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# ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO. 223
6 April 1956

## FREQUENCY DISCRIMINATION OF PURE AND COMPLEX TONES*



*Subtask under Psychophysiological Studies, AMRL Project No. 6-95-20-001, Subtask, Psychophysiological Interaction Problems.

RESEARCH AND DEVELOPMENT DIVISION
OFFICE OF THE SURGEON GENERAL
DEPARTMENT OF THE ARMY

Army Medical Research Lab, Fort Knox, Ky.
FREQUENCY DISCRIMINATION OF PURE AND COMPLEX TONES - R. Cramer and L. Zeitlin with the technical assistance of J. Zelnick

Report No. 223, 1 Dec 55 - 9 pp & ii - 2 illus - 2 tables - Project No. 6-95-20-001. Unclassified Report

The ability of subjects to discriminate small changes of frequency of pure and complex tones was investigated. Performance was significantly better in discriminating frequency changes in the middle and low frequency ranges of complex tones than of pure tones. A marked difference in individual ability to discriminate frequency changes was noted.

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# FREQUENCY DISCRIMINATION OF PURE AND COMPLEX TONES*

by

R. Cramer and L. Zeitlin
with the technical assistance of
J. Zelnick

from

Psychology Department
ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY

*Subtask under Psychophysiological Studies, AMRL Project No. 6-95-20-001, Subtask, Psychophysiological Interaction Problems.

Report No. 223
Project No. 6-95-20-001
Subtask AMRL S-5
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# ABSTRACT

## FREQUENCY DISCRIMINATION OF PURE AND COMPLEX TONES

### OBJECT

To compare subject efficiency in discriminating small changes of frequency of pure tones and complex tones, undertaken with a view toward providing more meaningful aural signal displays to the operators of mine detectors and similar equipment.

### RESULTS AND CONCLUSIONS

Utilizing the method of constant stimuli, subjects performed significantly better in discriminating small frequency changes of complex tones (repeated pulses of 15 micro-seconds pulse length) than in discriminating similar frequency changes of pure tones (sine waves). This difference persisted at the 3 base frequencies used, 190, 490 and 990 cycles per second. The superior discriminability of complex tones was attributed to the presence of overtones which made the discrimination task much easier. There was a marked difference in the ability of individual subjects to discriminate frequency change.

### RECOMMENDATIONS

Extension of this investigation to higher frequencies and other complex wave forms. If frequency modulated aural mine detector displays are used, complex wave forms are preferable to pure tones. If such displays are used operators should be selected on ability to discriminate frequency change rather than by conventional auditory testing methods.

Submitted 1 December 1955 by:

R. Cramer, Psychophysiologist
L. Zeitlin, 1st Lt, MSC
with the technical assistance of
J. Zelnick, Pfc

APPROVED: Ray G. Daggs
RAY G. DAGGS
Director of Research

APPROVED: William W. Cox
WILLIAM W. COX
Lt Colonel, MC
Commanding

# FREQUENCY DISCRIMINATION OF PURE AND COMPLEX TONES

## I. INTRODUCTION

At the request of the Engineer Research and Development Laboratories, experiments were designed to evaluate various types of displays for use in mine detection apparatus. The main objectives of this study were 1) to determine the most efficient means for presenting information to the operator, utilizing the existing mine detector heads and apparatus, and 2) to determine the essential characteristics of the signal which enables the operator to distinguish a mine from an anomaly and to develop a means of making full use of these characteristics. The present experiment is the first in a series concerned with comparing the sensitivity of subjects to small frequency changes of 2 types of tones, complex tones (repeated pulses) and pure tones (sine waves).

## II. EXPERIMENTAL

### A. Apparatus

1. Krohn-Hite push-button oscillator: an audio oscillator capable of generating tones from .01 to 99,999 cps. The tones are accurate to 4 significant figures and can be changed quickly from one frequency to another by means of push-buttons. It produces both sine and square waves.

2. Magnicord, tape recorder, Model PT6A, and Magnicord Amplifier, Model PT6J: a professional quality tape recorder and an amplifier with a minimum of flutter, wow and distortion.

3. Jensen Duette, 2-way speaker system: a speaker system capable of handling moderate amounts of power with relatively low distortion. It consists of an 8-inch woofer for low tones and a horn-loaded tweeter for the higher frequencies.

4. Arbitrary Signal Stimulator*: made to the Army Medical Research Laboratory specifications. It consists of a beat-frequency audio oscillator whose frequency can be varied over wide limits by

*Designed and constructed by Mr. Roger France, Engineer Research and Development Laboratories, Ft Belvoir, Virginia.

changing the bias voltage of the variable frequency oscillator feeding into various pulse shaping circuits. The Arbitrary Signal Stimulator is capable of producing a) tones of constant frequency which are amplitude modulated, b) frequency modulated pure tones and c) frequency modulated pulse tones of variable pulse length. For this experiment, only the pulse shaping circuit of this stimulator was used; the input was taken direct from the tape recorder.

5. Sound-Proof Room: approximately 10 x 12 x 8 ft and shielded both acoustically and electrically to minimize the effect of extraneous stimuli.

B. Subjects

Fifteen Army enlisted men served as subjects. Their hearing ability was not tested; however, all had Army Class A profiles and were presumed to have hearing adequate for all military purposes.

C. Method

Two sets of aural displays were presented to 3 or 4 subjects in each session. In one type of display the wave form used to produce the tones was sinusoidal. In the other, the tones were produced by rectangular pulses of 15 micro-second duration. The method of constant stimuli was used.

The stimulus consisted of a sequence of 3 tones. The first and last tones were of the same frequency; the middle tone varied a slight amount upward or downward in pitch. Each tone lasted one second, the entire sequence being 3 seconds long. There was no appreciable time lapse between the presentation of the first, second and third tones. The subject's task was to judge whether the middle tone was higher or lower than the first and third tones. If the subject thought that all of the tones were equal, he was instructed to guess whether the middle tone was higher or lower than the end tones.

The base frequencies selected were 190, 490 and 990 cps. The middle tones varied upward or downward 1, 2, 4 or 8 cps. Each of these variations was used 5 times upward and 5 times downward for each base frequency in each display program. This gave a total of 120 sets of stimuli per display. The different stimuli were arranged in random order as determined by a table of random numbers. There was a 5-second period of silence between presentation of successive stimuli. After a series of 23 stimuli had been presented, subjects were given a 2-minute rest period. Between display programs they were given half an hour rest period. During this time they were allowed to leave the experimental room. On successive days the programs were presented in alternate order.

A tape recording of one entire sequence of stimuli was made and used throughout the experiment. When the pure tones were presented the tape was amplified and fed directly into the loudspeaker system. When the complex tones were presented, the tape was amplified, fed into the pulse shaping circuit of the Arbitrary Signal Stimulator and then into the loudspeaker. The sound output of the loudspeaker system was adjusted so that the sound level in the room was at least 30 decibels (db) above the ambient sound level of the room (48 db). The subjects were seated in groups of 3 or 4, about 8 ft from the loudspeaker within an arc of 45° from the front of the speaker and occupied the same seats for both displays.

Figure 1 is an oscilloscope face tracing of both types of stimuli at 190 cps. Figure 2 is a harmonic analysis of the pulse wave form at 490 cps as shown by the Panoramic Sonic Analyzer, Model LP-1.*

## III. RESULTS AND DISCUSSION

Although all the subjects had Class A physical profiles, they showed a marked difference in ability to discriminate small changes of frequency around the 3 base frequencies. Table 1 shows the number of mistakes made per subject at each base frequency for each wave form. Out of the 120 stimuli presented in each condition the range of total errors per subject varied from 4 to 72. An analysis of variance (Table 2) shows that this difference between subjects is statistically significant beyond the .01 level. Since most hearing tests merely rate the loss in decibels at given frequencies and since all the subjects in this experiment were assumed to be within the normal range, a standard hearing test *per se* provides relatively little information about ability to discriminate small changes in frequency.

Perhaps the most striking result of this experiment was the fact that subjects showed significantly fewer mistakes in judging complex tone (pulse) stimuli than pure tone (sine wave) stimuli. This superior discrimination of pulse tone frequency changes held for all 3 frequencies used in the present study. The results shown in Table 1 were significant

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*Produced by Panoramic Radio Products, Inc., Mount Vernon, N. Y.

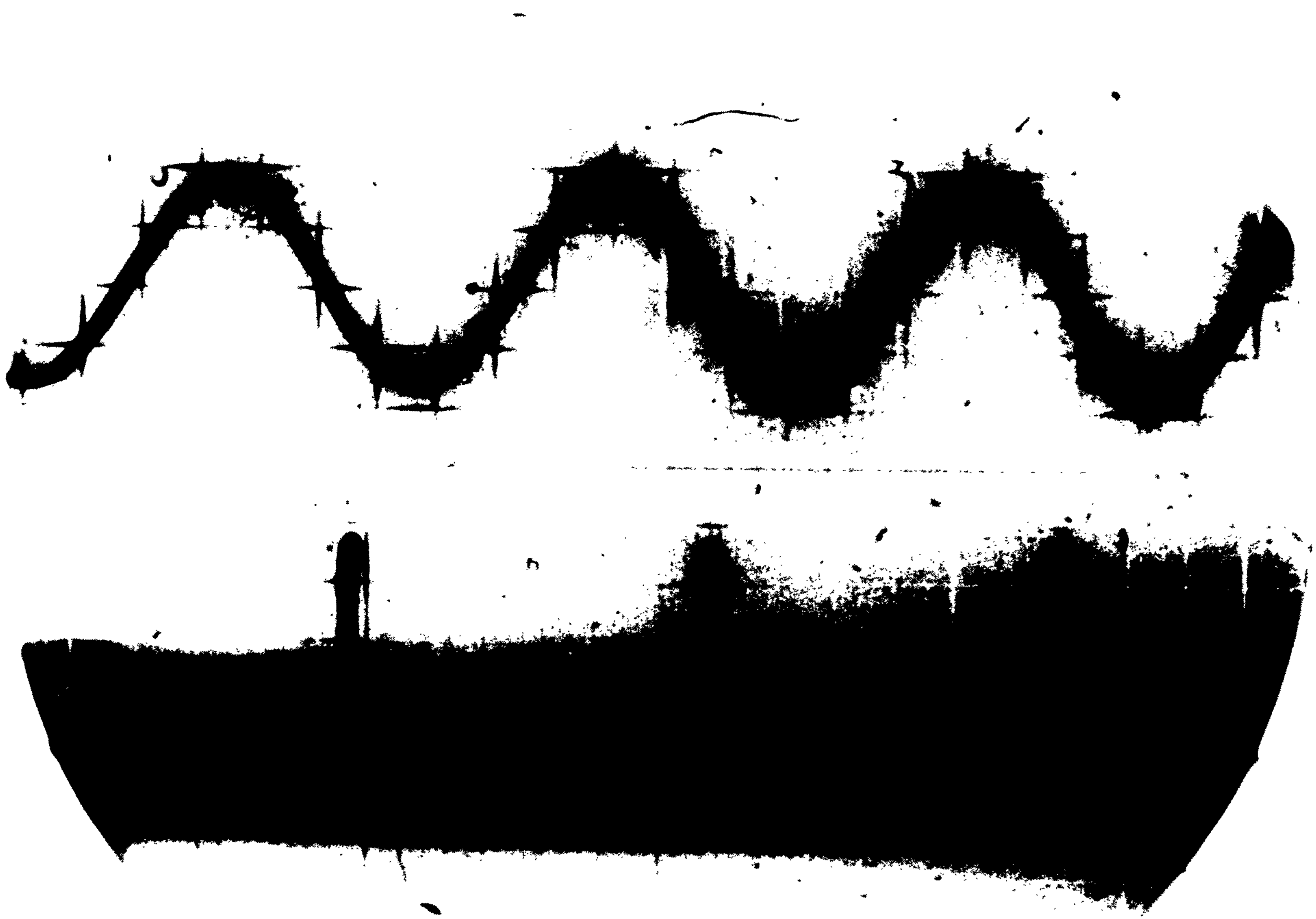

FIG. I WAVEFORMS OF TONES: PURE (ABOVE), PULSE (BELOW), AT 190 CPS.

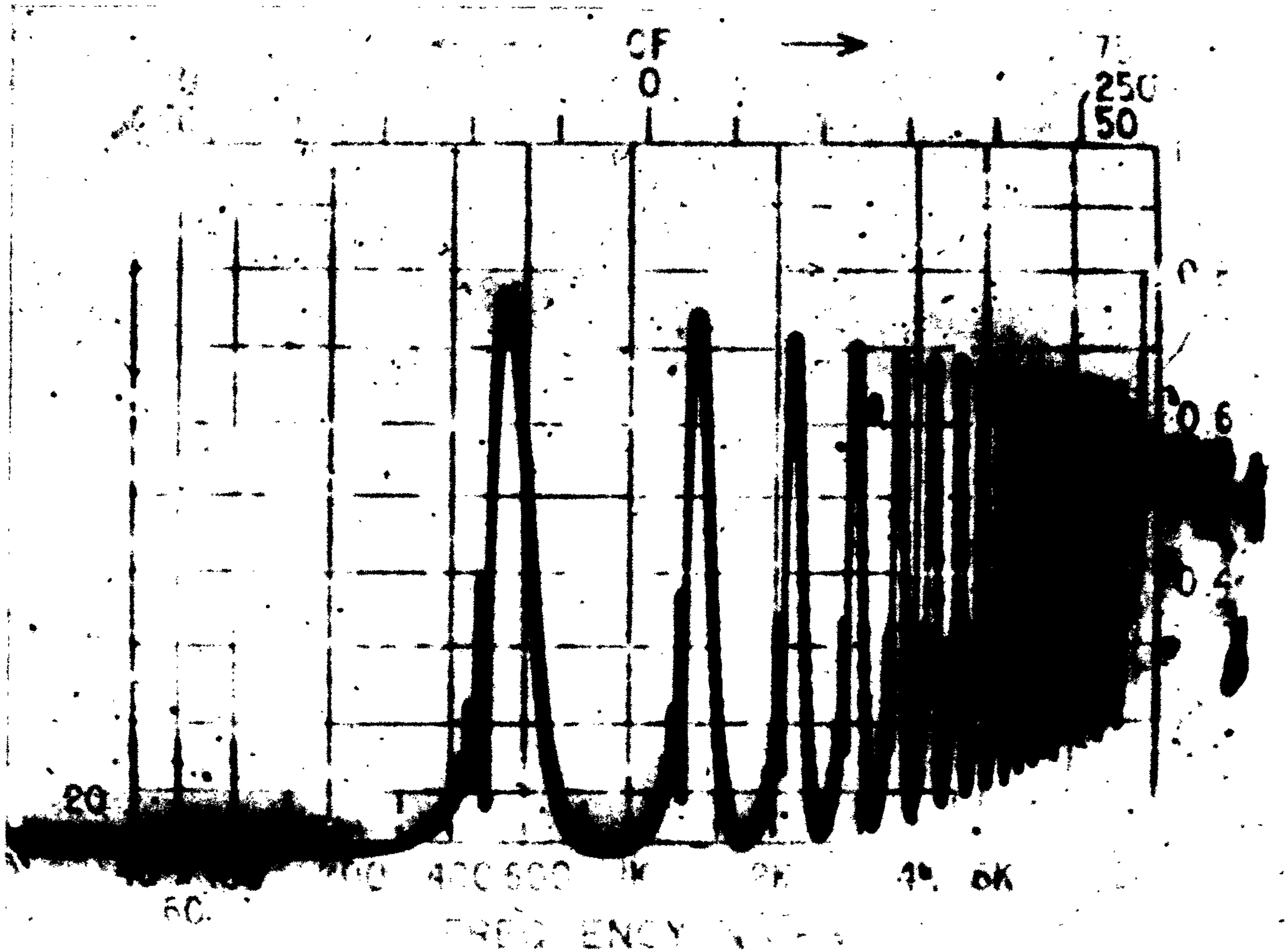


FIG. 2 HARMONIC ANALYSIS OF 490 CPS. PULSE WAVE (COMPLEX TONE).

TABLE 1

NUMBER OF ERRORS MADE TO PULSE TONES AND PURE TONES

| Subject | 190 cps Pulse | 190 cps Pure | 490 cps Pulse | 490 cps Pure | 990 cps Pulse | 990 cps Pure | Total Errors Per Subject Pulse | Total Errors Per Subject Pure |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 6 | 3 | 4 | 6 | 10 | 11 | 20 |
| 2 | 1 | 9 | 9 | 15 | 10 | 10 | 20 | 34 |
| 3 | 23 | 21 | 21 | 23 | 28 | 27 | 72 | 71 |
| 4 | 17 | 17 | 18 | 16 | 14 | 15 | 49 | 48 |
| 5 | 13 | 16 | 17 | 10 | 17 | 14 | 47 | 40 |
| 6 | 17 | 18 | 8 | 7 | 13 | 18 | 38 | 43 |
| 7 | 1 | 0 | 0 | 7 | 3 | 7 | 4 | 14 |
| 8 | 7 | 5 | 7 | 7 | 8 | 16 | 22 | 28 |
| 9 | 17 | 21 | 15 | 17 | 14 | 19 | 46 | 57 |
| 10 | 16 | 12 | 11 | 15 | 18 | 15 | 45 | 42 |
| 11 | 17 | 10 | 7 | 9 | 13 | 12 | 37 | 31 |
| 12 | 14 | 25 | 15 | 20 | 16 | 18 | 45 | 63 |
| 13 | 5 | 10 | 2 | 5 | 5 | 7 | 12 | 22 |
| 14 | 1 | 5 | 5 | 7 | 9 | 13 | 15 | 25 |
| 15 | 10 | 13 | 12 | 19 | 13 | 20 | 35 | 52 |
| Total Errors Per Frequency | 161 | 188 | 150 | 181 | 187 | 221 | 498 | 590 |

TABLE 2

ANALYSIS OF VARIANCE

| | Sum of Squares | df | Mean Squares | F |
|---|---|---|---|---|
| Frequencies | 108.16 | 2 | 54.08 | 4.10* |
| Subjects | 2760.62 | 14 | 197.19 | 14.94** |
| Waveforms | 94.05 | 1 | 94.05 | 14.83** |
| F x S | 369.51 | 28 | 13.20 | 2.08* |
| F x W | .81 | 2 | .41 | --- |
| S x W | 150.62 | 14 | 10.76 | 1.70 |
| Remainder | 177.52 | 28 | 6.34 | --- |
| Total | 3661.29 | 89 | | |

* Significant at .05 level

** Significant at .01 level

beyond the .01 level. Over the range of frequencies used in this experiment the subjects made approximately 18% fewer mistakes for complex tones than for pure tones.

There are several possible interpretations for the relatively greater ease in discriminating changes of frequency of complex tones as contrasted with pure tones. In the first place, the subject may be judging complex tones on the basis of changes in one of the harmonics rather than of the fundamental. A given change in the repetition rate of the pulse generating a complex wave is accompanied by a change 3 times greater in the third harmonic, for instance, and the subject may be responding to this more discriminable change in the harmonic and not to the change in the fundamental frequency or repetition rate.

It is probable that there is an interaction effect here due to the simultaneous operation of several frequency discriminating elements in the cochlea and central nervous system, rather than a simple addition of frequency change sensitivities at the harmonics. A more complete analysis of this problem will be presented in a later report.

The data of the present study show that there is a difference in the ease with which different subjects discriminate small changes of frequency at the different frequency levels used. Table 2 shows this difference to be significant at about the .05 level. With both types of wave form the total number of errors is slightly higher at the extreme frequencies, 190 and 990 cps. In this, the data are in agreement with published results dealing with continuously varying stimuli (5) and with discrete stimuli (2 and 3). The complex tone data consistently bear out the advantages accruing from the use of complex tones where a high degree of discriminability is required. An additional practical advantage of complex tones over pure tone signals lies in the greater stability of complex tones in the frequency-volume relationship (1, 4 and 6); the complex tones are more resistant to apparent frequency changes as the volume level of the signal increases or decreases. Accordingly, an operator in the field could adjust the volume level of his display to meet ambient noise conditions without appreciably distorting the display.

As expected, the interaction between frequency and subject was significant at the .05 level. It may be inferred from this that various subjects show differences in ability to discriminate small changes of frequency at the 3 base frequencies.

No other interactions were significant.

## IV. CONCLUSIONS

The ability to differentiate small changes in pitch of tones in the middle and low frequency range is significantly better with complex tones than with pure tones. This difference exists with the 3 frequencies 190, 490 and 990 cps used in this experiment. An average of 18% fewer mistakes for the 3 ranges was made with the complex tones.

There is a marked difference in the ability of different subjects to discriminate small changes in frequencies within the range of tones considered. The range of correct responses varies from 96.7% to 41%.

There is a significant difference in the number of incorrect judgments made at different frequencies by different subjects.

## V. RECOMMENDATIONS

1. When a frequency modulated mine detector display is used, complex tones, rather than pure tones, should be used because a) sensitivity to frequency change is greater with complex tones, at least within the frequency range studied here; b) a complex tone offers various economies in terms of power requirements for given levels of loudness; and c) pulse tones or complex tones have a greater resistance to apparent changes in frequency with changes in volume.

2. When frequency modulated signals are used with mine detector apparatus, operators should be selected on ability to discriminate frequency change rather than by conventional auditory testing methods.

3. An extension of this investigation to higher frequencies is desirable.

4. Other aspects of complex wave forms should be selected for further studies because of possible theoretical or practical advantages, such as easier discriminability or resistance to masking.

5. Further work should be carried out on various other aspects of the mine detector signal in order to determine what factors an experienced operator uses in differentiating mine signals from anomalies.

6. The relationships, if any, existing between measurements of absolute threshold, as exemplified by conventional audiometric techniques, and the ability to discriminate small changes in frequency should be determined.

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