Masking of Crosstalk by Speech and Noise*

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We performed three laboratory experiments of crosstalk thresholds using simulated telephone conversations. Two of these experiments involved masking of crosstalk by noise; the third involved masking of crosstalk by both noise and primary speech. In this paper, we present intelligibility and detectability threshold data from these experiments and discuss the usefulness of the intelligibility threshold data for determining telephone crosstalk objectives.

In general, the crosstalk threshold versus masking noise functions obtained from these experiments agreed fairly well with similar functions published earlier. These functions were found to be linear for high values of noise (about 20 dBrnC and higher) and markedly nonlinear for lower values of noise. For very low noise conditions (about 5-6 dBrnC or lower), crosstalk thresholds were almost independent of noise. Intelligibility thresholds were found to be 8-10 dB higher than the corresponding detectability thresholds and a difference of the same size was found between threshold values obtained (i) with background noise and (ii) with both background noise and background speech.

I. INTRODUCTION

1.1 *General Background*

In the process of transmitting speech over telephone channels, a portion of the speech energy occasionally gets transferred from one channel to another. This transferred energy is technically referred to as crosstalk. The presence of crosstalk in telephone circuits is objectionable for two main reasons. (*i*) Its presence may indicate to customers that they are receiving a telephone service which does not protect their

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own privacy. (*ii*) It may interfere with speech transmission and thus degrade the circuit quality.

Since the Bell System strives to maintain a certain standard of transmission quality and provide privacy to the customers, it is concerned with controlling all sources of circuit degradation, including crosstalk interference. Designing the telephone plant to guarantee complete absence of energy transfer between channels is not economically feasible. Therefore, to guarantee privacy and to maintain a certain standard of transmission quality, the usual engineering strategy (which is maintained with a high degree of probability) is to limit the crosstalk energy below a threshold such that (*i*) it is not intelligible and (*ii*) it does not subjectively degrade the circuit quality. This threshold is experimentally determined by subjective testing, using simulated telephone connections. It is then translated into engineering terms in the form of a transmission objective.

Prior to the completion of the tests reported here, crosstalk objectives for the telephone plant were based on the results of subjective tests conducted at Bell Telephone Laboratories about 30 years ago.[1] In the intervening period, however, there have been changes in the telephone plant, including the introduction of 500-type new telephone set and the 3A noise measuring set. Although it would have been possible to continue to use the previous data with appropriate conversion factors, a new series of tests was undertaken. This was done even though the difference between the near and earlier results was expected to be small, because small differences in objectives, even in the order of 1 dB, can indeed have important economic consequences in new designs.

One of the important areas of application for the present crosstalk data will be design requirements for new telephone sets. Here, the state-of-the-art now promises the possibility of increased telephone set gain at low cost. However, it also appears that loop crosstalk considerations will probably limit the extent to which this gain can be used to achieve economics in other parts of the plant. In order to facilitate studies of this type, it was considered important to have accurate and up-to-date subjective test results.

In addition to providing for the revision of the earlier crosstalk test results for the intelligibility threshold, the new test series afforded the opportunity to obtain data on the threshold of detectability and on the masking effects of speech as well as noise. Other factors which were considered worthy of study were differences between one-word and several-word intelligibility and the effect of letting the subject control the crosstalk level.

The primary results of the study are in terms of crosstalk coupling loss which is flat with frequency in the band from approximately 300 to 3300 kHz. In order to apply the results to systems where capacitive rather than flat coupling exists, correction factors must be applied. Appropriate correction factors, based on the results of a comparison study, have been included in Section III of this paper.

1.2 *Purpose of the Experiments*

In order to check the adequacy of the existing crosstalk objectives, transmission engineers need, among other things, psychophysical data on speech intelligibility thresholds for various background noise conditions. Experiment I was designed to collect psychophysical data of this kind; that is, data which could be used by transmission engineers to set transmission objectives for crosstalk.

Experiment II was designed to obtain data on crosstalk thresholds with both noise and primary speech on the circuit. The primary purpose here was to determine the difference between crosstalk threshold values obtained with both background speech and noise, and those obtained with background noise only. Such information is useful in evaluating certain crosstalk phenomenon. However, it should be recognized that in most applications, speech may not always be present to provide additional masking, and objectives must normally be based on the masking effects of noise only. A second purpose of this experiment was to obtain, for each experimental condition, a rating by the subjects of the overall transmission quality. Data on transmission quality ratings serve as important guidelines for establishing Bell System transmission objectives. This paper, however, presents only the threshold data.

Experiment III had essentially the same purpose as Experiment I, but two changes were made in the procedure. First, instead of hearing short sentences for crosstalk as in Experiment I, the subjects heard a recorded 2-way simulated telephone conversation. Second, instead of simply reproducing the crosstalk words heard as was done in Experiment I, each subject used his own criterion for determining intelligibility thresholds. The purpose here was to find if the threshold values and the intersubject variability as obtained in Experiment I could be significantly affected by introducing a somewhat less stringent criterion, namely, the subjects' own judgment about the intelligibility threshold.

II. METHOD

2.1 *Definitions of Thresholds*

Two kinds of speech (or crosstalk) thresholds were measured in these experiments: (*i*) The threshold of detectability, defined as the speech (or crosstalk) level at which the subject is just able to detect the presence of speech sounds with 50 percent probability. (*ii*) The threshold of intelligibility, defined as the speech (or crosstalk) level at which the subject is just able to understand the meaning of the speech content with 50 percent probability.

2.2 *Psychophysical Methods*

Of the various psychophysical methods which can be used for determining thresholds, we used two in the present experiments. In Experiments I and II, we used the *Method of Limit.* In this, the experimenter controlled the level of the stimulus (crosstalk material) presented to the subjects. The experiment started with the stimulus at a level well below the threshold. The level was increased by small but equal steps in subsequent presentations (a 3 dB step was used in this case). The series was stopped when the level was well above the intelligibility threshold. The next series started with the stimulus at some level above the intelligibility threshold and the level was decreased by the same step of 3 dB. The series was terminated when the level was well below the detectability threshold. At each presentation of the test condition, the subjects gave the desired response. For each subject, the midpoint of the transition between response and no response determined his threshold.

In Experiment III, we used a different psychophysical method, namely the *Method of Adjustment,* to determine the thresholds. This method required the subjects to adjust the stimulus level. For each experimental condition, the subject was first presented with a speech level well below the detectability threshold. He was asked to increase the level until speech was first detectable and then intelligible. Next, he started with a speech level well above the intelligibility threshold and decreased the level until it was no longer detectable.

2.3 *Experimental Conditions*

In Experiment I, five levels of white noise were presented to the subjects. These noise levels, as measured at the line terminals of the telephone set, were 18, 33.5, 38.5, 43.5 and 48.5 dBrnC respectively. (For explanation of dBrnC, see Aikens and Lewinski[2].) Short sentences taken from a list provided by Beranek served as crosstalk material.[3] For each noise level, two different sentences were used, one spoken by a male talker and the other by a female talker. There were thus a total of ten experimental conditions presented to the subjects.

In Experiment II, the same five noise levels used in Experiment I were each combined with five levels of primary speech, thus making a total of 25 experimental conditions. These 5 speech levels as measured at the line terminals of the telephone set used were −30, −35, −40, −45, and −50 VU respectively.

For each experimental condition in Experiment II, the subjects heard a 30-second simulated telephone conversation between male or female talkers which served as the primary speech in the circuit. Short sentences like those used in Experiment I served as crosstalk materials. For each of the 25 experimental conditions, a different primary speech segment and a different crosstalk sentence were used. Both male and female talkers were used in both. Thus, a test condition could have only male, only female, or a combination of male and female talkers.

In Experiment III the five noise levels of Experiments I and II were retained. However, instead of short Beranek sentences, simulated conversation segments between talkers were used as crosstalk material.

A Northern Electric VU Meter was used for all speech level measurements. One experienced meter reader made all the measurements following recommendations made by Carter and Emling, and as quoted by Brady.[4]

Equivalent Peak Level (epl)[5] measurements were also made on about 25 percent of the speech samples in these experiments. On the average, epl was found to be 10 dB higher than the corresponding VU measure. The standard deviation of the difference (epl-VU) was 0.9 dB.

2.4 *Anchor Conditions*

It was mentioned earlier that the subjects were asked to rate the transmission quality of each experimental condition during Experiment II. In order to give them a general idea of the range of transmission quality usually encountered in the telephone plant, selected speech samples were presented prior to each test session. This was done to anchor their judgment at the extremes of the rating scale. A set of six test conditions was thus presented to the subjects at the beginning of each test session in Experiment II. These consisted of simulated telephone conversations between pairs of talkers which were heard by the subjects through some very poor and some very good simulated telephone connections.

2.5 *Room Noise*

The room noise for Experiments I and II as measured by a sound level meter was 37 dBt,* A-weighting. The similar value for Experiment III was 41 dBt. (Experiment III was performed in a different test room.)

* dBt = dB relative to 0.0002 dynes/cm^2. This measure was referred to as dBRAP in earlier crosstalk tests by Edson.[1]

2.6 *Experimental Apparatus*

Block diagrams of the laboratory system used in the present experiments are shown and discussed in Appendix A.

2.7 *Procedure*

Two rooms were used in Experiments I and II. The control room contained the equipment required for manipulation during the experiments; the experimental room contained part of the apparatus and the subjects' booths. A test administrator monitored the test conditions using one of 12 parallel receivers in the experimental room.

Normally, eight to ten subjects took part in each experimental session. Before each experiment began, the test administrator reviewed the instructions with the subjects. Each subject was provided with an instruction sheet before the administrator reviewed the instruction.

At the beginning of each session, the subjects listened to the six anchor conditions. They were not required to make any response to these conditions. The actual experimental conditions followed these anchor conditions with a short announcement. To each stimulus condition, the subjects were required to take these steps: (*i*) Indicate whether or not they detected any background speech (that is, crosstalk). (*ii*) Write down all the interfering words that were intelligible. (*iii*) For Experiment II only, rate the transmission quality of the circuit on a 5-point scale.

The 25 test conditions in Experiment II were divided into five groups, each group being presented in one test session. For each subject, five test sessions were required for Experiment II and one session for Experiment I. Each test session in Experiments I and II took from 90 to 100 minutes, and was divided into 2 halves by a short break. No subject took part in more than one session per day. A total of 24 test sessions was required to run all the subjects through Experiments I and II. This was spread over a period of 7 weeks. As indicated earlier, the *Method of Limit* was used in Experiments I and II.

In Experiment III the *Method of Adjustment* was used with one subject at a time taking part in the experiment. Here, the subject was required to adjust a variable attenuator for his threshold settings. Each subject made two settings each for both detectability and intelligibility threshold—one for the crosstalk level going up from low volume to high volume, and the other for the crosstalk level going down from high volume to low volume.

The crosstalk materials used in Experiment III were two 30-second simulated conversations, one between a pair of male talkers and the other between a pair of female talkers. The same five circuit noise levels were used as in Experiments I and II. The subjects were given the following guidelines for their threshold criteria: (*i*) For the detectability threshold, the level should permit them to detect the presence of speech sounds without understanding them. (*ii*) For the intelligibility threshold, the level should permit them to understand about one complete sentence without appreciable effort. For each subject, one experimental session took approximately one hour.

For all experiments, the test conditions within a session were presented according to some predetermined random order which varied for different sessions. Also, the speech materials for crosstalk and primary conversation were recorded in such a way that the volume (in VU) was maintained at a fairly constant level across conversation segments.

2.8 *Subjects*

Thirty-one subjects, male and female, took part in Experiments I and II. Their ages ranged from 20 to 64. They were selected at random from employees at the Murray Hill location of Bell Telephone Laboratories. Six of these subjects had previous experience with psychoacoustic experiments; the rest had no such previous exposure.

In Experiment III, 39 subjects took part. Fifteen of them were subjects also in Experiments I and II including the six experienced subjects mentioned above.

The subjects were tested for hearing acuity before the experiments. All the subjects had about normal hearing in the range of 500–2000 Hz, considered important for speech intelligibility.

In general, it may be said that in terms of their age, sex, professional background and hearing level, the subjects represent a reasonably good cross section of Bell System customers.

III. RESULTS AND DISCUSSION

3.1 *Thresholds Data—Experiments I and II*

Figure 1 presents the group psychometric functions for detectability thresholds obtained from two experimental conditions providing the same amount of circuit noise. Curve a was obtained with a background noise of 18 dBrnC. Curve b was obtained with a background noise of 18 dBrnC and also a primary speech level of −30 VU. Both noise and VU measurements were made at the line terminals of the subjects' telephone set. The ordinate gives the percentage of the subjects detecting the crosstalk; the crosstalk volumes are plotted on the abscissa.

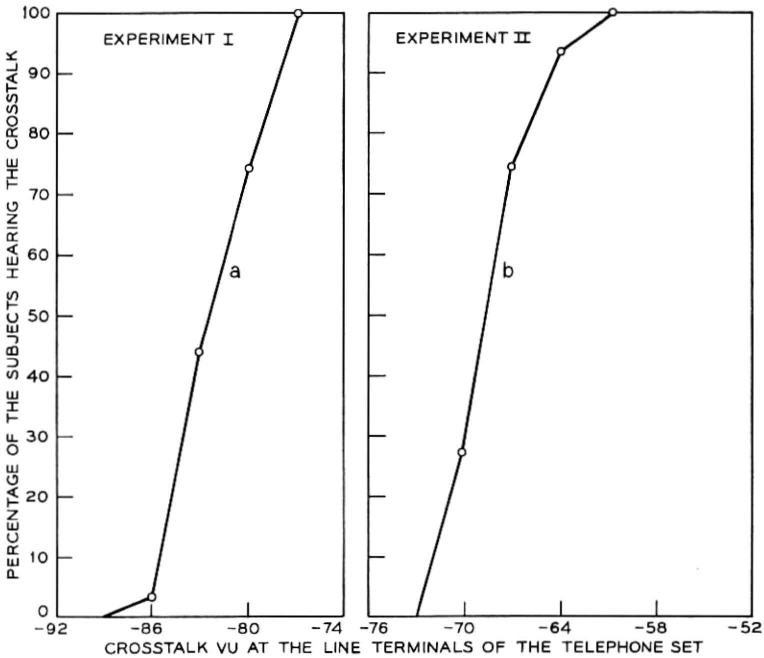

Fig. 1—Cumulative distributions of crosstalk detection, curves a and b refer to two experimental conditions: curve a, circuit noise 18 dBrnC; curve b, circuit noise 18 dBrnC, primary speech −30 VU. All measurements were made at the terminals of the telephone set.

The curves in Fig. 1 were drawn from the raw data. Similar detectability and intelligibility threshold (of one word or more) functions were drawn for all the experimental conditions in Experiments I and II. Since these functions appeared similar to cumulative normal curves, the raw data for each experimental condition were subjected to an unweighted-normal least-squares fit. The Kolmogorov–Smirnov[6] test was applied to determine any significant difference between the actual and the fitted cumulative normal curves. No difference was observed at the 5 percent level of significance. Group detectability and intelligibility thresholds were then obtained by finding the speech (or crosstalk) level corresponding to the 50 percent point on the fitted cumulative threshold function for each experimental condition.

Group threshold for each experimental condition was also calculated from the raw data by simply taking the average of all the subjects' individual thresholds for that condition as obtained from the *Method of Limit.*

A comparison between the threshold values of actual and fitted data for Experiments I and II is presented in Table I. Notice that the threshold values for corresponding experimental conditions are about the same. In Experiment I, two crosstalk sentences were used for each noise condition, one spoken by a male talker and the other by a female talker. In this table, they have been indicated by M and F respectively. The threshold values for these two sentences have been averaged for each noise condition since they were not significantly different. (In general, no significant difference in the threshold data was found between male and female talkers in any of the three experiments.) For Experiment II, the table presents the threshold values for each of the 25 experimental conditions. For each noise condition, the threshold values for the five primary speech levels were also averaged. All intelligibility threshold values in Table I are for intelligibility of *one word or more.*

Table II presents the standard deviation values corresponding to the mean thresholds of Table I as used for the least-squares normal fit. The data are presented for Experiment II only. On the average, variability in intelligibility threshold was found to be much larger than in detectability threshold.

For Experiment I, however, where there was no background speech as in Experiment II, variability in the threshold data was much lower and consistent over the range of noise levels used. For intelligibility threshold, standard deviation was of the order of 2.5 dB, and for detectability threshold, it was of the order of 2.0 dB. These values were used for the normal least-squares fit.

For any noise level in Experiment II, notice the change in threshold as a function of primary speech level as shown in Fig. 2. For detectability, no significant change in threshold values was observed over a 20 dB range of primary speech level (from −30 VU to −50 VU) for the four high noise levels between 33.5 and 48.5 dBrnC. However, with the low noise level (that is, 18 dBrnC), a threshold difference of 8.5 dB was found between the lowest and the highest speech level. In the case of intelligibility, the corresponding threshold shifts were found to be much larger. But here again, as in the case of detectability threshold, the ranges of the threshold shifts were relatively smaller for higher noise levels, as compared to the one obtained for 18 dBrnC.

Figure 3 presents the summary of the test results of Experiments I and II in terms of threshold as a function of circuit noise level. For Experiment II, each data point represents the average of the five threshold values (corresponding to five primary speech levels) for each circuit noise condition. For Experiment I, each data point represents the average of the two threshold values (male and female talkers) for each

TABLE I—GROUP CROSSTALK THRESHOLD FOR DIFFERENT EXPERIMENTAL CONDITIONS IN EXPERIMENTS I AND II

		Intelligibility Threshold Noise Level* (dBrnC)					Detectibility Threshold Noise Level (dBrnC)					
		18	33.5	38.5	43.5	48.5	18	33.5	38.5	43.5	48.5	
Fitted Data Primary Speech Level (VU)*	†M	−74.0	−62.9	−58.0	−50.9	−47.4	−82.0	−71.9	−67.6	−60.9	−55.2	Experiment I
	F	−76.0	−60.0	−55.0	−52.0	−45.3	−85.0	−73.1	−66.1	−61.8	−55.4	
	Avg.	−75.0	−61.4	−56.5	−51.4	−46.4	−83.5	−72.5	−66.8	−61.3	−55.3	
	−30	−50.4	−43.1	−40.5	−38.2	−31.9	−68.3	−60.9	−56.9	−52.0	−47.9	Experiment II
	−35	−61.8	−44.1	−40.1	−43.0	−36.2	−72.4	−61.4	−57.2	−52.3	−47.8	
	−40	−54.6	−51.9	−47.4	−42.7	−40.9	−68.6	−63.6	−56.6	−54.3	−47.4	
	−45	−53.0	−52.0	−47.3	−45.5	−39.1	−72.5	−65.4	−58.1	−57.0	−50.2	
	−50	−64.6	−54.4	−52.0	−46.3	−42.4	−78.5	−62.6	−62.7	−53.7	−46.7	
	Avg.	−56.9	−49.1	−45.5	−43.1	−38.1	−72.1	−62.8	−58.3	−53.9	−48.0	
Raw Data Primary Speech Level (VU)	M	−75.8	−62.8	−59.5	−50.2	−48.2	−82.2	−72.3	−67.7	−61.3	−55.0	Experiment I
	F	−77.2	−60.2	−54.1	−52.7	−44.2	−85.0	−72.8	−66.4	−62.0	−55.2	
	Avg.	−76.5	−61.5	−56.8	−51.4	−46.1	−83.6	−72.5	−67.0	−61.6	−55.1	
	−30	−51.0	−44.8	−40.3	−37.2	−33.5	−68.5	−61.3	−56.9	−52.2	−48.4	Experiment II
	−35	−61.0	−45.0	−40.6	−41.3	−37.8	−73.8	−61.9	−57.0	−52.3	−48.8	
	−40	−52.7	−50.8	−45.4	−41.9	−38.7	−68.0	−63.1	−57.9	−54.9	−48.1	
	−45	−54.3	−50.0	−45.8	−45.6	−39.4	−72.9	−65.5	−57.9	−56.5	−50.8	
	−50	−64.3	−54.0	−50.4	−47.2	−42.4	−77.7	−63.1	−62.8	−55.3	−48.7	
	Avg.	−56.7	−48.9	−44.5	−42.6	−38.4	−72.2	−63.0	−58.5	−54.2	−49.0	

* All noise and speech levels were measured at the line terminals of the subject's telephone set.
† M and F refer to male and female crosstalk sources respectively.

Table II—Standard Deviations Associated with Corresponding Mean Values of Experiment II Presented in Table I

	Intelligibility Threshold Noise Level (dBrnC)					Detectibility Threshold Noise Level (dBrnC)				
	18	33.5	38.5	43.5	48.5	18	33.5	38.5	43.5	48.5
−30	2.1	2.9	8.4	8.8	5.0	3.0	4.4	2.8	2.6	3.5
−35	6.3	7.0	8.1	5.5	5.2	4.7	2.0	2.1	3.0	3.6
−40	6.2	5.5	5.0	4.2	5.5	5.0	3.4	2.3	2.3	2.0
−45	8.9	8.0	5.3	2.9	1.7	3.4	2.6	3.1	1.9	3.5
−50	6.3	3.0	6.4	2.5	8.0	6.4	3.2	1.2	3.3	6.3

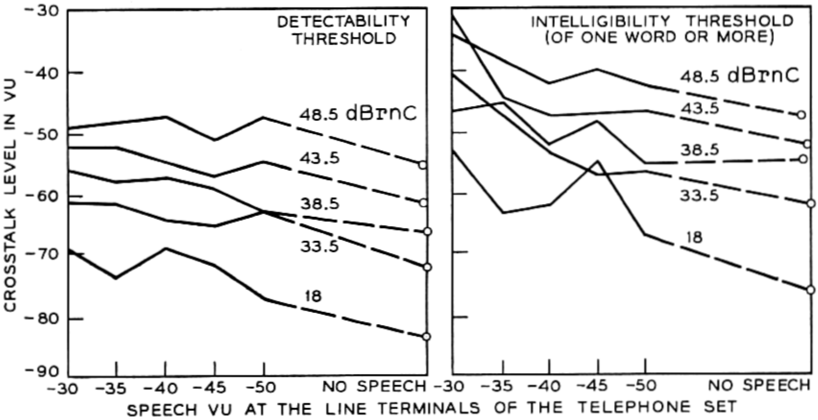

Fig. 2—Crosstalk threshold as a function of primary speech in the circuit. The different curves are for different values of circuit noise in dBrnC.

circuit noise condition. Two curves have been drawn for each experiment, one for the detectability threshold and one for the intelligibility threshold. These threshold functions show two important characteristics: (*i*) they are linear for the high noise levels and show a tendency to bend at the lower noise levels, and (*ii*) on the average, there is about a 10 dB shift between detectability threshold and intelligibility threshold.

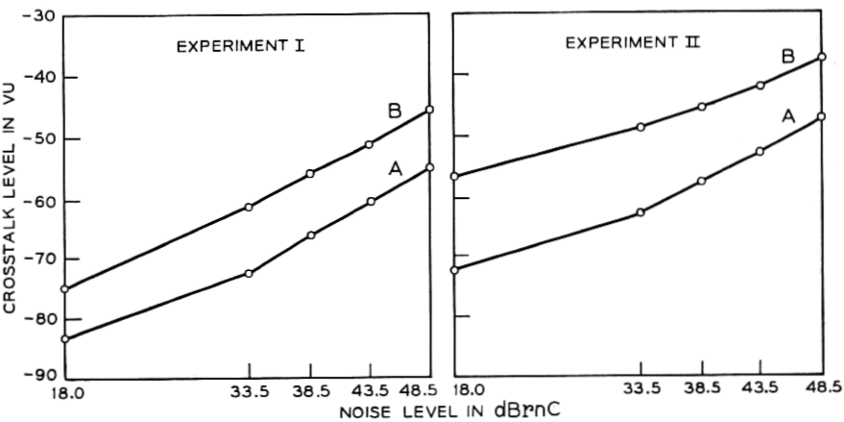

Fig. 3—Crosstalk threshold as a function of circuit noise. A represents detectability threshold; B, intelligibility threshold.

How do the threshold functions of Experiment I (with noise as background) compare with those of Experiment II (with both noise and primary speech as background)? Figure 4 presents this comparison. Two functions from each experiment have been presented, one for the detectability thresholds and one for the intelligibility thresholds. A very interesting finding comes out of this comparison: the detectability threshold function of Experiment II is about the same as the intelligibility threshold function of Experiment I. This suggests that crosstalk which is barely detectable in a circuit when people are talking becomes just intelligible when people pause or stop talking. Crosstalk objectives for the telephone plant are, however, based on threshold data obtained in the absence of any primary speech, that is, the kind of data obtained from Experiment I here.

3.2 *Comparison with Earlier Data*

Several other studies also have investigated the problem of masking of speech by noise. Unfortunately, due to lack of complete information, most of the previous data cannot be properly converted for precise comparison with the present data. However, there are two sets of data (Hawkins and Stevens[7] and Edson[8]) which could be compared with the present data (Experiment I) with proper conversions.

Figure 5 presents the comparison between Hawkins' and Stevens' data and those obtained from Experiment I. The dBrnC and VU readings of

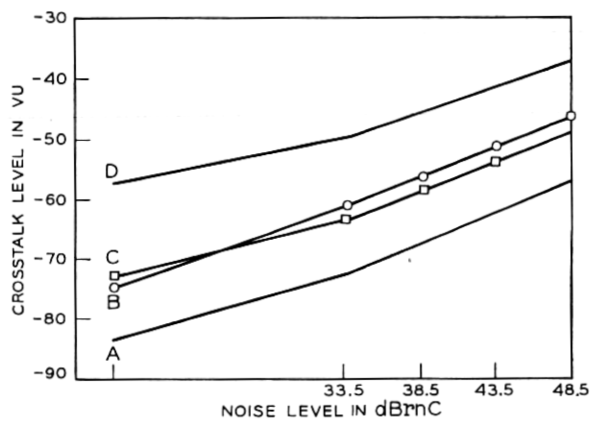

Fig. 4—Crosstalk threshold as a function of circuit noise. A represents detectability threshold and B, the intelligibility threshold in Experiment I; C, the detectability threshold and D, the intelligibility threshold in Experiment II.

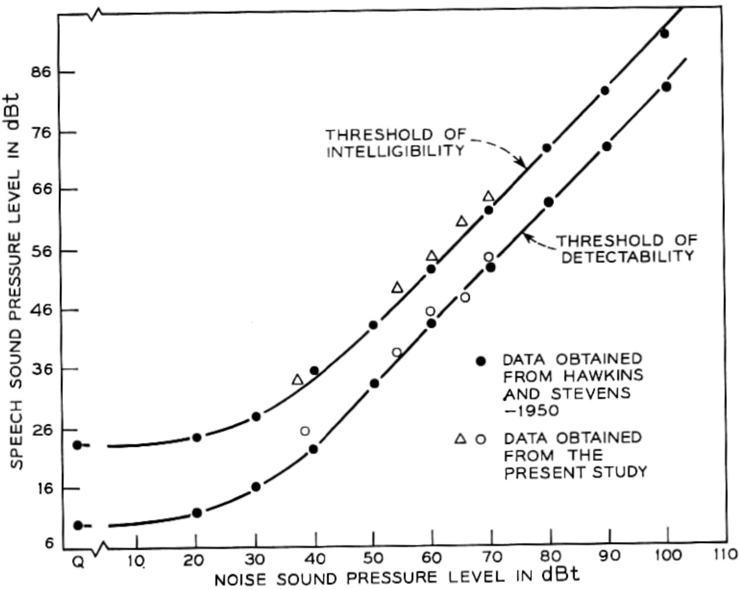

Fig. 5—Speech threshold as a function of background noise: a comparison between the present data and Hawkins–Stevens data.

the present data have been converted to noise and speech sound pressure levels respectively.

A portion of the experimental setup used by Hawkins and Stevens is shown in Fig. 6. In general, three main differences can be pointed out between their experimental conditions and those in Experiment I: (*i*) They used a PDR-10 earphone having a flat response over a much wider frequency band than the U1 telephone receivers used in the present experiments. (*ii*) They used a continuous passage as speech material whereas in Experiment I short sentences were used for the same purpose. (*iii*) They used the *Method of Adjustment*, that is, the subjects themselves adjusted the speech level and judged their own intelligibility threshold.

In Experiment I, on the other hand, the *Method of Limit* was used; that is, the speech level was controlled by the experimenter and the intelligibility threshold was based on the number of correct words reproduced by the subjects. Also, Hawkins and Stevens used a small group of four trained subjects; whereas in Experiment I, a total of 31 subjects were used. In spite of these differences, however, the agreement between the two sets of data is very good. On the average, corresponding threshold values between the two sets of data differ by less than 2 dB.

Edson's 1952 data had to be corrected for proper comparison with the present data. The final comparison between Edson's data and the present data is shown in Fig. 7. Both measurements are at the line terminals of a 500 type telephone set. The average difference between corresponding threshold values in the two sets of data is of the order of 4 dB here. It should be pointed out, however, that the present data points are for "one word or more intelligibility," whereas Edson's data points are for "four words or more intelligibility." Assuming that these two criteria produce a difference of about 2 to 2.5 dB (this was generally observed in Experiment I), the average difference between Edson's 1952 data and the present data for corresponding thresholds turns out to be of the order of 2 dB. Considering the various differences between the two sets of experimental conditions, a difference of this size is quite probable.

Experiment III was designed to check how much the results of Experiment I might differ by introducing a criterion for the intelligibility threshold which was not so well defined as in Experiment I and also by changing the criterion of intelligibility from "one word or more" to "about a sentence" in a continuous crosstalk situation. The subjects themselves adjusted the level of crosstalk for the threshold and used their own judgment to decide about both detectability and intelligibility thresholds. Both intelligibility and detectability thresholds were

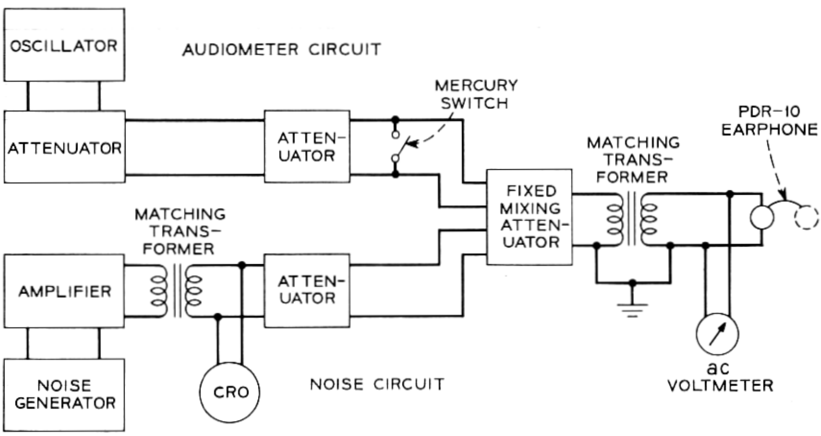

Fig. 6—Block diagram of the apparatus used for the measurement of pure tone threshold in the quiet and in the presence of white masking noise. (From Hawkins-Stevens.)

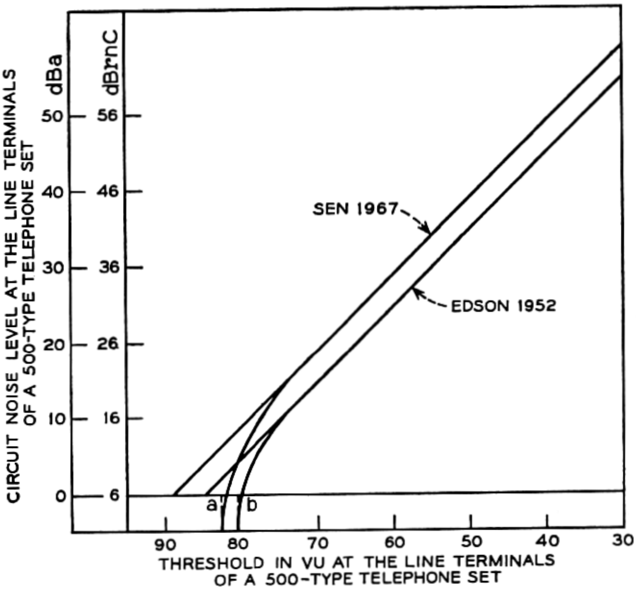

Fig. 7—Crosstalk intelligibility threshold as a function of noise. Note: Data points for noise levels below 18 dBrnC were taken from six trained subjects only in Sen's experiment.

found to be higher in Experiment III than their corresponding values in Experiment I. The average differences were 2.0 dB for intelligibility threshold, and 3.1 dB for detectability threshold. Actual differences were, however, larger for low noise levels than for high noise levels. It may be recalled that the threshold values in Experiment I are 50 percent threshold values. The threshold values of Experiment III compare with 80–90 percent threshold values for corresponding conditions in Experiment I. In other words, while using the *Method of Adjustment*, the subjects preferred to be more than 50 percent confident in making their threshold settings. The average standard deviation was found to be 2.8 dB as compared to 2.5 dB in Experiment I. A comparison between the results of Experiments I and III is shown in Table III.

3.3 *Crosstalk Thresholds for Flat and Capacitive Coupling Systems*

While considering the use of the present data (from Experiment I) for setting transmission objectives, it should be remembered that the experiments reported here were performed using only flat crosstalk coupling between adjacent channels. The data are, therefore, directly applicable to carrier systems.* A legitimate question, however, arises concerning the applicability of these data for the voice frequency systems in the lower frequency range where the coupling loss between adjacent channels is reduced by 6 dB per octave because of capacitive coupling.

To find out the difference in crosstalk intelligibility thresholds between the two above-mentioned cases, that is, flat and capacitive crosstalk coupling between adjacent channels, an experiment was recently performed by Koenig[9] using both males and females as crosstalk sources. It was found that the capacitive coupling system was, on the average, 2.0 dB more sensitive than the flat coupling system for male crosstalk and 1.06 dB more sensitive for female crosstalk. To be on the conservative side, therefore, it is recommended that in setting crosstalk objectives for the voice frequency systems using the present data from Experiment I, the obtained intelligibility thresholds should be lowered by 2.0 dB.

IV. SUMMARY AND CONCLUSIONS

This paper describes three recently performed laboratory experiments on crosstalk thresholds and presents the results. The experiments were performed using simulated telephone conversations. Detectability and intelligibility thresholds of crosstalk were obtained from the subjects. Thirty-one subjects were used in Experiments I and II, and 39 in Experiment III. Fifteen of these subjects took part in all three experiments. The subjects were chosen from among employees at the Murray Hill location of Bell Telephone Laboratories. Most of them had no previous experience in subjective tests of transmission quality.

Experiment II used both primary speech and circuit noise as masking stimuli while for Experiment I circuit noise was the only masking stimulus. The same five noise conditions were used in both experiments. The primary speech in Experiment II appeared in five levels. In both experiments, the experimenter controlled all levels of speech and noise. The subjects were required to indicate the presence and absence of crosstalk and reproduce the crosstalk words heard whenever they were intelligible. Short sentences spoken by both male and female talkers were used as crosstalk material.

Experiment III was in a way, a repeat of Experiment I with two major exceptions: (*i*) A continuous simulated telephone conversation instead of short sentence was used as crosstalk material. (*ii*) The subjects

* Because the coupling loss between adjacent channels is effectively flat or independent of frequency.

TABLE III—A COMPARISON BETWEEN THE RESULTS OF EXPERIMENTS I & III

	Experiment I. Crosstalk Material: Short Beranek Sentences									
	Intelligibility Threshold					Detectibility Threshold				
	NOISE LEVEL IN DBRNC									
	18	33.5	38.5	43.5	48.5	18	33.5	38.5	43.5	48.5
M	−75.8	−62.8	−59.5	−50.2	−48.2	−82.2	−72.3	−67.7	−61.3	−55.0
F	−77.2	−60.2	−54.1	−52.7	−44.2	−85.0	−72.8	−66.4	−62.0	−55.2
Avg.	−76.5	−61.5	−56.8	−51.4	−46.1	−83.6	−72.5	−67.0	−61.6	−55.1

	Experiment III. Crosstalk Material: Simulated Conversations.									
	Intelligibility Threshold					Detectibility Threshold				
	NOISE LEVEL IN DBRNC									
	18	33.5	38.5	43.5	48.5	18	33.5	38.5	43.5	48.5
M	−73.3	−59.6	−55.4	−51.0	−45.3	−79.8	−67.6	−62.1	−58.0	−53.4
F	−72.1	−58.4	−54.1	−50.3	−45.0	−80.1	−68.5	−64.0	−60.5	−55.2
Avg.	−72.7	−59.0	−54.8	−50.6	−45.1	−79.9	−68.0	−63.0	−59.2	−54.3

themselves controlled the crosstalk volume for obtaining thresholds. The criterion for intelligibility threshold was "about one sentence being understood."

In general, the results obtained from Experiments I and III agree fairly well with similar data published earlier. For circuit noise levels above 25 dBrnC measured at the line terminals of a 500-type telephone set, the crosstalk threshold increased almost linearly with noise. In the range of 10 to 25 dBrnC, the "threshold versus noise function" was found to be nonlinear. For low noise (below 10 dBrnC) levels, the threshold was found to be almost independent of noise, that is, the slope of the "threshold versus noise function" is almost zero. The data for low noise levels below 10 dBrnC were obtained from a supplementary experiment using six of the trained subjects.

In Experiment II, where primary speech was also introduced into the circuit, the "threshold versus noise function" was also approximately linear for high-noise level. No data were collected for low-noise level. It was also found in this experiment that a 20 dB shift in the primary speech level between −30 and −50 VU did not produce a significant change in the crosstalk threshold; the main variable affecting the threshold was noise. The five threshold values, corresponding to the five primary speech levels, were therefore averaged for each of the five noise conditions. These values were found to be approximately 10 dB higher than the corresponding values obtained in Experiment I where no primary speech was used. Within each experiment, the intelligibility threshold values were approximately 10 dB higher than the corresponding detectability threshold values. Also for the same amount of noise, the detectability threshold in the presence of speech was about the same as the intelligibility threshold in the absence of speech.

In terms of actual threshold values, the present data from Experiment I agreed extremely well with similar data published by Hawkins and Stevens when proper transformations were carried out. Exact transformation of Edson's data for comparison with the present data could not be done for lack of certain information. So the best possible transformation based on available information was carried out. Comparison of the threshold values for "four words or more" intelligibility showed a difference of the order of 2 dB between Edson's 1952 data and the present data. Considering that there were several differences in the experimental conditions, the latter difference seems quite reasonable. Comparison with any other data on similar studies was not possible because enough information was not available for proper transformation of those data.

The intersubject variability in the present data was found to be rather small, the average standard deviation being of the order 2.5 dB. This figure agrees very well with variability figures published by Falconer and Davis for similar experiments.[10] Most other authors did not supply any figures for intersubject variability but in a paper summarizing the results of masking of speech experiments Miller mentioned that in experiments of this type, the variability between subjects is usually very small.[11]

Finally, there is one suggestion about the criterion of intelligibility threshold that should be considered in setting transmission objectives for crosstalk. Intelligibility of "four words or more" has generally been used. Based on the small variability of the present data as discussed in the preceding paragraph, it is however suggested that a more stringent criterion, that is, intelligibility of "one word or more" should be seriously considered. While analyzing the results of the present experiments it was observed that when one word became easily intelligible, quite a few other words were also intelligible with a high frequency, except in rare cases where one particular word was considerably louder than the average speech level.

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APPENDIX A

A.1 *Apparatus Used in Experiments I and II*

The laboratory setup for Experiments I and II is shown in Fig. 8 in the form of a block diagram. A 2-channel tape recorder (A) served as the stimulus source, one channel providing the primary speech in Experiment II and the other channel providing crosstalk. A second tape recorder (B) was used for playing the six anchor conditions. The outputs from the 2-channel tape recorder were passed through two 600 ω attenuators, one for each channel, into a 600 ω mixing pad (C). A white noise generator was connected to one port of this mixing pad through a 1 : 1 bridging coil and a 600 ω attenuator designated as NS. The output of this mixing pad was connected to a standard 500-type telephone set through a McIntosh 10 watt program amplifier (No. 2), a 10-dB pad

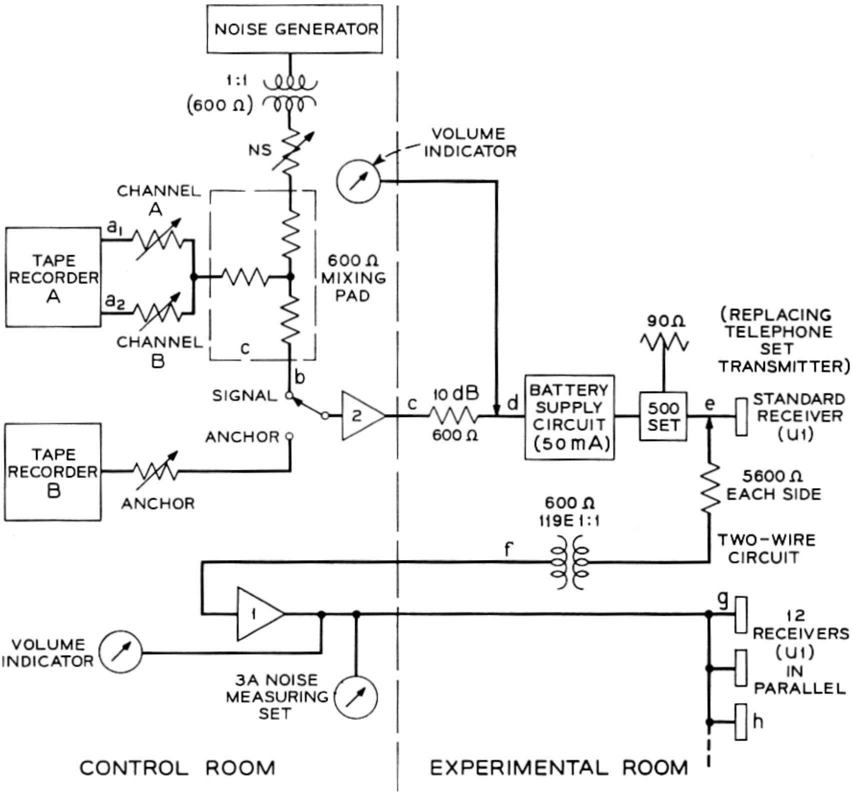

Fig. 8—Laboratory system for crosstalk Experiments I and II.

and a battery supply circuit providing 50 milliamps of current to the telephone set. The transmitter of the telephone set was replaced by a 90 ω resistor and the receiver was connected to 12 other receivers in parallel by means of a bridging arrangement comprising 2 resistors (5,600 ω each), a transformer, and another McIntosh 10 watt program amplifier (No. 1). The purpose of this amplifier was to equate the signal level at each of the 12 receivers with that in the standard receiver. Each one of the 12 parallel receivers (with the associated handset) was located in a separate booth thus permitting testing 12 subjects at a time.

A.2 *Apparatus Used in Experiment III*

The laboratory setup for Experiment III is shown in Fig. 9. This system is a simple version of the one shown in Fig. 8. A tape recorder was used for the crosstalk source. The attenuator termed SUBJECT was a 600 ω continuously variable attenuator which the subject used for

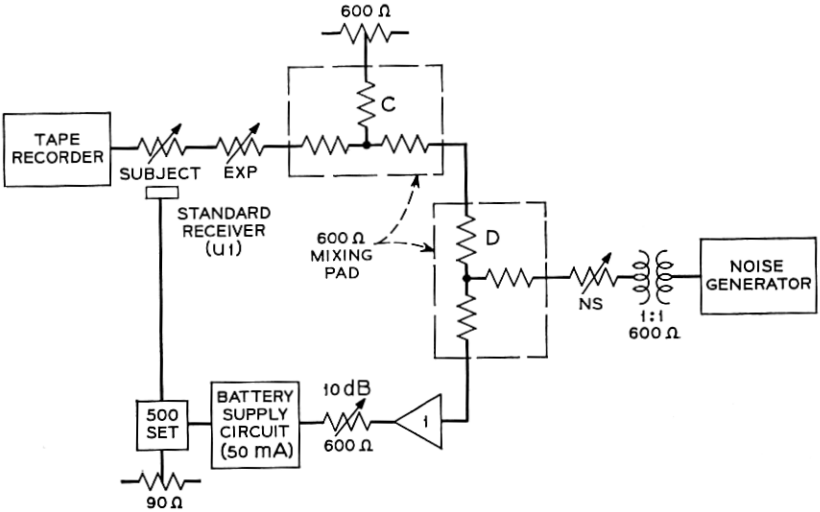

Fig. 9—Laboratory system for crosstalk Experiment III.

adjusting the crosstalk speech level. The attenuators termed EXP and NS were 600 ω attenuators which were under the control of the experimenter. The 600 ω mixing pad (C) was retained in the circuit so that primary speech could also be introduced if wanted. When no such primary speech was used, one port was terminated with a 600 ω resistor. The output of the mixing pad (C) was passed through a similar mixing pad (D) one side of which was connected to a white noise generator through a 600 ω attenuator termed NS and a 1 : 1 bridging coil since the noise generator was unbalanced.

A.3 *Frequency Response of the Experimental System*

Figure 10 presents the frequency response curve of the experimental system used in Experiments I and II. A graphic level recorder was used to plot this electrical to acoustic response of the system. The output of the oscillator was fed to channel A attenuator as shown in Fig. 8. Both A and B attenuators were set at high values and the input to the noise attenuator was terminated in 600 ω. Figure 10 shows the result from receiver No. 6 which had the average sound pressure level of all the 12 receivers used in the experiments. Results from other receivers were similar. The level recorder was plugged into the recorder jack of a B&K amplifier. The calibration was made at 1000 Hz point to correspond to the sound pressure level obtained for No. 6 receiver. The

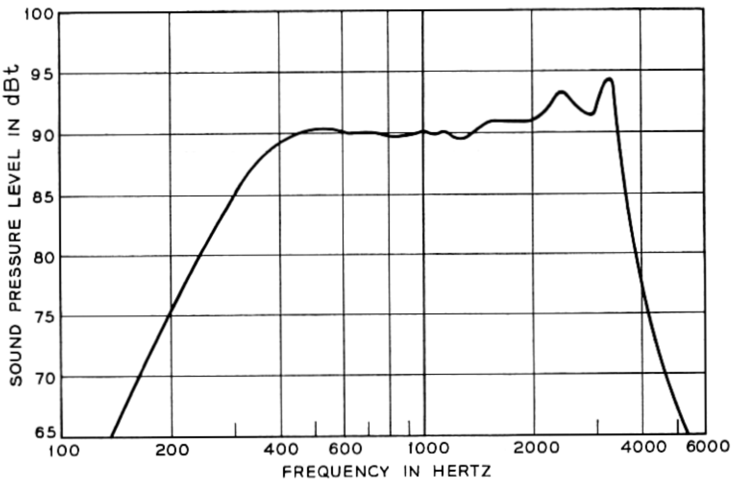

Fig. 10—Frequency response curve of the Laboratory system used in Experiments I and II.

frequency response of the system used in Experiment III was found to be similar.

A.4 *Calibration Data of the Experimental System*

Table IV presents the calibration data for the laboratory system used in Experiments I and II. A calibration tape was used for the bridging and terminated measurements. The input to the noise attenuator was terminated in 600 ω and A&B attenuators were set at 0 dB.

A.5 *Receiver Calibration*

Table V presents the receiver calibration data in terms of dB SPL values. The sound pressure levels (SPL in dB) of the receivers used in

Table IV—1000 Cycle Calibration Figures for the Laboratory System Shown in Figure 8

Location in the System	600 ω Termination*	Bridging*
a_1	−7 dBO†	−12 dBO
a_2	−7 dBO	−12 dBO
b	−18 dBO	−18 dBO
c	+2.5 dBO	+2.5 dBO
d	−7.5 dBO	−7.5 dBO
e	—	−19.5 dBO
f	−46 dBO	−45.5 dBO
g	—	−19 dBO

* A VU-meter was used to measure the levels of the 1000 Hz tone.
† dBO corresponds to .775 volt.

TABLE V—RECEIVER CALIBRATION DATA

Receiver No.	dB SPL
1	101.9
2	102.9
3	102.9
4	103.2
5	102.4
6	102.7
7	102.5
8	103.1
9	102.6
10	102.5
11	102.7
12	102.8
Standard Receiver	103.2

Note: The overall 250-3000 Hz variation of all the receivers relative to the standard receiver was within ± 1 dB.

Experiments I and II were determined by using an Artificial Ear system. A 1000 Hz calibration tone was used. Its level was −7.5 dBo at the point d in Fig. 8. The attenuators A and B were set to zero and the noise input was terminated in 600 ω. The standard receiver refers to the one shown in Fig. 8.

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