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THE DETECTION OF SIGNALS IN NOISE:
A COMPARISON BETWEEN THE HUMAN
DETECTOR AND AN ELECTRONIC DETECTOR

Report R-66

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UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

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ABSTRACT

In this experiment the response of an observer to aural signals in noise is compared to the fluctuating output of an electronic detection system whose constants are intended to be as close as possible to those of the human auditory detection system.

Of four variations of an electronic detector that were compared to the human observer, the best correlation between the electronic detector and the observer occurred for signals of duration 0.3 second, filter band pass 60 cps, square law detector with output smoothed with a low pass filter of time constant 0.15 second.

The lack of complete correlation between the responses to the signals of the observer and the electronic detector can be explained by assuming that the observer's threshold fluctuates randomly about a mean value with a dispersion of about 20% of the means, or alternatively that there is internal noise generated inside the observer's detection system which produces an equal dispersion at the threshold point.

The observer's false alarms are in time coincidence with noise fluctuations (as measured by the electronic detector) of the same average magnitude and dispersion as those calculated for an electronic detector with the same threshold fluctuation as that required to "explain" the observer's signal detection performance.

Unfortunately for the model, the observer's false alarm rate is approximately an order of magnitude lower than that calculated for an electronic detector with the fluctuating threshold. In fact, the observer's false alarms are actually fewer in number than those from a fixed threshold detector which is detecting the same fraction of the signals. This serious discrepancy indicates that even the most successful electronic detector model tested is deficient in some important manner.

THE DETECTION OF SIGNALS IN NOISE: A COMPARISON BETWEEN THE HUMAN DETECTOR AND AN ELECTRONIC DETECTOR

Chalmers W. Sherwin[1]
Frank Kodman Jr.[2]
John J. Kovaly[3]
Wilbert C. Prothe[3]
Jay Melrose[4]

For approximately three years a program of research was conducted by a group at the Control Systems Laboratory to investigate the human auditory system as a detector of signals imbedded in noise. The work of Schafer et al. (1), Garner and Miller (2), and Pumphray and Gold (3) revealed some basic characteristics of the auditory system when the ear was subjected to the task of detecting audio signals masked by noise. Additional information about the human auditory system was obtained from our own studies dealing with (a) errors in judgments of auditory signals (4); (b) auditory detection in noise of signals of randomly varying frequency (5); (c) signal detection in noise as a function of signal voltage with special reference to subject set (6); an analysis of integration time and power law detection in hearing (7). There was also a report (8) concerned with the statistical behavior of an electronic detection system. These studies led to the design and construction of an electronic system

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[1]Control Systems Laboratory and Department of Physics, University of Illinois, Urbana, Illinois.

[2]Department of Psychology, University of Kentucky, Lexington, Kentucky.

[3]On Active Duty with the United States Navy.

[4]Department of Speech, University of North Dakota, Grand Forks, North Dakota.

which might theoretically be expected to simulate signal detection in the human auditory system. The detector consists of a band-pass filter, a square law detector and an exponential integrator (simple R-C circuit). The bandwidth of the single tuned band-pass filter is 60 cylces. The detector is a true power detector and the integrator has time constants of 0.015, 0.05, 0.15 and 0.50 seconds. These were suggested by the critical band hypothesis (1), tone duration experiments (2, 8), and frequency modulation studies (9).

Utilization of the electronic detector device permits the observation of the detailed power fluctuations of the noise and signal plus noise and suggest a new avenue of investigation for observing and correlating certain functions of the auditory detector. A formal study was designed, therefore, to investigate the manner of auditory detection of signals of varying duration imbedded in thermal noise, and to compare the human performance with that of an electronic detector designed to perform the same task. The significantly new feature of the method is the idea of actually measuring each signal with its nearby noise and then making a detailed comparison of each electrical measurement with the human response.

I. PROCEDURE

Plan. The general plan of the study is to have four trained observers attempt to detect signals which were mixed with noise. Signal frequency is held constant with durations of 0.03, 0.10, 0.30, and 1.0 second. The signal plus noise ratios are empirically determined to yield approximately 60% detection for each duration.

The performance of the human detectors are then compared to the responses of the electronic detector.

Subjects. Four adult males served as observers. Audiometric examination disclosed no loss of 10 db or more in either ear at the octave frequencies from 250 to 4000 cycles. Each had approximately four weeks of practice detecting signals in noise.

The Preliminary Experiment. It was necessary first to determine the signal to noise ratio for 60% detection for each signal duration. Figure 1 is a block diagram of the apparatus used in the preliminary experiments to determine the signal levels and the noise level used here and in the final experiment. It was very convenient to store the information on magnetic tape. A loop of tape, consisting of a segment of recorded signal and the rest blank, was used to yield the prescribed signal duration. This loop was played continuously on a tape recorder whose output was fed into Channel #1 of a dual channel Magnecorder set to record. The output of a wide-band noise generator (upper limit 20 kc) was fed into a low-pass filter (upper limit 4 kc) and then to Channel #2. While the noise was continuously recorded on its channel, the output of the signal loop was transmitted according to a program derived from a table of random numbers which permitted successive signals to be spaced randomly from two to ten seconds. Fifty such signals were recorded on the signal channel for each signal duration.

On the playback, the output of each of the two channels was fed into a mixer, the average noise level being held constant for all four conditions. (Specifications of Noise Level and Signal

Level are reported below.) The signal and noise mixture was then fed to the earphones. Two subjects were used to determine the signal voltages needed to yield approximately 60% detection for each duration, noise constant. The signal voltage was first set so that the subjects reported 100% detection and then was gradually decreased until they detected about 30 of the 50 signals on three successive trials. These signal voltages, for a given signal duration, were used in making the four experimental tapes which were then used for the principle experiment.

Experimental Stimulus Tapes. The signal-loop and noise system described above permitted the signal and noise outputs to go to the mixer whose output was fed into the first channel of a dual channel tape recorder. In this manner one obtains about 5 or 6 minutes of exactly reproducible stimulus material. Each signal alone was fed into the second channel of the recorder, making a convenient record of the exact location of each signal. The noise level was kept constant as in the preliminary experiment and the signal level for the desired 60% detectibility was used. The stimulus items were programmed as follows for each tape. The first five were practice signals spaced two seconds apart. These were followed by 110 signals randomly spaced from two to ten seconds. At the beginning and end of each tape were one-minute recordings of signal and noise alone to be used for calibration purposes. A separate tape loop was used for each duration.

System for Signal Presentation. Figure 2 is a block diagram of the system used in the final experiment to present stimuli to the human detector and electronic detector. The output of

Channel 1 of the dual channel Magnecorder was fed into a mixer and then to the electronic detector and the human detector. Essentially, then, the two systems were making judgments on the same stimuli. The binaural headset containing a matched pair of PDR-3 earphones with type 1505 ear cushions was connected to the output of the Bogen Model PH 10 multi-range amplifier. At all times the average noise level was monitored by a Diatron Model 503E power-level meter at the output of the mixer. The stimuli were presented at a comfortable listening level. In order to correlate the performance of the two detection systems, Channel #1 of the Brush dual channel oscillograph recorded graphically the occurrence of the random signals and the human's identification of these signals. At the same time, Channel #2 of the oscillograph recorded the integrated signal plus noise fluctuations of the output of the electronic integrator.

Figure 3 shows a sketch of the circuit used as a model and also a typical section of the output of the electronic detector on the Brush Recorder.

Procedure with Subjects. Each observer participated in a number of practice periods detecting signals in noise using the preliminary tapes containing 50 signals. At the end of this period it was noted that all subjects possessed approximately equal ability in signal detection. This requirement was incorporated to lessen subject variability throughout the course of the experiment.

For each experimental run, the subject was seated comfortably in a reclining chair and handed the microswitch response key. The earphones were adjusted individually by the experimenter so as to provide a good acoustic seal. The subjects were instructed to be average, rather than liberal or hyper-cautious detectors. After a practice run with the preliminary tape, the test tape was played and the subject responded by depressing the micro-switch for each detection.

Experimental Controls. Each of the four different experimental tapes was presented to each subject once over a four day period. One experimental run per day per subject was permitted and these were counterbalanced for morning and afternoon listening over the course of the experiment. One hundred of the 110 signals were used for analysis, the first and last five were omitted in order to reduce possible learning effects.

Each tape containing signals of a given duration was played a total of four times to each observer, making 16 runs total for a given tape. On all 16 runs, of course, the electronic detector system recorded an identical pattern.

II. RESULTS

It will be recalled that in the preliminary experiment signal to noise ratios were determined which were intended to yield approximately 60% detection in the main experiment, and such signals and noise were recorded in permanent form. The first question to be answered, then, is whether or not the subjects were able to approximate this percentage for each duration, and the principle question is how the responses of the human detectors compare in detail to those of the electronic detector.

The mean signal detection levels of the observers are shown below. It is seen that the mean detection level for each

Table 1. Mean auditory signal detection level for each duration (Each result is the average for four observers who each made four runs of 100 signals).

	Duration (sec.)				
	0.03	0.10	0.30	1.00	Grand Mean
Detection Level (%)	58	61	65	59	61

condition closely approximated the desired 60% level. Each mean represents the average of the four subjects for one of the experimental conditions. The grand mean is further evidence for the desired detection level.

Of interest is the signal voltage (peak-to-peak) needed in the preliminary experiment to yield equal detection levels against a constant noise background. The values were:

Signal Duration (sec.)	Signal Voltage (peak-to-peak volts)
0.03	4.46
0.10	2.93
0.30	2.48
1.00	1.42

The values indicate that signal voltage to yield equal detection decreased with signal duration.

The frequency distributions of 100 signal plus noise samples*

*The electronic detector has an output voltage V_0 which is instantaneously proportional to $(V_i)^2$ where V_i is the input voltage. The integrator averages $(V_i)^2$. Thus the voltage at the output of the integrator is proportional to the average power level in the pass band during a preceding interval of about one time constant. The integrator output voltage is plotted on the abscissa in Figures 4 through 7, and labled "relative power".

observed at the output of the integrator are plotted in Figures 4 through 7. It should be recalled that the integrator time constant is always set to be equal to one half the signal duration, making it approximately optimum for detecting the signal. This accounts for the progressive narrowing of the distributions as the signal duration is increased.

The frequency distribution of the noise alone is shown as a smooth Gaussian curve in each of the Figures 4 through 7. One hundred samples of noise were randomly selected and measured, and a Gaussian with the same mean and dispersion was plotted. Theoretically (8), an integration of limited duration at the output of a square law detector should produce an excess, or "tail" on the high side of the noise distribution, which is of importance in the calculation of false alarm rates, but it would scarcely show on the figure. In any case, the simple Gaussian fits the 100 sample distribution within statistical error.

For the determination of false alarm probability, it is necessary to record the number of independent output states of the integrator due to the noise alone that were reached during an actual run. Using the fact that the spacing of independent samples is equal to two time constants of the integrator (8) and making use of the actual duration of noise on the tapes,* we have the data in Table 2. Thus both the observer and the electronic detector are rejecting a very large number of noise samples during one run. (The observer with a presumably fixed integration time constant of a few tenths of a second is expected

*The observer knows that after each detection another signal will not occur for at least 2 seconds. These noise intervals should not be counted for the observer, but this correction is negligible compared to statistical errors.

to reject one to two thousand noise samples per run.) In Figures 4 through 7, a line shows the threshold which 60% of the electronic detector's signal plus noise samples exceed.

Table 2. Number of Noise Samples per Run.

Signal Duration	No. of Independent Noise Samples in One Run
.03 second	20,000
0.1	6,000
0.3	2,000
1.0	570

If the observer acts on the same data as the electronic detector, and has a fixed threshold, he will detect all of the signals above this line and miss all of the signals below this line. Actually, as the figures show, the observers tend to detect the large signal plus noise samples and tend to miss the small samples. The correlation between observers and the circuit is the best for the 0.3 second duration signals (Figure 6.) For the .03 and 1.0 second signals the observers show relatively weak correlation with the electronic detector. The correlation is somewhat better for 0.1 second signals, and is the best for the 0.3 second signals. Other evidence (2, 7) shows that the effective integration time for the observer (in the 1000 cps range) is several tenths of a second, and thus the fact that of the four models the one with the 0.15 second integrator and the 0.3 second signal best matches the observer behavior supports the earlier results with a new kind of evidence.

Because the correlation between the electronic detector and the four observers is best for the 0.3 second signal, most of the analysis and interpretation will be concentrated on this case (Figure 6.) It seems likely that the cause of the deviations between the electronic detector and the observers is that the observers have fluctuating thresholds as discussed by Smith and Wilson. This assumption leads to some quantitative predictions for the 0.3 second signal and will be discussed below.

It should be remarked that observers did not correlate exactly either with their own previous runs, or with the runs of the other observers in qualitative agreement with the observations of Smith and Wilson.

The false alarm rates of the observers and of the electronic detectors are listed in Table 3.

Table 3. Number of False Alarms per Trial Reported by the Electronic Detector when Set to Report 60% of the Signals, and the Mean Number of False Alarms per Trial Reported by the Human Observers.

	Signal Duration (sec)			
	0.03	0.10	0.30	1.0
False Alarms				
Electronic Detector (one trial)	39±6	21±4	7±2.8	18±4
Human Observers (Average of 16 trials)	14±1	9±.7	3±.4	12±.9
Signal Detection Probability				
Electronic Detector	60%	60%	60%	60%
Human Observers (from Table 1)	58%	61%	65%	59%

The remarkable thing about Table 3 is that the observers consistently outperformed the electronic detector. They obtained about the same signal detection, but had only about half as many false alarms.* The integration time constant of the electronic

*If the false alarm rate of the circuit was decreased to that of the observers, the circuit would detect about 50% of the signals.

detector, furthermore, was optimized for each signal duration, whereas the observer's is presumably fixed at a few tenths of a second.

Another remarkable thing about the false alarms is that the observers practically never called a false alarm at the same noise fluctuation which caused the electronic detector to exceed its threshold. For example, for the 0.3 second signal (for which the highest signal detection correlation was obtained between the observers and the circuit) only once out of the 16 runs did one of the observers call a false alarm on one of the 7 circuit false alarms. There was on this same tape, however, one particular noise fluctuation of power level 20 (3 units below the 60% circuit threshold) which was called as a false alarm 35% of the time, all observers contributing. This was the only example of this sort, however.

It appears that the observers determine false alarms on a different basis then the simple circuit with fixed threshold. One difference is that the observers threshold seems to be fluctuating, as will be discussed below, but this still does not explain the unusually low false alarm rates of the observers, or their failure to respond to a reasonable fraction of the large noise fluctuations which actuated the electronic circuit.

<u>Results with the 0.3 Second Signal.</u> For the 0.3 second signal, the 60 cps single-tuned circuit, power detector, and 0.15 second integrator shows quite remarkable signal detection correlation with the four observers. The signals are initially equal, and their largeness or smallness in the signal plus noise

distribution is due entirely to the nearby noise as selected by the 60 cps filter and processed by the detector and integrator. Figure 6 shows that the observers detected the strongest signal plus noise samples 100% and only detected a few percent of the smallest signal plus noise samples. It is clear that the filtering and integrating processes in the ear plus brain are similiar to those in the electronic circuit.

A logical hypothesis is that the observer's thresholds are fluctuating randomly about some mean value near the 60% threshold line. This would explain the existence of signal detections below this line and also the failure to attain 100% detection above this line.

The signal-miss data shown in Figure 6 are adequately accounted for by assuming that the observer's threshold varies with a Gaussian distribution of $\sigma = 4.5$ power units, centered at 24 power units. This will explain why the observers do not always detect the same signals on successive trials, and why the different observers do not always agree among themselves.

The fluctuating threshold hypothesis predicts two new observables, however, in this experiment. First, the false alarms should be predominately caused by noise fluctuations which are lower in power level than those which alarm the fixed threshold detector. Second, the false alarms should be more numerous due to the non-linear shape of the noise distribution in the neighborhood of the threshold. Excursions below the mean value of the threshold cause false alarms to increase more rapidly than excursions above the threshold cause them to decrease.

We now calculate the false alarm behavior of an electronic circuit whose threshold varies randomly by the amount required to explain the observer's variable signal detection.

Let $\phi_1(x)$ be the Gaussian probability distribution of the threshold (determined from the observer's <u>signal detection</u> in Figure 6). It has a mean of 24 power units and dispersion $\sigma_1 = 4.5$. Let $\phi_2(x)$ be the probability distribution of the noise at the output of the integrator. This is approximately Gaussian, but has an excess at large values due to the fact that the integrator is only summing a finite number of samples from the square law detector (8). This effect is not noticeable in an ordinary plot of the noise distribution, but it does increase the false alarm probability as compared to a true Gaussian. In any case the integral of $\phi_2(x)$ is available graphically (8).

The probability that a noise sample of power level between x and x + dx will cause a false alarm is

$$P(x)dx = \phi_1(x) \left[\int_x^{\infty} \phi_2(x)dx \right] dx$$

P(x) is the probability distribution for those noise fluctuations which cause false alarms and is shown plotted with arbitrary amplitude in Figure 8. This is based, it will be recalled, upon the hypothesis that the observer's threshold is fluctuating in such a manner as to explain the signal-misses of the observers in Figure 6.

The next step is to actually measure the noise level one unit of the observer's reaction time before each false alarm response. The reaction time is accurately determined from the responses to true signals and is found to be very constant. There was a total of 16 runs using the same tape (4 runs for each of 4 observers) and there was a total of 46 false alarms recorded (~3 per trial). The noise power levels preceding each of the 46 samples are plotted as a frequency distribution in Figure 8, labeled "Observed False Alarms". The agreement between the observed and calculated distributions is quite striking.* There is one puzzling and significant discrepancy, however. Using the known number of independent noise samples at the output of the 0.15 second integrator, (2,000 from Table 2), the calculated distribution predicts 19 false alarms per run whereas the observers only reported 3 false alarms per run.

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*In the data analysis there is sometimes ambiguity as to which of at most two noise samples is located one reaction time ahead of the observer's response. (Reaction times were very nearly 0.3 seconds). We assume that the analysisist picks the larger of the two samples. If this uncertainty always occurred, and if the selection were done at completely random times, the resulting frequency distribution of the noise would only be shifted about 1.5 power units to the right in Figure 8. This is still very different from the observed false alarm distribution. In other words, there is reason to believe that the difference between the noise distribution and the observed false alarm distribution is real, and not artifact of the analysis.

This is a discrepancy of a factor of 6. Related to this is the fact that in 16 runs only once did any observer call a false alarm on any of the 7 noise samples which exceed the 60% threshold of the electronic detector -- and this in spite of the fact that in this power region, the observers were detecting about 60% of the true signals. We would expect say 3 or 4 of these large noise fluctuations to be reported per run, but observe that only 1/16 were actually reported, per run, by the observers.

It seems that the observers, when they call false alarms, do so at those power levels characteristic of their fluctuating thresholds. However, for some reason their false alarm rate is about an order of magnitude lower than that calculated for an equivalent electronic detector with the same threshold fluctuation.

Two things are clear. (1) The observers were slightly better detectors than the particular electronic circuit used, and (2) there are still unexplained differences between the observer's false alarm response and the calculated behavior of an electronic detector with a fluctuating threshold.

Perhaps the 60 cps passband for the electronic detector does not match the effective passband of the observers. Perhaps the observers do not have a very accurate power level detector. Perhaps the observer's integrators do not have the same exponential weighting as the simple electronic integrator. All of these things will contribute to the detailed output fluctuations of a detecting system, and could cause differences between the observers and the electronic circuit.

None the less, experiments with the 0.3 second signal show on a remarkably fine time scale a clear correlation with the behavior of the electronic circuit. Also, there is a similarity between the power level distribution of those noise samples preceding the observer's actual false alarms and those that would cause false alarms in an electronic detector with a randomly varying threshold.

Detailed analysis of the detection of the other signal durations has not been performed, because the electronic detector is more poorly correlated with the observers' performance. Presumably this is due to the electronic integration time constants being different from those effective for the observers, since the power level detector and the 60 cps pass filter are unchanged.

The theory of visual detection proposed by W. P. Tanner and J. A. Swets (11) and also by one of the authors (8) assume that the human observer makes a simple threshold judgement between two probability distributions, "noise alone" and "signal plus noise". These experiments not only support these ideas directly, but go further by showing how (for aural detection) the two distributions can actually be imitated to a fair approximation in the laboratory. However, the large quantitative discrepancy between the false alarm rate of the observer and the false alarm rate calculated for the fluctuating threshold model gives cause for concern. It is clear that the detection system models tested thus far are deficient in some important manner.

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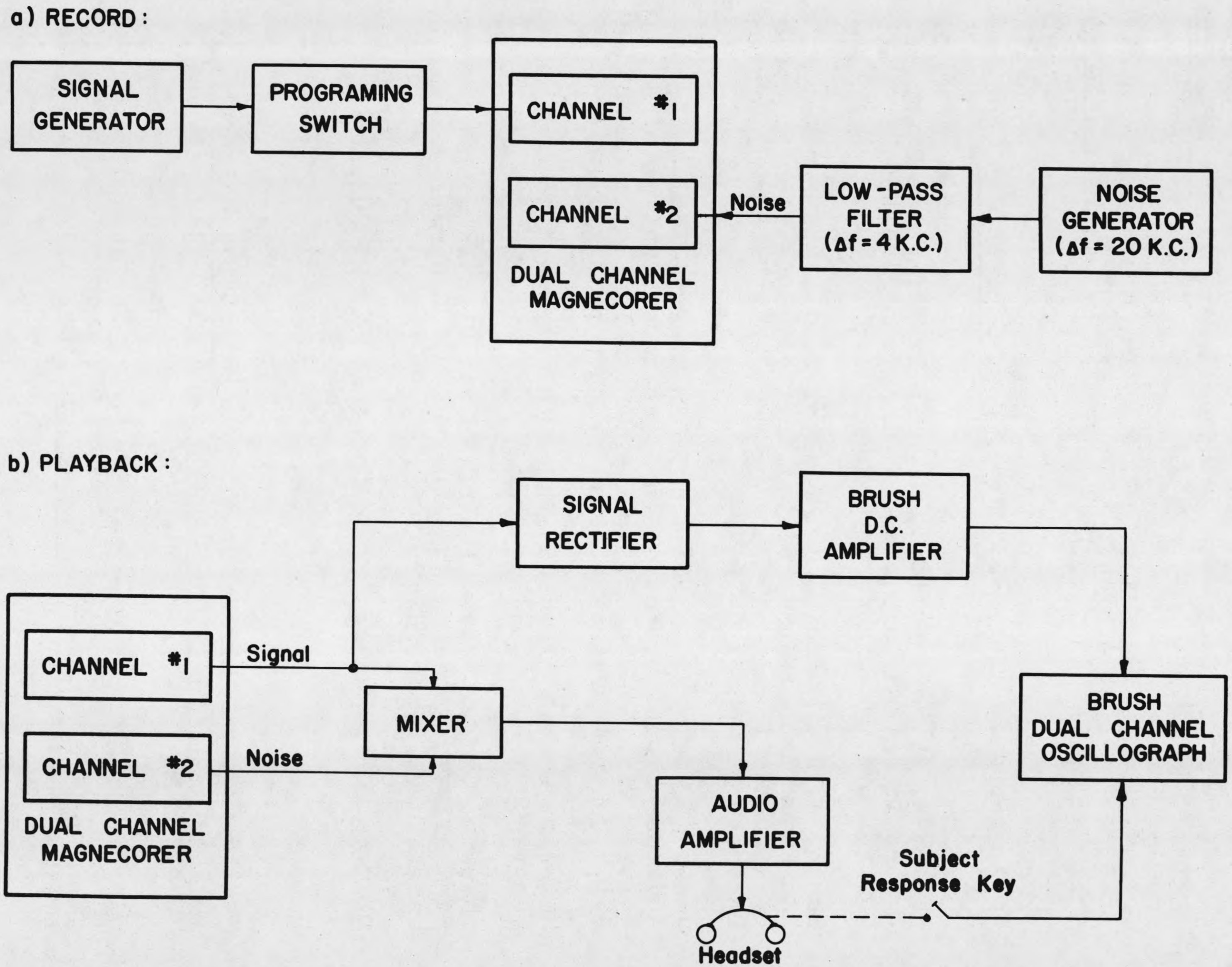

Figure 1. Block Diagram of Apparatus Used in the Preliminary Experiment. This experimental arrangement was used to determine the signal level needed for 60% detectability.

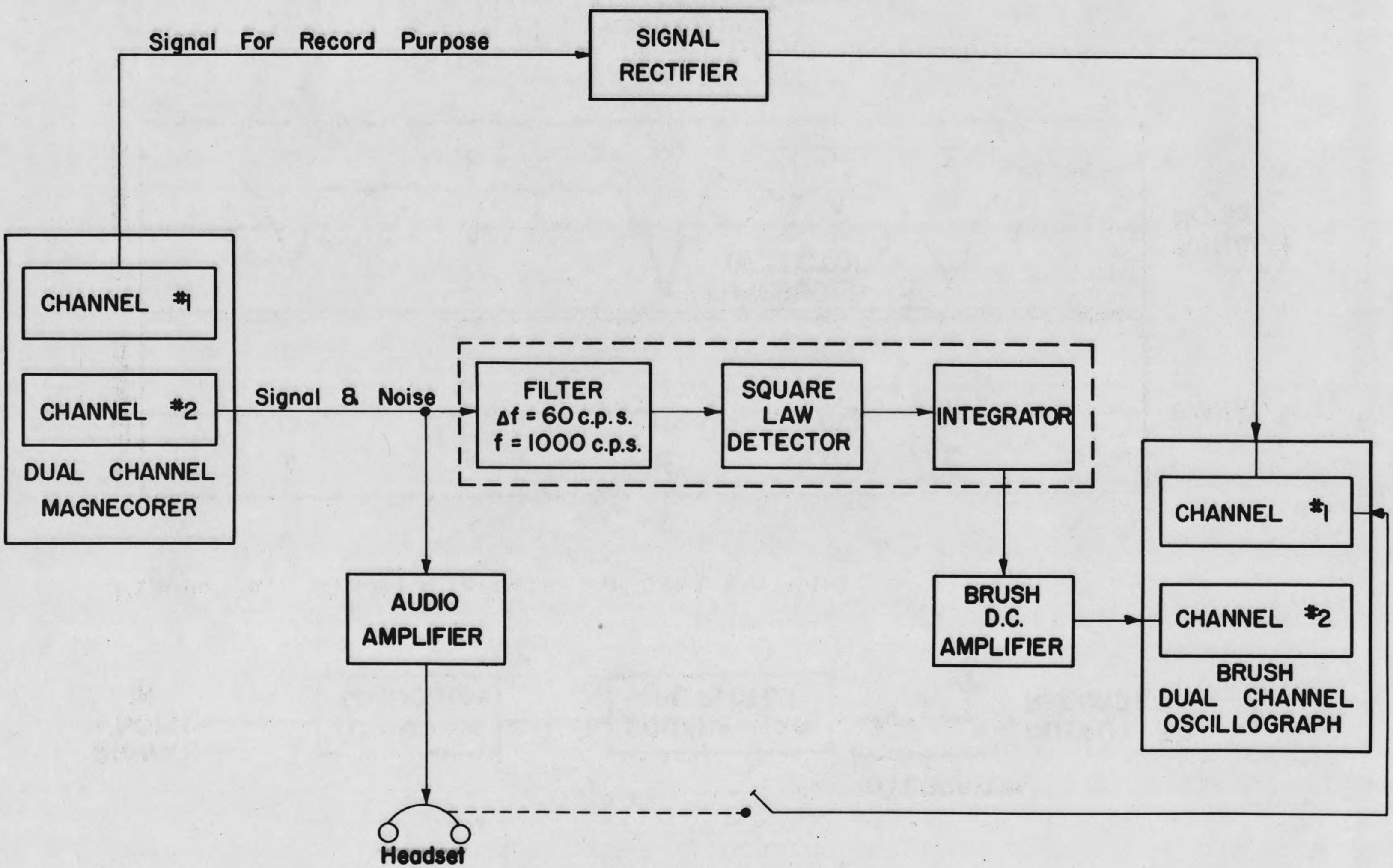

Figure 2. Block Diagram of Apparatus Used to Present Stimuli to the Human Detector and to the Electronic Detector.

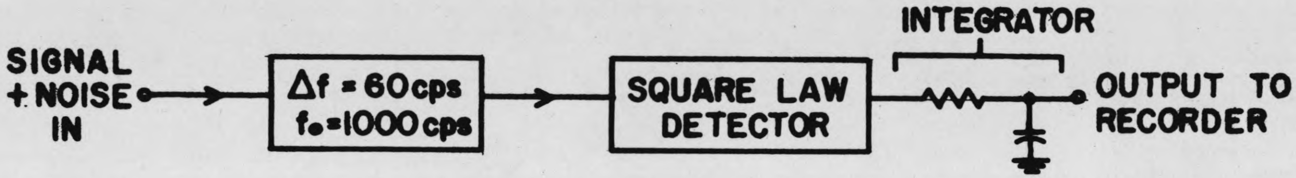

Figure 3a. Electronic Detector Used as Model.

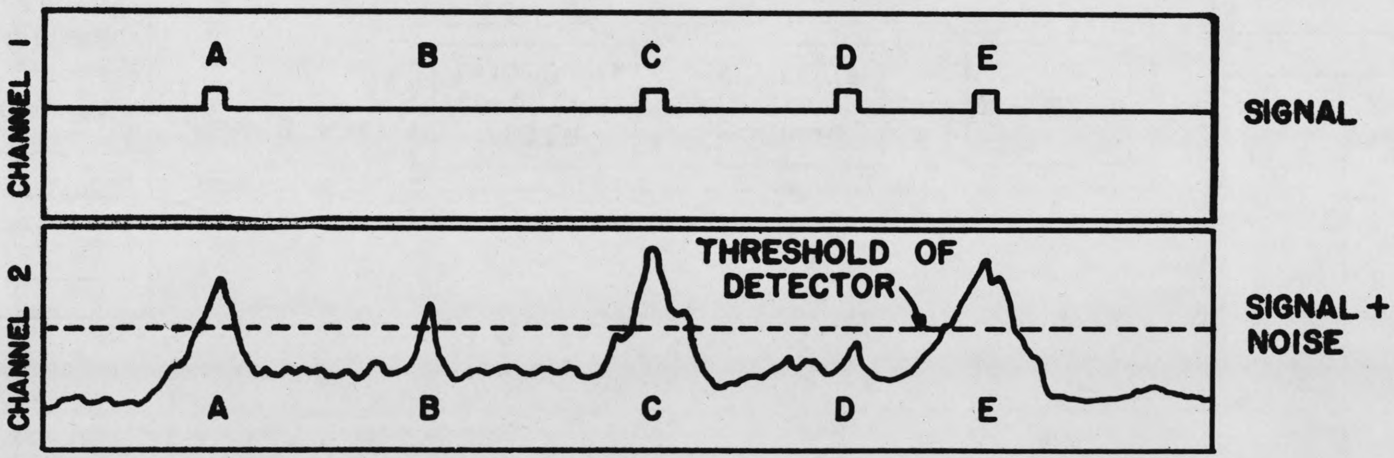

Figure 3b. A Typical Sequence of Events on the Brush Recorder.
A, C, E - Signal Detections.
B - False Alarm (Electronic Circuit).
D - Signal Miss.

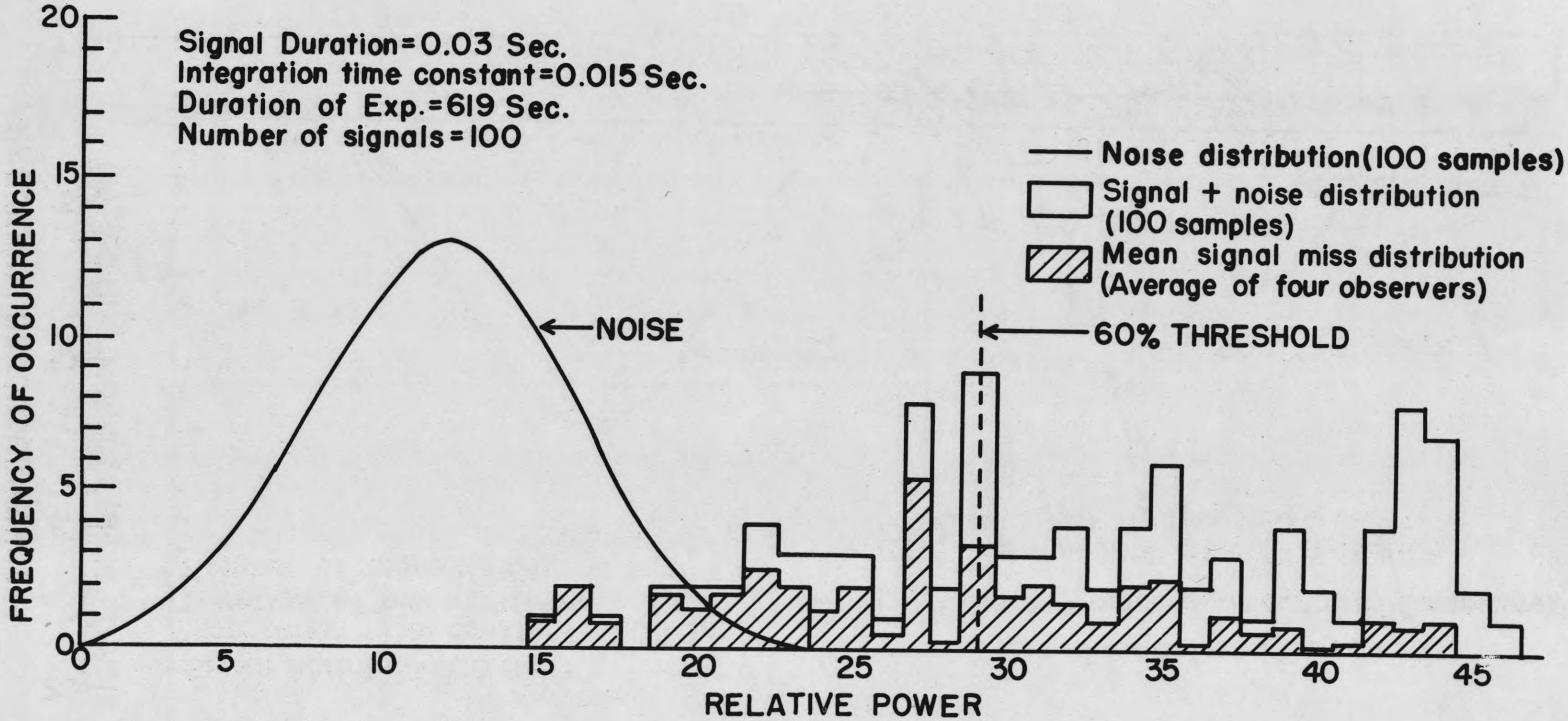

Figure 4. Distribution in Power at the Output of the Electronic Detector for 100 Samples of Noise and 100 Samples .03 second Signals Plus Noise. The shaded area represents the average signal-miss distribution of the four observers. The continuous noise curve is Gaussian based on 100 measured samples.

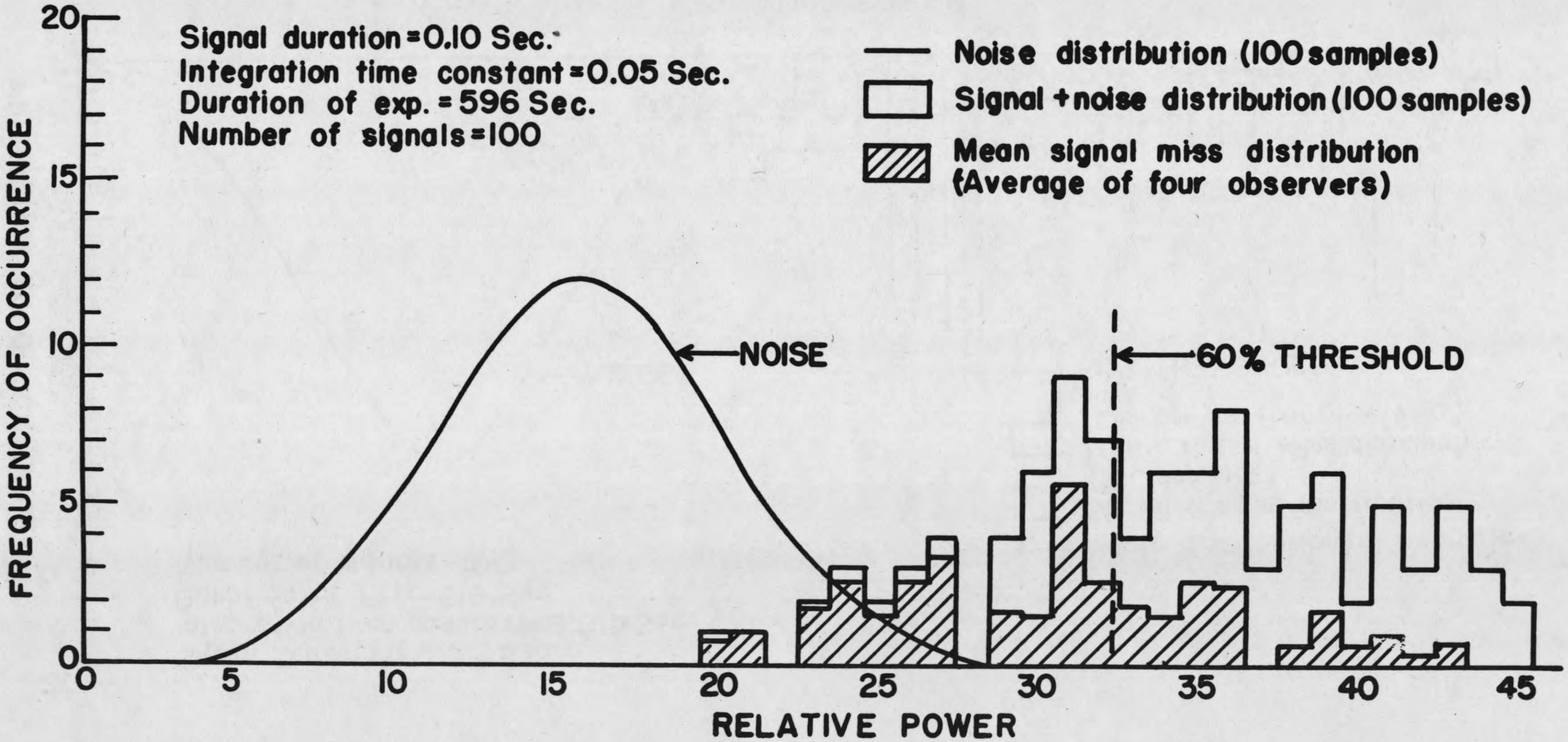

Figure 5. Distribution in Power at the Output of the Electronic Detector for 100 Samples of 0.1 second Signals Plus Noise. The shaded area represents the average signal-miss distribution of the four observers. The continuous noise curve is Gaussian based on 100 measured samples.

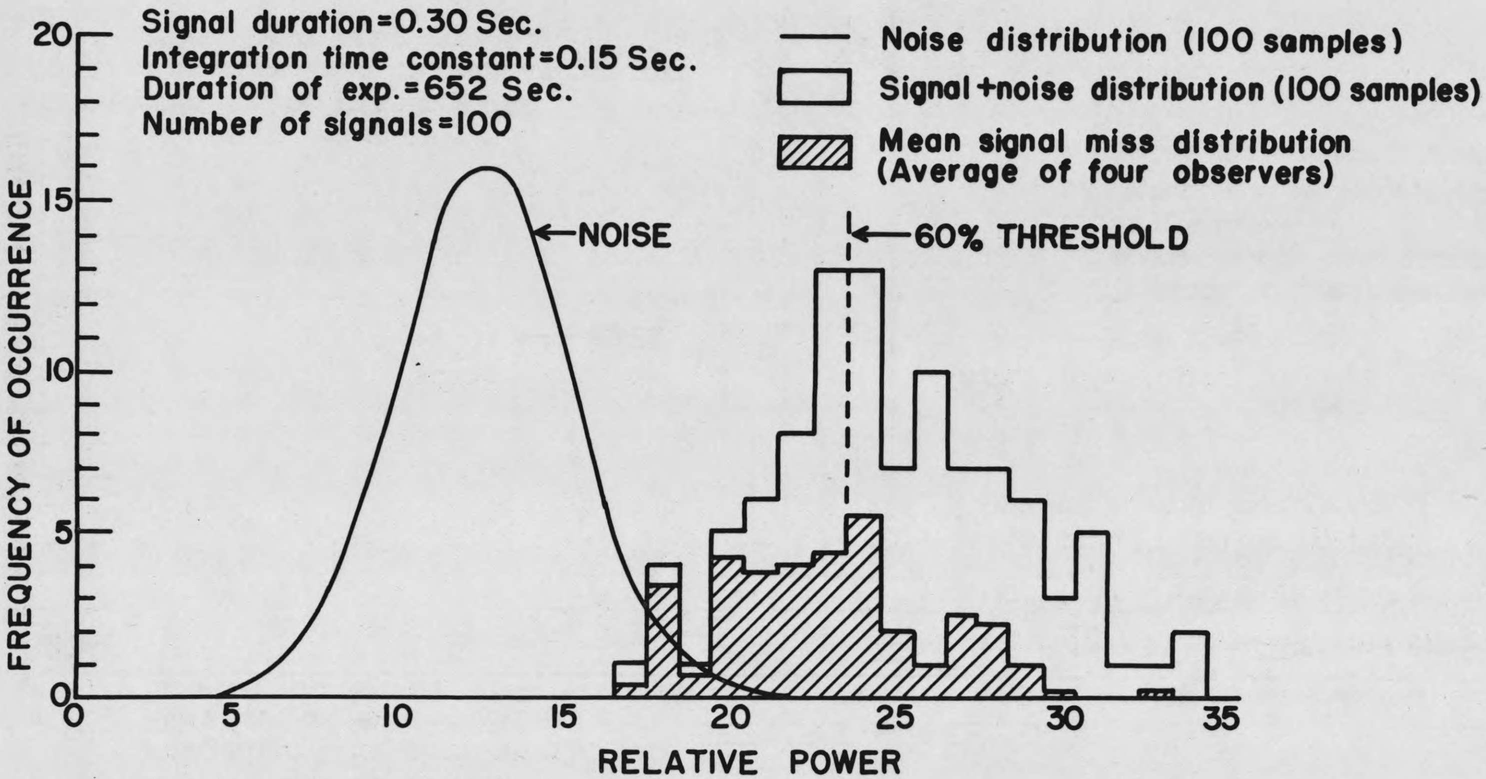

Figure 6. Distribution in Power at the Output of the Electronic Detector for 100 Samples of 0.3 second Signals Plus Noise. The shaded area represents the average signal-miss distribution of the four observers. The continuous noise curve is Gaussian, based on 100 measured samples.

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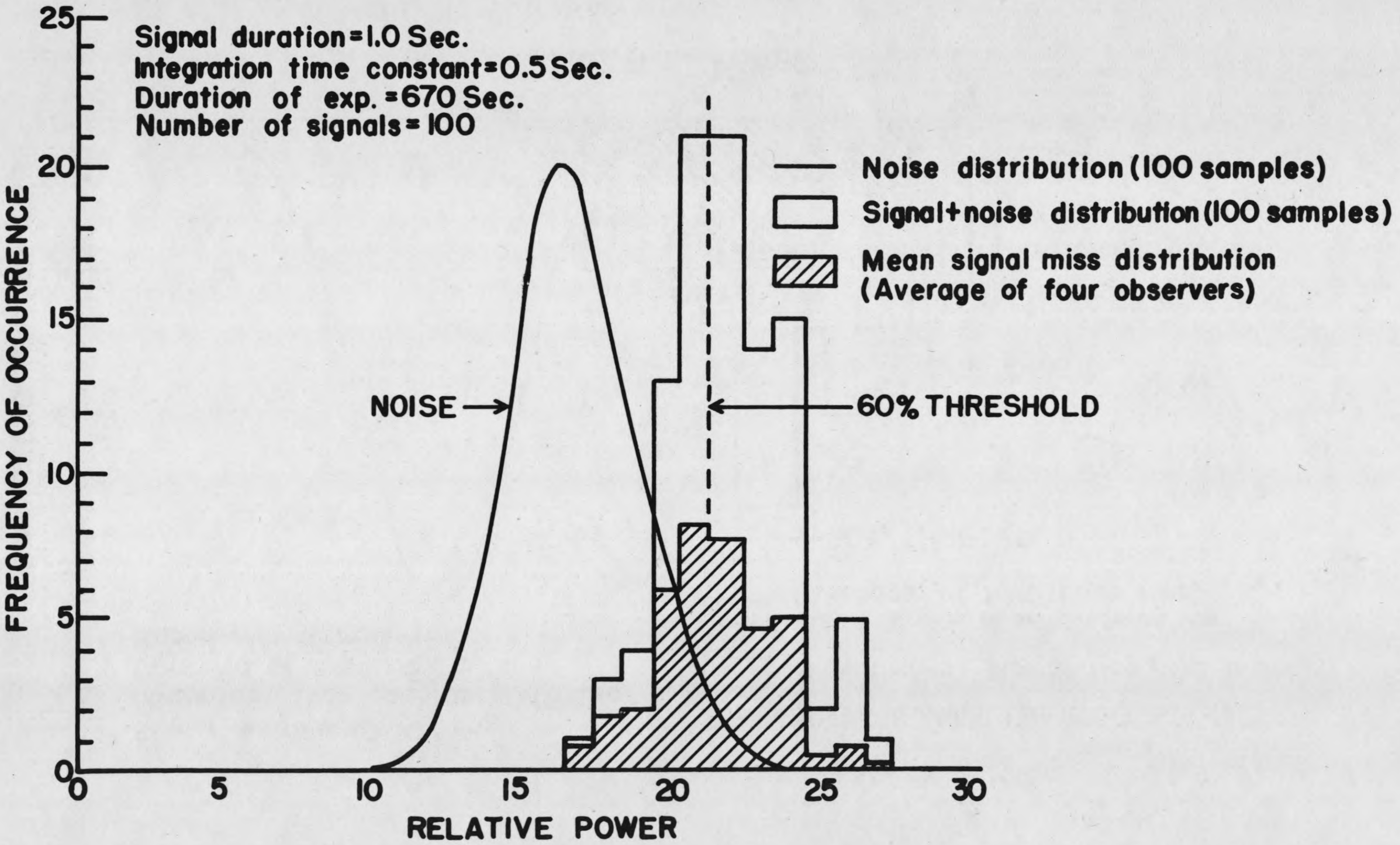

Figure 7. Distribution in Power at the Output of the Electronic Detector for 100 Samples of 1.0 second Signals Plus Noise. The shaded area represents the average signal-miss distribution of the four observers. The continuous noise curve is Gaussian, based on 100 measured samples.

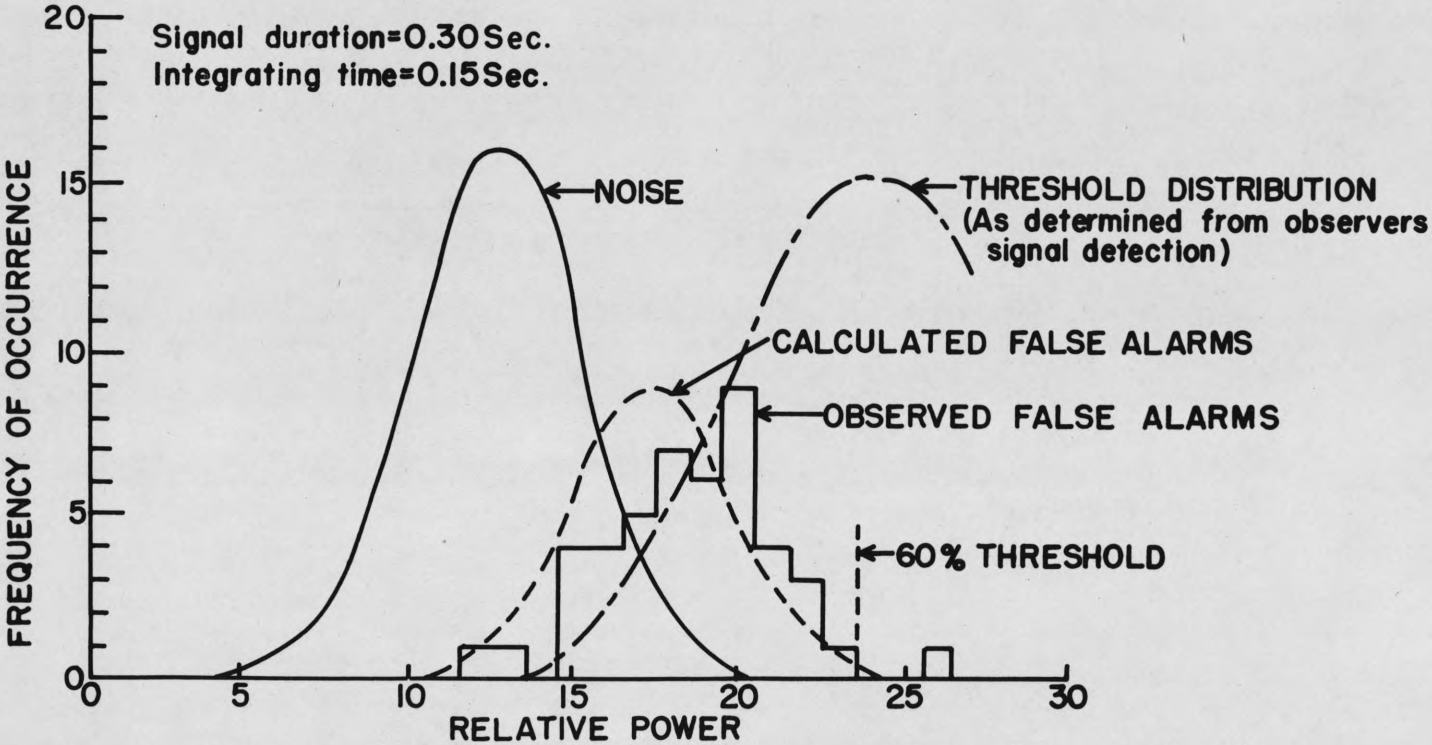

Figure 8. Noise Distribution and False Alarm Distribution as a Function of Relative Power. 0.3 Second Signal. The "observed false alarms" are 46 samples occuring in 16 runs using human observers. The "calculated false alarms" shows the shape (but not the absolute intensity) of the noise distribution which will cause false alarms in an electronic detector with the varying threshold shown.

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Appendix Table 1. Frequency Distribution, Mean Number of Signal Misses per Interval and Percentage of Signal Misses per Interval for the 100 Signals of 0.03 sec. Duration.

Relative Power	Frequency Distribution	Mean Number Signal Misses	% Signal Misses
15	1	.88	88
16	2	1.75	88
17	1	.94	94
18	-	--	--
19	2	1.69	84
20	2	1.06	53
21	2	1.69	84
22	4	2.56	64
23	3	2.06	69
24	3	1.06	35
25	3	2.13	71
26	1	.44	44
27	8	5.56	70
28	2	.06	3
29	9	3.38	38
30	3	1.69	56
31	3	1.81	60
32	4	1.44	36
33	2	.88	44
34	4	2.19	55
35	6	2.25	38
36	2	.06	3
37	3	1.25	42
38	1	.63	63
39	4	.94	23
40	2	.13	6
41	1	.44	44
42	4	1.00	25
43	8	.81	10
44	7	1.19	17
45	2	0.00	0
46	1	0.00	0
	100		

Appendix Table 2. Frequency Distribution, Mean Number of Signal Misses per Interval and Percentage of Signal Misses per Interval for the 100 Signals of 0.10 sec. Duration.

Relative Power	Frequency Distribution	Mean Number Signal Misses	% Signal Misses
20	1	.88	88
21	1	1.00	100
22	-	--	--
23	2	1.88	94
24	3	2.44	81
25	2	1.68	84
26	3	2.81	94
27	4	3.38	84
28	-	--	--
29	4	1.56	39
30	6	1.50	25
31	9	5.50	61
32	7	2.69	38
33	4	1.94	49
34	6	1.56	26
35	6	2.50	42
36	8	2.38	30
37	3	0.00	00
38	5	.63	13
39	6	1.88	31
40	2	.68	34
41	5	1.00	20
42	3	.19	6
43	5	.63	13
44	3	0.00	00
45	2	.40	2
	100		

Appendix Table 3. Frequency Distribution, Mean Number of Signal Misses per Interval and Percentage of Signal Misses per Interval for the 100 Signals of 0.30 Duration.

Relative Power	Frequency Distribution	Mean Number Signal Misses	% Signal Misses
17	1	.38	38
18	4	3.38	84
19	1	.75	75
20	5	4.25	85
21	6	3.56	71
22	8	3.68	46
23	13	4.25	33
24	13	5.75	44
25	7	1.75	25
26	10	.81	8
27	7	2.56	37
28	7	2.13	30
29	6	.75	13
30	3	.06	2
31	5	0.00	0
32	1	0.00	0
33	1	.18	18
34	2	0.00	0
	100		

Appendix Table 4. Frequency Distribution, Mean Number of Signal Misses per Interval and Percentage of Signal Misses per Interval for the 100 Signals of 1.00 sec. Duration.

Relative Power	Frequency Distribution	Mean Number Signal Misses	% Signal Misses
17	1	.75	75
18	3	1.94	65
19	4	2.13	53
20	13	7.13	55
21	21	9.25	44
22	21	8.75	42
23	14	4.56	33
24	15	4.88	33
25	2	.31	16
26	5	.88	18
27	1	.25	25
	100		

Appendix Table 5. Individual Relative Power Values in Sequence for the 100 Signals of 0.03 Second Duration.

Signal	Level	Signal	Level
1.	34	51.	31
2.	45	52.	16
3.	37	53.	32
4.	29	54.	29
5.	29	55.	17
6.	29	56.	28
7.	32	57.	26
8.	29	58.	44
9.	30	59.	33
10.	39	60.	34
11.	44	61.	24
12.	42	62.	42
13.	27	63.	29
14.	24	64.	43
15.	32	65.	44
16.	33	66.	25
17.	19	67.	42
18.	44	68.	44
19.	24	69.	23
20.	27	70.	39
21.	23	71.	23
22.	27	72.	27
23.	35	73.	27
24.	27	74.	29
25.	31	75.	43
26.	20	76.	27
27.	45	77.	38
28.	35	78.	46
29.	16	79.	29
30.	27	80.	22
31.	34	81.	44
32.	25	82.	30
33.	39	83.	36
34.	43	84.	43
35.	31	85.	21
36.	32	86.	20
37.	21	87.	40
38.	28	88.	42
39.	19	89.	37
40.	41	90.	35
41.	30	91.	43
42.	43	92.	34
43.	22	93.	22
44.	36	94.	29
45.	35	95.	39
46.	43	96.	40
47.	15	97.	43
48.	22	98.	35
49.	35	99.	44
50.	25	100.	37

Appendix Table 6. Individual Relative Power Values in Sequence for the 100 Signals of 0.10 Second Duration.

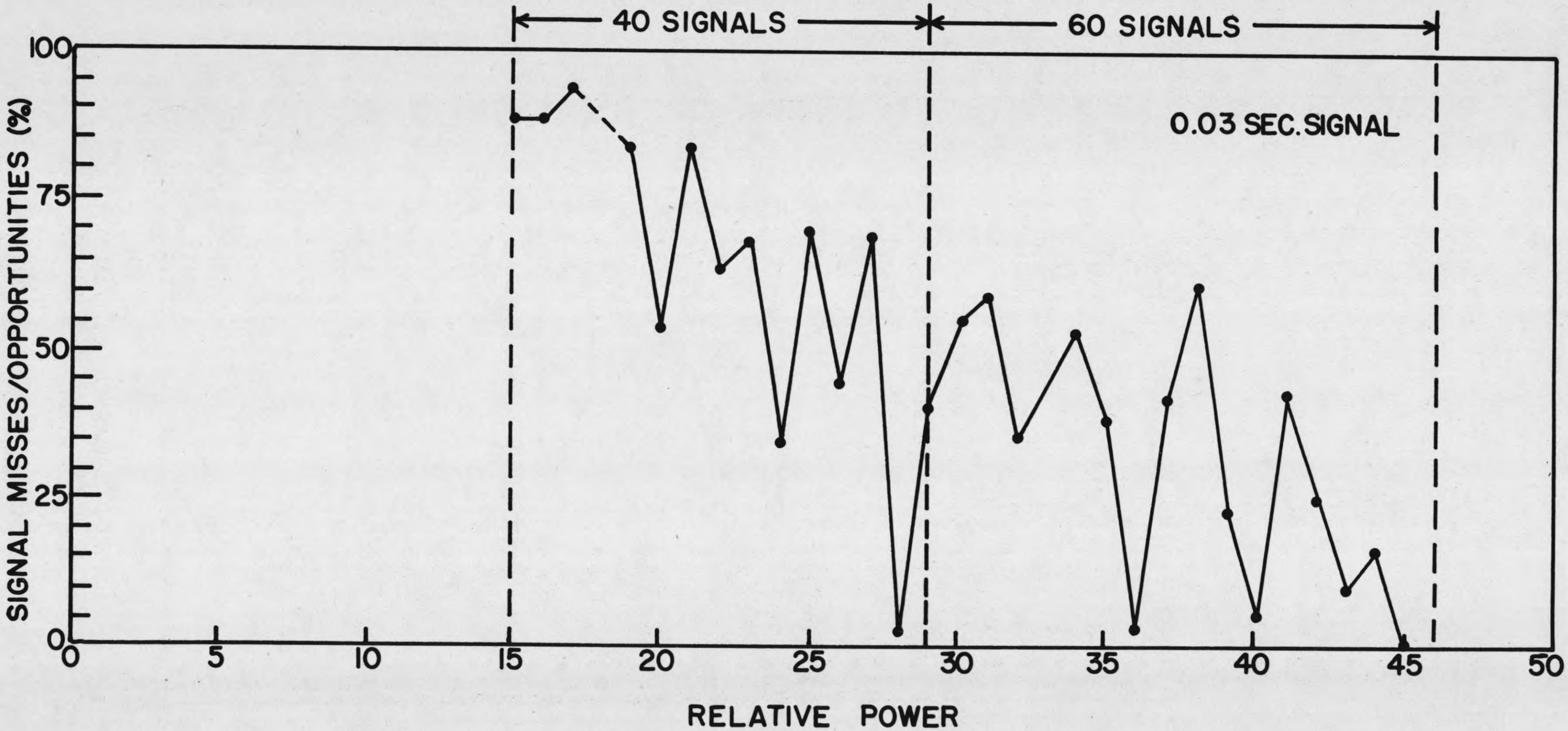
Signal	Level	Signal	Level
1.	22	51.	26
2.	23	52.	24
3.	22	53.	23
4.	22	54.	22
5.	22	55.	21
6.	21	56.	21
7.	20	57.	23
8.	21	58.	24
9.	24	59.	19
10.	21	60.	24
11.	21	61.	26
12.	24	62.	24
13.	24	63.	20
14.	19	64.	22
15.	18	65.	23
16.	25	66.	22
17.	20	67.	20
18.	24	68.	19
19.	23	69.	24
20.	21	70.	21
21.	21	71.	21
22.	24	72.	22
23.	20	73.	21
24.	20	74.	17
25.	23	75.	22
26.	22	76.	19
27.	18	77.	21
28.	25	78.	20
29.	22	79.	24
30.	20	80.	23
31.	23	81.	24
32.	20	82.	22
33.	22	83.	26
34.	21	84.	23
35.	21	85.	23
36.	22	86.	21
37.	22	87.	24
38.	21	88.	23
39.	23	89.	21
40.	22	90.	20
41.	22	91.	20
42.	21	92.	22
43.	23	93.	22
44.	20	94.	21
45.	21	95.	24
46.	22	96.	23
47.	20	97.	27
48.	18	98.	26
49.	24	99.	23
50.	21	100.	26

Appendix Table 7. Individual Relative Power Values in Sequence for the 100 Signals of 0.30 Second Duration.

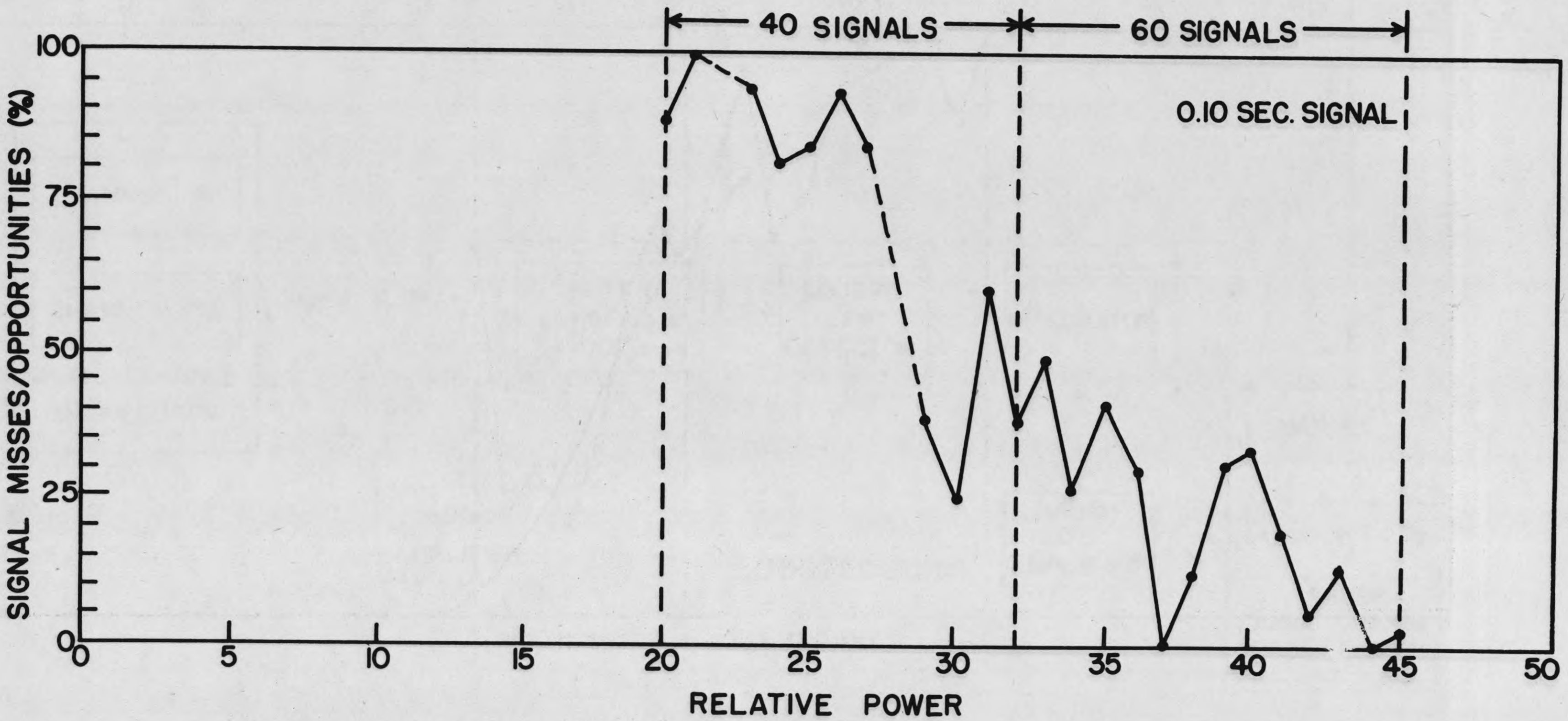
Signal	Level	Signal	Level
1.	23	51.	27
2.	21	52.	22
3.	24	53.	29
4.	22	54.	31
5.	26	55.	22
6.	30	56.	24
7.	25	57.	23
8.	26	58.	19
9.	27	59.	22
10.	28	60.	28
11.	26	61.	18
12.	24	62.	26
13.	28	63.	24
14.	29	64.	24
15.	32	65.	27
16.	21	66.	31
17.	24	67.	24
18.	22	68.	22
19.	33	69.	25
20.	31	70.	17
21.	34	71.	23
22.	26	72.	20
23.	21	73.	25
24.	23	74.	18
25.	29	75.	23
26.	29	76.	31
27.	22	77.	27
28.	23	78.	23
29.	24	79.	26
30.	20	80.	23
31.	21	81.	23
32.	26	82.	21
33.	24	83.	21
34.	29	84.	27
35.	25	85.	24
36.	20	86.	28
37.	29	87.	25
38.	28	88.	26
39.	31	89.	30
40.	27	90.	26
41.	23	91.	24
42.	24	92.	28
43.	27	93.	18
44.	25	94.	28
45.	23	95.	20
46.	23	96.	26
47.	34	97.	23
48.	20	98.	24
49.	25	99.	22
50.	18	100.	30

Appendix Table 8. Individual Relative Power Values in Sequence for the 100 Signals of 1.0 Second Duration.

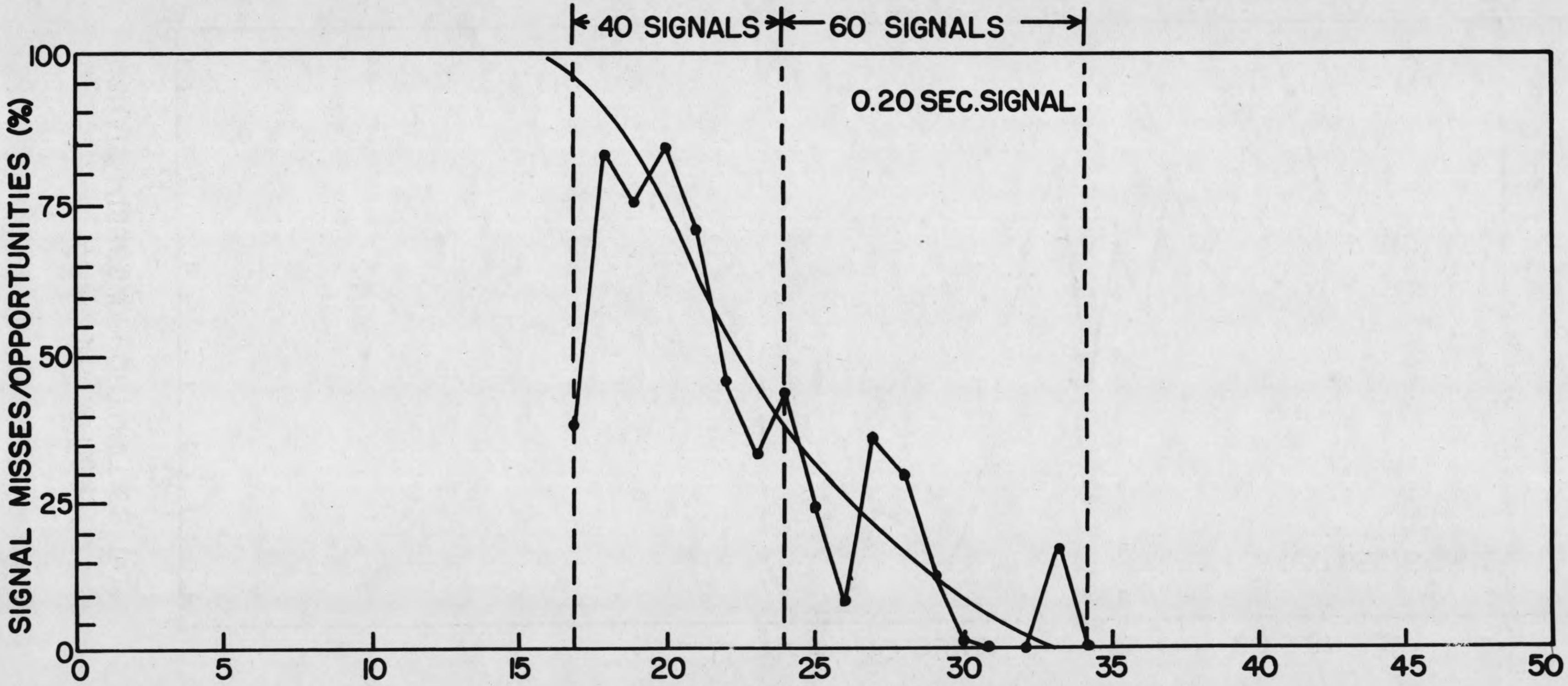
Signal	Level	Signal	Level
1.	44	51.	37
2.	26	52.	33
3.	30	53.	42
4.	41	54.	33
5.	30	55.	38
6.	32	56.	34
7.	41	57.	41
8.	31	58.	38
9.	37	59.	31
10.	23	60.	34
11.	37	61.	36
12.	43	62.	43
13.	24	63.	34
14.	36	64.	36
15.	31	65.	32
16.	39	66.	40
17.	31	67.	43
18.	42	68.	43
19.	35	69.	36
20.	24	70.	31
21.	31	71.	36
22.	31	72.	32
23.	30	73.	35
24.	35	74.	25
25.	33	75.	41
26.	29	76.	39
27.	42	77.	34
28.	27	78.	30
29.	44	79.	34
30.	35	80.	26
31.	35	81.	25
32.	38	82.	29
33.	27	83.	32
34.	38	84.	27
35.	45	85.	32
36.	32	86.	26
37.	39	87.	31
38.	27	88.	36
39.	38	89.	43
40.	30	90.	45
41.	21	91.	39
42.	40	92.	44
43.	39	93.	29
44.	33	94.	24
45.	39	95.	35
46.	23	96.	36
47.	34	97.	29
48.	32	98.	30
49.	36	99.	20
50.	31	100.	41



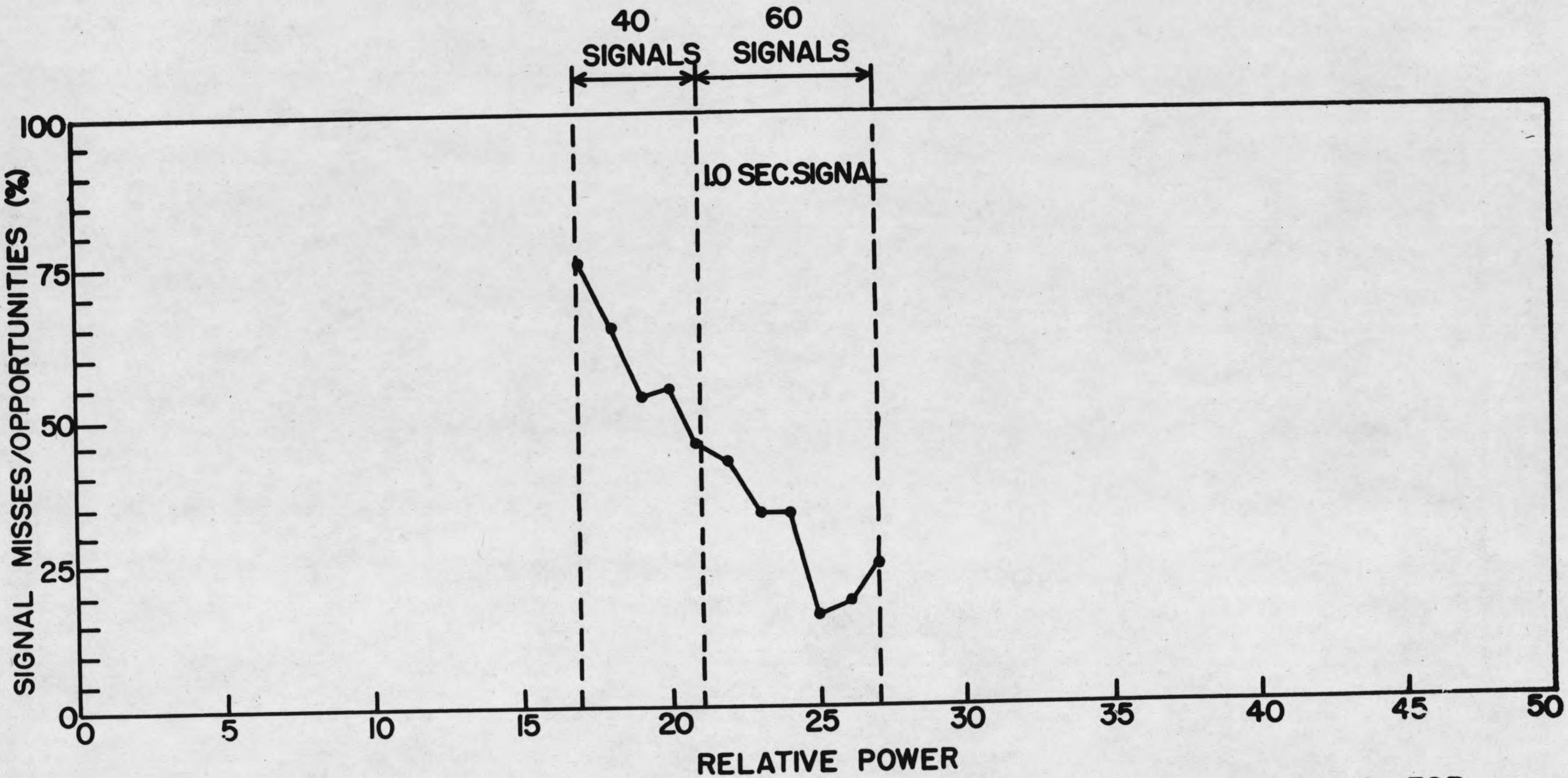
APPENDIX FIG. 1. PERCENTAGE OF SIGNAL MISSES PER TOTAL NUMBER OF SIGNALS FOR EACH INTERVAL OF THE DISTRIBUTION.



APPENDIX FIG. 2. PERCENTAGE OF SIGNAL MISSES PER TOTAL NUMBER OF SIGNALS FOR EACH INTERVAL OF THE DISTRIBUTION.



APPENDIX FIG. 3. PERCENTAGE OF SIGNAL MISSES PER TOTAL NUMBER OF SIGNALS FOR EACH INTERVAL OF THE DISTRIBUTION. THE SMOOTH CURVE IS USED TO OBTAIN THE OBSERVERS THRESHOLD DISPERSION USED IN FIG. 8 OF THE REPORT.



APPENDIX FIG. 4. PERCENTAGE OF SIGNAL MISSES PER TOTAL NUMBER OF SIGNALS FOR EACH INTERVAL OF THE DISTRIBUTION.

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