THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 50, No. 8, October, 1971
Printed in U.S.A.

The Transmission Performance of Bell System Toll Connecting Trunks

By J. E. KESSLER

(Manuscript received April 19, 1971)

A systemwide survey of the performance of Bell System toll connecting trunks was undertaken in 1966. Various results of this survey have been used in other studies since that time. This paper collects the main results in a single writing. The sampling plan and measurement procedures are discussed briefly. Measurement results are presented in distributional form and as estimates for the transmission parameters relating to loss, message circuit noise, impulse noise, relative envelope delay, P/AR, harmonic distortion, and physical characteristics. Some results are presented separately for major facilities and facility categories.

I. INTRODUCTION

The Bell System telephone network consists of a hierarchy of transmission facilities available for connecting one subscriber to another. These include the loops from the subscribers to their local telephone office, toll connecting trunks from the local to the toll office, and inter-toll trunks between these toll offices. Clearly, the transmission performance of a toll connection is affected by each part of this built-up connection. Overall measures of performance have been reported in previous connection surveys[1,2] and there has been a recently completed 1969–70 Connection Survey.[3–5] There is a concurrent need for detailed knowledge of the specific parts of toll connections. This information finds important applications in the setting of trunk objectives for the various transmission parameters, and in the effort to simulate, on a computer, a model of the Bell System transmission network. To this end, this paper reports various population estimates of the transmission performance of toll connecting trunks, based on a systemwide survey undertaken in 1966. Individual portions of this information have been used separately, and this paper serves to bring all the results together in a single document. To the author's knowledge, these data represent the only published estimates of toll connecting trunk performance. Although the mixture of facilities has changed with time, estimates of parameters for individual types of facility are expected to be reasonably stable.

A toll connecting trunk is defined as any trunk connecting an end office (class 5) with a toll office (class 4, 3, 2, or 1). For purposes of this paper each toll connecting trunk consists of the trunk facility and any office equipment associated with the trunk. The office equipment may be attenuation pads, hybrid transformers, repeating coils, etc. Figure 1 shows the various types of toll connecting trunks used in the Bell System.

In general, a toll connecting trunk consists of switching equipment at both ends and transmission facilities in between. Consistent with their application to trunk transmission objectives studies, trunks are measured on a switch-through-switch basis (see Fig. 2). This enables one to use these data in constructing estimates for overall connections. In toll offices measurements are made from a toll testboard, master test frame, or an outgoing trunk (OGT) board. In the end offices the testing is done from a master test frame or OGT board. Thus, the trunk includes (besides the actual facility of two-wire or four-wire voice-frequency cable, or carrier channel) the trunk circuit, repeating coils, four-wire terminating sets, and switching equipment, etc.

The toll connecting trunks in the survey were measured for the following transmission parameters:

(*i*) 1000-Hz loss
(*ii*) Frequency response

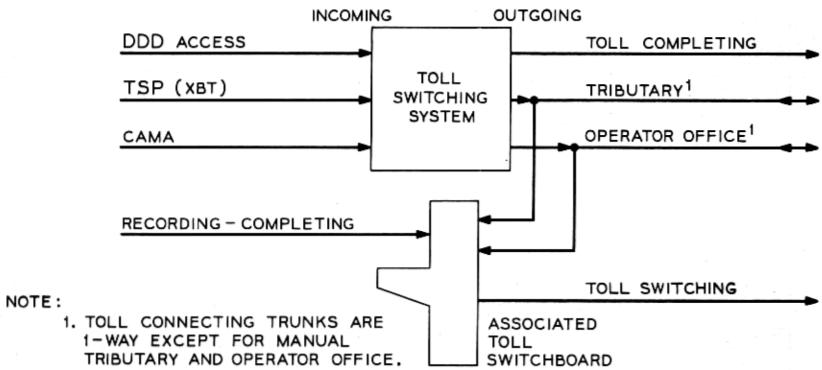


Fig. 1—Types of toll connecting trunks.

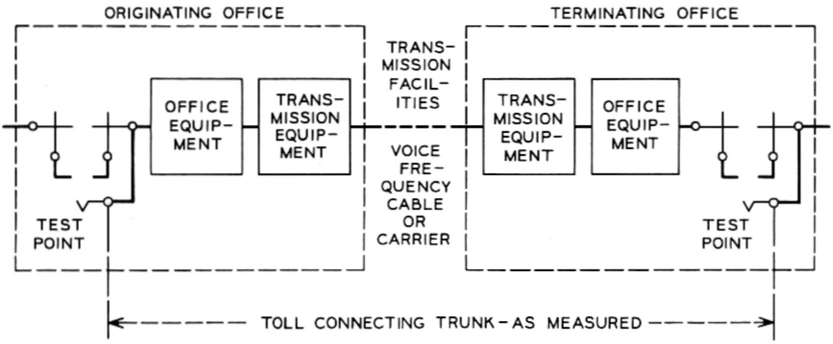


Fig. 2—Composition and testing arrangement.

(*iii*) Relative envelope delay
(*iv*) Message circuit noise
(*v*) Impulse noise
(*vi*) P/AR meter readings
(*vii*) Harmonic distortion
(*viii*) Level tracking on compandored facilities.

All measurements were made in both directions of transmission with the exception of impulse noise. It was measured only incoming to the class 5 office. The frequency response and relative envelope delay were measured at 17 frequencies from 200 to 3400 Hz. Bell Laboratories personnel carried out these measurements, with one person at each end of the toll connecting trunk.

In addition to actual measurements, information about trunk length, type of switching, and type of facility used for the toll connecting trunk was obtained from office records, such as circuit layout cards.

There are many different facilities in use as toll connecting trunks in the Bell System. This survey encountered several separably identifiable types of facilities and, where there was a significant sample, results are given for these facility subclasses.

II. SAMPLING PLAN

The sampled population consisted of all the Bell System toll connecting trunks in the continental United States and Canada. Although the exact number was not known, it was estimated that there were about 800,000 toll connecting trunks in service in 1966.

The sample of toll connecting trunks of this survey consisted of

150 trunks from 15 end offices, each having less than 400,000 annual outgoing toll messages (AOTM), and 242 trunks from 25 end offices each having more than 400,000 AOTM. These 392 trunks were measured for most parameters in both directions, thus yielding 784 population elements in the sample.

The sample design consisted of a two-stage plan with first-stage stratification and with the primary units selected with probabilities proportional to a measure of size. (See Refs. 6, 7, or 8 for a general discussion of sampling plans of this type.) The primary units were Bell System end office (class 5) buildings. These end offices were stratified into two disjoint subpopulations, according to the number of annual outgoing toll messages originating in the end office. This was done because a pilot survey in 1965 indicated that large end office buildings usually have shorter toll connecting trunks than small end office buildings. The large end offices also tend to use voice-frequency cable (VF) toll connecting trunks rather than carrier. By stratifying the population into two groups that tend to internal homogeneity one can more efficiently procure the necessary estimates with the desired precision. The confirmation of this rationale will be borne out in a later section discussing the physical characteristics of toll connecting trunks.

The frame for the first-stage sample was a list of the 9052 Bell System end office buildings in service on January 1, 1964. These end office buildings were divided into two subpopulations, according to whether they originated 400,000 AOTM or not. From stratum 1 of end office buildings with less than 400,000 AOTM, 15 end office buildings were selected. From stratum 2, twenty-five end office buildings were selected. Each end office building was assigned a probability of selection proportional to its AOTM. This measure of size had been used for the first-stage selection of offices in the concurrently conducted toll connection survey,[2] and practicality deemed its use again for the toll connecting trunk survey. There is a strong correlation between the AOTM and the number of toll connecting trunks in an end office building. The sampling of end office buildings in each primary stratum was performed independently.

For the second stage of sampling a listing of all toll connecting trunks in each primary unit (i.e., the selected end office building) was obtained. For controlling the complexity of the survey, a three-day visit was planned for each office. This practical constraint indicated the ability to measure 8 to 12 trunks in each office. Therefore, where possible, 12 toll connecting trunks were chosen by simple random sampling, independently in each primary unit. The toll connecting trunks thus selected become the second-stage units of the sample design.

It is possible for an end office to have trunks to more than one toll office building, requiring the tester at the toll office end of the trunks to travel to more than one building. The goal of testing 8 to 12 trunks from each end office was met except in three offices. In one office, only seven toll connecting trunks existed, and in the other two offices practical difficulties arose to limit the measurements to seven and five trunks.

The data analysis consisted of using estimation formulas appropriate for the sample design described previously. These formulas yield estimates of population parameters (i.e., mean, variance, standard deviation, and 90-percent confidence intervals) based on the sample data. The estimates are weighted to account for the structure of the sampling plan, with its stratification and selection proportional to a measure of size. Probability sampling of this type has the distinct advantage of providing estimates of the important characteristics of the population from which we sample, and at the same time providing a quantitative measure of the sampling error.

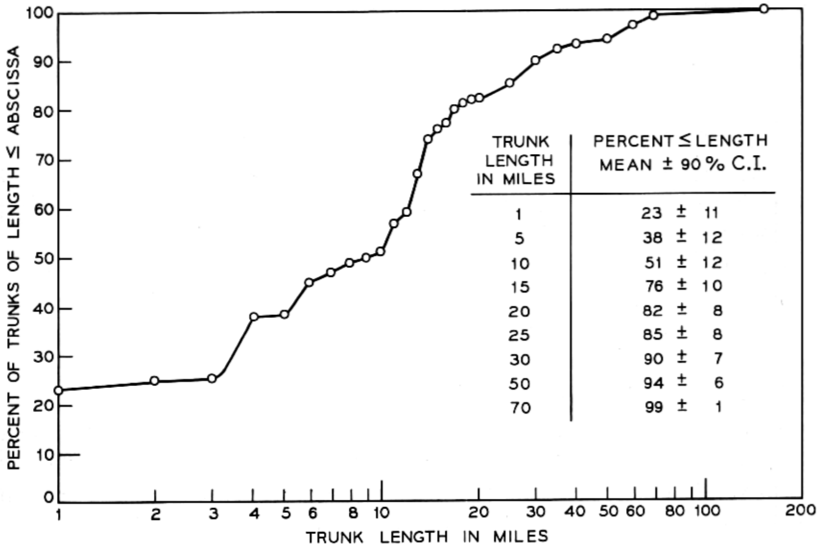
III. PHYSICAL CHARACTERISTICS

For each of the toll connecting trunks of the sample a record was obtained of some of its physical characteristics. This included the route length of the trunk, the type of switching at each end of the trunk, and the type of facility comprising the trunk. From these data, estimates were made of trunk length distributions, facility composition of toll connecting trunks, and percentages of different switching machines used.

3.1 *Trunk Length*

The trunk length distribution is shown in Fig. 3. A substantial amount (21 percent) of the trunks are intrabuilding trunks resulting from the end office and toll office being in the same building. In these cases the toll connecting trunk usually consists of a 2-dB pad and switching equipment in tandem with a short length of cable.

Basically, toll connecting trunks span short distances. About half the trunks are less than 10 miles long, and only 10 percent of the trunks



TRUNK LENGTH IN MILES	PERCENT ≤ LENGTH MEAN ± 90% C.I.
1	23 ± 11
5	38 ± 12
10	51 ± 12
15	76 ± 10
20	82 ± 8
25	85 ± 8
30	90 ± 7
50	94 ± 6
70	99 ± 1

Fig. 3—Trunk length distribution.

are longer than 30 miles. However, there were two trunks in the sample that were 151 miles long. This resulted from indirect geographic routing which added about 100 miles to their actual length.

As previously mentioned, the survey sample had a primary stratification based on the belief that large and small offices were significantly different with regard to the types and length of the toll connecting trunks associated with them. These differences are corroborated in Table I which shows the estimated length and type of facility in large and small offices. The metropolitan offices (i.e., large, over 400,000 AOTMs) tend to have toll connecting trunks much shorter than those in small offices, and they utilize voice-frequency cable to a much greater degree than the small offices.

A finer relationship between trunk length and type of facility is shown in Table II, in terms of three specific length intervals, 0–15, 15–30, and over 30 miles. The estimated percentage of each facility type used within each interval is given.

3.2 *Facility Composition*

The sample of 392 trunks contained many different facilities. Those types appearing sufficiently often to be estimated reliably are shown in Table III. The percentages of both categories of facilities and single types of facilities are estimated in Table III.

3.3 *Switching Machines*

The toll connecting trunk encounters some type of switching at both the end office (class 5) and the toll office (class 4 or higher). In this survey we noted the type of switching machine used at each end of each toll connecting trunk in the sample. The numbers of the type of switching machine used are classified by end office, toll office, and stratum, and are given in Table IV. There were 40 end office buildings and 66 toll office buildings in the survey, with some office buildings having more than one type of switching system.

It should be noted that these numbers of switching machines are only the types of switching that were found with the toll connecting trunks of this survey. They should not be taken to accurately represent the distribution of switching machines in the Bell System, since the basic population element that was sampled in this survey was a toll connecting trunk and not a switching machine. Also, even though the end office buildings of the primary strata selections may be related to switching machines, the same can not be said of the toll offices. In many cases, all the trunks from an end office home on the same switching machine in the toll office, thus biasing any estimates at the toll office.

At the toll offices there is a sizable amount of switching designated as "switchboard." This category is composed of those trunks for which the transmission measurements were made at a switchboard. Therefore, this category includes toll switching, recording-completing, and operator office trunks (see Fig. 2). This category does not constitute manual switching, where all of a customer's calls to the toll office have to be handled by an operator at a switchboard. In all the toll offices associated with this classification there also was a switching machine. This type of switching machine could have been used as an alternative designation to the switchboard classification. (In fact, operator office trunks may have a multipled switching machine appearance, as well as the switchboard appearance.) However, since the information recorded was to reflect the type of switching actually used by the sampled toll connecting trunks of the survey, the switchboard designation was chosen.

In the class 5 end offices encountered in this survey about 54 percent of the trunks utilized step-by-step switching systems, and 34 percent used No. 5 crossbar. These two types account for the bulk of the switching machines in use at the class 5 end of the sampled toll connecting trunks. At the toll office, crossbar tandem systems were used most frequently, followed by step-by-step systems and switchboards (with the conditions mentioned above defining switchboards).

IV. TRANSMISSION LOSS

4.1 *Frequency Response*

The loss of toll connecting trunks was measured at 17 frequencies, from 200 to 3400 Hz. The measurements were made switch-through-switch as shown in Fig. 1. At each frequency a tone at 0 dBm was transmitted over the trunk and measured at the receiving end with a 25A Gain and Delay Measuring Set. This procedure was repeated for each direction of transmission over the trunk. Since the design of the measurement equipment precluded measuring losses greater than 31 dB, it was not always possible to measure some trunks at the higher frequencies. This was the situation in particular on carrier facilities, such as N1, ON, and Lenkurt. For losses greater than 31 dB, the value of 31 dB was used. This provides a conservative estimate of the mean loss, but is more realistic than simply eliminating these readings. Also, this effect occurred only at 3300 and 3400 Hz, and only on some carrier facilities.

The frequency response statistics for all the toll connecting trunks in the survey are shown in Table V. The results show the mean and its associated 90-percent confidence interval, and an estimate of the standard deviation for each distribution that is considered. Table V also shows the loss estimates for the two types of facilities, carrier and voice-frequency cable, used by toll connecting trunks. It appears that the loss responses for both types of facilities are similar throughout most of the voiceband, with the carrier facilities having a sharper cutoff at the high and low frequencies.

4.2 *Loss Relative to 1000 Hz*

For the individual types of facilities it is useful to present the loss relative to 1000 Hz. This enables one to see the loss characteristics of the facility itself more readily than examination of the absolute value of loss does, since different loss design procedures are encountered among the many trunks. Table VI shows the loss relative to 1000 Hz for the more commonly used carrier facilities. Table VII shows the loss relative to 1000 Hz for the major VF facilities.

V. NOISE

The term noise is applied to a variety of electrical phenomena, all of which are unwanted additive signals and tend to interfere with the transmission of information. There are numerous sources of noise, some man-made and some not. Man-made noise is generated by power supply hum, faulty contacts, electrical apparatus, quantizing errors, etc. The noise from non-man-made sources can originate within or without the systems under measurement. All systems are prone to thermal noise from the random motion of electrons in conductors, as well as to atmospheric electrical disturbances.

The effects of these forms of noise depend, in part, on the type of signal being transmitted over the telephone communication channel. For analog speech signals the average power of the noise is of primary concern. Interference from many noise sources contribute to this type of noise, referred to as "message circuit noise." However, data signals suffer more severely from noise voltage peaks (whether of short or long time duration), which are classified as "impulse noise." A different procedure is used to measure these two noise parameters and each is reported separately in the following sections.

5.1 *Message Circuit Noise*

The level of background noise was measured using the 3A Noise Measuring Set (hence, the name 3A noise) with both C-message and 3-kHz flat weighting networks.[9] The noise measurements were performed for both directions of transmission on the trunk. The measurements were made during the normal business day.

A summary of the noise measured with C-message weighting and 3-kHz flat weighting is shown in Table VIII in terms of the mean and its 90-percent confidence interval, and standard deviation. Estimates for specific facilities and groups of facilities are included where there were sufficient data for useful statistics.

It can be observed that in all categories the 3-kHz flat noise level is higher than with C-message weighting, since the 3-kHz flat weighting does not attenuate the low frequencies nearly as much as C-message weighting. The flat noise on voice-frequency facilities was slightly higher than on carrier, probably because carrier systems have a higher cutoff frequency at the low end of the frequency band, below which nothing is transmitted.

The estimates of flat noise were significantly affected by the direction of transmission being observed. A subclass analysis based on this characteristic showed that average flat noise measured incoming to the end office (class 5) was considerably higher than that incoming to the toll office end of the trunk. Estimated statistics for the parameter, δ, defined as the end office flat noise minus the toll office flat noise, are given in Table IX. The difference in noise levels is more pronounced on voice-frequency cable facilities than on carrier facilities because there is less low-frequency energy transmitted on carrier facilities, in either direction, due to the action of channel filters.

Since the end office noise level is higher it suggests that its noise environment is worse than that of the toll offices. This could be due to extraneous low-frequency components (primarily 60 Hz and its harmonics) generated by office battery and other power plants. Reasoning that larger offices have more noise-producing loads one would expect the larger end offices (strata 2) to have higher average noise levels than the small end offices (strata 1). This is borne out in Fig. 4, where a difference of about 6 dB is observed. There is further support for these hypotheses in comparing the toll office flat noise of toll connecting trunks with the toll office flat noise of short intertoll trunks[10] (0–62.5 miles). The result, with 90-percent confidence limits, is shown in Table X.

The data for 3A noise with C-message weighting were also analyzed

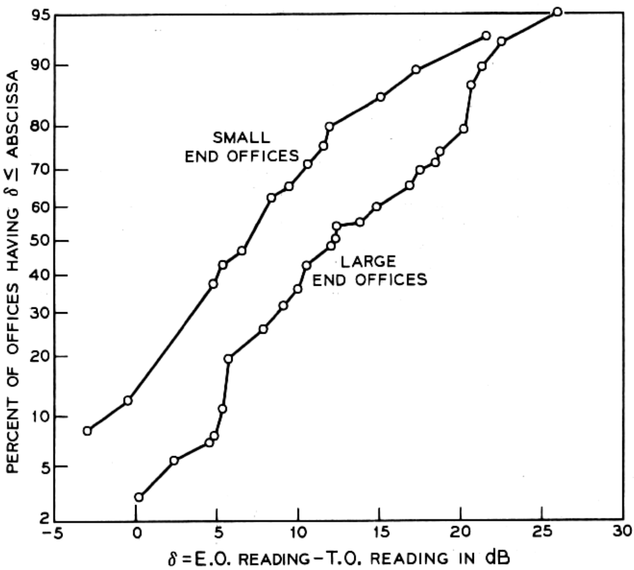


Fig. 4—3A noise with 3-kHz flat weighting.

with respect to trunk length. For this purpose six mileage bands were chosen, with each succeeding band being a doubling of the previous interval. The "double distance" criterion is chosen since previous studies[1,2,10] have shown a linear relationship between noise and double distance on toll connections. The toll connecting trunks of this survey are of relatively short length, but a similar linear relationship is evident, as shown in Table XI. Not only is there the effect of longer trunks accumulating more noise, but it should be recalled from Section III that the longer trunks are predominantly on carrier facilities. Both parameters, the length and facility type, contribute their effect to the noise level observed. The flat-weighted noise was independent of trunk length. This is still consistent with the past studies of intertoll trunks which showed only a very slight increase in flat noise with length for the shorter trunks.

5.2 *Background Noise on Compandored Trunks*

Since the syllabic compandor action on carrier facilities introduces a large loss to the noise in the absence of speech, a background noise reading with a quiet termination is not characteristic of a compandored channel in normal use (i.e., with speech present). In order to measure C-message weighted noise in a simulated speech condition, a holding tone was sent over the trunk in order to adjust the compandor gains, and then it was filtered out at the receiving end.

Measurements were made at four different levels of holding tone, in both directions of transmission on the trunk. The 1850-Hz tone was supplied by a Western Electric KS-19260 Pushbutton Oscillator, at levels of 0, -10, -20, and -30 dBm. After the tone was filtered out, the C-message weighted noise readings were made.

Among the compandored toll connecting trunks there were those using T1 carrier, a digital system.[11] This system uses instantaneous compandors which are active whether speech is present or not. The 1850-Hz holding tone introduced distortion products into the measured signal as the fundamental and harmonics of the 1850-Hz tone interacted with the sampling frequency of the T1 system. Contrary to analog systems, the noise on T1 is mostly quantizing noise introduced by the encoder in the terminal, there being relatively small amounts of line noise. For these reasons, the T1 data are treated separately from the analog data.

Table XII shows estimates of the mean, its 90-percent confidence interval, and the standard deviation of the C-message weighted noise as a function of input holding tone power level. A majority of the analog compandored trunks were on N1 carrier, and their characteristics are also listed separately. For the analog carrier systems the noise components in the terminal equipment are low compared to the line noise. Hence, the measurements should reflect the expandor action at the near end where the measurements are made. Since a compression and expansion ratio of 2 : 1 is being used we would expect a 5-dB change in noise level for each 10-dB change in input signal level. For the analog facilities there is a ratio of about 10 : 7 between the 0- and −10-dBm level inputs, and a ratio of slightly less than 10 : 5 for the level inputs between −10 and −30 dBm. This compares to the theoretical 10 : 5 ratio for perfect companding action.

5.3 *Impulse Noise*

Impulse noise was measured on a switch-through-switch basis, incoming to the class 5 offices. The measurements were made with the 6F Voiceband Noise Measuring Set using C-message weighting. The four counters of the 6F Set were adjusted to cover the range of 4 to 45 counts in the 15-minute recording interval. Then, on each trunk measured, the recorded impulse counts and associated threshold levels are used to interpolate the levels that would correspond to 45, 15, and 4.5 counts per 15-minute interval. The difference in the two levels that yield 4.5 and 45 counts is defined as the slope (in dB per decade) of the peak amplitude distribution. (See Ref. 12 for a discussion of these parameters.) On compandored facilities an 1850-Hz tone at a level of −14 dBm was applied to the trunk in the toll office in order to simulate data transmission trunk conditions. At the end office the tone was suppressed by a 90-dB band-reject filter with a 50-Hz bandwidth.

The results presented in Table XIII are estimates of the mean and standard deviation of the 45- and 15-count level distributions, with a 90-percent confidence interval on the mean estimate. The same estimates are shown for the slope. These data all apply at the switch at the receive end of the trunk. The compandored carrier trunks have a higher mean impulse noise level, but lower average slope, than the voice-frequency cable facilities. A lower slope indicates a narrower distribution of peak amplitudes, so that a smaller change in the reference count level is required to produce a change by a factor of ten in the impulse count. Figure 5 illustrates these points. With the exception of the estimates for all toll connecting trunks, the data of Table XIII and Fig. 5 result from trunks of less than 60 miles length. There were 13 trunks longer than 60 miles, all of them on compandored carrier facilities.

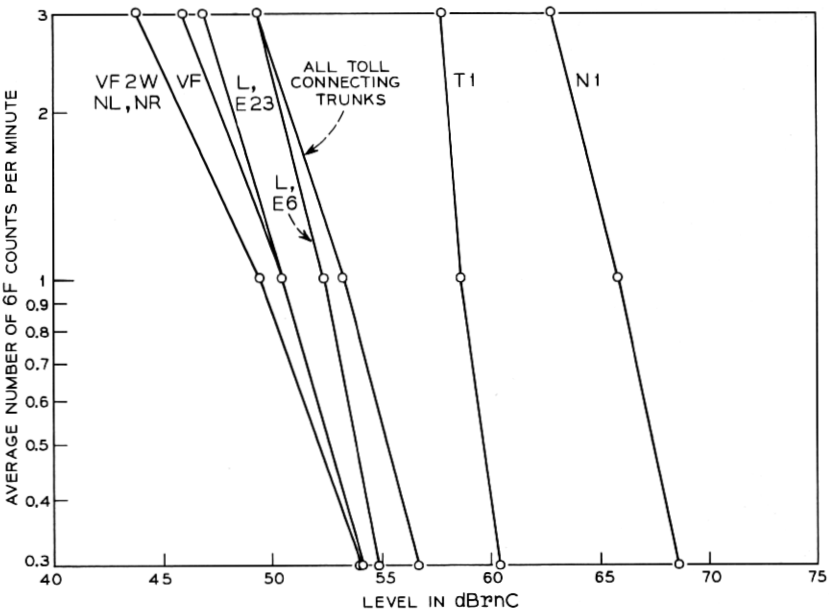


Fig. 5—Average impulse noise levels at receive switch.

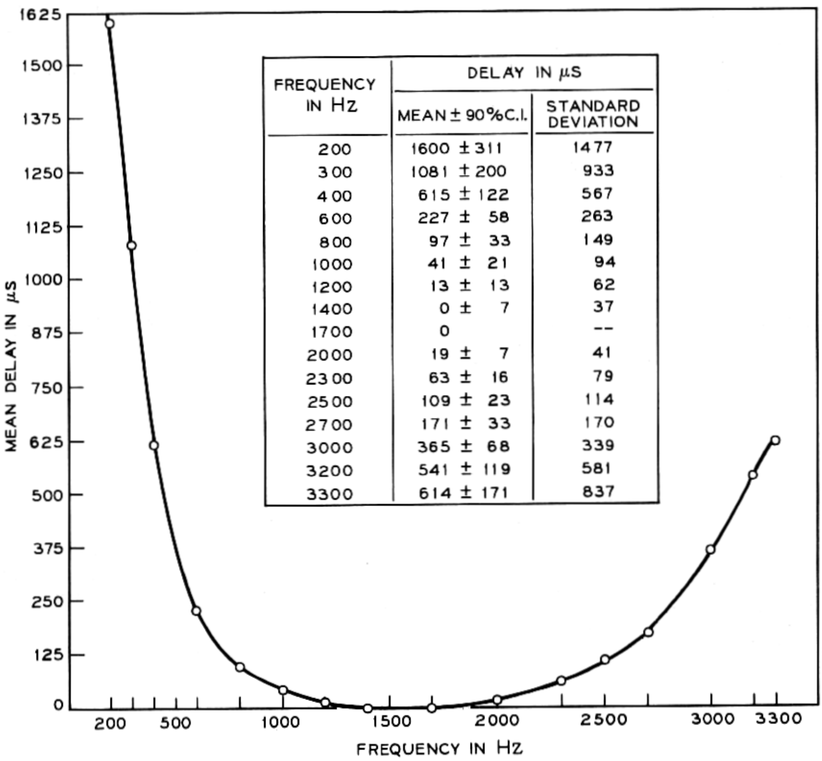
VI. RELATIVE ENVELOPE DELAY

In the transmission of complex waveforms a nonlinear phase shift characteristic of the transmission medium results in the distortion of the signal due to the differing amounts of delay of the different frequencies present in the waveform. This delay distortion can be assessed by measuring the relative envelope delay, which is the delay of the envelope of a low-frequency amplitude-modulated voice-freqeuncy carrier relative to the envelope delay at a reference voice-frequency carrier. The relative envelope delay is an approximation to the derivative of the phase characteristic, so linear phase would yield constant envelope delay. In this survey all the envelope delay measurements are relative to 1700 Hz.

The measurements of relative envelope delay were made using the 25A Gain and Delay Measuring Set and KS-19260 Oscillator. A pair of these was required at each end of the toll connecting trunk, so as to measure both directions of transmission.

The relative envelope delay data were analyzed both for toll connecting trunks in general, and for various subclasses of interest. The results show the estimated mean and its associated 90-percent confidence interval, and an estimate of the standard deviation of each distribution considered. Figure 6 presents the relative envelope delay characteristics based on the sample of all toll connecting trunks. This reflects the differing influences of different types of facilities. For example, the nonloaded voice-frequency cable facilities have essentially no relative delay at the higher frequencies, so the relative delay derives from the carrier and loaded voice-frequency cable facilities. Also, in all cases the office equipment associated with the transmission facility is a major contributor to the delay at low frequencies.[6]

The difference in the relative envelope delay between carrier and voice-frequency cable facilities is shown in Fig. 7. In general, the carrier facilities exhibit more relative envelope delay at the low and high frequency band-edges. The estimates for the carrier facilities are



FREQUENCY IN Hz	DELAY IN μS	
	MEAN ± 90%C.I.	STANDARD DEVIATION
200	1600 ± 311	1477
300	1081 ± 200	933
400	615 ± 122	567
600	227 ± 58	263
800	97 ± 33	149
1000	41 ± 21	94
1200	13 ± 13	62
1400	0 ± 7	37
1700	0	--
2000	19 ± 7	41
2300	63 ± 16	79
2500	109 ± 23	114
2700	171 ± 33	170
3000	365 ± 68	339
3200	541 ± 119	581
3300	614 ± 171	837

Fig. 6—Mean relative envelope delay (includes all types of facilities).

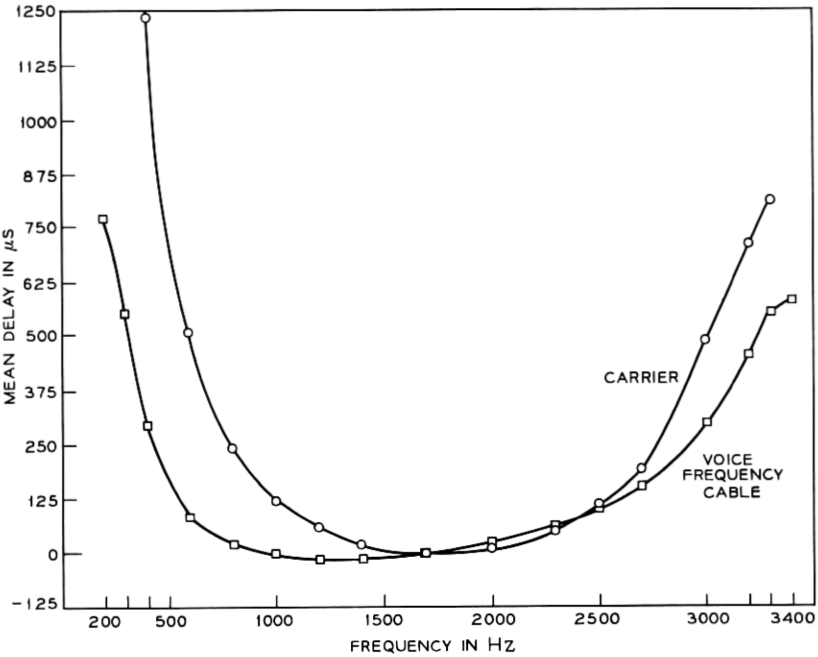


Fig. 7—Mean relative envelope delay (carrier and voice-frequency cable facilities).

only given up to 3200 Hz since excessive loss on the connection above this frequency precluded making the envelope delay measurements on the N1, ON, and O carrier facilities.

Tables XIV and XV show the estimates of relative envelope delay for specific facilities. These subclasses were considered since a sufficient number of trunks of each type was measured, and the trunks were from a number of different offices. The seven types of facilities tabulated represent the facilities more commonly used for toll connecting trunks and they comprised about 85 percent of the total sample for this survey. Among the carrier facilities the delay on T1 showed the least variability. The delay on N1 has been reported in the past[6] where N1 was being used as an intertoll trunk, and those findings are comparable to the values reported here, with N1 now used as a toll connecting trunk. Although all the voice-frequency cable facilities exhibit similar delay characteristics at low frequencies, there is a marked difference between loaded and nonloaded facilities at the higher frequencies. This accounts for the higher variances of the VF facilities in the higher frequencies, with the loaded VF facilities contributing most of this variance. The estimates of the variance for VF trunks with E6 or E23 repeaters are larger than other categories due to the correlation between delay and trunk length—the longer trunks exhibiting more delay. For example, the E23 measurements came from eight different offices, of which four offices supplied shorter trunks (5.3, 5.7, 6.2, 6.7 miles) and four offices had longer trunks (10.2, 11.7, 12.8, 16.3 miles).

In considering toll connecting trunks in general, the correlation between trunk length and relative envelope delay is neither significant nor consistent. This is due to having many different facilities in the total sample and also to measuring the combined effects of office equipment and facility for each toll connecting trunk. Thus, there is only a slightly discernible relation between delay and trunk length at low frequencies (below 1700 Hz), since office equipment causes the predominant effect. Above 1700 Hz the "VF Loaded" facilities exhibited a significant length correlation. These facilities were for trunks of roughly 1 to 18 miles in length. A subclass analysis based on three mileage bands is shown in Fig. 8. The 90-percent confidence interval for each estimated mean value of delay (above 1700 Hz) is also shown.

VII. P/AR

The P/AR (Peak-to-Average Ratio) meter[13] measures the ratio of the peak and full-wave rectified average values of a low duty-cycle pulse train transmitted over a transmission path. Its purpose is to provide a measure of the overall transmission distortion that is present from many different causes. The P/AR meter is most sensitive to envelope delay distortion and is also affected by noise, bandwidth reduction, gain ripples, nonlinearities such as compression and clipping, and other impairments. The P/AR reading is a indication of the general transmission quality of the voiceband channel. In particular, it is a measure of the phase linearity of the toll connecting trunk. If the P/AR signal were received entirely undistorted the P/AR meter would read 100. Distortion normally causes readings lower than 100.

Four P/AR meter readings were made on each toll connecting trunk in the survey. Both directions of transmission were measured, using both polarities of the nonsymmetrical P/AR test signal. However, since there was no significant difference between readings using the normal and inverted polarity test signal, the average of the two was used in deriving estimates. P/AR generators now in production have eliminated this effect by inverting alternate signals. Table XVI shows

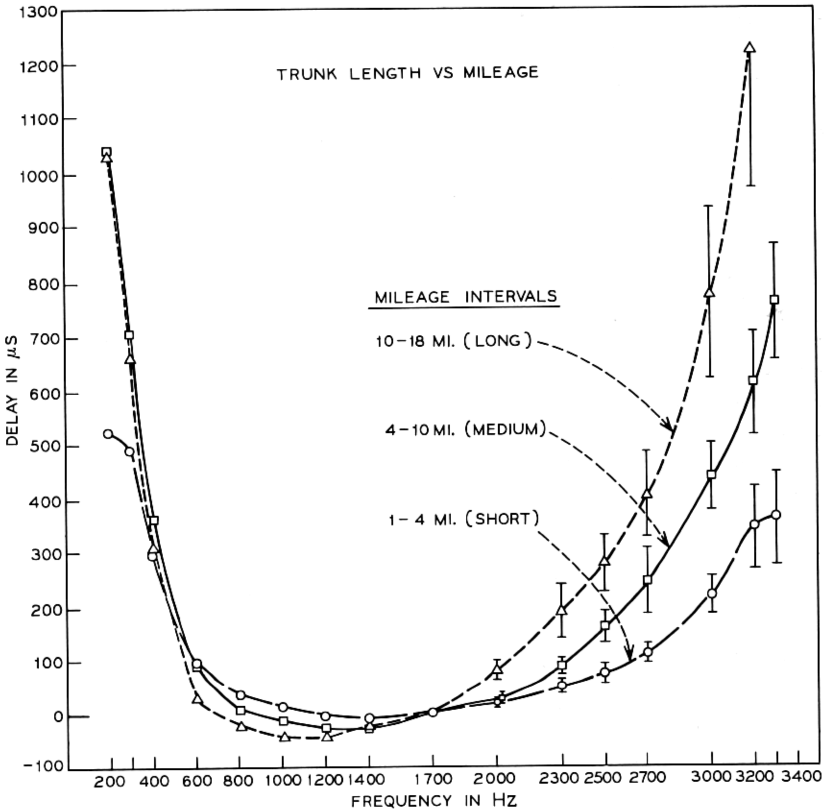


Fig. 8—Relative envelope delay (VF loaded facilities only).

the estimated values for the P/AR distributions of all toll connecting trunks and a variety of other subclasses based on types of facility.

It should be noted that different facilities have different distributions of P/AR readings, so that the same numerical value may indicate a lower than expected reading on one facility but be a higher than expected reading for a different facility. Hence, a comparison of subjective quality between trunks should be made only within a particular facility category, and not between categories. In general, comparing P/AR readings indicates the relative amount of intersymbol interference to be expected in each case.

Since the P/AR meter reading is affected by envelope delay and frequency response it is not surprising that there is a relationship between these parameters and the P/AR readings. In fact, there is a high degree of correlation between these characteristics, which implies that a trunk's relative performance in any of the three measures is a good indication of its general transmission quality with relation to other trunks of the same type.

To show the relationship between P/AR, envelope delay distortion, and loss, consider the performance of the more commonly used facilities with respect to the three mentioned parameters. Besides the mean P/AR reading for a category, the mean loss relative to 1000 Hz (dB) and the relative envelope delay (μs) at 3000 Hz will be used. These values for the major identifiable categories are shown in Table XVII.

Since P/AR, loss, and envelope delay have different underlying scales of measurement and unknown distributions, one method of measuring their relationship is by a rank correlation test.[14] This measures the agreement between the performance with respect to the three parameters. The seven categories of Table XVII can be ranked,* as follows:

	Delay	P/AR	Loss
VF no load no rptr	1	1	1
VF no rptr	2	2	3
T1	3	4	2
N2	4	3	4
VF loaded	5	5	5
VF repeatered	6	6	6
N1	7	7	7

This yields a coefficient of concordance[14] of 0.96, which is significant beyond the 0.01 point (if one feels that such small probabilities are significant). There evidently is a very high degree of correlation between these three transmission characteristics. In other words, if for a given facility one trunk exhibits a "better" P/AR reading than another trunk, it is also likely that it will have "better" loss and delay characteristics.

VIII. LEVEL TRACKING ON COMPANDORED FACILITIES

Of the 392 toll connecting trunks in the survey, 139 were on carrier facilities and these were compandored. These 139 trunks terminated in a total of 40 end offices.

* The number one (1) indicates lowest loss or delay, or highest P/AR reading.

Compandor tracking was measured by transmitting an 1850-Hz tone at each of four power levels (0, −10, −20, and −30 dBm) and then measuring the received level. Measurements were made in both directions of transmission, using a standard oscillator and the 25A Transmission Measuring Set (or 3A Noise Measuring Set for the −30-dBm level).

The channel net gain for any given input power level can be taken as the reference level, and the net gain for other input levels is then referred relative to the reference level. For example, Table XVIII shows the deviations from channel net gain, relative to a −10-dBm input, at the other input levels. So at each input power, the variable of interest is the net gain of that power level minus the net gain at −10 dBm. Estimated mean deviations relative to any other power level can also be obtained from Table XVIII.

IX. HARMONIC DISTORTION

The nonlinearities of the transmission path for the toll connecting trunks caused harmonic distortion of the signals being carried. The amount of harmonic distortion was determined by sending a 1000-Hz tone at each of four power levels (0, −10, −20, and −30 dBm) and measuring the power level of the received fundamental tone and the second and third harmonics. The fundamental was measured with a 25A Set if above −25 dBm. Below this level, a 3A Set with C-message weighting was used. The second and third harmonic measurements used the 3A Set with a narrow bandpass filter, centered at 2 or 3 kHz, in place of the C-message weighting network. The measurements were adjusted to reflect the loss of the bandpass filters. There was also a "measurement floor" to consider due to the sensitivity of the measuring equipment. This was determined to be 48 dB (i.e., a fundamental-to-harmonic ratio of 48 dB) so that harmonics more than 48 dB below the 1000-Hz fundamental were measured with increasing inaccuracy as the level decreased. Measurements were made in both directions of transmission.

The estimates of harmonic distortion are shown in Table XIX for all the toll connecting trunks measured in the survey. The results are presented as signal-to-harmonic distortion power ratios (S/D) showing means, confidence intervals, and standard deviations. An analysis of the data showed that the larger values of distortion (lower S/D ratios) almost always occurred on compandored systems (i.e., all the carrier facilities). The harmonic distortion on the noncompandored trunks (i.e., voice-frequency cable facilities) was usually below the "measurement floor," resulting in only a few accurate measurements on these facilities. Hence, they were not analyzed in detail. The results for compandored toll connecting trunks (carrier facilities) are shown in Table XX. Among these carrier facilities a subclass analysis of the more commonly used facilities is shown in Table XXI. The estimates there are for the signal-to-distortion ratio, i.e., the total harmonic distortion below the fundamental.

In studying Table XIX and XX one notes that the average distortion power is roughly the same for the second and third harmonics. However, the second and third harmonic distortion power distribution are dissimilar, as can be seen from the plot of their distributions in Fig. 9. It shows clearly that for the high distortion levels, a greater percentage of the trunks have second harmonic power exceeding a chosen level than third harmonic power. About 20 percent of compandored facilities have a fundamental-to-second harmonic distortion ratio less than 30 dB, while only one percent have a fundamental-to-third ratio less than

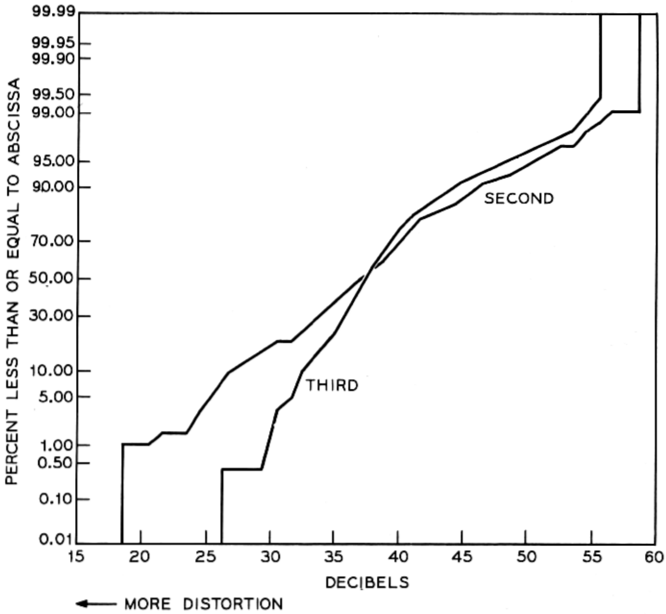


Fig. 9—Second and third harmonic levels in dB below first harmonic (received fundamental) for compandored systems—end and toll office data. Input level of fundamental = −10 dBm.

30 dB. Hence, when the total harmonic distortion is relatively large it is usually due to the second harmonic component. This feature is also evident in a distribution plot of the second and third harmonics for all toll connecting trunks, and implies a positive skewness[15,16] of the population of third harmonic measurements.

X. CONCLUDING REMARKS

The 1966 survey of toll connecting trunks has supplied information on the transmission characteristics of a key part of the built-up connection between subscribers. In addition, when combined with other such data, this information has been useful in generating a transmission model of the Bell System network.

Although carried out as a trunk survey, it was possible through subclass analysis to derive estimates of the transmission performance of toll connecting trunks using specific facilities. These included trunks using voice-frequency cable pairs, loaded and nonloaded, and those using voice-frequency repeaters, as well as the more commonly used short-haul carrier systems, N1 and T1. These trunk data reflect the effects of office equipment as well as those of the facilities.

Another use of the 1966 survey data has been in making comparisons with data from the 1964 Intertoll Trunk Survey.[10] Certain subclasses of each survey are similar enough to warrant investigation. For example, in both cases the trunks of 0 to 15 miles trunk length use voice-frequency facilities for about 80 percent of the trunks. Since their makeup is so similar their respective estimates for loss, noise, and delay can be compared. The agreement of these estimates is very good, and this lends mutual confidence to both estimates. The same is true if we consider the collection of trunks 15 to 30 miles long where N1 carrier was the predominantly used facility.

It should be remembered that although these results accurately picture the transmission characteristics of toll connecting trunks in 1966, with the passage of time changes can occur in the sampled population. Introduction of new facilities and the uneven growth of others are two obvious occurrences which create the need for continual updating of transmission data.

XI. ACKNOWLEDGMENTS

The 1966 toll connecting trunk survey represents the combined efforts of numerous people at Bell Laboratories, the American Telephone and Telegraph Company, and the Operating Companies. D. T. Osgood of the American Telephone and Telegraph Company served as coordinator between Bell Laboratories and the Operating Companies, and the actual measurements were performed by more than 20 Bell Laboratories people. T. L. Bequette, G. P. McNamara, and J. T. Powers, Jr., as well as the author, supplied the data analysis associated with the large body of information gathered by the survey. This task was greatly facilitated by the use of computing programs and techniques created by F. P. Duffy. Only through a lengthy, collective effort has this survey been completed, and it is here duly acknowledged.

REFERENCES

1. Nåsell, I., "The 1962 Survey of Noise and Loss on Toll Connections," B.S.T.J.' *43*, No. 2 (March 1964), pp. 697–718.
2. Nåsell, I., "Some Transmission Characteristics of Bell System Toll Connections," B.S.T.J., *47*, No. 6 (July–August 1968), pp. 1001–1018.
3. Balkovic, M. D., Klancer, H. W., Klare, S. W., and McGruther, W. G., "1969–70 Connection Survey: High-Speed Voiceband Data Transmission Performance on the Switched Telecommunications Network," B.S.T.J., *50*, No. 4 (April 1971), pp. 1349–1384.
4. Duffy, F. P., and Thatcher, T. W., Jr., "1969–70 Connection Survey: Analog Transmission Performance on the Switched Telecommunications Network," B.S.T.J., *50*, No. 4 (April 1971), pp. 1311–1347.
5. Fleming, H. C., and Hutchinson, R. M., Jr., "1969–70 Connection Survey: Low-Speed Data Transmission Performance on the Switched Telecommunications Network," B.S.T.J., *50*, No. 4 (April 1971), pp. 1385–1405.
6. Hansen, M. H., Hurwitz, W. N., and Madow, W. G., *Sample Survey Methods and Theory*, Vols. I and II, New York: J. Wiley and Sons, 1953.
7. Cochran, W. G., *Sampling Techniques*, New York: J. Wiley and Sons, 1963.
8. Kish, L., *Survey Sampling*, New York: J. Wiley and Sons, 1967.
9. Cochran, W. T., and Lewinski, D. A., "A New Measuring Set For Message Circuit Noise," B.S.T.J., *39*, No. 4 (July 1960), pp. 911–931.
10. Nåsell, I., Ellison, C. R., and Holmstrom, R., "The Transmission Performance of Bell System Intertoll Trunks," B.S.T.J., *47*, No. 8 (October 1968), pp. 1561–1613.
11. Fultz, K. E., and Penick, D. B., "The T1 Carrier System," B.S.T.J., *44*, No. 7 (September 1965), pp. 1405–1451.
12. Fennick, J. H., "Amplitude Distributions of Telephone Channel Noise and a Model for Impulse Noise," B.S.T.J., *48*, No. 10 (December 1969), pp. 3243–3263.
13. Cochran, W. T., "Measuring Waveform Distortion With a P/AR Meter," Bell Laboratories Record, *43*, No. 9 (October 1965), pp. 367–371.
14. Kendall, M. G., *Rank Correlation Methods*, 2nd ed., London: Charles Griffin and Co., 1955.
15. Snedecor, G. W., and Cochran, W. G., *Statistical Methods*, 6th ed., New York: J. Wiley and Sons, 1967.
16. Mood, A. M., *Introduction to the Theory of Statistics*, New York: McGraw-Hill Co., 1950.

TABLE I—ESTIMATED TRUNK LENGTH AND FACILITY TYPE IN LARGE AND SMALL OFFICES

Office Size	Trunk Length (Miles) Mean ± 90% C.I.	Type of Facility (%) Carrier	Voice Frequency
Small (<400,000 AOTM*) Stratum 1	25.2 ± 11.2	63	37
Large (≧400,000 AOTM) Stratum 2	6.7 ± 2.4	19	81

* AOTM: Annual Outgoing Toll Messages

TABLE II—TRUNK LENGTH VS FACILITY TYPE

Facility Type	Percent of TCTs in Length Categories		
	0–15 Miles	15.1–30 Miles	Over 30 Miles
N1 Carrier	5.8	42.0	27.0
T1 Carrier	10.2	4.6	—
Other Carrier*	1.0	32.1	73.0
Voice-Frequency Cable	83.0	21.3	—
	100.0	100.0	100.0

* The facilities in this category consist of ON, ON/R, O, N2, and Lenkurt carrier types.

TABLE III—FACILITY COMPOSITION OF TOLL CONNECTING TRUNKS

Facility Type	Percent of all TCTs Mean ± 90% C.I.
1. Carrier:*	34
N1	13 ± 8
T1	8 ± 8
Other†	10
2. Voice-Frequency Cable:	66
Nonloaded	23 ± 11
Loaded:	43 ± 13
Loaded, nonrepeatered	6 ± 5
Loaded, E6 repeater	26 ± 10
Loaded, E23 repeater	7 ± 6

* 3% of these are carrier facilities in tandem with a section of loaded voice-frequency cable.
† The facilities in this category consist of ON, ON/R, O, N2, and Lenkurt carrier types in quantities individually too small for reliable estimates.

TABLE IV—SWITCHING USED BY TOLL CONNECTING TRUNKS OF SURVEY

Type	Stratum 1 (<400,000 AOTM*)—15 Small End Offices					
	At End Office		At Toll Office		Total Both Ends	
	Trunks	Machines	Trunks	Machines	Trunks	Machines
SXS	120	12	34	4	154	16
5XB	20	2	48	6	68	8
SWBD	10	1	24	5	34	6
XBT	—	—	32	4	32	4
4A	—	—	12	2	12	2
Total	150	15	150	21	300	36

Type	Stratum 2 (≧400,000 AOTM)—25 Large End Offices					
	At End Office		At Toll Office		Total Both Ends	
	Trunks	Machines	Trunks	Machines	Trunks	Machines
SXS	91	9	36	5	127	14
5XB	115	13	11	2	126	15
XBT	—	—	119	16	119	16
1XB	25	4	7	2	32	6
SWBD	—	—	44	13	44	13
4A	—	—	25	6	25	6
PANEL	11	3	—	—	11	3
Total	242	29	242	44	484	73
Grand Totals	392	44	392	65	784	109

Notes:
SXS: Switchboard
5XB: No. 5 Crossbar
1XB: No. 1 Crossbar
SWBD: Switchboard
4A: 4A Crossbar
XBT: Crossbar Tandem

* AOTM: Annual Outgoing Toll Messages

TABLE V—FREQUENCY RESPONSE OF TOLL CONNECTING TRUNKS

Frequency (Hz)	Switch-to-Switch Loss (dB)					
	All Trunks		Carrier Facilities		Voice-Frequency Cable	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
200	8.1 ± 0.8	4.0	11.1 ± 1.3	4.5	6.6 ± 0.6	2.5
300	4.6 ± 0.3	1.9	5.4 ± 0.4	2.3	4.2 ± 0.3	1.6
400	3.7 ± 0.2	1.6	4.0 ± 0.4	2.1	3.5 ± 0.3	1.3
600	3.3 ± 0.2	1.5	3.5 ± 0.4	2.0	3.1 ± 0.2	1.2
800	3.0 ± 0.2	1.4	3.0 ± 0.4	1.8	2.9 ± 0.2	1.1
1000	2.8 ± 0.2	1.4	2.8 ± 0.3	1.7	2.8 ± 0.2	1.2
1200	2.8 ± 0.2	1.4	2.8 ± 0.2	1.6	2.9 ± 0.2	1.2
1400	2.9 ± 0.2	1.4	2.9 ± 0.3	1.7	2.9 ± 0.2	1.2
1700	3.1 ± 0.2	1.5	3.3 ± 0.4	1.8	3.0 ± 0.2	1.3
2000	3.3 ± 0.2	1.6	3.6 ± 0.4	1.9	3.1 ± 0.3	1.4
2300	3.5 ± 0.2	1.7	3.7 ± 0.4	2.0	3.4 ± 0.3	1.5
2500	3.8 ± 0.3	1.9	3.9 ± 0.5	2.2	3.8 ± 0.3	1.7
2700	4.3 ± 0.3	2.1	4.3 ± 0.5	2.3	4.2 ± 0.4	2.0
3000	5.6 ± 0.5	3.0	6.1 ± 0.9	2.9	5.3 ± 0.7	3.0
3200	8.9 ± 1.3	6.1	12.7 ± 3.0	6.8	7.0 ± 1.1	4.7
3300	12.4 ± 2.1	9.5	19.9 ± 5.2	10.3	8.5 ± 1.5	6.2
3400	15.2 ± 2.4	11.0	23.4 ± 6.1	10.8	10.9 ± 2.2	8.4

TABLE VI—LOSS RELATIVE TO 1000 Hz (dB) FOR CARRIER FACILITIES

Frequency (Hz)	N1		N2		T1	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
1000– 200	6.2 ± 0.5	0.4	4.5 ± 0.8	1.5	10.7 ± 0.6	1.6
– 300	2.2 ± 0.2	1.2	2.9 ± 1.0	1.7	3.0 ± 0.1	0.6
– 400	1.0 ± 0.2	0.8	1.5 ± 0.6	1.4	1.2 ± 0.1	0.2
– 600	0.6 ± 0.1	0.4	0.7 ± 0.3	0.6	0.3 ± 0.1	0.1
– 800	0.2 ± 0.1	0.2	0.5 ± 0.3	0.8	0.0 ± 0.1	0.1
–1000	—	—	—	—	—	—
–1200	0.0 ± 0.1	0.2	−0.2 ± 0.1	0.3	0.0 ± 0.1	0.1
–1400	0.1 ± 0.1	0.3	0.2 ± 0.1	0.7	0.1 ± 0.1	0.1
–1700	0.5 ± 0.1	0.5	0.5 ± 0.2	0.7	0.1 ± 0.1	0.1
–2000	0.9 ± 0.2	0.7	0.3 ± 0.1	0.5	0.3 ± 0.1	0.1
–2300	0.9 ± 0.3	1.0	0.9 ± 0.3	1.1	0.5 ± 0.1	0.2
–2500	1.2 ± 0.3	1.2	1.7 ± 1.0	2.7	0.7 ± 0.1	0.2
–2700	2.1 ± 0.4	1.4	1.7 ± 1.1	2.8	1.0 ± 0.1	0.2
–3000	4.8 ± 0.5	1.7	2.7 ± 2.1	5.3	1.9 ± 0.1	0.3
–3200	16.8 ± 0.8	2.5	3.7 ± 2.4	5.3	3.0 ± 0.1	0.3
–3300	—	—	3.4 ± 2.4	5.4	3.8 ± 0.2	0.3
–3400	—	—	5.3 ± 2.6	5.4	4.7 ± 0.2	0.3

TABLE VII—LOSS RELATIVE TO 1000 HZ (dB) FOR VOICE-FREQUENCY CABLE

Frequency (Hz)	VF2W Facilities							
	Nonloaded, No Rptr		Loaded, E23 Rptr		Loaded, E6 Rptr		Loaded, No Rptr	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
1000– 200	2.5 ± 0.5	1.2	4.1 ± 0.9	1.9	5.2 ± 0.9	2.2	2.2 ± 0.6	1.5
– 300	0.8 ± 0.3	0.7	1.1 ± 0.3	0.7	2.1 ± 0.5	1.2	0.5 ± 0.2	0.6
– 400	0.4 ± 0.2	0.5	0.6 ± 0.1	0.5	1.1 ± 0.3	0.8	0.1 ± 0.1	0.5
– 600	0.1 ± 0.1	0.3	0.4 ± 0.1	0.3	0.5 ± 0.1	0.5	0.0 ± 0.1	0.3
– 800	0.0 ± 0.1	0.1	0.0 ± 0.1	0.3	0.2 ± 0.1	0.3	0.0 ± 0.1	0.1
–1000	—	—	—	—	—	—	—	—
–1200	0.0 ± 0.1	0.1	0.1 ± 0.1	0.4	0.0 ± 0.1	0.3	0.1 ± 0.1	0.1
–1400	0.0 ± 0.1	0.3	0.2 ± 0.2	0.5	0.1 ± 0.1	0.3	0.1 ± 0.1	0.2
–1700	0.1 ± 0.1	0.5	0.3 ± 0.2	0.5	0.1 ± 0.1	0.4	0.3 ± 0.1	0.4
–2000	0.1 ± 0.2	0.6	0.5 ± 0.3	0.8	0.3 ± 0.1	0.5	0.5 ± 0.1	0.4
–2300	0.2 ± 0.2	0.8	0.8 ± 0.5	1.0	0.7 ± 0.1	0.5	0.9 ± 0.2	0.6
–2500	0.4 ± 0.2	0.9	1.2 ± 0.2	0.9	1.3 ± 0.2	0.8	1.2 ± 0.2	0.6
–2700	0.4 ± 0.2	0.9	1.7 ± 0.3	1.2	2.2 ± 0.4	1.1	1.4 ± 0.1	0.7
–3000	0.4 ± 0.2	1.0	3.0 ± 0.8	1.5	3.8 ± 0.7	1.9	2.3 ± 0.3	1.3
–3200	0.5 ± 0.2	1.0	5.0 ± 1.5	2.5	6.5 ± 1.2	2.9	3.5 ± 0.3	2.0
–3300	0.5 ± 0.2	1.0	6.8 ± 2.4	3.6	9.0 ± 1.7	4.2	4.6 ± 0.4	2.2
–3400	0.5 ± 0.2	1.0	11.4 ± 5.1	6.9	13.2 ± 2.6	6.1	6.2 ± 0.7	2.7

TABLE VIII—3A NOISE ON TOLL CONNECTING TRUNKS

Facility Type	C-Message Weighting			3-kHz Flat Weighting		
	Mean (dBrn)	90% C.I. (dB)	Std. Dev. (dB)	Mean (dBrn)	90% C.I. (dB)	Std. Dev. (dB)
Carrier						
N1	21.2	±0.9	4.8	34.7	±2.3	7.6
N2	17.5	—	8.1	38.8	—	7.9
T1	16.0	—	3.8	31.9	—	3.8
All Carrier	18.4	±1.7	6.4	33.3	±1.8	8.0
Voice-Frequency Cable						
Nonloaded, nonrepeatered	5.5	±1.4	4.4	33.5	±3.1	14.3
Loaded, nonrepeatered	9.5	±4.2	7.8	37.0	±3.2	13.2
Loaded, E6 repeater	11.3	±2.1	7.3	35.9	±3.3	11.1
Loaded, E23 repeater	13.2	±2.8	6.9	39.4	±4.4	11.4
All VF	9.5	±1.5	7.2	35.7	±1.9	12.7
All TCTs	12.5	±1.4	8.2	34.5	±1.5	11.4

TABLE IX—3A NOISE WITH 3-KHZ FLAT WEIGHTING
(δ = End Office Noise−Toll Office Noise)

Facility Type	Mean δ (dB)	90% C.I. (dB)	Std. Dev. (dB)
Carrier			
N1	6.1	±2.9	9.2
N2	9.0	—	10.9
T1	3.5	—	10.1
All Carrier	6.0	±2.7	9.9
Voice-Frequency Cable			
Nonloaded, nonrepeatered	18.7	±3.4	10.8
Loaded, nonrepeatered	19.5	±1.9	4.6
Loaded, E6 repeater	12.0	±2.9	9.2
Loaded, E23 repeater	13.9	±7.8	12.4
All VF	15.2	±2.3	10.4
All TCTs	12.1	±2.2	11.1

TABLE X—3A NOISE WITH 3-KHZ FLAT WEIGHTING

Survey	Mean (dBrn)	90% C.I. (dB)	Std. Dev. (dB)
1964 ITT Survey (0–62.5 miles)	29.4	±2.0	9.0
1966 TCT Survey (toll offices)	28.7	±1.4	9.0

TABLE XI—3A NOISE WITH C-MESSAGE WEIGHTING: TRUNK LENGTH ANALYSIS

Mileage Category	Mean (dBrnC)	90% C.I. (dB)	Std. Dev. (dB)
0.0– 2.0	5.5	±1.3	4.3
2.1– 4.0	9.5	±0.8	7.9
4.1– 8.0	12.3	±1.9	7.3
8.1–16.0	15.6	±2.0	6.6
16.1–32.0	17.3	±3.0	6.8
Over 32.0	19.0	±2.2	7.1

TABLE XII—C-MESSAGE NOISE AS A FUNCTION OF INPUT HOLDING TONE POWER

Transmit Level (dBm)	Received Noise Level (dBrnC)					
	Analog Systems (Syllabic Compandor)		N1 Carrier		T1 Carrier (Instantaneous Compandor)	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90%*	Std. Dev.
0	39.2 ± 1.8	6.3	41.9 ± 2.1	6.4	46.2 ±	2.0
−10	32.2 ± 2.0	6.5	35.1 ± 2.2	6.5	39.9 ±	2.1
−20	27.4 ± 2.0	6.4	30.5 ± 1.9	6.0	30.8 ±	2.1
−30	22.2 ± 2.1	6.3	25.7 ± 1.7	5.2	21.2 ±	2.0

* Confidence interval not shown because of small sample size.

TABLE XIII—IMPULSE COUNT LEVEL DISTRIBUTIONS

Facility Type	45-Count Level (dBrnC)		15-Count Level (dBrnC)		Slope (dB/decade)	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
N1 Carrier	62.8 ± 4.7	8.4	65.9 ± 4.7	8.4	5.8 ± 1.0	2.1
T1 Carrier	57.8 ± 4.3	7.6	58.7 ± 4.3	7.5	2.7 ± 0.2	1.8
VF2W:						
NL, NR	43.8 ± 4.3	10.1	49.5 ± 4.6	11.0	10.3 ± 1.3	3.8
L, NR	44.1 ± 4.2	10.2	54.1 ± 4.8	10.9	8.5 ± 2.6	4.3
L, E6	49.3 ± 1.9	7.0	52.4 ± 2.1	7.2	5.6 ± 0.6	2.0
L, E23	46.8 ± 1.5	6.7	50.4 ± 1.3	6.8	7.1 ± 0.9	3.4
All VF*	46.0 ± 1.9	8.7	50.5 ± 1.9	9.1	8.2 ± 0.7	3.9
All TCTs	49.4 ± 2.0	10.2	53.3 ± 1.9	10.0	7.3 ± 0.8	3.8

Notes: Measurement interval 15 minutes
L = loaded cable
NL = nonloaded cable
NR = nonrepeatered cable
E6, E23 = E6, E23 repeaters
* Includes 2-wire and 4-wire

TABLE XIV—RELATIVE ENVELOPE DELAY OF CARRIER FACILITIES*

Frequency (Hz)	Delay (μs)					
	N1		N2		T1	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
200	3390 ± 155	391	1602 ± 126	271	1707 ± 70	269
300	2055 ± 88	232	1245 ± 144	157	1113 ± 66	182
400	1134 ± 64	140	773 ± 101	115	683 ± 46	100
600	416 ± 36	75	324 ± 43	60	269 ± 12	36
800	175 ± 16	47	135 ± 13	47	117 ± 6	20
1000	63 ± 16	47	102 ± 27	69	50 ± 5	18
1200	27 ± 5	22	69 ± 34	86	15 ± 3	18
1400	6 ± 5	19	17 ± 10	28	0 ± 3	12
1700	0	—	0	—	0	—
2000	17 ± 7	18	41 ± 24	89	9 ± 1	7
2300	82 ± 6	24	30 ± 10	45	33 ± 2	10
2500	159 ± 13	40	40 ± 7	12	54 ± 3	19
2700	242 ± 13	49	108 ± 12	76	92 ± 3	9
3000	615 ± 19	91	170 ± 9	26	169 ± 4	15
3200	698 ± 23	99	201 ± 17	21	212 ± 2	18
3300	—	—	340 ± 15	53	238 ± 3	18
3400	—	—	429 ± 5	57	271 ± 3	16

* Includes office equipment.

TABLE XV—RELATIVE ENVELOPE DELAY OF VOICE-FREQUENCY CABLE FACILITIES*

Frequency (Hz)	Delay (μs): VF2W {Nonloaded Nonrepeatered: Mean ± 90% C.I.	VF2W {Nonloaded Nonrepeatered: Std. Dev.	VF2W-E6 Repeater: Mean ± 90% C.I.	VF2W-E6 Repeater: Std. Dev.	VF2W-E23 Repeater: Mean ± 90% C.I.	VF2W-E23 Repeater: Std. Dev.	VF2W {Loaded Nonrepeatered: Mean ± 90% C.I.	VF2W {Loaded Nonrepeatered: Std. Dev.
200	604 ± 60	202	679 ± 227	505	973 ± 522	700	872 ± 139	280
300	442 ± 48	159	559 ± 105	304	587 ± 271	400	570 ± 87	219
400	251 ± 30	92	297 ± 54	186	305 ± 131	217	299 ± 47	121
600	102 ± 14	39	64 ± 29	83	42 ± 55	87	96 ± 17	47
800	50 ± 7	21	−4 ± 26	55	5 ± 28	76	27 ± 11	25
1000	28 ± 4	12	−23 ± 21	45	−20 ± 24	38	5 ± 10	20
1200	13 ± 2	9	−29 ± 15	34	−41 ± 13	47	−11 ± 9	18
1400	6 ± 1	7	−22 ± 9	24	−29 ± 24	57	−10 ± 8	17
1700	0	—	0	—	0	—	0	—
2000	−6 ± 2	7	46 ± 16	39	57 ± 26	63	21 ± 13	20
2300	−10 ± 3	9	116 ± 36	76	142 ± 80	109	36 ± 17	26
2500	−11 ± 4	11	177 ± 56	113	212 ± 44	84	70 ± 27	45
2700	−13 ± 4	12	255 ± 75	156	299 ± 122	181	121 ± 43	68
3000	−13 ± 5	13	501 ± 148	310	576 ± 188	265	217 ± 68	103
3200	−9 ± 5	13	772 ± 229	470	899 ± 347	464	320 ± 126	167
3300	−8 ± 5	13	957 ± 309	627	1097 ± 440	577	341 ± 155	224
3400	−9 ± 5	13	1018 ± 363	711	1275 ± 601	802	398 ± 266	327

* Includes office equipment.

Table XVI—P/AR Estimates

Category	Mean ± 90% C.I.	Std. Dev.
1. All toll connecting trunks	93.6 ± 1.3	7.4
2. All carrier facilities:	90.9 ± 2.2	6.9
N1 carrier	88.8 ± 1.7	6.9
N2 carrier	96.2 ± 2.6	6.4
T1 carrier	96.1 ± 0.7	4.7
3. All voice-frequency cable:	95.0 ± 1.7	7.1
VF-nonloaded	98.6 ± 0.6	2.6
VF-loaded	93.1 ± 2.5	8.0
VF2W-E23 repeater	92.4 ± 3.8	6.2
VF2W-E6 repeater	92.3 ± 3.8	9.2
VF2W-loaded, nonrepeatered	97.0 ± 1.8	2.8
VF4W	92.5	4.0

Table XVII—Estimated Means of Related Transmission Parameters

Facility Type	Mean P/AR	Relative Envelope Delay (μs)	Loss* Relative To 1000 Hz (dB)
VF: no load, no repeater	98.2	−13	0.4
VF: no repeater	98.2	36	2.3
VF: loaded	93.1	475	3.6
VF: repeatered	92.5	522	3.8
Carrier: N1	88.8	615	4.8
N2	96.2	170	2.7
T1	96.1	169	1.9

* At 3000 Hz.

Table XVIII—Compandor Level Tracking
(Estimated Deviations from Net Gain at −10-dBm Input)

Input Power (dBm)	Mean ± 90% C.I. (dB)	Std. Dev. (dB)
0	−0.3 ± 0.1	0.5
−10	0	—
−20	0.7 ± 0.1	0.5
−30	1.2 ± 0.3	1.2

Table XIX—Statistics for the Ratio of Fundamental to Second, Third, or Total Harmonic Power in dB (All Toll Connecting Trunks)

Harmonic	Transmitted Level (dBm)							
	0		−10		−20		−30	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
Second	47.1 ± 2.4	9.3	48.1 ± 2.8	9.3	48.9 ± 3.0	9.6	48.0 ± 2.9	9.4
Third	46.6 ± 2.0	9.0	47.9 ± 1.8	7.9	49.0 ± 2.0	8.2	47.2 ± 2.0	8.4
Total	43.3 ± 2.3	8.9	44.3 ± 2.5	8.6	45.3 ± 2.8	9.0	43.9 ± 2.7	9.1

TABLE XX—STATISTICS FOR THE RATIO OF FUNDAMENTAL TO SECOND, THIRD, OR TOTAL HARMONIC POWER IN dB (CARRIER FACILITIES)

	Transmitted Level (dBm)							
	0		−10		−20		−30	
Harmonic	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
Second	36.0 ± 1.2	6.5	37.0 ± 2.9	7.3	37.9 ± 3.9	8.2	38.9 ± 3.1	7.2
Third	35.6 ± 2.1	6.0	38.2 ± 0.9	5.1	39.4 ± 1.5	5.6	39.2 ± 1.3	5.1
Total	32.0 ± 1.3	5.2	33.5 ± 2.0	5.5	34.4 ± 3.0	6.6	34.9 ± 2.4	5.8

TABLE XXI—SIGNAL-TO-DISTORTION RATIO FOR CARRIER FACILITIES (IN dB)

Transmitted Level (dBm)	Carrier Facility							
	N1		N2		ON		T1	
	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.	Mean ± 90% C.I.	Std. Dev.
0	28.0 ± 0.5	3.3	38.0 ± 1.0	4.2	32.5 ± 1.0	2.8	34.1 ± 0.2	3.7
−10	33.6 ± 0.6	4.0	38.9 ± 1.6	3.2	35.1 ± 1.2	3.0	29.3 ± 0.5	4.5
−20	36.7 ± 0.6	3.9	38.2 ± 0.8	4.7	35.6 ± 1.5	3.2	28.0 ± 0.4	4.7
−30	37.2 ± 0.6	3.5	37.0 ± 1.1	4.6	36.5 ± 0.6	3.2	30.0 ± 0.5	4.0