A New Objective for Message Circuit Noise

By D. A. LEWINSKI

(Manuscript received October 14, 1963)

The reduction and control of noise on message circuits must be based on sound noise objectives. For many years the Bell System over-all performance objective has been "26 dbrnc (20 dba) seldom to be exceeded at the telephone station set." In this article the derivation of a more flexible and operationally feasible noise objective is presented. This objective specifies a limit of 20 dbrnc not to be exceeded on subscriber loops, and stipulates various distributions for noise originating beyond class 5 offices on built-up connections. The objective is such as to provide Bell System customers with a noise grade of service ranging from 99 per cent good or better on short connections to 90 per cent good or better on intercontinental connections spanning distances up to halfway around the world.

I. INTRODUCTION

For many years the Bell System over-all performance objective for message circuit noise has been as follows: "Noise from all sources in a subscriber-to-subscriber connection should seldom exceed 26 dbrnc* (20 dba) at the line terminals of the station set." Since its inception this objective has been a primary influence in the design of broadband transmission systems, and it has served as a guide for the engineering and maintenance of the message network. But improved and new services have gradually changed the makeup and the performance requirements of the plant. Thus, work was recently undertaken to establish a new performance objective — one better suited to the noise conditions imposed by a changing communication network.

The new objective provides a long-range Bell System goal and, as such, serves as a guide for the design of future systems and for establishing maintenance procedures. In addition, it indicates those areas where

* The new unit for noise measurement with the 3-type noise measuring set is dbrnc.[1] Reference noise, "rn," is 10^{-12} watts of 1000-cps power, whereas "c" refers to C-message weighting.

efforts to improve the noise performance of existing systems should be directed. For economic and technical reasons, however, it appears to be impractical to upgrade the performance of all existing equipment, most of which was designed to earlier standards. Therefore, it will probably be a number of years before the level of performance and customer satisfaction associated with the new objective can be fully realized in the Bell System plant.

Derivation of the new objective necessitated two major systems engineering projects: (*i*) subjective tests to establish a quantitative description of the effects of noise experienced by telephone users in terms readily translatable into an over-all transmission standard; (*ii*) noise surveys to provide data on Bell System noise performance. From this information, system noise performance estimates were made and examined from the telephone user's standpoint. In addition, a model of system noise behavior was constructed. These steps were necessary in order to (*i*) establish a framework for the statement of the objective, and (*ii*) provide insight for the derivation of the associated numerics so that a desired level of customer satisfaction could be realized. In accord with present philosophy, customer satisfaction is stated in terms of "grade of service."[2]

We begin by discussing the work on the subjective effects of noise and emphasize how the results lend themselves to noise grade of service estimates. We then use the latter tool to evaluate system noise performance and show in turn that this requires the new objective to be comprised of two parts, (*i*) a limit for noise attributable to the customer's loop, and (*ii*) distributions for noise on toll connections where the average values and standard deviations of these distributions are length-dependent. Last, we derive the actual numerics which constitute the new over-all objective and are the basis for new noise objectives for design and maintenance.

II. SUBJECTIVE EFFECTS OF NOISE

2.1 *General*

In setting performance objectives for speech transmission it is important to have a quantitative description of the subjective effects of the transmission parameter under consideration. Instead of describing these effects on a psychological scale, experience has shown that simple expressions of attitude such as absolute judgments are adequate when the experiment is properly designed. Assessments made on an absolute basis can be readily transformed into satisfaction criteria, which in turn can be used as a foundation for over-all transmission objectives.

2.2 *Description of Tests*

To get a comprehensive picture of telephone user attitude toward noise, three subjective evaluations were actually undertaken. In addition to noise effects, the effects of received speech volume and signal to noise were also evaluated. Except for the relevant test instructions, each of these evaluations was conducted similarly by asking observers to appraise a series of simulated telephone calls in terms of a given set of response categories: excellent (E), good (G), fair (F), poor (P), and unsatisfactory (U).

The noise tests were conducted using 500-type station sets with received volume at a constant level of −28 VU,* and noise (a composite of power hum, switching office and thermal noise) varied between 18 and 62 dbrnc (set input) in 4-db steps. Three presentations consisting of different random permutations of the 12 test conditions were given to each participating group of observers.

The volume tests were conducted using both 302 and 500-type sets, the former being used primarily to tie in with previous work carried out by Coolidge and Reier.[4] Noise level was held constant at 26 dbrnc (set input) with received speech volume varied between −24 and −60 VU in 4-db steps. As in the noise tests, three different random permutations of the 10 volume conditions were given to each group of observers.

The signal-to-noise tests were conducted with 500-type sets with both noise level and received volume varied over 44 randomly given conditions compatible with the range of values used in the noise and volume tests.

In each of the above tests, the simulated speech-noise conditions consisted of two short sentences of spoken material mixed with the noise. The spoken material and the noise were taped on separate recorders and played simultaneously to the observers at the required levels through a network equivalent to 6000 feet of 24-gauge cable, representing a subscriber loop. Groups of six to eight observers were accommodated in a specially constructed subjective test room, comprised of individual cubicles equipped with telephones, as shown in Fig. 1. A loudspeaker placed in the center of the oval array supplied recorded room noise at a

---

* VU (volume unit) is the unit for expressing the magnitude of a complex electric wave when measured with a standard volume indicator.[3]

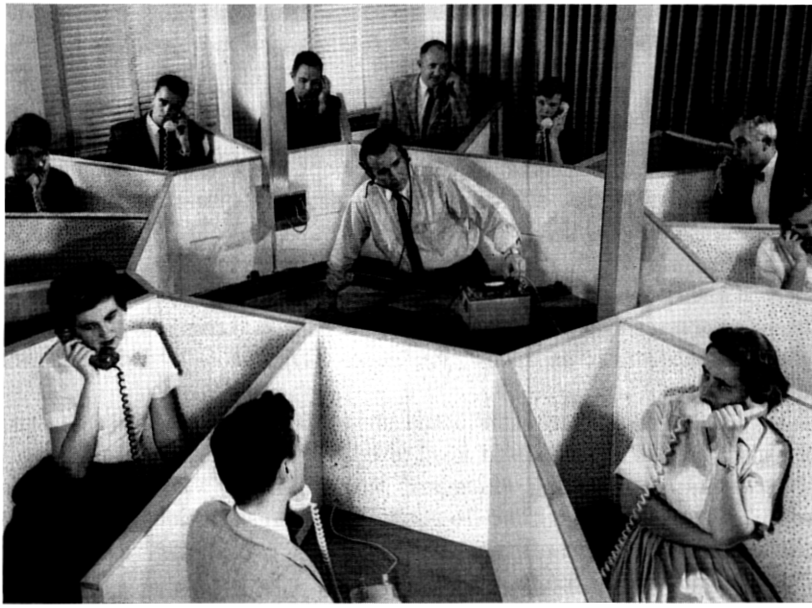

Fig. 1 — Observers at multiple listening positions during subjective test.

sound pressure level of 48 db re 0.0002 microbar. The line current in the test circuit was adjusted to 55 ma direct current to each station set.*

The test period for each group of observers fell into two parts: a preliminary period of introductory remarks which included instructions and a 15-to-25 minute period for the particular evaluation.

A total of 666 observers, both male and female, took part; all were chosen at random from among Bell Laboratories employees. None was required to participate more than once.

2.3 *Test Results*

While all three of the above tests are necessary to gain insight into customer attitude towards noise in the presence of speech transmission, only the noise test data are used in setting noise objectives. This reflects the present practice that transmission parameters be treated independently when deriving transmission objectives. As such, the data describing noise effects rather than the data on signal-to-noise are considered basic when deriving message circuit noise objectives. In general, however, the interdependence between noise and volume effects is recognized, and

* The significance of this choice of line current as it influences noise at the line terminals of the station set is discussed in Appendix A.

therefore the results of the noise-volume tests are potentially more useful for the evaluation and specification of over-all performance.[5]

The results of the noise tests plotted as "noise opinion curves" in cumulated categories are shown in Fig. 2. Presented in this way, the set of curves show the proportion of E (excellent), E + G (good or better), E + G + F (fair or better) and E + G + F + P (poor or better) judgments at particular noise levels over the range of values tested. In essence, these curves are estimates of $p(R \mid x)$, the conditional probability of placing a given noise level x in cumulated category R. A good model of opinion is obtained by fitting normal ogives, i.e., normal distribution functions, to the data points. As such, each curve can be defined by

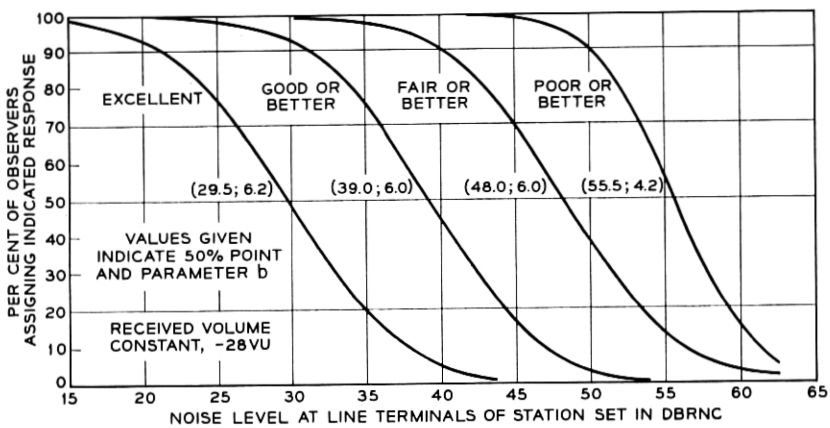

Fig. 2 — Noise opinion curves.

stating the 50 per cent point and the parameter "b," which is computed in the same way as the standard deviation of a normally distributed random variable.

The data shown are comprised only of second-presentation judgments, adjusted* for each observer where necessary to conform with

* The adjustment compensates for the uncertainty in judgment found in the neighborhood of the transition levels. As an example, consider a typical observer response

dbrnc	18	22	26	30	34	38	42	46	50	54	58	62
Category	E	E	G	G	F	G	F	F	P	U	P	U.

Here the first transition level is 24 dbrnc, since this value of noise is equally likely to be judged excellent or good. The second is 36 dbrnc since this level is equally likely to be judged good or fair and so on for 48 and 56 dbrnc. Thus the corresponding adjusted judgment would become

dbrnc	18	22	26	30	34	38	42	46	50	54	58	62
Category	E	E	G	G	G	F	F	F	P	P	U	U.

the four noise "transition" levels at which he essentially changed his judgment from one category to the adjacent one.

Many of the initial judgments in the first presentation appeared to be influenced by the lack of an "anchor." The observer's first judgment, for example, is either made at random or based on past experience. Thereafter his judgment is modified, so that in a short period of time his judgments tend to be made relative to the range of the stimuli presented. Thus the first set of data were the least reliable. During the third presentation it appeared that judgments were unduly biased, due to observer adaptation to the experiment. The second presentation data, between these extremes, seemed to be the best choice.

Collectively, these curves indicate that, in the presence of the desired received speech volume, noise levels up to about 30 dbrnc at the line terminals of the station set are quite acceptable. At 30 dbrnc, about 47 per cent of the subjects gave a rating of excellent, 47 per cent — good, and about 6 per cent — fair. Thereafter, degradation becomes increasingly evident: for example, notice the rapid decrease in per cent good and excellent response, as clearly indicated by the rate of change of the good-or-better noise opinion curve.

III. NOISE GRADE OF SERVICE

If it is assumed that the noise opinion curves $p(R \mid x)$, Fig. 2, are indicative of customer reaction to any particular telephone connection within the bounds of the noise levels tested, then for any probability density function $f(x)$ of noise levels on subscriber-to-subscriber telephone calls, the integral

$$\int_{-\infty}^{\infty} p(R \mid x) f(x)\, dx$$

evaluates the proportion of calls placed in category R, giving the expected value of customer opinion.* As such, this integral is very useful as a noise performance evaluation tool. It is also useful for specifying a desired "noise grade of service" which can be regarded as a statement of noise objective. Given a statement of objective in terms of a desired proportion of telephone connections assignable to a particular category

* Once category R is defined, $p(R \mid x)$ is simply treated as a function of x, say $g(x)$, called "opinion." Hence

$$\int_{-\infty}^{\infty} p(R \mid x) f(x)\, dx \equiv \int_{-\infty}^{\infty} g(x) f(x)\, dx = E[g(X)]$$

that is, the expected value of $g(X)$ where the random variable X is noise level.

R, i.e., a desired level of noise grade of service, one can solve for the noise density function $f(x)$ which, in turn, can serve as the objective "numeric."

It can be shown, however, that the correspondence between noise distribution and noise grade of service is not one-to-one. Infinitely many noise distributions yield the same noise grade of service. This means that there is considerable leeway in choice of distribution to satisfy a given grade-of-service requirement. Choices of requirement, on the other hand, are fairly narrow if customer preference is to be satisfied.

IV. NOISE SURVEYS

4.1 *General*

Having conducted tests to describe the subjective effects of noise and having established a means for using the results in an evaluation scheme such as grade of service, the next step in the derivation of an over-all noise objective is to obtain estimates of system noise performance. The determination of which estimates are pertinent is obviously an operational one. While subscribers are aware only of the total noise from all sources, there are two distinct types of plant which contribute: loops and trunks. Hence noise performance information is needed on the two basic parts of an over-all connection: that part which is assigned to the customer at all times (the loop including subset) and that part between end-offices (i.e., connections) which he shares with other customers.

A series of noise surveys were therefore made in the loop plant in 1960 and 1961, and in the toll plant on toll connections between end-offices in 1962. Toll, rather than toll-plus-local, connections were chosen for the population of "connections," so as to associate connection noise performance with that part of the plant which is more complex in makeup and which has the most costly noise problems.

4.2 *Loop Plant*

The loop plant was surveyed[6] by selecting six end-offices with at least one in each of five central office size strata characterized by offices having 1 to 999 lines, 1000 to 9999 lines, 10,000 to 19,999 lines, 20,000 to 29,999 lines and 30,000 lines or more. Using the known stratum statistics,[7] this approach enabled an extrapolation of the individual sets of data to provide a reasonably accurate estimate of noise on loops for the entire Bell System.

TABLE I — SUMMARY DATA — EXCHANGE AREA LOOP NOISE SURVEYS

Location of Survey		Marshall, Va.	Enola, Pa.	Waltham, Mass.	Kenosha, Wis.	Trois-Rivieres, Que.	Cambridge, Mass.	
Type office		SxS	SxS	#5 x-bar	SxS	SxS	#1 x-bar	panel
# Lines		400	2,200	14,600	19,800	22,700	67,600	
Sample size		148	158	149	123	178	109	
Nm (all lines) dbrnc	m	18.4	3.5	1.3	2.8	2.7	3.5	14.4
	s	14.1	8.3	9.8	7.7	10.8	5.4	4.3
	max.	53	33	32	27	38	14	35
Nm (ind. lines) dbrnc	m	11.0	0.1	−5.0	1.5	−2.3	—	
	s	11.1	5.8	4.2	7.2	6.5		
Nm (party lines) dbrnc	m	25.4	9.9	8.7	8.4	7.6	—	
	s	13.0	8.5	9.2	7.4	11.9		
Ng (all lines) dbrnc	m	31.4	27.2	24.4	17.6	18.5	9.3	
	s	13.3	6.3	8.2	7.3	9.8	5.9	
	max.	62	47	42	37	58	25	
Ng (all lines) dbrn 3 kc	m	65.0	63.3	53.4	49.5	53.5	38.5	
	s	14.8	8.3	8.4	7.5	7.7	6.2	
	max.	84	83	76	66	78	52	
* Party line balance, db	m	−51.6	−57.8	−58.3 / −52.5	−47.7	−53.9	—	
	s	6.4	6.7	6.1 / 6.2	6.2	6.4		
Loop loss, db	m	6.4	6.1	5.2	6.6	5.3	4.9	
	s	3.1	2.0	1.8	1.9	2.2	1.3	
	max.	15.5	11.7	9.2	11.3	11.5	7.2	
Transmitter current, ma.	m	60.4	55.6	44.9	46.3	46.5	47.8	42.7
	s	13.5	15.9	12.2	13.4	16.5	11.8	16.2

m = mean.
s = standard deviation.
* Balance for tip and ring party flat rate lines except Waltham, Mass., where balance is for ring party flat and tip party message rate lines.

The offices chosen were Waltham and Cambridge, Massachusetts; Kenosha, Wisconsin; Trois-Rivières, Quebec; Marshall, Virginia; and Enola, Pennsylvania. For each office a simple random sample of approximately 150 loops was selected for measurement. The loops were terminated in the central office "quiet-termination" and at the customer's location with a 500-type set. Measurements of "noise metallic" (*Nm*) were made with the 3A noise measuring set bridged across the line terminals of the station set and also from line terminals to ground (*Ng*) at the customer's location. Table I summarizes the results.

As is seen, the noise on loops in general is very low. However, it was found that there is considerable difference (7 to 14 db) between party line noise and the noise on individual lines. Except for the influence of some open wire lines in Marshall, Virginia (not uncommon for offices in stratum #1) the reason for this difference is that party lines are inherently more unbalanced than individual lines due to grounded ringers in party station sets. This is certainly evidenced by the party line balance row in Table I. Balance* is seen to be about −55 db on the average for party lines compared to −75 db for individual lines. Thus for noise induction from neighboring power lines one would expect, on the average, about 20 db more hum on party lines than on individual lines.†

Since it was found that loop noise at the higher levels is predominantly power line hum, noise-to-ground and balance data rather than actual Nm measurements were used to characterize noise in each central office area. Noise metallic (hum) distributions were derived from the expression Nm = balance + $(Ng + 40)$. To get best estimates of mean and standard deviation, regression analysis was performed over the six offices in their respective strata. Weighting these regression estimates by the corresponding stratum statistics[7] resulted in the over-all loop noise distribution of the Bell System shown in Fig. 3.

4.3 *Toll Plant*

Estimates of the noise levels that subscribers are currently experiencing on end-office to end-office toll connections were supplied by the 1962 connection survey described in a companion paper.[8] For completeness the sampling plan and the results will be summarized.

A sample of connections was selected using two-stage sampling. Sample size was determined on the basis of a desired precision of ±1 db in the over-all mean at the 90 per cent confidence level. The population contained the toll calls originating in all end-offices in Bell System service as of January 1, 1960. Seventeen offices were selected by sampling proportional to estimated size, the size estimates being defined by the number of customer lines served. For each of these offices, a self-weighting sample of previously made toll calls was chosen. The frames for the second-stage sample consisted of listings of all toll calls made during the busy hour of one business day. The sample calls were dupli-

* Balance is defined to be $Nm - (Ng + 40)$. This is consistent with 20 log Vm/Vg; Ng, as measured with a 3-type noise measuring set, is 40 db below the total voltage to ground.

† This can be remedied by the use of station sets with gas-tube isolators which essentially remove the ringer from ground during the talking condition. Such sets are often employed in severe cases.

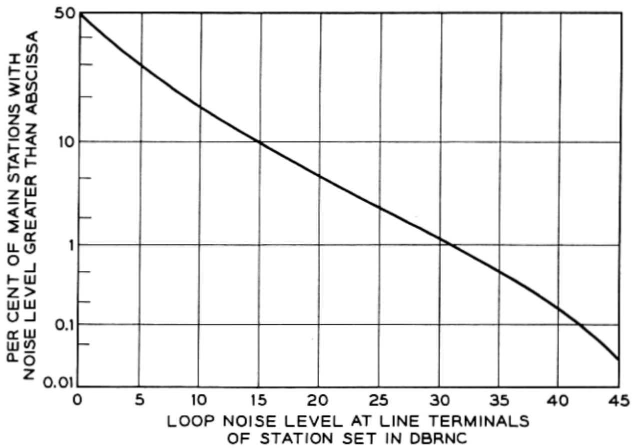

Fig. 3 — Loop survey data, 1961: estimated loop noise (power hum) distribution.

cated either via operator placement or by dialing between terminating class 5 offices. Noise and end-office to end-office loss were measured at the originating end-office with a 3A noise measuring set on a zero loop terminated in 900 ohms.

The results indicate that at the station set the toll connection noise distribution has a mean of 19.7 dbrnc and a standard deviation of 7.8 db. The data are accumulated in Fig. 4. In addition, it was found that the mean of the distribution of end-office to end-office loss is 7.7 db with a standard deviation of 3.0 db. Analysis of the relationship between noise level and airline distance indicates a linear increase in average noise level of 2.2 db per double distance, with variance decreasing with increasing distance.

V. EVALUATION OF NOISE PERFORMANCE

Once pertinent estimates of noise performance are in hand, the next step is to evaluate noise performance. Consider first an evaluation from the point of view of the present standard: 26 dbrnc (20 dba) seldom exceeded at the line terminals of the station set. From Fig. 4, it is seen that in the absence of loop noise approximately 23 per cent of the toll connections in the sample had noise in excess of 26 dbrnc at the line terminals. Whether or not this is satisfactory performance in terms of the present objective depends on the interpretation of the phrase "seldom exceeded."

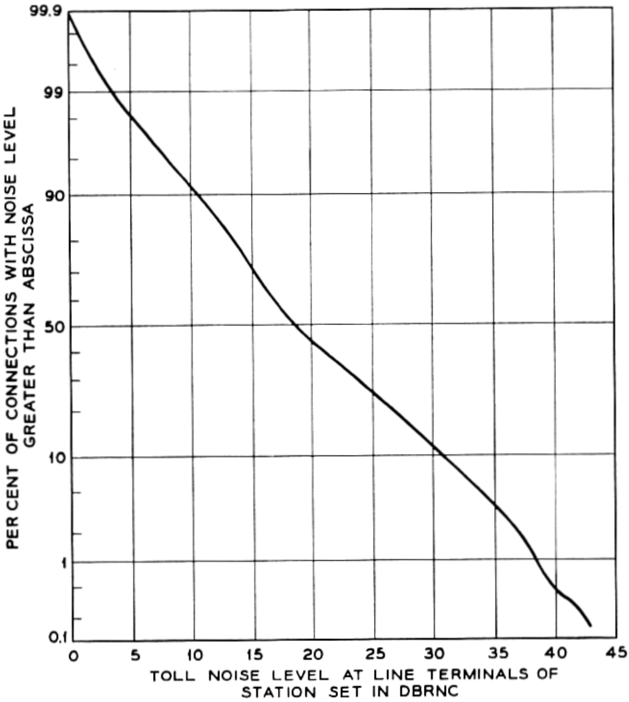

Fig. 4 — Connection survey data, 1962: distribution of noise levels on customer-placed toll connections. Mean = 19.7 dbrnc; standard deviation = 7.8 db.

A more specific statement for noise evaluation is obviously desirable. In terms of noise grade of service, discussed in Section III, 97.0 per cent of the measured values in Fig. 4 (i.e., connections) would be considered good or better and only 0.3 per cent poor or worse.* This may appear to be in contradiction to the finding that 23 per cent of the measurements do not meet the 26-dbrnc objective. The fact, however, is that when the average noise level is low, over-all grade of service is very impressive. But this does not assure satisfactory noise performance on all toll calls. For example, the noise on close to 1 per cent of the connections was found to exceed 39 dbrnc, which essentially defines a bound on the levels that telephone users consider good or better [i.e. for $x > 39$

* Grade of service for *measured* connection noise does not reflect the subjective effects associated with compandored links. In the absence of speech (i.e. when noise is measured) compandor action is such that the listener perceives a lower noise level. On the whole this effect is small. Estimates show that the above good-or-better noise grade of service figure is affected by less than 1.0 per cent and the poor-or-worse figure by less than 0.1 per cent.

dbrnc $p(E + G \mid x) < 0.5$]. Furthermore, from Fig. 5, we see that these higher values (the tail of Fig. 4) are attributable mainly to noise on the longer and thus more costly connections. Hence it is misleading to look only at grade of service for noise on *all* toll calls. The customer who primarily makes calls spanning long distances is apt to get poorer performance; for example, the connection survey showed that grade of service on calls within a 100-mile radius is 97.8 per cent good or better whereas on coast-to-coast calls it is only 86.5 per cent good or better. In order to avoid this shortcoming, it appears necessary to have a particular noise requirement for various physical lengths of connections, instead of a single number seldom exceeded for all lengths.

Consider next the noise contribution from the loop plant. On the basis of data in Fig. 3, close to 2 per cent or an estimated 800,000 customers (main stations) have loop noise in excess of the present 26-dbrnc objective. While this is only a relatively small percentage, loop noise is a problem to the affected customers because the same level tends to be present at all times. As stated earlier, the principal source of audible

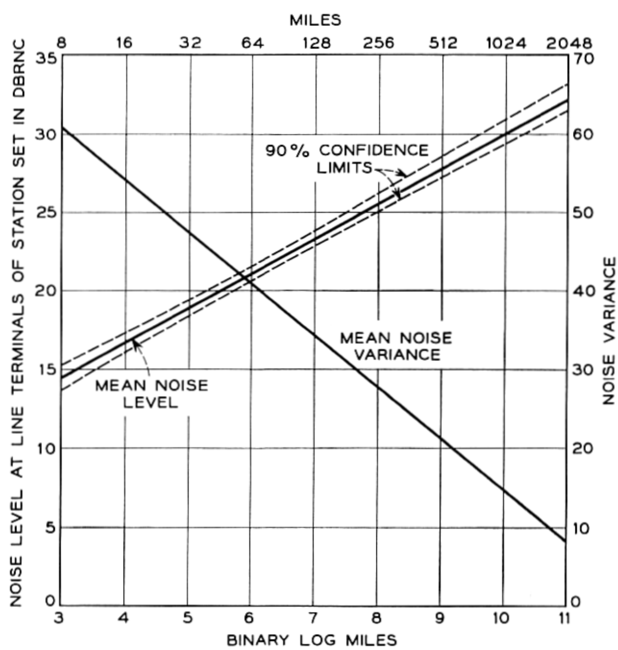

Fig. 5 — Regression of noise level vs distance and noise variance vs distance spanned by connections.

loop noise is power line induction, appearing as hum in the telephone circuit. The hum level is determined by the extent of the power system influence (which is fairly constant in any particular location) and the degree of balance of the line and terminal equipment. Party lines, because of the use of grounded ringers and other unbalanced station set circuitry, are found on the average to be much noisier than individual lines. If a telephone user has excessively high loop noise, it is almost certain that he is on a party line and that the noise is power line hum. Fig. 3 shows that an estimated 0.2 per cent of Bell System customers have 39 dbrnc of power hum loop noise. Since they can expect nearly this level on every call, their grade of service on both local and toll calls collectively will be only about 40 per cent good or better and as much as 10 per cent poor or worse.

VI. REQUIREMENTS FOR AN OVER-ALL NOISE OBJECTIVE

The present noise objective is not so formulated as to focus attention on substandard noise performance on the longer toll connections and the existence of power line hum on loops. To direct attention to areas of inadequate noise performance and emphasize the need for improvement of loops and trunks that are now substandard, we must select a noise objective that is not only satisfactory from the grade-of-service point of view, but is also in harmony with actual system noise behavior.

Fig. 5 shows that the average noise level on toll connections is positively correlated with airline distance. This implies that for noise contributed by the toll plant, the objective should be length-dependent. Short connections therefore should meet more stringent requirements than long ones, making the objective consistent with actual system performance. In addition, the objective should incorporate the inherent variability of noise level on connections spanning the same over-all distance and recognize that this variability decreases with distance, a fact also shown by Fig. 5. The most expedient way to incorporate these length dependencies is first to divide distance into a number of classes or categories (that is, short, medium, long, and intercontinental), then to establish for each class a suitable noise distribution, wherein mean noise increases and variance decreases with distance. A study of the connection survey data shows that the distributions may be assumed to be normal within each distance class.

With regard to the form and statement of the objective as it pertains to loop noise, Table I and Fig. 3 indicate that each central office area can be expected to have a small percentage of loops which will be quite noisy. Furthermore, because the noise is predominantly power hum it may be assumed that if a customer has a noisy loop then his noise level can be expected to be about the same on every call. To alleviate this situation, it would appear desirable to adopt one universal loop limit — a limit which would insure all telephone users the same noise grade of service on a long-term average basis.* The latter requirement is satisfied by a limit having the property that the desired grade of service assigned to any class of end-office to end-office connection is not significantly altered when a noise level equal to the limit is "added" to the numeric requirement for any of the connection classes.

VII. DERIVATION OF THE NEW OBJECTIVE

From the foregoing discussions, it may be concluded that an over-all noise objective should incorporate both a connection and a loop noise objective: for connections, it should state requirements on mean and standard deviation for noise as a function of distance; for loops, a limit not to be exceeded. The actual numerics, viewed in terms of grade of service, should assure high customer satisfaction and be economically feasible for the telephone company.

From the evaluation of the connection survey data, Section V, it was evident that noise grade of service could be impressive on the whole and yet not be acceptable on the longer connections. We stated, for example, that the grade of service on coast-to-coast connections is only 86.5 per cent good or better. In general, it will be found that grade of service *is* less satisfying on the longer connections, because of the increase in connection noise level with increasing airline distance. However, the number of toll calls established by customers decreases rapidly with increasing airline distance, so that a subclass such as all coast-to-coast connections will have a negligible influence on over-all grade of service. It follows therefore that: (*i*) it is insufficient to simply satisfy one over-all grade of service requirement; (*ii*) the same grade of service level cannot be expected on *all* lengths of connections, since the length-dependent increase in connection noise must be recognized. Appropriate adjustment for grade of service is therefore necessary. A study of various promising adjustments showed that "balance" may be achieved if grade of service does not vary with distance more than from near 100 per cent good or better to a minimum value of 90 per

* This assumes all customers to be "average" in their calling habits. Despite variability which is known to exist, this assumption is justified from a practical standpoint. Without it each customer could have a loop limit depending on his particular calling habits. This would be impossible to administer.

cent on the longest connections and, in the same way, from near 0 per cent poor to a maximum of 0.5 per cent.

The first step then is to satisfy the extreme requirements, that is, a grade of service of at least 90 per cent good or better and at most 0.5 per cent poor on the longest connections, i.e., on the class of intercontinental calls. On the assumption that noise on such connections is normally distributed, there exist many well-defined choices of mean and standard deviation that will satisfy these conditions. However, the choice can be narrowed, since the objective for the longest connections is constrained by our noise model to large values of mean and small values of standard deviation. While it is desirable to have as large a value of mean as possible, there cannot be too small a standard deviation because of the variation in circuit losses. The practical limit for standard deviation in view of the latter appears to be a value between 3 and 4 db. With a choice of standard deviation of 3.5 db, Fig. 6* implies that a mean of 30 dbrnc is permissible for the noise at the line terminals of the station set on the class of longest possible connections spanning an airline distance halfway around the world. Using these two parameters as an anchor at the upper end, we may now assign noise requirements to the remaining shorter connections. A satisfactory breakdown is shown in Fig. 7. Using binary log-mile cells, distance is divided into the four broad categories defining short, medium, long and intercontinental connections. The corresponding allowable values of mean and standard deviation for noise in these classes and the resulting grade-of-service values are indicated. It can be seen that all of the previously mentioned requirements are fulfilled.

Fig. 8 shows the 1962 connection survey noise data for each distance category and Fig. 9 shows the desired noise distribution functions in the same coordinates. Comparison of the two demonstrates that existing and desired performance are fairly compatible and that the assumption of normality is justified. Except for whatever improvement is required to overcome the subjective impairment due to compandors, little or no noise improvement is needed on short connections other than in the tail of the distribution, while on medium and long connections noise should be decreased respectively by about 3 and 4 db on the average and somewhat more in the tails. Since these improvements seem economically feasible in future system designs, the parameters in Table II were established as the new noise performance objective for customer-to-customer connections referred to the line terminals of the station set.

* A discussion of how grade-of-service curves may be readily constructed for normal distribution is given in Appendix B.

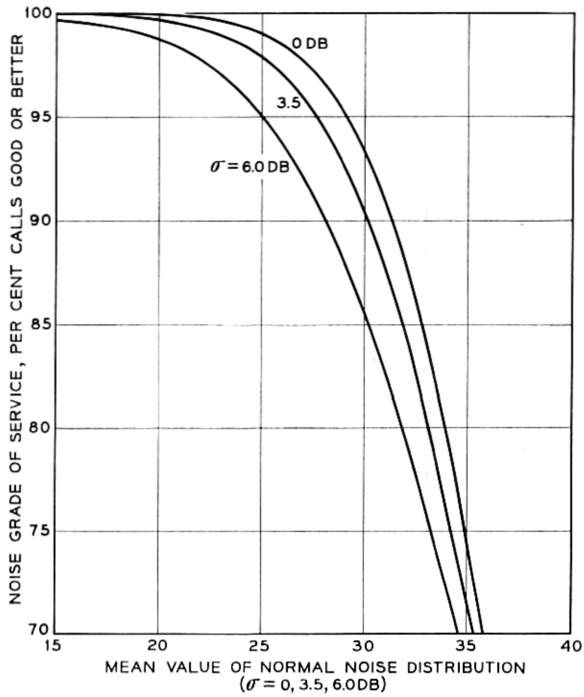

Fig. 6 — Grade of service for noise levels which are normally distributed.

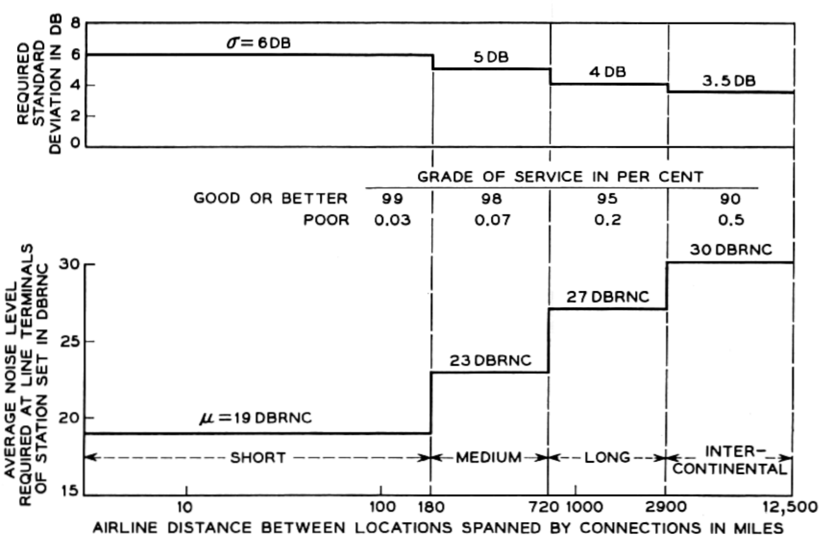

Fig. 7 — New over-all performance objective for noise on toll connections.

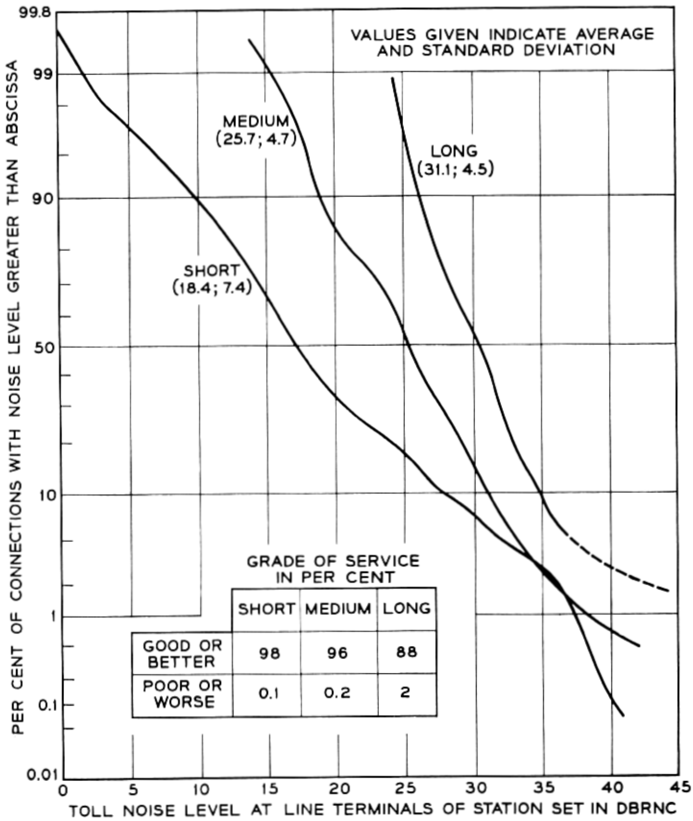

Fig. 8 — Noise performance of short, medium, and long toll connections — connection survey data, 1962.

Having this basic breakdown for the new objective for connection performance, we can now make a choice of loop limit. Fig. 10 shows grade of service for the range of loop noise levels up to 30 dbrnc in combination with the new noise requirements for each distance category. It is seen that no significant deterioration in grade of service results with loop noise less than 20 dbrnc. Above this value, however, there is a definite downward trend in per cent good or better and an upward trend in per cent poor. Hence, it is appropriate to choose a loop limit at 20 dbrnc. On the basis of Fig. 3, we see that an estimated 5 per cent, or approximately 2 million main stations, are above this value; hence corrective measures for reduction of noise on loops will be required throughout the system.

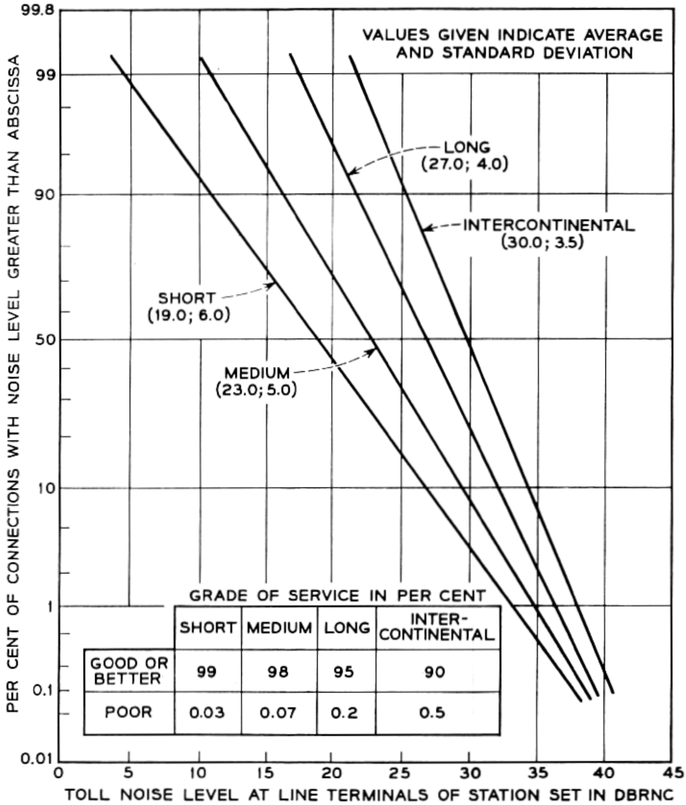

Fig. 9 — Breakdown of new over-all message circuit noise performance objective.

Finally, it is of interest to compare the new objective with the current 26 dbrnc seldom exceeded objective. We see from Fig. 9 that for connection noise 26 dbrnc may be exceeded on 12 per cent of the short connections, on 27 per cent of the medium connections, on 60 per cent of the long connections, and on 88 per cent of the intercontinental

Table II — New Noise Performance Objective

Airline Distance, miles	Mean, dbrnc	Standard Deviation, db	Grade of Service	
			Good or Better	Poor
Up to 180	19.0	6.0	99%	0.03%
181–720	23.0	5.0	98	0.07
721–2900	27.0	4.0	95	0.2
2901 and above	30.0	3.5	90	0.5

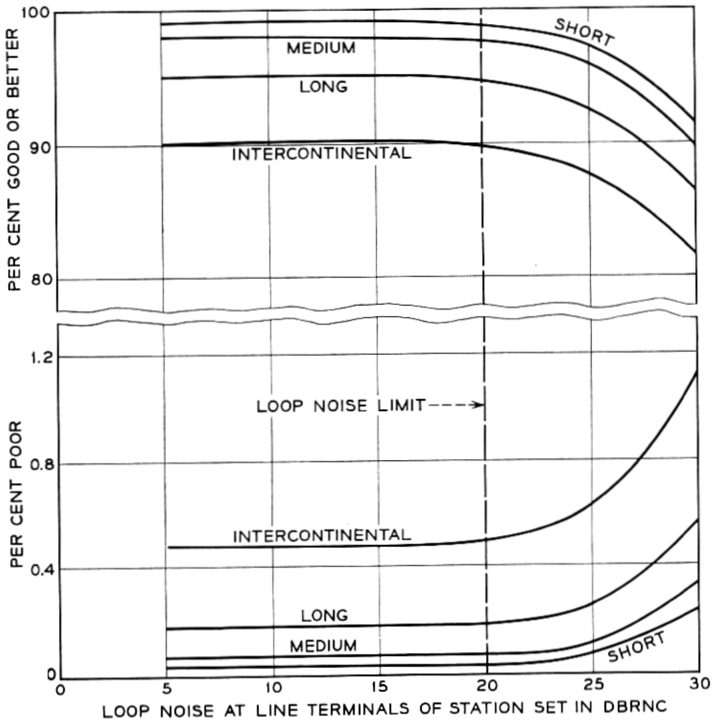

Fig. 10 — Grade of service for connection objective with loop noise.

connections. This implies that for connection noise the new performance objective is more lenient, in that it allows noise levels above 26 dbrnc for an appreciable per cent of calls. Notice, however, that the range is "restricted" to around 39 dbrnc, the 50 per cent point of "good-or-better" response, which is highly desirable. On the other hand, approximate evaluations show that the present design objective of 44 dbrnc at 0 TLP for a 4000-mile circuit would have to be made more stringent in order for the new over-all objective to be satisfied. Lastly, we note that for loop noise the limit of 20 dbrnc not to be exceeded is more stringent than the present objective would indicate.

VIII. ACKNOWLEDGMENTS

The contribution given by all those who participated in the subjective tests on noise effects and those who worked on the noise surveys is gratefully acknowledged. This includes many Bell Laboratories employees, A.T.&T.Co. personnel and operating telephone company people. In addition, I would like to thank my co-workers, without whose help this project could not have been carried out.

APPENDIX A

Noise Opinion and Noise at the Line Terminals of the Station Set

Noise "at the line terminals of the station set" refers to noise across the line terminals of a 500CD type telephone set on a loop drawing 55 ma. While rather specific, this choice of customer reference is a natural one, since the noise opinion curves (Fig. 2) refer to noise level measured across the line terminals of a 500CD set on a 55-ma test circuit. Moreover, there is no loss in generality in having this type of customer reference as a standard.

In the evaluation of message circuit noise, we are concerned with two main noise sources: that originating on connections beyond class 5 offices and that originating on receiver loops. Consider the noise originating on connections. The first step in its evaluation is to decide on a point of measurement. Operationally, the best point is at the end-office at the input to a zero loop terminated in 900 ohms. Take any level measured there, say x dbrnc. What will be the subjective effect of this level on customers? It will be slightly different for customers on short, medium, and long loops, yet the difference is small enough to be neglected because of the "equalizing" properties of the 500 set. The combined response of a receiving loop and 500 set is reasonably constant for the majority of customers; hence it may be assumed that "received noise volume" (for noise originating beyond class 5 offices) is independent of loop length. Thus to evaluate x dbrnc, we must determine what this level will be across the line terminals of a 500 set drawing 55 ma. From loop loss data it is estimated that the average loss of a 55-ma loop terminated in a 500 set is 5 db. Hence, we may postulate that the subjective effect of x dbrnc of connection noise is the same for all customers, and that it is given by referring to $(x - 5)$ dbrnc on the noise opinion curves. As a consequence, a statement of objective for noise on connections referred to "the line terminals" (in our sense) really means that at the point of measurement, that is, the class 5 office, the requirement is 5 db less stringent.

Consider now the evaluation of noise originating on loops. If measured across the line terminals of a 500 set, we would expect a different acoustic response for the same value of noise level on short, medium, and long loops. Fortunately, the difference is hardly noticeable. Noise originating on loops is predominantly power line hum concentrated at 180 and 300 cycles. At these frequencies the 500 set input impedance is essentially constant over the range of loop currents encountered in the field. Hence we can assume that the subjective effect of a particular loop noise level at the telephone set is the same for all values of loop current, which suggests that for loop noise the noise opinion curves are directly applicable to any line terminal measurements, whether on short, medium, or long loops. Therefore, an objective for noise on loops can be applied equally to all customers — even though specified "at the line terminals" in our sense. Finally, we note that to evaluate the combined (over-all) effect of x dbrnc of noise originating on *any* connections and y dbrnc originating on *any* loop, it suffices to refer to the opinion assigned to a noise level equal to the power sum of $(x - 5)$ and y dbrnc in Fig. 2.

APPENDIX B

Grade of Service for Normal Noise Distribution

In Section 2.3 we stated that normal ogives can easily be fitted to the response data which result from evaluating the subjective effects of noise by absolute judgment. As such, opinion in category R

$$p(R \mid x) = \int_{-\infty}^{\frac{x-a}{b}} \frac{\exp\left(-t^2/2\right)}{\sqrt{2\pi}}\, dt$$

where a is the value of x such that $p(R \mid a) = 0.5$ and b is a parameter equal to the "standard deviation" of the ogive curve. With this model for opinion, grade of service for any probability density function $f(x)$ of noise levels is given by

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\frac{x-a}{b}} \frac{\exp\left(-t^2/2\right)}{\sqrt{2\pi}}\, f(x)\, dt\, dx.$$

If $f(x)$ is normal with mean $\bar{x}$ and standard deviation σ, we have

$$\int_{-\infty}^{\infty} \int_{-\infty}^{\frac{x-a}{b}} \left[\frac{\exp\left(-t^2/2\right)}{\sqrt{2\pi}}\right] \left[\frac{\exp\left[-(x - \bar{x})^2/2\sigma^2\right]}{\sqrt{2\pi}\sigma}\right] dt\, dx.$$

On the assumption that σ is fixed, the above integral is a function of $\bar{x}$ only, say $F(\bar{x})$. Changing variables

$$\frac{x - \bar{x}}{\sigma} = y$$

and differentiating under the integral sign we get

$$F'(\bar{x}) = \int_{-\infty}^{\infty} \frac{\exp\left\{-\frac{1}{2}\left[y^2 + \frac{(\bar{x} + \sigma y - a)^2}{b^2}\right]\right\}}{2\pi b} dy.$$

Furthermore letting $b' = \sqrt{b^2 + \sigma^2}$ and $u = b'/b\{y + \sigma[(\bar{x} - a)/b'^2]\}$ we find

$$F'(\bar{x}) = \frac{\exp[-(\bar{x} - a)^2/2b'^2}{\sqrt{2\pi}b'}$$

Finally integrating between $-\infty$ and $\bar{x}$, we get

$$F(\bar{x}) = \int_{-\infty}^{\bar{x}} \frac{\exp[-(t - a)^2/2b'^2]}{\sqrt{2\pi}b'} dt = \int_{-\infty}^{\frac{\bar{x}-a}{b}} \frac{\exp(-t^2/2)}{\sqrt{2\pi}} dt$$

which is the value of grade of service for a normal probability density function $f(x)$ having mean $\bar{x}$ and constant standard deviation σ. The above integral is easily constructed with the aid of normal probability paper. Simply plot $F(\bar{x} = a) = 50$ per cent and $F(\bar{x} = a + \sqrt{b^2 + \sigma^2}) =$ 15.9 per cent, for the given category R, and join the two points by a straight line.

REFERENCES

1. Cochran, W. T., and Lewinski, D. A., A New Measuring Set for Message Circuit Noise, B.S.T.J., **39**, July, 1960, p. 911.
2. MacAdam, W. K., A Basis for Transmission Performance Objectives in a Telecommunication System, Comm. and Elect., No. 36, May, 1958, p. 205.
3. Chinn, H. A., Gannett, D. K., and Morris, R. M., A New Standard Volume Indicator and Reference Level, B.S.T.J., **19**, January, 1940, p. 94.
4. Coolidge, O. H., and Reier, G. C., An Appraisal of Received Telephone Speech Volume, B.S.T.J., **38**, May, 1959, p. 877.
5. Aikens, A. J., and Lewinski, D. A., Evaluation of Message Circuit Noise, B.S.T.J., **39**, July, 1960, p. 879.
6. Lewinski, D. A. and Nåsell, I., unpublished work.
7. Hardgrave, W. W., unpublished work.
8. Nåsell, I., The 1962 Survey of Noise and Loss on Toll Connections, B.S.T.J., this issue, p. 697.