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Loss-Noise-Echo Study of the Direct Distance Dialing Network

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A review of the current VIA Net Loss plan was made using a simulation model of the transmission characteristics of telephone connections. This model allowed the determination of the optimal loss which balanced the degradation due to talker echo and the degradation caused by its control on primary speech. The review reaffirmed current methods with some changes to allow for the emerging digital network.

I. INTRODUCTION

In any telephone connection, energy can be reflected back to the talking customer at any impedance discontinuity or at any junction between four-wire and two-wire circuits. This energy manifests itself to the talking customer as an echo of his own voice. If the reflected energy has sufficient amplitude and delay, it can be annoying and can interfere with the talker's normal speech process. Through the years, considerable effort has been made to reduce the amplitude of the talker echo by using impedance-matching procedures. However, it is not feasible to completely eliminate echo. Loss is therefore introduced into the connection to further attenuate the echo energy. The amount of loss needed increases with the delay of the echo signal relative to the talker's voice signal.[1] This loss also attenuates the talker's voice signal received at the far end of the connection. When the amount of loss needed for talker echo control causes undue degradation of the received voice signal, echo suppressors[2] are inserted into the connection. Echo suppressors function by selectively and dynamically changing loss in each direction of the connection in response to talker activity.

Currently, the amount of loss and the distance at which echo suppressors are applied are determined by the VIA Net Loss (VNL) plan. This plan was developed about 20 years ago.[3] Since that time more extensive use has been made of carrier systems. These systems have considerably less propagation delay than voice-frequency cable systems. Thus, there was a question whether the amount of loss specified by the VNL plan could not be reduced and the distance increased at which echo suppressors are introduced. Also, there was some question as to appropriateness of the through- and terminal-balance requirements used to specify the maximum allowable amount of impedance mismatch, and it was felt that some simplification of the loss plan could possibly result in some operational and economic benefits.

In addition, it will be possible with the introduction of the No. 4 Toll ESS switching system[4] for a digital trunk to be switched in digital form to another trunk without requiring digital channel banks to decode the signal to voice frequencies. However, present VNL design rules require loss to be introduced after the receiving channel bank equipment of each trunk. In a digital office, this would require either that a signal be decoded, loss inserted, and re-encoded; or that the encoded digital representation be changed by digital processing to a lower signal level. Either of these techniques would introduce additional cost and transmission impairments.

Because of these questions, a thorough review of the methods to control talker echo was initiated. This review included examining the appropriateness of using loss, balance requirements, and echo suppressors for talker echo control. To achieve this review, a comprehensive program was initiated to determine the transmission characteristics of the network, and to develop by subjective tests the relationship between measurable parameters and customer opinion of the quality of service. (The results of these studies are being published in other articles.[1,5]) These studies were then used in the development of a computer-simulation model which allowed the investigation of the optimal trade-off between the degradation due to talker echo and the degradation caused by its control on the primary speech. This paper reports on the results and recommendations arrived at by this investigation.

II. SUMMARY OF RECOMMENDATIONS

This review examined the appropriateness of various methods for talker echo control on three types of connections which, although not all occurring today, may all occur in the near future. These types are (*i*) connections using analog or digital facilities switched via analog switching systems—referred to as the analog network, (*ii*) connections using only digital facilities switched digitally—referred to as the digital network, and (*iii*) connections using portions of both types of networks—referred to as the mixed analog-digital network. This review led to the following recommendations.

(*a*) The VNL plan provides nearly optimal loss for connections over the analog network, and need not be changed.

(*b*) Some simplification of the VNL plan is possible. However, at this time, there appears to be no significant improvement in quality or economic benefit in making a change to such a plan for the analog network.

(*c*) There are significant quality, technological, and economic reasons for having a different loss plan for connections using the emerging digital network. The recommended plan is (1) a fixed-loss plan from Class 5 to Class 5 office of 6 dB for all lengths of digital connections and (2) the establishment of the nominal transmission level for digital toll offices of −3 TLP (transmission level point); a change from −2 TLP of analog toll offices.

(*d*) The two loss plans for the analog and digital networks are compatible. Connections using portions of both networks have transmission quality intermediate between that of the analog and digital networks.

(*e*) Terminal balance requirement objective should be that the echo return loss distribution for all types of toll-connecting trunks (TCT) should achieve or exceed a distribution with 50 percent ≧22 dB, and none less than 16 dB. All trunks connected to digital offices must meet this objective. This should be viewed as a long-term goal for other offices. Currently, two-wire trunks on analog switching systems will be allowed to meet their present lower requirement of 50 percent ≧18 dB, and none less than 13 dB.

(*f*) The present through-balance requirement at a two-wire switching point appears satisfactory. The through-balance requirement states that the echo-return loss distribution should achieve or exceed a distribution with 50 percent ≧27 dB, and none less than 21 dB.

(*g*) In general, echo suppressors should be applied at a trunk length where the improvement in transmission quality outweighs their inherent risks. Based on these considerations, echo suppressors in both the analog and digital network should be applied on

Table I — Regional center-regional center echo suppressor application rules

Echo suppressors should be applied on all RC-RC trunks except:

White Plains—Wayne
White Plains—Pittsburgh
White Plains—Rockdale
White Plains—St. Louis
Wayne—Pittsburgh
Wayne—Rockdale
Wayne—St. Louis
Pittsburgh—Norway
Pittsburgh—Rockdale
Pittsburgh—St. Louis
St. Louis—Dallas
St. Louis—Norway
St. Louis—Rockdale
Dallas—Pittsburgh
Dallas—Rockdale
Dallas—San Bernardino
Dallas—Wayne
Dallas—White Plains
Sacramento—San Bernardino

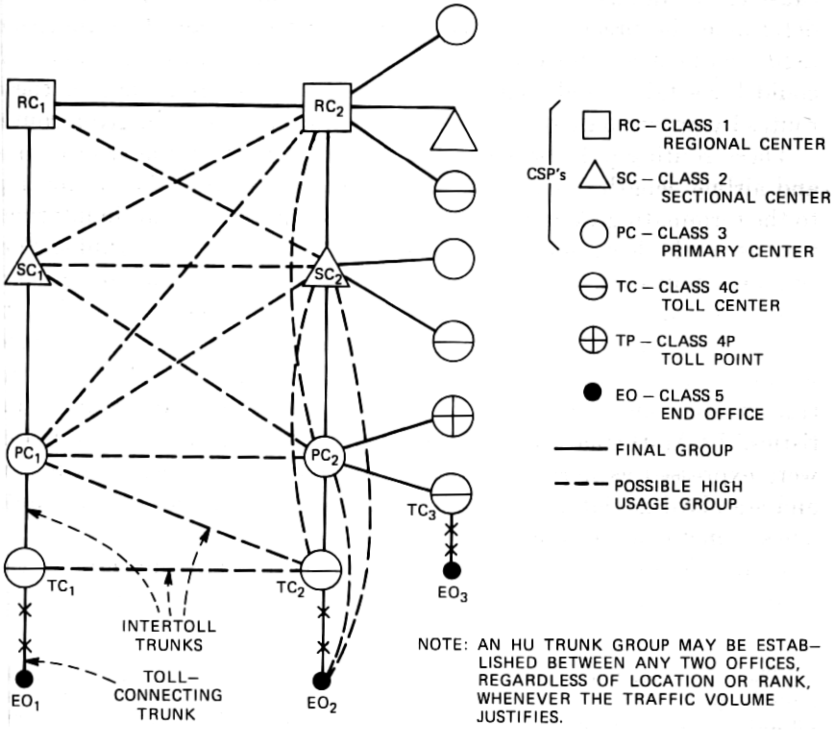
high-usage trunks greater than 1850 route miles in length rather than the present 1565-mile length. Regional-center-to-regional-center trunks should be equipped with echo suppressors, except for those trunk groups between the offices listed in Table I.

III. METHODOLOGY

The review process that led to the above recommendations was achieved through a computer-simulation model which allowed the investigation of the optimal trade-off between the degradation due to talker echo and the degradation caused by its control on the received speech. The approach used in the computer model was to duplicate within the computer the routing and transmission characteristics that could have occurred on a sample of actual calls in the network. From this information, estimates of the distributions of loss, noise, echo-path loss, and delay were obtained for various approaches to the control of talker echo. The merits of each approach were evaluated by using the transmission parameter distributions obtained from the model to predict customer opinion of quality of service. Estimates of customer opinion were obtained by subjective tests[1] in which customers rated a call having a given set of transmission parameters on a scale of "excellent," "good," "fair," "poor," and "unsatisfactory." By combining this information with the distributions of occurrences of the parameters, estimates were obtained of the expected percentage of customers who would rate a call "good or better" (good and excellent) or "poor or worse" (poor and unsatisfactory) if a large number of calls are made. These estimates are referred to as "grade-of-service."

A call using the DDD network involves the telephone set on the customer's premises, the communication path (the loop) to his local Class 5 office, a number of interconnected trunks to the far end Class 5 office, the far end loop and telephone set. The path between Class 5 offices chosen through the network is dictated by the Network Switching Plan. In this plan, the continental United States is divided currently into ten regional center areas. Within each region, the offices are interconnected in a hierarchical manner by final trunk groups. The most general hierarchical structure is illustrated in Fig. 1. In many cases, calls from a Class 5 office may be routed directly to a Class 1, 2, or 3 office and the chain of offices may not contain all five classes of offices. Regions are connected to another region by high-usage trunk groups or RC-RC final trunk groups. A high-usage trunk group may be established between any two offices whenever sufficient traffic exists.

The actual route chosen through the network depends on the availability of trunks at each of the offices in the hierarchical chain. At a



NOTE: AN HU TRUNK GROUP MAY BE ESTABLISHED BETWEEN ANY TWO OFFICES, REGARDLESS OF LOCATION OR RANK, WHENEVER THE TRAFFIC VOLUME JUSTIFIES.

Fig. 1—Hierarchical switching plan for DDD network.

given office, preference is given to the high-usage trunk group to the lowest-ranking office in the distant region. If all of the trunks in that group are busy, a high-usage trunk group to the next highest office in the distant region is chosen if it exists. If the high-usage trunk groups to all the offices in the distant region are busy, the final trunk group to the next office in its own hierarchical chain is chosen.

Figure 2 shows the hierarchical chains and the high-usage trunk groups that actually could be used for a call from the Brooksville, Florida-to-Cincinnati, Ohio, Class 5 offices. There are four possible routes, in order of their probability of occurrence:

(*i*) Brooksville–Jacksonville–Cincinnati,
(*ii*) Brooksville–Jacksonville–Pittsburgh–Cincinnati,
(*iii*) Brooksville–Jacksonville–Rockdale–Cincinnati,
(*iv*) Brooksville–Jacksonville–Rockdale–Pittsburgh–Cincinnati.

The simulation model duplicates with the computer the routing and the transmission properties of the Class 5 to Class 5 portion of a sample of 1500 calls made by customers throughout the United States.[6] Because each call has the possibility of several routes, it is impractical to determine the precise route used for a particular call. The approach used was to incorporate in the model all of the routes that each call could have taken and weigh the results obtained from each of these routes by an estimate of the probability of occurrence of a given route.

These routing data provide information as to the number of trunks and airline* length of each trunk in a connection from the originating to the terminating Class 5 office. It does not, however, contain information as to the loss, noise, and delay that occur on these trunks. Fortunately, trunk surveys have indicated that the transmission properties of a trunk are determined more by trunk length than by its geographical route. Thus, considerable simplification was obtained without much decrease in accuracy by assigning to each trunk the transmission characteristics derived from system-wide trunk statistics.[5,7,8] Mathematically, the loss, noise, and delay characteristics were expressed as normally distributed random variables with means and standard deviations that are functions of the length of the trunk. These functions are shown in Fig. 3.

In developing the estimated performance of the connections, the model individually evaluates each of the routes. Given the basic in-

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* The airline length of a trunk is the straight line distance between two offices. The route length of a trunk is the actual length of the trunk and is always longer than the airline length. The model estimate of the ratio of the route length to airline length is given as part of Fig. 3. The airline length of an entire connection is the straight-line distance between local Class 5 offices.

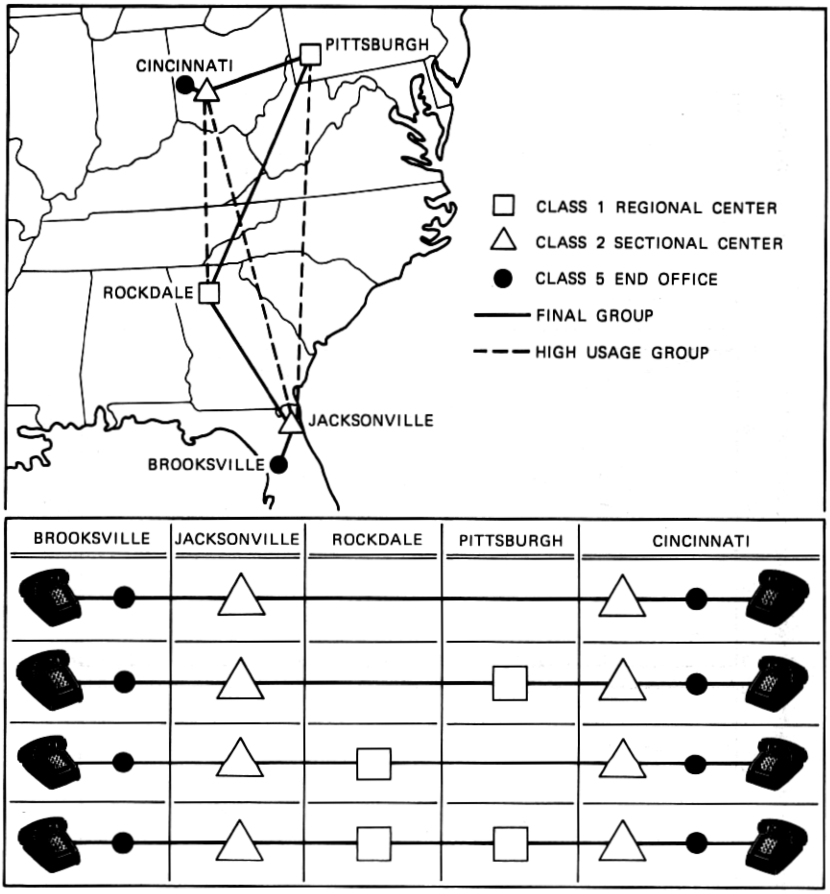

Fig. 2—Actual routing of call between Brooksville, Florida and Cincinnati, Ohio.

formation on the number of trunks and distances between offices, the model selects a random value from the appropriate distributions of delay, noise, and loss for each trunk. The delay value is added to the sum of delays from the previous trunks, the noise value in power is added to the previous noise value and attenuated by the loss value, and the loss is summed in dB to the sum of previous loss values. The process is then repeated for all trunks of a connection to obtain one estimate of the loss, noise, and delay which could occur on this connection. To obtain estimates of the range in values that could occur, the process of selecting values and summing is repeated many times, the exact number depending on the probability of the connection.

Once having an estimate of the entire distribution, estimates of the echo-path loss, the noise-loss grade-of-service, talker-echo grade-of-

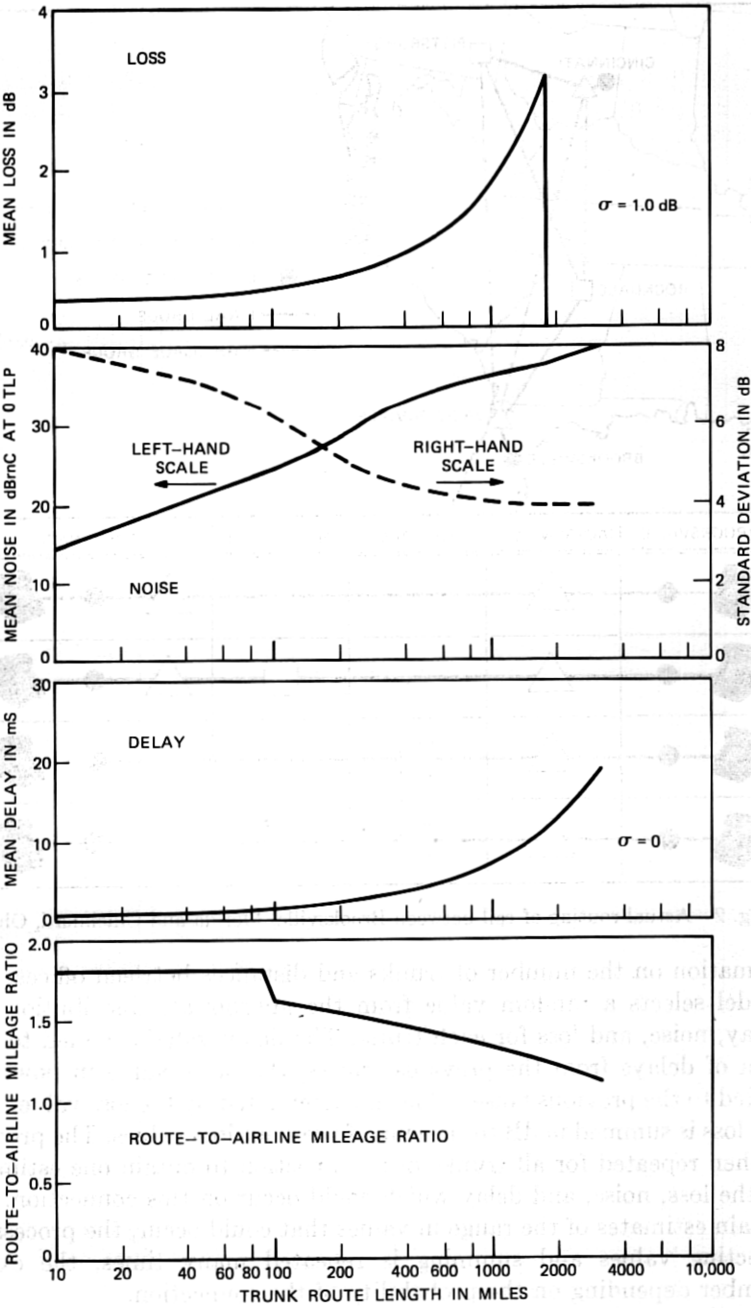

Fig. 3—Assumed trunk loss, noise, delay, and route-to-airline ratio for simulation model.

service, and noise-loss-echo grade-of-service are calculated using the subjective test results reported in Ref. 1. The parameters of the subjective test models were obtained from the loss, noise, and delay results by the formulae given in Fig. 4. In these computations, the average characteristics of loops and telephone sets were used since the emphasis in this study was on the change in the transmission characteristics of the Class 5 to Class 5 portion of the network. The echo-path loss measures the amount of attenuation of the echo energy reflected back to the talking customer. It includes the effects of the echo reflected at the impedance mismatch between the toll-connecting trunk and the customer loop at the Class 5 office and the echo reflections occurring

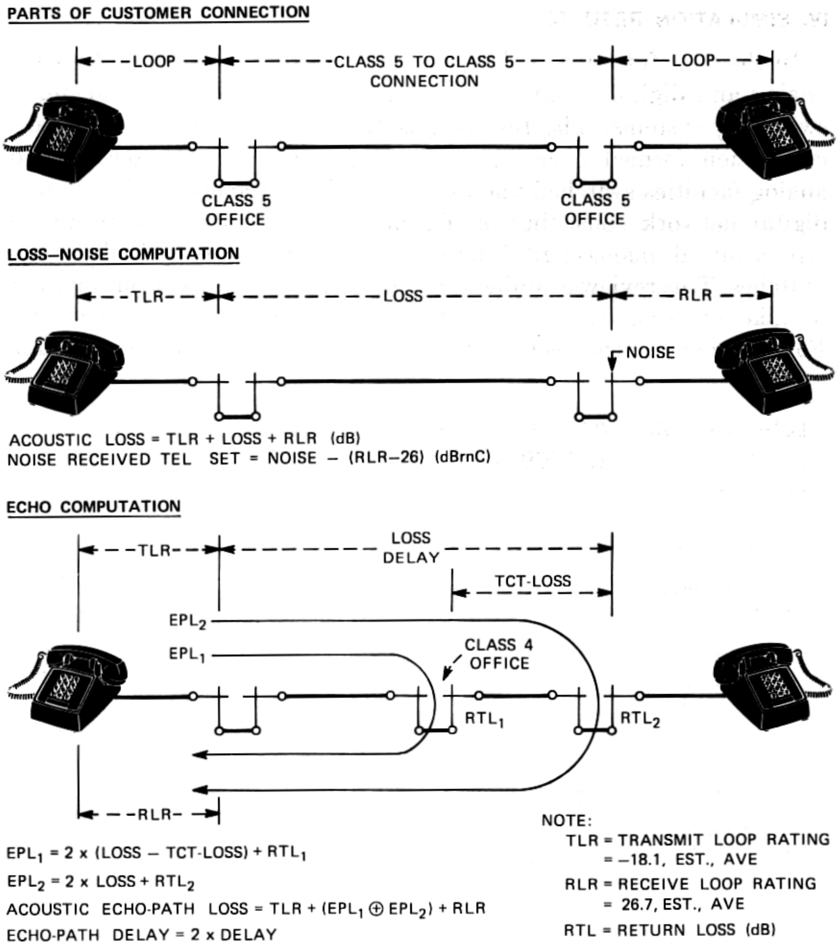

Fig. 4—Formulae used for deriving the parameters of the subjective test models.

in the trunk between the Class 4 toll office and the Class 5 office as measured by terminal balance procedures.

A number of assumptions were made in developing the model. Indeed, an important concept in modeling is to provide just sufficient detail to provide valid results. Too much information complicates the model and increases the computation time and cost. An indication of the validity of the model is obtained by comparing the loss, noise, and delay results with those of the 1969/1970 Connection Suvery[9] and the 1972 Echo Survey.[5] As shown in Tables II and III, the mean and standard deviation predicted by the model agree in all length categories within the statistical accuracy of the model and the surveys.

IV. SIMULATION RESULTS

In the near future, it will be possible to form a connection by using analog and digital facilities switched together via analog and digital switching systems. The resulting connection will be analogous to a connection formed over (*i*) a purely analog network consisting of analog facilities switched via analog switching machines, (*ii*) a purely digital network consisting of digital facilities switched digitally, or (*iii*) a mixed analog-digital network with both types of facilities and switches. This review examined the appropriateness of various methods of talker echo control for each of the analogous three types of networks. For convenience, the results given in this section are grouped according

Table II — Comparison of estimated loss and noise from model and 1969/1970 Connection Survey

A. Loss

Connection Length (Airline Miles)	Model		1969/1970 Survey	
	Mean (dB)	SD (dB)	Mean (dB)	SD (dB)
0–180	6.5	1.9	6.5 ± 0.7	2.0
180–725	7.6	2.1	7.3 ± 0.4	2.3
725–2900	7.8	2.5	7.7 ± 0.5	2.5

B. Noise

Connection Length (Airline Miles)	Model		1969/1970 Survey	
	Mean (dB)	SD (dB)	Mean (dB)	SD (dB)
0–180	21.9	6.0	18.7 ± 3.7	8.3
180–725	28.8	4.2	29.3 ± 0.6	3.1
725–2900	32.4	4.2	32.7 ± 0.6	3.5

Table III — Comparison of estimated round-trip delay and echo path loss from model and the 1972 Echo Survey

A. Round-Trip Absolute Delay

Connection Length (Airline Miles)	Model		1972 Echo Survey (1000-Hz Delay)	
	Mean (dB)	SD (dB)	Mean (dB)	SD (dB)
180–360	11.4	3.53	11.7 ± 0.8	3.4
360–725	16.4	5.51	16.4 ± 0.5	3.8
725–1450	23.0	5.77	24.8 ± 2.1	5.0
1450–2900	36.2	5.30	37.3 ± 1.3	6.1

B. Echo Path Loss

Connection Length (Airline Miles)	Model		1972 Echo Survey	
	Mean (dB)	SD (dB)	Mean (dB)	SD (dB)
180–360	22.7	4.4	23.1 ± 1.6	5.7
360–725	23.9	4.5	24.3 ± 2.2	6.8
725–1450	25.2	4.9	24.6 ± 2.2	6.3
1450–2900	21.0	4.6	23.3 ± 2.1	6.4

to the type of network. Within each of these three groups, control of talker echo by the use of loss, balance, and echo suppressors is discussed.

4.1 Analog network

4.1.1 Optimal loss

Loss in a connection reduces the amount of talker echo returned to the talker; however, it also attenuates the speech received from the far-end customer. Thus, there is a trade-off between the two types of degradation. Actually, a customer's opinion of his call is based on a joint assessment of these effects, since he experiences both effects during portions of his conversation. This joint assessment is measured through the loss-noise-echo grade-of-service estimates.

Quantitatively, the good or better value of this grade-of-service estimate will be slightly lower than the value of either the good or better loss-noise grade-of-service or the talker-echo grade-of-service which is individually lowest. This effect can be seen by examining Fig. 5. This figure contains an estimate of the percentage of customers who would rate a call good or better in terms of the acoustic loss of an end-to-end connection with average loops and a Class 5 to Class 5 connection of about 1300 airline miles. Also plotted are the individual loss-noise grade-of-service and echo grade-of-service. At low values

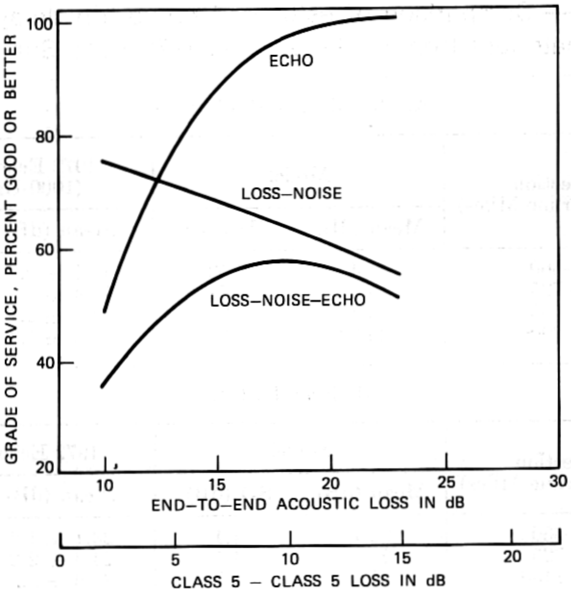

Fig. 5—Optimal loss for a 1270-airline-mile connection.

of loss, the value of the loss-noise-echo grade-of-service is determined by the echo grade-of-service. As the loss is increased, it follows the improvement in the value of the echo grade-of-service until the echo value exceeds the loss-noise grade-of-service. For loss values higher than this value, the loss-noise-echo grade-of-service follows the loss-noise grade-of-service.

Thus, the good or better loss-noise-echo grade-of-service as a function of loss increases to some maximum value and then decreases. The value of loss at which the good or better loss-noise-echo grade-of-service is a maximum is defined as the optimal loss. Because of the functional relationship between the good or better and poor or worse grade-of-service estimates, the optimal loss is also the value of loss which minimizes the poor or worse loss-noise-echo grade-of-service. For this particular example, the optimal loss is 18-dB acoustic loss, or about 10-dB connection loss between Class 5 offices.

The value of optimal loss for a given connection will depend upon the noise and delay associated with that connection. The value of loss will therefore vary between connections. A feeling for the range in optimal loss is obtained by plotting, as a function of airline length of the connection, the value at which 10, 50, or 90 percent of the connections would have an optimal loss value less than that value. The optimal loss for connections using analog facilities is shown in Fig. 6.

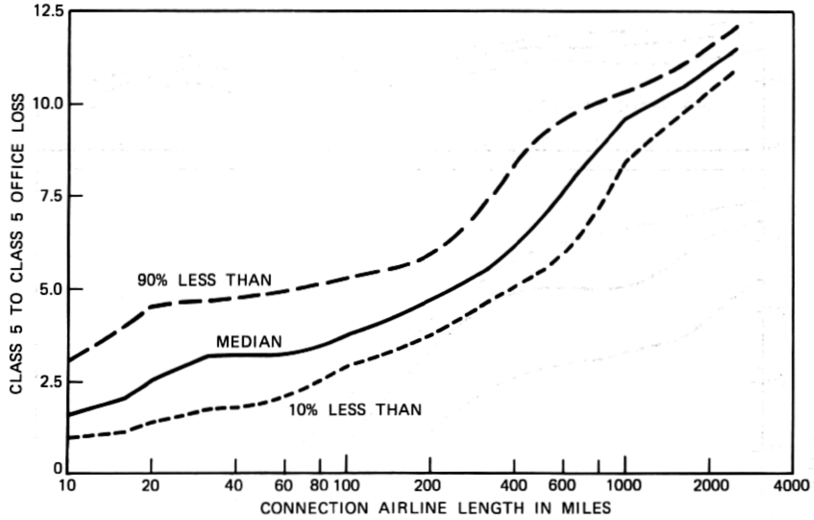

Fig. 6—Optimal loss for connections routed over analog network.

This figure shows that, for short distances, very little added Class 5 to Class 5 loss is desirable. As the length of the connection is increased, more loss is required to counteract the effect of increased delay on the talker-echo portion of the joint grade-of-service.

The grade-of-service obtained using this optimal loss is shown in Fig. 7 with the first graph showing, as a function of the connection airline distance, the talker-echo grade-of-service without echo suppressors being applied, and the next two graphs showing the loss-noise and loss-noise-echo grades-of-service. The set of curves plotted on each graph indicates, as a function of airline length, the value at which 10, 50, or 90 percent of the connections would have a grade-of-service greater than that value. For long connections, the loss-noise grade-of-service value is primarily due to noise, not loss. Some improvement in loss-noise grade-of-service would be possible with less loss. However, it would be small in comparison to the degradation in echo grade-of-service; thus, the optimal loss value tends to favor the control of echo.

These curves also indicate that satisfactory talker-echo grade-of-service can be obtained with loss control for all length connections. However, as is discussed later, somewhat better grade-of-service can be achieved on long connections by means of echo suppressors.

4.1.2 Loss allocation

The optimal loss value increases with increased end-to-end connection length. This variation is achieved in the network by allocating

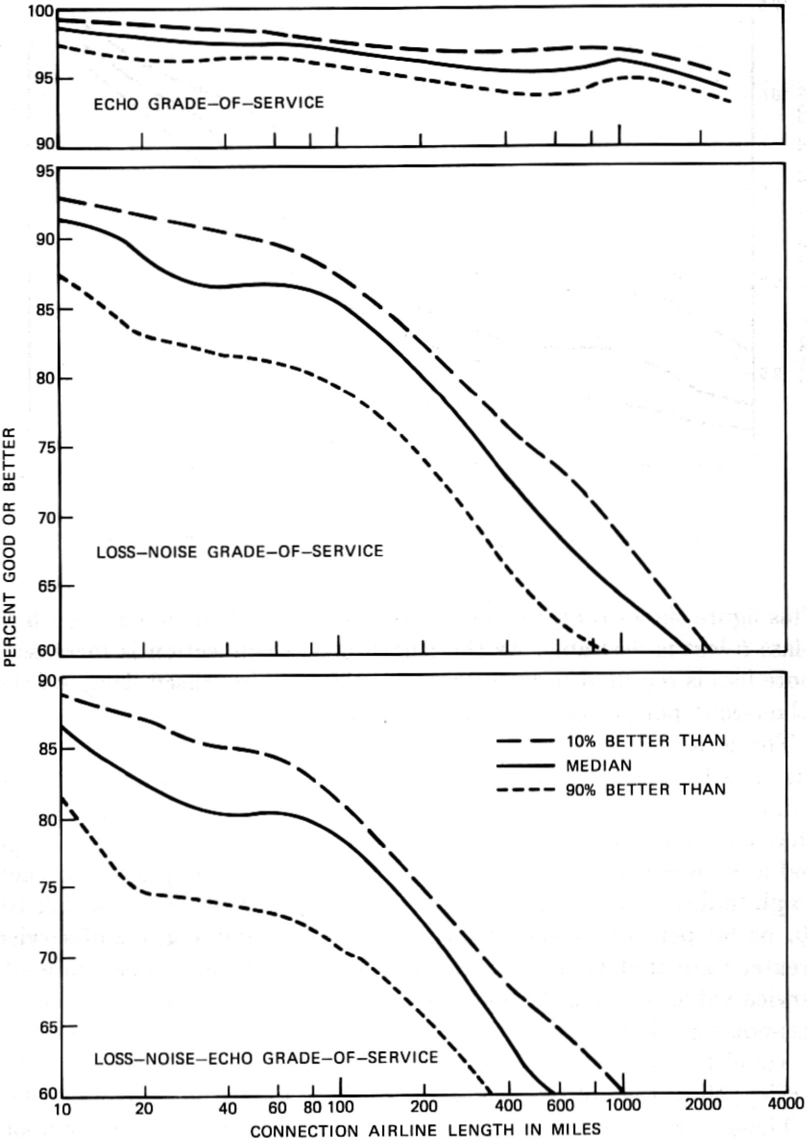

Fig. 7—Grades-of-service obtained for connections routed over the analog network if it were designed with optimal loss.

loss to the individual trunks of the connection such that the proper amount of loss is obtained when they are connected together. However, the trunks are usually used for both short connections and long connections. Any allocation plan must, therefore, be devised such that the proper amount of loss is obtained when these trunks are used in all length connections. At the same time, the allocation plan must also be easily implemented and administered. In general, these constraints mean that the actual connection loss can only approximate the optimal loss.

Practically, there appear to be three types of approximate allocation approaches:

(*i*) Fixed Loss—All connections are designed to have the same connection loss. An example of this plan is the switched digital network plan discussed in Section 4.2.
(*ii*) Compensated Loss—Trunks are assigned just enough added loss to compensate for their increased delay. An example of this plan is the current VNL plan.
(*iii*) Overcompensated Loss—The longer trunks are assigned more loss than needed to compensate for the delay of short trunks which normally occur as part of a longer connection.

In the remaining parts of this section, we examine the advantages and disadvantages of these three types of plans for use in the analog network.

4.1.2.1 Fixed loss plan. In a fixed loss plan, all connections have the same loss, irrespective of their length. This requires somewhat of a compromise with the optimal loss policy, which indicates that long connections should have more loss than short connections. A fixed loss plan is a satisfactory plan only if the increase in optimal loss with distance is not too large. Figure 8 shows the optimal loss for the analog network as a function of length of the connection. Two lines are drawn on this curve to represent two possible values for fixed loss. The higher value near 9 dB would approximate the optimal loss for longer connections out to some mileage where an echo suppressor would be used. However, it would provide 3 to 6 dB too much loss for shorter connections. The lower value of loss of 6 dB would provide a much better match to the required loss on short connections, but would provide insufficient loss for the longer connections. Thus, a fixed value of connection loss does not appear suitable for the analog network. Some variation in loss is needed with the length of the connection. This type of plan, however, is being adopted for the switched digital network because its optimum loss has less variability than that of the analog network. This is discussed in more detail in Section 4.2.1.

4.1.2.2 Compensated loss plan. In a length-compensated loss plan, loss is inserted in each trunk in proportion to the added amount of delay introduced by that particular trunk. Since the variation in optimal

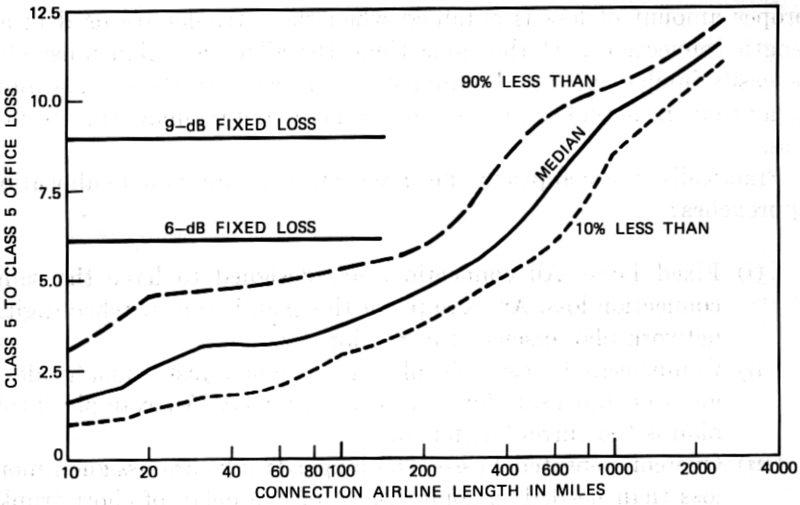

Fig. 8—Analog network connection loss of two fixed loss plans compared with optimal loss.

loss is primarily due to this effect, this type of plan provides a very good approximation to the desired loss.

The current VNL design plan is a prime example of this type of plan. The VNL plan has two classes of trunks, intertoll (ITT) and toll-connecting (TCT). The loss of intertoll trunks is determined for carrier trunks by the VNL formula (VNL = 0.4 + 0.0015 × trunk-length), while the loss of toll-connecting trunks is 2.5 dB plus that given by the VNL formula. The 0.0015-dB loss added for each mile in the carrier trunk VNL formula approximately compensates for the added propagation delay. The 0.4-dB factor which was originally introduced to compensate for loss variability in effect compensates for the delay of the carrier terminals.

Figure 9 is a comparison of the optimum loss with the loss obtained on connections using the VNL loss plan.* This figure indicates that the VNL plan provides slightly too much loss for short connections but is about optimal for long connections. Comparison with the median optimal loss for connections greater than 1000 miles is shown in Fig. 10. This graph shows the optimal loss for mean values of 18 and 22 dB and infinite return loss as measured by terminal balance procedures at the Class 4 office. The graph indicates that, with a mean value of 18-dB terminal balance return, the current network performance, the optimal value of loss should be about 0.5 dB greater than that supplied

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* In these comparisons, it is assumed that no echo suppressors are used and the loss given by the VNL formula is used for all length intertoll trunks.

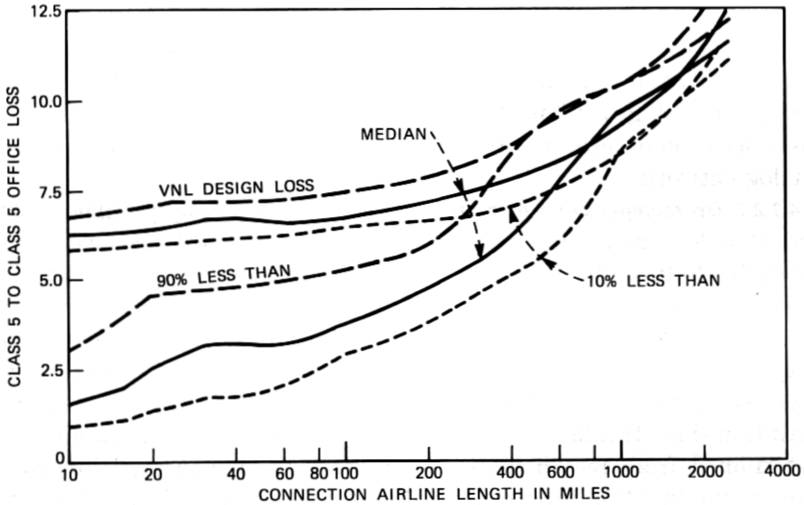

Fig. 9—Analog network connection loss obtained using VNL loss plan compared with optimal connection loss.

by VNL design. In general, the loss for VNL design corresponds most closely to the optimal loss with a mean return loss of 22 dB. This supports the long-term objective of a mean return loss at the Class 4 office of 22 dB as discussed in Section 4.1.3.

Although the VNL plan provides more than optimum loss for short connections, the difference is not sufficiently great to have any appreciable effect on grade-of-service. This can be seen by comparing

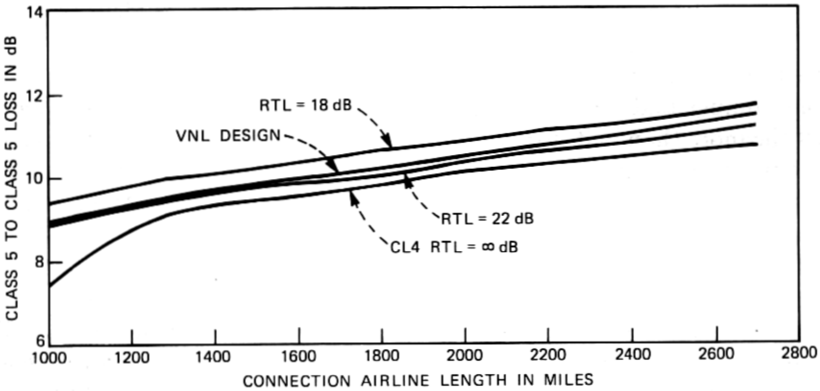

Fig. 10—Median analog network connection loss for connections with lengths greater than 1000 miles compared with median optimal connection loss obtained with average Class 4 terminal balance of ∞, 22, and 18 dB.

the talker-echo grade-of-service and the loss-noise grade-of-service curves using the VNL plan as given in Fig. 11 with those using optimal loss given in Fig. 7. Thus, the VNL plan is a very satisfactory plan for loss allocation in terms of providing nearly optimal performance for the analog network.

4.1.2.3 Overcompensated loss plan. There is one basic problem with the VNL loss plan. The realization of the increased loss with distance tends to make this plan difficult to administer. Currently, the 0.0015-dB-per-mile increase in loss is approximated by a 0.3-dB step about every 200 miles up to 1850 miles, the echo suppressor application length. This means that there are nine loss steps. Trunks having all these steps could exist in any given toll office. To initially install and maintain these trunks, the design loss of each individual trunk must be determined from record information. An overcompensated loss plan would simplify this process by reducing the reliance on recorded information by decreasing the number of loss steps. In such a plan, the longer trunks have more loss than is actually needed to compensate for the delay introduced by short trunks. The short trunks can then be operated at near-zero loss with improved performance when they are used in short connections.

Examination of the optimal loss curves and the facility types used for toll-connecting trunks indicated that about 6 dB of end-to-end loss is about optimum for short connections and approximately 9 dB is optimum for long connections. In addition, it is desirable for ease of conversion not to change the loss of toll-connecting trunks. With VNL design, toll-connecting trunks have an average loss of 2.9 dB which, for the new plan, will be assumed to be rounded to 3.0 dB.

Numerous possible plans could satisfy these broad guidelines. The differences between the various plans is the manner in which the variation in loss between short and long connections is achieved, i.e., the number and size of the loss steps and their application distances. Of the more than half-dozen plans evaluated with the simulation model, the most promising alternative to VNL was the simplest plan with only one step. Other plans with more steps did not appear to have any appreciable grade-of-service advantage to compensate for their added administrative complexity.

The most promising plan was to operate intertoll trunks less than 600 route miles at 0 dB loss, and trunks greater than 600 miles at 3 dB loss. Figure 12 shows the change in loss-noise grade-of-service, echo grade-of-service, and loss-noise-echo grade-of-service compared to that obtained for the VNL plan. This indicates that the loss-noise grade-of-service would be improved by about 3 percent, while the echo grade-of-

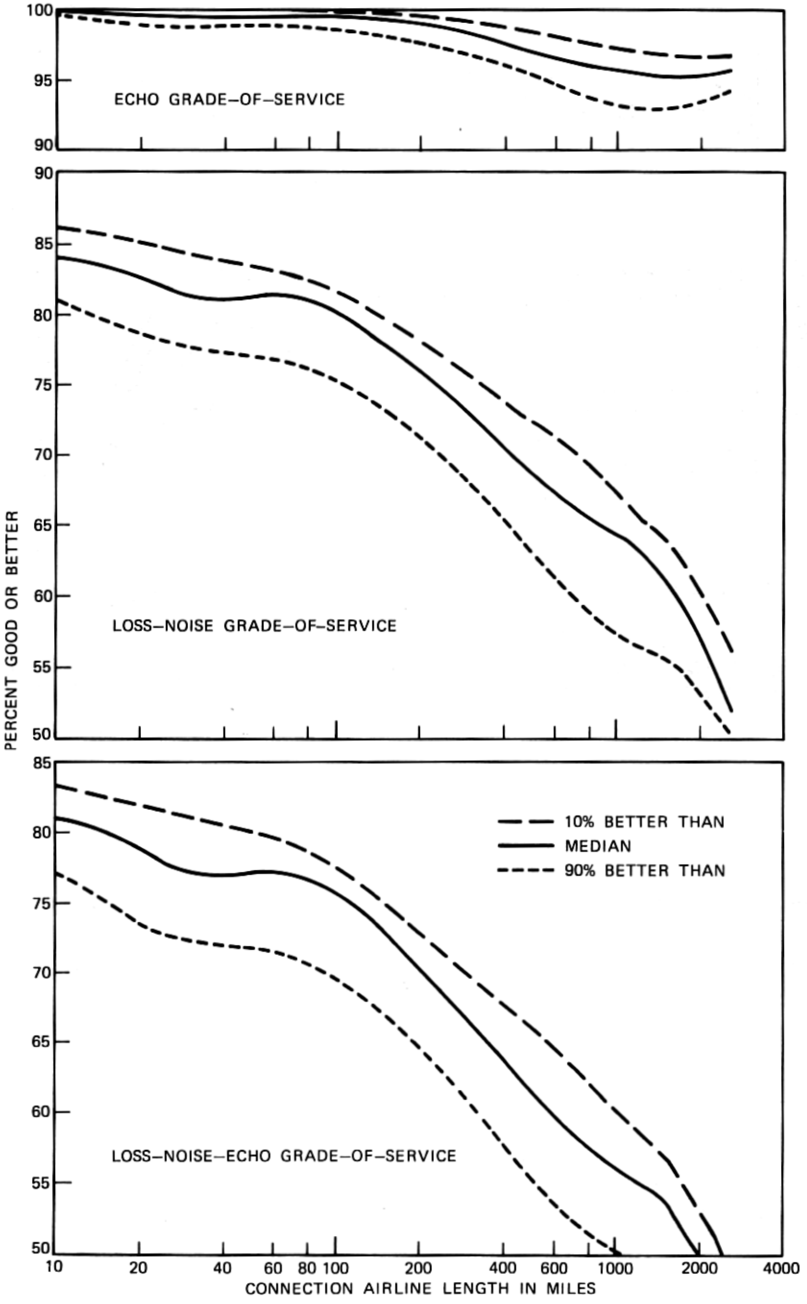

Fig. 11—Grades-of-service for analog network using VNL loss design. Loss inserted in all length trunks—no echo suppressors.

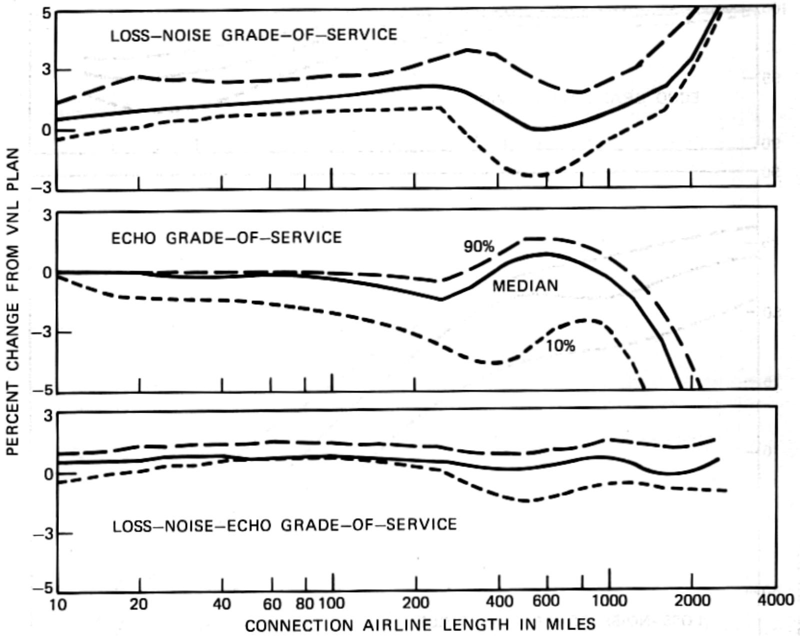

Fig. 12—Change in grades-of-service for possible new loss plan having intertoll trunks designed to 0 dB up to 600 miles and 3 dB for trunks greater than 600 miles.

service is degraded by about the same amount for connections greater than about 300 miles. Loss-noise-echo grade-of-service shows a modest improvement over that obtained by the VNL loss plan.

The simulation study, therefore, indicated that this plan was satisfactory. However, the simulation model predicts most accurately the average performance, not the performance that might occur on alternate routes with very low probability of occurrence, such as calls routed through sectional and regional centers. Although some performance degradation on these types of calls can be allowed because of their low probability of occurrence, extremely poor loss-noise due to multiple trunks with 3-dB loss, or poor echo performance due to the delay of a large number of carrier terminals, must be avoided.

An investigation indicated that multiple 3-dB trunks (trunks greater than 600 miles) could occur on calls routed through sectional centers toward several of the regional centers. This investigation also indicated that these types of calls would often have, with the new plan, an echo grade-of-service of around 70 percent good or better and a very high reliance on properly operating echo suppressors when they were used.

Because of these factors, the plan was altered to assign:

Intertoll Trunks	Loss	Mileage
Intraregional	0.5 dB	All lengths
Interregional	0.5 dB	<1000 mi.
	3.0 dB	>1000 mi.

Figure 13 shows the change in loss-noise grade-of-service, echo grade-of-service, and loss-noise-echo grade-of-service compared to that obtained using the VNL plan. These curves indicate that it provides essentially the same loss-noise-echo grade-of-service as the VNL plan at all connection lengths with some improvement in loss-noise grade-of-service at the expense of the echo grade-of-service. Since the joint loss-noise-echo grade-of-service is essentially the same, this plan is a suitable alternative to the VNL plan. Its main attraction is its administrative simplicity. It also has the advantage that only those trunks greater than 165 miles, about 44 percent, would have to be changed from current VNL design. However, at the present time there appears to be no appreciable long-term administrative economic benefit to

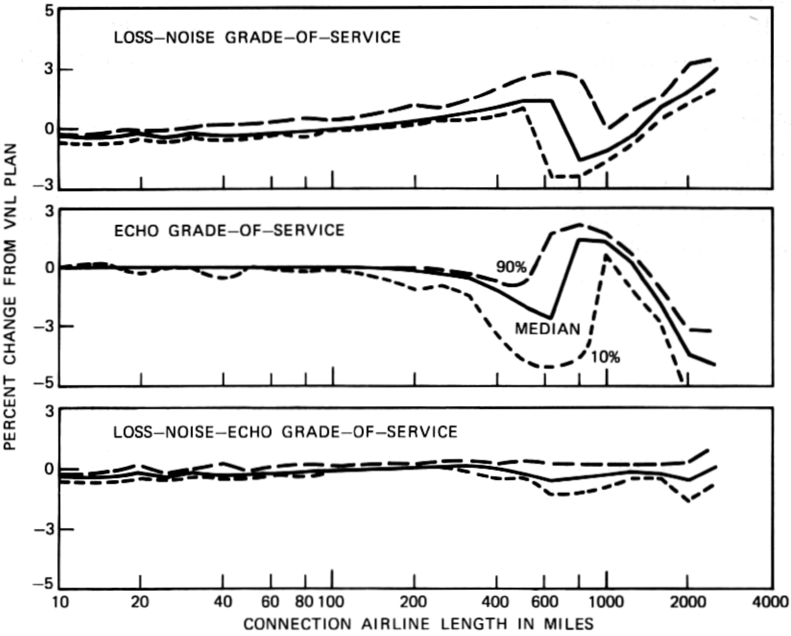

Fig. 13—Change in grades-of-service for the modified new loss plan having intertoll trunks designed to 0.5 dB up to 1000 miles and 3 dB for trunks greater than 1000 miles.

this plan. Since there would be some expense and some administrative difficulties during a changeover to this plan, continued use of the Via Net Loss plan was recommended.

4.1.3 Balance

The loss design plans assume that the predominant echo reflection occurs at the impedance mismatch of the toll-connecting trunk and the customer loop with any additional sources of echo being controlled by through and terminal balance requirements. The appropriateness of the present echo through and terminal balance requirements was reviewed as part of this study.

Intertoll trunk transmission facilities are designed on a four-wire basis that prevents intermediate echoes. However, many switching machines used for interconnection of intertoll trunks are two-wire and, therefore, require hybrids to effect the necessary four-wire to two-wire conversion. The amount of echo returned at these conversions depends on the impedance mismatch of the hybrids and the office cabling. This impedance mismatch is controlled by a through balance requirement which states that the distribution of echo return loss for the office shall achieve or exceed a statistical distribution having a mean of 27 dB and a minimum of 21 dB.

If two-wire offices are used for Class 3 or lower toll offices, the echo returned from an office just meeting this requirement will be 10 dB lower than that from other sources. This amount will have a negligible effect on the overall echo performance. Also, the requirement can usually be met or exceeded in current offices. Thus, the requirement appears to be satisfactory.

The effect on talker-echo performance of impedance irregularities at the distant toll office, and up to and within its Class 5 office, is controlled by terminal balance requirements. The current requirements allow a distribution of the terminal balance return loss values within an office with the median and minimum of the distribution being equal to or exceeding

	Median	Minimum
Two-wire facilities	18 dB	13 dB
Four-wire facilities	22 dB	16 dB.

The estimated mean value of the current network derived from the echo survey[5] is 18 dB.

In establishing a connection, a toll-connecting trunk having a given value of terminal balance return loss is assigned to the connection. Thus, on any given connection a customer experiences the effect of some return loss value from those which are allowed. The effect of a specific value was evaluated by assuming that all connections in the model had that specific value. The grade-of-service obtained was then compared with the ideal situation with no additional echo returned from Class 4 offices. This comparison indicated that the good or better echo grade-of-service with VNL loss design was only minimally affected by a Class 4 return loss of 22 dB and about 2-percent decrease for 18 dB. Of more importance, however, is the effect of the allowed lower values. In this case, a 3-percent decrease occurred for a return loss of 16 dB and 8-percent decrease occurred for 13 dB.

Based on this analysis, it appears that the four-wire facility requirement is satisfactory. However, it is undesirable to have 50 percent of all calls using two-wire facilities experiencing a 3- to 8-percent decrease in echo grade-of-service. Some improvement appears warranted with all toll-connecting trunks ultimately meeting or exceeding the four-wire facility requirement of a distribution with a median terminal-balance echo-return loss of 22 dB, minimum 16 dB. Thus, this requirement has been adopted as a long-term objective. However, it is recognized that, in many situations, this objective cannot be met currently. The current requirement should still be used for existing facilities, with emphasis placed on reducing the number of trunks having an echo return loss less than 16 dB.

4.1.4 Echo suppressor application rules

As indicated in the discussion of the optimal loss, loss can be used to control talker echo for all length connections using terrestrial facilities within the continental United States. However, the loss causes some degradation of the loss-noise grade-of-service. One can reduce the amount of this degradation by introducing echo suppressors. However, they cause some degradation, even under ideal conditions.

In actuality, there is, in addition, a potential risk that an echo suppressor might not be installed properly or maintained properly. In such a case, the degradation from the echo suppressor could be much greater than that caused by added amounts of loss. In general, echo suppressors should be applied at a trunk length which minimizes their inherent risks. To avoid more than one echo suppressor in a connection, echo suppressors should only be applied on trunks between regions, either on high-usage trunks or on regional-center-to-regional-center trunks.

4.1.4.1 High-usage interregional intertoll trunks. The application of an echo suppressor with zero trunk loss causes an improvement of the loss-noise-echo grade-of-service. Figure 14 shows the effect on the connection loss-noise-echo grade-of-service of applying echo suppressors on a high-usage trunk of a given mileage. When an echo suppressor is

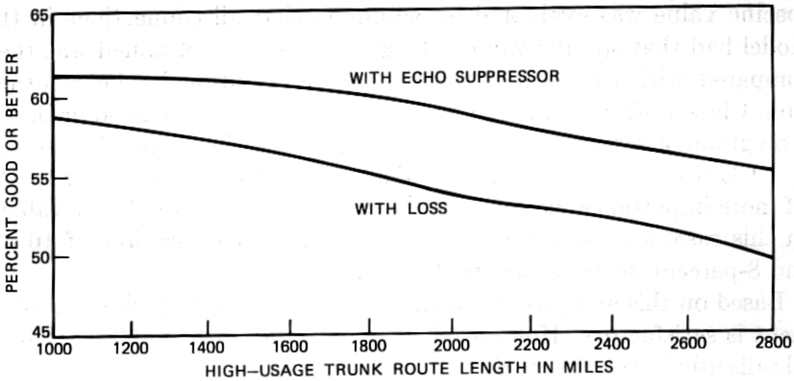

Fig. 14—Median loss-noise-echo grade-of-service for connection greater than 1000 miles when the high-usage trunk is designed according to VNL loss-design plan, or 0 dB loss and an echo suppressor.

applied, the grade-of-service jumps from the curve "with loss" to that value given by the curve marked "with echo suppressors." The latter curve takes into account the grade-of-service effect of nonperfect properly working echo suppressors. As can be seen, the amount of improvement obtained increases as the application distances increase. Figure 15a shows the percent improvement in the loss-noise-echo grade-of-service with the use of an echo suppressor. Figure 15b is a curve of the percentage of trunks existing at that mileage. It indicates that there is about 3-percent grade-of-service improvement if echo suppressors are applied to trunks with length of 1565 route miles. This improvement increases to about 5 percent at 1800 miles. Below 1800 miles, the improvement is less and the number of trunks that require echo suppressors increases markedly, as shown in the bottom part of Fig. 15b. Indeed, there are 50 percent more trunks in the 1600- to 1800-mile range than the 1800- to 2000-mile range. Thus, if echo suppressors were supplied below 1800 miles, there would be a substantial increase in the number of echo suppressors for a smaller, more questionable grade-of-service improvement. Furthermore, there would be a greater potential risk from improperly installed and maintained echo suppressors. For trunks greater than 1800 miles, a 5-percent improvement in average grade-of-service which can be achieved by applying echo suppressors above 1800 miles is considered significant. Thus, for high-usage trunks, it was recommended that a value of approximately 1800 miles be used rather than the previously used 1565 miles. For administrative reasons, a value of 1850 miles was chosen.

When echo suppressors are applied, the trunk loss for trunks greater than 1565 miles was reduced to 0 dB. With the shift of the echo suppressor application mileage to 1850 miles, some nonzero value of loss is needed for trunks between 1565 and 1850 miles. Optimum loss and administrative considerations indicated that a value of loss of either 2.6 or 2.9 dB is required. In general, these values of loss produce the same loss-noise grade-of-service, since at this distance the grade-of-service is mainly determined by the signal-to-noise ratio, while the echo grade-of-service improves with the higher values of loss. Thus, on an overall basis, a value of 2.9 dB was recommended.

Figure 16 shows the resulting loss-noise, echo, and loss-noise-echo grade-of-service for VNL loss design with echo suppressors applied at 1850 miles. The application of echo suppressors improves the loss-noise and loss-noise-echo grade-of-service for calls of lengths greater than about 1000 airline miles.

4.1.4.2 RC-RC intertoll trunks. The majority of traffic switched through a regional center (Class 1) is calls from local Class 5 offices directly homed on that office or alternate route traffic from local offices homed on the next lower office (Class 2). In these cases, the regional office is acting as a Class 4 or Class 3 office. However, because of the hierarchical

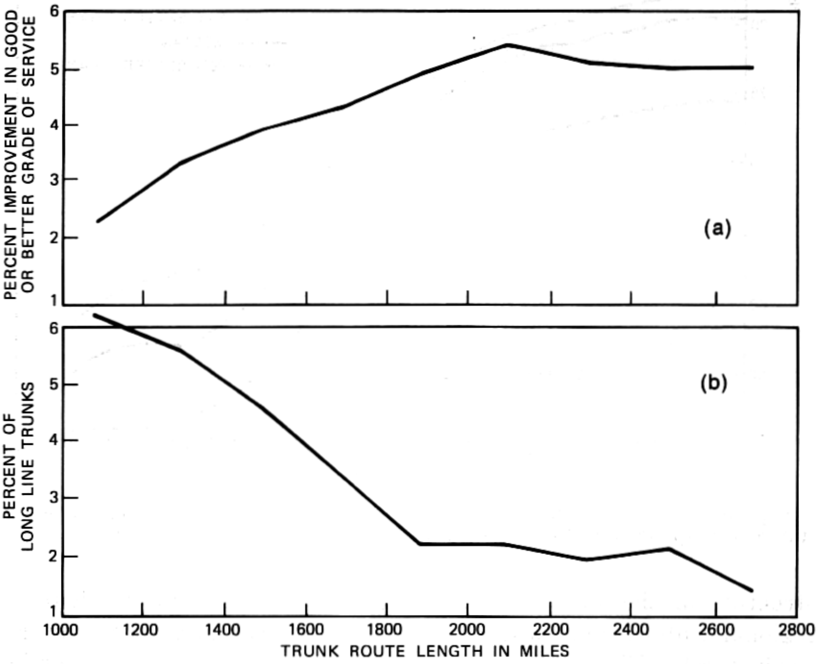

Fig. 15—(a) Percent improvement in loss-noise-echo grade-of-service with echo suppressors. (b) Percentage of trunks requiring echo suppressors if the echo suppressor is applied on high-usage trunks greater than the given length.

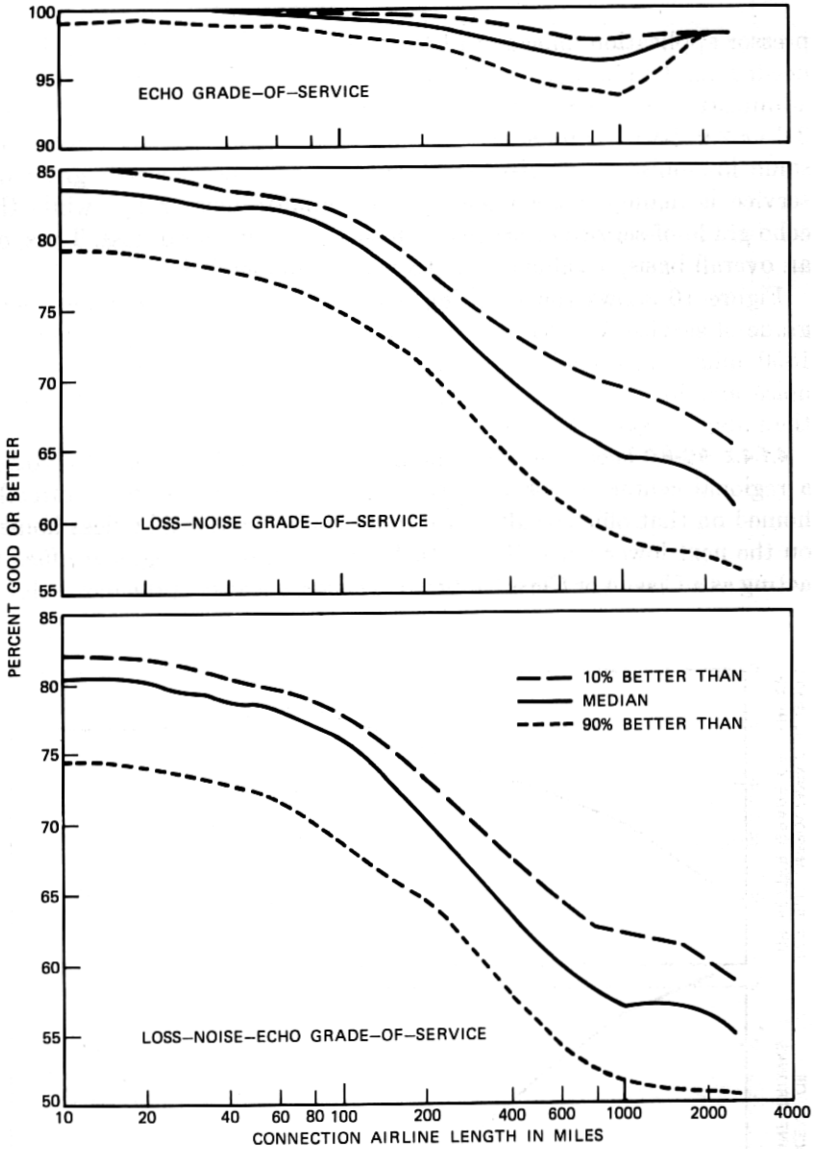

Fig. 16—Grades-of-service for analog network using VNL loss design with echo suppressors applied on high-usage trunks greater than 1850 route miles.

structure of the switching network, there is some traffic where the regional center is part of the final routing of a call originating lower in the hierarchy. These calls will have a larger number of trunks in tandem and greater trunk mileage than calls routed lower in the hierarchy or more directly routed through a regional center.

In general, the more directly routed calls through a regional center should have the same loss-noise-echo grade-of-service as calls routed through lower class offices. Final routed traffic could be allowed somewhat lower loss-noise-echo grade-of-service, but their grade-of-service should not be severely degraded. These considerations tend to require the use of echo suppressors at shorter distances than the 1850 route miles for high-usage intertoll trunks.

As part of this study, the need for echo suppressors was reviewed using the loss-noise-echo grade-of-service approach used for high-usage trunks. This study indicated that the trunk groups between the regional centers shown in Table I do not need echo suppressors and should be designed according to Via Net Loss design rules. All other trunk groups should be designed to 0 dB and have echo suppressors.

4.2 Digital network

With the advent of No. 4 Toll ESS,[3] it is possible to perform direct digital switching of bits coming from digital transmission systems. Economic studies of No. 4 Toll ESS indicates considerable economic advantages in using this approach. However, the VNL loss plan requires loss to be inserted in each trunk. This would require either that the digital signal be decoded to an analog signal, loss inserted, and the signal recoded, or that the encoded signal level be changed by some digital processing technique so that, when it is decoded, a lower signal level would be obtained. Either of these techniques would introduce additional cost and transmission impairments.

An alternative approach is to operate digital intertoll trunks at zero loss so that no conversion is required. This would mean that end-to-end connections over purely digital facilities would have a fixed loss. This section examines the appropriateness of using this approach in terms of the optimal loss concept. Section 4.3 examines the case where a call is routed over portions of both types of networks.

4.2.1 Optimal loss

For the all-digital network, the voice signal is digitally encoded and decoded only at the Class 5 office and only bits are switched at higher-class offices. This means that the noise on a call is that due to one pair of encoders and decoders. The delay has three components; the propagation delay, the delay of one pair of terminals, and the delay of digital buffering within each switching machine. The propagation delay is about the same as for the analog network, but the terminal and switching machine delays, which are about equal, are less than the delay of analog terminals. Thus, the connection delay is less than delay experienced on the same length call in the analog network. Also, the terminal balance return loss at a digital Class 4 office will have an average of more nearly 22 dB since economic studies indicate cost advantages in using digital carrier at very short distances.

The reduced noise and delay and increased Class 4 average return loss changes the optimal loss. Figure 17 plots, as a function of connection airline distances, the value at which 10, 50, or 90 percent of the connections would have an optimal loss value less than that value. A comparison of this curve with that of the analog network (Fig. 6) indicates that the amount of required loss is reduced. At 1000 airline miles, the 90-percentile optimal loss is reduced from 10.5 to 7.5 dB and the median from 9.5 to 6.5 dB.

The loss-noise, echo, and loss-noise-echo grade-of-service using this optimal loss is shown in Fig. 18. The roll-off in loss-noise grade-of-service is due to the increased loss for control of echo, since the noise is constant with distance. The shape of loss-noise-echo grade-of-service curves is essentially determined by the loss-noise grade-of-service except at longer lengths where a slight additional effect occurs due to the echo grade-of-service.

4.2.2 Loss allocation and level plan

As indicated in Section IV, it is highly desirable to have any required loss inserted before the digital encoder or after the decoder, so that no bit conversion is needed at intermediate offices. This would mean that all connections are designed to a fixed loss value. Since the optimal loss increases with the length of a connection, any fixed loss value will be a compromise between the need for higher loss for long connections and lower loss for short connections. This compromise is more appropriate to the digital network than the analog network, since the range in optimal loss is considerably less. In making this compromise, one would

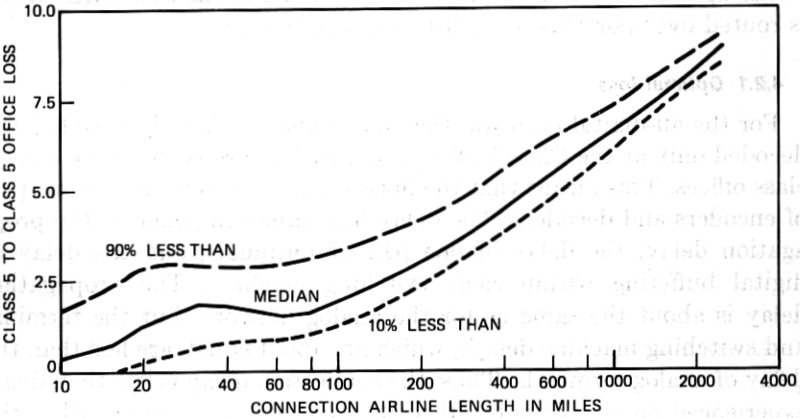

Fig. 17—Optimal loss for connections routed over digital network.

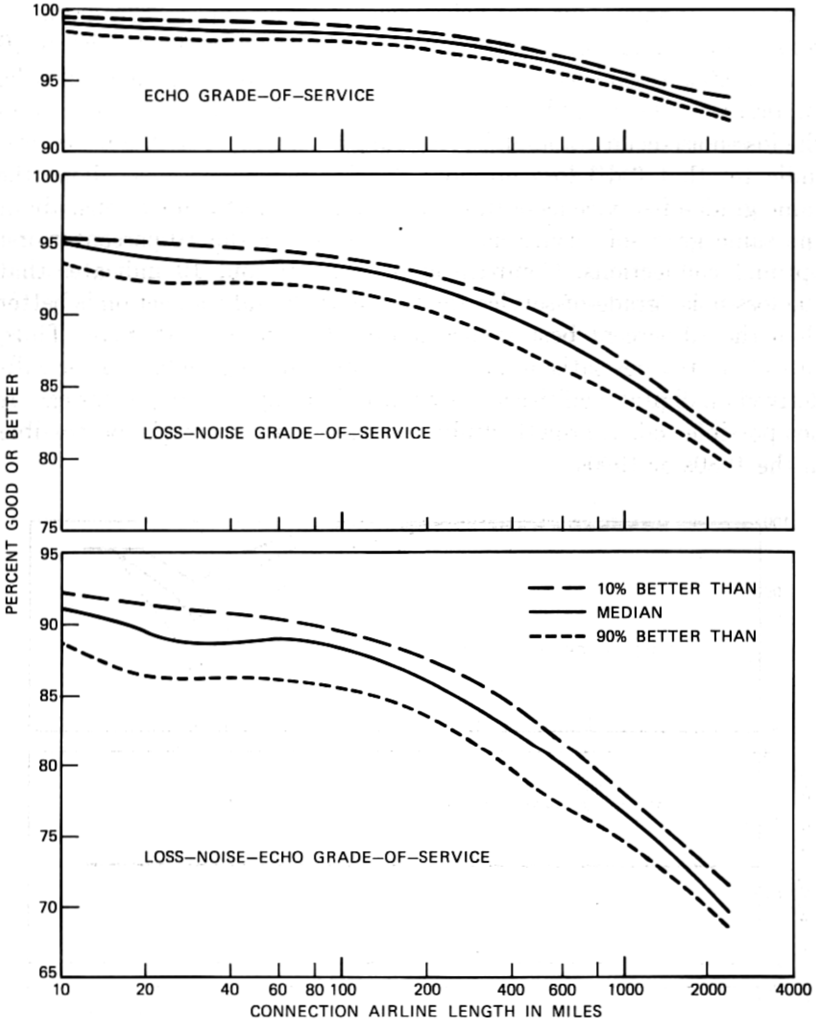

Fig. 18—Grades-of-service obtained for connections routed over digital network if it were designed with optimal loss.

like to have the same loss-noise-echo grade-of-service at about 1000 airline miles as that obtained with optimal loss, and at least as good a loss-noise-echo grade-of-service for short calls as currently obtained with VNL design. In general, since echo grade-of-service for longer calls is quite sensitive to changes in loss, the best compromise value tends to be one near the optimal loss value for longer connections. In the study, various values of loss were investigated with 6 dB of end-to-end loss chosen as best fulfilling the above philosophy.

Figure 19 shows the loss-noise, echo, and loss-noise-echo grade-of-service for connections switched on an all-digital network with 6 dB of end-office-to-end-office loss. This figure includes the effect of echo suppressors which will be discussed in the next section. Comparison of the loss-noise-echo grade-of-service values with those with optimal loss indicates that 6-dB loss provides, for longer connections, about the same grade-of-service as optimal loss and, for short connections, about the same grade-of-service as that obtained for the 10-percent worst optimal connections. Comparison of Figs. 16 and 19 indicates that the loss-noise grade-of-service for the short digital connection is better than the 10-percent best values obtained with the VNL plan. Thus, this plan provides satisfactory performance and was adopted for calls derived on digital facilities and switched digitally. Although this case is not possible today, growth studies indicate that this might be possible in the 1980s or 1990s.

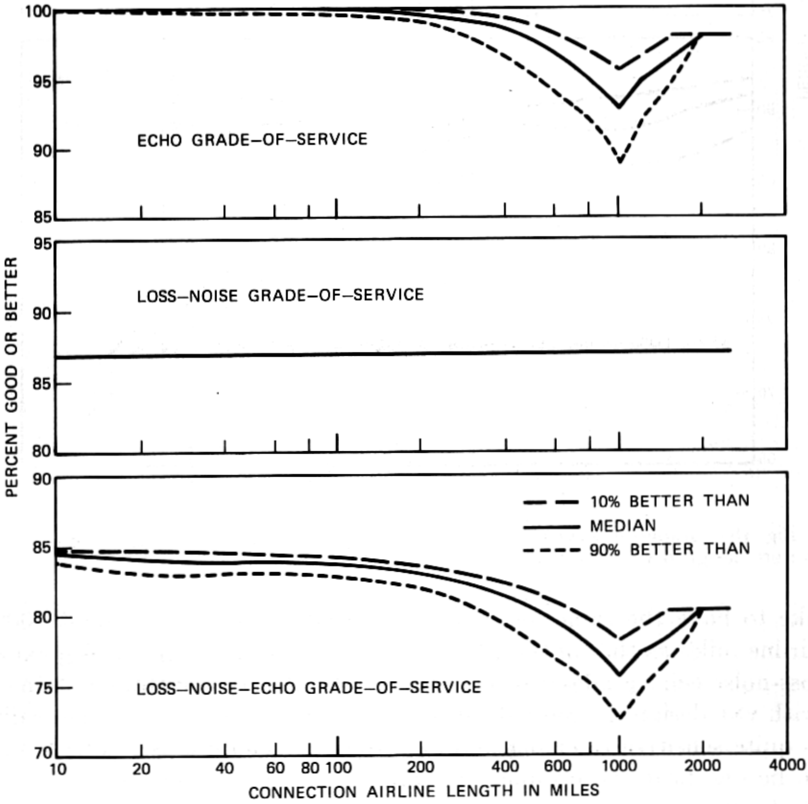

Fig. 19—Grades-of-service obtained on connections routed over digital network when it is designed to a fixed 6-dB loss and a median Class 4 terminal balance of 22 dB.

To avoid decoding at intermediate toll offices, the 6-dB end-to-end connection loss must be achieved by inserting loss in the toll-connecting trunks either in the transmit direction before the digital encoder or in the receive direction after the digital decoder. This loss is allocated equally (3 dB) based on the need for approximately the same connection loss when digital trunks are connected in tandem with analog trunks and maintenance considerations. The maintenance considerations are:

(*i*) The measured loss including test pads should be the same in each direction of transmission.
(*ii*) Test-tone levels should be at standard levels at the input and output of carrier systems.
(*iii*) Standard loop-around tests for digital carrier systems should be preserved.
(*iv*) The transmission level of existing analog offices should remain at 0 TLP and −2 TLP for local and toll offices.

Although the toll-connecting trunk is required to have 3 dB loss, there is no loss adjustment for a trunk on a digital facility connected to the digital office by a digital interface. Since the outgoing switch of a local office is defined as a 0 TLP, the necessary loss can only be achieved within the above constraints by having the end of the trunk at an effective −3 TLP. Actually, this transmission-level point does not exist in the normal sense of a definable analog signal, since a signal at the end of a trunk exists only as a bit stream within the office. The level only exists when the bits are decoded into an analog signal. Since the bit representation is not changed within the digital portion of the office, the output of the digital interface used for trunk testing is defined as a −3 TLP rather than the standard −2 TLP used with analog offices. This definition leads to the level plan for toll-connecting trunks connected to a digital office as shown in Fig. 20.

4.2.3 Balance

Digital switching offices will be four-wire; therefore, through balance considerations do not apply. However, toll-connecting trunks will originate or terminate at two-wire Class 5 offices and could use two-wire facilities. Thus, terminal balance measurements are required at digital toll offices.

The echo performance of the digital network is inherently more sensitive than the analog network to the terminal balance return loss requirement, because of the lack of loss in the intertoll trunks. The discussion in the previous section was predicated on a distribution with a median value of 22 dB for the terminal balance of digital offices.

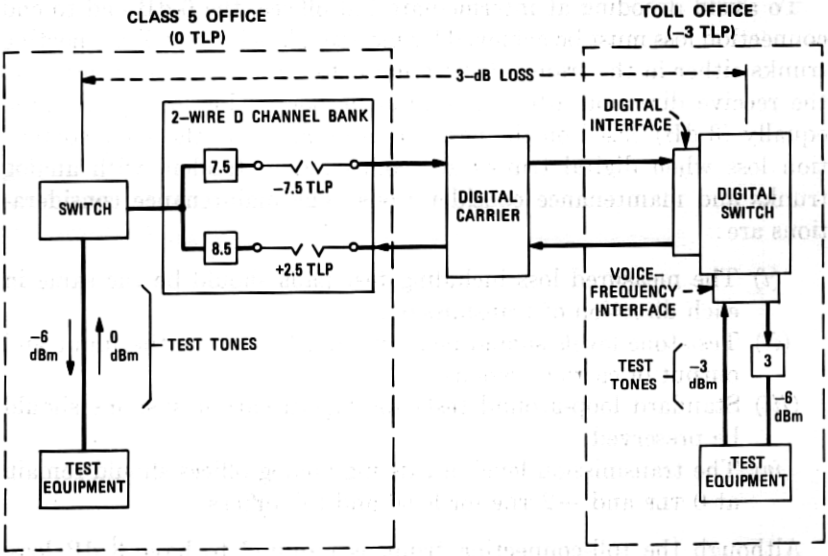

Fig. 20—Levels of a 3-dB toll-connecting trunk when connected through a digital interface to a digital office designated as a −3 TLP (transmission level point).

Figure 21 shows the echo grade-of-service for the digital network with the Class 4 median terminal balance assumed to be 18 dB. This indicates a drop of around 5 percentage points from that obtained with a median terminal balance of 22 dB (Fig. 19). This amount of drop is judged significant since it is not accompanied by an increase in loss-noise grade-of-service. Thus, the distribution of return losses for toll-

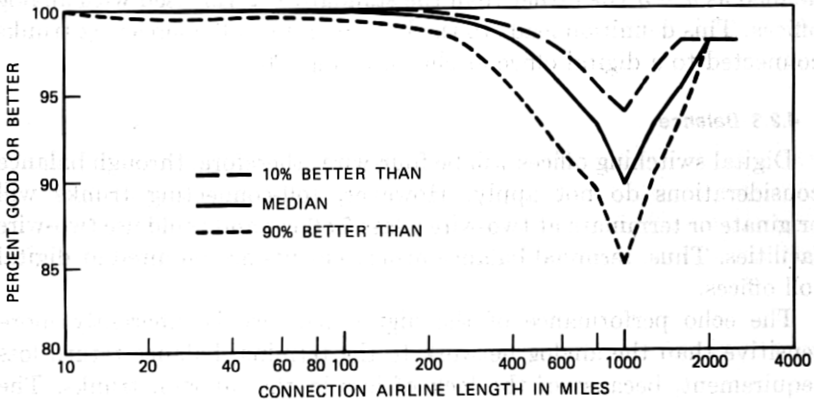

Fig. 21—Echo grade-of-service obtained on connection routed over digital network having a median Class 4 terminal balance of 18 dB.

connecting trunks in a digital office must achieve or exceed a statistical distribution having a median value of 22 dB, minimum of 16 dB. This agrees with the long-term objective for the analog network but is higher than that currently required for analog two-wire toll-connecting trunks. It is expected that the requirement is achievable when applied to all toll-connecting trunks as one group because of the economic advantage of trunks on digital carrier facilities.

4.2.4 Echo suppressor application rules

The loss-noise-echo grade-of-service for the digital network continuously decreases for longer distances because of the decrease in the echo grade-of-service. The amount of decrease is controlled by the echo suppressor application distance. Figure 19 shows the loss-noise, echo, and loss-noise-echo grade-of-service for the digital network when the echo suppressors are applied on high-usage trunks at the analog network mileage of 1850 route miles. The application of echo suppressors at this trunk distance affects the grade-of-service of calls of airline length greater than about 1000 miles. The minimum loss-noise-echo and echo grade-of-service appears satisfactory even though the echo grade-of-service is somewhat lower than that obtained for the analog network (Fig. 11). The joint loss-noise-echo grade-of-service is, however, significantly better. Since the joint assessment is the primary consideration, it appears that the echo suppressor rules for the analog network can be used for the digital network. A similar conclusion is obtained for application of echo suppressors on RC-RC trunks.

4.3 Mixed digital network

For sound transmission quality and technological and economic reasons, the analog and digital networks are being designed to different loss and level plans. Yet in many instances, a connection will be established over portions of both networks. One area of concern was the loss of the interconnecting trunks between an analog and a digital office. The definition of the digital interface as a −3 TLP and the maintenance constraints listed in Section 4.2.2 causes a trunk using digital facilities from an analog toll office to a digital toll office to have an effective loss of 1 dB, as shown in Fig. 22.

The loss of 1 dB on trunks using a digital facility is about the same loss as that required by the VNL design plan for a 500-mile trunk. Thus, this loss is higher than that normally used for trunks of less than this distance and lower for trunks longer than 500 miles. In general, this could mean that there might be either a loss-noise or an echo grade-of-service degradation for connections using these trunks.

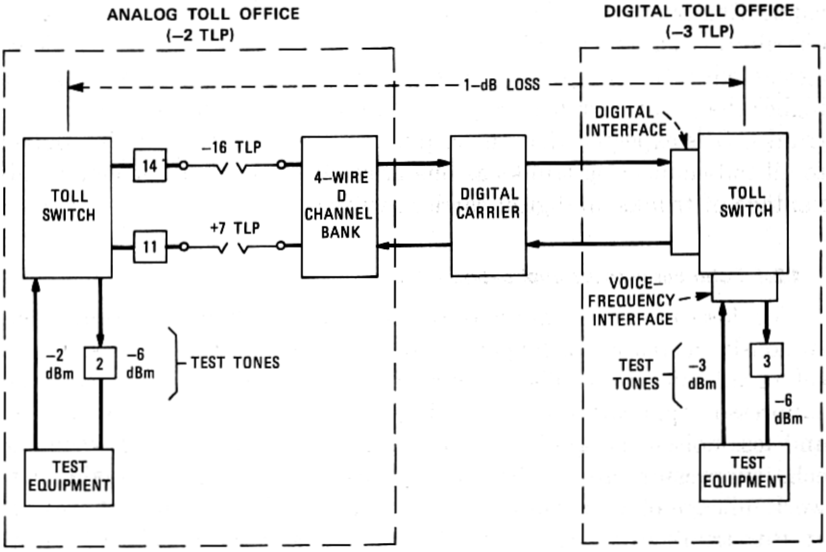

Fig. 22—Levels and loss of a digital intertoll trunk between an analog toll office (−2 TLP) and a digital office (−3 TLP).

The loss-noise and echo grade-of-service of connections containing one or two 1-dB interconnecting trunks was determined. The simulation results for both the cases indicate, as shown in Fig. 23, that the loss-noise performance of connections is improved because of the decreased noise on digital facilities. The echo performance is the same as that for connections using VNL-designed trunks. The improvement in loss-noise grade-of-service could be slightly greater if these trunks were designed for zero loss. Actually, the 1-dB loss provides 2-dB more path loss for talker-echo control. This is considered advantageous, since these trunks interconnect the digital network which is designed with minimum amount of loss and the analog network which has a large variability in return losses. Thus, the transmission performance of connections using both networks with digital interconnecting trunks appears to be quite satisfactory.

However, the simulation results for a trunk using an analog facility designed to a fixed loss of 1 dB indicated a loss-noise degradation for short connections and an echo degradation for medium length connections. Because of the grade-of-service degradation, it was recommended that all interconnecting trunks using analog facilities be designed to the same loss plan as normal analog trunks.

With these loss recommendations for interconnecting trunks, the transmission performance of connections using portions of both net-

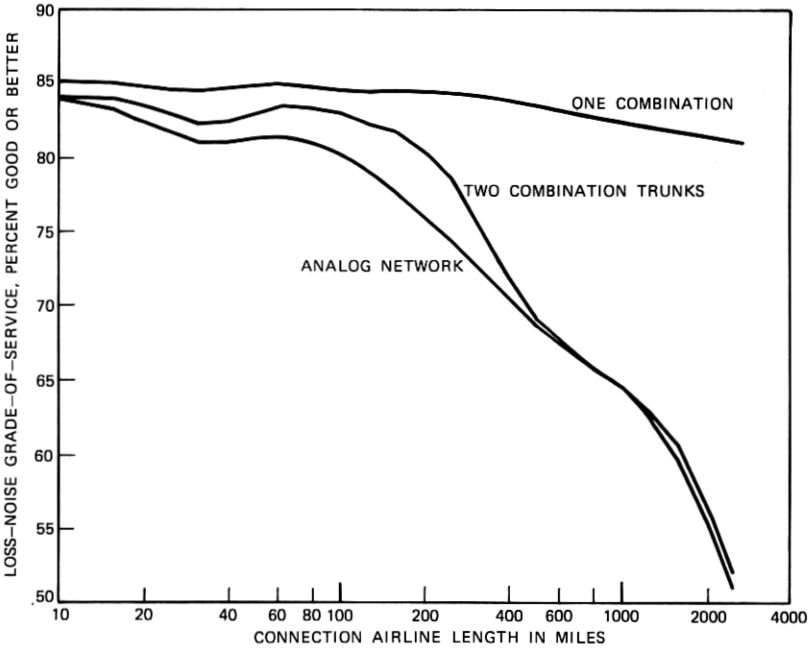

Fig. 23—Median loss-noise grade-of-service for a combined digital-analog connection and a pure analog connection.

works will be satisfactory. This allows introduction of isolated portions of a digital network such as digital switching machines and digital intertoll trunks. As continued growth occurs, these portions will be interconnected digitally, enabling connections to be routed on purely digital facilities.

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