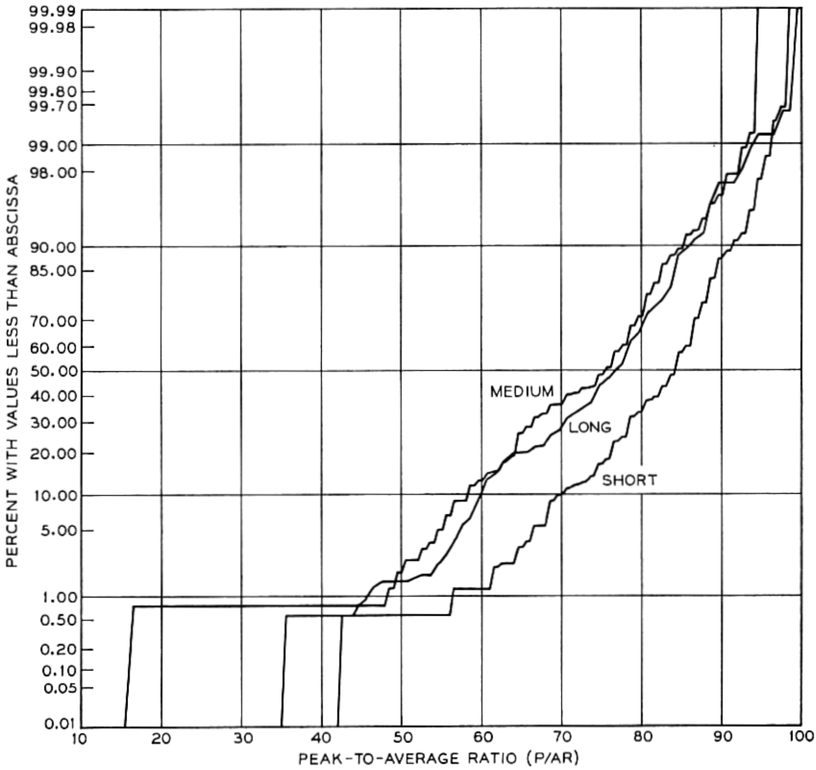

Fig. 6—Cumulative distribution curves: peak-to-average ratio (P/AR).

carrier supply frequencies are not identical. The change in frequency is called frequency offset. The offset is positive if the frequency increases and negative if it decreases. Absolute frequency offset is defined as the absolute value of the change in frequency.

A precise 1200-Hz signal was transmitted at −12 dBm. At the receiving end of the connection, a frequency counter with a 10-second averaging period was used to measure the frequency of the received signal. Results for absolute frequency offset are given in Table XI.

Distributions of absolute frequency offset are not normal. The value is 0 for 87, 59, and 43 percent of all connections in the short, medium, and long categories, respectively. Accordingly, 10-, 50-, and 90-percent points are listed in Table XI. The table indicates very little frequency offset was detected. However, an offset greater than 3 Hz was measured on two connections in the long mileage category.

TABLE XI—RESULTS FOR ABSOLUTE FREQUENCY OFFSET ON TOLL CONNECTIONS
(Percentage Points from Cumulative Distribution Curves)

Connection Length (airline miles)	Offset in Hz		
	10%	50%	90%
All	0	0	0.2
0–180	0	0	0.1
180–725	0	0	0.3
725–2900	0	0.1	1.1

5.8 *Level Tracking*

Level tracking is a measure of change in loss as a function of the power of a signal at the input to a connection. It provides an indication of the presence of compandored facilities, particularly any mismatch of signal-power-controlled compressor gains and expandor losses. Results are presented in Table XII in the form of deviations from the gain measured with −10-dBm input power. The results show that over the measured range there is a slight decrease in gain as the input test signal power is increased.

Distributions for gain deviations with signal power are skewed toward greater deviations. Thus, distributions for input powers greater than −10 dBm are negatively skewed, while distributions for input powers lower than −10 dBm are positively skewed. It is noted that the greatest deviations are concentrated in the medium length category. This reflects the fact that more compandors are likely to be encountered on medium length connections. This is indicated by the facility composition of intertoll trunks presented in Ref. 5. Medium-length connections often consist of a short intertoll trunk and a medium-length intertoll trunk in tandem or two short intertoll trunks in tandem. These arrangements increase the likelihood of encountering compandors.

5.9 *Nonlinear Distortion*

Estimates of nonlinear distortion were obtained using intermodulation and harmonic distortion measurements. For intermodulation distortion, two tones, 1250 Hz (tone A) and 700 Hz (tone B), were transmitted at −13 dBm each (−10 dBm total) and the power of each intermodulation product in Table XIII was measured. For harmonic distortion, a 525-Hz tone was transmitted at −12 dBm and the received

TABLE XII—DEVIATIONS FROM GAIN MEASURED WITH −10-dBm TRANSMITTED SIGNAL ON TOLL CONNECTIONS

Connection Length (airline miles)	0 dBm Input		−5 dBm Input		−15 dBm Input		−20 dBm Input	
	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)
All	−0.5 ± 0.1	0.5	−0.3 ± 0.1	0.3	0.4 ± 0.1	0.3	0.7 ± 0.1	0.6
0–180	−0.5 ± 0.1	0.5	−0.3 ± 0.1	0.3	0.3 ± 0.1	0.3	0.7 ± 0.2	0.6
180–725	−0.7 ± 0.2	0.5	−0.4 ± 0.1	0.3	0.5 ± 0.1	0.4	0.9 ± 0.2	0.7
725–2900	−0.5 ± 0.1	0.4	−0.3 ± 0.1	0.3	0.4 ± 0.1	0.3	0.6 ± 0.1	0.4

TABLE XIII—RESULTS FOR THE RATIO OF THE TOTAL RECEIVED POWER OF A TWO-TONE SIGNAL TRANSMITTED AT −10DBM TO INDIVIDUAL INTERMODULATION PRODUCT POWERS ON TOLL CONNECTIONS

Product A = 1250 Hz B = 700 Hz		All		0–180 Miles		180–725 Miles		725–2900 Miles	
Type	Freq. (Hz)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)
A − B	550	42.8 ± 2.3	10.6	43.2 ± 3.2	11.4	40.8 ± 1.8	7.7	42.9 ± 0.7	7.0
2B	1400	50.1 ± 2.5	11.5	51.3 ± 3.2	12.7	46.1 ± 1.7	5.8	46.8 ± 1.0	5.2
A + B	1950	43.9 ± 3.0	12.0	44.9 ± 3.8	13.1	39.9 ± 2.4	7.3	42.7 ± 1.4	6.7
3B	2100	54.3 ± 1.2	7.4	54.7 ± 1.5	8.0	53.5 ± 1.5	5.0	52.7 ± 1.6	5.0
2A	2500	48.6 ± 2.2	11.2	49.3 ± 2.9	12.3	45.7 ± 2.5	6.5	48.0 ± 1.5	6.0
2B + A	2650	50.0 ± 2.2	12.3	51.1 ± 2.8	13.6	46.0 ± 2.2	6.6	46.8 ± 1.1	4.8
2A − B	1800	43.6 ± 2.4	10.9	45.0 ± 3.1	11.9	39.3 ± 2.4	6.3	40.1 ± 1.3	4.9
Equivalent A ± B		42.1 ± 2.2	10.6	42.8 ± 3.0	11.6	39.0 ± 2.1	5.9	41.3 ± 1.2	5.7

powers of the signal, the second harmonic (1050 Hz), and the third harmonic (1575 Hz) were measured. Results in Tables XIII and XIV give the powers of the products in dB below received signal.

Current work on characterizing nonlinearities has shown that the power average of the second-order products should be used to compute second-order distortion and the 2A-B product used directly to compute third-order distortion.[17] This measure of second-order distortion is labeled "equivalent A ± B" product in Table XIII and was computed for each connection by taking the ratio of total received signal power to the average power of the A + B product, the A − B product, and the 2A and 2B products each adjusted by 6 dB to make them equivalent to A ± B products.[16] Figures 7 and 8 give the CDFs for second- and third-order ratios.

Nonlinear distortion is time-variable on some channels. When an intermodulation or harmonic distortion product varied with time, the maximum value was recorded. This causes estimates of nonlinear distortion to indicate slightly poorer ratios for second-order products. Laboratory simulations have shown that the maximum value is the best indication of performance for third-order products and the average of the maximum and minimum values should be used for second-order products.

Distributions for intermodulation distortion ratios exhibit positive skewness for short connections while the data for both medium and long connections generally are close to normal. For all ratios the standard deviation decreases in longer mileage categories. This trend is not true for the means of the distributions. Generally the mean is lowest for medium length connections.

The ratio of fundamental to second harmonic of the 525-Hz tone has a distribution which is positively skewed for short connections.

TABLE XIV—RESULTS FOR THE RATIO OF RECEIVED 525-Hz FUNDAMENTAL TO THE SECOND AND THIRD HARMONICS ON TOLL CONNECTIONS

Connection Length (airline miles)	Second		Third	
	Mean (dB)	S.D. (dB)	Mean (dB)	S.D. (dB)
All	41.8 ± 2.5	11.6	45.7 ± 2.4	12.3
0–180	42.6 ± 3.3	12.4	47.3 ± 2.6	13.3
180–725	38.2 ± 1.9	7.8	39.7 ± 2.4	6.3
725–2900	41.6 ± 1.4	7.6	42.0 ± 1.6	5.3

The distributions are close to normal for medium and long connections. The ratio of fundamental to third harmonic has a distribution positively skewed for both short and medium connections. The distribution is close to normal for long connections. Both ratios are poorest in the medium category. Standard deviations decrease in the longer categories.

The skewness in the distributions of ratios noted above reflects the fact that the harmonic or intermodulation product was very weak on some connections. When either an intermodulation or harmonic product was below the noise measured in a slot around the frequency of the product, the noise value was recorded. This leads to slightly lower ratios.

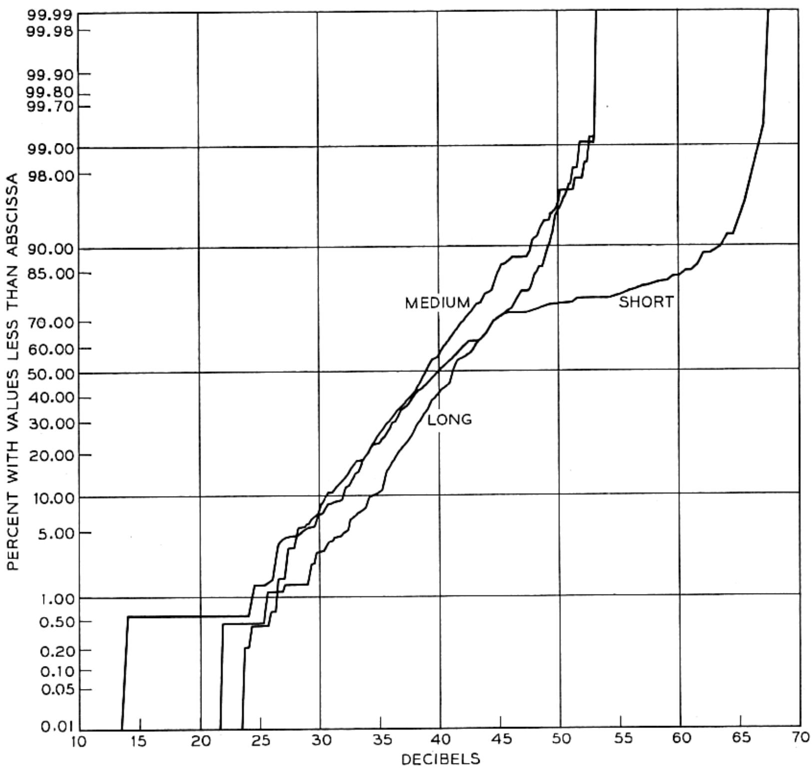

Fig. 7—Cumulative distribution curves: signal-to-second-order distortion product at −10 dBm transmit power.

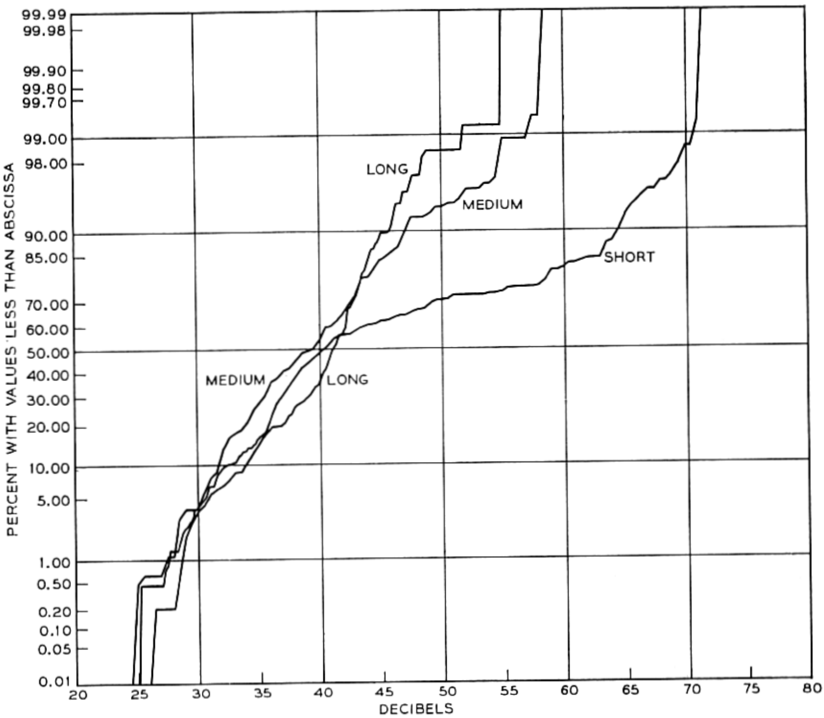

Fig. 8—Cumulative distribution curves: signal-to-third-order distortion product at —10 dBm transmit power.

5.10 *Peak-to-Peak Phase Jitter*

Phase jitter is defined as incidental frequency modulation or phase variations introduced into signals transmitted over telephone channels. To measure the components of jitter in several frequency bands, a 1700-Hz signal was transmitted at 0 dBm. At the receiving end, phase excursions of the 1700-Hz tone were detected. Peak-to-peak phase jitter in degrees was measured in six octave bands between 12 and 768 Hz and for the entire band of 12 to 768 Hz.

Distributions of phase jitter are not normal. In most instances, the distributions exhibit a high degree of truncation at 0 degrees. Accordingly, Table XV contains 10-, 50-, and 90-percent points for short, medium, and long connections in each frequency band measured. Results published for the 1966 survey described jitter components between 10 Hz and 120 Hz.[3] They are reproduced in Table XV. A

TABLE XV—RESULTS FOR PEAK-TO-PEAK PHASE JITTER ON TOLL CONNECTIONS
(Percentage Points from Cumulative Distribution Curves)

Frequency Band (Hz)	All			0–180 Miles			180–725 Miles			725–2900 Miles		
	degrees			degrees			degrees			degrees		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
12–768	0	3.0	7.0	0	2.0	6.0	2.0	4.0	8.0	2.0	5.0	9.0
12–24	0	0	2.0	0	0	1.0	0	1.0	3.0	0	1.0	3.0
24–48	0	0	1.0	0	0	1.0	0	1.0	2.0	0	1.0	2.0
48–96	0	0	2.0	0	0	1.0	0	1.0	4.0	1.0	2.0	5.0
96–192	0.3	0.3	1.3	0	0	0.3	0.3	0.3	2.3	0.3	0.3	2.3
192–384	0	0.5	1.5	0	0.5	1.5	0.5	0.5	1.5	0.5	0.5	1.5
384–768	0	0.6	1.6	0	0.6	1.6	0	0.6	1.6	0.6	0.6	1.6

(1966 Connection Survey Results)

Connection Length (airline miles)	Phase Jitter (degrees) (DDD)		
	10%	50%	90%
0–180	1	2	9
180–725	2	6	18
725–2900	3	12	21

comparison with the current results clearly indicates a dramatic improvement. There is much less jitter in the band 12 Hz to 768 Hz now, than in the much narrower band in 1966.

5.11 *Time to Receipt of Audible Ringing*

Time to receipt of audible ringing is defined as the interval of time which elapses between dialing the last digit of a telephone number and receiving the audible ringing signal. This was recorded for each test connection and the results are listed in Table XVI. Results for time to connect on DDD-handled calls are reproduced from the 1966 survey in Table XVII.

In the 1966 survey, calls were made to standard milliwatt supply terminations at the far-end offices.[3] Time to connect on DDD calls was recorded as the time which elapsed between dialing the last digit of the telephone number and receipt of the milliwatt signal. Since the milliwatt signal is transimtted about 100 milliseconds after application of the ringing signal, the measurement procedures of the surveys are comparable.

A note of caution must be given. Calls generally were placed at 8 a.m. and 12 noon in this survey and were held for approximately four hours. In 1966 they were placed at any time between the hours of 8 a.m. and 5 p.m.

The estimated mean and standard deviation for time to receipt of audible ringing are largest for medium-length connections in this survey. Distributions for time to receipt of audible ringing are close to normal in all mileage categories. A comparison with the 1966 survey shows that the confidence intervals overlap in all mileage categories.

VI. REMARKS

Comparisons have been made with past surveys. They indicate a

Table XVI—Results for Time to Audible Ringing on Toll Connections

Connection Length (airline miles)	Mean (seconds)	S.D. (seconds)
All	11.7 ± 1.8	4.3
0–180	10.8 ± 1.5	3.7
180–725	14.7 ± 3.2	5.0
725–2900	13.9 ± 2.6	4.5

TABLE XVII—RESULTS FOR TIME TO CONNECT ON DDD TOLL CONNECTIONS IN 1966

Connection Length (airline miles)	Mean (seconds)	S.D. (seconds)
0–180	11.1 ± 0.9	4.6
180–725	15.6 ± 1.0	5.0
725–2900	17.6 ± 2.1	6.6

trend towards improved transmission performance. Substantial improvement has been observed for phase jitter. Relative envelope delay distortion, attenuation distortion slope, and 1000-Hz loss results also indicate improvements.

In addition to the impairments previously measured to evaluate transmission performance, new measures have been made on a system-wide basis for toll connections. They include P/AR, frequency offset, level tracking, and nonlinear distortion. These should be of particular interest to those involved in data transmission.

Time-shared computer processing of data and the use of trained test teams at originating and terminating ends of connections are a powerful combination. They provide the advantages of control and flexibility. Since data "laundering" was concurrent with field operations, the data management system provided means for accurate and current reporting of survey results.

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