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THE EFFECT OF TONAL COMPONENTS IN SUBMARINE SONAR
ON SIGNAL DETECTION AND RECOGNITION

by

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and

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF022 01 04-9004 06

Released by

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COMMANDING OFFICER
Naval Submarine Medical Center
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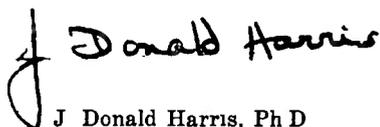
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SUBMARINE MEDICAL RESEARCH LABORATORY
U S NAVAL SUBMARINE MEDICAL CENTER REPORT NO 515

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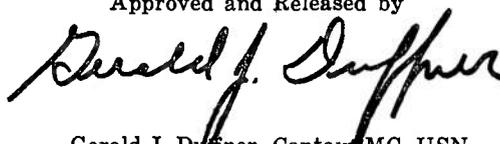


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SUMMARY

THE PROBLEM

To determine the effect of 60 Hz and 400 Hz tones and their respective harmonics on the ability of a sonar operator to detect and discriminate various signals

FINDINGS

These tones could be detected at fairly low intensity levels in the presence of various white noise bands. However, they were found to degrade performance on discrimination tasks only after reaching high levels of intensity.

APPLICATION

From the data collected, a limit will be imposed restricting the intensity level of tonal interference in a sonar system.

ADMINISTRATIVE INFORMATION

This investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF022 01 04-9004, Optimizing of the Special Senses in Submarine and Diving Operations. The present report is No. 6 on this Work Unit, was approved for publication on 14 March 1968, and designated as SubMedResLab Report No. 515. It was approved for public release and sale, its distribution is unlimited.

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ABSTRACT

Experiments were carried out to determine the effect of various tonal maskers on the sonar operator's ability to detect and discriminate signals. Thresholds were obtained for the detectibility of 60 Hz and 400 Hz and their respective harmonics to 360 Hz and 3200 Hz in the presence of various white noise bands. Thresholds were also obtained for detection of amplitude modulated and frequency modulated noise signals in the presence of these tones. Finally, data were collected on the ability to detect an amplitude modulated signal in the presence of two of these tones presented simultaneously.

It was found that although the tones could be detected even at very low intensities, it took very great levels (100 dB SPL) in most cases to mask the ability to discriminate the amplitude and frequency modulated signals. In the presence of multiple tones the discrimination of an amplitude modulated signal became more difficult. This result is obvious because of the additional masking added by the injection of a second tone.

Further research should be carried out on the effects of multiple tones on the audiogram and on the ability to discriminate different types of signals.

THE EFFECT OF TONAL COMPONENTS IN SUBMARINE SONAR ON SIGNAL DETECTION AND RECOGNITION

INTRODUCTION

Masking, by definition, refers to the amount by which the threshold of audibility is raised by the presence of another sound. Generally speaking, the resultant masking pattern of a pure tone masker depends upon the activity pattern of the tone within the cochlea. At low intensities the cochlea activity is confined to a narrow region which is frequency-dependent. However, as the masking tone is increased in intensity the cochlea activity spreads out towards the basal end (high frequencies), while maintaining its maximum at the locus of the original tone. Thus, at higher intensities, the masking pattern spreads unsymmetrically to the higher frequencies.

Of course, since white noise contains components of all audible frequencies, sounding simultaneously, it is the case that the resultant masking pattern of such noise cannot be a function of any specific frequency. It is the case that as the intensity of a white noise increases, there is a corresponding increase in masking, and this is generally independent of frequency (Stevens & Hawkins, 1950).

Physiologically, this rise in threshold across the auditory spectrum is a result of a deficiency in the total number of neural elements (hair cells) which normally contribute to give a tone loudness, i.e., the nerve fibers which are activated by the masking sound are not available to contribute to the loudness of a simultaneous tone. Thus, auditory thresholds are raised as a result of a lack of available neural elements.

Until approximately a decade ago it was generally assumed that a loud auditory stimulus of a given frequency only generated masking effects to higher frequencies, but had little effect upon lower (see Wegal & Lane, 1924). Research within the last decade has established that this relationship does hold for pure tone stimuli maskers (Spieth, 1957), but does not when a narrow band noise is utilized (Bilger & Hirsh, 1956, Deatherage, Davis, & Eldridge, 1957, Spieth, 1957). The

latter phenomenon has been named "remote masking" (Spieth, 1957), and occurs when the thresholds for low frequencies are raised by a high-pass band of noise at approximately 80-dB (re 0002 dyne/cm²), and above.

Generally speaking, the physiological explanation of remote masking is based upon the distortion introduced in the ear at high intensities, that is to say, the non-linearity of the bio-electric output of the ear.

The cochlea microphonic in the higher turns of the cochlea (CM₃), which represents the lower frequencies of the auditory spectrum, reproduces the envelope of the auditory stimulation, whether the envelope is random, as in noise, or normal, as in amplitude modulated tones. This response is the result of a mechanical transmission from the first to the third turn of the cochlea. Thus, a high-turn (low-tone) response to a high frequency sound can mask normal low-frequency responses to a low-frequency sound.

1 METHOD

Overall Design

The present experiments were designed to determine the interfering effects of certain tones on the performance of submarine sonar operators. The fundamental tones of interest were 60 Hz and its harmonics to 360 Hz, and 400 Hz and its harmonics to 3200 Hz.

Phase I was one of detection of the tones. The question was: what were the minimal levels at which these tones could be heard when immersed in a band of white noise? The primary bands of interest were 600-2400 Hz, 300-1200, 150-600 and 1200-4800 Hz.

The significance of the two tones of interest, and their respective harmonics, arises from the fact that the two line frequencies used in submarines are 60 and 400 Hz. The rationale behind the detection study was that if the tones could not be heard then they could certainly not interfere with the effectiveness of the operator.

Phase II involved a discrimination task, the purpose of which was to investigate the

possibility that these tonals would hamper the ability to discriminate signals (both FM and AM discriminations)

The discrimination was between a steady state white noise and a modulated white noise. The tones were injected and raised to appropriate levels of intensity so that they would mask the difference between the two white noises. The logic was that if the tones were kept below the level at which they would hamper discrimination ability and they would not cause a serious auditory problem during a sonar watch.

The third portion of the experiment (Phase III) also involved a modulation, but it was a frequency modulation, rather than an amplitude modulation, as in Phase II. The task was to discriminate between the modulated and unmodulated noise while tones of varying intensity and frequency interfered. Phase II and III essentially sought the same information: can discrimination ability be hampered by the interfering tones?

Frequent observations by a trained Sonar expert were obtained and he was of the opinion that Phase III was a very real situation while Phase II was somewhat artificial.

The fourth portion (Phase IV) reconstructed the apparatus as used in Phase I. All aspects and procedures of this phase were identical to those of the former except the level of the white noise masker. In Phase IV two additional levels of the filtered white noise (600 to 2400 Hz) were utilized (a "high comfortable hearing level" (CHL) and "low CHL").

Phase IV was designed to determine whether a linear relationship existed between a change in the level of filtered white noise and thresholds for tones within the passband of the filter.

Phase V was designed to investigate the discrimination of AM and FM signals in the presence of more than one masking tone.

Subjects

No significant hearing loss was displayed by any subject as determined by pre-experimental Bekesy audiograms. Degree of listening experience, however, varied widely among observers at the outset of experimentation.

Apparatus Calibration Description

The calibration procedure for all phases of the present study was as follows. All equipment was set up exactly as it was to be in the actual testing situation. The earphone, in an MX-41/AR cushion was removed from the Otocup and placed face down into a standard 6-cc coupler (9A). Mounted at the bottom of the coupler was a calibrated 640 AA Western Electric condenser microphone which drove a Western Electro-Acoustic Laboratories, Inc., Sound Pressure Level Meter. A voltmeter, at the same time, was connected in parallel with the earphone. The sound (either tone or noise) was turned on and the gain adjusted so as to yield the desired Sound Pressure Level (SPL) re 0002 dyne/cm². The voltage value necessary for such an SPL was then recorded. Figure 1 indicates schematically the apparatus utilized to measure the Sound Pressure Levels and equivalent voltage measurements at all frequencies of interest.

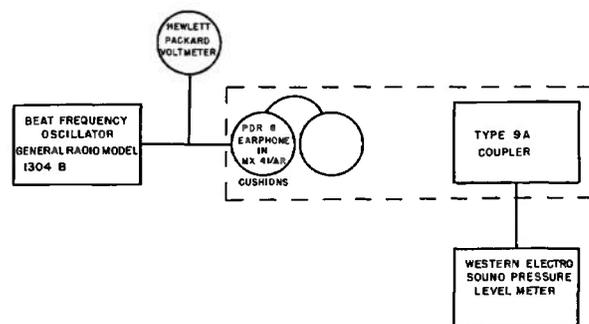


Fig 1 Apparatus utilized to measure sound pressure levels and equivalent voltage measurements at fourteen frequencies

Phase I

Apparatus.

The apparatus for Phase I consisted of the following: A model 901-B Grason-Stadler white noise generator, a Model 829-E Grason-Stadler electronic switch, a General Radio Model 1304-B Beat Frequency Audio Oscillator, a Model E 3262 Grason-Stadler recording attenuator, a Model 400-DR Hewlett-Packard Vacuum Tube Voltmeter, a matching transformer, a mixing transformer, an Allison Model 2-B high pass-low pass filter, a Western Electro-Acoustic Sound Pressure Level Meter, and a Model PDR-8 Earphone in Otocups.

Figure 2 displays the block diagram of the equipment used in Phase I

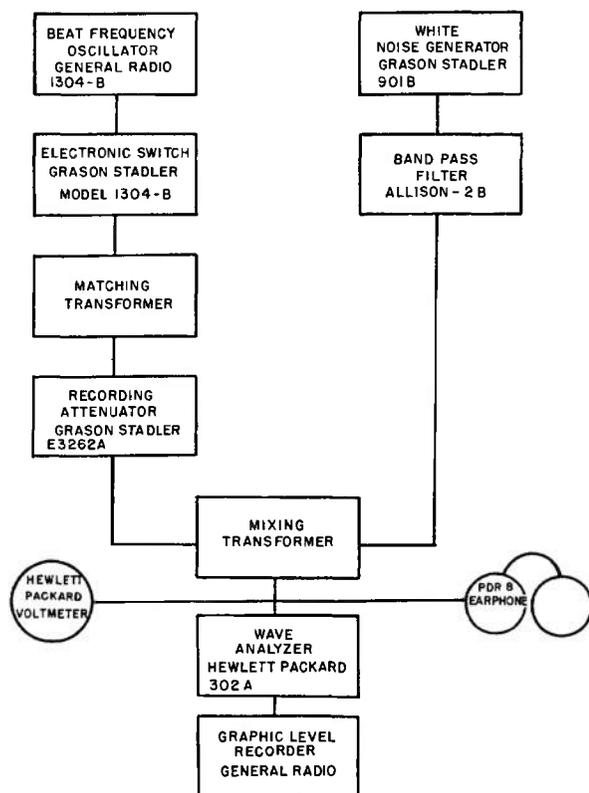


Fig 2 Block diagram of the equipment used in Phase I

Procedure Phase I

Prior to the initiation of Phase I it was necessary to equate all frequencies (60, 120, 180, 240, 300, 360, 400, 800, 1200, 1600, 2000, 2400, 2800, and 3200 Hz) in terms of Sound Pressure Level (SPL). Accordingly, all frequencies were adjusted to an SPL of 84.5 dB. Table I indicates the voltages necessary to produce an SPL of 84.5 dB at all frequencies of interest.

An arbitrary Comfortable Hearing Level (CHL) of 87 dB SPL was chosen as the level of the 600-2400 Hz white noise masker. This level represented a voltage of 0.85 volt measured across the PDR-8 earphone.

Each subject was tested individually in a silent room, anechoic for all components down to 200 Hz, which provided a sufficiently

quiet atmosphere for experimentation. Further noise reduction was accomplished by mounting the PDR-8 earphone in Otocups, and by covering the subject's unused ear with another Otocup.

The subjects were allowed to choose a preferred ear on which they would wear the headphone on all subsequent trials. However, under no circumstance was a subject permitted to switch ears after his initial choice had been made.

Each trial consisted of a concurrent presentation of a tone-in-noise. The tone was pulsating at a rate of 500 millisecond (ms) (rise/decay = 10ms, duty cycle = 70%), while the white noise masker remained at a constant level.

The subject's task was simply for 2 min to "track" his threshold for the tone within the band of white noise, that is, the subject depressed a lever when he heard the tone, and released it when he no longer heard it. This "Bekesy" type tracking task was performed four times for each subject at each of the fourteen frequencies of interest.

Phase II

Apparatus.

The apparatus arrangement in Phase II consisted of a Model 901-B Grason-Stadler noise generator, which fed into an Allison Model 2-B high pass/low pass filter with 36 dB/oct skirts, which filtered the broad band white noise to a 600-2400 Hz band. From the filter the noise was fed to an electronic switch/interval timer unit (Grason-Stadler Model 829-E electronic switch and Grason-Stadler Model 471 interval timer). These two instruments programmed the "on-off" cycles and duration of the white noise signal which was to be presented. The timer and switch combination had the capability of turning the signal on, leaving it in for any specified time, and then turning it off. A General Radio Model 1304-B beat frequency oscillator was used to generate the tones. The oscillator, in turn, was fed into a power amplifier (Altec Model 1569-A), which subsequently led into an attenuator. From the attenuator the tone was fed into another channel of the

electronic switch and timer unit. There it was pulsed at the same rate as the noise. The output from the first channel of the electronic switch was fed to another electronic switch-timer unit where the "on-off" time of the noise was regulated in such a manner that it created an amplitude modulation. From the output of the electronic switches the signals were mixed at a double pole-double throw (DPDT) toggle switch. The switch could be turned left or right manually. If it was moved left the two signals were presented, if right, they were off. From the switch the signals were fed into the PDR-8 earphone. All voltages to be presented were measured in parallel with the earphone.

A block schematic diagram of the apparatus used in Phase II may be seen in Fig 4.

Procedure

A trial consisted of the presentation of two events, each consisting of a simultaneous noise and tone. The difference between the two events was that in one of them the noise component was modulated as opposed to a steady state in the other. The modulation was very fast (70 ms on/50 ms off) (see Fig 3). The effect was a rapid perturbation in the noise.

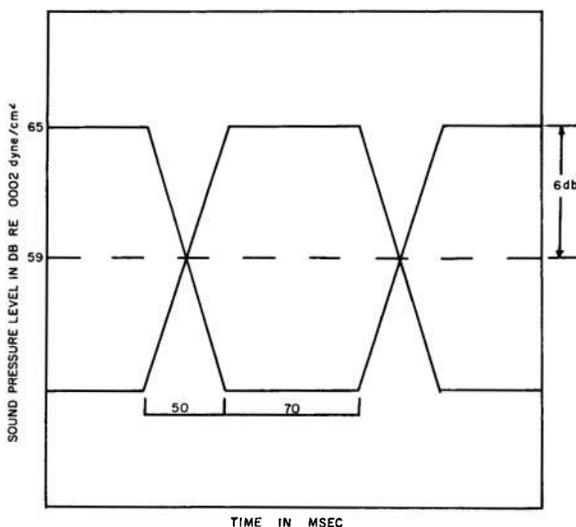


Fig 3 Schematic diagram showing rate and degree of amplitude modulation in Phase II

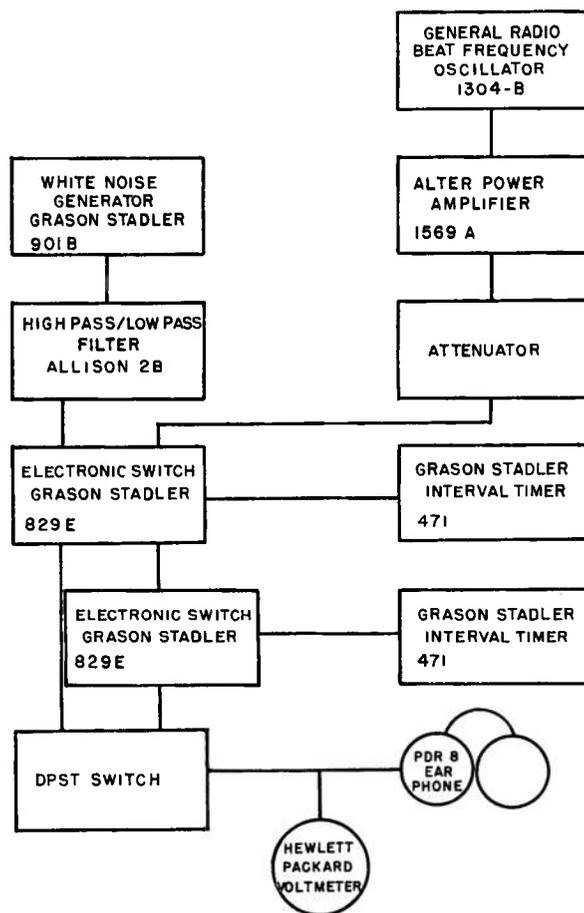


Fig 4 A block schematic diagram of the apparatus Phase II

Each event was presented for 2 sec followed by 1 sec of silence. After the presentation of the two events the signals were turned off and the subject made his judgment. A trial is schematically diagrammed in Fig 5.

The schematic diagram of Fig 5 illustrates that the modulation could have been in either the first or second event depending upon a prearranged order devised by the experimenters from a table of random numbers.

The task of the subject was to say which event contained the modulated noise, either 1 or 2. The subject was required to guess if he wasn't sure. The trials were so arranged that one intensity level of the tone was presented four times. In other words, the two events making up a trial were repeated four times at any one intensity level of the tone.

The intensity level of the tone was changed after the fourth presentation. It was raised until the tone obliterated the ability of the subject to judge in which event the noise was

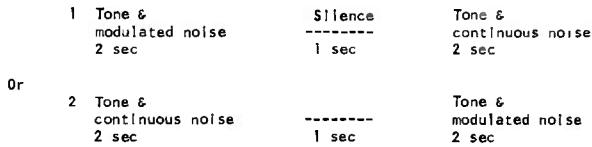


Fig 5 Illustration of typical trial sequences in Phase II and III

TABLE I

VOLTAGES ACROSS THE PDR-8 EARPHONE NECESSARY TO PRODUCE 84.5 DB SPL AT FOURTEEN FREQUENCIES

Frequency (Hz)	Voltage
60	066
120	058
180	053
240	053
300	053
360	053
400	052
800	050
1200	048
1600	050
2000	045
2400	036
2800	025
3200	030

perturbed. The criterion for what was considered a correct unit was three out of four correct responses at any one intensity level. If the subject was incorrect in two out of the four presentations, he was considered to be operating at chance level, and at that point the session was terminated.

The threshold for discrimination was taken to be the intensity level of the tone just below the level at which the subject first made two or more errors.

The above procedure was carried out for all fourteen frequencies of interest two times. Seven subjects were used in this phase of the experiment.

Again, as in Phase I, calibration in terms of Sound Pressure Level was required. However, in Phase II, all frequencies were adjusted to 90 dB SPL. Table II indicates the voltages necessary to produce the above sound pressure at all frequencies.

TABLE II

VOLTAGES NECESSARY IN THE PDR-8 EARPHONE TO PRODUCE A 90 DB SPL AT ALL FREQUENCIES OF INTEREST

Frequency (In Hz)	Voltage
60	160
120	140
180	125
240	120
300	110
360	100
400	100
800	100
1200	090
1600	095
2000	085
2400	065
2800	050
3200	065

Phase III

Procedure

The procedure in this phase consisted of exactly the same events as in Phase II except that modulation was now a frequency instead of an amplitude modulation. The passband of an Allison Model 2B filter was changed by the use of a General Radio mechanical sweep and oscillation drive set to a 30° rotation and adjusted so that the noise was modulated up and down in frequency at a 2.5 cycle/sec rate.

The frequency response of the filter at the low end of the sweep was between 580 and 2300 Hz. The upper end was a range of 630 to 2530 Hz. The central position of the sweep drive was a passband of 600 to 2400 Hz. The sweep drive is a mechanical device consisting of a motor that turns an extension rod back and forth. The speed and the arc of the rotation may be adjusted independently of one another. The end of the extension rod was attached to one of the adjustment knobs of the filter. That knob was attached by a rope loop to the other adjustment knob, an arrangement that permits a rotation of both adjustment knobs simultaneously. In this manner the skirts of the filter were altered and a frequency-modulated (FM) noise was created.

The subject's task was to pick out the frequency modulated noise from the continuous noise. In other words, the task is exactly the same as in Phase II, except for the fact that the noise was now frequency modulated.

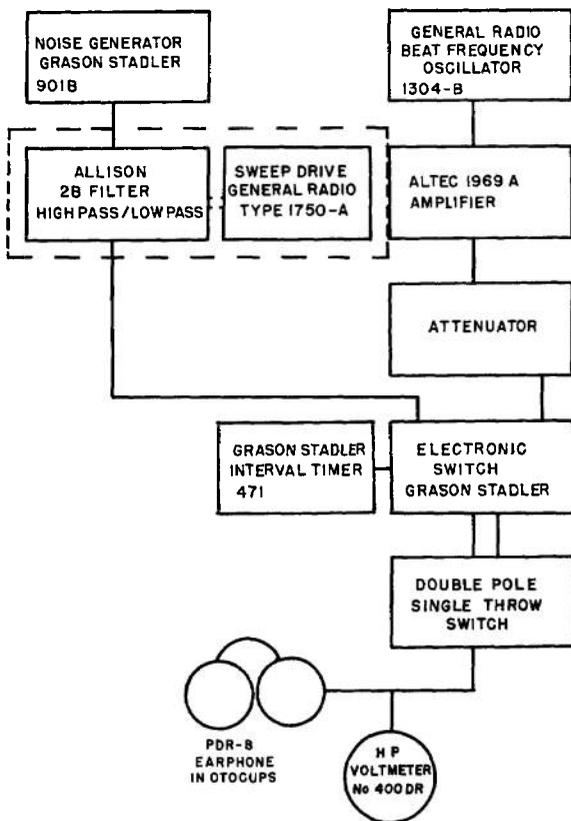


Fig 6 Block diagram of the apparatus used in Phase III

Because this phase involved FM the apparatus was slightly different from that of Phase II (Fig 6). The oscillator fed into a power amplifier which then fed into an attenuator. The attenuator fed into channel "B" of an electronic-switch-timer unit, and out to a toggle switch. The designation of channel B means that this is one of two separate switching units, that are placed on the same unit. There can be two separate inputs and outputs from the same unit, one from channel A and one from channel B.

The second segment of the circuit starts with the noise generator and feeds into the 600-2400 Hz bandpass filter. The filter is attached to the sweep drive unit as described above. From the output of the filter the noise is sent to channel A of the electronic switch. Here it is timed for a 2-sec "on," 1-sec "off" cycle (as is the tone) and sent to the toggle switch. At the toggle switch the tone and noise are mixed and sent to the PDR-8 earphone. All voltages are measured at the headphone.

Phase IV

Procedure.

The procedure for the present phase parallels that used for Phase I. However, two additional levels of filtered white noise were utilized. The first, 70 dB SPL, was chosen as a "low" Comfortable Hearing Level by an experienced sonar technician. That is, he chose the lowest level which could be listened to effectively by a sonarman. The second, 92 dB SPL, was chosen as a "high" CHL, or the highest listening level which a sonarman could listen to effectively. The voltages necessary to produce 70 and 92 dB respectively are 0095 and 0145 volt.

Again, each of the six subjects was told to "track" for 2 min each, his threshold for each of the fourteen tones in the presence of noise.

For reference purposes, absolute thresholds obtained in silence were recorded. This was accomplished by the elimination of the white noise generator from the system, and by the placement of an attenuator between the recording attenuator and the earphone.

Phase V

Threshold data were collected to determine the ability to discriminate a steady state from an amplitude modulated (AM) white noise signal in the presence of multiple tones. The most complete data were collected for the 600 to 2400 Hz passband. The tone combinations used were 400 and 800, 400 and 1200, and 400 and 1600 Hz. The intensity of the tones could be raised or lowered together in 1 dB steps while the noise level was constant. The task was the same as that in Phase II of this study.

RESULTS

Phase I Detection

Subject traced threshold for each of 14 tones in the presence of a two-octave band of noise. Four different noise bands were used, threshold data were obtained at each band. Data are in Tables III, IV and V, in terms of dB SPL re 0002 dynes/cm².

The physical characteristics of the masking noise are graphed in Fig 7. The skirts of the filter were 36 dB per octave.

Figure 11, Curve (a) shows the masked audiogram in the noise of Fig 7. The masked thresholds for tones below 400 Hz are somewhat higher than thresholds in quiet. Although these lower frequencies are not yet in the noise passband, we find that the phenomenon of remote masking is acting at very

TABLE III

MEAN THRESHOLD VALUES OF TONES IN A 87 DB SPL NOISE BAND OF 600 - 2400 Hz FOR EIGHT LISTENERS

Subject	Frequency (In Hz)					
	60	120	180	240	300	360
1	76 0	66 1	61 1	60 5	61 7	62 2
2	71 4	67 4	64 4	54 6	42 8	45 0
3	79 5	70 0	67 7	63 5	64 0	61 2
4	81 4	70 5	64 4	63 2	64 4	59 2
5	74 4	65 9	59 7	56 5	51 9	50 7
6	64 1	27 4	58 2	39 7	36 9	39 6
7	71 1	63 0	54 5	55 0	49 5	44 5
8	85 1	78 5	74 6	76 2	74 2	69 4
Mean Threshold	75 37	63 60	63 07	58 65	55 68	53 97

TABLE IV

MEAN THRESHOLD VALUES OF TONES IN A 87 DB SPL NOISE BAND OF 600 - 2400 Hz FOR SEVEN LISTENERS

Subject	Frequency (InkHz)							
	4 KHz	8	1 2	1 6	2 0	2 4	2 8	3 2
1	60 0	75 1	75 7	79 9	80 0	83 2	80 2	78 9
2	45 7	78 9	80 4	80 4	79 4	85 5	83 2	80 1
3	48 5	78 1	78 4	81 0	80 5	83 5	81 7	79 7
4	53 0	75 2	78 2	81 0	78 7	82 0	81 6	77 7
5	56 8	70 2	76 5	78 0	76 2	81 8	79 8	78 5
6	57 5	75 7	79 0	79 0	78 8	85 0	81 0	79 7
7	65 1	73 1	75 7	81 0	81 6	85 0	80 9	78 0
Mean Thresh	55 23	75 19	77 71	80 04	79 32	83 73	81 22	78 95

TABLE V

MEAN THRESHOLD VALUES OF TONES IN THREE WHITE NOISE BANDS AT 87 DB SPL THRESHOLD VALUES IN DB SPL

150-600 Hz

Frequency	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
Mean Threshold	82 5	70 6	73	77	81 6	83 1	82 5	73 5	60 6	54	43	37	34 5	25

300-1200 Hz

Frequency	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
Mean Threshold	84	71	66	72	81	76	76	79	79	76	72	64	64	-

1200-4800 Hz

Frequency	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
Mean Threshold	76	67	61	54	49	41	33	53	72	74	77	83	83	81

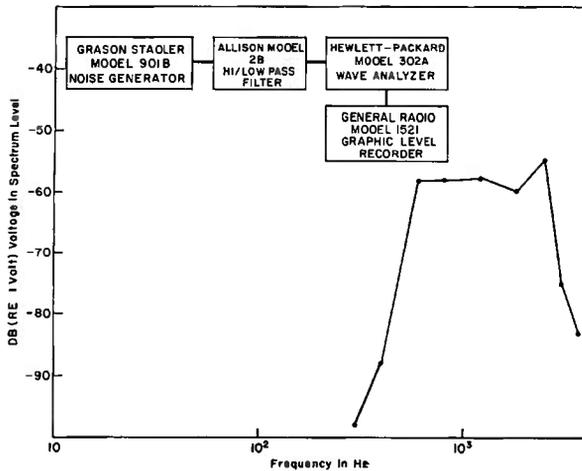


Fig 7 Spectrum level plot of an 87 dB noise in a 600-2400 Hz band The broadband voltage is -24 dB re 1 volt

low frequencies, and also some masking effects due to the imperfect skirts of the filter. The audiogram from 60 to 400 Hz shows the usual decrease in threshold as the ear becomes progressively more sensitive. From 400-2400 Hz masking increases, and thresholds rise and remain steady at about 65 dB greater than in quiet. The rise in threshold from 400 to 2400 Hz is attributable to the fact that masking is asymmetrical, that is, a tone will mask frequencies higher than itself more efficiently than lower frequencies. In terms of most efficient masking, the signal tone 800 Hz, for example, is masked only by those frequencies in the noise band of 800 Hz and lower (about 11% of the noise band). The signal tone 2400 Hz, on the other hand, is efficiently masked by those frequencies of the noise band from 600-2400 Hz or about 100% of the passband. Going above the passband the thresholds are still high but there seems to be a tendency toward a decrease as the 3200 Hz tone is approached.

The masked thresholds in the 300-1200 Hz band appear in Table V and Curve (c) in Fig 11. The characteristics of the passband are seen in Fig 8. The form of the masking curve corresponds rather closely to that of the thresholds in the 600-2400 Hz band. Remote masking is seen in the very low frequencies, filter imperfection causes raised thresholds at frequencies lower than the passband, and a considerable rise in masking throughout the passband. Finally, as the high end of the band is passed, masking falls again.

Data for the 1200-4800 Hz band are in Table V and band characteristics in Fig 9. Curve (b) in Fig 11 shows the masking. This curve closely follows the threshold in silence curve at low frequencies except for some remote masking at 60 Hz. At 800 Hz one finds a rise in threshold due to the first real influence of the passband. In the middle of the passband the thresholds follow the same critical band masking patterns as for the other bands. The thresholds for tones above this passband were not taken, but had they been, the results would probably have been similar to results for the other bands discussed.

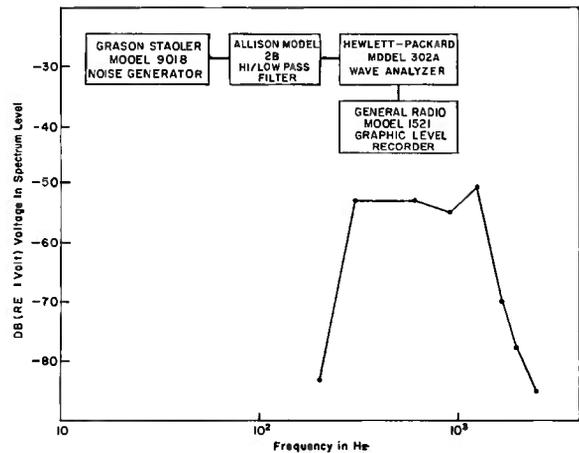


Fig 8 Spectrum level plot of an 87 dB noise in a 300-1200 Hz band The broadband voltage is -24 dB re 1 volt

Results for the 150-600 Hz band are in Table V and Curve (d) in Fig 11. The band characteristics are in Fig 10. The data for this band may be explained in exactly the same manner as the data for the three previous bands.

From the results of this phase of the study it can be seen that the major theory of masking that is followed is the critical band theory. Critical band theory, established by Fletcher (1940) is based upon two assumptions: (1) "that we neglect the masking produced by all the components of the noise except those whose frequencies lie within a narrow band around the frequency of the masked tone, and (2) that, when the tone is just audible against the background of white noise, acoustic power of the tone is the same

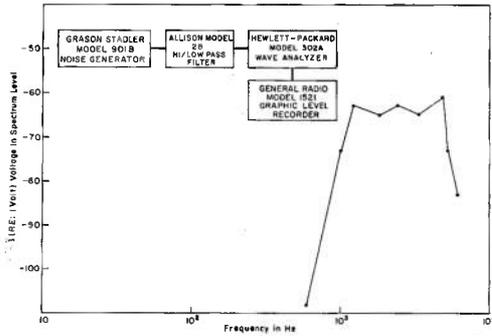


Fig. 9 Spectrum level plot of an 87 dB noise in a used in Phase II. is - 24 dB re: 1 volt.

as the acoustic power of the noise components within the narrow band" (Licklider, 1951). The asymmetry of masking is evident in the fact that the thresholds for tones in the low end of the passband were almost always lower than those in the high end of the passband, and that at high noise intensities tones relatively quite high in frequency are masked to some extent.

The phenomenon that explains the results at low frequencies is that of remote masking. It is seen that the 60 Hz tones are masked for all noise bands on the order of 6 to 10 dB. This is best explained by remote masking at passband frequencies of high intensity, as explained in the intriduction to this paper.

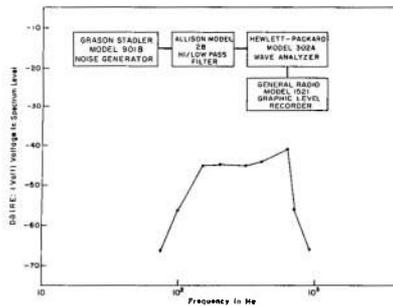


Fig. 10 Spectrum level plot of an 87 dB noise in a 150-600 Hz band. The broadband voltage is - 24 dB re: 1 volt.

An interesting phenomenon that occurred was that there were a group of tones that were perhaps an octave and a half below the passband that could be heard by the listener at intensities as low as -80 dB re: 1 volt. For instance, in the 1200-4800 Hz band at an intensity of about -55 dB re: 1 volt, the 400 Hz could be heard when it was -80 dB re: 1 volt. It can be calculated that because

of levels (at or near threshold), and distance from the noise band, tones at threshold level have completely negligible masking effects. To determine what level would mask the intelligence would merely involve applying masking theory for a given sensation level.

PHASE II AND III: DISCRIMINATION OF AMPLITUDE AND FREQUENCY MODULATION OF NOISE IN THE PRESENCE OF PURE TONE COMPONENTS

This phase used the same comfortable hearing level (CHL) as used in Phase I (87 dB SPL re: .0002 dynes/cm²). When testing was begun it became clear that the discrimination within a noise of that great an intensity could not be masked by any level of the masker tone. It was therefore necessary to lower the CHL to 65 dB re: .0002 dynes/cm². The 65 dB level was the minimal acceptable by a trained sonar operator as a CHL. Even at this level it can be seen from Table VI that discrimination of an AM noise band of 600-2400 Hz is very easy even when intensities of higher than 100 dB SPL are employed as masker tones. Wherever 100 dB is indicated in Table VI, it means that at maximum intensity used, the discrimination could not be masked.

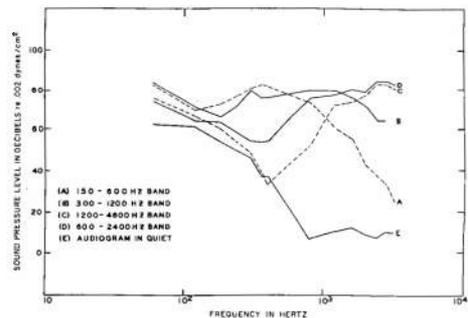


Fig. 11 Threshold for the 14 frequencies of interest in four bands of white noise at 87 dB re: .0002 dy/cm². Also shown is the audiogram in quiet.

The only frequencies that masked the discrimination at all were 800 and 1200 Hz. The reasons behind this phenomenon are relatively straightforward. At 800 Hz a tone that is at very high sensation level creates a masking pattern on tones in the passband such that it masks all those frequencies about 800 Hz and a few hundred Hz below

800 Hz This was the situation in the present study The entire information in the band of noise was masked by the 800 Hz tone at high sensation levels The same is true at 1200 Hz except the sensation level must be even higher because the downward spread of masking must now cover almost 600 Hz of the noise band (from 1200 down to 600 Hz) This relationship is drawn from the fact that the threshold for discrimination for 1200 Hz is higher than that for 800 Hz This would not hold for a 400 Hz tone because even at maximum sensation levels used, the tone could not obliterate all of the information in the passband Frequencies above 1200 Hz mask mainly the upper end of the passband and leave the intelligence, somewhat below the frequency of interest, unmasked

Another interesting problem that arose was that if the rate of temporal discontinuity was made too fast or too slow the masking ability of the tone was radically changed In some cases even the 800 and 1200 Hz tones could not mask the noise A very limited choice in the rate of temporal discontinuity remained for us to use if it were to be possible to achieve any masking whatsoever

Tables VII and VIII demonstrate the results of the frequency modulation (FM) discrimination The tonal's ability to mask the discrimination is very low It was again necessary to lower the CHL to 65 dB SPL

and search for a rate of modulation that would give some kind of masking results The explanation of the only positive results,

TABLE VII

FREQUENCY MODULATION DISCRIMINATION
THRESHOLD OF DISCRIMINATION IN DB/SPL
LOW FREQUENCIES

Frequency (Hz)	60	120	180	240	300	360
S ₁	100	100	100	100	100	100
S ₂	100	100	100	100	100	100
S ₃	100	100	100	100	100	100
S ₄	100	100	100	100	100	100
S ₅	100	100	100	100	100	100
S ₆	100	100	100	100	100	100
S ₇	100	100	100	100	100	100
Mean	100	100	100	100	100	100

TABLE VIII

FREQUENCY MODULATION DISCRIMINATION
THRESHOLD OF DISCRIMINATION IN DB SPL
HIGH FREQUENCIES

Frequency (Hz)	400	800	1200	1600	2000	2400	2800	3200
S ₁	100	83.5	96.5	100	100	100	100	100
S ₂	100	90	91	100	100	100	100	100
S ₃	99	89.5	98	100	100	100	100	100
S ₄	100	94.5	100	100	100	100	100	100
S ₅	100	95	100	100	100	100	100	100
S ₆	100	96	91	100	100	100	100	100
S ₇	94	94	96	100	100	100	100	100
Mean	99.7	91.7	96.7	100	100	100	100	100

TABLE VI

AMPLITUDE MODULATION DISCRIMINATION
THRESHOLD OF DISCRIMINATION IN DB SPL

Frequency (Hz)	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
S ₁	100	100	100	100	100	100	100	83.5	96.5	100	100	100	100	100
S ₂	100	100	100	100	100	100	100	90	91	100	100	100	100	100
S ₃	100	100	100	100	100	100	100	89.5	98	100	100	100	100	100
S ₄	100	100	100	100	100	100	100	94	100	100	100	100	100	100
S ₅	100	100	100	100	100	100	100	96	91	100	100	100	100	100
S ₆	100	100	100	100	100	100	100	95	100	100	100	100	100	100
S ₇	100	100	100	100	100	100	100	94	96	100	100	100	100	100
Mean	100	100	100	100	100	100	100	90	96	100	100	100	100	100

800 and 1200 Hz, can be explained in the same manner as the amplitude discrimination was explained

This is comforting in that interfering tones did not interfere with the ability to make either AM or FM discriminations even if the tones were at fairly high intensities

PHASE IV GENERAL LINEARITY OF MASKING INCREASE WITH INCREASE IN OVERALL LEVEL

Figure 12 shows that there is some degree of linearity of threshold between the three CHL's that were used. The dynamic range of the normal CHL is considered the high and low used in this test (70 and 92 dB SPL re 0002 dynes/cm²). The data is in Tables IX and X

TABLE IX

THRESHOLDS FOR FOURTEEN TONALS OBTAINED
IN A 600-2400 Hz WHITE NOISE AT 70 DB SPL

Frequency (Hz)	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
Mean Threshold re 0002 dy/cm ²	74.3	63.3	52.4	44.7	35.7	33.0	37.6	52.5	59.7	54.3	52.5	58.5	51.0	44.3

TABLE X

THRESHOLDS FOR FOURTEEN TONALS OBTAINED
IN A 600-2400 Hz WHITE NOISE AT 92 DB SPL

Frequency (Hz)	60	120	180	240	300	360	400	800	1200	1600	2000	2400	2800	3200
Mean Threshold re 0002 dy/cm ²	76.8	58.7	51.7	48.5	47.3	52.7	61.2	80.0	86.3	81.6	82.4	80.0	78.3	76.8

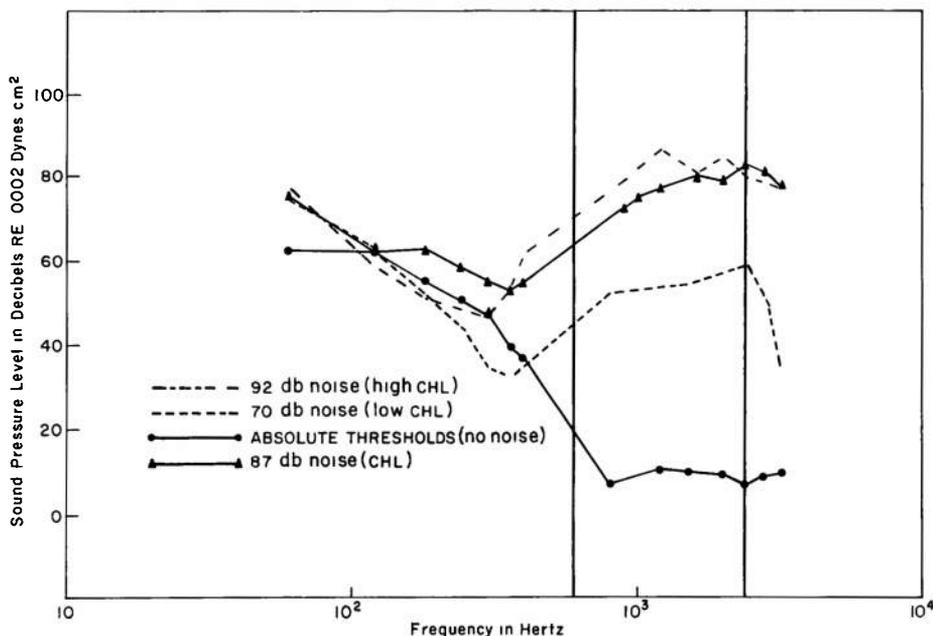


Fig 12 Thresholds of fourteen tones in the presence of a 600-2400 Hz white noise masker at overall levels of 70, 87 and 92 dB SPL. Also shown is the absolute threshold curve taken in the absence of noise

On further testing, the break in linearity occurred at a broad band level of -19 dB re 1 volt (92 dB SPL re 0002 dy/cm²). When the white noise was at any higher level than this, further changes in the CHL did not yield linear changes in threshold. This observation was made on the 1200-4800 Hz band, however, the broad-band level is applicable to any other band, realizing that the spectrum level will decrease or increase as a function of the filter passband.

PHASE V.

AM DISCRIMINATION IN THE PRESENCE OF MULTIPLE TONES

The thresholds for discrimination in Phase V are shown in Table XI. The data demonstrates that the addition of another tone in the passband lowers the ability of an operator to detect a signal. The 1200 cycle tone alone yielded a discrimination threshold of 96 dB. The addition of the 400 cycle tone lowered this value to 91 dB. The results for the 1000 cycle tone are even more dramatic. The threshold for either 400 or 1600 Hz alone was over 100 dB, while the combination of the two yielded a threshold of 89 dB. This is a clear indication that further data should be collected with multiple tones in the various passbands.

Interpretation

The data presents the masked audiograms of discrete frequencies in units both of voltage and of sound pressure level. An acceptable upper limit on intensity of discrete frequencies may be drawn by restricting unwanted tones to levels which are below that of the masked audiograms. In essence, if a tone is not audible it surely will not degrade the performance of an operator on a sonar watch. This generalization is conservative in that the level of the tone needed to destroy information in a passband is determined by its masking ability and in many cases the level needed may well exceed the masked audiograms.

TABLE XI
THRESHOLDS FOR DISCRIMINATION OF AMPLITUDE MODULATION IN THE PRESENCE OF MULTIPLE TONES

400 & 800 Hz	400 & 1200 Hz	400 & 1600 Hz
92	89	87
90	89	90
91	95	84
90	92	89
95	89	94
Mean 91.6	90.8	88.8

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13 ABSTRACT <p>Experiments were carried out to determine the effect of various tonal maskers on the sonar operator's ability to detect and discriminate signals. Thresholds were obtained for the detectability of 60 Hz and 400 Hz and their respective harmonics to 360 Hz and 3200 Hz in the presence of various white noise bands. Thresholds were also obtained for detection of amplitude modulated and frequency modulated noise signals in the presence of these tones. Finally, data were collected on the ability to detect an amplitude modulated signal in the presence of two of these tones presented simultaneously.</p> <p>It was found that although the tones could be detected even at very low intensities, it took very great levels (100 dB SPL) in most cases to mask the ability to discriminate the amplitude and frequency modulated signals. In the presence of multiple tones, the discrimination of an amplitude modulated signal became more difficult. This result is obvious because of the additional masking added by the injection of a second tone.</p> <p>Further research should be carried out on the effects of multiple tones on the audiogram and on the ability to discriminate different types of signals.</p>			

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