THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 57, No. 1, January 1978
Printed in U.S.A.

Physical and Transmission Characteristics of Customer Loop Plant

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(Manuscript received May 25, 1977)

A recent Bell System customer loop survey was jointly conducted by AT&T and Bell Laboratories. Bell Labs developed the sampling plan and performed the data analysis while AT&T assumed responsibility for the sample selection, data collection, and all intermediate data processing prior to analysis. This paper presents the principal physical composition and calculated transmission statistical characterization of customer loop plant as defined by that survey. Comparisons of data obtained from this survey and a similar survey made in 1964 are also presented.

I. INTRODUCTION

A recent Bell System customer loop survey was jointly conducted by AT&T and Bell Laboratories. Bell Labs developed the sampling plan and performed the data analysis while AT&T assumed responsibility for the sample selection, data collection, and all intermediate data processing prior to analysis.

This paper presents the principal results of this Bell System customer loop survey. This survey provides a statistical characterization of both the physical composition and the calculated transmission characteristics of customer loop plant. Comparisons of data obtained from the survey and a similar survey made in 1964 are also presented.

The characterization of the Bell System customer loop plant as defined by the 1964 loop survey was published in 1969 by P. A. Gresh.[1]

The current Bell System survey consisted of a simple random sample of 1100 main stations selected from the population of all Bell System main stations. Lines serving official telephones, foreign exchanges, dial teletypewriter exchanges (TWX), and special services were, however, omitted from the survey, as it was felt their design would not be representative of customer loop plant.

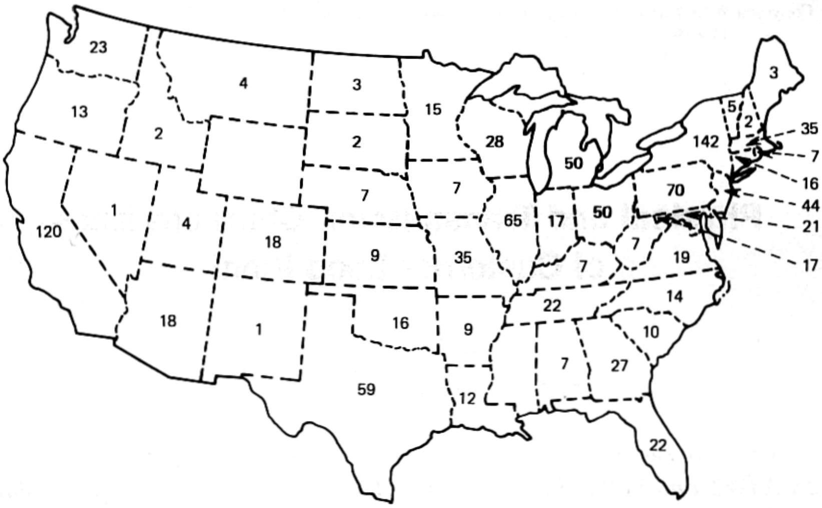


Fig. 1—Geographic distribution of sampled loops, 1973 customer loop survey.

Analysis of the 1100 sampled main stations consisted of encoding and keypunching the raw data to enable computer processing. A number of computer programs were then accessed which in addition to tabulating the physical composition of subscriber loops also calculated and evaluated the transmission performance of the customer loop plant.

II. DESIGN OF THE SURVEY

Definition of the sampling population, sampling plan, and sample size were based on the statistical model used in the 1964 loop survey. The population for the current survey was defined as all 57,293,521 Bell System main stations as of January 1, 1973. A simple random sample was drawn with the size determined so as to provide precision equal to that obtained in the 1964 survey. The precision was measured by the width of the 90% confidence interval for the estimated mean working length. The desired confidence interval (at 90 percent confidence level) of ±450 feet on the average cable distance to the sampled main stations dictated a sample size of 1100 randomly selected main stations. The actual sample produced a ±490 foot confidence interval. The survey had a wide geographical dispersion with every state except Wyoming contributing to the sample and heavier contributions from the metropolitan areas (Fig. 1).

III. LOOP SURVEY RESULTS—PHYSICAL COMPOSITION

Data obtained in the 1973 loop survey included a detailed physical makeup diagram of each of the sampled loops. Distributions of such

Table I — 1973 Loop Survey: Summary of main station characteristics

Main station quantity	Mean 1964	Mean 1973	90% Confidence limits on mean (±) 1964	90% Confidence limits on mean (±) 1973	Significant level for difference of means, %
Working length	10,613 ft	11,413 ft	476 ft	490 ft	99
Total bridged tap	2,478 ft	1,821 ft	172 ft	113 ft	99+
Working bridged tap	228 ft	121 ft	74 ft	53 ft	95
Airline distance	7,758 ft	8,410 ft	386 ft	395 ft	95
Working length airline distance	1.50	1.51	.03	.05	<80

Note: Drop wire excluded except when individual lengths exceed 400 feet.

items as type of cable construction, composition by gauge, pair size of cables and grade of service (individual or multiparty service) distribution were generated in addition to such physical quantities as working length to main station and total bridged tap. These quantities are defined in the illustration on the next page. Similar data was gathered in 1964 and a comparison of the two surveys had been made to detect changes in

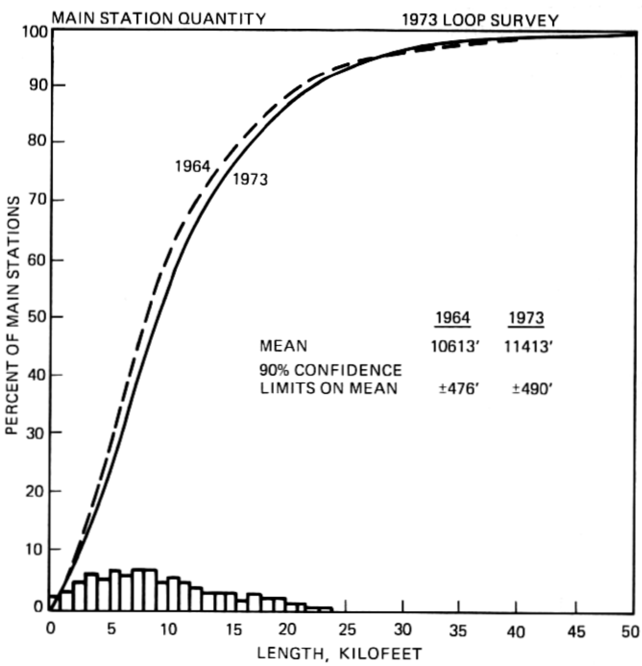


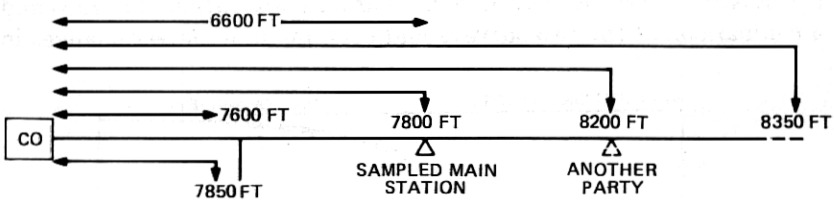
Fig. 2—Working length to main station.

plant composition over the intervening 9 years between the two surveys.

Table I gives the means and confidence limits for the principal physical properties of both the 1964 and 1973 surveys and the level of significance for the observed differences. Cumulative distributions of these quantities are presented in Fig. 2 through 5. The distribution of working bridged tap is not given, since 93 percent* of the sampled main stations were served by loops having zero working bridged tap and consequently the distribution is not particularly useful.

As Table I indicates, the estimated average working length from the central office to the main station is 11.4 kilofeet with 90 percent probability that the true mean value lies within ±490 feet of this estimate. Notice that this is 800 feet longer than the average in 1964 and that this observed increase can statistically be said to be a true increase.

Loop Sketch Showing Main Station Quantities



Main Station Quantities

Working length to sample (WL)	7800 ft
Total bridged tap (TBT)	800 ft
Working bridged tap (WBT)	400 ft
Airline distance to sample (AL)	6600 ft
Working distance/airline distance (ratio)	1.238

Analyses of principal loading characteristics of loop plant are given in Table II. As indicated, the percent of loaded loops has increased from 16.4 to 22.9 percent. The majority of this 6.5 percentage point increase is attributable to an increase in loops requiring loading (main stations served by loops over 18 kilofeet in length). A second contribution to the increase is attributed to the fact that greater care has been taken to assure that loops in excess of 18 kilofeet are loaded (long nonloaded loops have decreased from 1.5 percent to 1.0 percent). The final contribution

* 92 percent of the sampled main stations were individual lines and 14 percent of the 8% party-line stations were working alone.

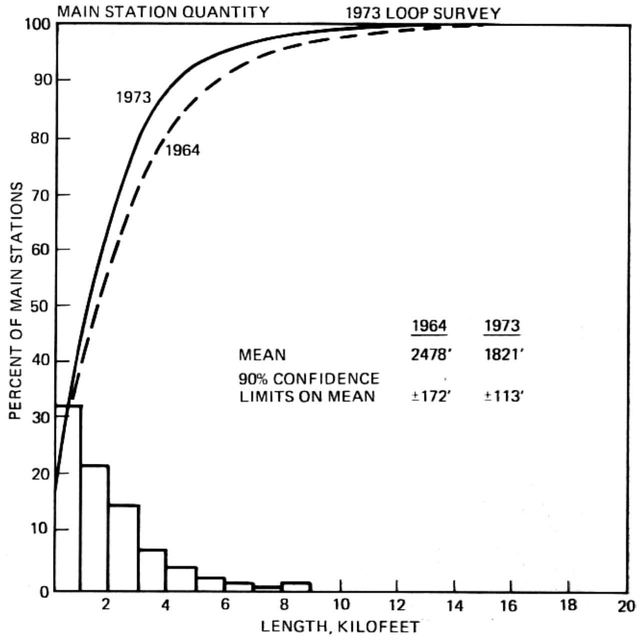


Fig. 3—Total bridged tap.

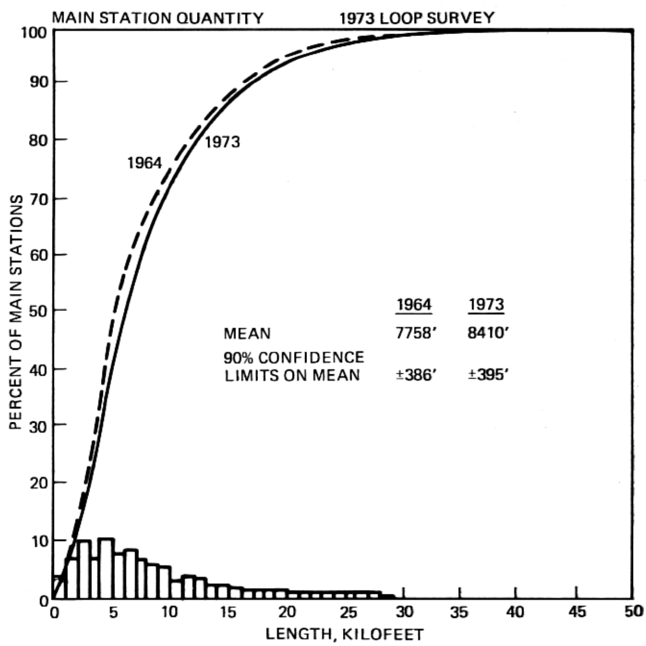


Fig. 4—Airline distance to main station.

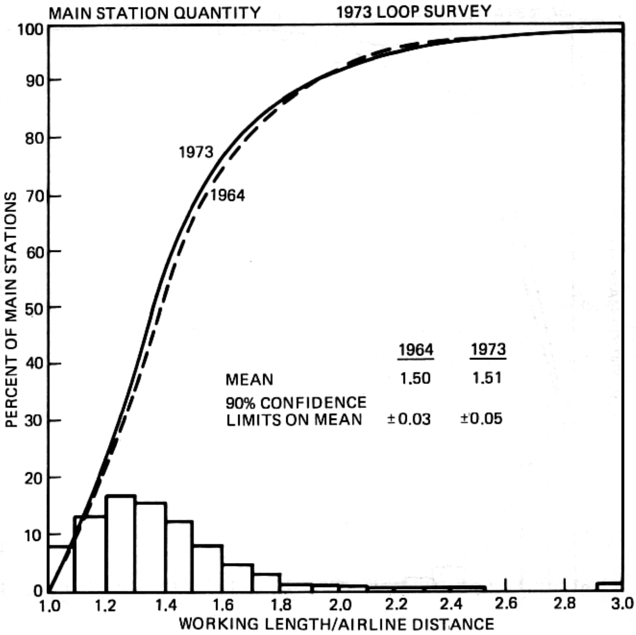


Fig. 5—Ratio of working length to airline distance.

to the increase in loaded loops is the fact that the percentage of main stations served by short loaded loops has increased (from 4.6 percent to 6.7 percent). This increase in short loaded loops can not be accounted

Table II — 1973 Loop survey: Summary of principal loading information

Main stations served by	1964 % MS	1973 % MS	1973 90% Confidence Interval (±%)	Change Since 1964 Level of Significance
Loaded loops	16.4	22.9	2.1	99+
With H88	15.5	22.6	2.1	99+
With loading other than H8	0.9	0.3	0.2	93
Less than 18 kf central office to main station and loaded*	4.6	6.7	1.2	97
Having load spacing deviations exceeding ±500 feet	5.3	8.6	1.4	99+
exceeding ±120 feet†	NA	18.5	1.9	—
Nonloaded loops	83.6	77.1	2.1	99+
Long nonloaded loops (>18 kilofeet)	1.5	1.0	0.5	<80

† The normal confidence intervals for percentages close to 0 are not meaningful and so are indicated by (—).
* Based on distance from CO. to sampled main station and does not necessarily indicate improper design.

for by an increase in PBX/centrex services (PBX/centrex service has increased from 1.8 percent in 1964 to 2.5 percent in 1973).

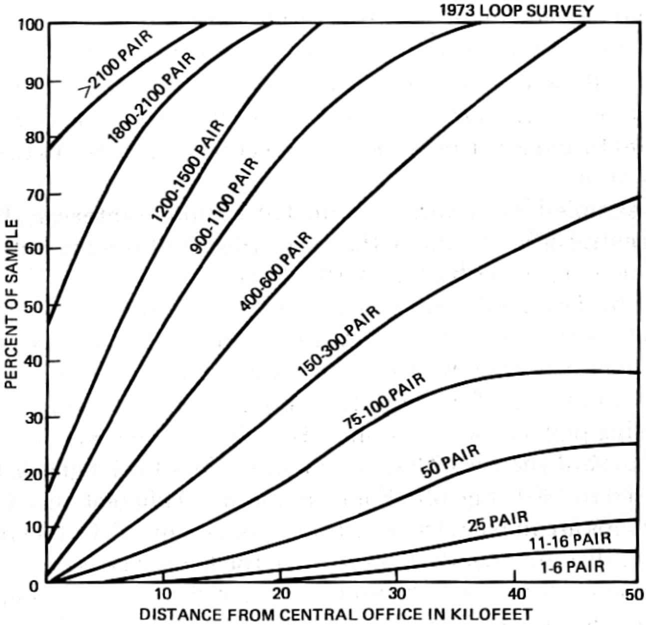
Survey data analysis also provides information on loop plant composition by gauge, pair size, type of construction (aerial, buried, or underground), and grade of service as a function of distance to the sampled main station.

The sampled loops were examined at 1 kilofoot intervals, beginning at the central office, to obtain the various distributions presented in Figs. 6–9. The gauge distribution at 10 kilofeet, for example (Fig. 7a), was derived by determining the gauge of each loop sample at the 10 kilofoot point of all 494 loops which extend beyond 10 kilofeet. A number of conclusions can be drawn from these analyses. First, inspection of pair sizes as a function of distance from the central office (Fig. 6a) reveals decreasing pair size with distance. But also notice that there has been a shift toward the use of larger pair size cables for longer distances as compared to 1964 (Fig. 6b). For example, at 30 kilofeet only 47 percent of the loops are in pair sizes of 100 pairs or less in 1973 while in 1964, at the same distance, nearly 75 percent of the loops were served by cables of 100 pairs or less. Similarly, examination of the gauge distribution (Fig. 7a) shows a transition to coarse gauge with increasing distance (at 20 kilofeet only 30 percent of the sampled loops consist of finer than 22 gauge cable). It can also be seen (Fig. 7b) that there has been a shift since 1964 toward use of the finer gauge cables at further distances from the central office. For example at 10 kilofeet, 28 percent of the loops sampled in 1973 were contained in 26 gauge cables while in 1964 only 15 percent of the loops were contained in 26 gauge cables at this distance.

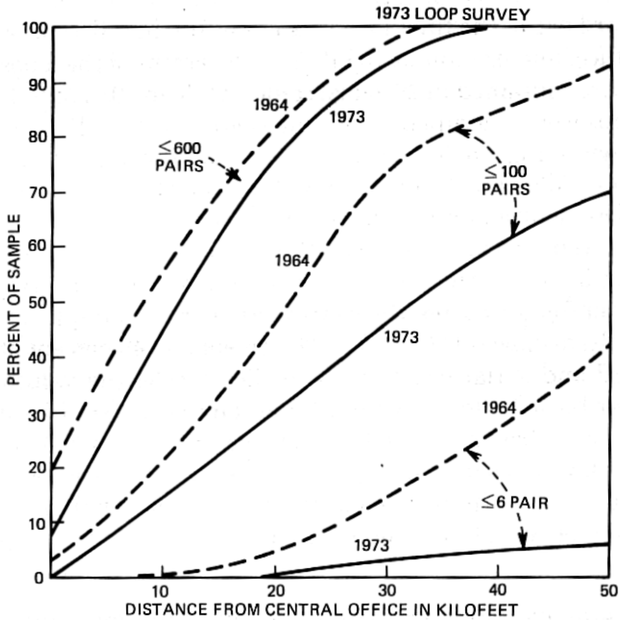
As shown in Fig. 8a, longer loops are predominately either aerial or buried (at 35 kilofeet, 52 percent of the sampled loops were constructed with buried facilities and 48 percent with aerial). Figs. 8b–d show that in the intervening 9 years between the two loop surveys there has been an increase in buried cable coupled with decreasing use of aerial facilities with greater distance from the central office. For example, in the 1973 survey at the distance of 20 kilofeet, 36 percent and 49 percent of all plant was buried and aerial respectively, while in 1964 the values were 12 percent for buried and 72 percent for aerial (aerial facilities consist of both wire and cable). Noteworthy also is the grade of service distribution (Figs. 9a–c), which shows with greater distance from the central office the increasing use of individual party service coupled with more uniform distribution of two-, four-, and eight-party service than was prevalent in 1964.

IV. LOOP SURVEY RESULTS—TRANSMISSION PERFORMANCE

The 1973 loop survey data also provided sufficient information to derive the equivalent "T" network for each loop which was then used

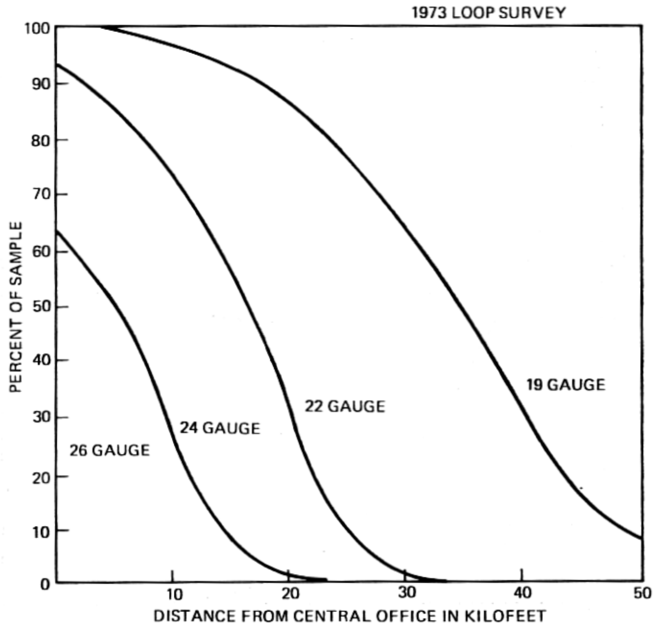


(a)

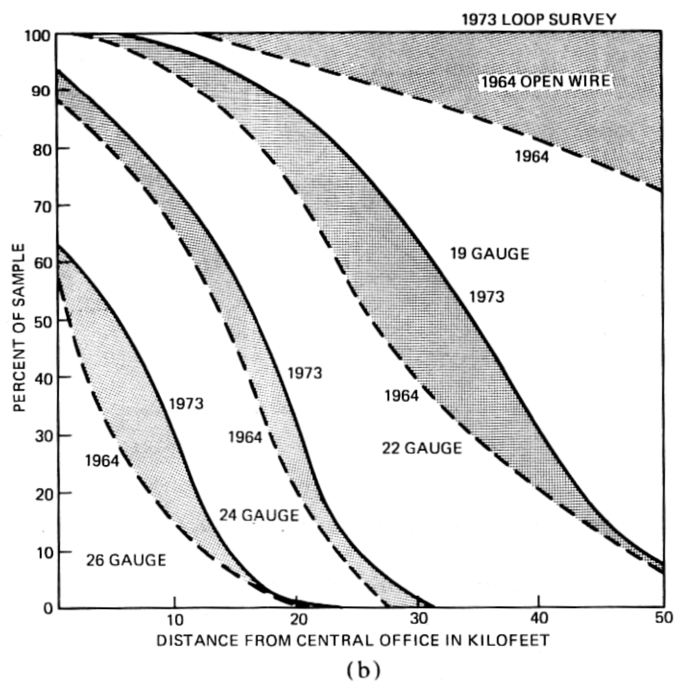


(b)

Fig. 6—(a) Pair size distribution. (b) Pair size distributions, 1973 vs. 1964 surveys.



(a)



(b)

Fig. 7—(a) Gauge distribution. (b) Gauge distributions, 1973 vs 1964 surveys.

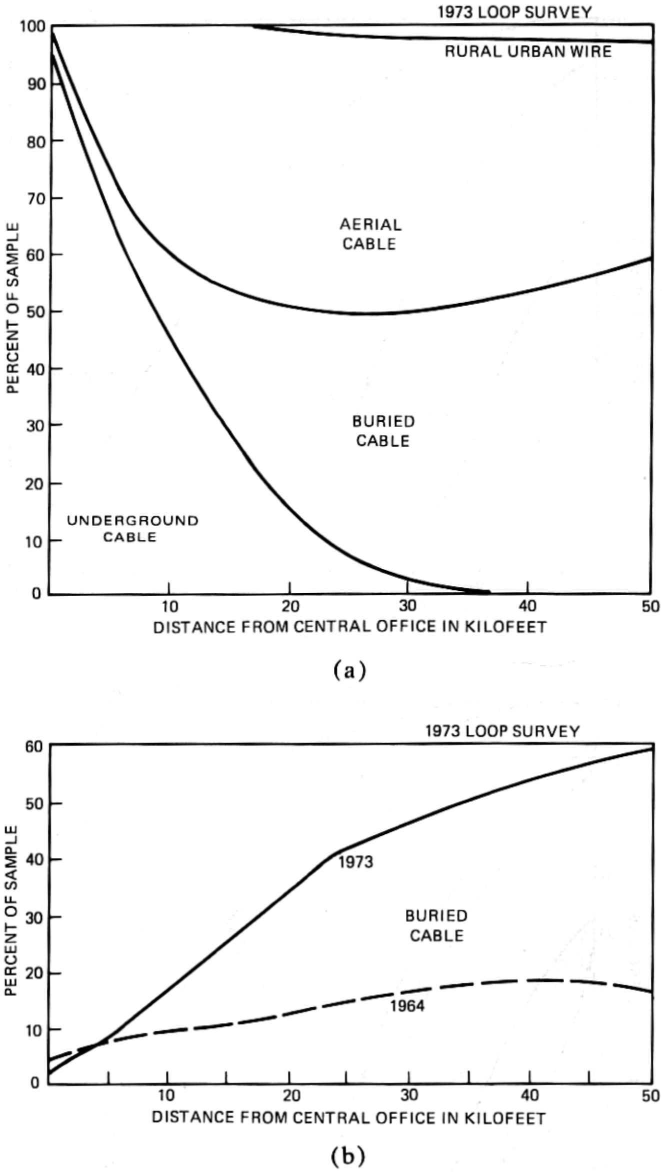
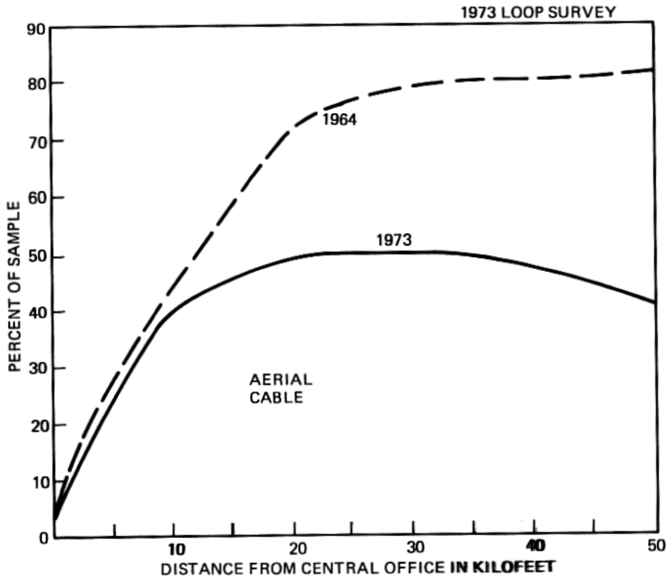
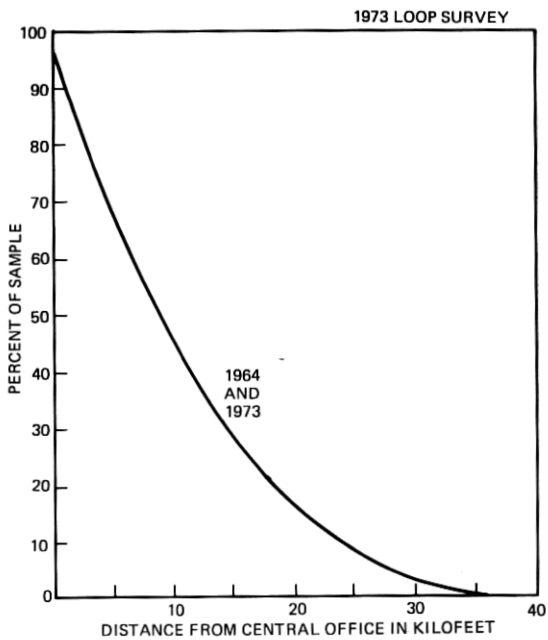


Fig. 8—Type of construction. (a) Distribution. (b) Buried cable.

to derive the calculated transmission loss at nine voice-band frequencies. In the 1964 loop survey, the loss of each sampled loop was determined by two methods: theoretical calculations as described above, and actual measurements. Comparison of the calculated and measured transmission losses showed that calculated losses based on the physical composition

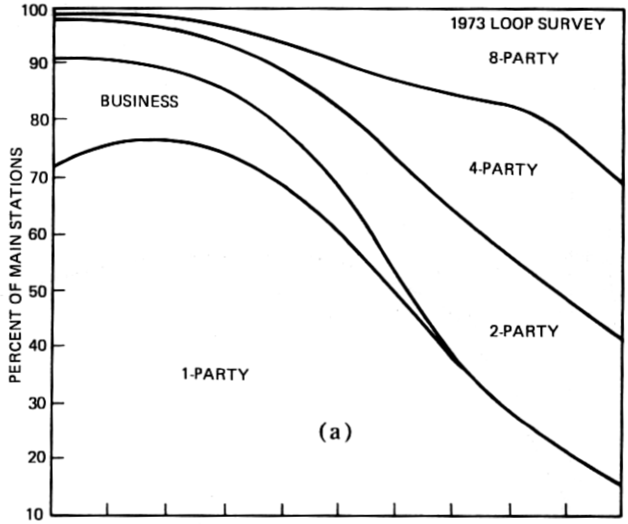


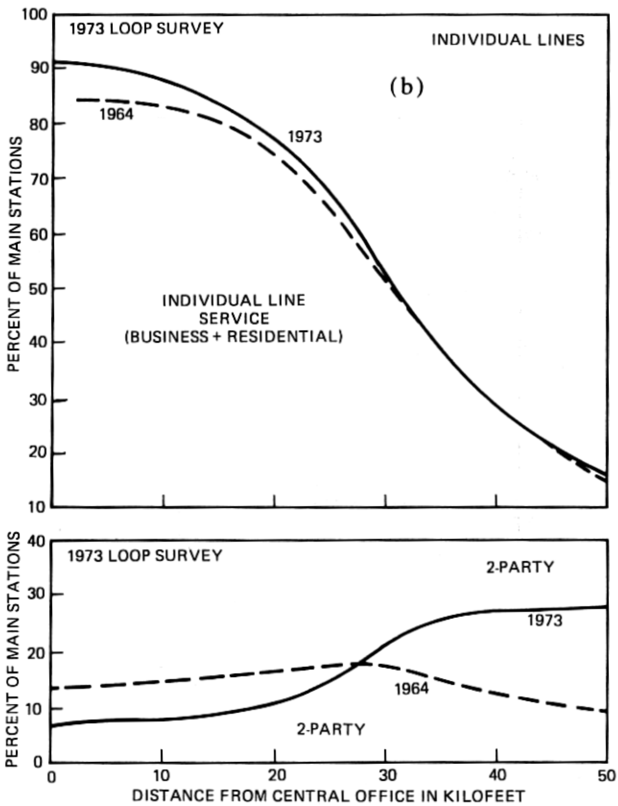
(c)

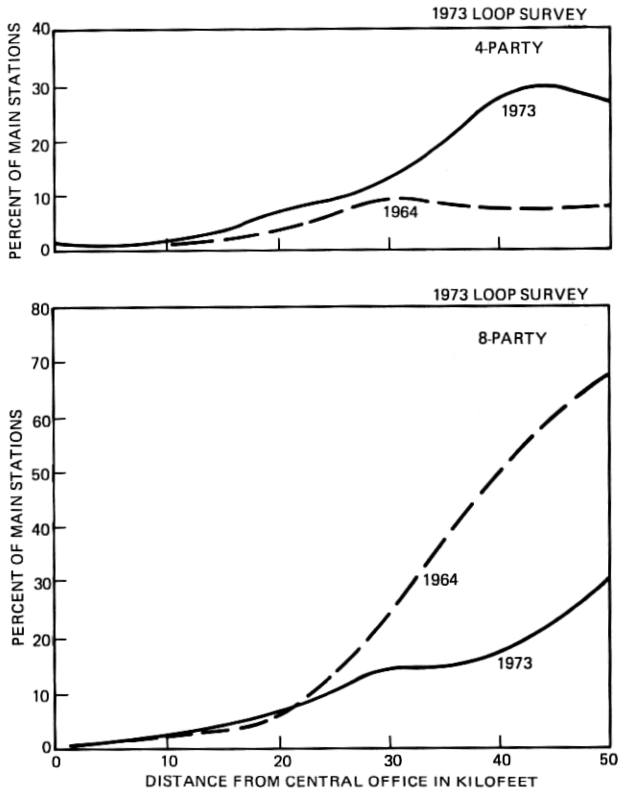


(d)

Fig. 8—(c) Aerial (cable and wire). (d) Underground cable.


100
90
80
70
60
50
40
30
20
10
PERCENT OF MAIN STATIONS
1973 LOOP SURVEY
8-PARTY
BUSINESS
4-PARTY
2-PARTY
1-PARTY
(a)


100
90
80
70
60
50
40
30
20
10
PERCENT OF MAIN STATIONS
1973 LOOP SURVEY
INDIVIDUAL LINES
(b)
1964
1973
INDIVIDUAL LINE
SERVICE
(BUSINESS + RESIDENTIAL)
40
30
20
10
0
PERCENT OF MAIN STATIONS
1973 LOOP SURVEY
2-PARTY
1973
1964
2-PARTY
0
10
20
30
40
50
DISTANCE FROM CENTRAL OFFICE IN KILOFEET



(c)

Fig. 9—Type of service. (a) Distribution. (b) Individual lines and two-party. (c) Four-party and eight-party. One-, two-, four-, and eight-party include residence service only. Business includes PBX, centrex, and coin.

of the loops were sufficiently close to the measured transmission losses. Consequently, actual transmission measurements were not made on the sampled loops in the 1973 survey. The distribution of calculated insertion losses at 1, 2, and 3 kHz, a scatter diagram of the 1 kHz insertion losses, return loss at 3 kHz, echo return loss (equal weighting over the 500 to 2500 Hz band), and dc resistance are presented in Figs. 10–13.

The cumulative distributions of calculated 1, 2, and 3 kHz insertion losses for customer loop plant is presented in Fig. 10. Note that approximately 98 percent of all Bell System main stations are served by loops having 1 kHz insertion loss less than or equal to 8 dB with a calculated mean loss of 3.7 dB. Similarly, at 3 kHz the calculated mean loss is 7.5 dB with 95 percent of all main stations served by loops having less than 15 dB insertion loss. A scatter diagram of 1 kHz calculated insertion

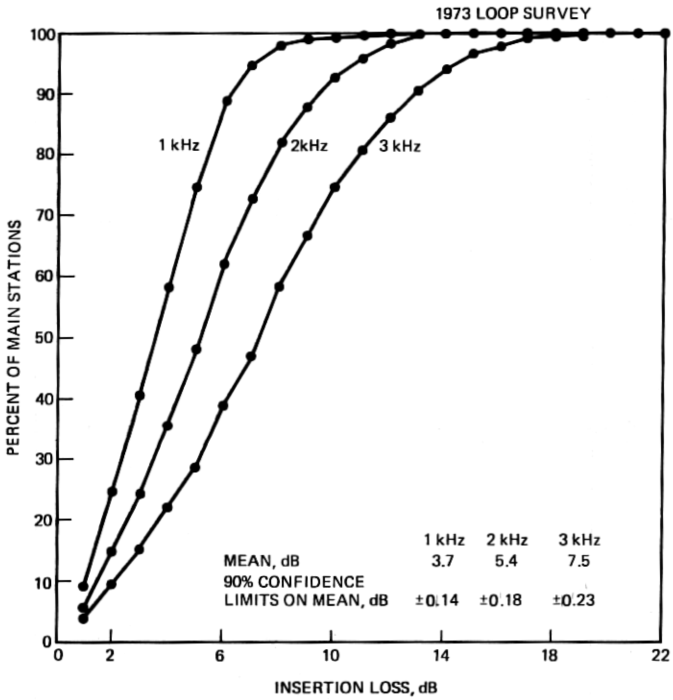


Fig. 10—Insertion loss.

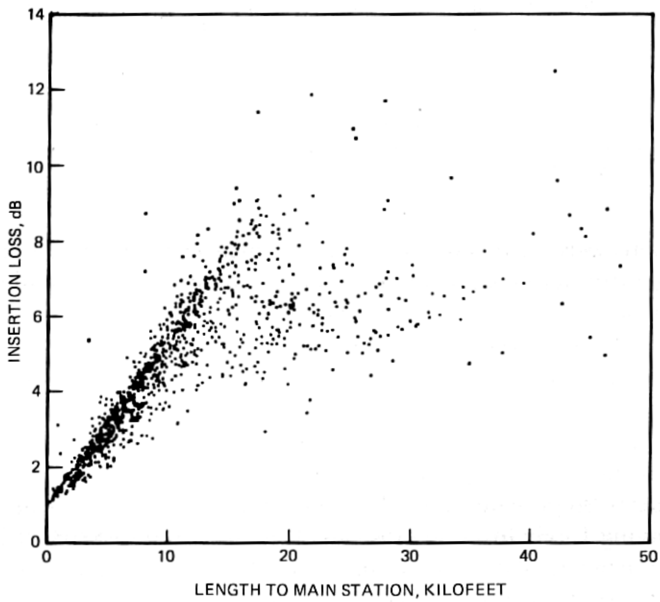


Fig. 11—Scatter diagram of calculated 1-kHz insertion losses.

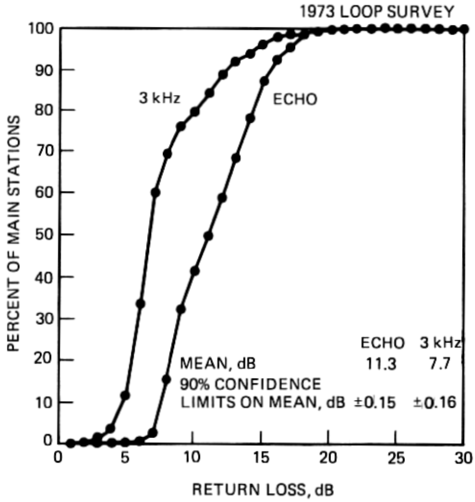


Fig. 12—Return loss.

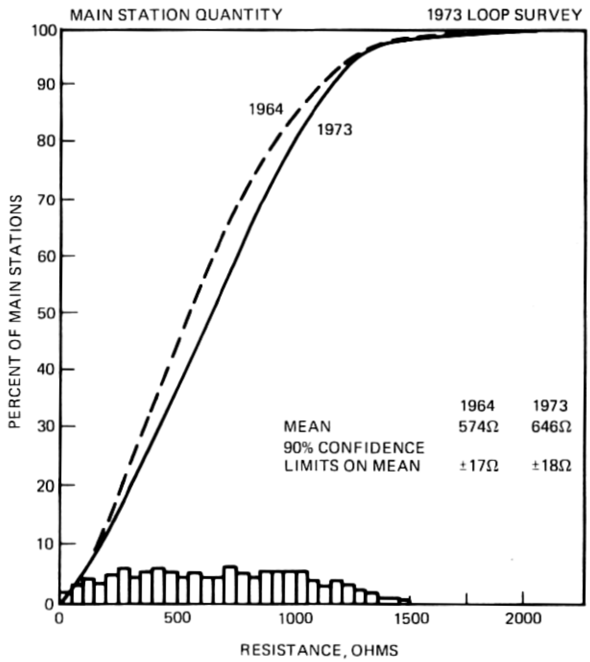


Fig. 13—Calculated resistance to main station.

loss as a function of loop length is shown in Fig. 11. Table IV presents calculated insertion loss at nine voiceband frequencies. Note that mean insertion losses across the voice band have increased, principally because

Table IV — Insertion loss (calculated with 900-ohm terminations at both ends)

Freq., Hz	1964 Mean, dB	1964 90% Confidence Interval, dB (±)	1973 Mean, dB	1973 90% Confidence Interval, dB (±)	1973 St. Dev., dB	Difference 1964–1973 Significance Level
200	2.4	0.06	2.9	0.16	3.2	99+
300	2.5	0.07	2.8	0.10	2.1	99+
500	2.7	0.08	3.0	0.11	2.3	99+
1000	3.5	0.10	3.7	0.14	2.8	94
1500	4.3	0.13	4.6	0.16	3.2	98
2000	5.3	0.16	5.4	0.18	3.6	<80
2500	6.2	0.18	6.4	0.21	4.1	<80
3000	7.3	0.21	7.5	0.23	4.7	<80
3200	7.9	0.23	8.3	0.26	5.2	93

of an increase in the use of finer gauge cable and the resulting increase in average loop resistance (Fig. 13).

Calculated return loss performance is presented in Table V for nine frequencies and the cumulative distributions for the 3 kHz return loss and echo return loss is shown in Fig. 12. Note that it has remained essentially unchanged since 1964.

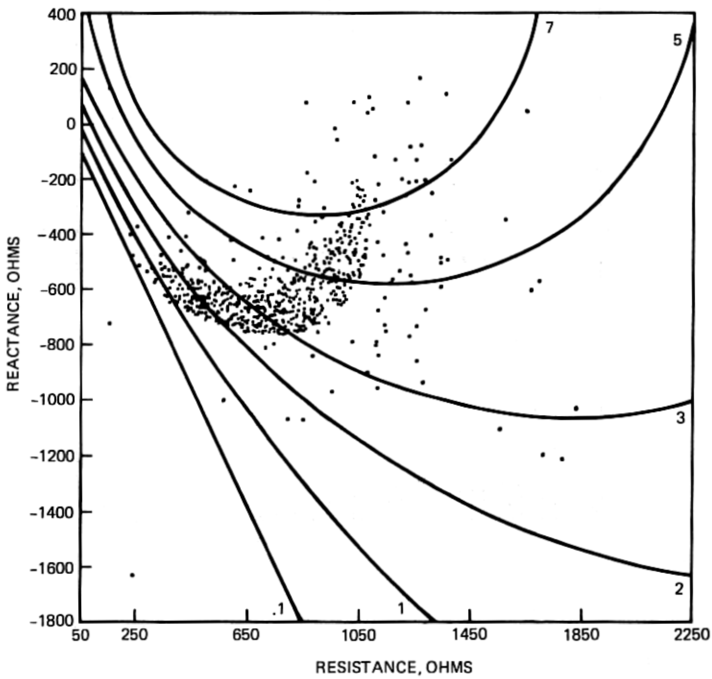


Fig. 14—Nonloaded loop input impedances at 1 kHz. *RL* circles based on 500-type telephone set impedance (22-gauge H88 cable termination at the central office).

Table V — Return loss (calculated using a 900 ohm + 2μF termination)

	1964		1973			Difference
	90% Confidence		90% Confidence		St.	1964–1973
Freq., Hz	Mean, dB	Interval, dB (±)	Mean, dB	Interval, (dB (±)	Dev., dB	Significance Level
200	8.0	0.11	8.3	0.10	2.0	99+
300	10.2	0.12	10.3	0.11	2.2	<80
500	13.4	0.17	13.1	0.16	3.2	97
1000	15.4	0.30	15.3	0.31	6.2	<80
1500	13.1	0.27	13.3	0.28	5.6	<80
2000	10.9	0.25	11.2	0.27	5.3	82
2500	9.1	0.20	9.1	0.20	4.0	<80
3000	7.7	0.16	7.7	0.16	3.2	<60
3200	7.1	0.15	7.0	0.15	2.9	<60
Echo	11.2	0.15	11.3	0.15	3.1	<80

The final transmission characteristic to be presented is the loop input impedance at the station set. The input impedance of each loop was computed by using the equivalent "T" network for each loop.

Central office terminations equivalent to four-wire trunks and two-wire trunks were represented by 900 ohms plus 2.16 μF and midsection

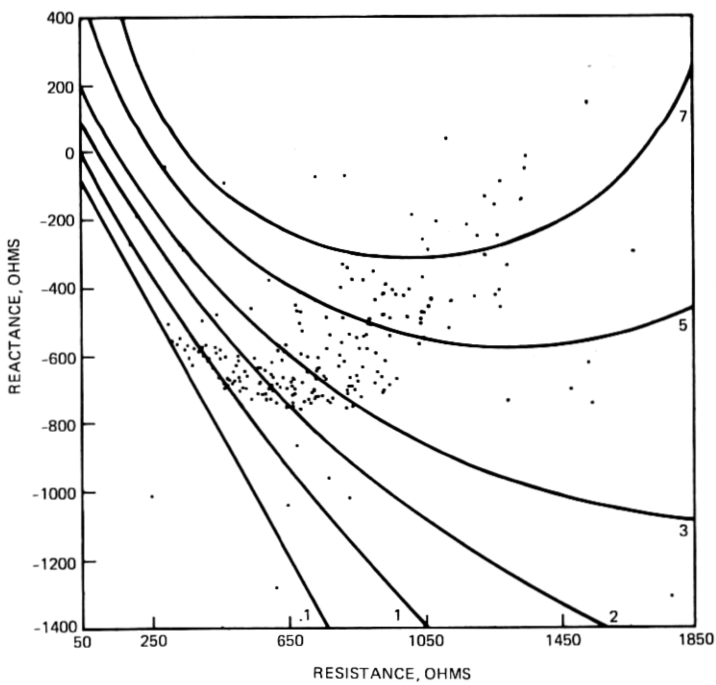


Fig. 15—Loaded loop input impedances at 1 kHz. *RL* circles based on 500-type telephone set impedance (22-gauge H88 cable termination at the central office).

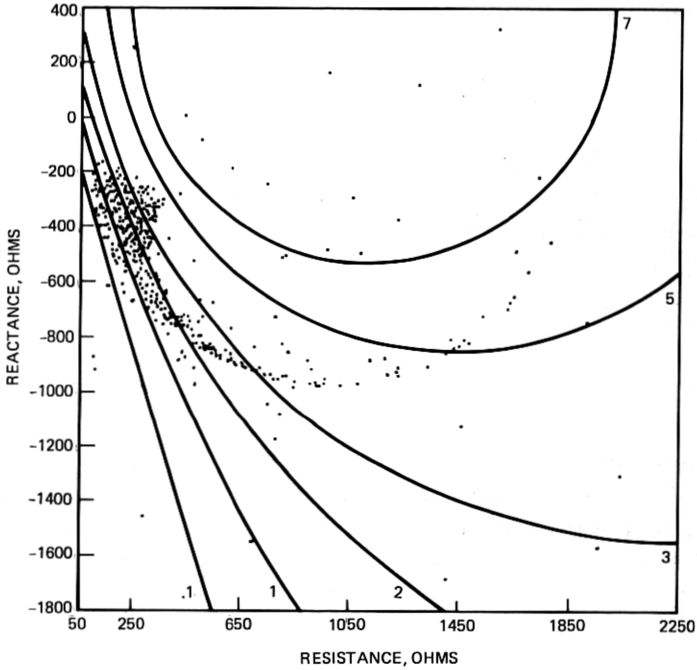


Fig. 16—Nonloaded loop impedances at 3 kHz. *RL* circles based on 500-type telephone set (22-gauge H88 cable termination at the central office).

input impedance of 22-gauge H88 loaded cable, respectively. Intraoffice calls were simulated based on a Monte Carlo technique of selecting 500 pairs of loops. Using a random number generator a loop was chosen from the 1100 loops in the 1973 loop survey data base. The central office termination was the input impedance as measured at the central office of another randomly chosen loop.

Scatter diagrams of loop input impedance at the station set are presented for 1 and 3 kHz voiceband frequencies. There is wide variation in the input impedance of loaded and nonloaded loops; consequently the two populations (849 nonloaded and 251 loaded loops) were separated for this study. Return loss circles at 0.1, 1, 2, 3, 5, and 7 dB are also superimposed on the scatter diagrams. The return loss circles were based on the 500-type telephone set as the reference impedance since 84.3 percent of the sampled loops in the 1973 loop survey were terminated with this type of telephone set. Further, since loaded loops have nearly 15 mA lower loop current than nonloaded loops, the mean loop currents of the individual populations were used.

The scatter diagrams for loops with simulated two-wire trunk terminations (22-gauge H88 loaded cable) are presented in Figs. 14 through 17. The dispersion of points can be partially attributed to the use of

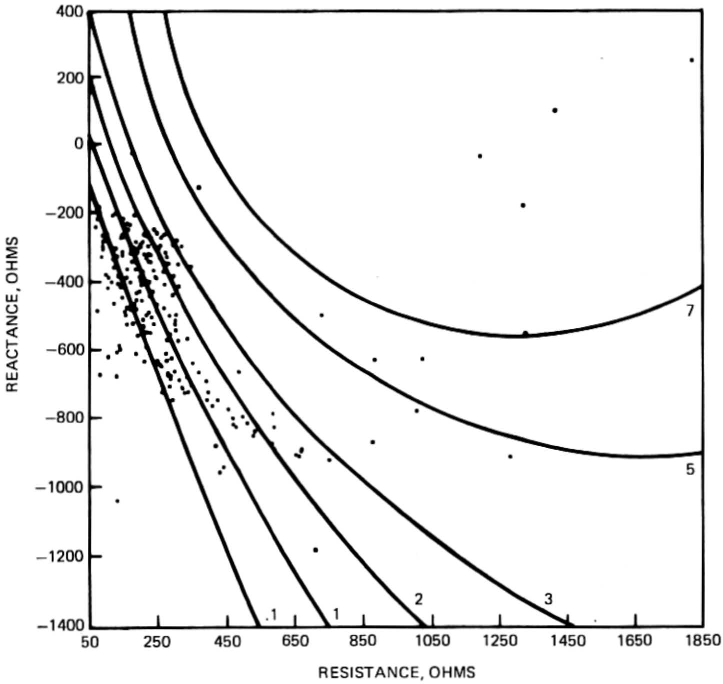


Fig. 17—Loaded loop input impedances at 3 kHz. *RL* circles based on 500-type telephone set impedance (22-gauge H88 cable termination at the central office).

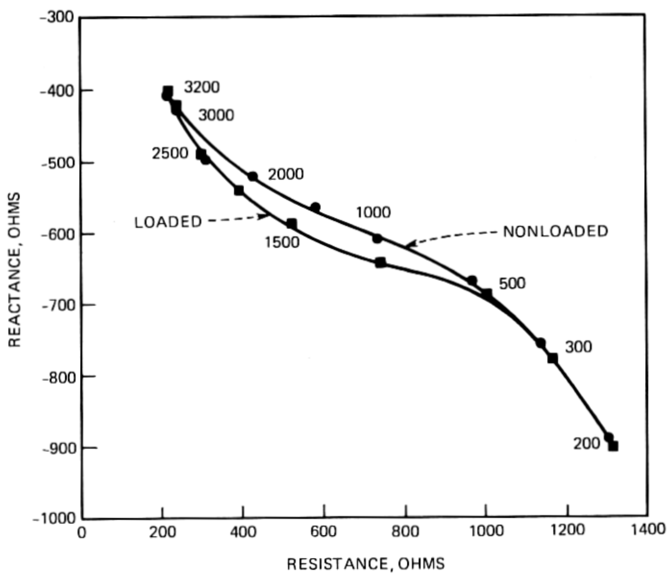


Fig. 18—Median input impedances at all nine frequencies for loaded and nonloaded loops (22-gauge H88 cable termination at the central office).

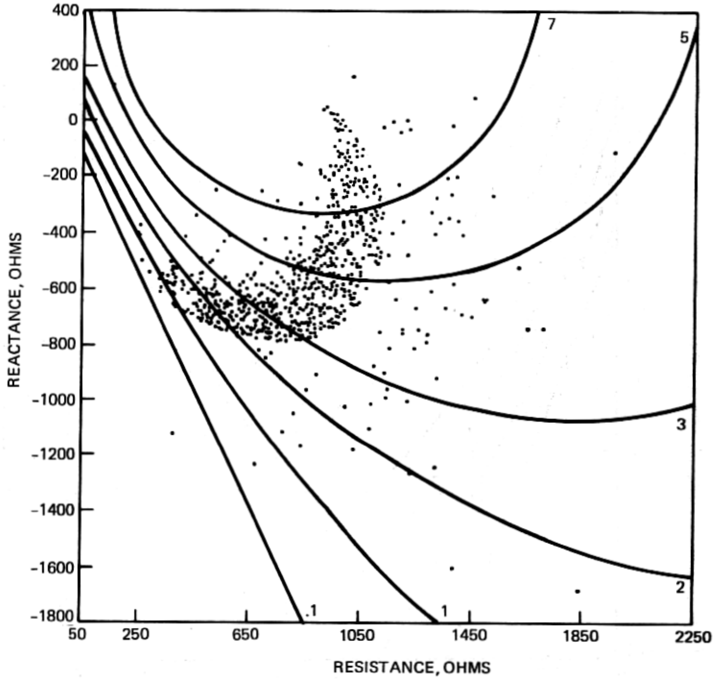


Fig. 19—Nonloaded loop input impedances at 1 kHz. *RL* circles based on 500-type telephone set impedances (900 ohm + 2.16 μF cable termination at the central office).

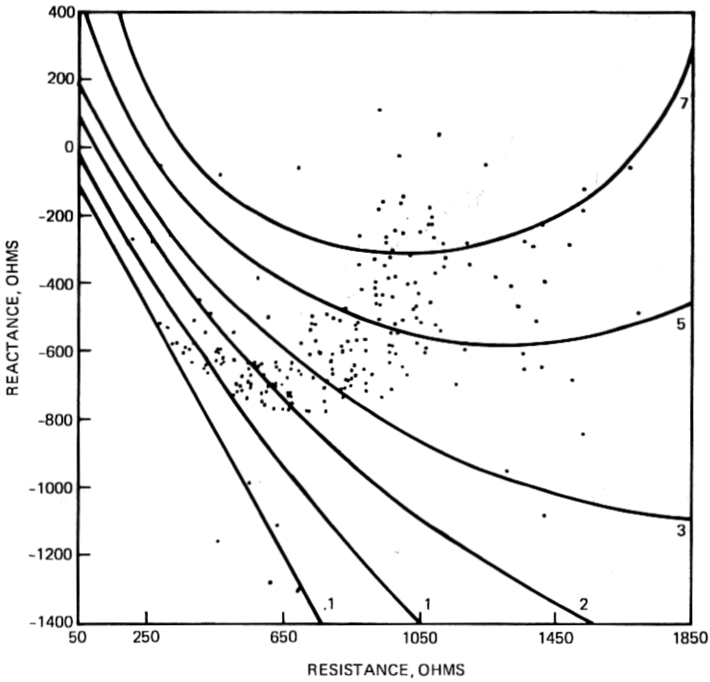


Fig. 20—Loaded loop input impedances at 1 kHz. *RL* circles based on 500-type telephone set impedances (900 ohm + 2.16 μF cable termination at the central office).

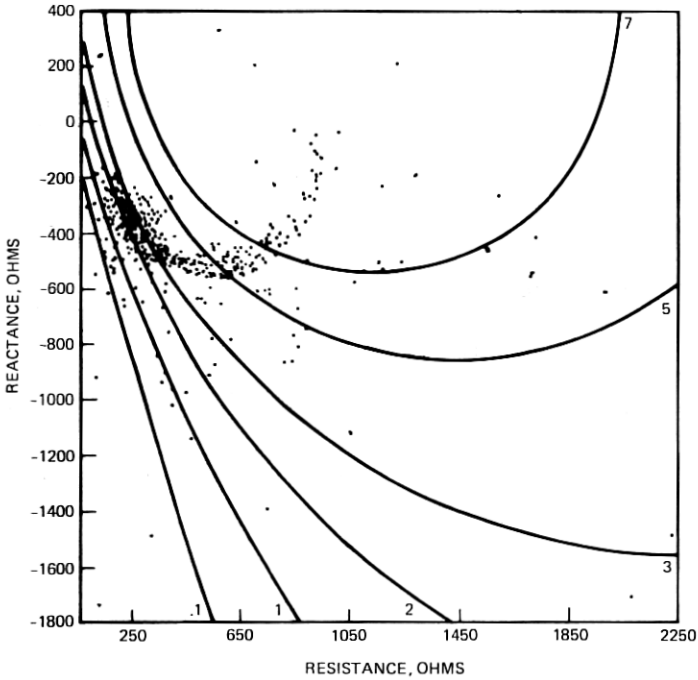


Fig. 21—Nonloaded loop input impedances at 3 kHz. *RL* circles based on 500-type telephone set impedances (900 ohm + 2.16 μF cable termination at the central office).

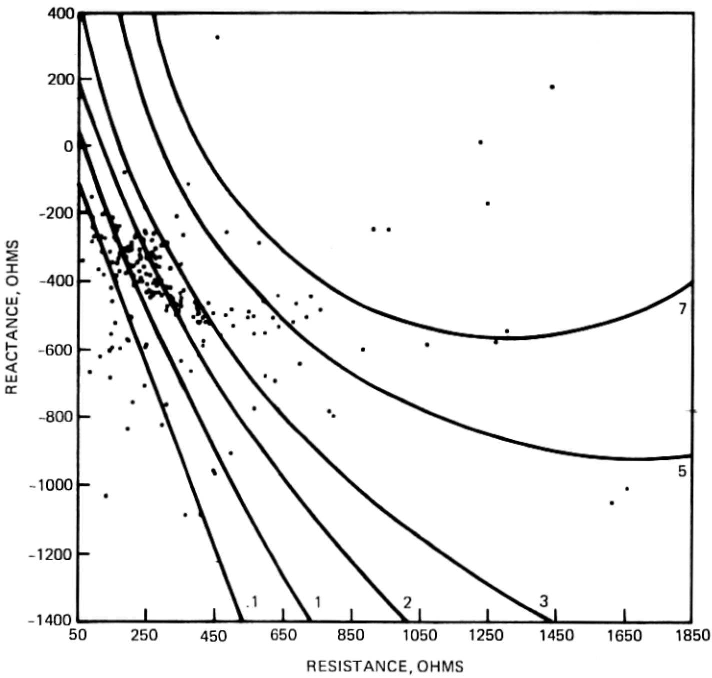


Fig. 22—Loaded loop input impedances at 3 kHz. *RL* circles based on 500-type telephone set impedances (900 ohm + 2.16 μF cable termination at the central office).

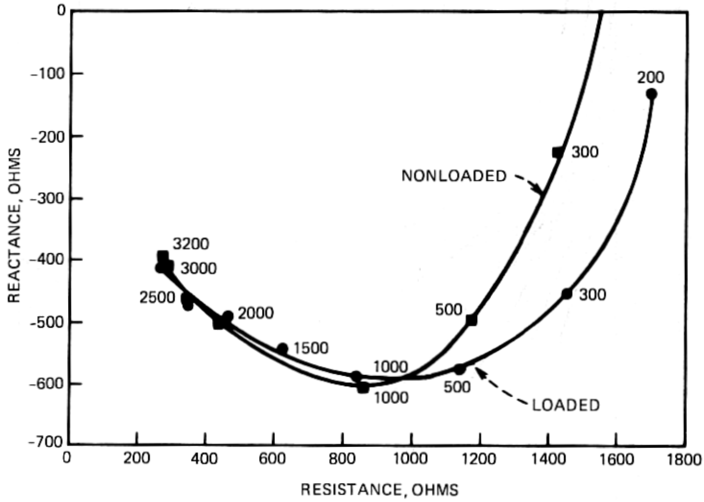


Fig. 23—Median input impedances at all frequencies for loaded and nonloaded loops (900 ohm + 2.16 μF cable termination at the central office).

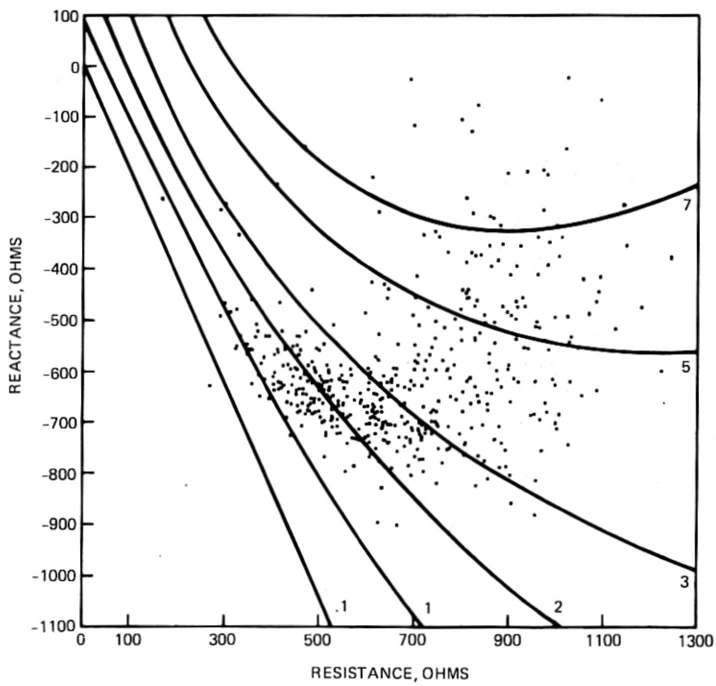


Fig. 24—Intraoffice simulation input impedances at 1 kHz. *RL* circles based on 500-type telephone set impedance.

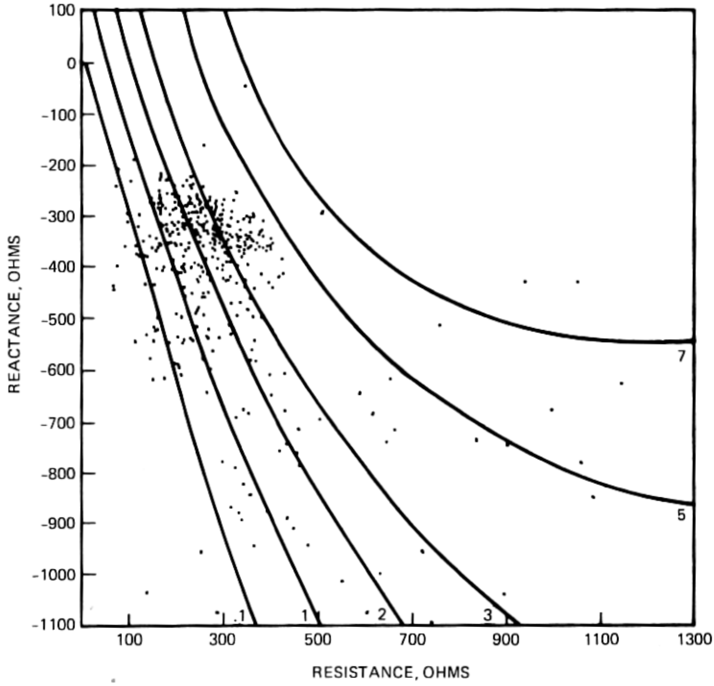


Fig. 25—Intraoffice simulation input impedances at 3 kHz. *RL* circles based on 500-type telephone set impedance.

coarser gauge cable than is required to meet the resistance design objective of 1300 ohms. Notice that loaded loops (Figs. 15 and 17) are more scattered due to their vulnerability to load coil spacing irregularities than are the nonloaded loops (Figs. 14 and 16). Median impedances at all nine voiceband frequencies for simulated two-wire trunk terminations are shown in Fig. 18. The scatter diagrams for loops with simulated four-wire trunk terminations (900 ohms plus 2.16 μF) are shown in Figs. 19 through 22. Similarly, the scatter plots indicate more irregularities present in loaded loops than nonloaded ones. Curves of the median input impedances at all nine voiceband frequencies of loaded and nonloaded loops with a four-wire trunk termination at the central office are presented in Figure 23. The intraoffice call simulation results can be seen in the scatter diagrams presented in Figs. 24 and 25. These reveal the effect of connecting together two random loops, one terminated by a station set and the other's impedance calculated at the station set. The median input impedances for intraoffice calls are presented in Fig. 26 along with median impedances of simulated two-wire and four-wire trunk terminations of nonloaded loops.

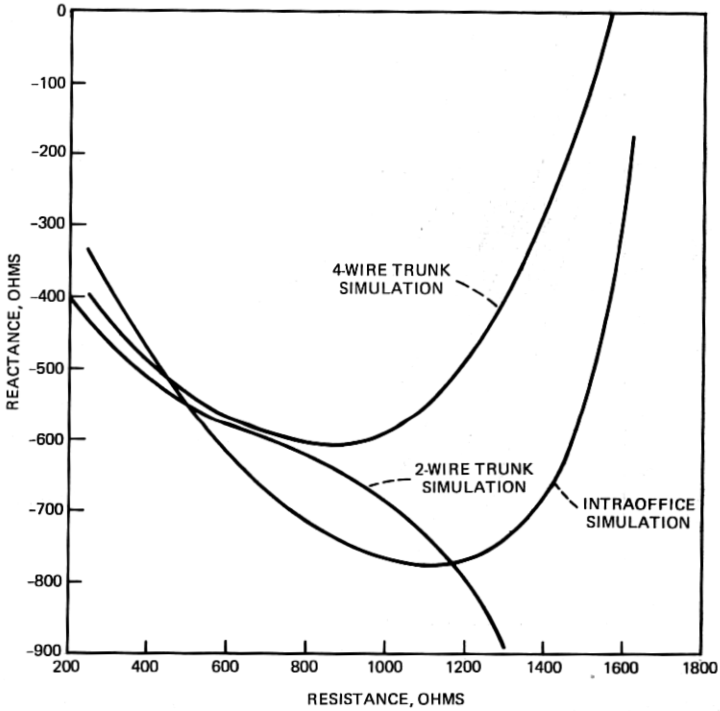


Fig. 26—Median input impedances at all nine frequencies for simulated intraoffice calls, simulated two-wire trunk terminations (22-gauge H88 loaded cable), and simulated four-wire trunk terminations (900 ohm + 2.16 μF cable) of nonloaded loops.

V. CONCLUSIONS

The analyses of the 1973 loop survey can be summarized in the following four principal results.

(*i*) The average customer loop length is currently 11.4 kilofeet with only 4 percent of the main stations located beyond 30 kilofeet from their serving office. The length distributions show a statistically significant (99 percent level of significance) increase in average loop length since 1964, with the average loop length increasing by 800 feet.

(*ii*) The average calculated 1 kHz insertion loss of the Bell System loop plant is currently 3.7 dB* with 95 percent of all main stations being served by loops having a calculated 1 kHz loss of less than 7.5 dB. At 3 kHz the average calculated loss is 7.5 dB with 95 percent of all main stations served by loops having less than 15 dB insertion loss.

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* Anomalies in plant design and record errors will tend to make actual losses slightly higher than calculated losses. For example, the 1964 loop survey, which included actual loss measurements as well as calculated losses, showed that average measured loss at 1 kHz was approximately 0.3 dB higher than the calculated value.

(*iii*) The percentage of main stations served by loaded loops has increased since 1964 from 16.4 to 22.9 percent. Sixty percent of the increase is a direct result of the increase in the percent of customer loops requiring loading (loops longer than 18 kilofeet). The remainder is attributed to an increase in the use of loading for loops shorter than 18 kilofeet and a reduction in the percentage of nonloaded loops longer than 18 kilofeet.

(*iv*) Average dc resistance to the sampled main station has increased from 574 to 646 ohms since 1964. This increase is attributed to the trend towards the use of finer gauge cable in the loop plant combined with an increase in the average customer loop length.

VI. ACKNOWLEDGMENTS

The author wishes to acknowledge N. Reina and C. Schroeder of AT&T who selected the sample, collected the data, and verified its accuracy. Without their contributions this paper could not have been written.

REFERENCE

1. P. A. Gresh, "Physical and Transmission Characteristics of Customer Loop Plant," B.S.T.J., *48*, No. 10 (December 1969), pp. 3337–3385.