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TRANSMISSION OF BACKGROUND CONVERSATION BY THE TA-341 TELEPHONE--ETC(U)
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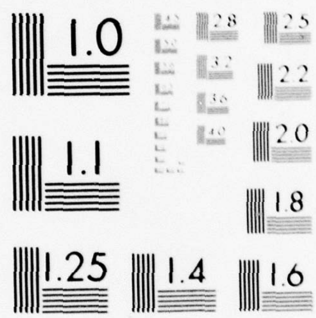
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Technical Memorandum 10-78

# TRANSMISSION OF BACKGROUND CONVERSATION BY THE TA-341 TELEPHONE SET: THE PROBLEM AND PROPOSED SOLUTIONS

James C. Geddie
Joel T. Kalb



April 1978
AMCMS Code 612716.H700011



U. S. ARMY HUMAN ENGINEERING LABORATORY
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

| REPORT DOCUMENTATION PAGE | | READ INSTRUCTIONS BEFORE COMPLETING FORM |
|---|---|---|
| 1. REPORT NUMBER (14) HEL-TM-<br>Technical Memorandum 10-78 | 2. GOVT ACCESSION NO. | 3. RECIPIENT'S CATALOG NUMBER |
| 4. TITLE (and Subtitle) (6)<br>TRANSMISSION OF BACKGROUND CONVERSATION BY THE TA-341 TELEPHONE SET, THE PROBLEM AND PROPOSED SOLUTIONS. | | 5. TYPE OF REPORT & PERIOD COVERED (9)<br>Final rept., |
| | | 6. PERFORMING ORG. REPORT NUMBER |
| 7. AUTHOR(s) (10)<br>James C. Geddie<br>Joel T. Kalb | | 8. CONTRACT OR GRANT NUMBER(s) |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS<br>U.S. Army Human Engineering Laboratory<br>Aberdeen Proving Ground, MD 21005 | | 10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS<br>AMCMS Code 612716.H700011 |
| 11. CONTROLLING OFFICE NAME AND ADDRESS | | 12. REPORT DATE (11)<br>Apr[redacted]78 |
| | | 13. NUMBER OF PAGES<br>28 |
| 14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) | | 15. SECURITY CLASS. (of this report)<br>Unclassified (12) 32p. |
| | | 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE |

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Voice Communications
Speech Security
Telephone Security
Noise Attenuation
Noise Cancelling Microphones
Communication Security
Dynamic Expansion
Program Expander
Speech Intelligibility
Voice Operated Relay (VOX)
Push-to-Talk Switch
Acoustics
Human Factors Engineering

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this experiment was to examine the degree to which the TA-341 telephone set picks up background conversation and to test some alternative handset and headset configurations to determine whether hardware either currently in use by the Army or other commercially available equipment could offer a practical solution to the problem. Eight passive devices were examined in detail and were evaluated in terms of their ability to reject backgrouud conversation without affecting the intended communication. None proved successful. Therefore, an active device—an electronic program expander (EPEX)—was built and tested. It demonstrated
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20. ABSTRACT (Continued)

a high degree of success in meeting the requirements against which the passive devices had been tested. Details both of the operational characteristics and of the circuit design of EPEX are reported.

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# TRANSMISSION OF BACKGROUND CONVERSATION BY THE TA-341 TELEPHONE SET: THE PROBLEM AND PROPOSED SOLUTIONS

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## ACKNOWLEDGEMENTS

We gratefully acknowledge the technical guidance and advice provided by Mr. Georges Garinther and Mr. Harold Forst, assistance in data collection from Ms. Nancy Dukes, photographic support from Mr. Bill Nemeth and logistic help in obtaining subjects for the experiment from SFC Lloyd Hanna.

## CONTENTS

## TRANSMISSION OF BACKGROUND CONVERSATION BY THE TA-341

## TELEPHONE SET: THE PROBLEM AND PROPOSED SOLUTIONS

### INTRODUCTION

The telephone set TA-341 is a field telephone which is used in tactical operations centers (TOC) at division level and above. Reports from users in the field indicate that it is a sensitive, effective device for voice communications. However, its acoustic sensitivity poses a problem for its users (4). The telephone effectively transmits not only the intended conversation, but background conversations as well. Any conversation being conducted in the vicinity of the telephone is likely to be picked up and transmitted intelligibly over the telephone through nonsecure lines to another station, or possibly to an intercept anywhere on the line. Since discussions in the TOC frequently concern classified and otherwise sensitive information, this tendency to pick up and transmit background conversations poses a security problem.

Users have been aware of this problem for some time and it was examined by Garinther (1975). He responded to a request for assistance by testing the telephone set and proposed several possible solutions to the problem. Among the solutions discussed were:

a. Changing the standard operating procedure (SOP) so that security conversations were not conducted near the telephone.

b. Installing a push to talk (PTT) switch.

c. Installing an attenuation cup.

d. Reducing the gain of the telephone.

e. Adding masking noise in the room.

f. Installing a threshold gating circuit (VOX).

Garinther's data were collected by using a series of phonetically balanced (PB) monosyllabic word intelligibility tests. This test was selected because it is an American National Standard Test which has been widely used and is most discriminating in the moderate to high intelligibility region.

It has been the judgment of users that solution a is not practical. The results of Garinther's test indicated the following concerning the other proposed solutions.

- Solutions b and f would solve the problem while the phone was unattended, but background conversations could still be picked up while the phone was in use.

- Solutions c and d require reducing the gain or attenuating the signal by 42 dB (limiting the transmitted level of the primary conversation) to reduce intelligibility of the background talker below 25 percent with the phone located 1 meter from the speaker.

● Solution e required a masking level of 58 dB to reduce intelligibility of the background speech to 65 percent. Since a PB word intelligibility of 75 percent will provide approximately 98 percent sentence intelligibility, this reduction appears insufficient.

The purpose of the present experiment is to examine the degree to which the TA-341 picks up background conversations and, using this as a baseline, to test some other alternative equipment to determine whether other hardware in the Army's inventory or other commercially available equipment can offer a practical solution to the problem.

The equipment considered here includes:

a. the TA-341 telephone set

b. the TA-341 with a noise cancelling microphone installed

c. the TA-838 telephone set

d. the TA-938 telephone set

e. the TA-312 telephone set

f. the H-189 handset

g. the H-161 handset

h. the TA-341 with a leaded vinyl attenuator attached to the mouthpiece.

## METHOD

This experiment assessed the relative degree to which various communications handsets and headsets in present or planned use by the Army tend to transmit intelligibly background conversations.

The intelligibility tests were conducted using the American National Standard Institute (ANSI) Phonetically Balanced (PB) Intelligibility Test. The test material consists of 20 lists of 50 phonetically-balanced words each. Each list is of approximately the same difficulty. The talker reads the words in a "carrier sentence" at 6-second intervals and the listener writes down each key word. The intelligibility of a device is determined by the proportion of words correctly understood.

### Subjects

Subjects in the experiment were six male soldiers from a company of Soldier/Operator/Maintainer Test and Evaluation Troops assigned to the Materiel Test Directorate at Aberdeen Proving Ground. Their ages ranged from 19 through 28 years and ranks from E-2 to E-5 with a median service time of 2 years, 8 months. The median education level was 12 years (high school). None reported any known hearing loss and all subjects were screened for auditory acuity on the TRACOR Rudmose RA-206 audiometer. None had a hearing loss greater than 5 dB over the range from 500 to 4,000 Hz.

Apparatus

1. Intelligibility Testing

Tape recordings of the PB word lists were made through each handset while mounted on an artificial head (Figure 1). The source of the lists was a loudspeaker which had been equalized to produce a flat spectrum and was located 2 meters from the handset with the head facing the loudspeaker. The long term average sound pressure level of the PB words measured at the handset was 65 dB(A) which represents the normal vocal effort of a background talker at a distance of 1 meter. The lists, which were recorded in an anechoic chamber, were then played back to the subjects to determine the relative intelligibility of each headset.

A calibration signal was placed on each tape recording using an artificial voice (B&K 4215) placed 2.5 cm from the headset receiver. This calibration signal was a 1 kHz tone and produced 95 dB at the receiver which is the average sound pressure level of a telephone user at the receiver. The output of each telephone was measured in dBm (referenced to 0.775 volts) for each test tone and is listed in Table 1.

TABLE 1

Electrical Characteristics of the Test Items

| Test Item | Background Speech Level at Headphones (dB) | Telephone Output with Calibration Tone Input (dBm) | Gain Required to Equalize Phone Outputs (dB) |
|---|---|---|---|
| 1. TA-341 | 30 | -14.0 | 0 |
| 2. TA-341/Mod | 24 | -22.5 | 8.5 |
| 3. TA-838 | 25 | -13.7 | -0.3 |
| 4. TA-938 | 25 | -18.2 | 4.2 |
| 5. TA-312 | 31 | -32.7 | 18.7 |
| 6. H-189/TA-341 | 24 | -43.0 | 39.0 |
| 7. H-161 | 24 | -28.1 | 14.1 |
| 8. TA-341/LM | 15 | -14.0 | 0 |

The intelligibility tests were conducted with the subjects seated in an anechoic chamber to minimize distractions from external noise (Figure 2). The word lists recorded for each handset were played back through a decade attenuator to a cushioned headset (Roanwell headset with type 10357 telephone receivers-Air Force Stock Number 5935).

During playback, the calibration tone recorded for each handset was always adjusted to an output level of 0 dB VU which corresponded to a level of 14.5 dBm into the attenuator.

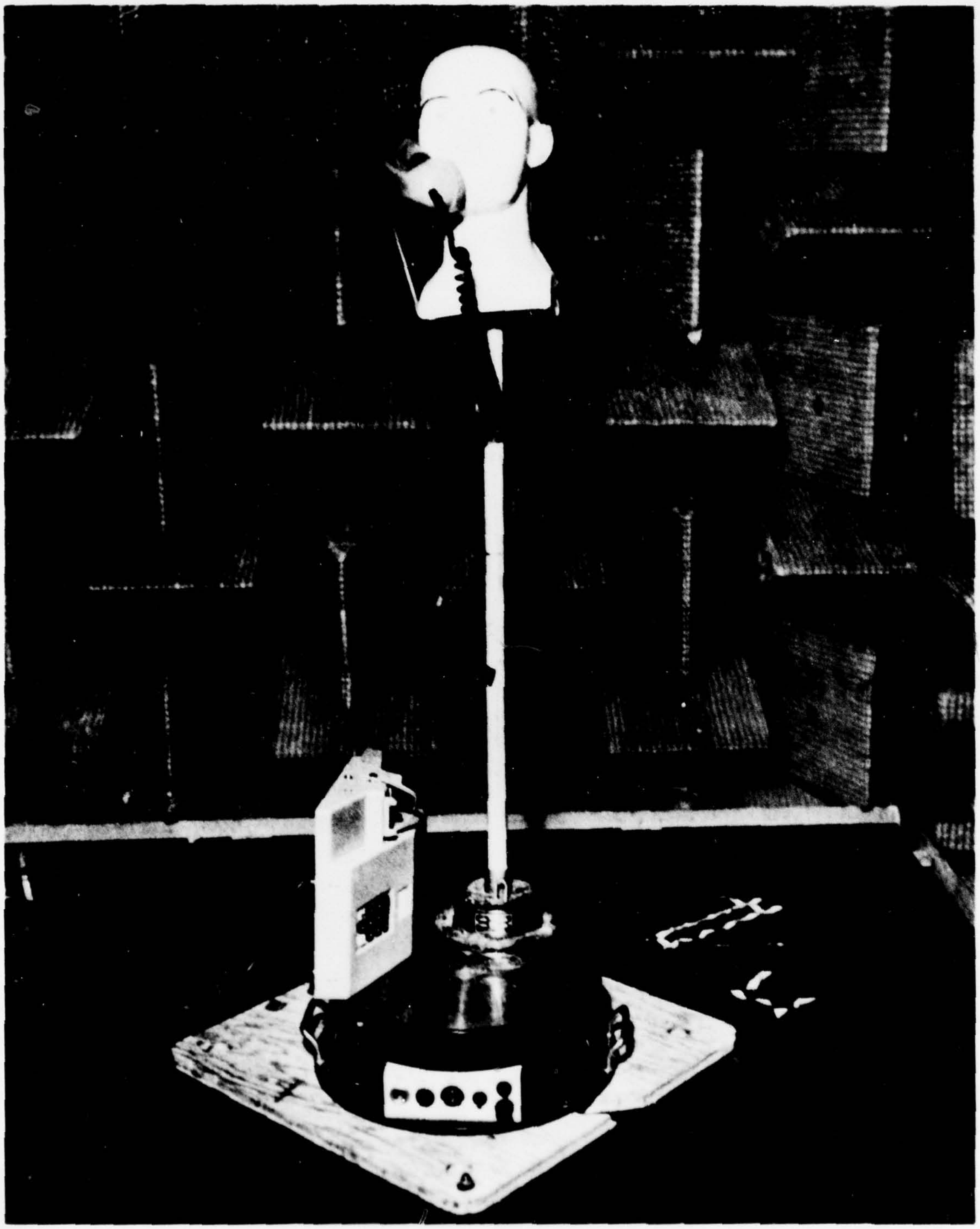

Figure 1. TA-341 telephone set prepared for directional sensitivity measurement.


Figure 2. Subject in the testing situation.

Prior to conducting the test, it was subjectively determined to set the attenuator at 50 dB in order to provide a moderately difficult listening level thereby producing intermediate test scores. The reason for this procedure is further discussed in the 50 dB attenuation Section under DISCUSSION. The actual sound pressure level produced by each telephone at the listener's ears by the PB words was then measured with an artificial ear (B&K Type 4151) and the results are presented in Table 1.

2. Directional Sensitivity of the Test Items

In order to characterize the tendency of a telephone to receive background conversation from different directions, directional sensitivity was measured. These tests were conducted in an anechoic chamber by positioning each telephone handset on an artificial head which was rotated 2 meters in front of a loudspeaker (Figure 1). Rotation was about a vertical axis passing through the telephone mouthpiece with the 0 degree position defined by the head facing the loudspeaker. The head, which was located on a turntable, was rotated synchronously with polar graph paper on a B&K 2305 Graphic Level Recorder.

Pink noise (spectral level slope of -3 dB/octave) was equalized by a B&K spectrum shaper to produce a flat frequency response on one-third octave bands centered at 500, 1000, 2000 and 4000 Hz (Figure 4A in Appendix A). To prevent overlapping of the traces on the polar graph paper, the four frequency plots were started 5 dB apart at the 0 degree position. This position provided a reference sensitivity to compare with the sensitivities at other directions for each of the four frequencies. These reference values at the 0 degree position of the head were then measured for each phone and are shown plotted in Figure 3A in Appendix A. These measurements when taken together show which telephones are the most sensitive for a given direction and frequency for a background talker.

## Procedure

Upon arrival, subjects were given a brief explanation of the agenda for the day and were escorted to the auditory testing booth for screening.

Following the hearing test, they were briefed on the background of the problem, the reason for the test and their role in the experiment. The instructions included assurances that while it was important that they perform as well as possible on the task, only the hardware was being tested and not their hearing, or spelling, or any other ability. Subjects then filled out a personal data collection form. The results were given in the Subjects section.

A PB word list was presented over the headset at a level of 65 dB for familiarization and subjects were asked to copy down the words as practice. All subjects correctly received 100 percent of the words during the familiarization run.

Subjects were then offered an opportunity to ask any questions they had about the experiment and the data collection began.

Subjects were escorted into the anechoic chamber and were seated so that they could not see each other. They were asked to be as still and as quiet as possible in order to concentrate on the word lists and to avoid distracting each other.

Data were collected using two subjects at a time, but the order of presentation of devices was randomized so that the devices presented were usually different for the two subjects.

The 50-word lists were started simultaneously for the two subjects and finished within a few seconds of each other. During each session, two lists were presented to each subject without interruption. This amounts to approximately 10 minutes per session. Subjects were given a 10-minute break between sessions to avoid fatigue effects.

At the conclusion of the data collection, subjects were invited to ask any other questions they had, were thanked for their cooperation, and were released.

### Experiment Design and Analysis

The dependent variable in this experiment was the number of PB words correctly copied from each presentation of a 50-word list. The independent variable was the test item. All word list/test item combinations were presented to each subject, and in order to control other effects such as fatigue and learning, the order of presentation was randomized for each subject.

A completely randomized analysis of variance (3) of words correctly copied was performed as an overall test for significance of differences among test item means. Tukey's Honestly Significant Difference (HSD) was the test statistic used to evaluate significance of differences between mean numbers of correctly copied PB words for each test item.

## RESULTS

### Analysis of Variance

The overall analysis of variance of the number of PB words correctly copied is presented in Table 2. The F test significant at the .01 level indicates that some set of orthogonal comparisons among means is also significant.

TABLE 2

Analysis of Variance of PB Words Correctly Copied
(Across All Test Items)

| Source | SS | df | MS | F |
|---|---|---|---|---|
| 1. Between Groups | 5951.8 | k-1 = 7 | 850.26 | $[\frac{1}{2}] = 16.777^*$ |
| 2. Within Groups | 6824.2 | N-k = 124 | 50.679 | |
| 3. Total | 12236 | N-1 = 131 | | |

$^*p<.01$

## Pairwise Comparisons

Tukey's Honestly Significant Difference (HSD) was the test used for pairwise comparisons. As indicated in Table 3, item 8, the TA-341 with the leaded vinyl mask has statistically significantly lower scores than item 1 (the TA-341) or item 2 (the TA-341 plus noise-cancelling microphone). These differences, therefore, have a probability of less than .01 of occurring by chance, if the means were sampled from the same population. However, it must be remembered that an attenuation of 50 dB has been introduced into the signal. Removing that attenuation restored all devices–including the TA-341/LM–to essentially 100 percent intelligibility. Therefore, unless one is willing to accept a substantial (up to 50 dB) attenuation of the primary talker's speech, the differences, although statistically significant, are not practically significant.

The absence of other significant comparisons indicates that, at the .01 level of significance, the other differences are not above chance level.

# DISCUSSION

## The 50 dB Attenuation

As indicated above, it was noted in preliminary runs that when the word lists were played into the cushioned headphones at the same level as produced by the telephones during the recording, the percentage of words correctly copied was close to 100 percent for all devices. This result would also be obtained in the telephone network provided the listener was in quiet surroundings and was able to amplify the background speech to intelligible levels. This procedure is only limited by the electrical noise present in the telephone system which would also be amplified along with the background speech.

In order to increase the sensitivity of our measurements to the differences in intelligibility which may exist among the devices, a constant attenuation of 50 dB was introduced. This allowed measurements in a region of the function relating speech sound pressure level and intelligibility at which a small difference in speech level produces a relatively larger change in word intelligibility as indicated in Figure 3.

## Push to Talk (PTT) Switches

The PTT switch mentioned earlier as a possible solution to the problem would be completely effective in eliminating background conversation if the talker were able to operate the switch rapidly enough to insure that the microphone could transmit only during the primary conversation. But therein lies its most serious limitation. A typical practice when using a field telephone equipped with a PTT switch is to conduct the entire conversation–including talking and listening–with the switch depressed. This practice defeats its security value during conversation.

Even when the talker releases the switch at the end of each transmission, background conversation during the transmission is picked up. No talker can operate the switch quickly enough to eliminate intersyllable background speech, and during the stress of a rapidly changing tactical situation may not remember to release the switch at all during a conversation.

## TABLE 3

### Comparison Among Means of Test Items

$$HSD = q_{\alpha\gamma}\sqrt{\frac{MSerror}{n}}$$

$$HSD_{.01} = 5.12\sqrt{\frac{50.679}{2}} = 25.77$$

TA341 : $\overline{X}_1 = 38.04$
TA341/M : $\overline{X}_2 = 32.67$
TA838 : $\overline{X}_3 = 32.63$
H189 : $\overline{X}_4 = 33.00$
TA312 : $\overline{X}_5 = 32.50$
TA938 : $\overline{X}_6 = 36.50$
H161 : $\overline{X}_7 = 23.42$
TA341/LM: $\overline{X}_8 = 9.25$

DIFFERENCES AMONG MEANS

| | $\overline{X}_1$ | $\overline{X}_6$ | $\overline{X}_4$ | $\overline{X}_2$ | $\overline{X}_3$ | $\overline{X}_5$ | $\overline{X}_7$ | $\overline{X}_8$ |
|---|---|---|---|---|---|---|---|---|
| $\overline{X}_1$ | — | 1.54 | 5.04 | 5.37 | 5.41 | 5.54 | 14.62 | 28.79* |
| $\overline{X}_6$ | | — | 3.50 | 3.83 | 3.87 | 4.00 | 13.08 | 25.25* |
| $\overline{X}_4$ | | | — | .33 | .37 | .50 | 9.58 | 23.75 |
| $\overline{X}_2$ | | | | — | .04 | .17 | 9.25 | 23.42 |
| $\overline{X}_3$ | | | | | — | .13 | 9.21 | 23.38 |
| $\overline{X}_5$ | | | | | | — | 9.08 | 23.25 |
| $\overline{X}_7$ | | | | | | | — | 14.17 |
| $\overline{X}_8$ | | | | | | | | — |

*p<.01

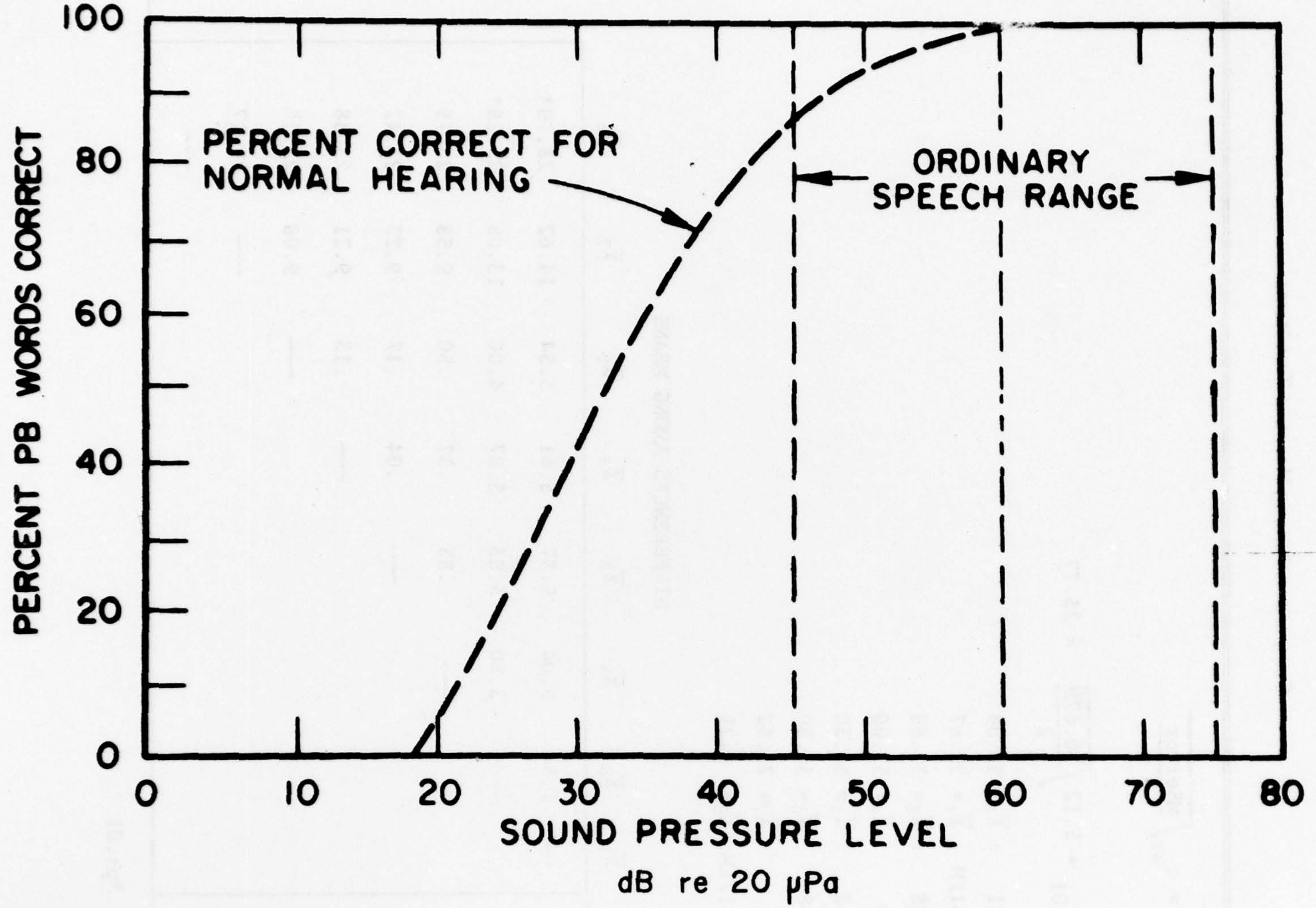


Figure 3. Relationship between speech level and intelligibility. After Davis (1948).

The clear need is for a signal processing device which can eliminate background conversation without affecting the intended communication—and do this on a very short time base with no additional requirement placed on the user.

## Electronic Program Expander (EPEX)

None of the above discussed devices were able to meet the need for a way of sharply attenuating or eliminating background conversations without degrading the intended communication. Therefore, consideration was given to designing an electronic device which would provide the required attenuation automatically when an individual was not talking and—more critically—between words and some syllables of telephone users' speech. The resulting electronic program expander (EPEX) was built and tested.

The EPEX design is based upon the use of a light emitting diode and a photoresistor to attenuate "instantaneously" signals below a certain criterion level, thus effectively blocking background conversations during pauses in the intended communication. Initial attempts to test the device in the same way the other test items were evaluated were unsuccessful. The EPEX reduced the signal level of background conversations not just below intelligibility, but below detectability—without degrading the intended communication. It was, in other words, so completely effective under the condition of the experiment that the background speech level was unmeasurable.

More detailed information concerning EPEX and its performance and operating parameters and requirements is presented in Appendix B.

# CONCLUSIONS

The data collected in this experiment indicate that the intelligibility differences of background talkers for the various handsets and headsets tested are not judged to be of practical significance. Also, the directivity patterns for these items do not provide characteristics which sufficiently reduce the intelligibility of a background talker.

An additional observation relative to the TA-341/LM should be mentioned. In trying to talk with this device, a good seal between the vinyl cup and the talker's face is needed. But when he talks, pressure builds up in the cup, inevitably breaking the seal and interfering with speech. In addition, a problem is posed for users with a mustache or beard in even achieving a seal, not to mention maintaining it.

The electronic program expander described in this report eliminates most of the speech of a background talker so that it could not be picked up and transmitted intelligibly over nonsecure telephone lines, and merits further consideration both for inclusion in the design of future telephone sets and as an applique for sets currently in use.

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## APPENDIX A

## DETAILS OF TEST ITEMS

## DETAILS OF TEST ITEMS

### TEST ITEMS

The following communications devices were compared in this experiment on their sensitivity to background conversations:

a. The TA-341 was evaluated in the same configuration in which it is used in the field.

b. The TA-341 was also evaluated with its microphone replaced by the Roanwell Confidencer C-505D (Figure 1A).

c. The TA-838 telephone set is the item planned to replace the TA-341 in the Army's inventory. Its acoustic response appears to be identical to that of the TA-341.

d. The TA-938 is a commercial, non-militarized version of the TA-838.

e. The TA-312 is a field telephone in very wide, high density use in the Army.

f. The H-189 handset is the standard handset for the Army's current family of tactical FM radios. It was included because it is a high density item and might be adaptable to landline use. Since it is not a complete telephone set, it was used with a separate amplifier in the experiment.

g. The H-161 is the headset used by armor crewmen. It is designed to cancel background noise and was used with a separate amplifier.

h. The standard TA-341 telephone was fitted with a leaded vinyl attenuator cup attached to its mouthpiece (Figure 2A).

### DIRECTIONAL SENSITIVITY

Spectra for a 0 degree (or head facing speaker) position are shown plotted on two identical sets of axes in Figure 3A. On the right are the TA-341 and its modifications while the left includes the four alternate phones. The vertical scale is in dB units arbitrarily chosen so that 0 dB represents the highest measured spectrum level for any phone (at 2 kHz for the TA-938). The TA-341, TA-838, and TA-938 are the most sensitive phones and have nearly the same frequency response to background sounds. The TA-312 and TA-341/Mod have a similar frequency response to the TA-341 but are about 10 dB less sensitive. In the latter case, this may be due to inadequate gain in the modification element (Roanwell Confidencer microphone with amplifier) when installed in the TA-341. Quite different spectra occur in the TA-341/LM and H-161. In the first case, the lead vinyl mask shields the TA-341 microphone from the higher speech frequencies by 15 dB. In the case of the H-161, the response at 4 kHz is nearly the same as for the TA-341 while the 15 dB reduction in the lower speech frequencies results from phase cancellation of the longer wavelength sounds by the noise canceling microphone. The TA-341/H-189 response was reduced 20 dB for all frequencies because the microphone signal from the radio transmitter type microphone was insufficient to drive the TA-341 amplifier for full output.

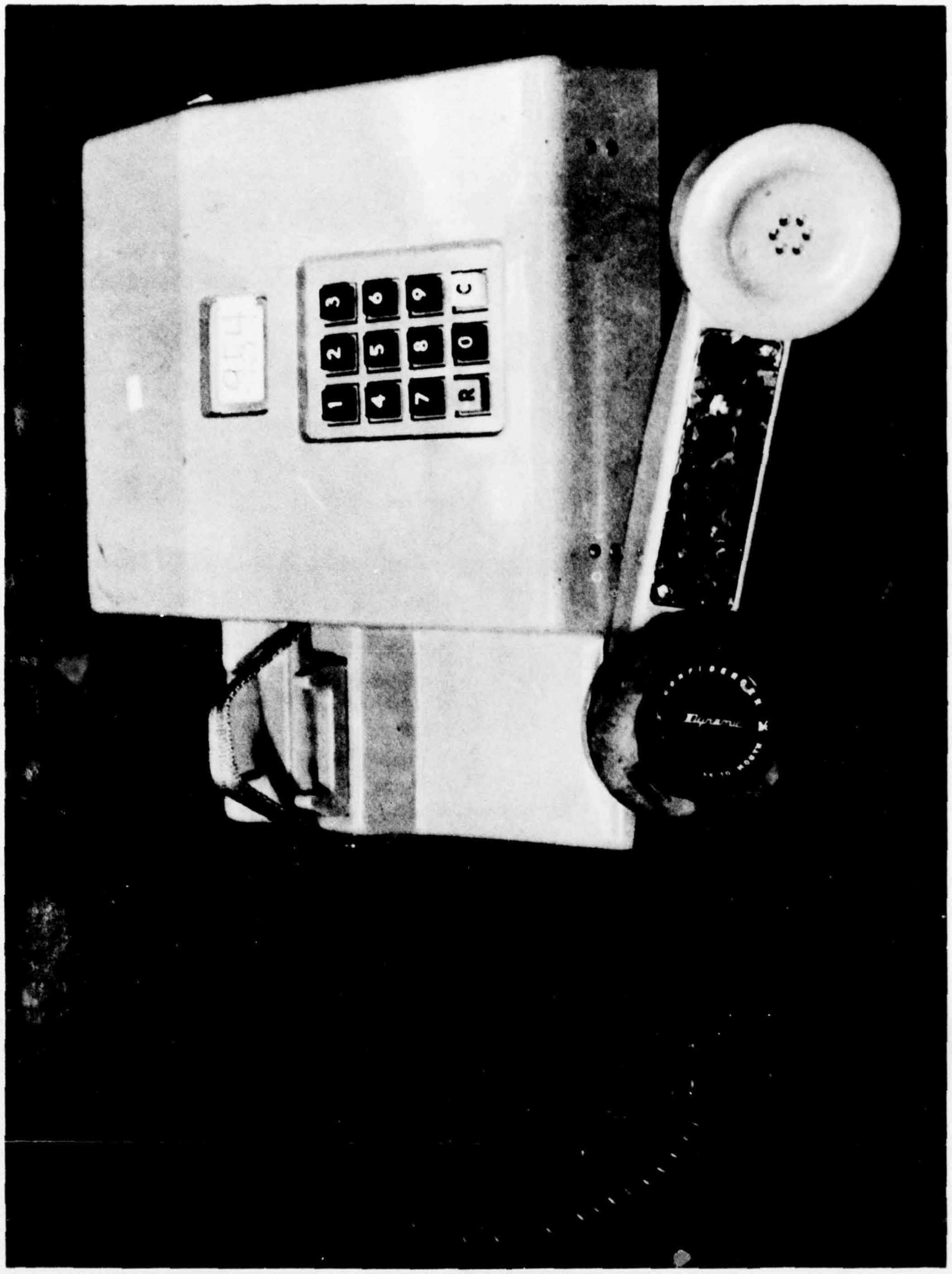


Figure 1A. TA-341 with noise canceling microphone.


Figure 2A. TA-341 with leaded vinyl mask.

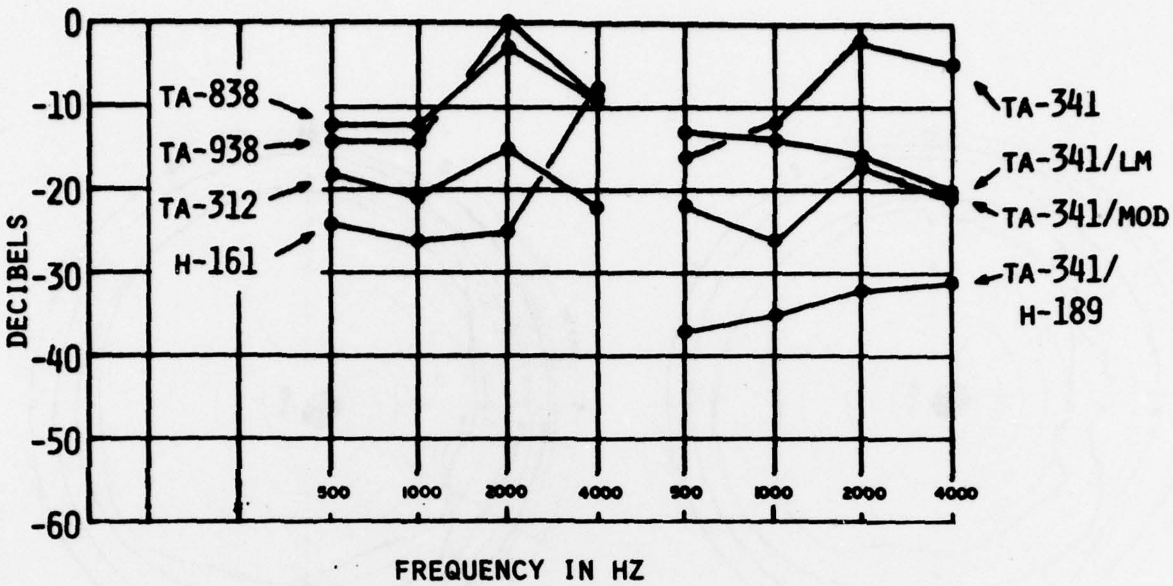


Figure 3A. Sensitivity of telephones at four frequencies.

The directional plots for the telephones are also shown in Figure 4A. Most of the phones received 500 Hz and 1 kHz equally well from all directions and discriminated against the higher frequenices by 10 dB in those directions for which the head shielded the microphone. The H-161 showed a more pronounced directional sensitivity of 10 dB at the lower frequencies and a 20 dB variation at 4 kHz probably due to cancellation between sound waves arriving at the microphone after traveling different paths around the head.

These variations in sensitivity with frequency and direction are insignificant in comparison with signal variations resulting from different background talker locations and the reflected sound paths present in enclosures.

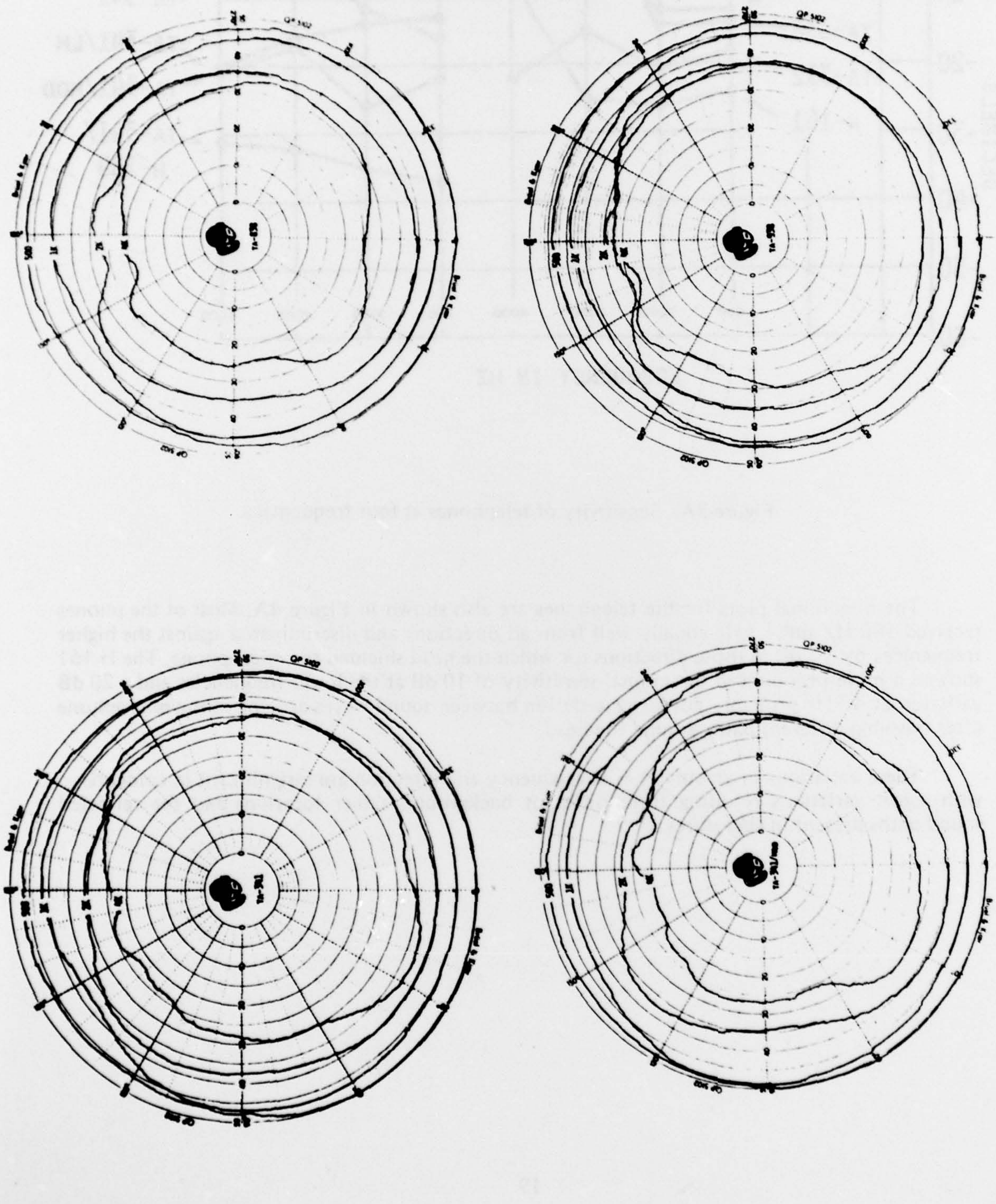

Figure 4A. Directional sensitivity of telephones (part 1).

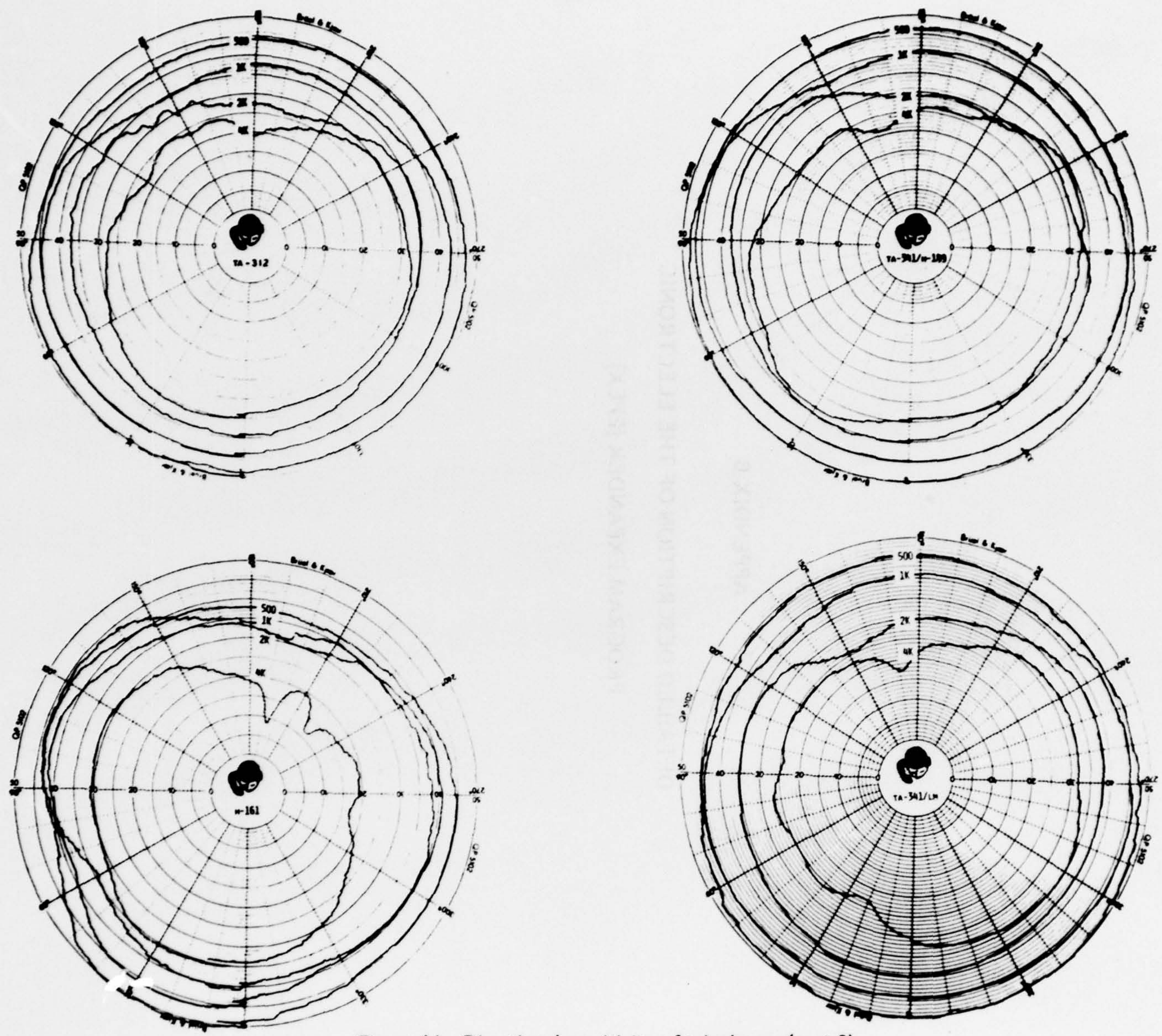


Figure 4A. Directional sensitivity of telephones (part 2).

APPENDIX B

DETAILED DESCRIPTION OF THE ELECTRONIC

PROGRAM EXPANDER (EPEX)

# DETAILED DESCRIPTION OF THE ELECTRONIC PROGRAM EXPANDER (EPEX)

## EPEX PERFORMANCE AND REQUIREMENTS

Similar to the Voice Operated Relay (VOX), an Electronic Program Expander (EPEX) is a signal switching circuit having a threshold level which allows higher level speech signals to pass and lower level signals to be greatly attenuated. The effect of VOX and EPEX on speech is different, however, because the VOX relay is a mechanical device having a relatively long activation time (on the order of 10 msec) while the electronic EPEX responds within 10 $\mu$sec after the speech exceeds threshold level; hence, the EPEX transmits more of the attack of initial speech syllables. Another difference occurs when the speech falls below the threshold level between words. The VOX remains fully on and background sounds can be heard. This persistence time is usually on the order of a second, so that a number of background words would be understood during speech pauses. Shortening the persistence time leads to undesirable interruptions of speech and background noise as well. In contrast, the EPEX begins to attenuate with a decay rate of 8.7 dB for every 35 msec as soon as the speech ends. Since nearly 20 percent of ordinary conversational speech is silence, speech is absent 200 msec out of every second so the EPEX would start attenuating six times per second (200 msec/35 msec). The result is a rapid quieting of the background noise between words without a loss in intelligibility of the user's speech.

The EPEX can be installed in the signal path either internally to the phone or externally between the transmit terminal and the send wire of the 4-wire telephone connection. The supply voltage must be at least 8.2 volts but not more than 30 volts; the TA-838 has an acceptable 30-volt supply but the TA-341 has only a 6-volt supply so that a DC-to-DC converter circuit would be needed to power the EPEX. The current required by the circuit is 15 ma which is negligible compared to that used by the telephones.

Figure 1B shows the attenuating action of the EPEX for a situation where the average speech level is 95 dB for the telephone user and 65 dB for the background talker who is 1 meter away. For the typical talker, the speech signal varies over a 30 dB range between speech maxima which are exceeded only 10 percent of the time and speech minima which are exceeded 80 percent of the time. In this situation there is negligible speech signal overlap and the EPEX threshold setting of 10 dB in this signal region will allow the user speech to be transferred while blocking the background speech.

While the situation in Figure 1B assumes two average talkers, more extensive speech signal overlap is possible for a louder than average background talker and a weaker than average telephone user. Average levels in speech can vary by $\pm$ 10 dB. This would not occur in practice, however, because the telephone user would literally not be able to hear himself talking over the telephone since the two speech levels would be nearly the same. He would consequently, either talk louder or else ask the loud background talker to speak more softly.

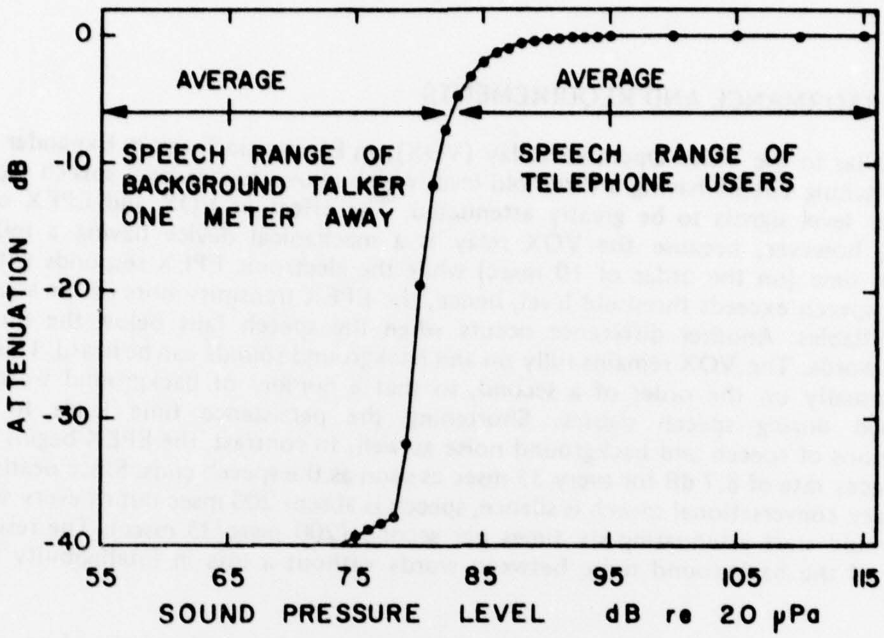


Figure 1B. Attenuation function for EPEX.

## EPEX CIRCUIT DESCRIPTION

### Balanced to Single-Ended Input Circuit

This circuit presents a 660 ohm input impedance to the telephone sending terminals (black and green on the four-wire TA-341 telephone set). It simulates an input transformer in that common mode rejection in amplifier 1 (Figure 2B) is 60 dB below 100 Hz and rejects all but differential signals received on the telephone line. The output impedance of the amplifier is very low (<1 ohm) with a large amount of negative feedback and thus presents a very low driving impedance to the light dependent resistor (LDR). This characteristic improves noise immunity.

### Detector - Limiter Threshold Circuit

This amplifier circuit (amplifier 2 in Figure 2A) as well as the LDR is driven by amplifier 1. It is non-inverting for high input impedance, has a variable (1 to 170) gain and a 6 dB/octave roll-off below 75 Hz to avoid amplifying the DC offset voltage of the previous amplifier stage.

$$\text{Gain} = \left(1 + \frac{R}{r}\right) \frac{1 + (\frac{1}{2}\pi f\,[R+r]\,C)^2}{1 + (\frac{1}{2}\pi f\,[RC])}, \text{ where}$$

R - variable resistance

r - constant resistance

C - capacitance

f - frequency

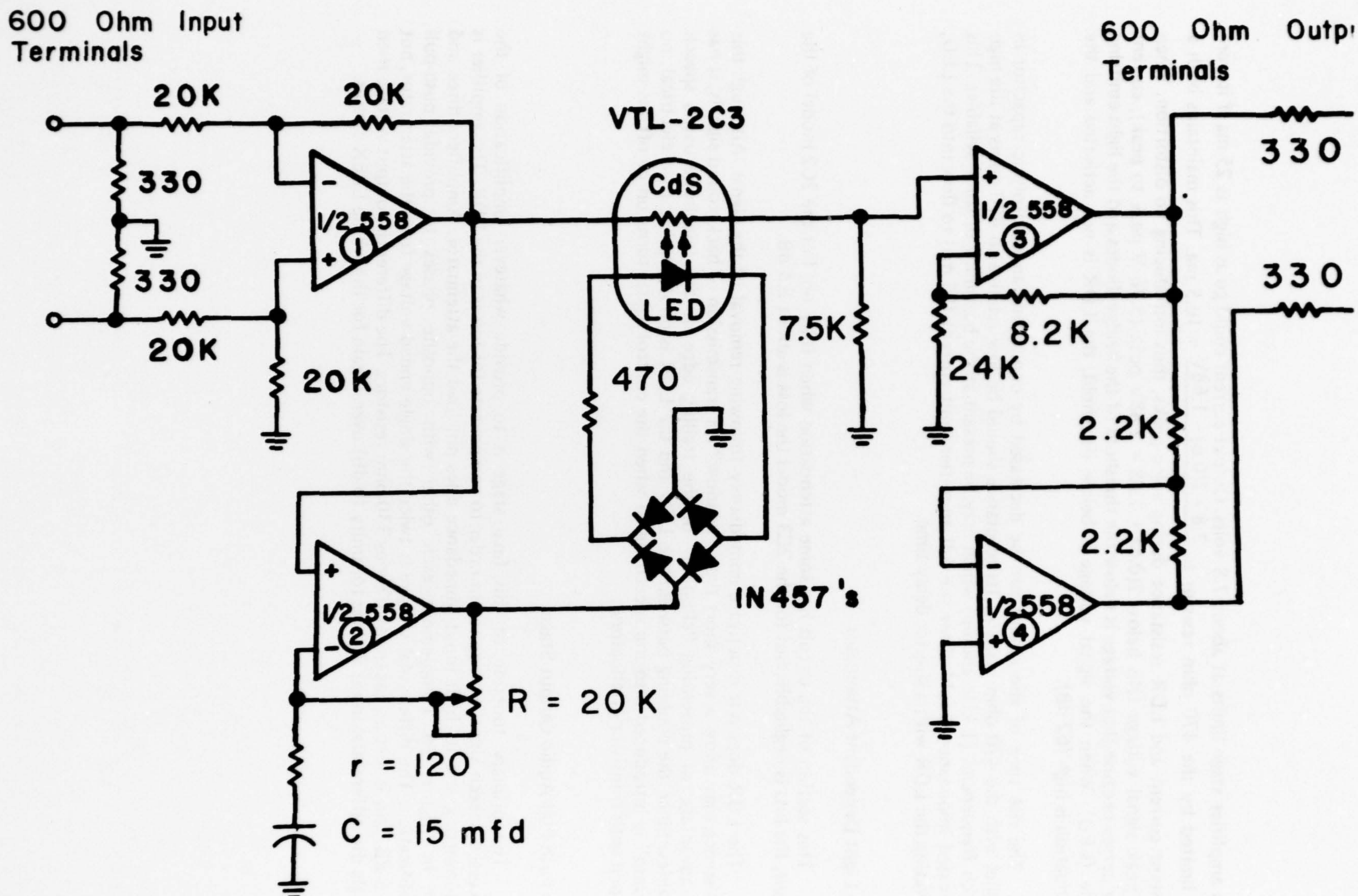


Figure 2B. EPEX schematic diagram.

This amplifier stage limits at about 7.8 volts. Output current could go as high as 25 ma if it were not limited by the 470 ohm resistor to $\frac{7.8 - 2(0.6) - 1.68V}{470}$ = 10.5 ma. This maintains both a constant current and LDR resistance during voice peaks, thus introducing no distortion. When the peak signal voltage falls below 2(0.6) + 1.68 = 2.88V peak (5.76 V peak to peak), current flow ceases because that voltage is below the threshold of the bridge diodes and the light emitting diode (LED). When the signal voltage is below threshold, the LDR is not activated and the attenuation is high (62 dB).

The rise time of the circuit can be decreased by connecting an electrolytic capacitor in parallel with the 470 ohm resistor. Its reactance should be low relative to 470 ohms at the high speech frequencies (1 kHz and up) which may be present at the beginning of some syllables. This decreased impedance would allow the full amplifier limit current (25 ma) to flow into the LED, activating the LDR with a shorter delay time.

## The Light Dependent Attenuator

This section of the circuit has some attenuation when fully on. For the 2C2 model of the circuit, the loss is negligible, but for the 2C3 model the loss is about 2.5 dB.

The LDR does not deactivate immediately following removal of the signal. Although this persistence may allow a very short time "window" for transmission of background signals, it has the advantage of preventing "clipping" of the trailing edge of the telephone user's speech syllables. Since the coupling between the LED and the LDR is photic rather than electrical, no "thump" is introduced into the speech signal when the control signal turns on or off (as might happen with transistor attenuators).

## The Push-Pull Audio Output Stage

The primary function of this final stage is to provide whatever amplification of the processed speech signal is required in order to compensate for losses in the LDR. The amplifier is non-inverting and its high input impedance does not load the attenuator. Amplifiers three and four in Figure 2A complement each other with opposite phases to provide push-pull amplification. The differential voltage is twice the single ended voltage from the attenuator, but the 6 dB gain is lost across the two series 330 ohm resistors. The differential output voltage then equals the differential input voltage for unity (0 dB) overall gain for the whole EPEX circuit.