Subjective Evaluation of Delay and Echo Suppressors in Telephone Communications

By R. R. RIESZ and E. T. KLEMMER

(Manuscript received August 9, 1963)

The effect of transmission delay upon the quality of a telephone circuit was investigated using naturally occurring telephone conversations. Round-trip delays of 600 and 1200 msec went almost unnoticed at first when no echo sources or echo suppressors were present in the circuit. After exposure to pure delays of up to 2400 msec, considerable dissatisfaction, indicated by rejection of the circuit, developed with the 600- and 1200-msec delays. When echo sources and echo suppressors were added to the circuit, some dissatisfaction developed immediately for round-trip delays of 600 and 1200 msec. No adaptation to the effects of delay occurred; in fact dissatisfaction increased with experience under certain conditions.

I. INTRODUCTION

The preceding two papers describe the nature of the problems introduced into telephone circuits by delay and echo and the attempted solution of these problems through the design of echo suppressors. The present paper describes recent determinations of the degradation of transmission quality caused by pure delay and delay plus echo and echo suppressors. The studies reported were all done by the human factors research department of Bell Telephone Laboratories.

Other groups have studied the effect of delay upon voice transmission. These include the research department of Bell Telephone Laboratories, Stanford Research Institute, Italian Telecommunications Administration and the British Post Office. Unfortunately, none of this work has yet been published. In general, these studies have found little degradation with pure delay, even for round-trip delays over one second, although some objection did occur in one experiment with natural conversations with 1410-msec round-trip delay. These same subjects did not find the delay objectionable during structured conversation, however.

All of the experiments described in the present paper were performed by introducing experimental circuits into naturally occurring telephone conversations. This method was chosen because of the previous finding, here and elsewhere, that the subtle conversational difficulties produced by delay and echo suppressor action do not often occur in structured conversations.

The general plan of the study was first to evaluate the effect of pure delays and then evaluate the effect of echoes, echo suppressors and delays for several different echo suppressors described in a companion paper.[1] When it became obvious in the first two experiments that continued exposure to long delays had a marked effect upon the user's reaction to shorter delays, a third experiment was conducted in which each subject was exposed for some weeks to only a single value of a given delay.

The primary measure of transmission quality in the present studies is the percentage of calls on which the circuit was rejected as unsatisfactory by the users for normal use. In addition, for some of the calls made under each condition, the users were called back and asked about the circuit.

II. SIMULATION APPARATUS: SIBYL

The simulator called SIBYL, which permits the insertion of experimental circuits into existing telephone lines, has been previously described by H. D. Irvin.[2] With this device it was possible to introduce controlled delay through the use of magnetic disc delay units (Echovox Sr.), echo suppressors and return loss to simulate field echo conditions. The simulator could be inserted into any call originated by any member of a panel of users without letting him know of its insertion.

III. EXPERIMENT 1: DEGRADATION IN TRANSMISSION QUALITY DUE TO ADDED PURE DELAY

3.1 *Apparatus*

For the pure delay tests a complete four-wire network was employed as shown in Fig. 1. Artificial sidetone was provided, and loss and noise were adjusted to values representative of the standard circuit. None of the calls were monitored; that is, complete privacy of conversation was maintained. For each call through the simulator, the originating number,

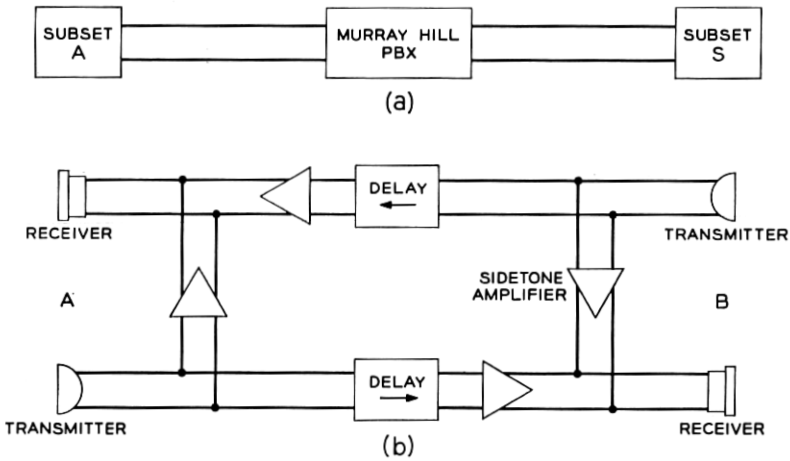

Fig. 1 — Circuit used to introduce delay in experiment 1: (a) standard circuit between PBX subsets, (b) experimental circuit between four-wire subsets used to introduce transmission delay.

called number and length of call were recorded as well as the time at which the call was rejected for the rejected calls.

3.2 *Subjects*

Eighteen members of the administrative staff at the Laboratories who called each other frequently were asked to serve as subjects. They were told that some of the calls that they originated would be routed over a simulated satellite circuit, but they did not know which calls would be affected or what the changes in the circuit were. They were instructed that if they found any circuit "unsatisfactory for normal telephoning" they could dial the digit "3" without hanging up or breaking the connection, and the standard circuit would be restored. Only the calling party was able to reject the circuit.

3.3 *Test Conditions*

Because of the necessity for a complete four-wire connection, the delay was inserted only on calls in which one of the subjects called another. The simulator was inserted on every such call unless it was in use by another pair of subjects. Since the simulator could handle only one call at a time, when one pair of subjects was routed through the simulator, all other subjects would receive the standard circuit even if they called each other.

The experiment continued for 12 weeks. The general plan of the experiment was to alternate between delays of 600 and 1200 msec each working day for 12 weeks. This schedule was changed in the fifth and sixth weeks, during which the 1200-msec delay was alternated each day with 2400-msec and the 600-msec delay was not used at all. The reason for inserting the 2400-msec delay in the fifth week was that there were almost no rejections during the first four weeks, which raised the question as to whether the subjects were not having any difficulty due to the delay or were not associating unusual conversational difficulties with the telephone circuit. It was correctly assumed that the 2400-msec delay would produce identifiable circuit-related difficulty. All but two of the 18 subjects made or received at least one call over the 2400 msec circuit during the two weeks it was used. The final six weeks at 600- and 1200-msec delay show the users reaction to these lesser delays after exposure to the longer delay. The trend during this six-week period is particularly important. The negative reaction of the users to the longer delay may be expected to generalize to the shorter-delay calls which are made in close time proximity. That is, after exposure to the 2400-msec delay, the users may reject any circuit on which they note any characteristics of a delay circuit. If this is the only effect, then the rejection rate should jump suddenly after exposure to 2400 msec and then return (perhaps slowly) to the former level when the 2400-msec condition is removed.

If, on the other hand, exposure to the longer delay teaches the users to identify conversational difficulties which are also present at shorter delays, then the rejection rate should not fall after removal of the longer delay. Indeed, it may well be expected to continue to rise as the learning continues.

3.4 *Results*

The percentage of calls rejected for each two-week period of the experiment is plotted in Fig. 2 for each delay separately. The grouping of weeks by twos provides an average of 29 calls per point with a minimum of 16 calls, whereas single weeks would have as few as six observations per point. None of the calls at 600 msec delay were rejected in the first four weeks and only 3 of 50 calls at 1200 msec were rejected by two different subjects. The 2400-msec delay was rejected more than half the time during weeks 5 and 6 when it was employed (18 of 34 calls). In the two weeks following exposure to 2400-msec delay there were still no rejected calls at 600 msec, but in the final four weeks 13 subjects

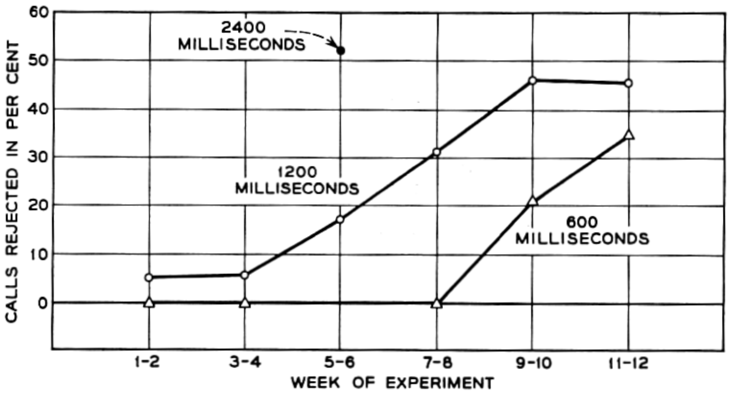

Fig. 2 — Percentage of calls rejected as a function of weeks for each pure delay condition separately. Combined data from 18 subjects, all of whom were exposed to all delays. Number of observations per point varies from 16 to 37. The 2400-msec delay was used during weeks 5 and 6 only. Rejections on standard circuit calls were less than 1 per cent.

made 61 calls at 600 msec and four of these subjects rejected a total of 17 calls.* The 1200-msec delay showed an increasing rejection rate after week 5, and during the last four weeks, 17 subjects made 66 calls at 1200 msec and eight of these subjects rejected a total of 31 calls.†

Because the circuit difficulties introduced by delay are not apparent until after some conversation has taken place, it is of interest to ask how long the call has been in progress before rejection occurs. The median time to dial out the simulator for all rejected calls was 22 seconds. The median length of rejected calls was 133 seconds, including talking time both before and after rejection. For comparison, the median length of nonrejected calls was only 94 seconds. Thus, rejected calls tend to be longer calls and they are rejected fairly early in the call. Lest this finding be interpreted as implying that users are more likely to reject calls early that they anticipate will last long, analysis of later data shows that such is not the case.

The rejection rates of the delayed calls may be compared to the probability of rejecting a call on the standard telephone circuit. In the pure delay experiment it was possible to record attempted rejections of standard circuits by the subjects. These numbered 36 in 6688 calls, or less than one per cent.

---

* These four subjects rejected 1 of 6, 2 of 12, 5 of 11, and 8 of 22 calls respectively.

† These eight subjects rejected 1 of 2, 1 of 5, 2 of 2, 2 of 3, 2 of 7, 3 of 4, and 18 of 21 calls respectively.

3.5 *Discussion*

The extent to which the 2400-msec exposure, actually experienced by 16 of the 18 subjects, influenced the over-all results has not been established. It cannot be assumed that the high rejection rate at 1200 msec would ever have been reached if 2400 msec had not been introduced. The rejection rate at 600 msec has undoubtedly been influenced by the exposure to 1200 and as well as 2400 msec. The importance of such interaction effects was not appreciated until after the more extensive tests at experiments 2 and 3. Regardless of the probable influence of the 2400-msec exposure and the 600–1200 mixture on the results, it is significant that the subjects show no sign of becoming accustomed to delay and adapting their conversations to its presence.

Individuals vary widely in their reaction to delay. One of the test subjects rejected 27 of the 36 calls he made at 1200 msec. Since the remaining 17 subjects rejected 17 of their 118 calls over the 10-week period at that value of delay, it can be seen that this one subject had an important effect on the total results. Of course, such strong objectors cannot be ignored in planning communications systems.

Because of the large differences in calling rate and rejection rate among the subjects and the small number of calls which could be sampled, the absolute levels of rejection rate shown in Fig. 2 cannot be taken as representative of larger populations of calls and users. The qualitative finding of increasing rejection rate with experience with the delays used is clear, however, for several of the subjects who must be assumed representative of a significant proportion of the total population.

3.6 *Summary*

Pure delays up to 1200 msec, round-trip, added to a telephone circuit did not result in much user dissatisfaction with the circuit for users with limited experience in using such circuits.

After further experience, which included limited exposure to 2400-msec delay, considerable dissatisfaction developed for delays of 600 msec and 1200 msec when these were intermixed.

IV. EXPERIMENT 2: DEGRADATION IN TRANSMISSION QUALITY DUE TO DELAY, ECHO AND ECHO SUPPRESSOR (INTERMIXED DELAYS)

4.1 *Apparatus*

The arrangement of the SIBYL simulator for experiment 2 is shown in Fig. 3. It differed from experiment 1 in that normal 2-wire connections

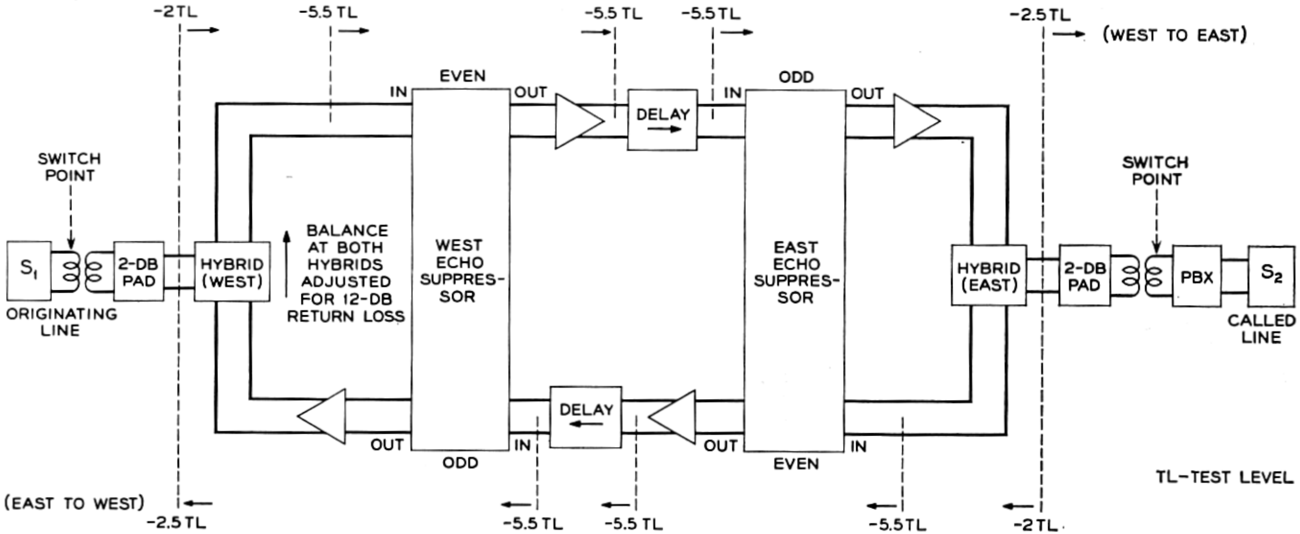

Fig. 3 — Satellite simulator circuit for experiments 2 and 3 showing method of introducing delay and echo suppressors. The level at the two-wire connection of the hybrid is arbitrarily designated as −2 test level. The levels at other points use the same reference. The overall loss between switch points is 4.5 db. For the modified 1A suppressor the adjustments were as follows. Zero test level sensitivity: even, −41 dbm; odd, −41 dbm. Actual sensitivity: even, −46.5 dbm; odd, −46.5 dbm. Hangover: even, 18 msec; odd, 50 msec.

were maintained between the telephone sets and hybrid transformers. Return loss[3] was set at 12 db; about 15 per cent of normal long-distance connections have a return loss and echo worse than this value.

The four echo suppressors employed are described in the preceding article by Brady and Helder.[1] They will be designated here, as in the previous article, by 1A, BH, GN and AM. Delay was produced by Echovox, Sr. magnetic disc units in the 4-wire portion of the circuit.

For each call through the simulator, the originating number, called number, length of call, and time of rejection (if rejected) were recorded.

4.2 *Subjects*

The subjects were 101 employees of the Murray Hill Laboratories representing a wide cross section of occupations and ages. None of the subjects were working on transmission quality or satellite projects. Because some of the subjects shared a telephone, there were only 94 telephone lines. Any call originating from these telephones could be routed through the simulator regardless of its destination. This is different from experiment 1, in which only calls between subjects could receive the experimental circuit.

4.3 *Instructions*

As in experiment 1, the subjects were not informed as to the nature of the degradation which would occur, nor were they cued as to which calls were routed through the simulator. They were instructed that some of the calls they originated would be routed over a simulated satellite circuit, and that if they found any such call unsatisfactory for normal telephoning they could restore the standard circuit merely by dialing a "3" without hanging up or breaking the connection.

4.4 *Test Conditions*

In addition to the four different echo suppressors and several delays, several experimental circuits were employed which involved adding loss or noise to an otherwise standard circuit. This was done to establish a relation between percentage of calls rejected and the more conventional types of circuit degradation.

On any one day of the experiment only one echo suppressor and four delays were employed; on other days the four loss conditions or the four noise conditions were employed. There were seven different daily conditions and four values of the appropriate parameter within each daily condition, as shown in Table I.

TABLE I — DESCRIPTION OF TEST CONDITIONS USED IN EXPERIMENT 2

Suppressor 1A	50	200	600	1200	msec delay
Suppressor BH	50	200	600	1200	msec delay
Suppressor GN	50	200	600	1200	msec delay
Suppressor AM	50	200	600	1200	msec delay
Noise	26	32	38	44	dbrn noise*
Loss 1	6	9	12	15	db added loss
Loss 2	6	10	15	21	db added loss

* The noise was a recorded mixture of thermal noise and power hum selected to be representative of actual noise on telephone circuits. It was measured at the line terminals of the calling subject across his 500-type station set using a Western Electric 3A noisemeter with C-message weighting.

The main experiment lasted for eight weeks. On three days of each five-day week, three of the echo suppressors were used; on one of the remaining days the noise conditions were used, and on the other day the loss conditions were used. The order of suppressors, noise and loss was varied so that each of these occurred on different days each week. In addition, the sequence of values within days was varied so that each value occurred at a different time each day. The values within days were changed every twenty calls. Thus, the first 80 calls each day were assigned to the four experimental values given in Table I in some previously determined order. On most days 100 calls were made through the simulator, the final 20 calls being over a standard circuit to provide a basis of comparison. As an example of the schedule, suppressor 1A might be used Monday with the first 20 calls at 600 msec delay, with the second 20 calls at 200 msec, with the third 20 calls at 1200 msec, and with the fourth 20 calls at 50 msec; the final 20 calls might use the standard circuit. On Tuesday, the four noise conditions might be inserted.

Whether or not any particular subject received the simulator circuit when he placed a call was dependent upon whether or not the simulator was in use. It could handle only one call at a time. The other controlling factor was that no subject was given two calls on the simulator in immediate succession.

Echo suppressors BH and GN were used for the entire eight weeks of the experiment. Suppressor AM was not available until the fifth week, at which time it was substituted for suppressor 1A, which had been used along with BH and GN during the first four weeks.

Loss 1 (6–15 db range) was employed the first two weeks, during which time it became clear that the range was too small, whereupon loss 2 (6–21 db) was substituted for the final six weeks. The noise conditions were used one day a week for all eight weeks.

Following the eight weeks of the main part of the experiment, an additional three weeks were run in which only one suppressor and one delay was used for the entire week. This was done in order to see if users would learn to adapt to the circuit changes with more practice under one condition. During the last of these additional weeks (week 11) the subjects were called back after each rejection and asked about the reason for rejection. After the eleventh week, the subjects were informed that the experiment was over.

Table II reviews the plan of the entire experiment by weeks.

TABLE II — PLAN OF EXPERIMENT 2 BY WEEKS

Week of Experiment										
1	2	3	4	5	6	7	8	9	10	11
1A suppressor			AM suppressor					BH at 600 msec only all week	GN at 600 msec only all week	BH at 600 msec only all week
BH suppressor										
GN suppressor										
Loss 1		Loss 2								
Noise										

(For variation within days during weeks 1–8, see Table I. Each horizontal row of Table II represents one weekday.)

4.5 *Results*

The percentage of calls rejected at each delay is shown in Table III for each suppressor separately. There is little difference among the four suppressors. Suppressor AM shows a slightly higher rejection rate than the other suppressors, but it was tested only during weeks 5–8 and the difference may well be due to an increased sensitivity after training on the delay circuits (suppressor BH showed exactly the same number of rejects as suppressor AM during weeks 5–8). A three-way analysis of variance confirms that there was no statistically significant difference in rejection rate among the four suppressors.* Therefore, the data from all suppressors are pooled in Fig. 4, which shows the rejection rate as the first eight weeks of the experiment.

* Differences between suppressors can be demonstrated by special techniques other than natural conversation, as has been shown by M. B. Gardner and J. R. Nelson.[4] Their acceptability in natural conversations would seem to be the ultimate criterion, however.

TABLE III — REJECTION RATE FOR EACH SUPPRESSOR AND DELAY

	Round-Trip Delay in msec				
Suppressor	50	200	600	1200	All Delays
1A*	5	15	25	39	21
BH	7	11	24	41	21
GN	4	17	22	38	20
AM†	9	20	36	40	26
All suppressors	6	15	26	39	

Combined data for first eight weeks of experiment 2. Each table entry is based on 80 calls for suppressors 1A and AM and 160 calls for suppressors BH and GN. Table entries are percentage of calls rejected.
* Tested during weeks 1–4 only
† Tested during weeks 5–8 only

The standard condition is shown on Fig. 4 for comparison. Of 766 calls over the standard circuit, 10 (1.3 per cent) were rejected.

Fig. 5 shows the rejection rate for each value of added loss and the standard circuit with no added loss. All subjects are combined over the eight weeks during which the loss conditions were run.

Fig. 6 shows the rejection rate for each value of noise for all subjects and weeks combined. The standard circuit for internal calls had a 6-dbrn noise level and is plotted at that point.

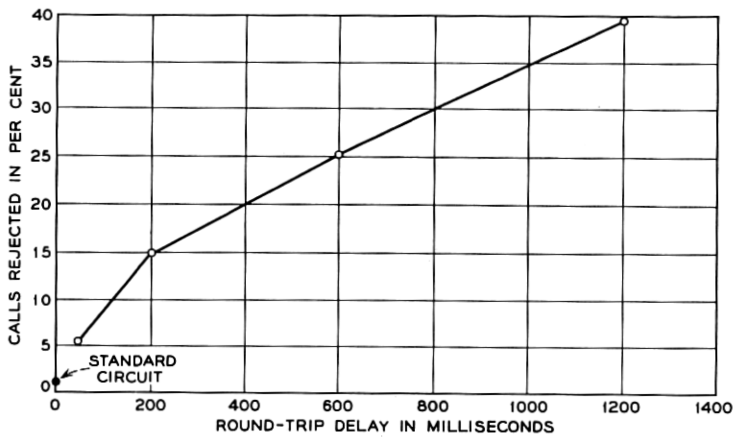

Fig. 4 — Rejection rate as a function of delay: combined data from 101 subjects using four echo suppressors for a total of eight weeks. All subjects were exposed to all delays and suppressors; each point represents 480 calls, except for the standard circuit point, which represents 766 calls.

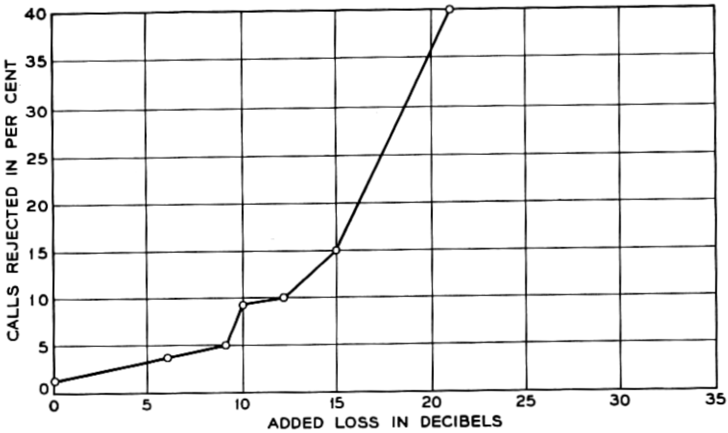

Fig. 5 — Rejection rate as a function of added loss: combined data from 101 subjects. The 9- and 12-db added-loss conditions were run during the first two weeks only, and represent 40 calls each. The other points represent 120 or 160 calls each, except for the zero added-loss point (standard circuit), which represents 766 calls.

4.6 *Effect of Experience*

The above figures summarize the data over the first eight weeks of the experiment and thus leave unanswered the question about change in rejection rate with experience. Do the circuits with delays, echoes and suppressors show an increased rejection rate with exposure, as shown in Fig. 2 of the pure delay tests? Evidence on this question is presented in Fig. 7, which shows rejection rate as a function of weeks of the experi-

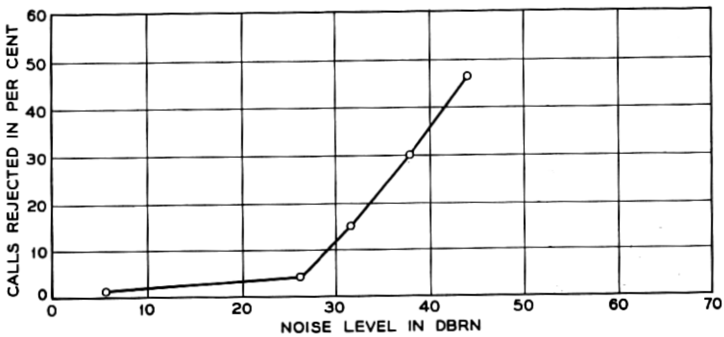

Fig. 6 — Rejection rate as a function of noise level: combined data from 101 subjects. Noise was a mixture of thermal noise and power line hum measured across the terminal set by a Western Electric 3A noise meter with C-message weighting. Each point represents 160 calls, except the 6 dbrn point, which represents 766 calls; the 6 dbrn point is the standard circuit condition.

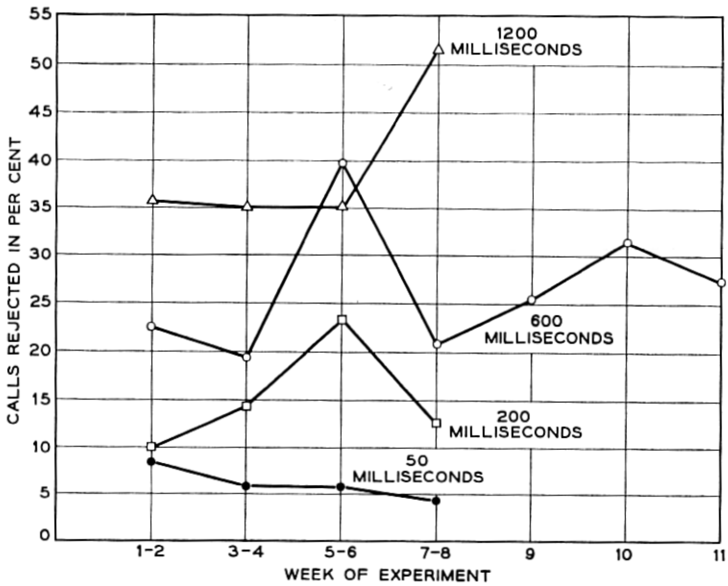

Fig. 7 — Rejection rate as a function of weeks of experiment: data from 101 subjects using all echo suppressors in use each week. Each point represents 120 calls, except points for weeks 9–11, which represent 268 or 480 calls each. Only the 600-msec delay condition was used on weeks 9, 10 and 11.

ment for each delay condition separately. The data from all suppressors are combined since there was no meaningful difference among suppressors. The changes in rejection rate over weeks shown in Fig. 7 are quite erratic, but for each delay above 50 msec the rejection rate was higher in the second half of the experiment than in the first half. The rejection rate at 50 msec actually decreased with weeks, but it should be pointed out that none of the changes with experience are statistically significant in this experiment.

4.7 *Interview Results*

The results of calling the subjects back after they had rejected a circuit is shown in Table IV. This procedure was followed only in week 11, and included 70 calls. Chopping and echo rank first among types of annoyance, which is to be expected from the action of the suppressor. Noise and loss comments do not refer to experimentally added noise and loss, since these conditions were not employed in the eleventh week. The echo suppressor does put in loss during double talking and its action does interrupt line noise originating at the other end of the circuit,

TABLE IV — RESPONSES OF SUBJECTS TO INTERROGATION CALL IMMEDIATELY FOLLOWING THEIR REJECTION OF THE CIRCUIT DURING WEEK 11 (BH SUPPRESSOR, 600 MSEC DELAY)

Why did you reject the circuit?		
	Echo	47%
	Chopping	36%
	Noise	21%
	Low volume	11%
	Delay	13%
Would the circuit have been acceptable for a transatlantic call?		
	No	51%
	Marginal	28%
	Yes	21%

A total of 70 interviews was made.

facts which may account for at least some of the loss and noise comments.

Table IV also shows the percentage of responses of several types to the question as to whether the circuit they had rejected would be acceptable for transatlantic calls. (They had been instructed to reject circuits unacceptable for normal telephoning.) Almost 80 per cent of the respondents said the quality would be unacceptable or marginal for transatlantic service.

4.8 *Length of Calls*

The relation between length of call and rejection rate was investigated by combining the data from all suppressors and delays of 200 msec or more. For 532 calls lasting 30 seconds or less the over-all rejection rate was 8 per cent. For 391 calls lasting 2.5 minutes or more the over-all rejection rate was 51 per cent. Another way of looking at the relation between length of call and rejection is to consider the length of rejected and nonrejected calls. Nonrejected calls had a median length of about one minute. Rejected calls have a median length of about 2.5 minutes and have a median time of rejection of about half a minute for the delay conditions. The probability of rejecting a call at any point was looked at as a function of the total length of the call. There was no relationship; that is, subjects do not show a tendency to quickly dial out calls which they know will last long.

Calls going outside the Murray Hill Laboratory* are longer on the

* The breakdown of calls by destination was: Murray Hill extension, 62 per cent; tie lines, 23 per cent; outside local, 14 per cent; DDD, 1 per cent.

average than calls to inside extensions and show a higher rate of rejection. There is no meaningful indication that the change in rejection rate for outside calls is either more or less than would be expected from their longer duration.

4.9 *Discussion*

In interpreting the results of experiment 2 it must be kept in mind that all subjects were potentially exposed to delays up to 1200 msec each week.* As in experiment 1, we must suspect that this exposure influenced the rejection rate at the lesser delays; experiment 3 provides data on this point. However, exposure of telephone customers to delays up to 1200 msec is not inconceivable in future satellite systems, and the present experiment — which gives the average user one such call every two weeks — is perhaps a reasonable approximation to one such system.

Two facts should be borne in mind in extrapolating from the laboratory experiments to field usage. One is that the return loss in the laboratory tests was set at a level somewhat worse than the average field expectation. Return losses in operating systems would be expected to be equal to or worse than the laboratory value in only about 15 per cent of all calls. The other factor is that the average laboratory call is much shorter than the average long-distance call; our results show that longer calls are rejected at a much higher rate. Thus, the laboratory rejection rates cannot be applied directly to all field calls, but do indicate potential difficulty in a significant proportion of long distance calls with intermixed delays such as those in experiment 2.

4.10 *Conclusions*

(*i*) Intermixed delays from 200 to 1200 msec produce substantial rejection rates under the conditions of the present experiment.

(*ii*) There was no meaningful difference among the four echo suppressors tested.

(*iii*) There is no evidence of increased tolerance of delay with experience nor on long distance calls.

(*iv*) Rejection rate increases greatly with length of call.

---

* Those people who made many calls did talk over the maximum delay each week. Many subjects who used their phone little did not talk over the maximum delay each week, but they do not influence the rejection rate as much, either.

V. EXPERIMENT 3: DEGRADATION IN TRANSMISSION QUALITY DUE TO DELAY ECHO AND ECHO SUPPRESSOR (FIXED DELAYS)

In the previous experiments, delays up to 1200 msec were intermixed each week so that all subjects were exposed to the entire range of delays. Experiment 3 modified the procedure of experiment 2 in that no subject ever talked over a longer delay than that assigned to his group, and separate groups of subjects were exposed to maximum delays of 50, 200, 400 and 600 msec.

5.1 *Apparatus*

The SIBYL simulator arrangement was the same as that used in experiment 2, except that only one echo suppressor was used (suppressor BH). Fig. 3 of experiment 2 shows a block diagram of the simulator which applies equally well to experiment 3.

5.2 *Subjects*

Eighty employees of the Murray Hill Laboratory served as subjects. None had served in any previous simulator experiment. During the course of the experiment 24 subjects changed rooms, left or otherwise became unavailable. Their data was removed from the analysis.

5.3 *Instructions*

The instructions to the subjects were the same as in experiment 2: that is, they were told to dial out any circuit which they found unsatisfactory, but they were not told the nature of the degradation and were not cued as to which calls were routed through the simulator.

5.4 *Test Conditions*

During the first week of the experiment all subjects were exposed to the 50-msec delay condition only. That is, on any call they initiated they would receive the simulator with a 50-msec delay unless another subject was already using the simulator. After the first week the 80 subjects were divided into four groups of 20 each, matched approximately on calling rate as determined from the first week. The sequence of delays to which each group was exposed is shown in Table V. Note that subjects in each group were never exposed to delays longer than that assigned from the fifth through fourteenth weeks.

Because the delay could not be changed instantaneously when any

Table V — Sequence of Delays for Each Group of Experiment 3; Suppressor BH was Used Throughout

	Week of Experiment															
Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	50 →				600											→
2	50	200												→		
3	50	200	400											→		
4	50	200	600											→		

Table entries are round-trip delay in msec.

particular subject picked up his telephone, it was necessary to divide the 8-hour day into four 2-hour periods and make the simulator, with appropriate delay, available to only those subjects who were assigned the same delay. The sequence of conditions within each day was rotated in such fashion that each group of users had access to the experimental circuit at a different time each day. Of course, they were not informed of this scheduling.

Group 1, which had the 50-msec delay for the first four weeks, was changed to 600 msec on week five. Since so few calls at 50 msec were rejected, it was not considered necessary to continue the 50-msec condition beyond week four. Group 4 was changed to 600 msec in order to increase the number of subjects at this delay, which is perhaps the most important one for questions of satellite communications. In order to combine groups 1 and 4 for an equivalent number of weeks at the 600-msec delay, data from two additional weeks (weeks 15 and 16) were taken from group 1.

The noise and loss conditions of experiment 2 were not used in experiment 3. Another difference from experiment 2 was that no control was exercised over the number of calls made each day under each of the experimental conditions. Rather, a time period was set aside each day for each condition, as previously described.

As in the previous experiments, the data recorded consisted of calling number, called number, length of call, and time of rejection if any.

During the eighth and fourteenth weeks the subjects were called back immediately after rejecting a circuit and also were called on a sample of simulator calls which were not rejected. They were asked what, if anything, they had noticed about the circuit on the previous call.

Finally, after the above schedule had been completed, the subjects of groups 1 and 4 were given one week of mixed delays of 200, 600 and 1200 msec in a fashion similar to experiment 2. This was done to check the possibility that differences in results between experiments 2 and 3 might have been due to a chance difference in subjects.

5.5 *Results*

During the first week of experiment 3, when all subjects were on the 50-msec delay, 73 of them made at least one call over the simulator. A total of 475 calls were made, of which eight, or less than 2 per cent, were rejected. Group 1 continued on 50 msec through the fourth week. During those four weeks they made a total of 376 calls, of which two, or less than 1 per cent, were rejected. In view of the low rejection rate and the fact that no calls at all were rejected during the third and fourth weeks, group 1 was changed to 600-msec delay on the fifth week.

The 200-msec delay condition was given to all subjects except group 1 during the second week and to group 2 only from the third through fourteenth weeks. During the second week 13 of 265 calls, or less than 5 per cent, were rejected.

The main body of results from experiment 3 is shown in Fig. 8, which plots rejection rate as a function of delay. In the solid curve, different subjects are represented at each delay; that is, each subject appears only at the delay value which was the maximum to which his group was exposed, except for group 1, which appears in both the 50-msec and 600-msec conditions for the main part of experiment 3. This combined group was also given the added week of mixed delays, shown by the dashed line. Fig. 8 shows a low rejection rate at 200-msec delay (2 per cent), less than 8 per cent rejection at 400-msec delay and 14 per cent rejection at 600-msec delay. These figures may be contrasted with the rates from experiment 2 shown in Fig. 4 — which are roughly double these values — and the rejection rates for mixed delays during the one-week extension of experiment 3, which are only slightly below those of Fig. 4.

5.6 *Effect of Experience*

Experiment 1, with pure delays presented in an intermixed fashion, showed a large increase in rejection rate with continued experience. Experiment 2, with echoes and suppressors added, showed little increase. The results of experiment 3 are shown in Fig. 9, which plots average rejection rate as a function of weeks of experience at maximum delay. The data from the 200-, 400- and 600-msec delay groups are plotted in this figure. Data from all groups are combined in such fashion that the first point plotted represents the first two weeks each group was at its maximum delay (not including the added week of mixed delays to 1200 msec).

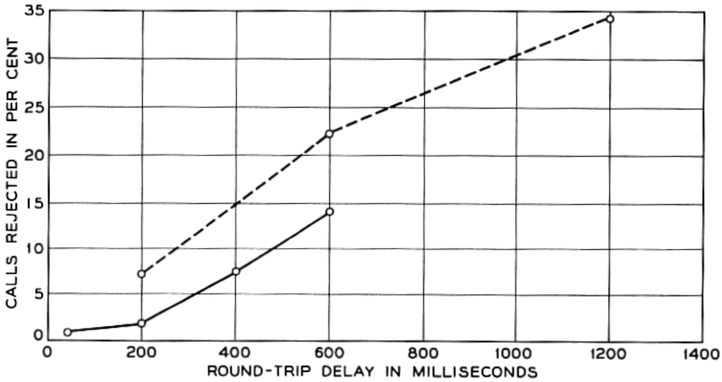

Fig. 8 — Rejection rate as a function of delay. Each point represents separate groups of 12 to 25 subjects, except that the 50-msec group (group 1) was later given 600-msec delay and is included with the subjects initially assigned to 600 msec (group 4). The light dashed line shows the result of exposing this combined group (1 and 4) to the mixed delays of experiment 2 for one week. Each point of the solid curve represents 376–774 calls. Each point of the dashed line represents 53–68 calls.

Fig. 9 shows a trend toward increasing rejection rate with experience on fixed delays, but as in experiment 2 the increase is small compared to the pure delay condition in experiment 1.

5.7 *Interview Results*

The results of calling the subjects back after they had made a call over the simulator are shown in Table VI. This table is in two parts: one for the case in which the simulator call had not been rejected and one for rejected calls. If the call had not been rejected, more than half the subjects noticed nothing different about the circuit; other comments were spread over many categories, echo being the largest. If the call had been rejected, half the subjects reported objectionable echo and all other categories of comments were higher than for the nonrejected calls. As in experiment 2, the suppressor will introduce loss during double talking which will subjectively make the circuit sound low in volume, and it will sometimes chop and mutilate echo, room noise and even speech in such a way as to sound like line noise. It is very difficult for the user to identify the exact nature of difficulties with those circuits.

5.8 *Destination and Length of Call*

The findings of experiment 2 on destination and length of call were substantiated in experiment 3. Long calls are rejected at a higher rate. Outside calls are longer and are rejected more than inside calls.

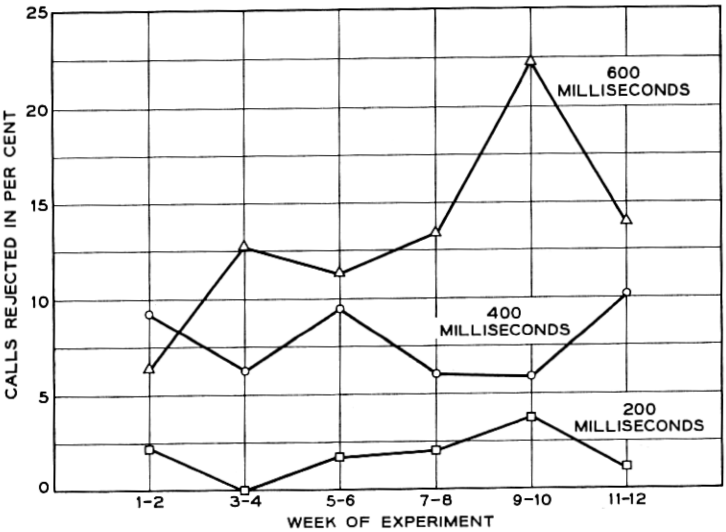

Fig. 9 — Rejection rate as a function of weeks at maximum delay. Data from all groups of experiment 3 combined as of the start of their respective weeks at the maximum delay to which each was exposed (200, 400, 600 msec). The added week of mixed delays to 1200 msec is not included. Each point represents 47 to 163 calls.

VI. GENERAL DISCUSSION AND SUMMARY

The effects of transmission delay upon the quality of a telephone circuit are not as obvious to the user as the more conventional degradations such as noise, loss and distortion. Indeed during most of a conversation over a delayed circuit there is no degradation. When degradation does occur it can often be misinterpreted by the user as being due to the other speaker. Slow responses, excessive interruptions and complete failures to respond (because the question was lost in the circuit) are examples of such difficulties.

It is not surprising, therefore, that in more than half the conversations involving pure delays of 1200 msec, or 600 msec plus echo and suppressors, the users are not aware that there is anything different about the circuit.*

In the pure delay condition the effect is particularly subtle since echo and speech mutilation are absent. Experiment 1 shows that it takes

* That there is an effect, however, is indicated by the fact that the users tend to talk for shorter times over these circuits. The median length of call over the 600-msec circuit with echo and suppressors is 24 per cent shorter than call length on the standard circuit.

TABLE VI — RESPONSES OF SUBJECTS TO INTERROGATION CALL IMMEDIATELY FOLLOWING A CALL OVER THE SIMULATOR

Rejected Calls	
Why did you reject the circuit?	
Echo	58%
Chopping	10%
Noise	22%
Low volume	18%
Delay	10%
Nonrejected Calls	
Did you notice anything different on your last call?	
Noticed nothing	52%
Echo	23%
Chopping	7%
Noise	0
Low volume	13%
Delay	11%

Only data from 600-msec delay (suppressor BH) are included, since rejection rates and therefore sample size at lesser delays were too small to be meaningful. Percentages are based on 40 rejected calls and 56 nonrejected calls.

considerable experience, and experience with long delays, before the effects of pure delay are recognized and rejected. Because of the limited scope of experiment 1 it is not possible to say exactly how much pure delay can be tolerated in telephone transmission, but it is clear that 2400 msec is completely unacceptable even on the first few calls and that intermixed 600 msec and 1200 msec are both rejected at fairly high rates by users who have been sensitized to delay circuits.

When echoes and echo suppressors are added to the circuit and delays up to 1200 msec are intermixed, even the 200-msec delay shows up with a significant rejection rate (15 per cent).

It might be thought that users would be more tolerant of long distance calls than internal calls and therefore that the rejection rates shown in all three of the present experiments are pessimistic. Analysis of the long distance calls made in experiments 2 and 3 does not support this view. In both cases the long distance calls were rejected at a significantly higher rate than internal calls. Although the difference in rejection rate can probably be attributed to length of call, long distance calls in operating systems average longer than those in the present study, and overseas calls are considerably longer on the average.

Experiment 3 showed that the use of fixed maximum delay conditions for each subject decreases the user dissatisfaction with circuits of shorter delays compared to the intermixed situation. When separate groups of subjects were exposed to different values of maximum delay, the group exposed to 200 msec rejected only 2 per cent of the calls, and even at 600 msec the rejection rate was only 14 per cent, compared to 26 per cent in experiment 2, in which delays up to 1200 msec were intermixed.

Individual users' reactions to delay, echo and suppressor action differed widely. Among each group of subjects there was at least one who never rejected any of the simulator circuits. At the other extreme, the most critical subject had a rejection rate three to five times the group average. There was a slight tendency for the heavy users to be more critical, but this is likely due entirely to the increase in rejection rate with experience.

There was no meaningful difference in rejection rate among the four echo suppressors tested. None offered a measurable advantage over a modified version of the suppressor most commonly used today.

Finally, what do the results of these experiments mean for international communications? From the present experiments it would seem safe to conclude that noticeable degradation in transmission quality may occur under some circumstances with delays as low as 200 msec and with any of the currently available echo suppressors. The circumstances include low return loss and users who have been sensitized to the problems created by transmission delay.

Degradation increases with delay until at 1200-msec round-trip delay and any present echo suppressor, more than one-third of the calls were rejected as being unsatisfactory under the conditions of these experiments. An increase in circuit loss of approximately 20 db was required to produce the same rejection rate.

The degradation due to transmission delay in any telephone transmission system must be weighed against the cost and other degradations inherent in alternative transmission systems of less delay. It is clear, however, that the influence of delays of 200 msec or more should be considered in designing international voice communications systems to carry natural conversations.

VII. ACKNOWLEDGMENTS

P. T. Brady contributed much to the design and carrying out of the experiments and analysis of the data. A. P. Winnicky was in charge of the SIBYL simulator, which was modified and maintained under his direction by C. H. Sturner. Mrs. M. T. Brinkerhoff, Mrs. G. A. Wesner and Mrs. M. K. Collyer operated the SIBYL console. G. K. Helder, M. B. Gardner and J. R. Nelson assisted in the installation and maintenance of the echo suppressors. Mrs. N. W. Shrimpton wrote several computer programs for analysis of some of the data. Miss M. J. Billington interviewed the subjects for experiments 1 and 2. Mrs. V. A. Bull carried out call-back of the subjects and performed much of the data analysis for this article. J. E. Karlin consulted in all phases of the experiments.

REFERENCES

1. Brady, P. T., and Helder, G. K., Echo Suppressor Design in Telephone Communications, B.S.T.J., this issue, p. 2893.
2. Irvin, H. D., Studying Tomorrow's Communications . . . Today, Bell Laboratories Record, **36**, November, 1958, p. 399.
3. Emling, J. W., and Mitchell, D., The Effects of Time Delay and Echoes on Telephone Conversations, B.S.T.J., this issue, p. 2869.
4. Gardner, M. B., and Nelson, J. R., Combating Echo in Speech Circuits with Long Delay, J. Acoust. Soc. Am., **35**, Nov., 1963, p. 1762.