The Transmission Performance of Bell System Intertoll Trunks

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A systemwide survey of the transmission performance of Bell System intertoll trunks was undertaken in 1964. The sample design used for the survey is described briefly. The main purpose of the paper is to present survey results. Thus, the physical composition and some physical attributes of the trunks are given. The transmission measurement procedures are summarized, and measurement results are presented in distributional form for 1000-Hz loss, frequency response, background noise, impulse noise, and relative envelope delay. Among the results noted are an increase in average noise level and a decrease in noise level standard deviation as the trunk length is increased. The frequency response of long trunks is superior to that of short trunks. Measurement results are presented separately for major transmission facilities.

I. INTRODUCTION

The Bell System toll network consists of a hierarchy of toll offices interconnected by transmission paths called intertoll trunks. A toll call between two subscribers is built up of a tandem connection of several transmission paths which are joined by switching.

At each end of such a connection is a loop that connects the subscriber's telephone set with a local telephone office. The local telephone offices connect with toll offices by toll connecting trunks. These toll offices are connected by either a single intertoll runk or by several intertoll trunks through intermediate toll offices. The transmission performance of a toll connection between subscribers is thus influenced by the performance of each trunk and loop in the connection.

Systemwide improvement in transmission performance by a category of trunks is directly measured by the corresponding improvement in built-up connections. Systems engineering on transmission objectives, therefore, requires information about the relation between transmission performance on trunks and the corresponding transmission performance that results on built-up connections. Such information is meaningful only if it is based on accurate information about the transmission performance of the various entities of importance; that is, the intertoll trunks separated into mileage categories, the major transmission facilities used in the toll plant, the toll connecting trunks, the loops, and the built-up connections. This need for information constitutes the basic reason for undertaking the intertoll trunk survey discussed in this article.

The introduction of data transmission over the switched telephone network has brought with it the need for information about transmission parameters that are of only minor importance for the transmission of spoken messages. The discussions of impulse noise and envelope delay in Sections VII and VIII both deal with this category of parameters.

Each intertoll trunk consists of trunk facility and office equipment in tandem. The trunk facility supplies a transmission path between the two toll offices connected by the trunk. The office equipment contains signaling devices and attenuators, and sometimes echo suppressors and hybrid transformers. There are several different transmission facilities in the Bell System toll network. The most important are voice-frequency facilities, compandored short-haul cable carrier, coaxial cable carrier, and microwave radio.

Survey results are presented both for various trunk lengths and for selected transmission facilities. The results for trunks take a slightly different form than for facilities. The frequency response for facilities gives the difference between the loss at a certain frequency and at 1000 Hz, while the frequency response for trunks gives the actual switch-to-switch loss at each frequency. Thus the trunk results depend on facility mixture, loss design, and loss maintenance of trunks, while none of these factors influence the facility results. Background noise levels for facilities are referred to a standard zero transmission level point, while those for trunks are referred to the receive switch of each trunk. Facility mixture, loss design, and loss maintenance of trunks affect the trunk results but not the facility results.

There is not such a separation of results for impulse noise; both facility results and trunk results are referred to the receive switch. The reason for this is the expectation that the switching equipment contributes to the impulse noise level on an intertoll trunk. Relative envelope delay is given separately for facilities and trunks; varying facility mixture and various types of office equipment influence the trunk results in different mileage categories.

The facility composition of intertoll trunks considerably influences their transmission performance. Facility composition is continuously changing; the most important change in recent years is the introduction of new short-haul carrier systems with improved transmission characteristics.

II. SAMPLING CONSIDERATIONS

2.1 *Definition of Population*

A sampling plan tailored to the structure of the Bell System intertoll network was established and followed carefully. The objective was to design the survey so that the sample data could be used to make estimates of characteristics associated with the entire population. An important preliminary step is to give a precise definition of the population so that the extent and limitation of the survey results are known.

An intertoll trunk is defined as a trunk between two toll offices, that is, between two separate toll switching units that both have one of the long distance switching plan classifications: regional center (class 1), sectional center (class 2), primary center (class 3), or toll center or toll point (class 4). In case one toll office building (or complex of buildings) contains only one toll switching machine, it is counted as one toll office. This means that a manual switchboard in the same building as a switching machine is not counted as a separate toll office, and trunks between such a switchboard and the switching machine do not qualify as intertoll trunks. If a building contains two or more switching machines that are separately identified and that have access to different groups of trunks and where the trunks between the machines are designed as intertoll trunks, then these switching machines are considered as separate toll offices. So-called tandem offices that can connect with the long distance network are classified as toll offices. Trunks between tandem offices are regarded as intertoll trunks if they can carry traffic to or from the long distance network.

Every intertoll trunk allows transmission in two directions, but measurements in the survey and hence characterization of performance are made only in the receive direction. Therefore, it is clear that the trunks themselves do not constitute the population elements.

Rather, a population element is identified with each direction of transmission of an intertoll trunk. One requirement for inclusion in the population is that the trunk have both of its terminations within the USA (excluding Alaska and Hawaii) or Canada. A further requirement is dictated by the administrative necessity of confining the measurements to Bell System toll offices. This further requirement states that the receive termination of a particular direction of transmission of an intertoll trunk should be located in a Bell System toll office. This implies that those intertoll trunks that have both endpoints in Bell System toll offices give rise to two population elements, while those that have one termination in a Bell System toll office and the other in an independent office are counted just once.

2.2 *Sampling Plan*

The sampling plan used in the survey is a two-stage plan with substratification which is self-weighting within each substratum and where the first-stage sample is selected with probabilities proportional to measures of size. (See Hansen, Hurwitz and Madow[1] for a general discussion of this type of sampling plan.) The primary units were Bell System toll offices as defined in the preceding section. A substratification is a stratification of the population elements in each sampled primary unit. The substrata were defined in the same way for all primary units; they are identified with length-categories of intertoll trunks as shown in Table I.

The first step in the sampling plan was to establish a frame for the first-stage selection. The frame listed all Bell System toll offices and gave for each the number of intertoll trunks terminating in the office. The number of trunks per office was used to form probabilities for the first-stage selection of primary units. Such a probability was computed for each office as the quotient of the number of intertoll

TABLE I—DEFINITION OF SUBSTRATA

Substratum number	Trunk length l	
	Miles	km (approx.)
1	$0 < l \leq 62.5$	$0 < l \leq 100$
2	$62.5 < l \leq 125$	$100 < l \leq 200$
3	$125 < l \leq 250$	$200 < l \leq 400$
4	$250 < l \leq 500$	$400 < l \leq 800$
5	$500 < l \leq 1000$	$800 < l \leq 1600$
6	$1000 < l \leq 2000$	$1600 < l \leq 3200$
7	$2000 < l \leq 4000$	$3200 < l \leq 6400$

trunks terminating in that office to the total number of trunk terminations found in all Bell System toll offices.

After the sample size had been determined, as discussed in the next section, this frame was used for selecting a first-stage sample of 48 primary units. Randomness was assured by using lists of random numbers. The selection was made with replacement. As a result, three toll offices were selected twice. The first-stage sample therefore contains 45 different toll offices representing 48 primary units. The sampling was done with replacement in order to correspond with the specific assumptions made in the derivation of the estimation formulas.[1] More efficient sampling without replacement is being considered for future surveys.

The next step of the sampling plan was to acquire detailed information about the selected offices. This consisted of lists of all intertoll trunks terminating in the selected offices, giving for each the trunk number, the distant termination, and the actual trunk length in miles. These lists were used to establish frames for the second-stage sampling in each substratum of each toll office.

The final step in the sampling plan was to select sample elements from these frames. In this selection, all population elements in a given substratum of a sampled toll office were given the same probabilities of inclusion. The selection was made with tables of random numbers, without replacement. It resulted in lists of specific trunks to be measured in the survey. To these lists were appended lists of "spare" trunks which were resorted to only when a trunk in the original list was not available for testing when the measurements were taking place.

2.3 *Determination of Sample Size*

The size of a survey sample ideally should be determined to give maximum precision for fixed cost, or to minimize the cost while achieving a required precision. Many transmission parameters were measured for each trunk in the intertoll trunk survey. An ideal sample size would, therefore, recognize precision requirements for each of these parameters; but for most of them it was far from obvious how the precision requirements should be stated. The sample size therefore was determined to maximize the precision of estimates of background noise levels (measured with the 3A noise level meter[2]), combined with some basic cost constraints. This parameter was chosen as the crucial one in determining sample size because meaningful precision requirements could easily be stated.

To estimate the precision expected from a survey requires estimation of variance components. There had been no systemwide survey of Bell System intertoll trunk transmission performance before 1964, so direct variance estimates based on previous survey results were not available. Variance estimates were therefore derived, based partly on a small pilot survey and partly on an indirect approach that used data available for some selected transmission facilities.

Experience has indicated that many transmission parameters show a dependence on trunk length. It is therefore of interest to present survey results by mileage categories. This in turn carries with it the desirability of making precision estimates within the same mileage categories.

Table II lists the widths of the 90 percent confidence intervals for the mean 3A noise level that were expected in each of the seven mileage categories of Table I. These expectations are based on the above-mentioned variance estimates combined with a sample size of 151 trunks in each mileage category. This sample size was acceptable from a cost standpoint, and the expected confidence interval widths were in line with precision requirements. The increased precision with longer trunks results from the smaller noise variance for long trunks, discussed in Section VI. Since the longest trunks have the highest average noise level, it was deemed desirable to require greater precision for these trunks. The final sample contained a total of 1069 trunks.

The last column in Table II gives the precision that was actually achieved in the survey. A higher variability than expected was found in the first two substrata; hence the achieved precision was somewhat poorer than expected. Otherwise the precision achieved was uniformly better than expected. This is a reflection of using unnecessarily pessimistic variance estimates in substrata 3 to 7.

Table II—Width of 90 Per Cent Confidence Intervals for Mean of Distribution of 3A Noise Levels

Substratum	90 percent confidence interval (dB)	
	Expected	Achieved
1	±1.3	±1.7
2	±1.3	±1.4
3	±1.2	±1.0
4	±1.1	±0.6
5	±1.0	±0.5
6	±0.8	±0.4
7	±0.9	±0.4

2.4 *Data Analysis*

All estimation formulas associated with the sample design described above are based on so-called ratio estimators.[1] Such estimators have the undesirable feature that in general they are biased. However, the bias decreases with sample size and can be ignored for large enough samples. Furthermore, ratio estimators have the desirable property that their sampling variance is small and that they allow a large amount of flexibility in the data analysis. The most important aspect of this flexibility is related to the analysis of subclasses of the population. Examples of this usage of the ratio estimator appear in most of the sections that follow where results are presented for specific transmission facilities.

All of the results presented here refer to the population defined above. In many cases where means, standard deviations, and proportions are discussed, these are estimates of population parameters based on the sample data. Because of the structuring of the sample, the estimate of the population mean, for example, is often weighted and therefore not identical with the unweighted sample mean.

The amount of data treated here is large and the data analysis formulas are complicated. Therefore, digital computer programming has been used extensively in all of the data analysis work.

Much effort was put into "data cleaning," that is, in scrutinizing the data collected in the field for errors, omissions, and inconsistencies. Several errors were unveiled and corrected. Most important among these were erroneous readings of the measurement instrument, errors in the facility classification, and errors in transcribing the data onto IBM cards.

III. PHYSICAL CHARACTERISTICS OF INTERTOLL TRUNKS

The results reported here are based on various record data distinct from the transmission measurement results discussed in Sections IV through VIII.

3.1 *Trunk Lengths and Airline Distances*

Trunk length information was included for each trunk listed in the frame from which the second stage sample was selected. For each of these trunks it was also possible to compute the airline distance between toll offices. This information was used to estimate the distribution of trunk lengths and the distribution of the ratio of trunk length to airline distance. The sampling plan used to achieve this was a one-stage cluster sampling plan where the selection of clusters coincided with the selection of primary units discussed in Section II.

Table III gives the distributions of both trunk length and trunk mileage. It shows that although only 3 percent of the intertoll trunks are longer than 2000 miles, no less than 25 percent of the total intertoll trunk mileage is accounted for by trunks longer than 2000 miles.

The distribution of the ratio of trunk length to airline distance shows some small variations with the airline distance between toll offices. Thus, ratios up to five were found on a small proportion of the trunks that connect toll offices separated by less than 180 airline miles. On the other hand, the distribution was confined to ratio-values less than two when the airline distance exceeded 1450 miles. The average ratio over all trunk lengths was found to be 1.40.

The distribution of the ratio is quite naturally truncated by one at the lower end, and it has a strong positive skewness. The transformed variable $y = \log_{10}(r - 1)$, where r is the ratio of trunk length to airline distance, is, however, close to normal in its distribution. Computed over all trunk lengths, y has a mean of -0.53 and a standard deviation of 0.64. The mean of y corresponds to a trunk length to airline distance ratio of 1.29, which is close to the median of the ratio. The fact that the median of r is lower than the mean reflects the positive skewness of the distribution of the ratio.

3.2 *Toll Office Characteristics*

At the time the first-stage sample was selected in early 1964 there were 1544 Bell System toll offices in the USA and Canada that qualified under the toll office definition in Section II. It was estimated that the same geographical area contained more than 600 additional toll offices that were independently owned and therefore excluded from selection as primary units in the sample.

Table III—Distributions of Trunk Length

Trunk length (miles)	Percentage of trunks	Percentage of trunk mileage
0– 62.5	35	3
62.5– 125	21	6
125 – 250	14	8
250 – 500	11	12
500 –1000	9	19
1000 –2000	7	27
2000 –4000	3	25

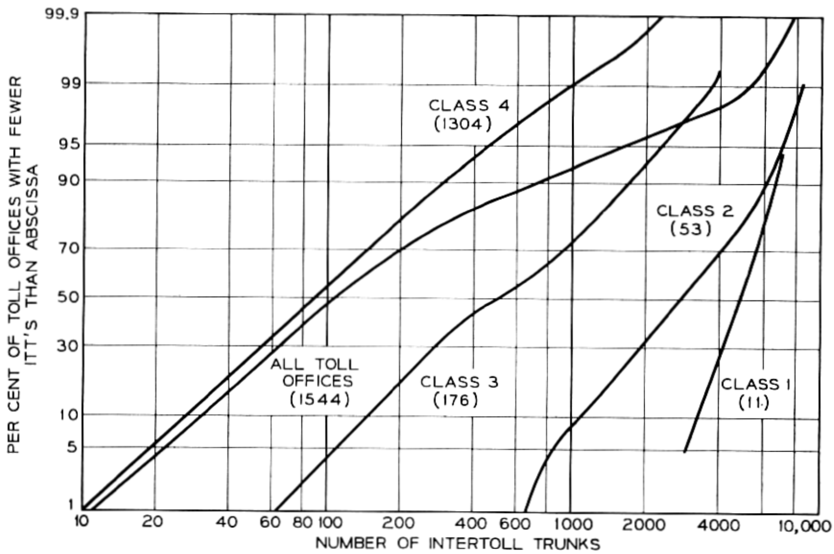

Fig. 1 — Distributions of sizes of toll offices.

The sizes of Bell System toll offices are represented by distribution curves in Fig. 1. Office size is measured by the number of intertoll trunks terminated in the toll switching machine. The figure demonstrates that office size increases with office class, and that the office size distribution is approximately log-normal within each of the four classes of offices. The number of Bell System toll offices belonging to each class is also given in the figure.

Table IV is another way to demonstrate the high concentration of intertoll trunks in large toll offices. This table gives the estimated percentage of intertoll trunks within each of seven mileage categories and over-all trunk lengths that interconnect toll offices of indicated classes. Notice that an estimated 50 percent of all intertoll trunks interconnect toll offices of class 1, 2, or 3. From Fig. 1 we find that toll offices of these classes constitute only 16 percent of all Bell System toll offices. Table IV also shows that 94 percent of the intertoll trunks have at least one of their end-points in a toll office of class 1, 2, or 3. The table further indicates that the concentration of trunks to high level toll offices is even more pronounced if attention is restricted to mileage categories that contain trunks longer than 125 miles.

The combined percentage estimates for all intertoll trunks terminat-

TABLE IV—PERCENT OF INTERTOLL TRUNKS INTERCONNECTING TOLL OFFICES

Office class		Per cent of intertoll trunks within mileage category							Percent of all intertoll trunks
From	To	0–62.5	62.5–125	125–250	250–500	500–1000	1000–2000	2000–4000	
1, 2	1, 2	8	6	20	38	66	66	89	24
1, 2, 3	1, 2, 3	23	35	58	79	96	97	100	50
1, 2, 3	4	63	60	40	21	4	3	—	44
4	4	14	5	2	—	—	—	—	6
Percent of all intertoll trunks		35	21	14	11	9	7	3	100

ing on at least one end in each of the four classes of toll offices are:

Regional centers	21 percent
Sectional centers	58 percent
Primary centers	47 percent
Toll centers or toll points	50 percent

Closely associated with office rank is the type of switching machine used in the office. From the standpoint of transmission performance the major distinction in toll switching equipment arises from the use of 4-wire versus 2-wire switching, since the latter will ordinarily require additional equipment (a hybrid transformer and impedance matching network) to convert a 4-wire transmission path to a 2-wire path for switching.

Table V lists the estimated percentages of intertoll trunks within each mileage category that interconnect two 4-wire machines, two

TABLE V—PERCENT OF INTERTOLL TRUNKS INTERCONNECTING SWITCHING MACHINES

Switch type		Percent of intertoll trunks within mileage category							Percent of all intertoll trunks
From	To	0–62.5	62.5–125	125–250	250–500	500–1000	1000–2000	2000–4000	
4-wire	4-wire	9	6	25	44	70	77	91	26
2-wire	4-wire	41	54	60	47	29	23	9	44
2-wire	2-wire	50	40	15	9	1	—	—	30
Percent of all intertoll trunks		35	21	14	11	9	7	3	100

2-wire machines and a 2-wire with a 4-wire machine. In 1964 there were 73 4-wire toll switching machines (types 4A or 4M crossbar) in service in the Bell System; the table shows that 26 percent of all intertoll trunks interconnect these toll offices and that 70 percent touch at least one of them.

The combined percentage estimates for all intertoll trunks terminating on at least one end in one of the four major types of Bell System toll switching machines are:

4A or 4M crossbar	(4-wire)	70 percent
Crossbar tandem	(2-wire)	40 percent
Number 5 crossbar	(2-wire)	19 percent
Step-by-step	(2-wire)	29 percent

3.3 *Facility Composition*

More important than toll offices in terms of transmission performance is the facility makeup of intertoll trunks. Percentage estimates of intertoll trunks within each mileage category and over-all trunk lengths are listed according to line facility makeup in Table VI.

TABLE VI—FACILITY COMPOSITION OF INTERTOLL TRUNKS

Facility	Percent of intertoll trunks within mileage category							Percent of all intertoll trunks
	0–62.5	62.5–125	125–250	250–500	500–1000	1000–2000	2000–4000	
Voice frequency	29	3	1					11
N1-carrier	42	11	9					19
ON-carrier	22	47	17	1				20
C or J carrier		6	3	1				2
K-carrier	1	5	8	5	2	1		3
L-carrier	2	5	14	15	15	4	4	7
Microwave radio	3	16	25	51	42	33	55	21
L-carrier and radio		1	6	9	28	53	37	9
N1 and ON carrier	1	5	2					2
Noncompandored carrier combinations			4	4	8	7	4	3
Compandored and noncompandored carrier combinations		1	11	14	5	2		3
All intertoll trunks	35	21	14	11	9	7	3	100

The table partitions all intertoll trunks into eleven facility categories. (For detailed descriptions of the commonly found telephone carrier systems see Refs. 3 through 7.) The microwave radio category includes all the commercial telephone carrier systems using line-of-sight radio as the transmission medium. A majority of the trunks in this category used the TD-2 radio system. Four specific single facility categories include the two short haul cable carrier systems, N1 and ON, the long-haul K-carrier system, and coaxial cable carrier, designated L-carrier. (Most intertoll trunks in this category used L3-carrier.) Trunks made up entirely of the older C or J open wire carrier systems were combined into one category because they represent such a minor contribution to the toll network. The most widely used combination of the two long-haul line facilities, coaxial cable carrier and microwave radio, and the two short-haul facilities, N1-carrier and ON-carrier, are listed separately for emphasis. Intertoll trunks made up of all other combinations of carrier facilities are divided into two categories on the basis of whether any compandored carrier (N1-, ON- or O-carrier) was used in their makeup.

The voice frequency category in Table VI includes only those intertoll trunks made up entirely of voice frequency facilities. Eleven percent of the intertoll trunks fall into this category but 80 percent

Table VII — Channel Bank Makeup of Intertoll Trunks

Channel banks		Percent of intertoll trunks within mileage category							Percent of all intertoll trunks
Number	Type	0–62.5	62.5–125	125–250	250–500	500–1000	1000–2000	2000–4000	
0	Voice Frequency	29	3	1					11
2	N1	41	10	9					18
4	N1	1	1						1
2	O	22	47	13	1				19
4	O			4					1
2	C		5	1	1				1
2	A	6	27	56	74	76	66	52	37
4	A		1	3	9	17	26	37	6
6	A				1	2	6	10	1
8	A							1	0
≥ 4	A and N1			4	3	2	1		1
≥ 4	A and O		1	7	11	3	1		2
≥ 4	N and O	1	5	2					2
All intertoll trunks		35	21	14	11	9	7	3	100

of these are shorter than 15 miles and 93 percent shorter than 62.5 miles. Trunk records revealed that about 1 percent of all intertoll trunks contain a section of voice frequency facilities in tandem with carrier facilities. These trunks were classified by their carrier facility makeup for Table VI. Using this rule for facility classification, 83 percent of all intertoll trunks have a homogeneous line facility composition and more than half of the remainder are made up of the long-haul combination of coaxial cable carrier and microwave radio.

The estimated percentages of all intertoll trunks containing any of the eight major carrier facility types in their facility makeup, in descending order of facility occurrence, are:

Facility	*Percent*
Microwave radio	33
ON-carrier	24
N1-carrier	22
L-carrier	18
K-carrier	6
C-, J-, or O-carrier	4

The estimates given in Table VI do not differentiate between carrier facility combinations connected at voiceband frequencies and those connected at group, supergroup, or mastergroup frequencies, nor do they distinguish tandem combinations of the same facility type connected at voice frequency from single facility trunks.

Information about the number of voice frequency modulators and channel bank filters used in intertoll trunks is, however, given by Table VII. This table lists percentage estimates of intertoll trunks within each mileage category and over-all trunk lengths classified by the types and number of voiceband channel banks in their makeup. The 13 categories listed identify all carrier trunks with five types of channel bank, but not with a specific equipment configuration, for several generations of a particular type of channel bank are found in service. A-type channel banks[8] are used on the long haul carrier facilities, J, K, L, and microwave radio; N1-type is used on N1-carrier; O-type on O- and ON-carrier; and C-type on C-carrier. Note that when intertoll trunks made up entirely of voice frequency facilities are included, 86 percent of all intertoll trunks encounter no more than one pair of channel banks and only 5 percent are equipped with combinations of dissimilar channel banks.

The degree of interconnection of various facilities to form a trunk is only party exposed by Tables VI and VII. It is common to combine facilities that use A-type channel banks without demodulating to voice frequency. This is done by the use of group, supergroup, and mastergroup connectors.

Table VIII shows the use of such high frequency connectors in Bell System intertoll trunks. Notice that this table is only concerned with those trunks that contain at least one pair of A-type channel banks. Furthermore, any portion of such a trunk that contains channel banks different from the A-type is disregarded. The table indicates a strong trend toward a larger number of connectors for the longer trunks. Thus, the average number of group connectors increases monotonically from 0 for short trunks to 1.8 for trunks longer than 2000 miles. Likewise, the average number of supergroup connectors increases from 0 for short trunks to 2.3 for trunks in the 2000-4000 mile category.

The average number of high frequency connectors, that is, of connectors at group, supergroup, or mastergroup frequencies on trunks with A-type channel banks can be found in each mileage category by addition of the corresponding averages for each of the three categories of connectors. Thus, the average number of high frequency connectors on trunks with A-type channel banks in the 2000-4000 mile category equals 4.2. No trunks in the sample shorter than 1000 miles contained more than 5 high frequency connectors. Among the trunks in the 1000-2000 mile category, 2 percent contain 8 or more high frequency connectors, while 3 percent of the trunks longer than 2000 miles contain 8 or more high frequency connectors.

3.4 *The Number of FM Terminals per Radio Facility*

The intertoll trunks in the sample that used microwave radio as a transmission facility were analyzed to determine the number of FM terminals per radio facility. Frequency modulation and demodula-

Table VIII—Average Number of Pairs of A-Type Channel Banks and High Frequency Connectors on Intertoll Trunks with A-Type Channel Banks

Miles	0–62.5	62.5–125	125–250	250–500	500–1000	1000–2000	2000–4000	All Trunks
Pairs of A-banks	1.0	1.0	1.0	1.1	1.2	1.4	1.6	1.2
Group connectors	0.0	0.1	0.2	0.5	1.1	1.7	1.8	0.7
Supergroup connectors	0.0	0.1	0.2	0.5	0.8	1.4	2.3	0.7
Mastergroup connectors	0.0	0.0	0.0	0.1	0.1	0.3	0.1	0.1

tion is resorted to when groups, supergroups, or mastergroups of voice frequency channels are dropped from a radio system at an intermediate point. The number of pairs of FM terminals in a radio facility is important from a design standpoint because of its effect on the resulting noise level.

Table IX lists the average radio facility length, the average number of pairs of FM terminals per radio facility, and the average length between FM terminals for seven different mileage categories. The length of a radio facility is the sum of the lengths of all sections of radio facility used on a given trunk. This rule of computation is used even when the radio facility sections of a trunk are not all adjacent to each other. The most important result indicated by Table IX is that the length between FM terminals is strongly correlated with the radio facility length.

The average length between FM terminals computed over all radio facilities is 240 miles, while the average length between FM terminals for radio facilities longer than 2000 miles is 495 miles. The average length between FM terminals is approximately proportional to the square root of the radio facility length. For a radio facility length of 4000 miles, the average length between FM terminals is estimated at 620 miles. Correspondingly, the average number of pairs of FM terminals for a 4000 mile long radio facility is approximately 6.5. The distribution of the number of pairs of FM terminals for radio facilities longer than 2000 miles shows that only one percent contain 9 or more pairs of FM terminals in tandem.

IV. 1000-HZ LOSS

The switch-to-switch loss of intertoll trunks at 1000 Hz have been analyzed. The term switch-to-switch loss is used to refer to the total loss between outgoing switch appearances at the originating and terminating ends of a trunk. It equals the loss inserted into a connection by switching the trunk into an operating condition.

The loss at 1000 Hz can be studied from three different viewpoints: design, performance, and maintenance. The switch-to-switch loss at which each trunk in the sample was designed to operate was extracted from trunk records in each of the toll offices visited. The actual switch-to-switch loss was found by measurement. The maintenance effect is measured by the difference between measured loss and design loss, if it is assumed that all trunks met the design value exactly when they were first put into service.

TABLE IX—RADIO SYSTEM COMPOSITION VERSUS RADIO SYSTEM LENGTH

Radio facility length (miles)	Average radio facility length (miles)	Average number of pairs of FM terminals per radio facility	Average length between FM terminals (miles)
0–62.5	39	1.0	39
62.5–125	80	1.3	64
125–250	173	1.5	120
250–500	341	2.1	168
500–1000	708	2.8	255
1000–2000	1264	3.8	337
2000–4000	2565	5.2	495

4.1 *Design Loss*

The scatter diagram of Fig. 2 shows how the design losses of intertoll trunks vary with trunk length. Intertoll trunks are designed according to the via net loss concept discussed by H. R. Huntley.[9] According to this concept, the design loss for carrier trunks increases linearly with trunk length from 0.5 dB to 2.6 dB, from 165 to 1565 miles; this is shown as an exponential trend in Fig. 2 because of the logarithmic mileage scale. Trunks longer than 1565 miles and trunks between regional centers are designed to have a loss of 0 dB and to be equipped with echo suppressors. Fig. 2 shows that in 1964, such trunks had generally a design loss of 0.5 dB. The deviations from these rules

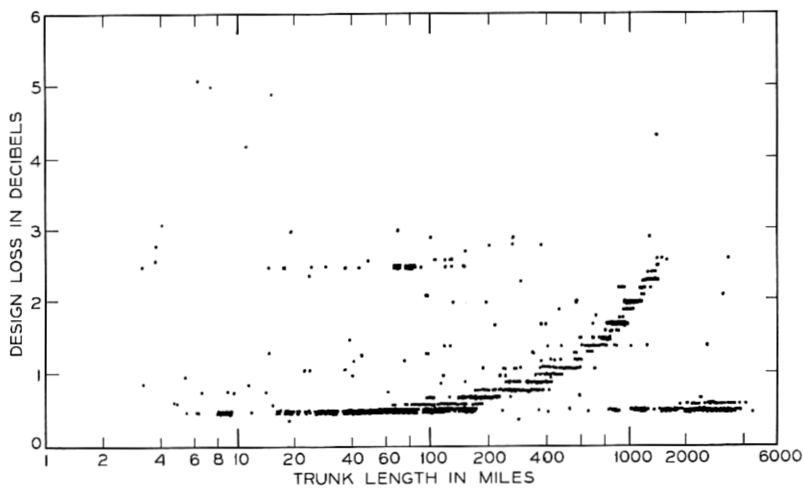

Fig. 2—Scatter diagram of switch-to-switch design loss versus trunk length.

are given by trunks on noncarrier facilities and trunks in "unbalanced" toll offices, that is, 2-wire toll offices of class 1, 2, or 3, that do not meet certain objectives for uniformity in office cabling impedance. The scatter diagram indicates that the design loss distributions are non-normal; definite modes exist at loss values given by the via net loss computation. The scatter diagram also shows that the adherence to a uniform loss design improves as the trunk length increases.

A summary of the results of the data analysis for design loss is given in columns 2 and 3 of Table X. As in most tables in Sections IV to VIII, estimates are given of the mean and the standard deviation of the population distribution, and the mean is equipped with its estimated 90 percent confidence interval. The first seven mileage categories in this table correspond to the seven substrata defined earlier. A further breakdown has been made of the sixth substratum, which contains trunks between 1000 and 2000 miles long. The reason for this additional breakdown is the design rule already mentioned that prescribes the use of echo suppressors and a switch-to-switch loss of 0 dB for all trunks longer than 1565 miles as well as on trunks between regional centers.

The break in the sixth mileage category is at 1465 miles rather than at 1565 miles because all trunks in the sample between 1465 and 1565 miles long were equipped with echo suppressors and had a design loss of 0.5 dB. None of these trunks interconnected two regional centers, and according to present design practices only 17 percent of them

TABLE X—INTERTOLL TRUNK SWITCH-TO-SWITCH LOSSES AT 1000 Hz

Trunk length (miles)	Design loss (dB)		Measured loss (dB)		Measured loss minus design loss (dB)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
0 – 62.5	0.9 ± 0.2	1.0	1.2 ± 0.2	1.4	0.3 ± 0.2	1.0
62.5 – 125	1.0 ± 0.3	0.9	1.2 ± 0.3	1.3	0.1 ± 0.2	1.1
125 – 250	0.8 ± 0.1	0.4	1.1 ± 0.2	1.2	0.3 ± 0.2	1.2
250 – 500	1.0 ± 0.1	0.3	1.4 ± 0.2	1.1	0.4 ± 0.2	1.1
500 –1000	1.5 ± 0.1	0.3	1.9 ± 0.2	1.1	0.4 ± 0.2	1.0
1000 –2000	1.6 ± 0.2	0.9	2.1 ± 0.2	1.3	0.4 ± 0.2	1.1
2000 –4000	0.6 ± 0.1	0.2	0.9 ± 0.1	1.2	0.3 ± 0.1	1.2
1000 –1465	1.9 ± 0.2	0.7	2.3 ± 0.3	1.2	0.3 ± 0.2	1.1
1465 –2000	0.6 ± 0.1	0.4	1.3 ± 0.3	1.2	0.8 ± 0.3	1.2

would be equipped with echo suppressors and have a design loss of 0 dB, while the remaining 83 percent would be without echo suppressors and have a design loss of 2.6 dB. This difference does not mean that the 1964 trunks were incorrectly designed; rather, it reflects a small change in design rules that has been introduced after 1964.

Table X shows the same trend in mean design loss observed from the scatter diagram. The improved adherence to a uniform loss design with increasing trunk length is seen from the decrease in standard deviation with trunk length. The only notable exception is found in the 1000 to 1465-mile category. The higher standard deviation here is caused by the fact that 14 percent of the trunks in this category interconnect regional centers. These trunks would, by present design practices, be equipped with echo suppressors and have a design loss of 0 dB, while in 1964 their design loss was 0.5 dB. An additional one percent of the trunks in this mileage band are estimated to have been equipped with echo suppressors and accordingly have a design loss of 0.5 dB. According to present design rules, these trunks would not contain echo suppressors, and their design loss would be 2.6 dB.

4.2 *Measured Loss*

All survey measurements of intertoll trunks were made so as to describe as closely as possible the transmission characteristics from switch through switch as they appear when the trunk is being used in a built-up connection between subscribers. The maintenance and testing facilities provided in each toll office, such as toll testboards and code test lines, are geared toward the same objectives and were therefore used extensively in the survey.

The loss measurements were made with the far end of the trunk connected to a 1000 Hz one-milliwatt testing power source. This connection was either supplied by a dialable test termination or it was made manually at the far-end test board. The received level was then measured at the near-end toll office.

Figure 3 is a scatter diagram of measured loss versus trunk length. The fourth and fifth columns of Table X list the corresponding means with 90 percent confidence intervals and standard deviations in each of the mileage categories already discussed. The distributions are essentially normal with a slight positive skewness in some length categories. It is quite remarkable that no trace remains in the distributions of measured loss of the very pronounced non-normality of the

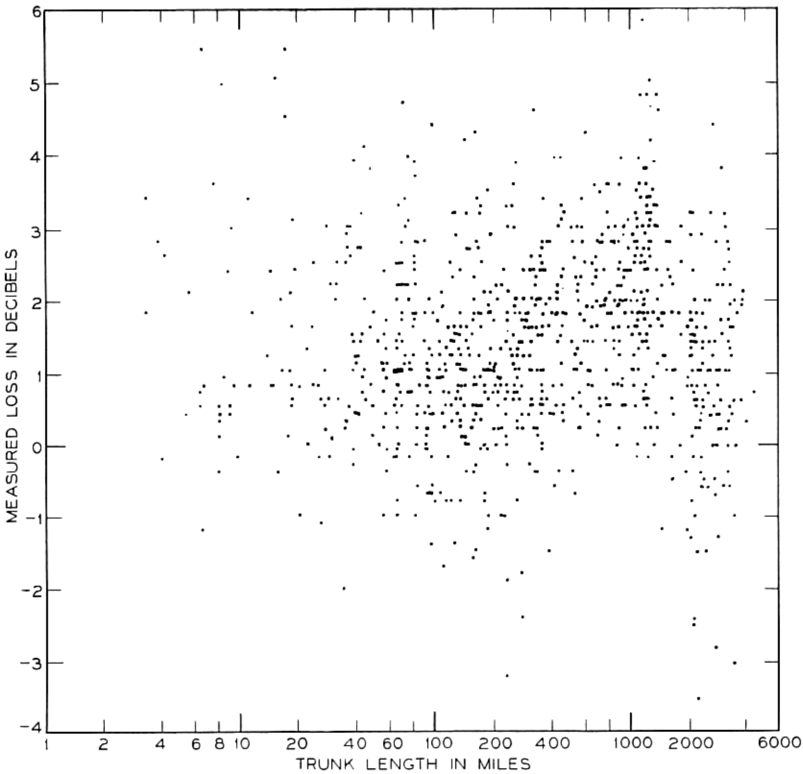

Fig. 3 — Scatter diagram of switch-to-switch measured loss versus trunk length.

distributions of design loss. The reason for this is that the variability resulting from maintenance overshadows the design variability.

Table X shows that the average measured loss follows the same pattern as the average design loss as a function of trunk length. The standard deviations of measured loss decrease as trunk length increases over the first four mileage categories, similar to what was observed for design loss in the previous section. After this, however, the standard deviation remains generally constant and it can be noted that it is substantially larger than the standard deviation of the corresponding design loss distributions.

4.3 *Loss Maintenance*

The loss maintenance of intertoll trunks can be studied by considering the difference between measured loss and design loss. The last two columns of Table X summarize the results. The distributions of these loss differences within mileage categories are all close to normal.

The table shows that the measured losses are on the average somewhat larger than the design losses. Comparison of the third and seventh columns shows that the standard deviation of the loss difference is larger than the standard deviation of the design loss, as stated in the previous section.

Finally, we notice that the standard deviation shows a small but statistically significant increase with trunk length over the mileage categories that contain short-haul trunks (up to 250 miles), and that it also increases (again significantly) with trunk length over the mileage categories to which long-haul trunks belong (longer than 500 miles). This indicates that within each of these two broad classes of trunks, the longer trunks are somewhat more difficult to maintain at the loss value at which they have been designed to operate. This is to be expected since the longer trunks contain more sources for loss variation and more points where loss adjustment can be applied.

V. FREQUENCY RESPONSE

5.1 *Measurement Procedure*

Frequency response was measured by noting the loss at each of 9 frequencies throughout the voiceband. Tones were sent from a variable frequency oscillator located at the far end toll testboard and the received level was noted at the near end toll testboard. The frequency of each tone was verified by a frequency counter at the receive end and received levels were measured using the meter available at the toll testboard. The frequencies of measurement were 200, 300, 400, 1000, 1700, 2300, 3000, 3200, and 3400 Hz. The frequency response of the office meter was also noted and measured loss values were arithmetically corrected for any roll-off in the meter.

Since the range of the office meters was generally limited to switch-to-switch losses less than 31 dB, it was not always possible to measure loss at all nine frequencies. This was the case for trunks with compandored carrier systems where the loss at 3400 Hz was almost always beyond the range of the meter. In this situation a value of 31 dB was arbitrarily assigned as the switch-to-switch loss. Such a procedure is necessary to provide a realistic, albeit conservative, estimate of the mean loss at 3400 Hz for groups of trunks with varying facility composition.

5.2 *Frequency Response of Facilities and of Office Equipment*

As we mentioned, all frequency response measurements in the survey were made from test board to test board, that is, they included the sum of the effects of the facility and the office equipment at each end. In order to isolate these separate contributions, the assumption was made that the frequency response of office equipment and facility are independent random variables which add to produce the overall switch-to-switch frequency response of a trunk.

Each major facility category was divided into three different subclasses: those in which the trunk has 2-wire switching at both ends, those with 2-wire at one end and 4-wire at the other, and those with 4-wire at both ends. For the largest categories, that is, those containing one and two pair of A-channel banks, the largest proportion of the sample was found in the category with 4-wire switching at each end. The two subclasses consisting of trunks with one pair of A-channel banks and 4-wire switching at each end and trunks with two pair of A-channel banks and 4-wire switching at each end were used to estimate the frequency response of A-channel banks and of 4-wire office equipment.

The difference between the estimated frequency response characteristics for these two subclasses of trunks was taken as the frequency response of facilities with one pair of A-channel banks. An estimate of twice the frequency response of office equipment for 4-wire offices was obtained by subtracting the above estimate for facilities with one pair of A-channel banks from the frequency response for trunks with one pair of A-channel banks and 4-wire switching at each end.

The frequency response of two sets of 2-wire office equipment was estimated in an analogous manner, using results for trunks with one pair of A-channel banks and 2-wire switching at each end in conjunction with the facility estimates. The separate estimates for the frequency response of the facility and the two types of office equipment were combined and found in excellent agreement with observed frequency response for trunks with 2-wire switching at one end and 4-wire at the other.

The estimates for office equipment thus obtained were then used to obtain estimates of frequency response for the other types of facilities. Table XI shows the estimates of mean, standard deviation, and 90 percent confidence interval for the mean of facility loss differences relative to 1000-Hz loss. The loss estimates omitted from the table correspond to switch-to-switch losses in excess of 31 dB.

TABLE XI — FACILITY LOSS DIFFERENCES IN dB RELATIVE TO 1000 Hz LOSS

Frequency (Hz)	A channel banks		O channel filters		N1 channel filters		VF cable	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
200	1.2 ± 0.6	1.2	13.1 ± 1.5	5.2	4.4 ± 1.4	2.7	2.0 ± 1.5	2.7
300	0.1 ± 0.3	0.5	2.9 ± 0.7	1.8	0.7 ± 0.5	0	0.1 ± 0.7	1.4
400	0.3 ± 0.2	0.5	0.4 ± 0.3	1.0	0.3 ± 0.3	0.7	0 ± 0.4	1.1
1700	−0.2 ± 0.2	0.4	0.3 ± 0.3	0.8	0.3 ± 0.2	0.6	−0.1 ± 0.2	0.3
2300	−0.3 ± 0.2	0.2	0.2 ± 0.4	1.6	0.4 ± 0.4	0.8	−0.1 ± 0.3	0.2
3000	0.3 ± 0.3	0.7	2.9 ± 0.5	2.0	4.5 ± 0.6	1.6	2.0 ± 0.7	1.4
3200	0.7 ± 0.4	0.8	8.9 ± 0.6	2.1	17.4 ± 1.2	4.3	4.2 ± 1.0	2.3
3400	2.3 ± 0.4	0.7	···	···	···	···	8.9 ± 2.0	4.6

Notice that the bandwidth of a facility with A-channel banks is superior to that of the short haul facilities with O-carrier or N1-carrier channel filters. In fact, a facility with three pair of A-channel banks in tandem will have greater bandwidth than either of the short-haul carrier facilities. It may also be noticed that between the short-haul carrier facilities, N1-carrier has the superior frequency response characteristic at low frequencies while facilities with O-carrier terminals are superior at the high frequencies.

The loss differences for office equipment are given in Table XII. Comparison with Table XI shows that office equipment may contribute more to switch-to-switch loss at low frequencies than a pair of A-channel banks. This is especially true when both offices use 2-wire switching, in which case the mean loss difference of office equipment at low frequencies exceeds even that of two pair of A-channel bank facilities in tandem.

5.3 *Frequency Response of Trunks*

The loss data were also analyzed within the mileage categories defined previously. The results of this analysis are presented in Table XIII. A general trend toward smaller values of mean loss and standard deviation with increasing trunk length is evident at both the lower and higher frequencies of the voice band. Hence the longer trunks are seen to have a frequency response characteristic that is superior to that of the shorter ones. This reflects the transition from compandored carrier on short-haul trunks to A-channel banks for long-haul trunks and is consistent with the superior performance of long-haul carrier noted previously. The high percentage of voice frequency cable and N1-carrier in the shortest category accounts for

TABLE XII—LOSS DIFFERENCES IN dB RELATIVE TO 1000 Hz LOSS FOR OFFICE TRUNKING EQUIPMENT

Frequency (Hz)	4-Wire office		2-Wire office	
	Mean	Standard deviation	Mean	Standard deviation
200	0.7 ± 0.8	0.4	1.4 ± 0.9	1.3
300	0.3 ± 0.5	0.4	0.7 ± 0.5	0.8
400	0.3 ± 0.4	0.3	0.3 ± 0.2	0.1
1700	0.1 ± 0.3	0.2	0.2 ± 0.2	0.2
2300	0.2 ± 0.3	0.3	0.4 ± 0.3	0.5
3000	0.3 ± 0.5	0.1	0.4 ± 0.4	0.4
3200	0.3 ± 0.5	0	0.4 ± 0.4	0.4
3400	0.6 ± 0.7	0.5	0.5 ± 0.6	0.9

Table XIII—Switch-to-Switch Loss in dB on Intertoll Trunks

Frequency (Hz)	Miles 0–62.5 Mean	Standard Deviation	62.5–125 Mean	Standard Deviation	125–250 Mean	Standard Deviation	250–500 Mean	Standard Deviation
200	8.9 ± 1.5	6.0	12.6 ± 2.0	7.9	8.8 ± 1.3	7.5	7.0 ± 1.1	6.1
300	3.4 ± 0.5	2.4	4.1 ± 0.7	2.4	3.5 ± 0.4	3.0	3.2 ± 0.4	2.6
400	2.1 ± 0.3	1.8	2.2 ± 0.3	1.5	2.2 ± 0.2	1.7	2.5 ± 0.3	1.7
1000	1.2 ± 0.2	1.4	1.2 ± 0.3	1.2	1.1 ± 0.2	1.2	1.4 ± 0.2	1.1
1700	1.6 ± 0.3	1.6	1.6 ± 0.3	1.5	1.5 ± 0.2	1.6	1.5 ± 0.2	1.3
2300	2.1 ± 0.3	1.9	1.8 ± 0.3	1.8	1.7 ± 0.2	1.8	1.8 ± 0.2	1.6
3000	5.1 ± 0.6	3.2	5.3 ± 1.3	6.2	4.2 ± 0.7	4.2	3.5 ± 0.5	3.2
3200	12.4 ± 1.6	8.2	10.0 ± 1.6	7.3	8.2 ± 1.9	7.8	5.1 ± 0.9	5.7
3400	22.8 ± 2.6	11.4	22.5 ± 2.8	12.4	16.4 ± 3.3	12.8	9.6 ± 1.6	9.7

Frequency (Hz)	Miles 500–1000 Mean	Standard Deviation	1000–2000 Mean	Standard Deviation	2000–4000 Mean	Standard Deviation
200	5.7 ± 0.4	3.4	5.3 ± 0.3	2.6	4.2 ± 0.4	2.4
300	2.9 ± 0.2	1.4	3.0 ± 0.2	1.5	1.9 ± 0.3	1.5
400	2.8 ± 0.2	1.4	3.0 ± 0.3	1.5	1.9 ± 0.2	1.4
1000	1.9 ± 0.2	1.1	2.1 ± 0.2	1.3	0.9 ± 0.1	1.2
1700	1.8 ± 0.2	1.3	1.9 ± 0.2	1.4	0.9 ± 0.2	1.4
2300	2.0 ± 0.2	1.3	2.1 ± 0.2	1.5	1.1 ± 0.2	1.4
3000	3.2 ± 0.4	2.9	3.2 ± 0.3	1.7	2.3 ± 0.2	1.6
3200	4.2 ± 0.5	3.9	3.8 ± 0.3	2.2	2.9 ± 0.2	1.7
3400	7.2 ± 0.8	6.1	7.3 ± 0.6	4.5	6.1 ± 0.5	2.7

the superior low frequency performance of trunks in that category compared with trunks from 62.5 to 125 miles long where O-carrier terminals predominate (see Table VII).

In the first two mileage categories notice that the estimated mean loss at 3400 Hz is above 20 dB. Included in these estimates are a high percentage of assigned values of 31 dB for loss too high to be measured. Hence these estimates are best interpreted as indicating a mean loss in excess of 20 dB rather than as true estimates of mean loss. A similar statement holds for the estimated mean loss at 3400 Hz in the 125 to 250 miles category; that is, the estimate of 16.4 dB indicates mean loss exceeding 16 dB. With these exceptions the effect of assigned values is to provide more realistic estimates rather than to alter the interpretation of the estimates.

A comparison between frequency responses for short and long intertoll trunks is made in Fig. 4. It contains plots of the median switch-to-switch losses as a function of frequency for trunks in the first and last of the seven mileage categories. Notice that these are not median curves in the sense that 50 percent of all frequency response curves lie on or below these curves; rather, they connect such points at each frequency that 50 percent of the trunks have a lower

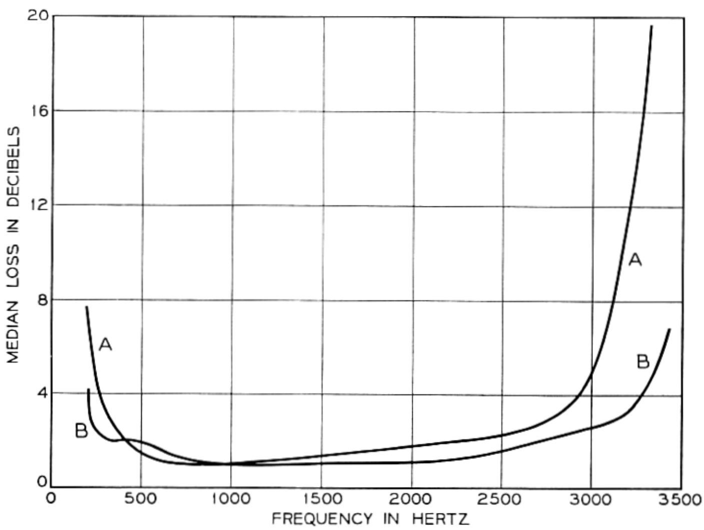

Fig. 4 — Median switch-to-switch loss for (a) short (0 to 62.5 miles) and (b) long (2000 to 4000 miles) intertoll trunks.

loss at that frequency. Fig. 4 shows clearly the larger bandwidth for the longer trunks.

VI. BACKGROUND NOISE

The noise on a telephone communication channel affects the transmission of both spoken messages and data signals. From a practical standpoint, the noise is important only when it is interfering with or disturbing to the transmission of a signal. Hence the noise evaluation of a telephone communication channel seeks to quantify the interfering or disturbing effect of the noise in relation to particular types of information bearing signals. The character of this evaluation takes different forms for different types of signals. The disturbing or annoying effect of noise for spoken messages is related to the time-average noise power, while the most interfering effect of the noise on a data signal is related to the peaks of the noise voltage. Thus, although we are dealing with the same noise in either case, different aspects of that noise are important for different types of signals. In presenting survey results, we refer to "background noise" when dealing with those noise aspects that basically affect the transmission of spoken messages, while we use "impulse noise" to describe those aspects that most seriously affect data transmission.

6.1 *Measurement Procedure*

All measurements of background noise in the survey were made with the far end of the trunk connected to a quiet termination, supplied either by a dialed test termination or by a manually established connection. Noise levels were then measured at the near end with the 3A noise measuring set used both with C-message weighting and with 3-kHz flat weighting. All noise measurements were made during the busy period of an ordinary business day.

6.2 *Results of 3A Noise Level Measurements*

A scatter diagram of 3A noise levels with C-message weighting versus trunk length is shown in Fig. 5. All noise levels here are given "as measured," that is, referred to the receive switch of each measured intertoll trunk. The scatter diagram exhibits clearly the important facts that the mean noise level increases with the length of the trunk, while the variability decreases.

The regression line in Fig. 5 gives an estimate of the mean noise level under the assumption that the mean noise level is linearly

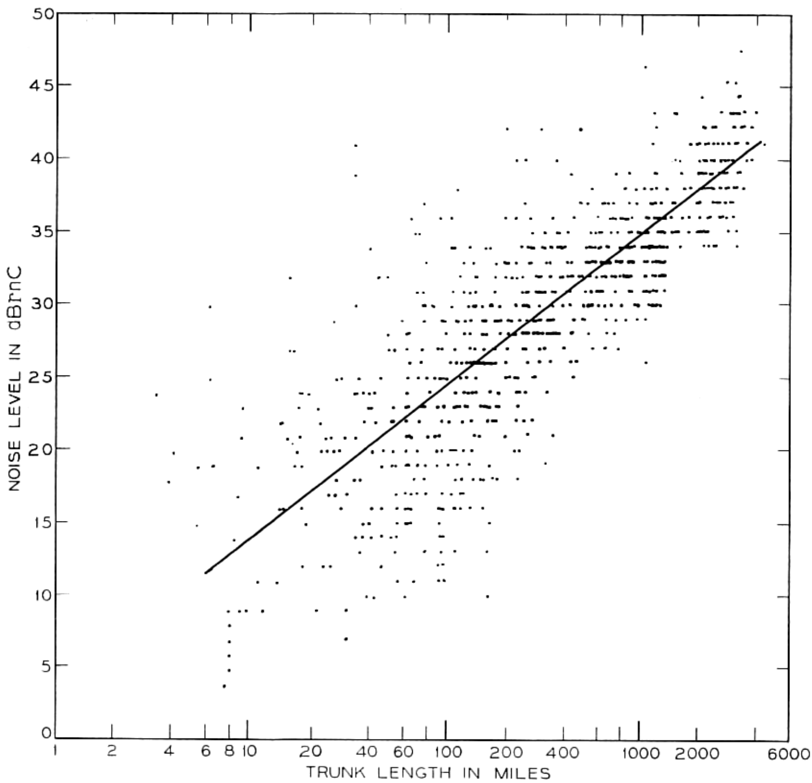

Fig. 5 — Scatter diagram of 3A noise level at receive switch versus trunk length.

related to the logarithm of the trunk length. The equation for the regression line is

$$N = 3.7 + 3.1 \log_2 l$$

where l is the trunk length in miles and N is the average 3A noise level in dBrnC. This equation shows that the average noise level increases by 3.1 dB for each doubling of length of trunk and that the average noise level at 4000 miles is 40.8 dBrnC.

The fact that the variance is not constant with the trunk length affected this regression analysis; the least squares fit to the noise levels as a function of the logarithm of the trunk length was weighted in inverse proportion to the variance about the regression line. This means that higher weight was given to those observations that show a small spread about their mean. The variance about the regression line was in each case computed as the variance in a mileage category minus the contribution to that variance that occurred because the mean noise level varies with the trunk length.

The means and standard deviations of the noise distributions in each of the mileage categories discussed earlier are listed in the second and third columns of Table XIV. As before, the mean is given with its 90 percent confidence interval. The strong dependence of both mean and standard deviation on the trunk length is again clearly exhibited. The discontinuity in loss design rules around 1500 miles is seen to result in a noticeable extra increase in the average noise level, since the rise of 3.1 dB from 34.4 to 37.5 dBrnC occurs for an increase in trunk length that is approximately half of what corresponds to a double length. The noise distributions in each of the mileage categories are all close to normal with only a small tendency toward positive skewness in some of the categories.

Compandored carrier facilities are used extensively on short-haul trunks as shown in Section III. These facilities have the property that the noise level during quiet intervals is lower than the noise level during periods when speech or some other signal is transmitted over the facility. Tests have shown that the subjective reaction to this noise behavior is approximately accounted for by adding 5 dB to the noise level measured in a quiet interval. The resulting noise level is commonly referred to as an "effective" noise level. The distributions

TABLE XIV—3A NOISE LEVEL AT RECEIVE SWITCH

Trunk length (miles)	Noise level			
	Measured		Effective*	
	Mean (dBrnC)	Standard deviation (dB)	Mean (dBrnC)	Standard deviation (dB)
0 – 62.5	18.1 ± 1.7	7.5	21.6	8.6
62.5– 125	22.0 ± 1.3	6.2	25.2	5.8
125 – 250	26.4 ± 1.0	5.3	28.0	4.8
250 – 500	30.6 ± 0.6	4.4	30.9	4.2
500 –1000	33.1 ± 0.5	2.9		
1000 –2000	35.1 ± 0.4	3.0		
2000 –4000	39.4 ± 0.4	2.6		
1000 –1465	34.4 ± 0.4	2.8		
1465 –2000	37.5 ± 0.7	2.5		

* Including subjective compandor penalty.

of effective noise levels for various length categories of trunks are obviously influenced by the proportion of trunks in the category that contain compandored carrier.

The fourth and fifth columns of Table XIV give means and standard deviations of distributions of effective noise levels in those mileage categories where there is a noticeable difference between the average effective noise level and the average measured noise level. These results have been derived by adding 5 dB to the measured noise level on each trunk composed entirely of compandored facilities, and adding a correspondingly lower value to the measured noise level on the trunks made up of a tandem connection of compandored carrier facilities and noncompandored facilities. Comparison of the second and fourth columns shows that the average difference between effective and measured noise levels ranges from 3.5 dB for trunks shorter than 62.5 miles to 0.3 dB for trunks from 250 to 500 miles long.

The noise performance of the most important transmission facilities used in the intertoll trunk plant was estimated from the survey data by subclass analysis. The results are summarized in Table XV. Notice that noise distribution estimates are not given for all mileage categories of each transmission facility. The short-haul carrier facilities N1 and ON are restricted to the first three mileage categories by their capabilities (compare with Table VI). Results for these as well as for other facilities are presented only in those cases where the sample

Table XV—Measured 3A Noise Level Referred to 0 TLP

Trunk length (miles)	Voice frequency facility		N1 carrier		ON-carrier	
	Mean (dBrnCO)	Standard deviation (dB)	Mean (dBrnCO)	Standard deviation (dB)	Mean (dBrnCO)	Standard deviation (dB)
0–62.5	16.6 ± 3.1	8.6	25.1 ± 2.0	5.7	18.9 ± 1.5	4.6
62.5–125	...	...	29.0 ± 1.9	4.3	21.8 ± 2.0	5.5
125–250	...	...	29.3 ± 1.5	3.0	23.0 ± 1.5	4.0

Trunk length (miles)	Coaxial cable carrier		Microwave radio carrier	
	Mean (dBrnCO)	Standard deviation (dB)	Mean (dBrnCO)	Standard deviation (dB)
62.5–125	...	...	29.8 ± 1.9	4.1
125–250	31.1 ± 1.9	3.0	31.2 ± 2.1	4.7
250–500	34.5 ± 1.4	4.0	34.0 ± 0.9	3.9
500–1000	36.0 ± 1.1	2.9	37.2 ± 0.6	2.5
1000–2000	...	...	39.1 ± 0.7	2.4
2000–4000	...	...	42.8 ± 0.6	2.3

contained at least 10 trunks. The noise levels have here been referred to a conventional reference point called the zero transmission level point (0 tlp). Intertoll trunks operate with the transmitting switch at a transmission level of −2 dB relative to 0 tlp, and with the receiving switch at a transmission level of −(2+design loss) dB. The mean noise level at 0 tlp was computed by adding 2 plus the mean measured loss to the mean measured noise level. The variance was calculated by subtracting the variance of measured losses from the variance of measured noise levels. In this way, it is seen that the noise level computed at 0 tlp does not include effects resulting from the loss variability of trunks. Thus the random variables representing noise level at 0 tlp and measured loss can be regarded as independent.

Table XV shows that voice frequency facilities have a lower average noise level than the compandored short-haul carrier systems N1 and ON, while the standard deviation is higher. The average noise level on N1-carrier, which is a double-sideband system, is more than 6 dB higher than the average noise level on the single-sideband ON-carrier system.

Microwave radio facilities are used for a wide range of trunk mileages. The trend with increasing mean and decreasing standard deviation as trunk length is increased is clearly visible from the table. This trend is in line with the results already mentioned for 3A noise levels on trunks. The trend can be explained theoretically by regarding a transmission facility as a tandem connection of a number of noise sources n, with n being directly proportional to the facility

Table XVI—Measured Flat-Weighted 3A Noise Level at Receive Switch

Trunk Length (Miles)	Noise level: Mean (dBrn flat)	Noise level: Standard deviation (dB)
0–62.5	29.4 ± 2.0	9.0
62.5–125	30.2 ± 1.4	7.3
125–250	31.9 ± 0.8	4.9
250–500	34.9 ± 0.7	4.8
500–1000	36.3 ± 0.5	3.3
1000–2000	37.7 ± 0.6	2.9
2000–4000	41.3 ± 0.5	2.4
1000–1465	37.2 ± 0.7	2.7
1465–2000	39.6 ± 0.9	2.9

length. The resulting noise level on the facility is then the power sum of n components. Recent work by Marlow[10] and Nåsell[11] has shown that the mean of a power sum increases while the standard deviation decreases as the number of component variables n is increased.

Table XVI summarizes the results of 3A noise readings with 3-kHz flat weighting. Trends similar to those for 3A noise levels with C-message weighting are indicated; the mean increases with trunk length while the standard deviation decreases. Noise level readings taken with a 3-kHz flat weighting network are mainly used to indicate the presence of low-frequency noise components on a measured channel. Such noise levels do not in general propagate along telephone trunks since their main frequencies fall below the lower cut-off frequency of most telephone channels.

VII. IMPULSE NOISE

One of the major sources of impairment to the successful transmission of digital data over telephone circuits is the appearance of short-term, high-level peaks of noise 12 to 50 dB above the background noise. These peaks are called "impulse noise" because they frequently resemble the impulse response of a bandpass filter when viewed on an oscilloscope.

Impulse noise and its interfering effects on various voice-band data signals have been studied extensively in recent years by Fennick and others.[12, 13, 14] It has been characterized in terms of peak amplitude distributions, burst durations, frequency spectra, distributions of the intervals between impulses and conditional probability of receiving a second impulse within "t" units of time from an initial impulse. Among these, the distribution of peak amplitudes above selected threshold levels provides an adequate and useful description of the impulse noise process with instrumentation of minimum complexity.[15] It is not the object of this section, therefore, to expand or improve upon the methods of characterizing impulse noise now used, but rather to use one of these methods to describe the impulse noise performance as measured during the 1964 intertoll trunk survey and to identify some factors that significantly influence its character.

7.1 *Impulse Noise Description*

The impulse noise on any one transmission channel can be described by the time-average of the number of noise bursts that exceed a threshold level as a function of threshold level. This functional relation is referred to as the peak amplitude distribution. Experience has shown that the relation between the logarithm of the average counting rate and the threshold level is in many cases approximately linear, that is,

$$L = L_1 - K \log_{10} C. \tag{1}$$

Here, L is the threshold level in dBrn at which the average counting rate is C counts per minute, as observed on a 6A impulse noise counter,[15] L_1 is the impulse noise level that corresponds to an average counting rate of one count per minute, and K is the slope of the peak amplitude distribution. It expresses the dB decrease in threshold level that increases the average counting rate by a factor of ten.

7.2 *Measurement Procedure*

During the field measurement phase of the survey, a 15 minute magnetic tape recording was made of the trunk noise for each intertoll trunk in the sample. Trunks containing no compandored carrier facilities in their makeup were terminated at the distant end either in a dialed quiet termination or, in the case of one-way incoming trunks, in a termination supplied manually at the transmitting end of the trunk.

If a trunk contained any compandored carrier, a low-frequency tone (325-350 Hz) was transmitted at −13 dBm from the distant toll testboard in order to operate the compandors with a simulated, fixed-power data signal. This tone was removed by filtering before the noise was recorded. To ensure that all impulse noise data were collected during a period of peak channel loading and switching activity at both ends of the trunk, it was required that noise be recorded only when the local time at both ends of the trunk fell between 9:15 and 11:45 a.m. or 1:15 and 4:15 p.m.

After the field measurement phase of the survey was completed, each tape recording was played back in the laboratory and monitored simultaneously by eight 6A impulse counters with threshold levels spaced 3 dB apart. Each 6A counter was equipped with a voiceband weighting network.[15] The playback gain was adjusted so that the 6A counts covered the range from 4 to 45 counts during the 15 minute observation period for each sample trunk. Using relation (1), the levels corresponding to 45, 15, and 4.5 counts, respectively, were determined by interpolation between the levels that in each case gave a count higher and lower than the count for which the corresponding

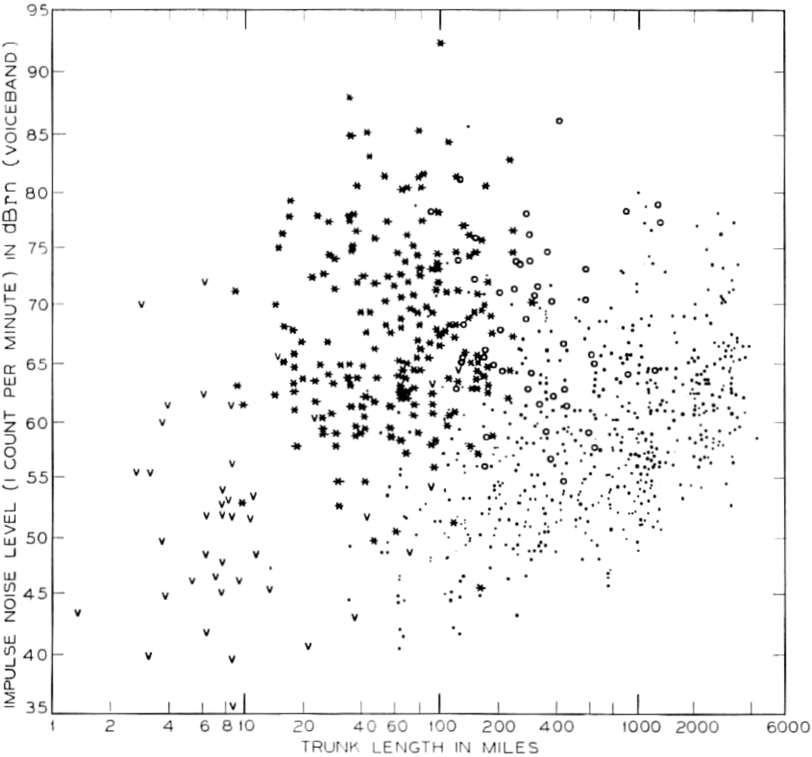

Fig. 6 — Scatter diagram of impulse noise level versus trunk length. v = voice-frequency trunks; * = trunks containing only compandored carrier; o = trunks containing both compandored and noncompandored carrier; · = trunks containing only noncompandored carrier.

level was sought. The slope of the peak amplitude distribution was computed for each trunk as the difference between the interpolated 4.5 and 45 count levels.

7.3 *Results of Impulse Noise Measurements*

The 1963 survey of impulse noise on Bell System carrier facilities revealed that mean threshold levels corresponding to a 6A counting rate of 3 counts per minute were significantly higher on the short haul compandored carrier facilities, N1 and ON, than on long haul carrier facilities.[16] In recognition of this, the scatter diagram of impulse noise levels versus trunk length, shown in Fig. 6, reflects the following partition of intertoll trunks:

(*i*) Trunks made up entirely of compandored carrier facilities (N1, ON, or O),

(*ii*) Trunks made up of any combination of compandored carrier with noncompandored carrier facilities (part N1, ON or O),

(*iii*) Trunks made up entirely of noncompandored carrier facilities (C, J, K, L and microwave radio), and

(*iv*) Trunks made up entirely of voice frequency facilities.

Trunks in the first three categories that include a short section of voice frequency facilities in tandem with carrier facilities were classified by their carrier facility makeup.

Fig. 6 suggests the following trends:

(*i*) Impulse noise levels measured on trunks containing *any* compandored carrier are distinctly higher than on noncompandored trunks.

(*ii*) Impulse noise levels measured on mixed facility trunks containing any compandored carrier are dominated by the compandored carrier impulse noise.

(*iii*) Impulse noise levels measured on noncompandored trunks are correlated with trunk length.

These trends are described quantitatively by the results shown in the figures and tables that follow. Tables XVII and XVIII summarize estimates of the mean, standard deviation, and 90 percent confidence interval for the mean for the impulse noise level (corresponding to an average of 1 count per minute) and the slope. All noise measurements were made on trunks and therefore are referred to the level of the receive switch.

In Table XVII estimates are presented for all intertoll trunks and for nine subclasses defined by transmission facility. These subclasses include trunks made up entirely of the five major Bell System carrier facilities, voice frequency facilities, and the common long haul combination of coaxial cable carrier and microwave radio. The remaining categories partition all carrier intertoll trunks whether single facility or mixed, into those using only noncompandored carrier facilities and those using any compandored carrier facilities. Table XVIII summarizes estimates for the latter two trunk categories within seven mileage categories. Voice frequency trunks are eliminated from Table XVIII because 93 percent of them are shorter than 62.5 miles; impulse noise on these trunks is therefore adequately characterized by Table XVII.

Table XVII—Summary of Impulse Noise Results, at Receive Switch, Over All Trunk Lengths

Facility type	Impulse noise level (1 count per minute)		Slope	
	Mean (dBrn VB)	Standard deviation (dB)	Mean (dB per decade)	Standard deviation (dB)
Voice frequency	51.4 ± 2.5	8.4	8.2 ± 0.8	3.4
N1 carrier	68.7 ± 1.8	7.9	6.9 ± 1.2	4.3
ON-carrier	66.7 ± 1.8	7.3	5.5 ± 0.8	3.2
K-carrier	58.3 ± 2.5	9.8	9.2 ± 1.3	6.3
L-carrier	54.9 ± 2.2	7.6	6.6 ± 0.7	3.5
Microwave radio	57.3 ± 1.4	7.0	7.9 ± 0.7	4.1
L-carrier and microwave radio	59.9 ± 1.7	6.3	7.3 ± 0.5	3.7
Any compandored carrier	67.8 ± 1.3	7.6	6.2 ± 0.7	3.9
Noncompandored carrier	57.8 ± 1.0	7.6	7.7 ± 0.4	4.1
All intertoll trunks	61.6 ± 1.2	9.7	7.1 ± 0.4	4.0

Table XVIII—Summary of Impulse Noise Results, at Receive Switch, For Carrier Intertoll Trunks

Mileage stratum	Compandored carrier	Impulse noise level (1 count per minute)		Slope	
		Mean (dBrn VB)	Standard deviation (dB)	Mean (dB per decade)	Standard deviation (dB)
0–62.5	ANY	67.1 ± 1.8	8.0	6.3 ± 1.1	4.3
	NONE	52.5 ± 2.8	5.5	7.2 ± 1.8	3.1
62.5–125	ANY	69.4 ± 1.8	7.2	6.3 ± 0.9	3.4
	NONE	55.1 ± 3.3	9.2	9.2 ± 1.3	5.0
125–250	ANY	67.0 ± 1.5	6.3	6.0 ± 0.9	3.4
	NONE	56.7 ± 1.6	7.6	8.2 ± 0.8	4.6
250–500	ANY	67.8 ± 2.4	6.6	5.0 ± 0.5	1.9
	NONE	58.4 ± 1.6	7.3	7.7 ± 0.6	4.0
500–1000	ANY	66.4 ± 3.6	5.9	4.3 ± 1.9	2.6
	NONE	58.8 ± 1.5	6.4	6.9 ± 0.6	3.6
1000–2000	NONE	59.9 ± 1.1	6.1	7.2 ± 0.5	3.5
2000–4000	NONE	63.2 ± 1.3	5.0	7.1 ± 0.3	2.8

Table XVII supports the observation made from the scatter plot: the average impulse noise level is 10 dB higher on trunks containing any compandored carrier than on trunks using no compandored carrier. On the other hand, the average slope is 1.5 dB higher for noncompandored carrier trunks. The differences between mean impulse noise levels observed for the three facility categories L-carrier, microwave radio, and the combination of L-carrier and microwave radio is not a reflection of different impulse noise performance of these facilities. If a comparison between the three is made within mileage categories, one finds no significant differences. The differences observed in Table XVII depend on the varying length distribution of the three facilities combined with the fact that the average impulse noise level increases with trunk length for trunks on noncompandored carrier facilities.

Some of the results of Table XVII are depicted graphically in Fig. 7. The intertoll trunks are partitioned into three major facility categories, voice frequency trunks, trunks made up of noncompandored carrier facilities, and trunks containing any compandored carrier. For each facility category, a peak amplitude distribution is given by

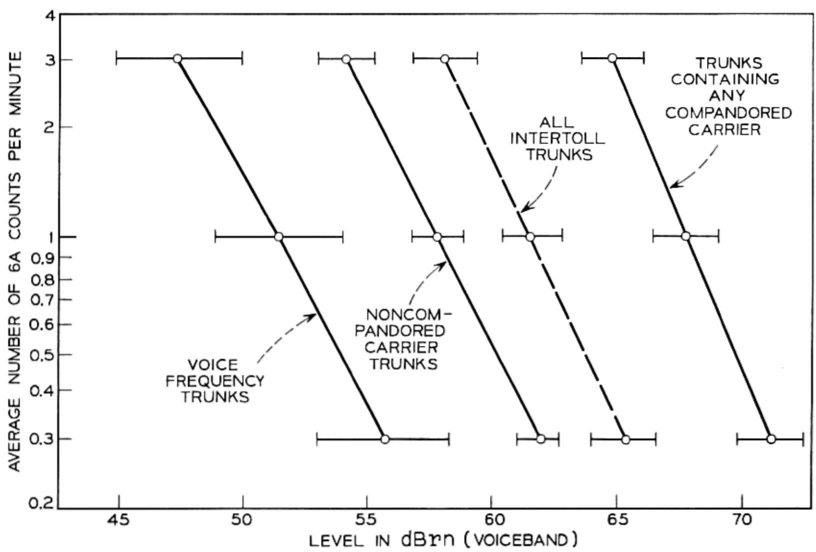

Fig. 7 — Average impulse noise levels at receive switch with 90 percent confidence intervals.

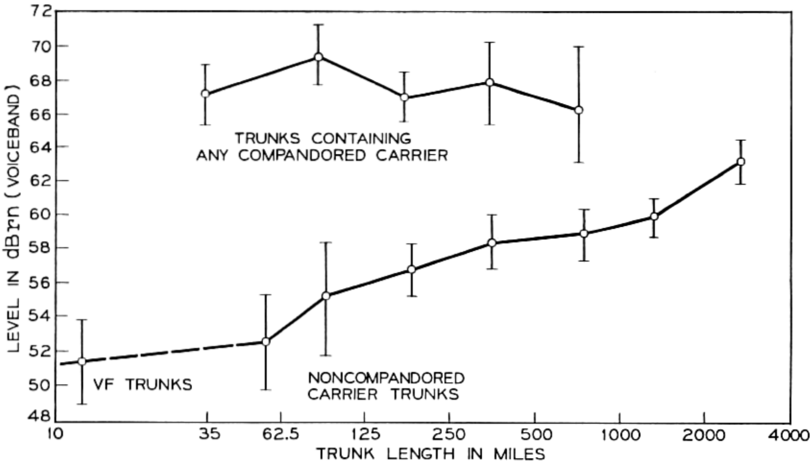

Fig. 8 — Average impulse noise level (1 count per minute) at receive switch with 90 percent confidence intervals.

the curve that connects the mean impulse noise levels at which an average of 3, 1, and 0.3 counts occur per minute.

Table XVIII demonstrates how the average impulse noise level on noncompandored carrier trunks increases with increasing trunk length, while the average impulse noise level on trunks containing any compandored carrier shows no significant change. The table also indicates a tendency for the slope to decrease with trunk length within each of these two facility categories. Furthermore, standard deviations of both impulse noise level and slope tend to decrease with trunk length for each of the two facility categories.

Fig. 8 clearly portrays the relationship between average impulse noise level and trunk length. Abscissa values for points plotted in this figure are the mean trunk lengths within each mileage-facility category.

For each of the categories given in Tables XVII and XVIII the distribution function was estimated for both the impulse noise level and the slope. Distributions of the impulse noise levels in all these categories are very nearly normal and therefore are adequately defined by the distribution parameters given for them. The distributions of the slope show a positive skewness, however, and so Fig. 9 is included to show the amount of this skewness for the two major trunk facility categories referred to throughout this section.

Estimation of the slope of peak amplitude distributions is mean-

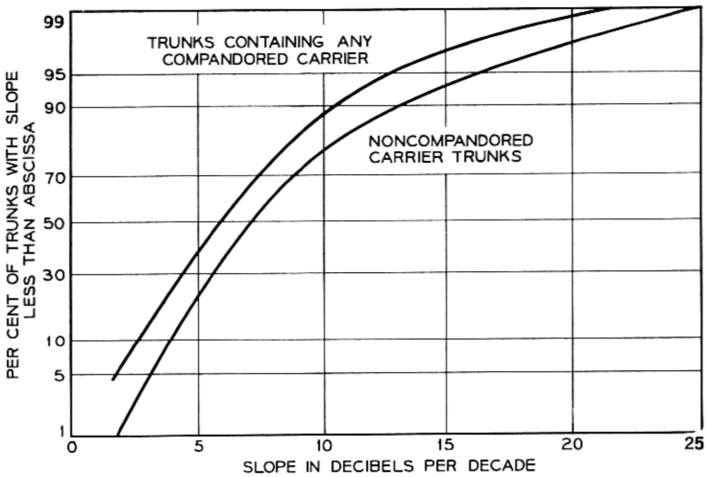

Fig. 9 — Distribution functions of slope of peak amplitude distributions.

ingful only to the extent that relation (1) is a good approximation to the relation between counting rate and threshold level. Fig. 7 indicates a high degree of linearity in the functional dependence between the logarithm of the average counting rate and the average threshold level in dBrn. However, this does not guarantee linearity of individual peak amplitude distributions. Some insight into the latter can be gained by studying the difference, Δ, between the level at which 15 counts occur in 15 minutes and that level at which 15 counts in 15 minutes would be predicted on the basis of the levels at which 45 and 4.5 counts occur in 15 minutes and using the linearity assumption in (1).

The 90 percent confidence interval for Δ includes zero for all subclasses of trunks listed in Table XVII, except K carrier. Excluding this category, the mean Δ values range from 0.3 to 0.7 dB, and the standard deviations of Δ range from 0.8 dB for L carrier to 1.5 dB for microwave radio. The mean Δ for K carrier trunks is 1.2 dB with a 90 percent confidence interval of $\pm$0.5 dB. This indicates a nonlinear peak amplitude distribution for trunks made up entirely of K carrier. The standard deviation of Δ is 2.7 dB for these trunks.

Fig. 8 demonstrates that the impulse noise level for noncompandored carrier trunks is correlated with length, but Fig. 5 shows that background noise level is also correlated with length. In an effort to assess the relative significance of these two factors on impulse noise, a weighted multiple linear regression analysis was performed on the impulse noise level corresponding to 3 counts per minute for noncompandored trunks versus the logarithm of trunk length in miles and the background noise level as measured with the 3A noise measuring set. The least squares fit was weighted in inverse proportion to the variance of impulse noise levels about the regression plane.

This regression analysis gave the following result:

$$L_3 = 33.2 + 0.08 \log_2 l + 0.65\, N, \tag{2}$$

where L_3 is the average impulse noise level in dBrn(VB) corresponding to an average 6A counting rate of 3 counts per minute, l is the trunk length in miles, and N is the background noise level in dBrnC. As with all results reported in this section, both L_3 and N refer to noise levels measured at the receive switch of an intertoll trunk. Relation (2) shows that the correlation between impulse noise level and trunk length is very low if the background noise level measurement is included as an independent variable in the regression analysis.

A weighted linear regression analysis of the impulse noise levels as a function of trunk length alone gave the result:

$$L_3 = 37.9 + 1.9 \log_2 l. \tag{3}$$

Thus the average impulse noise level L_3 on noncompandored carrier trunks increases by 1.9 dB for each doubling of the trunk length. Such a strong correlation between these two variables was to be expected because of (2) and the dependence of average background noise level on trunk length discussed in Section VI.

VIII. RELATIVE ENVELOPE DELAY

Relative envelope delay can be used to characterize nonlinearity of the phase characteristic. It is the delay of the envelope of an amplitude modulated carrier relative to the envelope delay at a reference carrier frequency. As such it provides an approximation to the derivative of the phase characteristic. Hence linear phase corresponds to constant delay, or zero relative envelope delay. The reference frequency chosen for all measurements in the survey was 1800 Hz. That is, the envelope delay of each trunk in the sample is given relative to the envelope delay of the same trunk at 1800 Hz.

8.1 *Measurement Procedure*

Envelope delay was measured with a loop-around technique. Whenever possible a trunk was looped back onto itself at a 4-wire point in the distant office, thus ensuring the same facility composition in each direction of transmission. Delay was then measured from a 4-wire point in the near-end office. Since voice frequency patch bays are standard 4-wire points for most carrier systems, they were used both for point of measurement and point of loop back when available. For facilities not appearing at a voice frequency patch bay, an alternate point of measurement and loop-back was selected. In offices where compandored carrier systems terminated only at the circuit patch bay this point was used; and for voice frequency facilities, the repeater jacks were used. For 2-wire voice facilities the trunk to be measured was looped back onto its cable quad pair, thus assuring similarity of loading, repeater type, and spacing. The loop-around measurements were converted arithmetically to one-way values in a manner described later.

In order to characterize each trunk as completely as possible, measurements were also made on the office trunking equipment between the toll test board and the voice frequency patch bay (or similar points where the facility measurements had been made). Measurements between the toll testboard and the voice frequency patch bay in 4-wire switching offices were made from the test board with a loop-back at the voice frequency patch bay. In offices with 2-wire switching, two separate measurements were made on the office equipment: one from the toll test board to the voice frequency patch bay and a second from the voice frequency patch bay to the toll test board.

8.2 *Loop-Around to One-Way Conversion*

As already mentioned, relative envelope delay on facilities was measured with a loop-back technique. The requirement to characterize the transmission performance by one-way data, therefore, makes it necessary to find a method for converting the loop-around data to one-way delay. This conversion presents a problem, since a direct division by two of each two-way delay reading would lead to an underestimation of the standard deviation of the distribution of one-way delay readings, even though the mean of the same distribution would be correctly estimated.

The classification of trunks into homogeneous facility categories is of importance here, since it allows us to view the delay in the two directions of transmission of the trunk as *independent,* identically distributed random variables. Within each such facility category, the following conversion formula was used at each frequency:

$$d_1 = \frac{\bar{d}_2}{2} + \frac{d_2 - \bar{d}_2}{(2)^{\frac{1}{2}}} \tag{4}$$

where d_1 is the desired one-way delay for a given sample trunk, d_2 is the measured loop-around delay for the same trunk and $\bar{d}_2$ is the estimated mean loop-around delay for all trunks in the category.

The use of a ratio estimator in the sample survey estimation formulas means that $\bar{d}_2$ is not an unbiased estimator of the mean loop-around delay. However, this estimator is asymptotically unbiased. Therefore, if the sample size within the facility category is large enough, the bias of $\bar{d}_2$ can be neglected, and its variance can be neglected in comparison with the variance of d_2. The covariance of d_2 and $\bar{d}_2$ is likewise negligible. Under these conditions it is easily shown that:

$$E(d_1) = \tfrac{1}{2}E(d_2) \tag{5}$$

and

$$\text{Var}\ (d_1) = \tfrac{1}{2}\ \text{Var}\ (d_2). \tag{6}$$

The conversion formula (4) is thus seen to have the desired properties for a large enough sample size in the corresponding trunk category. It has, however, been used for conversion from two-way to one-way delay in all of the facility categories regardless of size. The bias introduced in this way is certainly less serious than the errors that would occur through a simple division of each measured loop-around delay by two.

8.3 *Delay on Facilities*

The data were analyzed separately for each of the facility categories. The results include estimates of the mean, standard deviation, and 90 percent confidence intervals for the means. These results for facilities with one pair of A-type channel banks, one pair of O-carrier channel filters, one pair of N1-carrier channel filters are presented in Table XIX and in Fig. 10. The curves for facilities with A-channel banks and O-carrier channel filters are quite symmetric while the curve for N1-carrier channel filters is not. Measurements at high frequencies could not always be made on the compandored carrier systems because of excessive attenuation, as mentioned previously.

Delay characteristics are additive. That is, the relative envelope delay for two or more facilities in tandem may be obtained by adding the individual delay curves for each of the component facilities. For

TABLE XIX—RELATIVE ENVELOPE DELAY FOR MAJOR FACILITY CATEGORIES

Frequency (Hz)	Delay (μs)					
	A Channel banks		O Channel Filters		N1 Channel Filters	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
400	1096 ± 29	213	1545 ± 30	131	513 ± 11	50
600	538 ± 11	79	671 ± 9	61	143 ± 4	22
800	315 ± 6	48	357 ± 7	43	36 ± 5	18
1000	180 ± 3	27	212 ± 5	33	−20 ± 4	14
1200	104 ± 3	25	118 ± 5	30	−26 ± 4	14
1400	57 ± 2	19	54 ± 3	21	−26 ± 3	11
1600	21 ± 1	12	15 ± 2	11	−17 ± 2	9
1700	8 ± 1	9	5 ± 1	7	−9 ± 2	6
1800	0		0		0	
2000	2 ± 2	15	5 ± 2	12	27 ± 2	8
2200	29 ± 4	29	31 ± 3	20	79 ± 2	10
2300	51 ± 4	33	53 ± 4	25	117 ± 4	14
2400	77 ± 5	37	81 ± 4	31	162 ± 4	17
2600	147 ± 6	44	161 ± 6	44	252 ± 7	23
2800	257 ± 7	51	293 ± 10	63	393 ± 9	31
3000	444 ± 8	61	537 ± 15	89	750 ± 23	84
3200	837 ± 10	79	936 ± 33	154	...	...
3300	1279 ± 14	109	...	...	...	...
3400	1837 ± 29	186	...	...	...	...

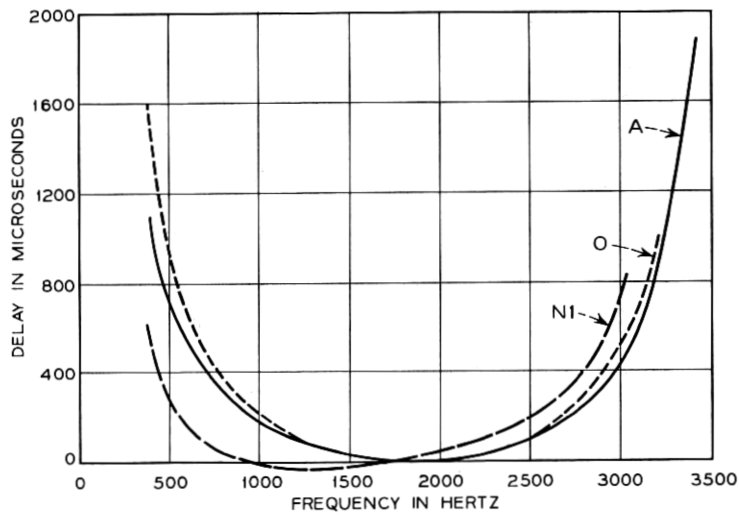

Fig. 10 — Mean relative envelope delay for facilities with A-type channel banks, O-carrier channel filters, and N1-carrier channel filters.

example, the delay characteristic of a trunk facility containing one pair of A-channel banks in tandem with an ON system may be obtained by adding the data for a facility with one pair of A-channel banks and that for a facility with one pair of O-carrier terminals. This follows from the fact that the voiceband channel filters are, with two notable exceptions dealt with later, the only significant contributors to envelope delay on carrier facilities.

Variance for a tandem facility category is similarly estimated by the sum of the variances. Precision in the form of 90 percent confidence intervals for the mean may also be estimated by "addition" of confidence intervals in the same manner as standard deviations (square root of sum of squares). Estimates of the cumulative distribution functions have indicated that the assumption of normality is justified within facility categories. Hence the percentage points of the distribution functions may be estimated from the means and standard deviations.

The property of additivity was directly used in the data analysis. That is, delay for facilities with two pair of A-channel banks was assumed to be the sum of that for two facilities, each with one pair of A-channel banks. Similarly, delay for facilities with three pair of A-channel banks was regarded as the sum of three separate A-channel bank facilities. The data for facilities with one, two, or three pairs of A-channel banks were then pooled to provide the estimates for a facility with one pair of A-channel banks given in Table XIX and Fig. 10. This procedure has the advantage of producing greater precision than use of only data for facilities with one pair of A-channel banks.

In addition to channel bank filters, other factors which may contribute to the over-all delay on a facility are group connectors and K-carrier modems. The most noticeable effects of these are found on edge channels of the basic group (channels 1 and 12). Estimates of the additional delay contributed by each of these are given in Table XX. The results for group connectors are also shown in Fig. 11 which presents the delay curves for A-type channel banks with and without the effects of group connectors on edge channels.

The delay contributed by group connectors reflects the specific combination of an older and a newer generation of such connectors that existed in the plant in 1964. The newer generation gives smaller additional delay than the older one. It is therefore expected that the additional delay resulting from group connectors will decrease as the proportion of new group connectors in the plant increases. Table XX shows that the low frequency effect of a K-carrier modem is similar

TABLE XX—ADDITIONAL MEAN RELATIVE ENVELOPE DELAY ON EDGE CHANNELS FROM K-CARRIER MODEMS AND GROUP CONNECTORS

Frequency (Hz)	Delay (μs)			
	K-Carrier modem		Group connector	
	Channel 1	Channel 12	Channel 1	Channel 12
400	517	842	455	−138
600	334	253	314	−121
800	231	114	233	−109
1000	164	73	154	−90
1200	117	32	103	−67
1400	76	5	65	−47
1600	37	0	32	−27
1700	20	−2	16	−13
1800	0	0	0	0
2000	−34	−3	−27	39
2200	−63	0	−50	90
2300	−80	−8	−63	122
2400	−93	−17	−68	158
2600	−120	−28	−84	244
2800	−147	−27	−99	360
3000	−170	−38	−115	533
3200	−238	−121	−127	851
3300	−296	−59	−133	1058
3400	−293	217	−141	1349

to that of a group connector on channel 1. In fact, a K-carrier modem contributes more excess delay at 400 Hz than one group connector. This is seen to be true for both channels 1 and 12 associated with the K-carrier modem. We may also notice that on channel 12, unlike channel 1, a K-carrier modem will also add delay to the highest frequencies of the voice band. In Fig. 11 we observe that for channel 12, the effect of a group connector is to produce a shift of the delay curve toward the left and an attendant asymmetry. This is seen to be opposite to the effect on channel 1 and also somewhat greater in magnitude. For a K-carrier modem, the effect on both channels 1 and 12 will be similar to that of a group connector on channel 1; that is, a shift of the entire delay curve to the right.

8.4 *Office Equipment Delay*

The results for office equipment are presented in Tables XXI and XXII for 4-wire and 2-wire offices, respectively. The left part of Table XXI shows the results of loop-around measurements, with the measurements being made at the toll test board (ttb) and the loop-back at the voice frequency patch bay (vfpb). The right part of this table indicates that the relative envelope delay is lower if the loop-back is made at the circuit patch bay (cpb) instead of at the vfpb. The difference between these two sets of readings is attributable to the single frequency signaling units located between the cpb and the vfpb. Voice frequency facilities and older types of compandored carrier systems generally do not use in-band single frequency signaling units, so the data on the right side of Table XXI apply specifically to the delay of office equipment associated with such facilities.

The results in Table XXII for office equipment in 2-wire offices show a small difference between the delays in the two directions of transmission. Also, slightly lower values of delay are recorded where the transmission path does not contain a signaling unit. The difference is, however, not as large as in the case of 4-wire offices. This could result from the fact that the delay in 2-wire offices shows greater variability than the delay in 4-wire offices, as indicated by the estimates of standard deviation. This greater variability and a smaller sample size combine to produce less precise estimates, thus masking the contribution of the signaling units.

The existence of 4-wire to 2-wire hybrid transformers in offices

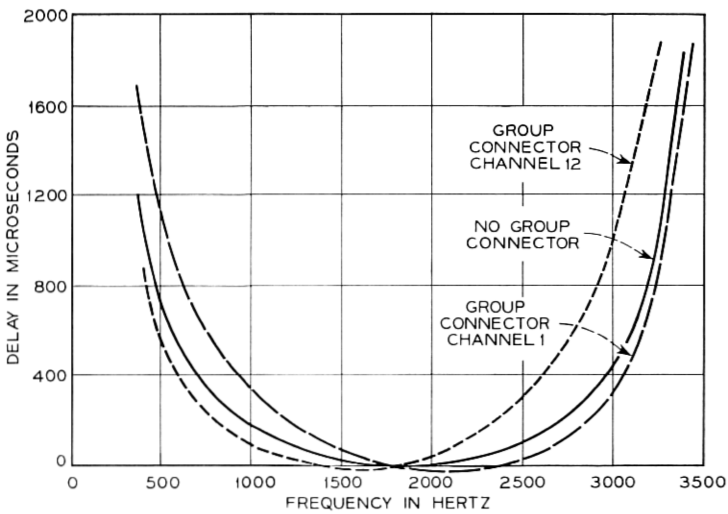

Fig. 11 — Mean relative envelope delay on edge channels for facilities with one group connector and one pair of A-type channel banks.

Table XXI—Relative Envelope Delay of Equipment in 4-Wire Offices

Frequency (Hz)	Delay (μs)			
	TTB-VFPB-TTB*		TTB-CPB-TTB*	
	Mean	Standard deviation	Mean	Standard deviation
400	307 ± 9	48	195 ± 6	15
600	122 ± 3	20	77 ± 2	6
800	62 ± 2	12	35 ± 1	4
1000	35 ± 1	8	19 ± 1	3
1200	20 ± 1	5	11 ± 1	4
1400	10 ± 1	5	6 ± 1	4
1600	5	4	2 ± 1	2
1700	2	2	1	1
1800	0		0	
2000	−4	2	−2 ± 1	2
2200	−7 ± 1	8	−3 ± 1	3
2300	−6 ± 1	5	−4 ± 1	3
2400	−5 ± 2	8	−5 ± 1	3
2600	−6 ± 1	6	−6 ± 1	3
2800	−6 ± 1	9	−7 ± 1	3
3000	−16 ± 1	7	−8 ± 1	3
3200	−14 ± 1	5	−8 ± 1	3
3300	−14 ± 1	5	−8 ± 1	3
3400	−15 ± 1	4	−9 ± 1	3

* TTB, toll test board; VFPB, voice frequency patch bay; CPB, circuit patch bay.

with 2-wire switching is also noteworthy. Observe that the office equipment delay in 2-wire offices is approximately twice that in 4-wire offices. The use of different types of hybrid coils and wiring arrangements may also account for the higher variability encountered in 2-wire offices.

The office equipment contribution to the total relative envelope delay of intertoll trunks becomes appreciable compared with the facility contribution only at low frequencies. Tables XXI and XXII show that the average office equipment delay amounts to no more than 50 μs per office throughout the frequency range from 1000 to 3400 Hz.

8.5 *Delay on Trunks*

After conversion of the loop-around delay on facilities to one-way data the results were combined with the data on office equipment to obtain estimates of the total switch-to-switch delay on trunks. The

TABLE XXII—RELATIVE ENVELOPE DELAY OF EQUIPMENT IN 2-WIRE OFFICES

Frequency (Hz)	Delay (μs)							
	TTB-VFPB*		VFPB-TTB		TTB-CPB		CPB-TTB	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
400	338 ± 24	67	294 ± 50	118	307 ± 28	70	272 ± 41	99
600	137 ± 10	28	130 ± 22	52	120 ± 10	25	108 ± 16	39
800	68 ± 6	16	67 ± 12	29	58 ± 4	12	53 ± 8	20
1000	38 ± 3	10	38 ± 8	18	33 ± 3	10	30 ± 4	12
1200	21 ± 2	7	22 ± 5	12	17 ± 1	4	16 ± 2	7
1400	12 ± 2	5	12 ± 2	7	10 ± 1	5	9 ± 1	4
1600	5 ± 1	3	5 ± 1	4	4 ± 1	3	4 ± 1	2
1700	2 ± 1	2	2	2	2 ± 1	2	1	2
1800	0		0		0		0	
2000	−3	2	−4 ± 1	3	−3 ± 1	2	−3	2
2200	−6 ± 1	3	−6 ± 2	5	−5 ± 1	3	−5 ± 1	3
2300	−7 ± 1	3	−8 ± 3	6	−6 ± 1	3	−6 ± 1	3
2400	−8 ± 1	3	−9 ± 3	6	−7 ± 1	3	−7 ± 1	4
2600	−10 ± 1	5	−11 ± 3	8	−8 ± 1	3	−8 ± 1	4
2800	−11 ± 1	4	−12 ± 4	8	−10 ± 1	4	−10 ± 1	4
3000	−12 ± 1	4	−14 ± 5	9	−11 ± 1	4	−10 ± 2	5
3200	−13 ± 1	4	−15 ± 5	10	−12 ± 1	4	−11 ± 2	5
3300	−14 ± 1	4	−16 ± 5	11	−13 ± 2	4	−12 ± 2	6
3400	−14 ± 1	5	−16 ± 5	11	−13 ± 2	4	−12 ± 2	6

* TTB, toll test board; VFPB, voice frequency patch bay; CPB, circuit patch bay.

delay for the office equipment at the far end of a trunk was generally taken to be the mean delay characteristic for the type of office equipment involved. That is, for each trunk the far-end office equipment was identified by whether 2-wire or 4-wire switching was used and whether in-band single frequency signaling units were present. The appropriate mean delay curve was then taken to represent the delay of the far-end equipment. The exception to this rule occurred when both near-end and far-end offices had 4-wire switching and both used the same type of signaling (that is, both used in-band single frequency signaling or neither did). In this case, the delay as measured for both directions of transmission on the near-end office equipment of a given trunk was taken as representative of the total office equipment delay for that specific trunk. In all other cases only the receive direction of the near-end office equipment measurement was added (the mean delay curves used for far-end office equipment were for the transmit direction). When the near-end office equipment was measured on a loop-around basis and the far-end was not similar the loop-around value was divided by two to represent the receive direction of the near-end equipment. A loop-around to one-way conversion similar to that used on the facility data was not used here because of the relatively small variances encountered.

The resultant data for switch-to-switch delay were grouped into mileage categories. The mean, standard deviation, and a 90 percent confidence interval for the mean were then estimated for the trunks in each mileage category. The results of this analysis are presented in Table XXIII. The lower relative envelope delay in the shortest mileage category reflects its high percentage of N1-carrier and voice frequency cable facilities.

The data for delay at frequencies above 3200 Hz in this category refers mainly to the characteristics of voice frequency cable, since high loss generally precluded measurements on N1 and ON systems in this frequency range. A gradual increase in delay is also evident with increasing trunk length at the higher frequencies. This trend is caused by the increased use of tandem facilities and group connectors on longer trunks (compare with Tables VII and VIII). A similar increase in delay with trunk length is not observed at the lower frequencies since the transition from mainly 2-wire switching on short trunks to 4-wire switching on long trunks produces a decrease in the contribution of office equipment to overall delay (compare with Tables V, XXI, XXII).

Figure 12 compares delay characteristics for short and long intertoll trunks. It contains plots of the median relative envelope delay curves for trunks in the first and last of the seven mileage categories. The asymmetry of the curve for short trunks reflects the previously noted facts that N1 carrier channel filters dominate in this length category and that the delay curves for that facility are not symmetrical.

IX. CONCLUDING REMARKS

The transmission performance of intertoll trunks has an important influence on the transmission performance of built-up connections between subscribers. Notice, however, that the latter cannot be derived in a simple manner from the former since the relation between the two is influenced by a number of factors, such as customer calling habits, toll network routing patterns, and automatic alternate routing probabilities, as well as by the transmission performance of toll connecting trunks.

It should come as no surprise that important differences have been noticed between intertoll trunk performance and connection performance. One example illustrates this. The regression analysis reported in Section VI shows the mean 3A noise level with C-message weighting to increase by 3.1 dB per double length of intertoll trunk. In contrast to this, the 1966 connection survey[17] showed the average noise level on built-up connections to increase by only 2.0 dB for each doubling of the airline distance between end-offices.

Some earlier survey activities have been directed at establishing the transmission performance of selected transmission facilities.[16] The results of such surveys cannot be used to directly estimate the performance of trunks. On the other hand, the results discussed in this paper show that a survey of intertoll trunks can be used to arrive at performance estimates of both trunks and facilities. This is possible since any given facility constitutes a subclass of the population of trunks. The powerful technique of subclass analysis on sample survey data can, therefore, be applied directly. It is seen from this that a systemwide trunk survey supplies more information than a survey of specific transmission facilities.

The dynamic growth of the toll plant should be taken into account in applying the results given here. An important aspect of this growth is the introduction in recent years of the new short-haul carrier facilities N2, N3, and T1. Their transmission characteristics

TABLE XXIII—SWITCH-TO-SWITCH RELATIVE ENVELOPE DELAY OF INTERTOLL TRUNKS

Frequency (Hz)	Delay (μs)					
	0–62.5 miles		62.5–125 miles		125–250 miles	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
400	1177 ± 137	592	1869 ± 114	529	1877 ± 164	758
600	448 ± 65	274	815 ± 63	277	838 ± 75	360
800	199 ± 39	169	425 ± 33	165	446 ± 41	198
1000	89 ± 27	119	235 ± 18	110	253 ± 26	134
1200	37 ± 17	76	124 ± 11	77	140 ± 15	85
1400	7 ± 11	62	58 ± 7	46	71 ± 8	50
1600	−4 ± 6	35	17 ± 4	23	25 ± 4	25
1700	−5 ± 5	34	5 ± 2	12	8 ± 2	13
1800	0		0		0	
2000	14 ± 6	38	7 ± 5	28	7 ± 6	40
2200	51 ± 9	49	48 ± 12	68	49 ± 12	70
2300	76 ± 11	70	77 ± 16	89	85 ± 19	110
2400	110 ± 13	71	115 ± 23	120	131 ± 27	155
2600	186 ± 17	102	224 ± 47	240	224 ± 30	168
2800	305 ± 27	154	414 ± 100	501	380 ± 50	279
3000	559 ± 53	273	597 ± 51	362	624 ± 54	300
3200	712 ± 81	414	980 ± 80	548	1027 ± 76	461
3300	801 ± 151	648	1248 ± 135	714	1390 ± 116	640
3400	900 ± 230	861	1856 ± 195	789	1956 ± 182	961

Frequency (Hz)	Delay (µs)							
	250–500 miles		500–1000 miles		1000–2000 miles		2000–4000 miles	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
400	2020 ± 146	854	1926 ± 108	783	1978 ± 143	889	2111 ± 156	958
600	929 ± 69	386	880 ± 50	359	938 ± 70	443	1007 ± 77	477
800	514 ± 38	214	497 ± 29	213	543 ± 44	285	579 ± 44	286
1000	292 ± 24	135	277 ± 17	132	308 ± 26	178	337 ± 27	177
1200	165 ± 15	87	154 ± 11	87	178 ± 17	116	196 ± 16	112
1400	85 ± 9	52	80 ± 7	55	97 ± 11	72	107 ± 9	69
1600	31 ± 4	26	29 ± 4	28	36 ± 4	34	37 ± 4	32
1700	10 ± 2	15	10 ± 2	17	14 ± 3	22	14 ± 2	17
1800	0		0		0		0	
2000	2 ± 4	30	2 ± 3	33	−2 ± 3	34	4 ± 5	36
2200	36 ± 10	71	36 ± 8	76	34 ± 7	75	53 ± 12	76
2300	70 ± 14	99	70 ± 10	97	67 ± 10	97	92 ± 16	102
2400	110 ± 19	136	110 ± 14	123	107 ± 12	124	138 ± 22	131
2600	210 ± 30	206	214 ± 24	201	212 ± 17	185	257 ± 34	200
2800	365 ± 45	316	378 ± 42	335	377 ± 26	271	445 ± 53	311
3000	619 ± 68	460	615 ± 53	403	656 ± 48	430	758 ± 83	463
3200	1066 ± 64	427	1129 ± 85	604	1246 ± 84	710	1406 ± 133	776
3300	1497 ± 94	531	1635 ± 103	732	1850 ± 111	926	2094 ± 178	1046
3400	2052 ± 119	632	2298 ± 136	965	2600 ± 169	1157	3033 ± 268	1458

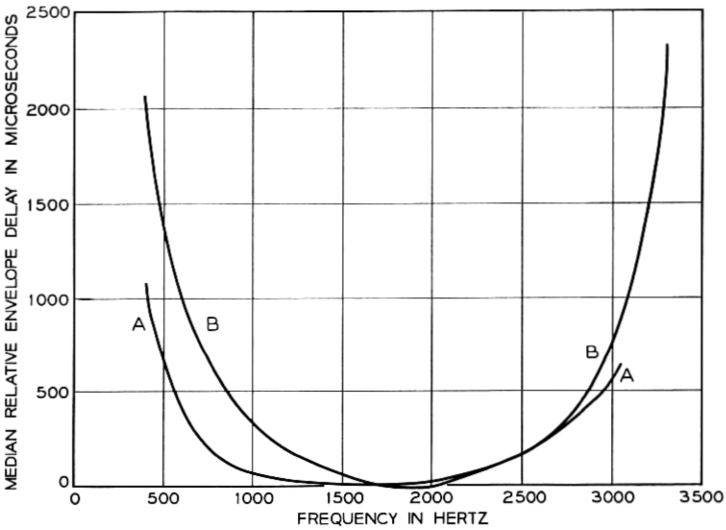

Fig. 12 — Median relative envelope delay for (a) short (0 to 62.5 miles) and (b) long (2000 to 4000 miles) intertoll trunks.

are, in practically all aspects, superior to those of the carrier facilities N1 and ON, which dominated the short-haul trunk plant in 1964. The trend in trunk performance because of this is expected to be toward improved performance. Specifically, the background noise levels on short-haul carrier trunks should decrease, and their bandwidth should increase to be more nearly comparable with the bandwidth of long-haul trunks.

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About 90 Bell System craftsmen were involved in establishing the trunks for testing, while the measurements were made by 18 employees of Bell Laboratories. R. J. Christie, Miss M. L. Chubb, F. P. Duffy, J. H. Fennick, Mrs. C. A. Gadberry, J. E. Kessler, and J. T. Powers, Jr., all of Bell Laboratories, made important contributions in data analysis. M. Derzai (Bell Telephone Company of Canada) suggested the normalizing transformation of the ratio of trunk length to airline distance. R. C. Terreault (also Canada) estimated the effective background noise levels. The contributions of all of these people are gratefully acknowleged.

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