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1980 Bell System Noise Survey of the Loop Plant

By D. V. BATORSKY* and M. E. BURKE†

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This paper presents the principal findings of measurements taken in 1980 of voltages and current induced in Bell System loops by commercial power lines. These findings give designers of new, solid state, electronic switching and terminal equipment a detailed characterization of power induced signals. The last Bell System noise survey was in 1964, and since then power system load and telephone loop length have increased. Use of shielded cable has grown, and the number of poorly balanced party lines has decreased. The net result is that the loop plant contribution to main-station levels of induced longitudinal and metallic voltages indicate only a slight increase at the 90th percentile of 1 to 2 dB since 1964—an increase too small to be considered statistically significant. When the central office and loop plant contributions are combined, main station metallic noise shows a decrease at the 90th percentile of 6 dB since 1964. Because of diurnal variations, distributions of peak noise levels on a loop over a 24-hour period are 4 to 6 dB higher than corresponding distributions based on one-time measurements made during business hours. This survey provides the first characterization of induced longitudinal current based on measured data. Finally, as a result of the stratified, two-stage sampling scheme used for the survey, differences among urban, suburban, and rural environments have been identified, and the unique behavior of long rural loops has been highlighted.

I. INTRODUCTION

1.1 Survey motivation and objectives

Since the earliest days of telephony, commercial power systems have imposed significant constraints on the design of the Bell System

* AT&T Bell Laboratories; present affiliation Bell Communications Research, Inc. † AT&T Bell Laboratories.

network. In fact, the evolution from open wire to shielded cable with twisted pairs was in part a response to the need for reduced susceptibility to induced noise. Despite the tremendous progress in reducing plant susceptibility through use of shielded cables, improved mitigation techniques,[1] and better-balanced plant, induction in the loop plant remains a major concern because of increasingly stringent design specifications and changing service requirements. For example, modern solid state transmission equipment is often more vulnerable to damage from longitudinal voltages than were earlier generations of equipment. In addition to existing Bell System objectives, several public utility commissions have recently established noise standards for subscriber loops. This latter development, along with the restructuring of the Bell System, implies a need to develop programs to assess the performance of both power and telephone systems with respect to noise parameters. A detailed knowledge of noise in the loop plant is necessary to address these and similar issues.

Since the last Bell System noise survey, which was conducted in 1964,[2] significant changes have occurred in the power and telephone plants. The open-wire plant, which still served a significant percentage of loops in 1964, is virtually nonexistent today, and poorly balanced party lines, once a major cause of noisy loops, are rarely encountered. In contrast to these positive developments, power system loads have doubled since 1964, and homes, businesses, and utilities increasingly employ nonlinear devices, which can be potent sources of telephone interference. In addition, subscriber loop lengths have increased approximately 14 percent since 1964.[3] The net effect of such changes cannot easily be predicted, but it is clear that the plant conditions present in 1964 no longer exist. Also, the 1964 noise data provide no information on longitudinal currents, noise spectra, central office voltages, or the effects of diurnal variations, all of which are now considered important to design and performance specifications.[4,5] Until now these parameters have been considered only by more localized measurement programs.[6]

Thus, the pressing need for up-to-date noise characterizations and the limitations of previous systemwide noise data led the Electrical Protection and Interference Department of Bell Laboratories to conduct the 1980 Bell System noise survey. The result of that survey is a characterization of induced noise at subscriber and central office ends of telephone pairs in the Bell System, with special consideration of the noisier long pairs.

1.2 Scope of paper

This paper discusses the design and presents the results of the 1980 Bell System noise survey. The presentation emphasizes the information most relevant to establishing induced noise characterizations. Section II briefly introduces the physical mechanisms and models associated with induction in the loop plant. Section III describes the survey design, defines measured and derived noise parameters, and concludes with a summary of the principal results. Section IV presents noise data measured at the central office interface, and Section V presents data measured at the main station interface. Finally, Section VI provides concluding comments. The appendix expands on the survey design, details the method of sample selection, and illustrates the mathematical technique used to derive means and cumulative distributions.

II. OVERVIEW OF POWER INDUCTION

Power distribution lines are the principal source of induction in telephone lines, and are a natural consequence of both systems serving a common public and frequently sharing rights of way. Power line induction is a function of the magnitude of the net three-phase power currents and the distance over which telephone lines are exposed to these currents.[7,8] Urban, suburban, and rural areas represent significantly different environments with respect to these parameters.[6] At one extreme are the densely populated urban areas, which tend to have relatively well-balanced, three-phase power systems and relatively short telephone loops. At the other extreme are rural areas, which are typically characterized by single-phase power distribution and long loops. Suburban areas generally encompass a wide range of intermediate conditions.

The induced longitudinal (or common mode) disturbances,[9,10] i.e., noise-to-ground and longitudinal current (as defined in Section 3.2), that result from power line exposures are essentially equal for both wires of a pair.[10] Metallic noise (defined in Section 3.2) results primarily from electrical imbalances or asymmetries in the circuits formed by each wire of the pair. Since the metallic noise level depends on the longitudinal excitation, a measure of imbalance is the ratio of metallic noise to longitudinal noise (see Section 3.2 for a specific definition).

Imbalances result from differences between series resistances and shunt capacitances of the two wires of a pair. (Components of this capacitance are discussed by Miller.[11]) These imbalances determine the level of noise appearing on a subscriber circuit. Therefore, wire pair cables are manufactured to minimize asymmetries, and circuit terminations are designed to achieve good balance.[10,12]

Power induction influences telephone system design in two distinct ways. The 60- and 180-Hz spectral components, which usually dominate the induced signals, affect dissipation ratings, power arrangements, and signaling characteristics of telecommunication equipment interfacing with the loop plant.[6,13,14] The voiceband harmonics of 60 Hz have an impact on transmission quality. The harmonics usually arise from nonlinearities of the power distribution transformers, which, because of symmetry conditions, predominantly generate odd multiples of 60 Hz.[8,15–17] Among these harmonics, the "triple-odd" harmonics of 60 Hz, i.e., odd multiples of 180 Hz, are of particular interest because they tend to add in phase on all three phases of a multigrounded-neutral (MGN) power distribution system.

Diurnal variations in power system loads not only produce significant changes in induction levels but may also cause changes in spectral content.[6] For instance, an increase in the power system load increases the 60-Hz component of the current and produces greater 60-Hz induction in the telephone plant. However, harmonic levels may be reduced, because the increased power system current is accompanied by an increased voltage drop in the power lines. As a result of the increased drop, the voltage excitation of distribution transformer cores is slightly reduced, which leads to reduced harmonic generation.[13,16]

Although the above paragraphs highlight those aspects of induction phenomena most relevant to a basic analysis of the survey data, an appropriate measure of exposure length requires further discussion. From physical considerations it can be argued that total loop length* is the most direct measure of potential exposure, particularly in the case of measurements from the central office to an on-hook station. On the other hand, if measurements are made at a main station location, the choice between working length and total length is less obvious. However, examination of survey data indicated that main station noise distributions that used either working or total loop length as a parameter provided required information. Hence, we chose total loop length as the length parameter to be used in this paper. Figure 1 shows the distributions of loop lengths of assigned working pairs.†

Once the length parameter had been chosen, it was desirable to define long loops since they were most likely to have the highest induction.[2] For the 1980 survey, long loops were arbitrarily defined as those having total lengths greater than 20 kft; all remaining loops were considered short. Two main considerations suggested this breakpoint. First, based on the 1973 loop plant survey,[3] this definition

* Total length is the sum of working loop length plus all bridged tap length. Working length is the length of wire pair in which dc current flows when a station goes off hook; bridged tap length is the additional length of wire pair bridged onto the working length.[3]

† Throughout this paper, distributions are characterized with respect to the population of working assigned pairs, unless stated otherwise. In 1980 there were approximately 89,900,000 working assigned pairs in the Bell System, which excludes Southern New England Telephone and Cincinnati Bell.

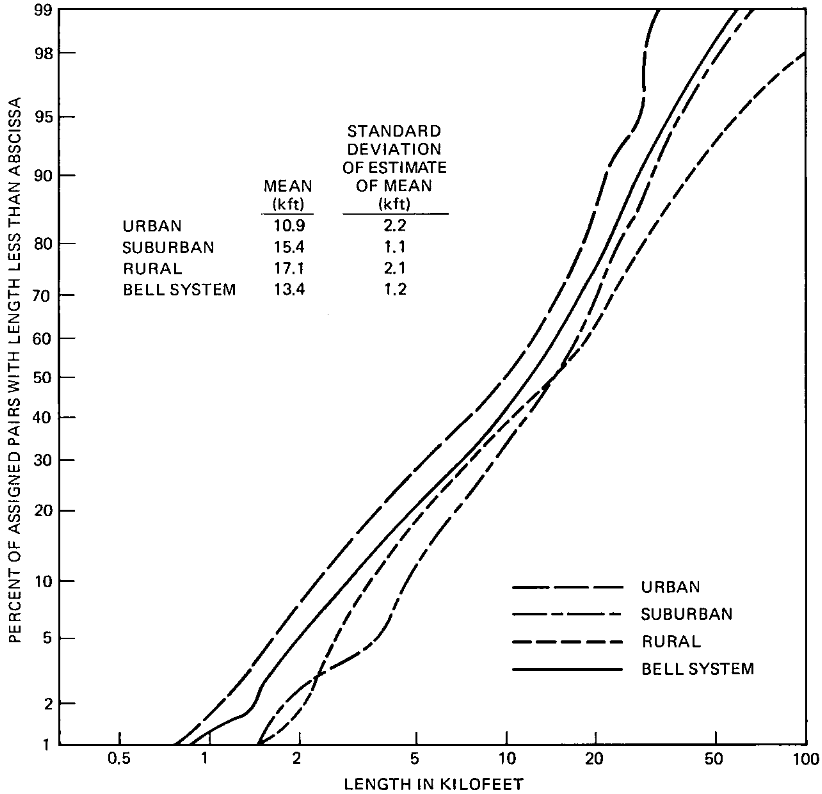

Fig. 1—Total loop length for urban, suburban, rural, and Bell System loop populations.

assured the selection of a reasonable number of long loops without unduly increasing the complexity or size of the sample. Second, the authors believed that a number of applications of the survey results would require separating the loop population at approximately 20 kft, since that is approximately the dividing line between loaded and nonloaded loops. For example, loop electronics that operate on nonloaded loops would serve the short loop population. Also, the increased use of subscriber carrier systems should continue to reduce the proportion of physical loops exceeding 20 kft in total length.

Since induced signal levels are a function of both exposure length and details of the power system configuration, the measured levels for a given length have a large variance.[7] In addition, for wire pairs significantly under 10 kft in total length, currents in local grounds will contribute a component to the noise[14] that is not length dependent. As a result, induced noise on wire pairs in areas with heavy power usage, such as industrial areas near power plants, may not show a strong length dependence until longer exposure lengths are reached. For very long exposures there is a decrease in the rate of increase of induced noise. Wire pairs can be modeled as lossy transmission lines.* As exposure lengths increase much beyond 30 kft, the mean level of induced signals increases much more with length than for exposures of intermediate length. This is a direct result of the attenuation of signals induced remotely from the observation point.

III. OVERVIEW OF SURVEY

3.1 Survey design

A major objective of the 1980 noise survey was to characterize statistically the induced voltages and currents present at central office and subscriber loop interfaces. An additional goal was to identify the small percentage of Bell System loops experiencing high induction levels, without using a large sample size. To accomplish this, we stratified the Bell System into urban, suburban, and rural wire centers. Urban wire centers were defined as those serving more than 1000 assigned pairs per square mile (ap/sq.mi.), suburban centers, between 45 and 1000 ap/sq.mi., and rural centers, less than 45 ap/sq.mi. This stratification assured representation of noisy loops, which were assumed to be the long loops (over 20 kft in total length) in the suburban and rural environments.

The survey sample was selected using a stratified, two-stage sampling scheme. The 36 sampled wire centers were geographically dispersed as shown in the appendix: 6 were urban wire centers, 18 suburban, and 12 rural. The loops to be tested were randomly selected from physical loops in a wire center. To limit the scope of the loop survey, we excluded loops providing special services or served by carrier systems. We tested 30 to 40 assigned pairs in each wire center. Table I summarizes the number of tested loops in the survey and compares the proportions of loops in the survey and Bell System populations. A relatively high proportion of rural loops was used to identify high induction loops. The appendix gives details on the survey design.

Once the measurements were completed, cumulative distributions and means for the various noise parameters were obtained for urban, suburban, and rural strata and for the Bell System. In addition, distributions were calculated for short loops in each strata and long loops in the nonurban strata. The statistics were calculated using a general ratio technique as described in the appendix.

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* These models can be developed from the results in a paper by Parker,[9] Appendix A of a paper by Wilson,[10] or Appendix E of a book by Smith.[18]

Table I—Composition of tested loop and Bell System loop populations

	Urban		Suburban		Rural		Subtotal	
	(a) Loops in Survey							
	Number of Tested Loops	Percent of Total Surveyed Loops	Number of Tested Loops	Percent of Total Surveyed Loops	Number of Tested Loops	Percent of Total Surveyed Loops	Number of Tested Loops	Percent of Total Surveyed Loops
Long loops	20	1.6	194	15.5	155	12.3	369	29.4
Short loops	161	12.8	450	35.8	276	22.0	887	70.6
Total	181	14.4	644	51.3	431	34.3	1256	100
	(b) Percent of Bell System Loops in 1980							
Long loops	6		12		3.5		21.5	
Short loops	43		29		6.5		78.5	
Total	49		41		10		100	

3.2 Noise parameters and their measurements

The measured and derived noise quantities, which are illustrated for a particular configuration in Fig. 2, are defined as follows:

1. *Noise to ground*, N_g, is the average of the tip and ring conductor voltages to ground. Conventionally, it is measured using a 3-kHz flat or a C-message weighted filter. The resulting rms values are expressed in units of dBrn and dBrnC, respectively. Figure 1 shows the conversion from rms voltage to dBrn; the same formula holds for the conversion from C-message weighted rms voltage to dBrnC.

2. *Metallic noise*, N_m, is the voltage across a nominal 600-ohm resistor connected between the tip and ring conductors of a pair. The magnitude of the metallic noise is expressed in units of dBrn or dBrnC. C-message weighted metallic noise is a direct electrical measure of the noise perceived by the customer.[19]

3. *Longitudinal current*, I_L, is the sum of the tip and ring short-circuit currents to ground. During the survey this current was determined from the voltage across a 10-ohm resistor connecting tip and ring to ground.

4. *Longitudinal impedance* is calculated as the ratio of longitudinal voltage to longitudinal current. Only the magnitude of the impedance is available from the survey data.

5. *Balance*, *B*, is 20 times the logarithm of the ratio of the C-message

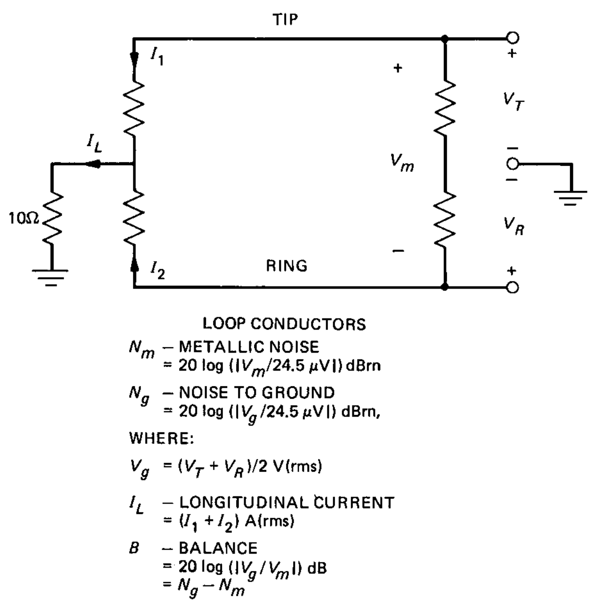


Fig. 2—Measured noise parameters.

weighted noise-to-ground voltage to the C-message weighted metallic noise voltage, or, equivalently, N_g-N_m (dBrnC).

A one-time set of measurements of the above parameters was made at main station and central office interfaces on 1256 loops at random times between 8:30 AM and 4:30 PM local time. These business hour measurements were made essentially simultaneously at both ends of the loop. The one-time business hour measurements at the main station provided the data most directly comparable to that of the 1964 survey.

To characterize the diurnal variation and spectral content of the noise parameters, automated measurements were made at central office and main station interfaces for at least 24 hours. Automated measurements at the central office were made for all noise parameters for about 950 of the tested loops. At the main station, automated noise-to-ground measurements were made for 195 loops.

Corresponding to one-time and automated measurements, two types of cumulative distributions are used to describe the electrical parameters. Consistent with previous surveys, business hour distributions are calculated from data obtained by the one-time measurements made on each loop. Daily maximum and daily median distributions are calculated from the maximum and median levels reached on each loop in a 24-hour period as determined by the automated measurements. In the following, business hour distributions are discussed unless stated otherwise.

3.3 Principal findings

Tables II and III summarize induction levels at main station and central office interfaces in terms of 3-kHz flat and C-message weighted noise to ground, longitudinal current, and metallic noise. (Distributions for the more important parameters are given in Sections IV and V. However, a normal distribution can be assumed for the other parameters as long as it is understood that the actual tails of the distributions are not modeled well. The distributions presented in Sections IV and V provided the basis for understanding the limitations of such models.) The estimates in Tables II and III generally have 90-percent confidence intervals of ±2 dB. The appendix discusses the derivation of these confidence intervals. Maximum levels in Tables II and III represent measured data obtained by considering both the 1980 survey and its pilot, conducted in 1979.

In addition to these statistics, other findings are as follows:

1. Noise to ground, metallic noise, and longitudinal current at the central office have been characterized for the first time (see Table II). The 90th percentile of the longitudinal current is −12 dBmA (0.25 mA).

Table II—Central office noise to ground, longitudinal current, and metallic noise as measured to on-hook stations

	Mean	Median	90th Percentile	Maximum*
(a) Central Office Noise to Ground (dBrn)				
Urban	65	64	79	100
Suburban	73	72	88	114
Rural	79	81	92	110
Bell System	**70**	**68**	**87**	**114**
Bell System (DM)†		**73**	**91**	
(b) Central Office C-Message Weighted Noise to Ground (dBrnC)				
Urban		<40	47	77
Suburban		46	66	85
Rural		54	69	83
Bell System		**41**	**61**	**85**
Bell System (DM)†		**45**	**62**	
(c) Central Office Longitudinal Current (dBmA)				
Urban		−40	−26	−2
Suburban		−30	−8	25
Rural		−23	0	21
Bell System		**−34**	**−12**	**25**
Bell System (DM)†		**−32**	**−7**	
(d) Central Office C-Message Weighted Metallic Noise (dBrnC)				
Urban			10	38
Suburban			17	46
Rural			19	53
Bell System			**15**	**53**
Bell System (DM)†			**21**	

* Largest values measured at any time as part of the survey.
† Results are from distributions of daily maximums on measured loops. All other statistics except maximums are for one-time measurements made during business hours.

2. The median of the *main station noise to ground* as measured during business hours was 61 dBrnC. Although this represents a measured increase of 2 dB since 1964, the increase cannot be considered statistically significant. The median of the daily maximum noise to ground, which had not been previously characterized, was 67 dBrnC. This difference in medians indicates a substantial diurnal variation in noise magnitudes. The 540-Hz component (ninth harmonic of 60 Hz) typically dominates C-message weighted noise to ground.

3. The 90th percentile of *main station metallic noise* on the loop plant, as measured during business hours, is 11 dBrnC, and 4 percent of the loops exceed the traditional reference levels of 20 dBrnC. When contrasted to the comparable 1964 distribution calculated from Gresh,[2] there is an increase of 1 dB in the 90th percentile value. However, this increase cannot be considered statistically significant.

Table III—Main station noise to ground, longitudinal current, and metallic noise as measured to main distributing frames

	Mean	Median	90th Percen-tile	Maximum*
(a) Main Station Noise to Ground (dBrn)				
Urban	86	87	103	111
Suburban	96	95	108	134
Rural	96	95	108	117
Bell System	**91**	**92**	**106**	**134**
Bell System (DM)†		**96**	**110**	
(b) Main Station C-Message Weighted Noise to Ground (dBrnC)				
Urban	—	57	70	90
Suburban	68	67	83	94
Rural	70	69	85	101
Bell System	**—**	**61**	**80**	**101**
Bell System (DM)†		**67**	**82**	
(c) Main Station Longitudinal Current (dBmA)				
Urban	9	9	20	30
Suburban	16	16	28	47
Rural	**15**	**17**	**28**	**47**
Bell System	**13**	**13**	**25**	**47**
(d) Main Station C-Message Weighted Metallic Noise (dBrnC)				
Urban			5	31
Suburban			12	37
Rural			**16**	**51**
Bell System			**11**	**51**

* Largest values measured at any time as part of the survey.
† Results are from distributions of daily maximums on measured loops. All other statistics except maximums are for one-time measurements made during business hours.

4. The 90th percentile of main station metallic noise measured to a central office quiet termination during business hours is 13 dBrnC. Comparable results for 1964[2] indicate a 90th percentile of 19 dBrnC. For reasonable assumptions on the variance of the 1964 estimates, it is concluded the 90th percentile level has decreased approximately 6 dB. This measurement of main station metallic noise includes both loop plant and central office contributions. Since the loop component has remained approximately constant, the improvement is attributed to a reduction in the central office contribution to the metallic noise.

5. *Central office metallic noise* measurements are usually of interest as an indication of metallic noise at the main station. Simultaneous measurements at the two interfaces indicate that central office metallic noise measured to an on-hook main station is generally higher than main station metallic noise measured to the quiet termination of the central office. Based on the measured central office diurnal variations,

daily maximum distributions of main station metallic noise are between 3- and 6-dB higher than the business hour distributions for corresponding percentiles.

6. Power lines induce significantly different levels of noise to ground and longitudinal currents in urban and nonurban loops. This difference exists because nonurban environments have longer loops and typically higher net power currents than urban environments. Urban short loop distributions of longitudinal noise parameters are typically 6- to 10-dB lower than the nonurban short loop distributions. The importance of loop length is illustrated by the fact that for a nonurban stratum the median noise to ground for short loops (with total lengths less than or equal to 20 kft) is about 15-dB lower than for long loops (with lengths longer than 20 kft).

IV. CENTRAL OFFICE RESULTS

The need for information on noise parameters at the interface between the central office and the loop has grown as new generations of solid state loop and trunk terminating equipment have appeared.[4,5] The 1980 Bell System noise survey provides the first relatively complete characterization of induction at this interface. Since central office loop testing systems, such as the Mechanized Loop Testing system (MLT),[20] usually make noise measurements to on-hook main stations, data obtained under similar conditions (see Fig. 3) are of primary concern. However, since central office metallic noise depends on the metallic termination at the main station, it can be argued that central office metallic noise with an off-hook station is a more relevant measure of transmission quality. For this reason, metallic noise data obtained with an ungrounded 632Ω resistor replacing the on-hook station set (see Fig. 3a) are also considered.

4.1 Central office noise to ground

The central office measurements confirm the postulates underlying the induction model used during the survey design (see Section II). Those postulates are: urban environments generally have shorter loops than nonurban; induction increases with loop length; urban loops, as a result of well-balanced power systems, have lower induction-per-unit length than nonurban loops; and nonurban long loops have the highest induction levels. Business hour distributions of central office C-message noise to ground given in Fig. 4 support the conclusion that urban loops have less induction that nonurban loops. The distributions of total loop lengths given in Fig. 1* confirm that urban environments have a higher proportion of short loops than nonurban environments.

* In every plot of cumulative distributions, a straight line would imply a normal distribution.

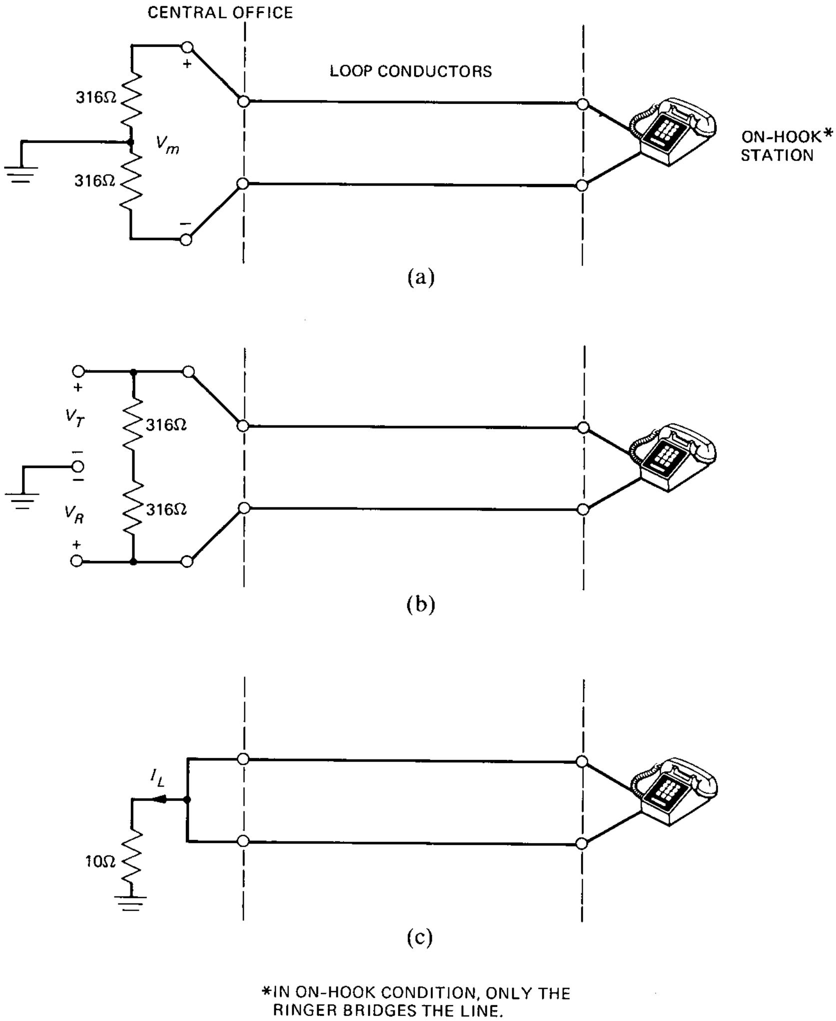


Fig. 3—Central office measurement configurations used in survey.

As a basis for further consideration of the postulates, Fig. 5 presents the noise-to-ground distributions for nonurban long and short loops, where long loops are greater than 20 kft in total length and short loops are less than or equal to 20 kft in total length. The urban long loop distribution, which is not shown, had a median of 42 dBrnC and a 95th percentile of 63 dBrnC. Because the variance associated with the estimator of this distribution is large, as a result of the limited number of urban long loops in the sample (Table Ia), the distribution is not plotted. (Because of the small sample size, urban long-loop distribu-

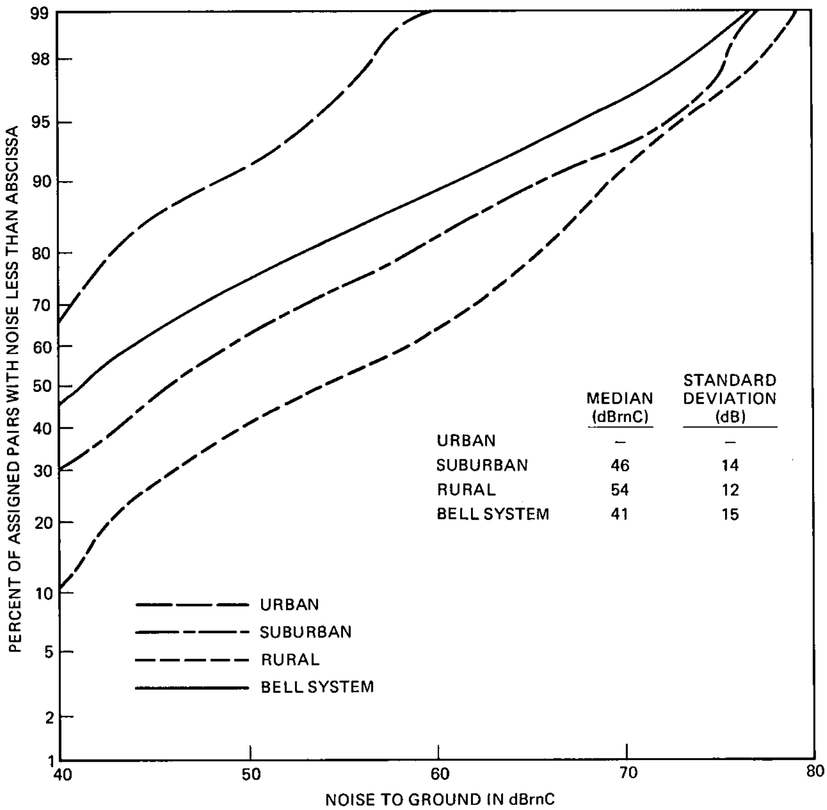


Fig. 4—Central office C-message weighted noise to ground for urban, suburban, rural, and Bell System loop populations.

tions will not be plotted at all in this paper.) However, a reasonable* normal fit to the distribution confirms that urban long loops have lower induction levels than nonurban long loops. A comparison of the nonurban long and short loops on Fig. 5 shows that induction generally increases with loop length. Based on the short loop distributions, the urban loops are seen to have lower induction levels than the nonurban environments. This is consistent with the assumption that urban power systems are typically well balanced.

Figure 6 illustrates the effects of diurnal variation by presenting the distributions of the 24-hour median and maximum levels of C-message and 3-kHz flat weighted noise to ground. The daily median and

* A reasonable fit implies that based on a Kolmogorov-Smirnov test, the fit could not be rejected at the 5-percent significant level.[21]

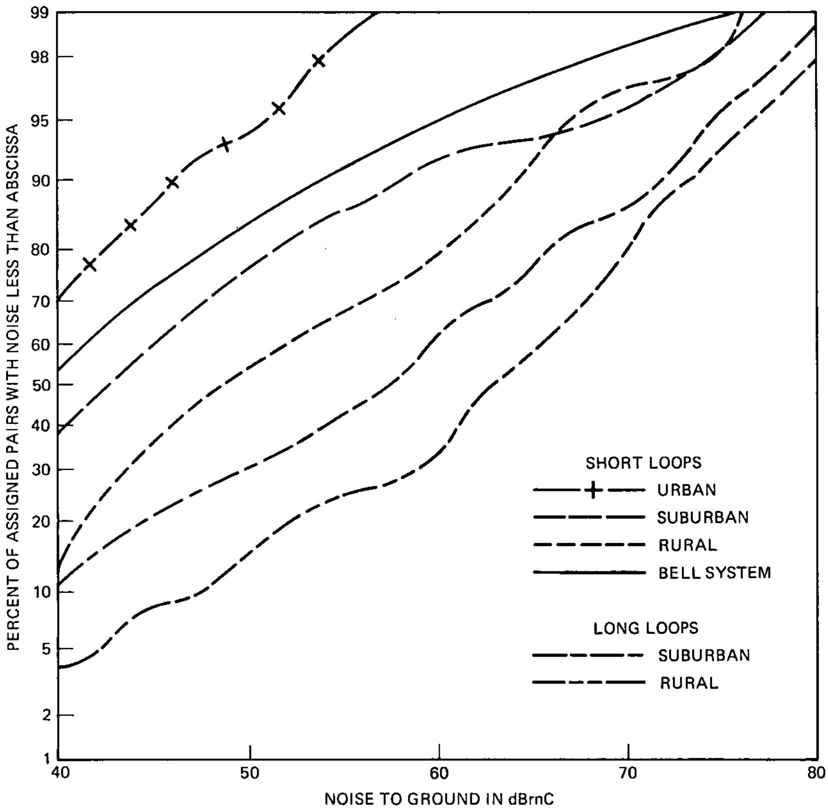


Fig. 5—Central office C-message weighted noise to ground for long (>20 kft) and short (≤20 kft) loops.

maximum distributions are derived from the median and largest reading, respectively, of the 24 hourly measurements made on each loop. The 3-kHz flat and C-message weighted distributions of maximums are displaced positively from the distributions of the daily medians by approximately 6 and 4 dB, respectively. The Bell System distribution of the 24-hour median levels is nearly identical to the business hour distribution of noise to ground calculated independently from one-time measurements, as can be seen by a comparison of C-message weighted distributions on Figs. 4 and 6.

Figure 7 presents the distributions of the noise-to-ground harmonic levels at the odd multiples of 60 Hz. (Even harmonics of significant amplitudes are sufficiently rare that their presence constitutes a powerful noise diagnostic tool.) The Bell System distribution of each component has been characterized by its median and quartiles. For each component the distribution was derived from the daily median

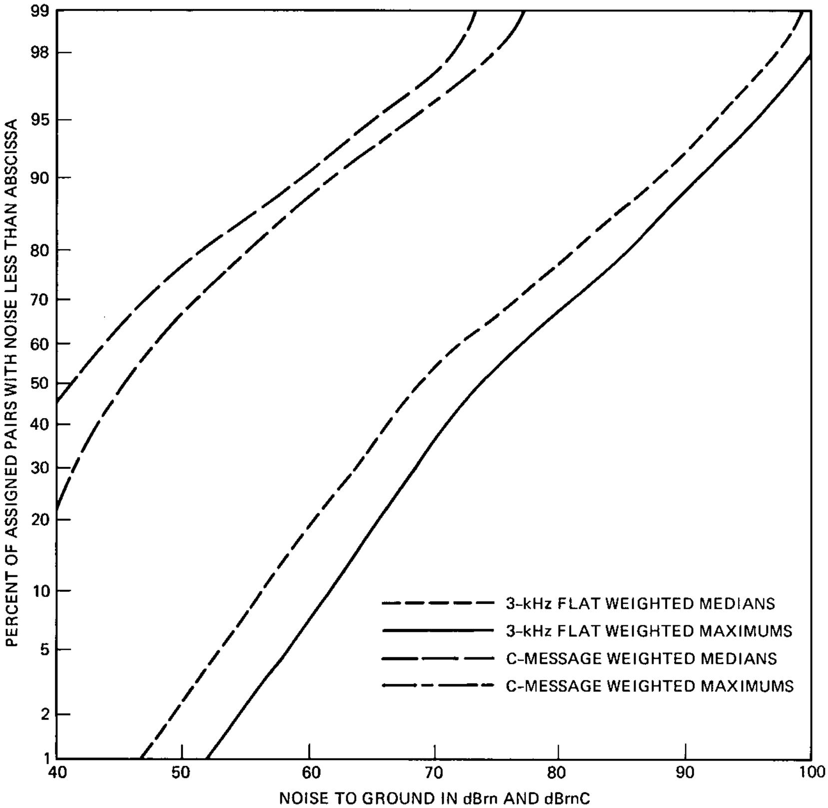


Fig. 6—Central office median and maximum noise to ground in a 24-hour period.

levels occurring on each loop. The spectral components decrease monotonically as frequency increases, except for the 9th and possibly the 15th harmonics, which are triple odd harmonic components, as defined in Section II. The ninth harmonic (540 Hz) generally proves to be the primary interfering frequency when C-message weighting is applied.

4.2 Central office longitudinal current

Because the majority of central office terminations have a low longitudinal impedance under operating conditions, longitudinal current provides a more direct characterization of longitudinal induction at the central office interface than does longitudinal voltage. Despite the importance of longitudinal current, only estimates based on the 1964 survey were available previously. The 1980 current data are summarized in Table II, and distributions are given in Fig. 8.

Longitudinal current and noise to ground are not independent

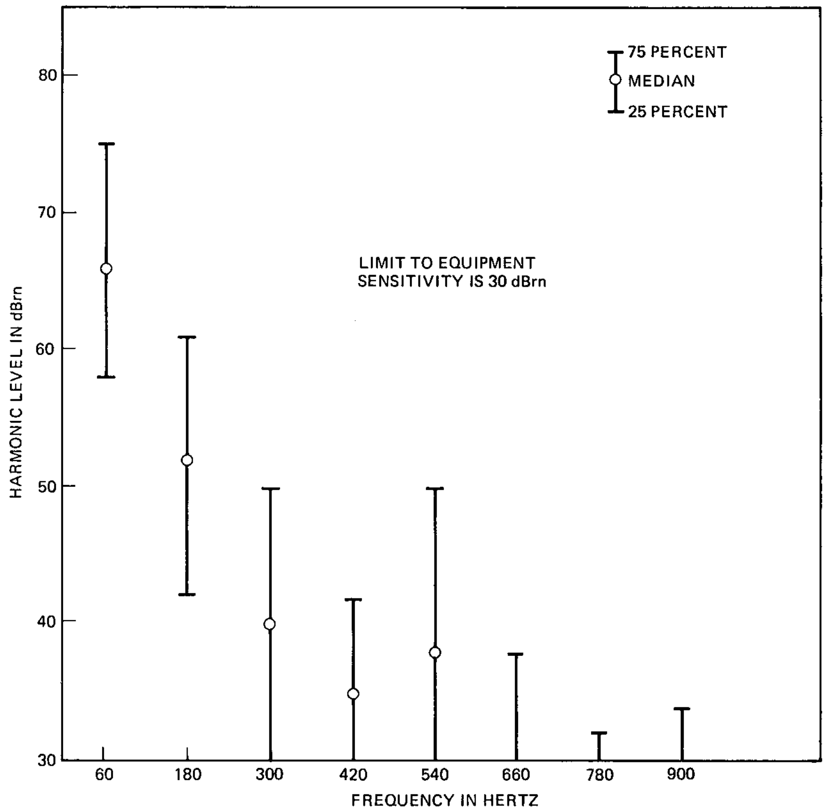


Fig. 7—Distributions of spectral levels of central office noise to ground.

variables, since they are related by the longitudinal input impedance of the loop. The magnitude of the longitudinal impedance is defined as the ratio of the magnitudes of central office noise to ground to longitudinal current. A scatter plot of longitudinal impedance at 540 Hz versus total loop length is presented in Fig. 9 for a subset of loops included in the survey, and is indicative of the behavior of the total loop population. Figure 9 shows that the impedance decreases essentially linearly with increasing loop length to beyond 30 kft, where transmission line loss effects become important. (A transmission line model with reasonable assumptions on loop resistance and capacitance to ground can be used to derive comparable results.)[18]

The longitudinal impedance at the central office is determined by the capacitance to ground of the cable pair, and the slope in Fig. 9 can be used to estimate the cable capacitance-per-unit length. The capacitance corresponding to the slope of Fig. 9 is 0.037 μF/kft (0.2 μF/mi).

Since longitudinal impedance decreases with loop length whereas

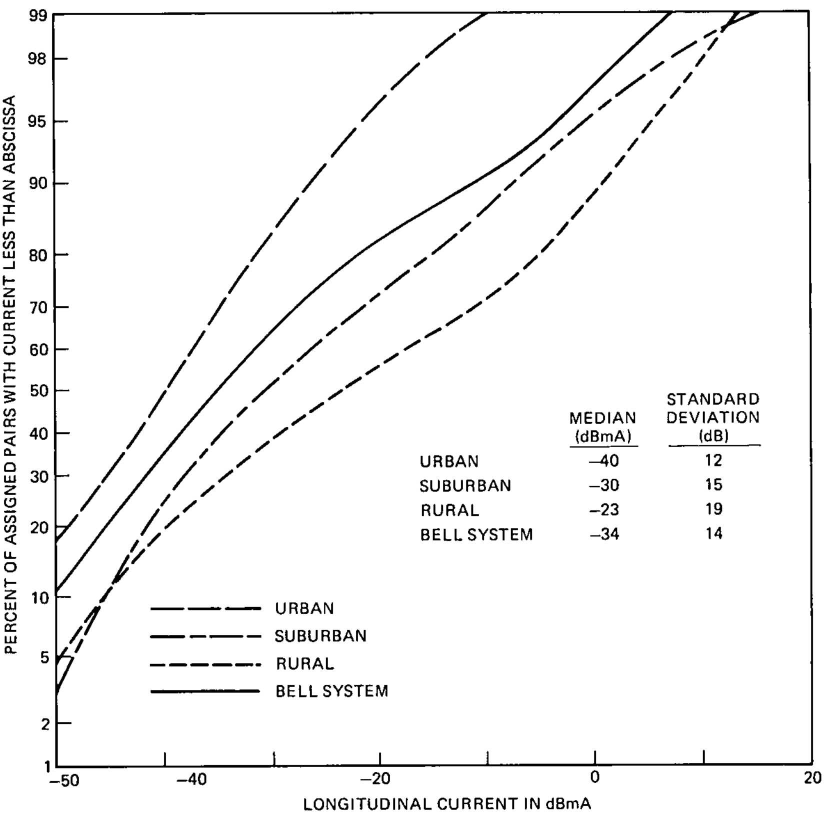


Fig. 8—Central office longitudinal current for urban, suburban, rural, and Bell System loop populations.

noise to ground generally increases with loop length (Section 3.1), longitudinal current should exhibit a stronger dependence on loop length than does noise to ground. To illustrate this point, Fig. 10 presents current distributions for nonurban long and short loops. The separation between current distributions for long and short loops in either nonurban environment is about 10 dB greater than the separation of corresponding noise-to-ground distributions (see Fig. 5).

The capacitive nature of the longitudinal impedance for a large percentage of loops, i.e., 95 percent are under 30 kft, causes the spectrum of the longitudinal current to differ from the spectrum of its driving source, the noise to ground. As a direct consequence, the separation between 3-kHz flat and C-message noise-to-ground measurements on each loop differs from the separation of the corresponding longitudinal current measurements. Figure 11 shows that a separation of 10 to 15 dB exists between 3-kHz flat and C-message weighted

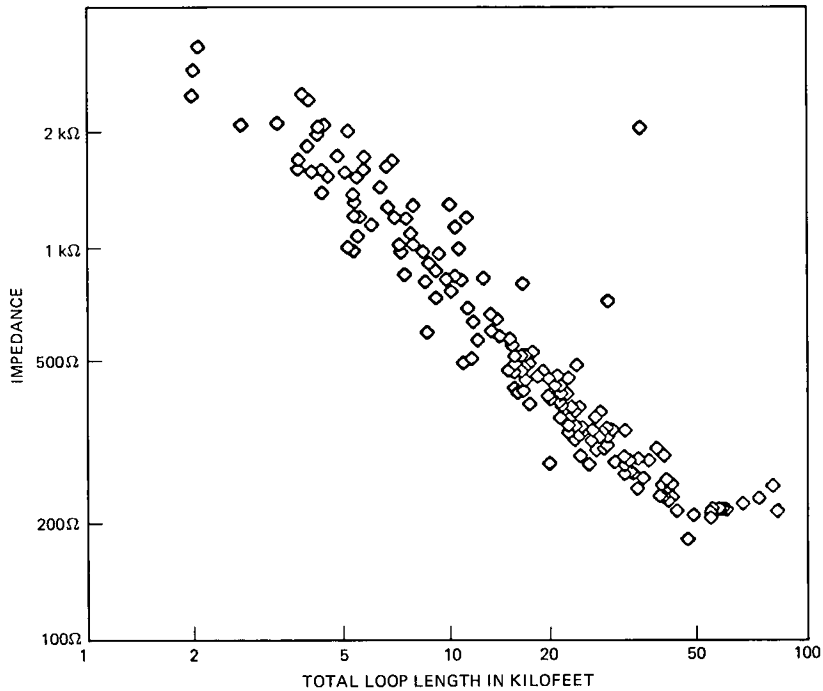


Fig. 9—Central office longitudinal impedance at 540 Hz versus total loop length.

distributions of longitudinal current. This contrasts sharply with the approximately 30-dB difference between 3-kHz flat and C-message weighted distributions of noise to ground (see Fig. 6).

4.3 Central office metallic noise

Metallic noise is produced by induced longitudinal voltages and currents acting on imbalances that are located at loop terminations and distributed throughout the loop. In addition, coupling from other loops in the cable can contribute to measured metallic noise. Figure 12 provides the central office distributions of metallic noise measured with on-hook station sets (see Fig. 3a). Figure 13 provides the central office distributions of metallic noise measured with a 632Ω termination replacing the on-hook station and simulating an off-hook station set. Included on the latter plot is the Bell System distribution of metallic noise for the on-hook condition. In general, it is found that the on-hook distributions for the various strata show significantly higher levels than the corresponding off-hook distributions.

Since induction increases with loop length and the imbalances are generally cumulative, metallic noise levels are generally greater on longer loops. Figure 14 presents the on-hook distributions of C-

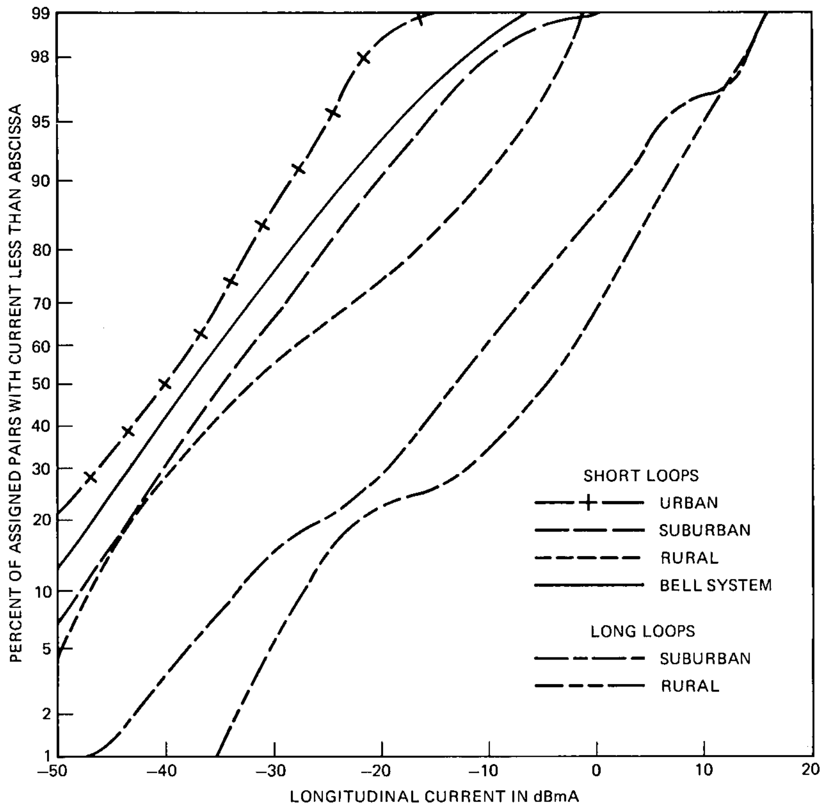


Fig. 10—Central office longitudinal current for long (>20 kft) and short (≤20 kft) loops.

message weighted metallic noise for nonurban long loops and for short loops. The distributions for the long and the short loops are widely separated at low noise levels, but with the exception of long rural loops, approach one another in the region of the upper tails. The long rural loops with greater than 30-dBrnC metallic noise represent about 0.15 percent of the total loops in the Bell System.

Bell System metallic noise distributions of daily median and maximum levels for on-hook conditions at the main station show the same general relationship observed for the noise to ground. Harmonic levels of central office metallic noise show a behavior similar to the noise-to-ground harmonic curve (e.g., a local peak occurs at 540 Hz).

V. MAIN STATION RESULTS

The 1980 noise survey measurements made at main station interfaces update and expand data on noise voltages, and provide new data

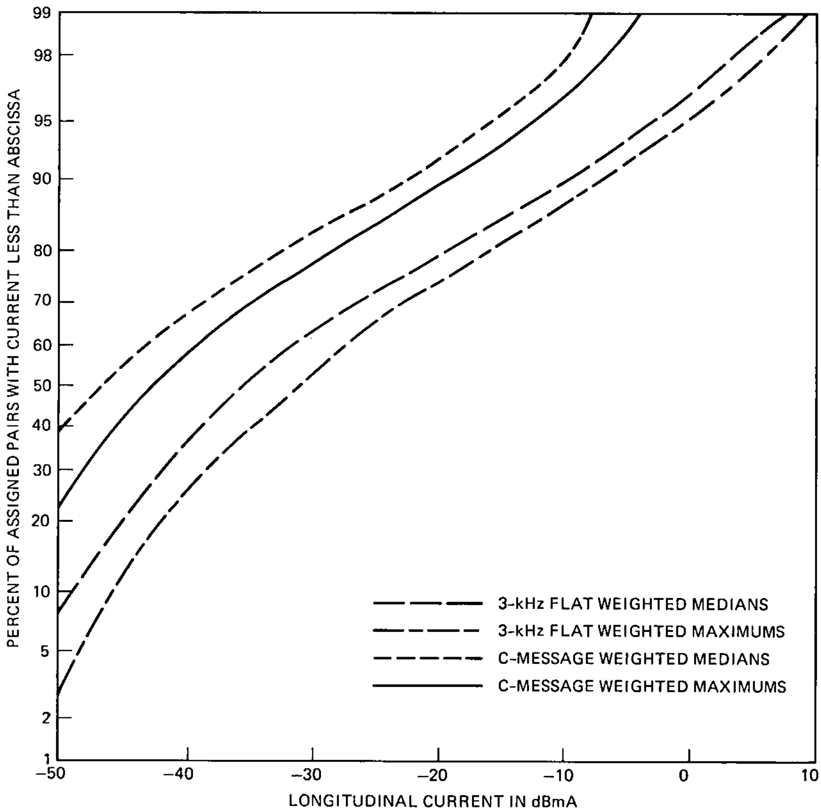


Fig. 11—Central office median and maximum longitudinal current in a 24-hour period.

on longitudinal currents. Since under normal operating conditions the loop has a balanced, grounded termination at the central office, main station longitudinal and metallic voltage measurements were made to balanced terminations at the central office. Two balanced office terminations were used. To determine the loop plant contribution to metallic noise, a well-balanced, grounded resistive termination was installed at the main distributing frame with the central office disconnected from the loop (see Fig. 15a). The second termination was established by calling into the quiet termination. The quiet termination is a 900Ω balanced test termination located at the central office. Metallic noise measurements made to the latter termination are influenced by noise present on intraoffice cables and any imbalance associated with these cables or the office quiet termination. To determine the maximum longitudinal currents that may exist at the main station,

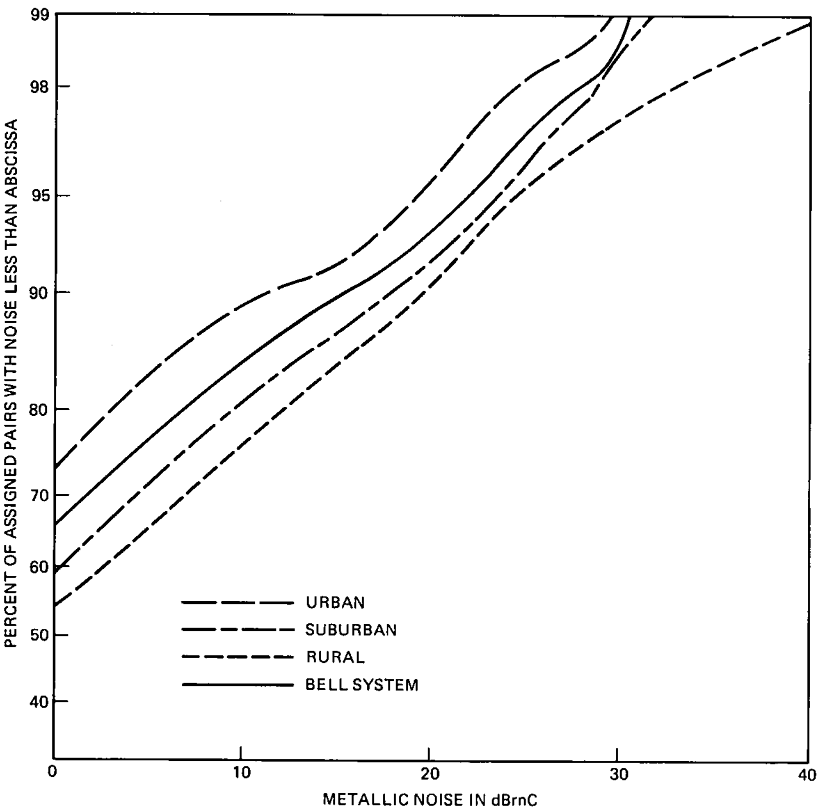


Fig. 12—Central office C-message weighted metallic noise to on-hook main station for urban, suburban, rural, and Bell System loop populations.

the short-circuit longitudinal currents were measured with tip and ring grounded through 10 ohms at the central office (see Fig. 15b).

Table II summarizes noise to ground, longitudinal current, and metallic noise data as measured at main station interfaces with a balanced, grounded termination at the main distributing frame. (Measurements to the quiet termination are considered in Sections 5.1 and 5.3.) The Bell System noise to ground medians of 92 dBrn and 61 dBrnC given in Tables IIa and b are found to be 2 dB higher than computed 1964 median levels. The 90th percentile of the metallic noise in Table IId is 1 dB higher than the 90th-percentile level of 10 dBrnC computed from 1964 distributions.[2] Thus a consistent pattern of higher 1980 levels is indicated; however, the confidence intervals on these estimates do not permit a statistically meaningful determination of the increase. Computations were necessary in order to compare the 1980 and 1964 data because Gresh presented the 1964 distributions

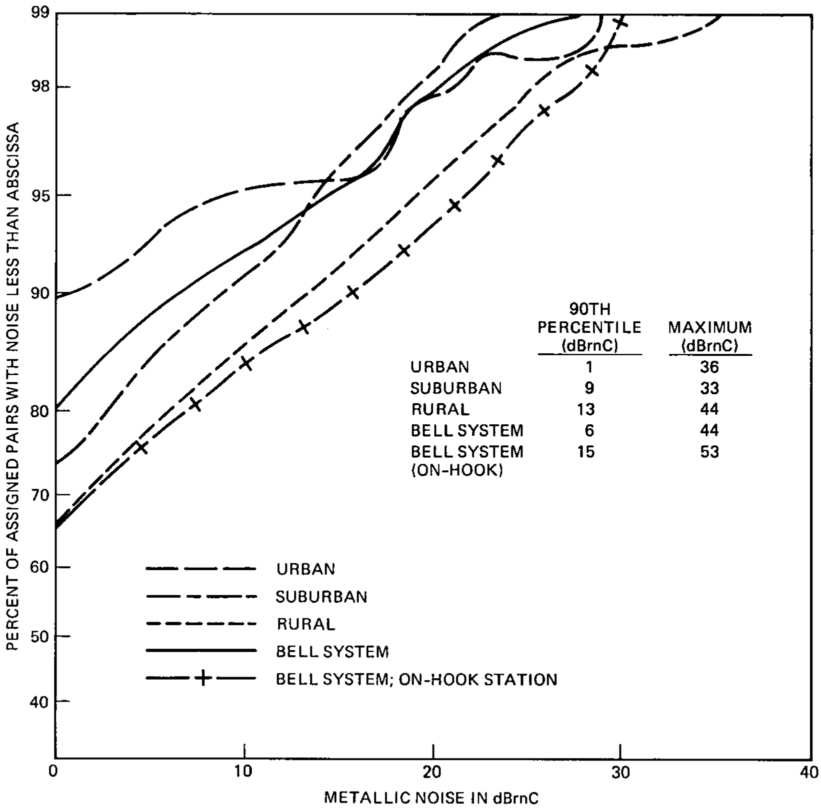


Fig. 13—Central office C-message weighted metallic noise to off-hook main station for urban, suburban, rural, and Bell System loop populations.

with respect to the population of main stations, whereas this paper presents distributions with respect to the population of assigned pairs. Transformation of 1964 distributions to an assigned pairs basis required using the distributions for the individual and party lines as published by Gresh and calculating weighted means of the percentiles for each noise level. The weights are the proportion of assigned pairs serving individual and party lines in 1964, 88 percent and 12 percent, respectively. The transformed distributions differed only slightly from those obtained directly from Gresh's distributions for individual lines.

5.1 Main station to ground

Figure 16 presents distributions for C-message weighted, main station, noise to ground as taken in 1980 during business hours. Four statistics are shown for each curve: the median, the mean, the standard deviation of the estimate of the mean (sdem), and the standard

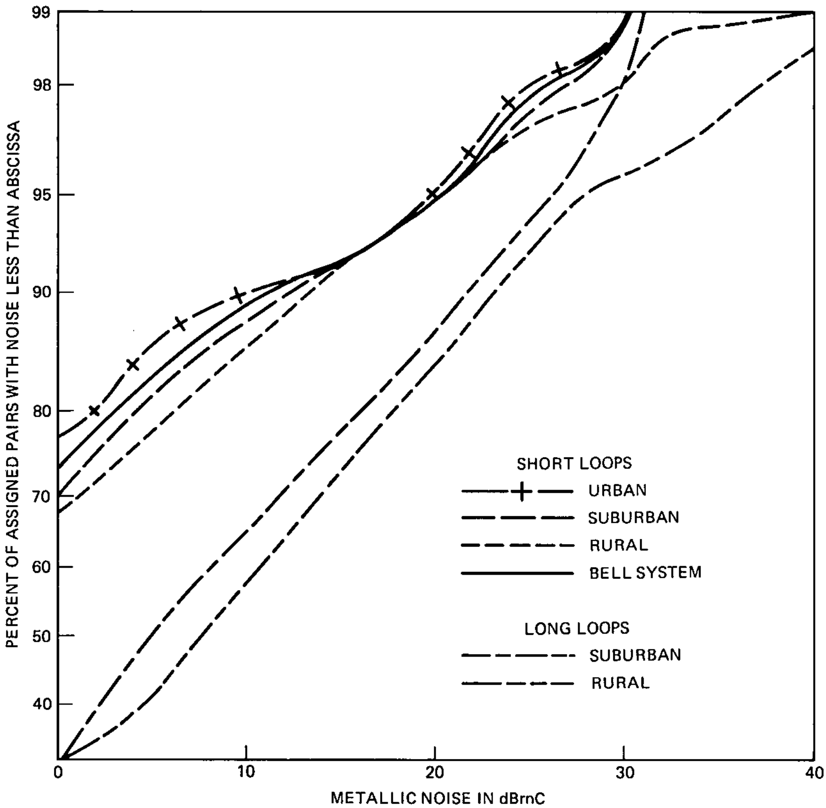


Fig. 14—Central office C-message weighted metallic noise to on-hook station for long (>20 kft) and short (≤20 kft) loops.

deviation of the distribution(s). The 90-percent confidence interval for the mean is 1.67 times the sdem. As an example of the significance of these distributions, Fig. 16 shows that the Bell System lines that exceed 90 dBrnC, a commonly recognized maintenance objective, are largely in nonurban areas. The percentage of Bell System loops exceeding 90 dBrnC is estimated to be 1.4 percent; the upper bound to the 95-percent confidence interval for this estimate is 4 percent.

Noise-to-ground measurements presented in this section were made to balanced resistive terminations at the main distributing frame (see Fig. 15a). The derived distributions are identical to those obtained using quiet terminations in the office. This implies that no significant longitudinal voltage source is present in intraoffice wiring.

Figure 17 presents the distribution of noise to ground for nonurban long and for short loops, where short loops are less than or equal to 20 kft in total length and long loops are greater than 20 kft in total

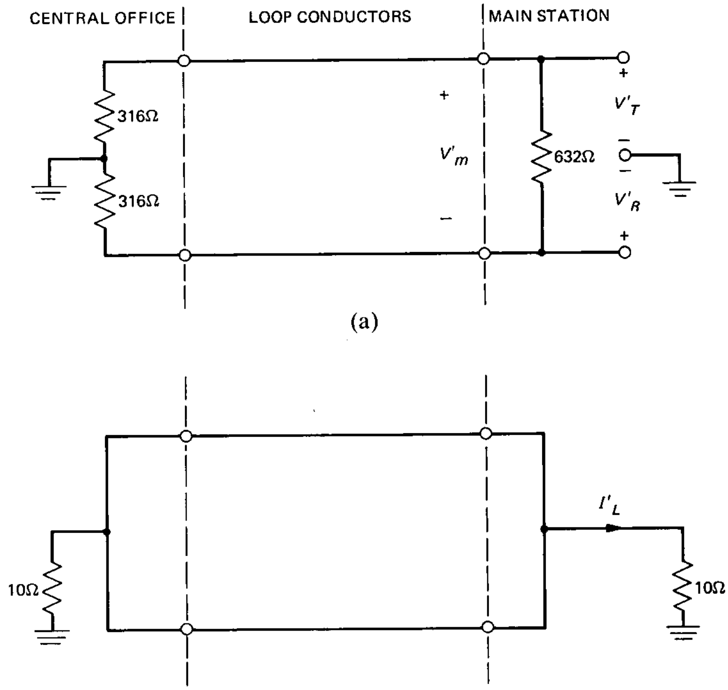


Fig. 15—Main station measurement configurations. (a) Metallic noise and noise to ground measurements. (b) Longitudinal current measurement.

length. The medians of long and short loops for a given nonurban population differ by 13 to 15 dB. As was the case for central office measurements (see Section 3.1), this dependence on loop length accounts for much of the difference between urban and nonurban distributions of noise to ground.

For typical subscriber loop terminations, which have a ground at the central office and no ground at the main station, the 3-kHz flat weighted noise to ground is the most direct measure of power exposure. Figure 18 presents the distributions of this important parameter. The 3-kHz flat weighted distributions are displaced by approximately 30 dB from the corresponding C-message weighted distributions of Fig. 16.

The changes in power load responsible for the central office diurnal noise variations also produce diurnal variations at the main station. The magnitude of the effect on 3-kHz flat and C-message weighted noise to ground is illustrated by Fig. 19, as well as by Table II. This information and the curves of Figs. 16 and 17 show that the business hour distributions are significantly lower than the daily maximum

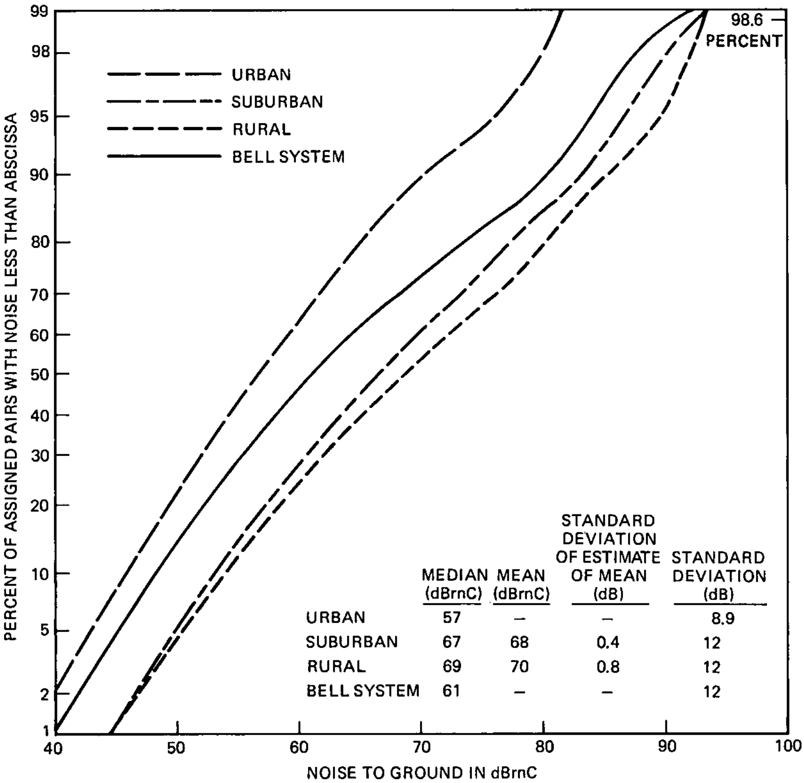


Fig. 16—Main station C-message weighted noise to ground for urban, suburban, rural, and Bell System loop populations.

distributions. At the 90th-percentile points, the difference is estimated to be 4 dB for the 3-kHz flat weighted data and 2 dB for the C-message weighted data. The differences remain essentially constant for percentiles greater than the 90th. These findings are consistent with the results of Heirman.[6]

Figure 20 describes the relative spectral content of main station noise to ground. For Fig. 20 all hourly measurements on all loops for which diurnal measurements were made were equally weighted. The harmonic levels for each waveform were divided by the 3-kHz flat weighted magnitude to obtain a normalized amplitude. An analysis of these normalized harmonic levels indicates that the spectral components at 60 and 180 Hz dominate the 3-kHz flat weighted voltage spectrum. When C-message weighting is applied to the measured data, the 540-Hz component is generally dominant. The remaining odd harmonics between 300 and 900 Hz (the 5th through the 15th har-

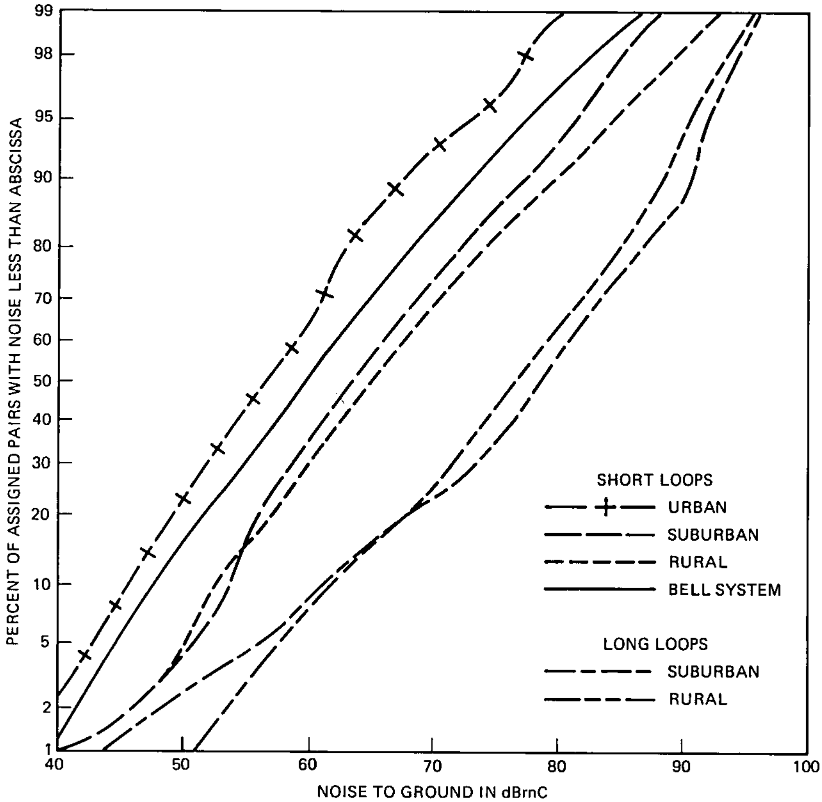


Fig. 17—Main station C-message weighted noise to ground for long (>20 kft) and short (≤20 kft) loops.

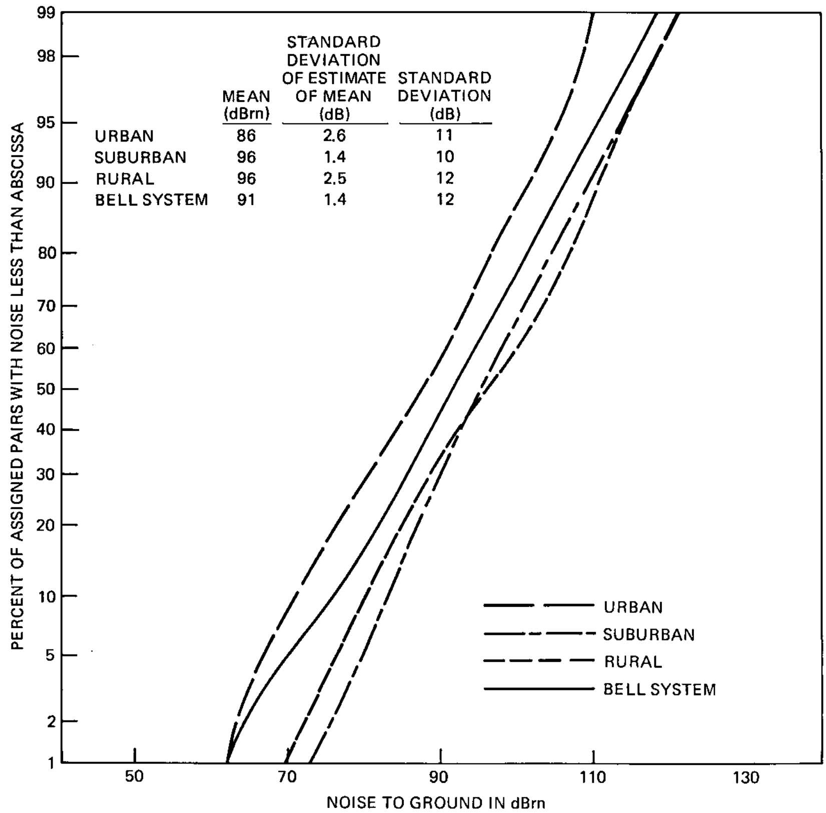
monic) are of lesser but approximately equal importance in determining C-message weighted noise levels.

5.2 Main station longitudinal current

Station equipment employing terminations with a low impedance to ground can be subjected to substantial induced longitudinal currents. The first measured characterization of these main station currents is summarized in Fig. 21. As a point of reference, the current on 1 percent of Bell System assigned pairs exceeded 80 mA (38 dBmA). Currents measured at the main station are significantly higher than at the central office because of the change in termination conditions (compare Figs. 3c and 15b).

5.3 Main station metallic noise

Figure 22 presents the main station C-message weighted metallic noise distributions obtained with a termination at the main distrib-



	MEAN (dBrn)	STANDARD DEVIATION OF ESTIMATE OF MEAN (dB)	STANDARD DEVIATION (dB)
URBAN	86	2.6	11
SUBURBAN	96	1.4	10
RURAL	96	2.5	12
BELL SYSTEM	91	1.4	12

Fig. 18—Main station noise to ground for urban, suburban, rural, and Bell System loop populations.

uting frame. Since 20 and 30 dBrnC are standard levels of reference,[22] the corresponding percentiles are indicated on Fig. 22. Figure 23 presents distributions for the nonurban long loops and short loops. Although nonurban long loops generally have higher longitudinal induction levels than short loops, Fig. 23 shows that except for the long rural loop distributions, the difference between the various metallic noise distributions becomes smaller in the upper tail of the distributions. A reasonable conjecture explaining the observed convergence of distributions in the region of 30 dBrnC is that operating company engineers make special efforts to limit metallic noise on high induction loops.

Up to this point the discussion has centered on noise measured with a balanced resistive termination at the main distributing frame. However, Bell System recommended objectives for metallic noise refer to

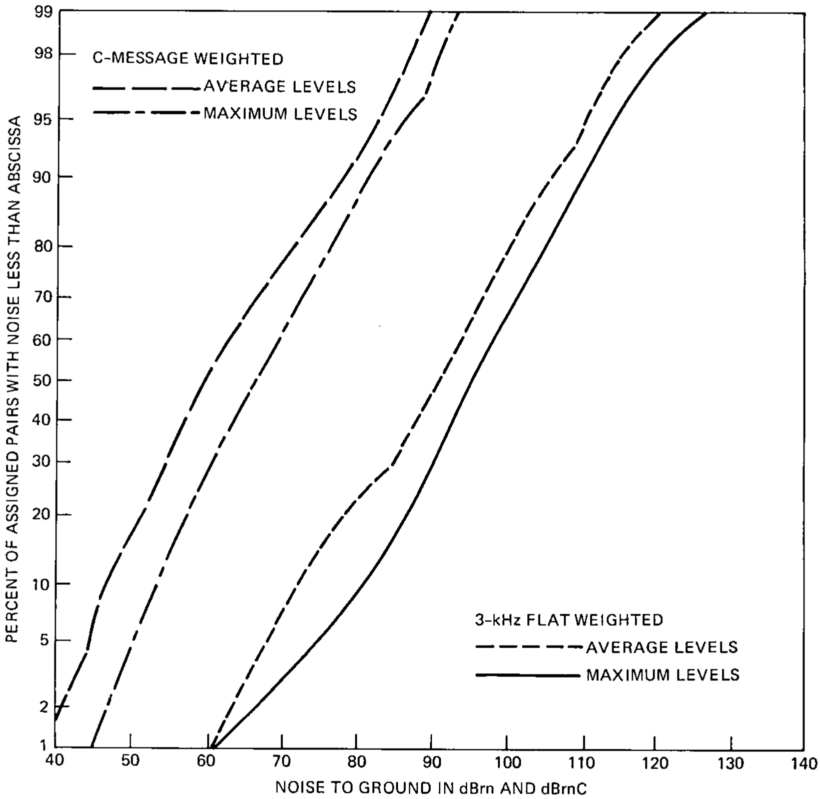


Fig. 19—Maximum and average main station noise to ground in a 24-hour period.

noise as measured to the central office quiet termination. Figure 24 presents main station distributions of metallic noise measured under this condition. Since the quiet termination is accessed by a call to the central office, the metallic noise is influenced by the imbalances and noise introduced by battery plant and intraoffice cables, and noise within the central office switch. The effect of these sources can be seen in Fig. 25, which presents the Bell System distributions for metallic noise measured with the main distributing frame and quiet terminations. For a given percentile, metallic noise measured to the quiet termination is generally greater than the metallic noise measured to the main distributing frame. The two distributions show a maximum separation of 6 to 7 dB but approach one another in the upper tail of the distributions. This apparent convergence, which was not evident in results obtained in 1964,[2] could be attributed to statistical uncertainties in the tails of the data.

In recent years the relationship between measurements of metallic

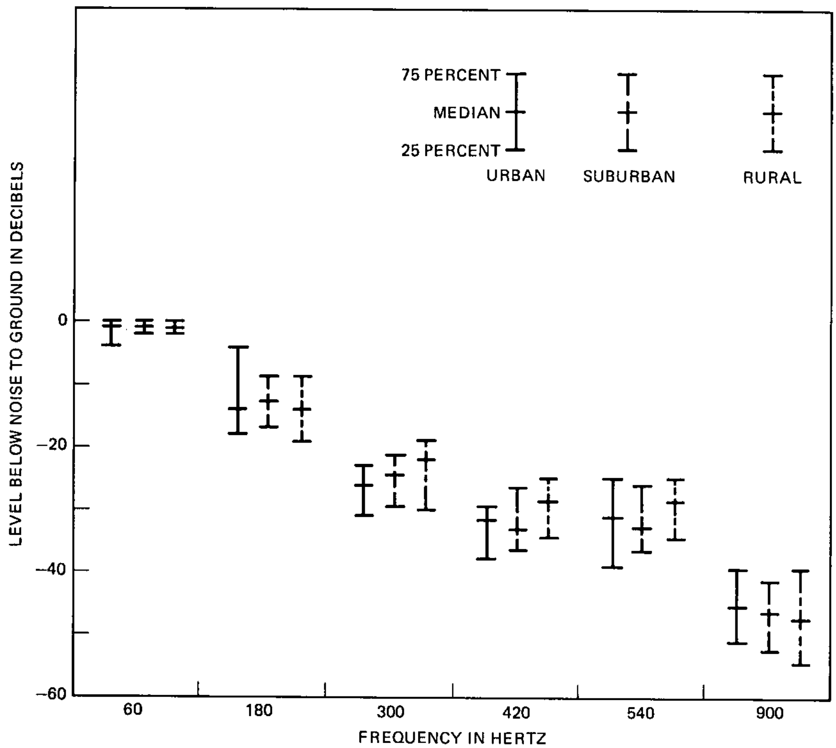


Fig. 20—Distributions of normalized spectral components of main station noise to ground.

noise at the central office and at the main station has been of considerable interest. Although much work remains to be done, Fig. 25 provides the basis for a comparison of four metallic noise distributions. Two curves present distributions of central office metallic noise measured with on-hook and simulated off-hook main station terminations (see Section 4.3). The second set of two curves present distributions of main station metallic noise obtained with quiet and main distributing frame terminations. Figure 25 shows that the distribution of central office metallic noise measured to an on-hook station is generally higher than the other distributions and that all the distributions approach one another in the upper tails. As can be seen, the two central office distributions bracket the main station measurements in the range of greatest interest. This suggests that the application of special main station terminations may permit estimates of the upper tail of the subscriber noise distributions from central office measurements.

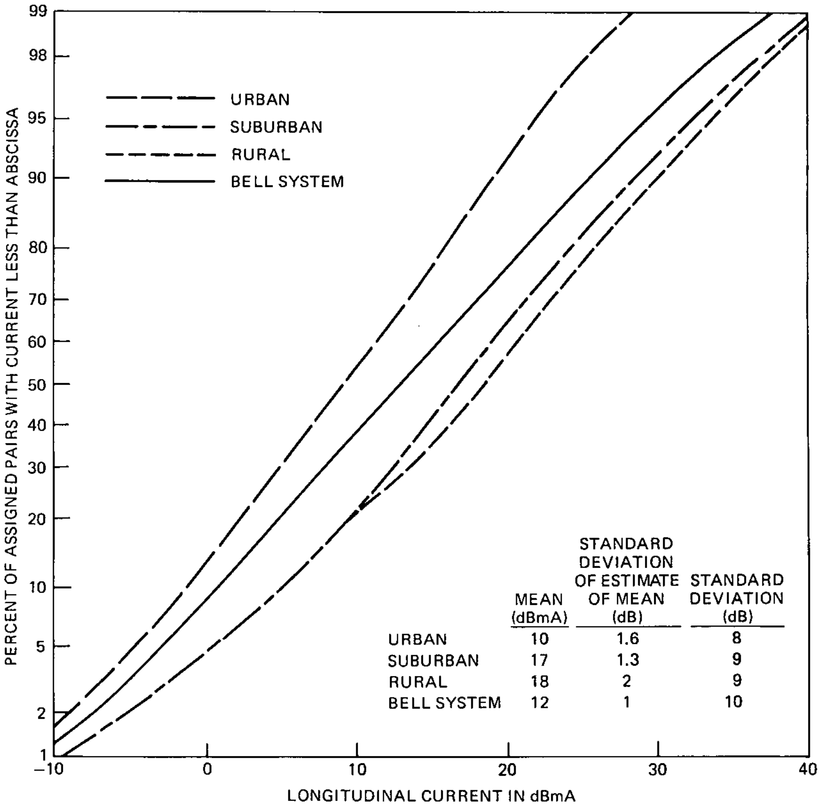


Fig. 21—Main station longitudinal current for urban, suburban, rural, and Bell System loop populations.

5.4 Balance

Balance is a measure of loop plant susceptibility to power system induction that complements the direct measures of power induction such as noise to ground and metallic noise. Balance as used in grade of service studies[22] and used by operating company engineers is defined as the difference in decibels between the main station C-message weighted noise to ground and metallic noise. This definition is implicitly based on the assumption that power induction is the main source of metallic noise. If this assumption is not satisfied—a condition that occurs when a significant component of metallic noise comes from sources such as crosstalk or office noise—then the result of a balance calculation may be misleading. Thus, to avoid this difficulty while still characterizing the susceptibility of the 1980 loop plant, balance was calculated only for those loops with a main station metallic noise of

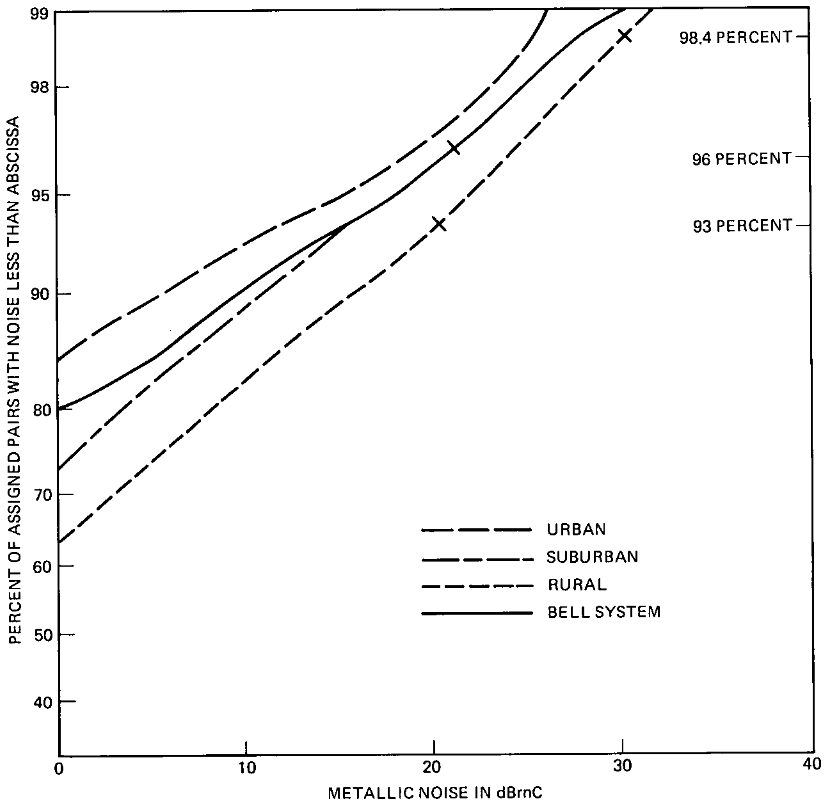


Fig. 22—Main station C-message weighted metallic noise as measured to main distributing frame for urban, suburban, rural, and Bell System loop populations.

greater than 0 dBrnC, a procedure which eliminated about 50 percent of the tested loops.

A scatter plot of balance versus noise to ground is given in Fig. 26 and suggests an interesting phenomenon. As we discussed in Section 4.3, metallic noise is generally below 30 dBrnC even on loops with high induction levels. Figure 26 indicates that the minimum balance improves as the induction increases and that the improvement in most instances is just sufficient to limit the worst-case metallic noise to 30 dBrnC. Since the increasing minimum balance cannot be attributed to a physical mechanism, this behavior suggests that operating company personnel have taken special measures to limit metallic noise to levels recommended in Bell Operating Company requirements. The cluster of plotted points on Fig. 26 with high induction and high balance indicates that a balance of 70 to 80 dB is achievable on noisy loops.

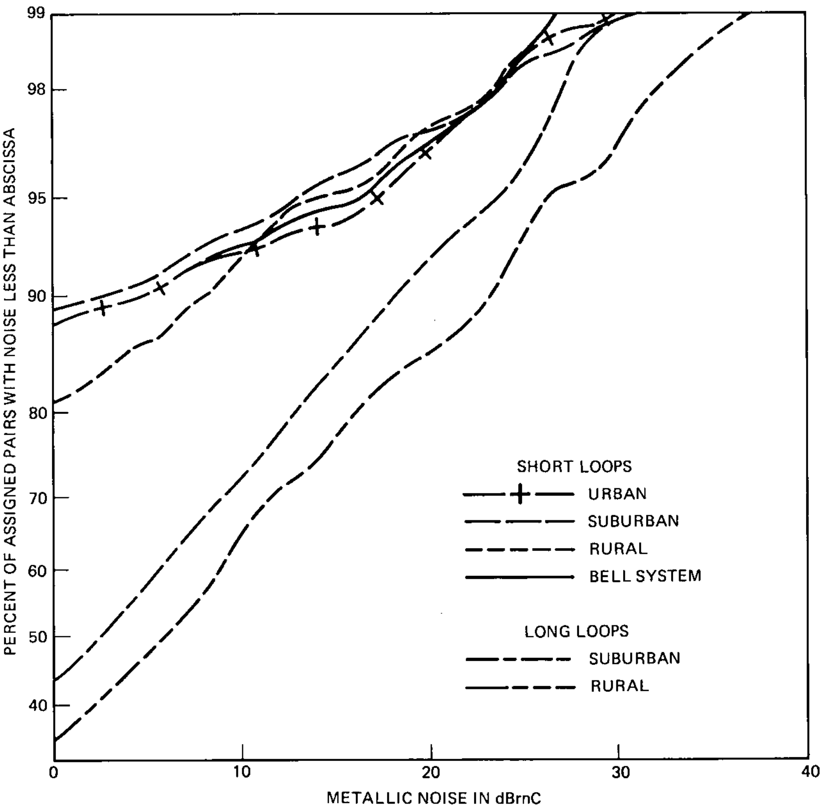


Fig. 23—Main station C-message weighted metallic noise as measured to main distributing frame for long (>20 kft) and short (≤20 kft) loops.

VI. SUMMARY

This report of the findings of the 1980 noise survey describes induced noise voltages and currents observed at subscriber and central office loop interfaces. The noise-to-ground, metallic noise, and longitudinal current measurements made as part of the survey have resulted in statistical descriptions of amplitude distributions, diurnal variations, and spectra of these quantities. As a result of the stratification used, differences between urban and nonurban environments have been identified, and the unique behavior of rural long loops has been highlighted. Moreover, it is evident that the operating company engineer plays an important role in controlling the metallic noise at subscriber locations.

This comprehensive characterization of the response of the loop plant to power line induction satisfies a pressing need for the data

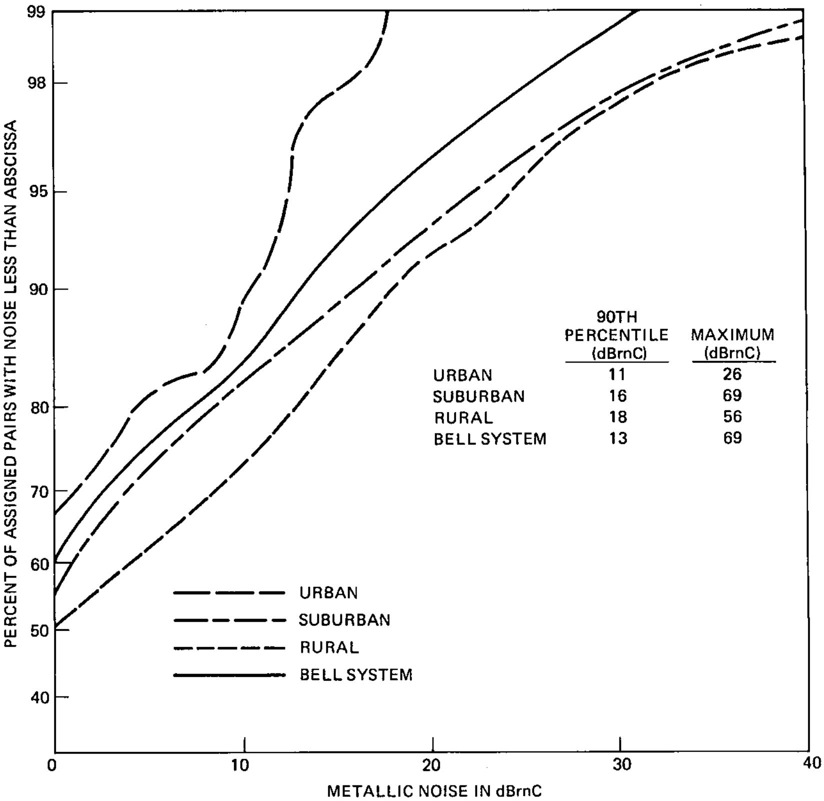


Fig. 24—Main station C-message weighted metallic noise as measured to quiet termination for urban, suburban, rural, and Bell System loop populations.

necessary to establish loop noise performance criteria and equipment design standards. In the long term, the insights into the inductive interference process provided by the 1980 survey will also lead to improved techniques for diagnosis and mitigation of induced noise problems.

VII. ACKNOWLEDGMENTS

The authors, together with G. A. DeBalko, J. M. Kornacki, and R. J. Biola, planned and executed the survey. A. O. Casadevall and D. K. Guha assisted in field work. Special thanks go to A. H. Carter, who supported the survey with his personal commitment, and to R. L. Carroll and W. H. von Aulock for their valuable technical and editorial reviews. The authors also wish to acknowledge the assistance of J. A.

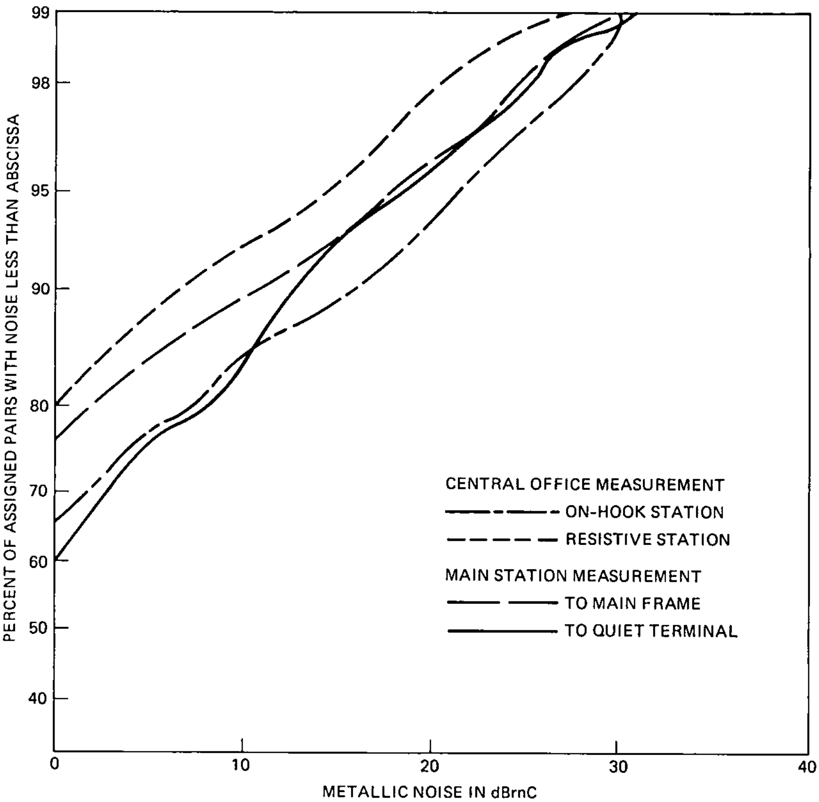


Fig. 25—Comparison of central office and main station metallic noise distributions.

Maher in formulating the statistical design and analysis techniques used. We also thank A. R. Eckler for his review of the appendix. Finally, the authors dedicate this paper to the memory of D. W. McLellan, who initially proposed the noise survey.

APPENDIX

Sample Design

This appendix describes the sample design of the 1980 noise survey. Section I details the method of selecting the sample and concludes with a description of the final sample. Section II describes the statistical techniques that were applied to the measured data and illustrates them with an example. The basic concepts of the sample design described here have been investigated in more detail by I. Nasell[23] and J. A. Maher.[24]

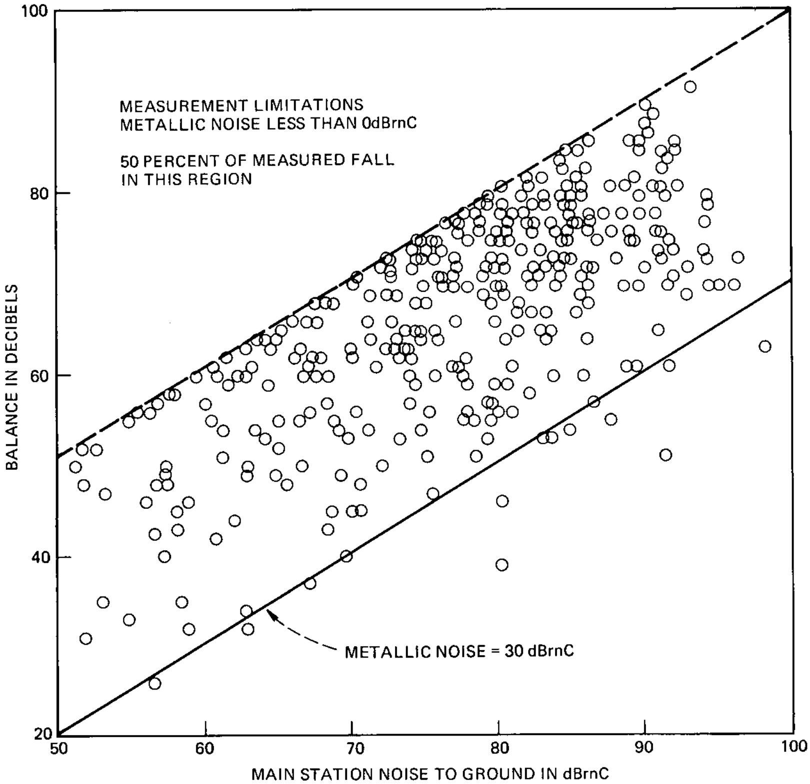


Fig. 26—Main station balance versus C-message weighted noise to ground.

A.1 Sample selection

A stratified, two-stage sampling plan was used to select sample units from the universe of working assigned pairs in the Bell System. Wire centers were stratified according to their assigned pairs per square mile (ap/sq.mi.). Urban centers served more than 100 ap/sq.mi., rural centers less than 45 ap/sq.mi., and suburban centers the intermediate densities. In the first stage of sampling, wire centers in each stratum were chosen with a probability proportional to size; in the second stage, assigned pairs were chosen randomly in each office. If a multiparty line was selected, then one of the main station locations was randomly chosen as the test point.

The next several paragraphs describe the method used to implement this sampling plan. The first step was to obtain a description of all the wire centers in the Bell System through the use of 1978 plant utilization data and a 1976 survey of the Bell System Outside Plant

Engineering records. Using the CLLI (Common Language Location Identifier) code as an index, comparisons were made between these two databases to obtain the number of assigned pairs and the area served by each wire center. (Neither database had sufficient information to be used alone.) Since CLLI codes can be reassigned as wire centers are created and restructured, it was necessary to verify that a unique wire center had been identified. If the 1976 and 1978 assigned pairs differed by less than 12 percent, i.e., the expected growth rate, it was assumed that a unique identification had been made.

The next step in implementation of the sampling procedure required defining stratum boundaries. This process was based in part on a characterization of central offices from which the sample of long loops had been selected for the 1964 loop survey.[2] The results of that study interpreted in light of the expected differences among the urban, suburban, and rural induction environments suggested a boundary

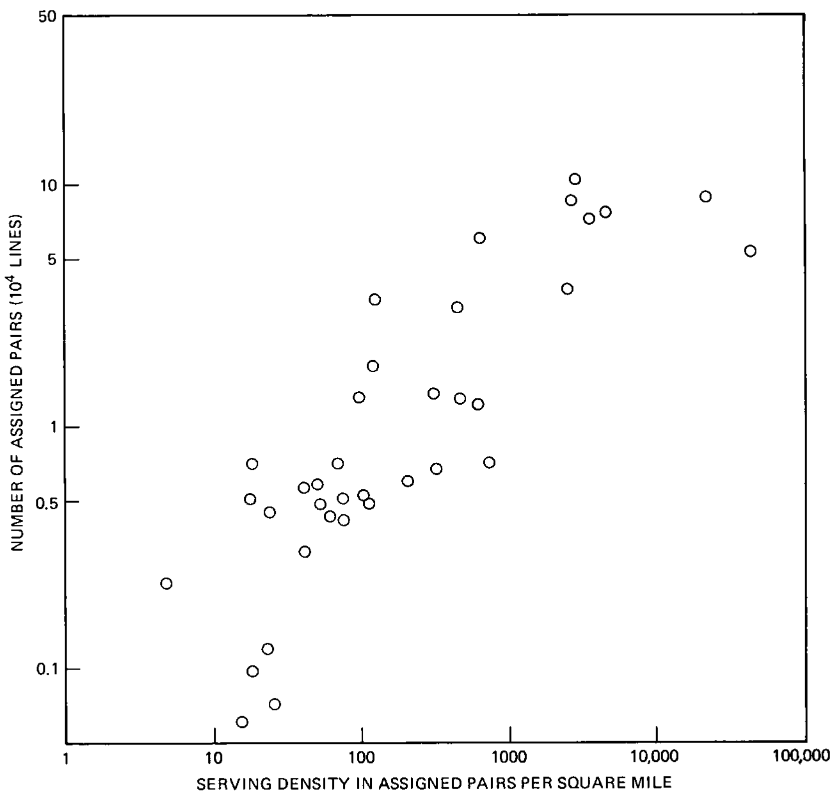


Fig. 27—Sampled wire center size versus serving density.

between rural and suburban offices of 45 ap/sq.mi. The choice of the urban boundary of 1000 ap/sq.mi. was based on the desire to balance the number of assigned loops in the urban and suburban categories.

Finally, a pilot survey in 1979, which included wire centers from the three strata, provided the basis for determining the final sample size. The criterion for the 1980 survey was that the mean noise to ground at the main station for each stratum should be determined with a 90-percent confidence interval of 2 dB. Although it is not immediately evident, post-survey analysis showed that the sample size arrived at based on this criterion was sufficiently large to include the noisier, longer loops of the rural and suburban populations. The final sample consisted of approximately 1256 loops, and the testing took 10 months.

Tables IV and V and Figs. 27 and 28 summarize the characteristics of the sample and locate the test sites. Table IV presents the proportion of loops and wire centers in each stratum and in the final sample. As we discussed in Section A.2, knowledge of the proportions of loops in each stratum is necessary to estimate statistical noise parameters. The relatively high porportion of suburban and rural loops in the sample results from the survey goal of characterizing the longer, noisier Bell System loops in a statistically meaningful way.

Surveys of the Bell System frequently use office size rather than office density as a criterion for stratification. Figure 27 illustrates the

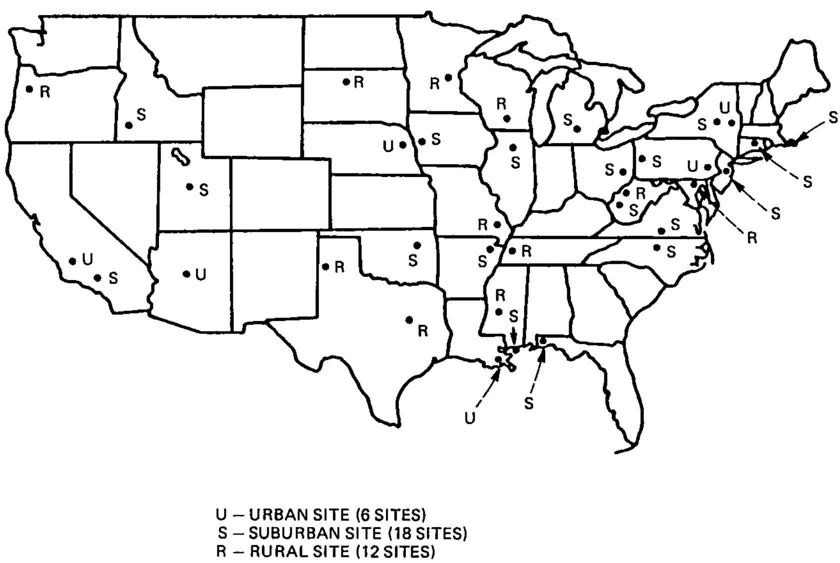


Fig. 28—Location of survey test sites.

Table IV—Percent of loops and central offices in urban, suburban, and rural environments

Sample	Urban (%)	Suburban (%)	Rural (%)
Assigned pairs in Bell System	49	41	10
Wire centers in Bell System	13	34	53
Loops in survey	14	51	34
Wire centers in survey	17	50	33

range of office sizes and densities present in the 1980 survey. Larger offices generally have higher serving densities, but as might be expected, a high correlation does not exist.

A.2 Estimates of statistics

This section describes the method used to estimate the means and cumulative distributions of the various noise parameters and the method used to estimate the variances of these estimates. The data used to form these estimates are assumed to have no significant experimental bias.

Ratio estimators were used to estimate means and cumulative distributions.[23] The form of the estimator given below is appropriate to the case of wire centers selected with a probability proportional to size and a random sampling of pairs within the centers.[23] The size assumed during the sample selection was the number of assigned pairs in each wire center in 1978. During the survey more recent information on office size was obtained. The formulas presented here and used in this report assume that the size of each wire center did not change from 1978 to the time of the survey. Nasell allows for a correction if wire center size did change; several distributions recalculated using this correction did not change significantly.

The forms of the estimators are summarized below. The statistic to be calculated for the Bell System population is assumed to be f. This statistic could be the mean of a parameter, or it could be the proportion of loops that have a parameter with a value less than a given level, x. Note that if f is this proportion of loops, then $f(x)$ is the cumulative distribution function. The ratio estimate of f can be written

$$f = \frac{\sum_{i=1}^{3} \left((w_i/n_i) \sum_j \bar{n}_{ij} \right)}{\sum_{i=1}^{3} \left((w_i/n_i) \sum_j \bar{d}_{ij} \right)}, \tag{1}$$

with

Table V—Summary of 1980 survey sites

Operating Company	Wire Center	CLLI	Environment	Test Dates
NET	Harwich, Massachusetts	HRWCMAMA	Suburban	4/28–5/2
SNET	Coventry, Connecticut	CNTYCTOO	Suburban	5/5–5/9
NJ Bell	Burlington, New Jersey	BURLNJBU	Suburban	2/18–2/22
Bell of PA	Sharpsville, Pennsylvania	SRVLPASH	Suburban	4/21–4/25
	Philadelphia, Pennsylvania	PHLAPAPE	Urban	12/1–12/5
C & P	Keedysville, Maryland	KDVLMDKV	Rural	3/17–3/21
	Montgomery, West Virginia	MTGMMVMG	Rural	4/7–4/11
	Oakhill, West Virginia	OKHLWVCH	Suburban	3/24–3/28
	Danville, Virginia	DAVLVADA	Suburban	3/31–4/4
Southern Bell	Pleasant Garden, North Carolina	GNBONCPL	Suburban	11/17–11/21
	Gulf Breeze, Florida	GLBRFLMA	Suburban	11/10–11/14
South Central Bell	Yazoo City, Mississippi	YZCYMSMA	Rural	10/20–10/24
	Ripley, Tennessee	RPLYTNMA	Rural	10/13–10/17
	Biloxi, Mississippi	BILXMSED	Suburban	10/27–10/31
	New Orleans, Louisiana	NWORLAMA	Urban	11/3–11/7
Southwestern Bell	Hale Center, Texas	HLCTTXHC	Rural	9/8–9/11
	Tyler, Texas	TYLRTXCH	Rural	9/15–9/19
	Campbell, Missouri	CMPBMOCH	Rural	9/29–10/3
	West Memphis, Arkansas	WMMPARMA	Suburban	10/6–10/10
	Tulsa, Oklahoma	TULSOKFI	Suburban	9/22–9/26
Pacific Bell	El Toro, California	ELTRCA11	Suburban	8/18–8/22
	Gardena, California	GRDNCA01	Urban	8/11–8/15
Pacific Northwest Bell	Dallas, Oregon	DLLSOR58	Rural	8/4–8/8
Mountain Bell	Springville, Utah	SPVLUTMA	Suburban	7/21–7/25
	Phoenix, Arizona	PHNXAZMA	Urban	8/25–8/29
	Twin Falls, Idaho	TWFLIDMA	Suburban	7/28–8/1
Illinois Bell	Bolingbrook, Illinois	BGBKILBK	Suburban	5/19–5/23
Ohio Bell	Uhrichsville, Ohio	UHVLOH92	Suburban	4/14–4/18
Michigan Bell	Lansing, Michigan	LNNGMIMN	Suburban	5/12–5/16
Northwestern Bell	Council Bluffs, Iowa	CNBLIADT	Suburban	6/16–6/20
	East Soderville, Minnesota	SDVLMNSO	Rural	5/26–5/30
	Mobridge, South Dakota	MBRGSDCO	Rural	6/9–6/13
	Omaha, Nebraska	OMAHNEIZ	Urban	6/23–6/27
New York Tel	Albany, New York	ALBYNYSS	Urban	12/8–12/10
	Clarksville, New York	CLVLYNCK	Rural	12/11–12/16
Wisconsin Bell	Richmond, Wisconsin	RCMDWI11	Rural	7/7–7/11

$$\bar{n}_{ij} = \left(\sum_k u_{ijk} x_{jk}\right) / m_{ij} \tag{2}$$

and

$$\bar{d}_{ij} = \left(\sum_k u_{ijk}\right) / m_{ij}, \tag{3}$$

where the sum over index i is a sum over the strata, the sum over index j is a sum over offices in a stratum, and the sum over k is a sum over loops in an office. The proportion of assigned pairs in stratum i is w_i. The number of loops measured in office j of stratum i is m_{ij}. The number of offices in stratum i is n_i.

The parameters u_{ijk} allow for the determination of f for any prespecified subpopulation of tested loops, e.g., long or short loops. If the tested loop is a member of the subpopulation, $u_{ijk} = 1$; otherwise $u_{ijk} = 0$. The special case of a ratio to size estimator assumes all tested loops are to be considered and $u_{ijk} = 1$ for all loops.

If the mean of a parameter is required, then x_{jk} is equal to the measured value of the parameter. If the proportion of loops with a parameter less than x is required, then $x_{jk} = 1$ if the measured value is less than x, and $x_{jk} = 0$ if the measured level is greater than or equal to x.

For a given stratum the statistic corresponding to f is

$$f_i = \frac{\sum_j \bar{n}_{ij}}{\sum_j \bar{d}_{ij}}, \qquad i = 1, 2, 3. \tag{4}$$

At the office level the statistic corresponding to f is

$$f_{ij} = \bar{n}_{ij} / \bar{d}_{ij}. \tag{5}$$

This report considers only the variance of the ratio-to-size estimator. For this case the variance is[23]

$$v^2(f) = (w_1)^2 v_1^2(f_1) + (w_2)^2 v_2^2(f_2) + (w_2)^2 v_3^2(f_3), \tag{6}$$

where $v_i^2(f_i)$ is the variance of f_i, $i = 1, 2, 3$.

The variance of f_i is

$$v_i^2(f_i) = \frac{1}{n_i(n_i - 1)} \left[\sum_{j=1}^{n_i} (f_{ij} - f_i)^2 \right], \tag{7}$$

where n_i is the number of offices in stratum i.

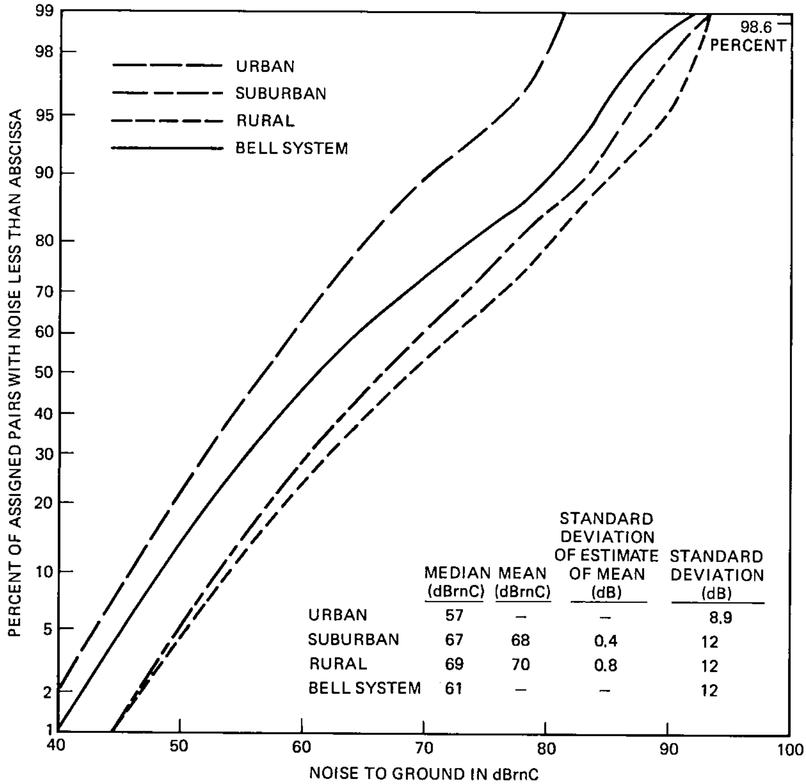


Fig. 29—Main station C-message weighted noise to ground for urban, suburban, rural, and Bell System loop populations.

As an illustration, Fig. 29 shows the distribution of the C-message noise to ground at the main station for the urban, suburban, rural, and Bell System environments. As is the case in Fig. 29, Bell System distributions for noise parameters generally lie between the distributions for urban and suburban environments with a larger variance than either.

Table VI presents statistics relevant to the median and 90th percentile of the rural and Bell System C-message weighted noise to ground. Two statistically equivalent confidence intervals are considered.[25] One confidence interval assumes that the quantile, x, is given and that a 90-percent confidence interval for the estimate of the percentile, $f(x)$, is to be calculated. This confidence interval is symmetrically located with respect to the estimate of the percentile and has a length of twice 1.67 times the sdem, where the sdem is the square root of the variance, v^2. The second confidence interval assumes that the percentile is given and that a 90-percent confidence interval for the quantile is to be determined. Since this confidence interval is not

Table VI—C-message weighted noise-to-ground statistics

(a) Median C-Message Noise to Ground

	Rural Loops	Bell System Loops
Quantile	69 dBrnC	61 dBrnC
LLCI*	67 dBrnC	60 dBrnc
ULCI†	70.5 dBrnC	62 dBrnC
CIP‡	±5%	±3%

(b) 90th Percentile C-Message Noise to Ground

	Rural Loops	Bell System Loops
Quantile	85 dBrnC	80 dBrnC
LLCI*	84 dBrnC	78.5 dBrnC
ULCI†	86.5 dBrnC	80.5 dBrnC
CIP‡	±2%	±1.5%

* Lower limit of 90% confidence interval for quantile.

† Upper limit of 90% confidence interval for quantile.

‡ 90% confidence intervals for percentile.

necessarily symmetric, upper and lower limits of the interval must be given.

Table VI indicates that for assigned pairs in rural environments, the 90th percentile of the C-message weighted noise to ground at the main station is 85 dBrnC. The confidence interval on the percentile means that for the given noise level of 85 dBrnC, the estimate of the percentile would have fallen between 88.7 and 91.3 percent for 90 percent of the possible samples that could be chosen by the sampling scheme described here. Equivalently, for the given percentile of 90 percent, the estimate of the noise level would have fallen between 78.5 and 80.5 dBrnC for 90 percent of possible samples.

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AUTHORS

Donald V. Batorsky, BSEE and MSEE, 1965, Ph.D. (Electrophysics), 1972, Polytechnic Institute of Brooklyn; AT&T Bell Laboratories, 1965–1983. Present affiliation Bell Communications Research, Inc. At AT&T Bell Laboratories Mr. Batorsky worked on the analysis of Electromagnetic Pulse coupling to large communication systems, low-frequency inductive interference into distribution telephone plants, and wideband access planning. Currently, he is a District Manager in the Distribution Capabilities and Architecture Division of Bell Communications Research, Inc., where he is responsible for loop cost modeling and architecture.

Michael E. Burke, B.S. (Electrical Engineering), 1977, Case Western Reserve University; S.M. (Electrical Engineering), 1979, Massachusetts Institute of Technology; AT&T Bell Laboratories, 1977—. Mr. Burke has worked on the interaction between power and telephone lines. He is currently working in the Exploratory Loop Systems Department. Member, IEEE, Eta Kappa Nu, Sigma Xi.