AD NUMBER
AD875237
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; AUG 1970. Other requests shall be referred to Air Force Technical Applications Center, VSC, Alexandria, VA 22313. This document contains export-controlled technical data.**
AUTHORITY
usaf ltr, 25 jan 1972

AD875237

AD No. ___
DDC FILE COPY

AFTAC Project No. VELA/T/0701/B/ASD

SIMULATION OF ADAPTIVE ON-LINE MAXIMUM-LIKELIHOOD PROCESSING

Technical Report No. 11

SEISMIC ARRAY PROCESSING TECHNIQUES

Prepared by

Ronald J. Holyer

Stanley J. Laster, Project Scientist

Frank H. Binder, Program Manager
Area Code 214, 238-6521

TEXAS INSTRUMENTS INCORPORATED
Services Group
P.O. Box 5621
Dallas, Texas 75222

Contract No. F33657-70-C-0100
Amount of Contract: $339,052
Beginning 15 July 1969
Ending 14 July 1970

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Order No. 624
ARPA Program Code No. 9F10

20 August 1970

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F33657-70-C-0100.

AFTAC Project No. VELA/T/0701/B/ASD

SIMULATION OF ADAPTIVE ON-LINE MAXIMUM-LIKELIHOOD PROCESSING

Technical Report No. 11

SEISMIC ARRAY PROCESSING TECHNIQUES

Prepared by

Ronald J. Holyer

Stanley J. Laster, Project Scientist

Frank H. Binder, Program Manager
Area Code 214, 238-6521

TEXAS INSTRUMENTS INCORPORATED
Services Group
P.O. Box 5621
Dallas, Texas 75222

Contract No. F33657-70-C-0100
Amount of Contract: $339,052
Beginning 15 July 1969
Ending 14 July 1970

Prepared for

AIR FORCE TECHNICAL APPLICATIONS CENTER
Washington, D. C. 20333

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY
Nuclear Monitoring Research Office
ARPA Order No. 624
ARPA Program Code No. 9F10

20 August 1970

Acknowledgment: This research was supported by the Advanced Research Projects Agency, Nuclear Monitoring Research Office, under Project VELA-UNIFORM, and accomplished under the technical direction of the Air Force Technical Applications Center under Contract No. F33657-70-C-0100.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, A 'TAC.

Qualified users may request copies of this document from:

Defense Documentation Center
Cameron Station
Alexandria, Virginia 22314

ABSTRACT

On-line adaptive maximum-lieklihood processing has been simulated on the IBM S/360 computer to investigate some of the problems associated with on-line processing. The problems considered were the presence of signals in the data, dead or noisy channels, and signal model errors in adaptive beamsteers. Experimental results indicate that relatively simple techniques are effective in reducing the detrimental effects of these on-line problems to an insignificant level.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONT'D)

SECTION I

INTRODUCTION AND SUMMARY

The performance characteristics of adaptively-designed maximum-likelihood time-domain filters have been the subject of several previous investigations.[1,2,3,4] Positive results on these studies have created interest in an adaptive on-line processor where the ability of the processor to automatically change with time-varying data statistics could be used to great advantage.

Certain practical problems, however, not normally encountered in off-line operation are inherent to processing in an on-line adaptive mode. The presence of signals in the data is a problem if the adaptive processor adapts to the signal, thus losing signal-passing and noise-rejection capabilities. Another practical problem is dead or noisy channels. The dead channel case could be especially serious since the adaptive algorithm in its efforts to minimize output would weigh the dead channel heavily. Other problems are anticipated in the formation of directional adaptive beams. In these cases the moveout of the signal across the array may not coincide to an exact multiple of the digital sampling interval on every channel. Thus, the signal model must be approximated to the nearest sample point. This difference between signal and signal model may result in signal attenuation. These problems must be investigated prior to implementation of adaptive on-line processing. The purpose of the experiment described in this report is to examine the effects of these on-line problems by simulation of an on-line processor on the IBM/S/360 computer.

The signal problem was handled by a simple algorithm for a time-varying signal detection threshold. This threshold was used as the criterion of signal presence whereby filter-coefficients were frozen (adaption omitted) when signals were present. Data with signals added at S/N ratios

0.5, 4, and 10 were processed. Examination of the filters as they existed immediately after the signals showed no significant degradation of their noise-rejection or signal-passing capabilities.

Detection of dead or noisy channels was achieved by means of another algorithm whereby a bad channel was zeroed and the filter coefficients for that channel were distributed evenly among the remaining good channels. This distribution of the filter weights was necessary to preserve the maximum-likelihood constraints. Comparison of wavenumber responses and total mean-square error values before and after channel detection showed the results of channel deletion on filter performance to be insignificant.

By modification of the computer program which calculates wavenumber responses of filters, the effects of signal model errors were simulated and found to be small.

A previous study[5] dealt with some of these problems. The present experiment, however, carries the investigation further. Previously signals were processed and their effects measured but no attempt on on-line signal detection and filter freezing was made as has been done in this experiment. Similarly, channel deletion and addition effects were measured, but an on-line process by which data quality control could be performed was not attempted.

SECTION II

ADAPTIVE MAXIMUM-LIKELIHOOD ALGORITHM

The adaptive maximum-likelihood algorithm programmed was the "full-gradient" algorithm which has been described in previous reports.[1,5] According to this algorithm the filter output at time t, Y_t, is given by

$$Y_t = \sum_{i=1}^{NC} \sum_{j=1}^{LF} F_{i,j}^t X_{i,t-j} \quad (2\text{-}1)$$

where $F_{i,j}^t$ is the filter weight of the i^{th} channel and j^{th} point at time t

$X_{i,t}$ is the input data of the i^{th} channel at time t

NC is the number of channels

LF is the length of the filter.

The filters are updated according to the equation

$$F_{i,j}^{t+1} = F_{i,j}^t + 2KY_t(\bar{X}_{t-j} - X_{i,t-j}) \quad (2\text{-}2)$$

where

$$\bar{X}_{t-j} = \frac{1}{NC} \sum_{i=1}^{NC} X_{i,t-j}$$

K is the rate of convergence parameter.

The filter coefficients must satisfy the constraints

$$\sum_{i=1}^{NC} F_{i,j}^t = \delta_{j,k} \quad (2\text{-}3)$$

where

$$\frac{LF}{2} < k \leq \frac{LF+1}{2} .$$

If the filters initially satisfy these constraints, then Equation 2-2 insures that all subsequent updates will also satisfy the constraints.

The filter update becomes unstable and the filter output grows exponentially with time if the convergence parameter K exceeds some maximum value K_{max} given by[7]

$$K_{max} = \frac{1}{(NC)(LF)[R(o)]} \qquad (2\text{-}4)$$

where

R(o) is the average single channel zero-lag autocorrelation of the input data.

For the processing done in this experiment, K in Equation 2-3 is replaced with a time-vary constant, λ_t , given by

$$\lambda_t = \frac{2K\,(1-e^{-m/t})}{LF\sum_{i=1}^{NC} P_{i,t}} \qquad (2\text{-}5)$$

where

$$P_{i,t} = (1-\mu)(\bar{X}_t - X_{i,t})^2 + \mu P_{i,t-1}$$

μ is the memory time constant factor, $0<\mu<1$

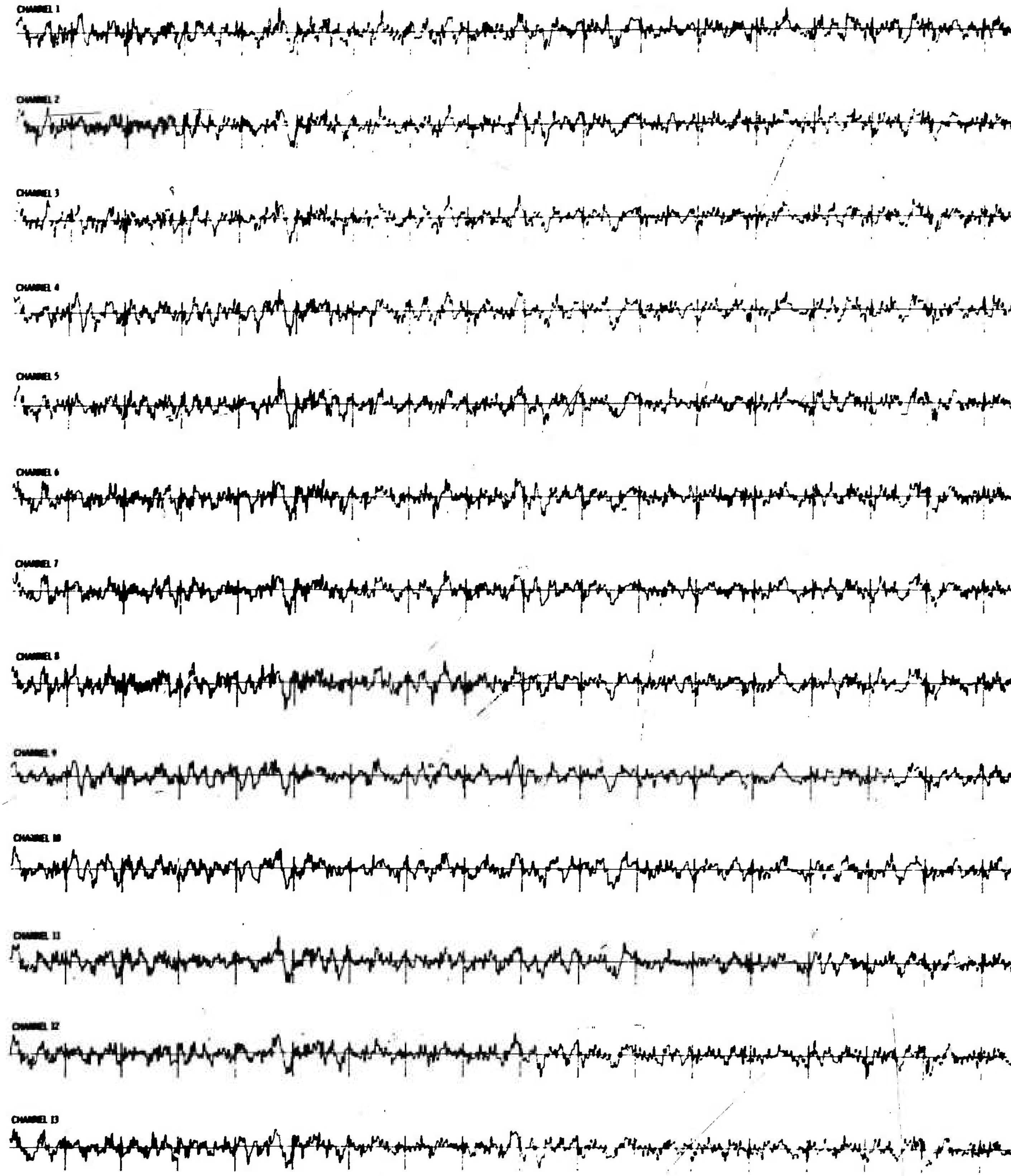
m is a decay factor, $t > 0$.

The denominator in Equation 2-5 is a time-varying estimate of the denominator in Equation 2-4.

SECTION III
DATA

One data sample was used as the basis for the processing in this experiment. This one sample was modified by the addition of signals and deletion of channels to simulate anticipated on-line problems.

The data (noise sample 1014) consisted of 13 channels of 2560 points each. The sample interval of the digital data was 0.072 sec. The data is plotted in Figure III-1 and the geometry of the array from which the data was recorded is shown in Figure III-2. The power spectrum of Channel 1 is shown in Figure III-3.


CHANNEL 1
CHANNEL 2
CHANNEL 3
CHANNEL 4
CHANNEL 5
CHANNEL 6
CHANNEL 7
CHANNEL 8
CHANNEL 9
CHANNEL 10
CHANNEL 11
CHANNEL 12
CHANNEL 13

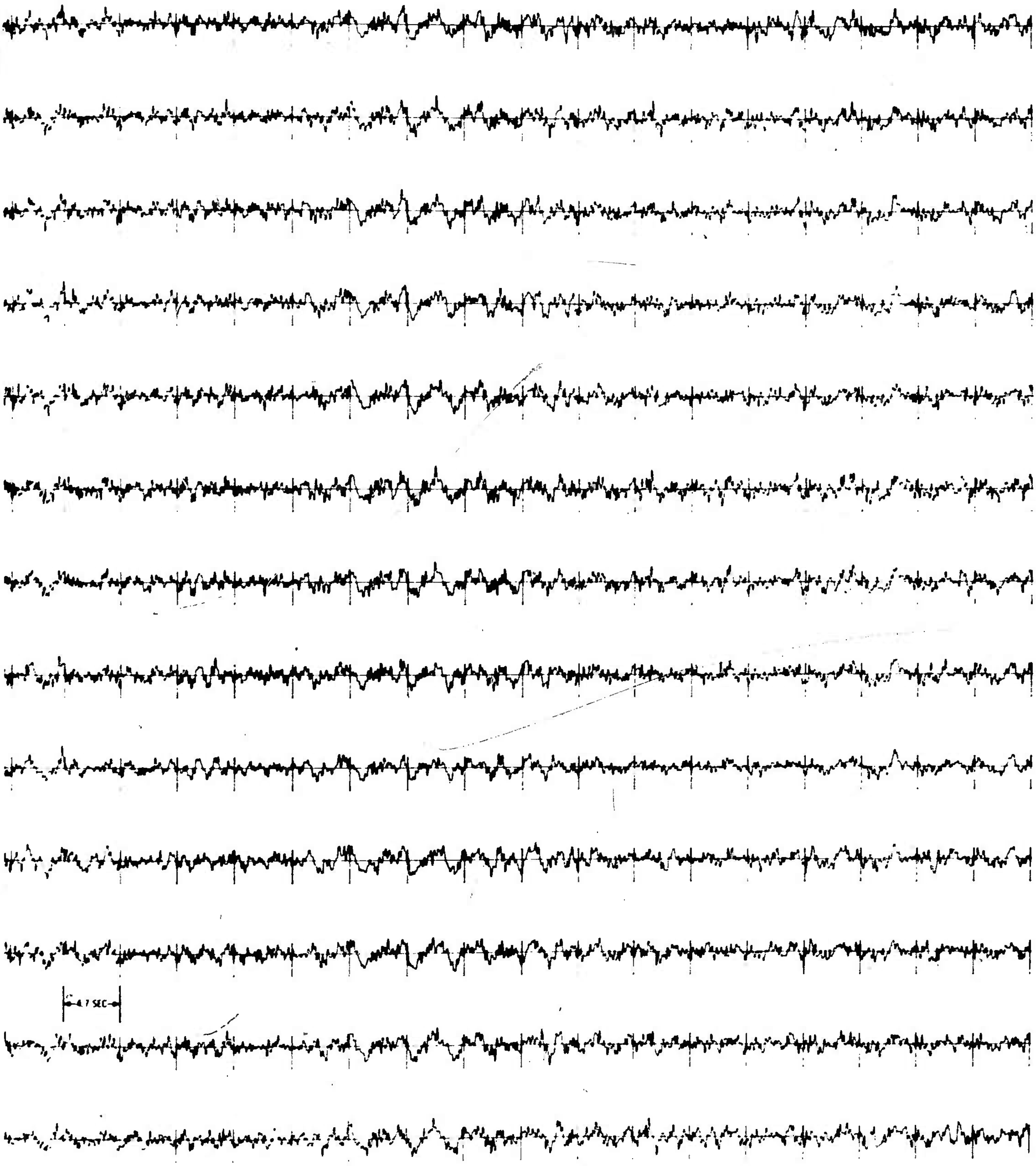


Figure III-1. Short-Period Noise Sample 1014

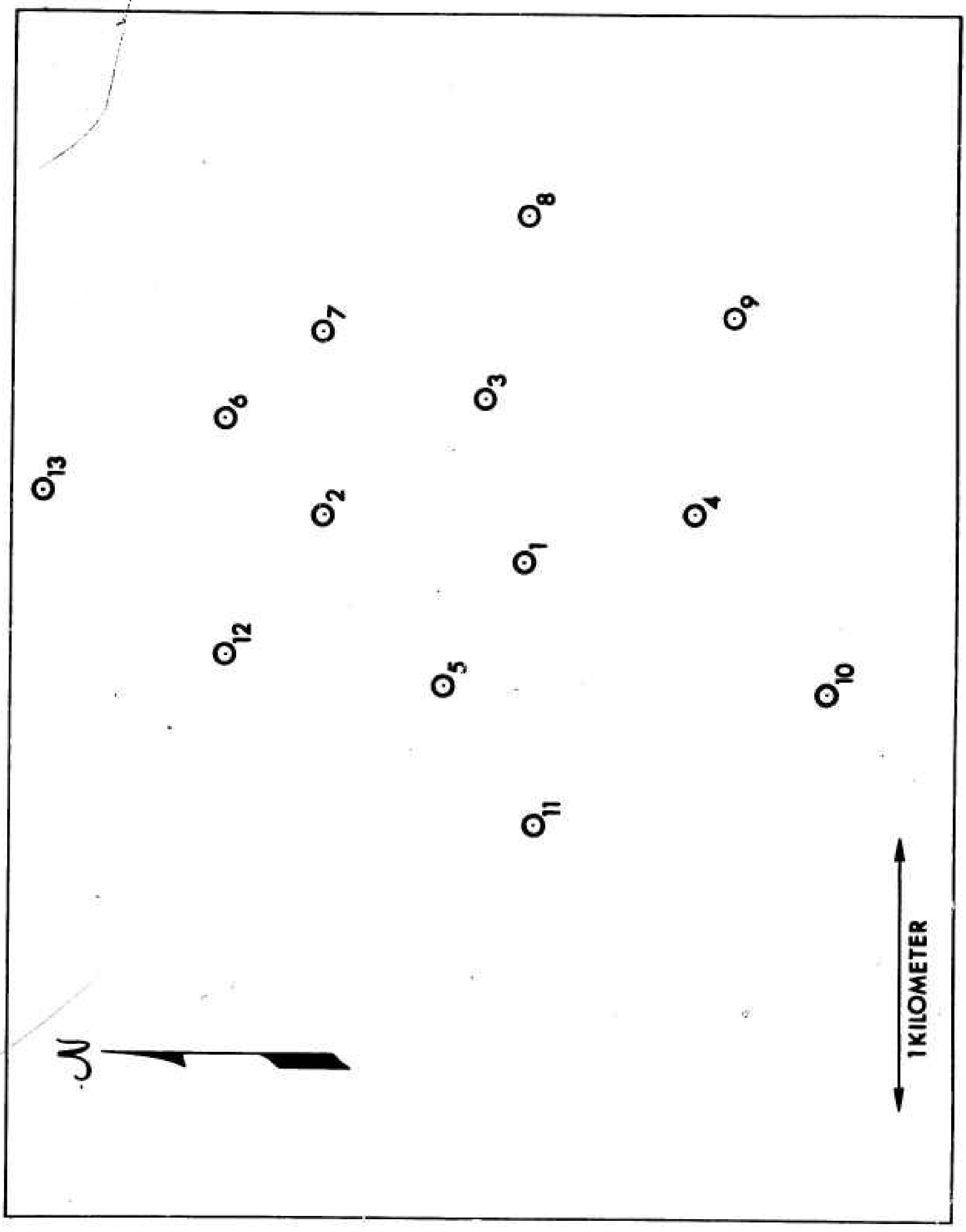


Figure III-2. 13-Channel Array Geometry

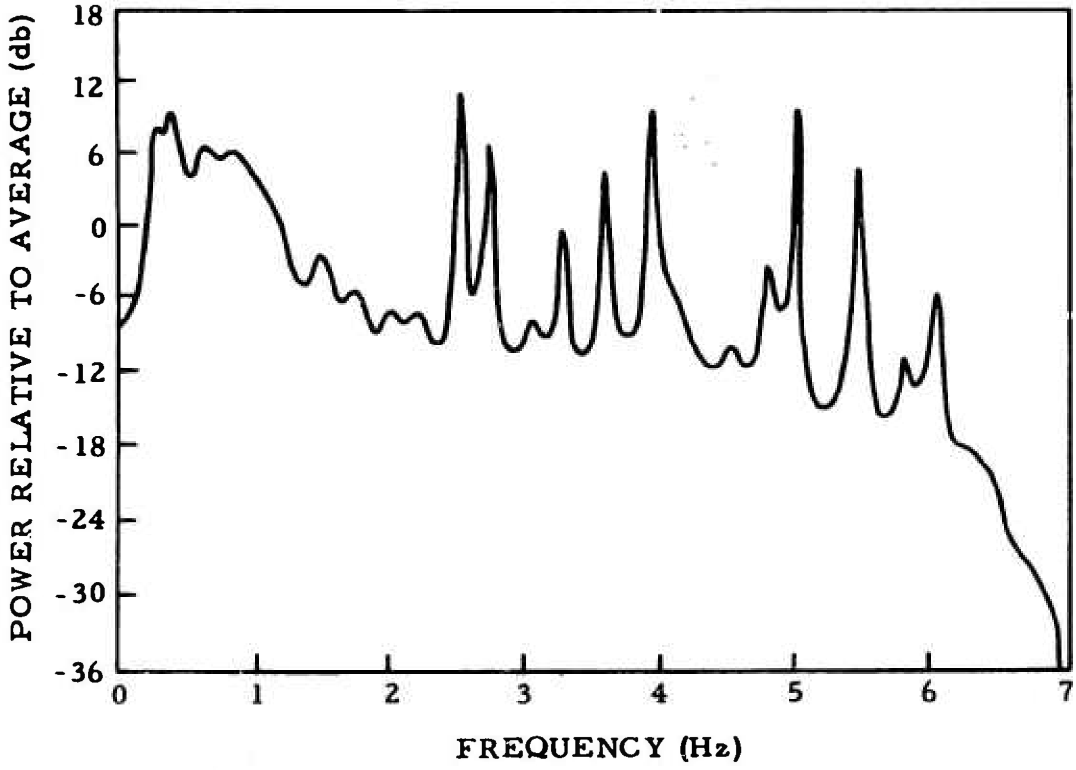


Figure III-3. Power Spectrum of Channel 1 of Noise Sample 1014

SECTION IV
SIGNAL PROBLEM

A. STATMENT OF THE PROBLEM

The adaptive maximum-likelihood filter is constrained from adapting to a signal if the signal matches the theoretical signal model. However, in the real world of on-line processing signals will not generally match the signal model exactly. Thus, the possibility of filter adaption to signals exists. Such adaption would introduce signal attenuation as well as loss of noise-rejection into the filter. It has been shown[5] that this signal attenuation in some cases can be significant. Thus, in on-line applications some scheme must be implemented to eliminate or at least minimize this problem. One such scheme has been applied experimentally here with good results.

B. SIGNAL DETECTION ALGORITHM

To detect the presence of signal, the filter output, Y_t, is compared with a time varying threshold value, Q_t,

$$Q_t = (1-\eta)\, Y_t^2 + \eta\, Q_{t-1} \qquad (4-1)$$

where η is the memory time constant factor for Q_t, $0<\eta<1$.

Signal is considered present if

$$Y_t > T\, Q_t^{1/2} \qquad (4-2)$$

where T is a variable threshold parameter. The factor $Q_t^{1/2}$ is an estimate of the standard deviation of the filter output. When signal is detected the filters are frozen (update omitted) to prevent adaption of the filters to the signal.

C. DETERMINATION OF A THRESHOLD VALUE

The first problem in implementing the signal detection algorithm is to determine the best value of T to use in Equation 4-2. One would like to make T as small as possible to increase probability of signal detection while on the other hand, T must be sufficiently large to prevent excessive signal alarms when no signal is present.

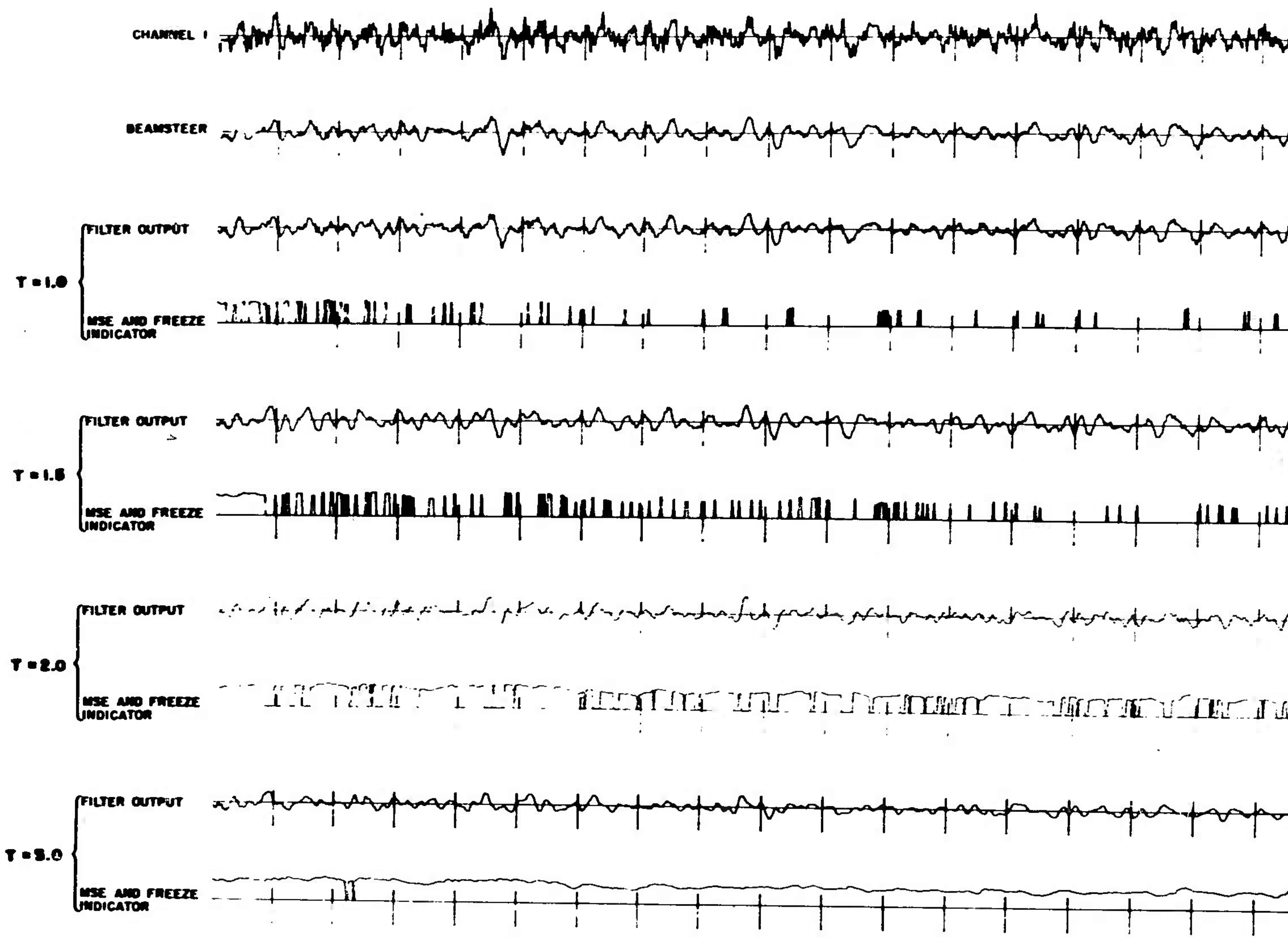
To determine the T value resulting in the best trade-off between signal detection and false alarm probability the noise data were processed with various T values ranging from 1 to 3. The filter applied was a 29 point (~2 sec) filter where the initial filter weights at the beginning of each pass through the data were given by

$$F^{1}_{i,j} = \begin{cases} 0 & j \neq 15 \\ \frac{1}{NC} & j = 15 \end{cases} \quad . \qquad (4\text{-}3)$$

Thus, the output of the filter for the first point is equivalent to the beamsteer output. As the filter adapts the filter output should show improvement over the beamsteer.

Using a convergence parameter of 0.25 times the theoretical maximum, data were processed with the results shown in Figure IV-1 for $\eta = 0.90$ and Figure IV-2 for $\eta = 0.995$. For each T value the filter output is shown along with an additional trace which indicates the mean-square filter output. A signal detection condition and associated filter freezing is denoted by a zero point in the mean-square output trace. In Figures IV-1 and IV-2 the increase in signal false alarms with decreasing T is apparent.

The question is how small can T be made before the false alarm problem becomes significant? From Figures IV-1 and IV-2 a percentage of false alarms for each T value could be calculated. However, such calculations would not be worthwhile since it is not known what percentage of false alarms results in what degree of impairment of filter performance. An alternate and more meaningful approach to analysis the data in Figures IV-1 and IV-2 was therefore taken. The average improvement of the filter output over the beamsteer in points 1792 through 2304 was calculated for each case.



CHANNEL 1
BEAMSTEER
FILTER OUTPUT
T = 1.0
MSE AND FREEZE INDICATOR
FILTER OUTPUT
T = 1.5
MSE AND FREEZE INDICATOR
FILTER OUTPUT
T = 2.0
MSE AND FREEZE INDICATOR
FILTER OUTPUT
T = 3.0
MSE AND FREEZE INDICATOR

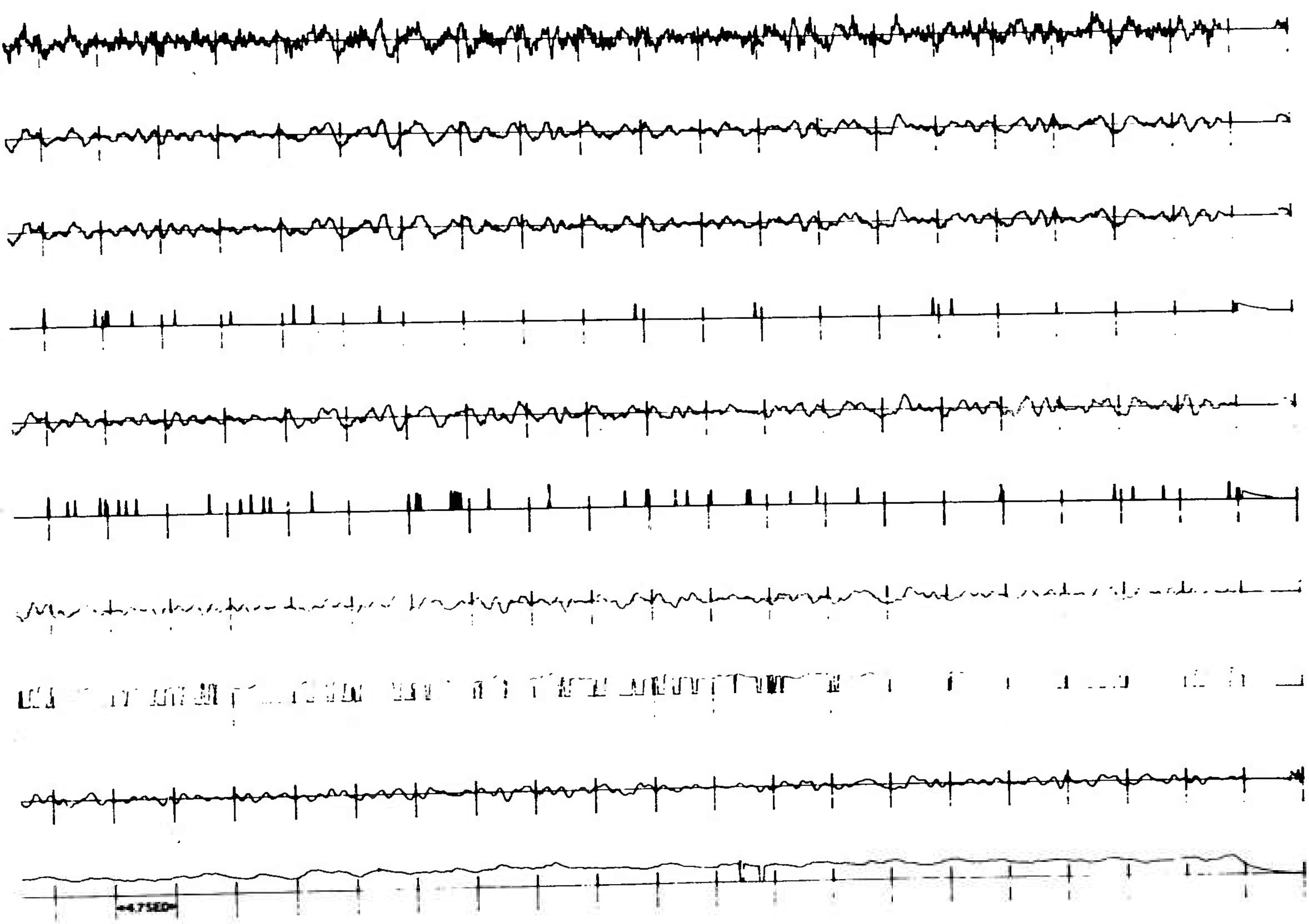
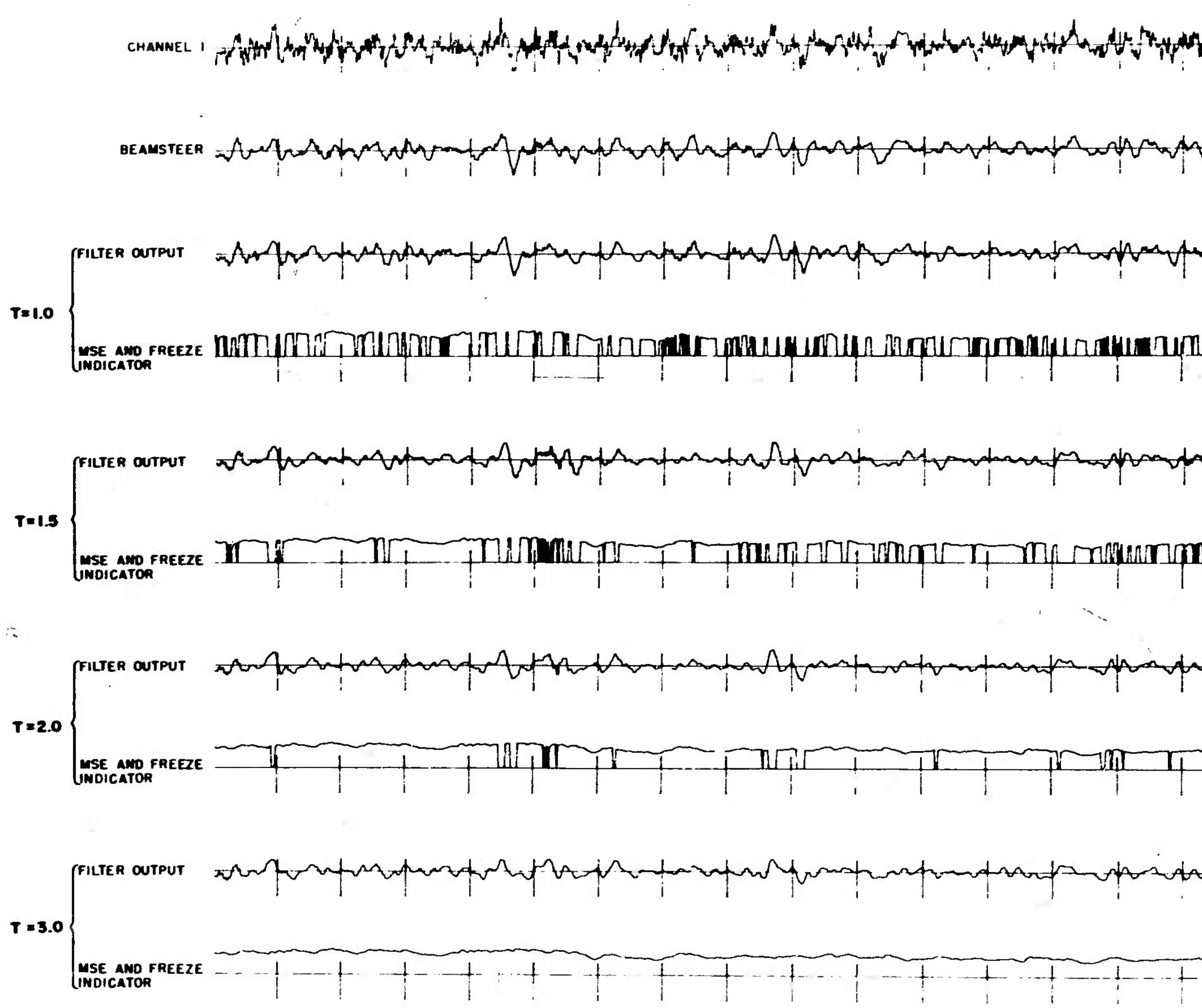


Figure IV-1. Adaptive Processor Outputs for Various T Values, $\eta = 0.9$



CHANNEL 1
BEAMSTEER
T=1.0
FILTER OUTPUT
MSE AND FREEZE INDICATOR
T=1.5
FILTER OUTPUT
MSE AND FREEZE INDICATOR
T=2.0
FILTER OUTPUT
MSE AND FREEZE INDICATOR
T=3.0
FILTER OUTPUT
MSE AND FREEZE INDICATOR

A

Figure IV-2. Adaptive Processor Outputs for Various T Values, $\eta = 0.995$

B

When no freezing occurred the improvement was 3.32 db. Thus, improvements in this interval less than 3.32 db for the various T values indicate the degree to which the signal false alarms are impairing the filter performance.

Filter improvements over beamsteer for all cases shown in Figures IV-1 and IV-2 are plotted in Figure IV-3 as a function of T . From this figure there appears to be little difference between the $\eta = .90$ and $\eta = .995$ cases. It was concluded that an T value of 3 (signal threshold of 3 standard deviations) was the minimum acceptable value for these data.

D. SIGNAL PROCESSING

A signal recorded at the same array as noise sample 1014 was added to the noise sample at signal-to-noise ratios of 0.5, 4, and 10, where signal-to-noise ratio is defined as

$$S/N = \frac{1/2\ (\text{maximum peak-to-trough signal amplitude})}{(\text{rms value of the noise})} \qquad (4\text{-}4)$$

Figure IV-4 is a plot of the noise plus signal data for the S/N = 4 case. The signal was 410 points (29 sec) long and was added to the noise sample at points 1639 through 2048. The power spectrum of Channel 1 of the signal data are shown in Figure IV-5. The signal did not exactly fit the infinite velocity signal model, but has an apparent velocity of approximately 20 km/sec from the northwest.

Processing of the three signal data sets began in each case with the initial filter being a filter previously designed from an ensemble of five noise samples; noise sample 1014 being one of the five. Processing then proceeded with a convergence parameter equal to 5% of the theoretical maximum and the signal detection threshold, T, equal to 3. Results of the processing of the S/N = 0.5, 4, and 10 cases are shown in Figures IV-6 through IV-8 respectively. In each of these figures Channel 1, the filter output, the beamsteer,

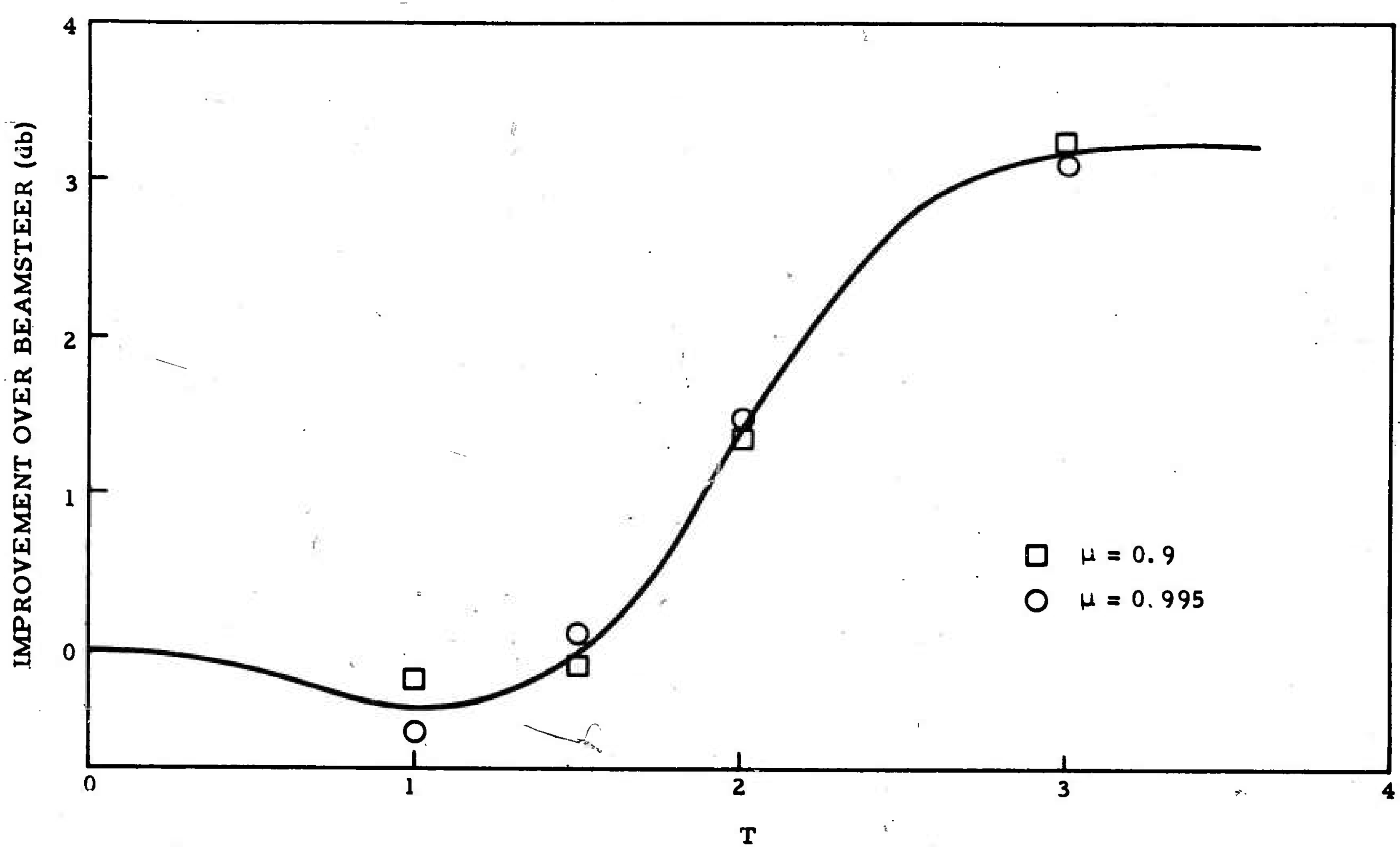
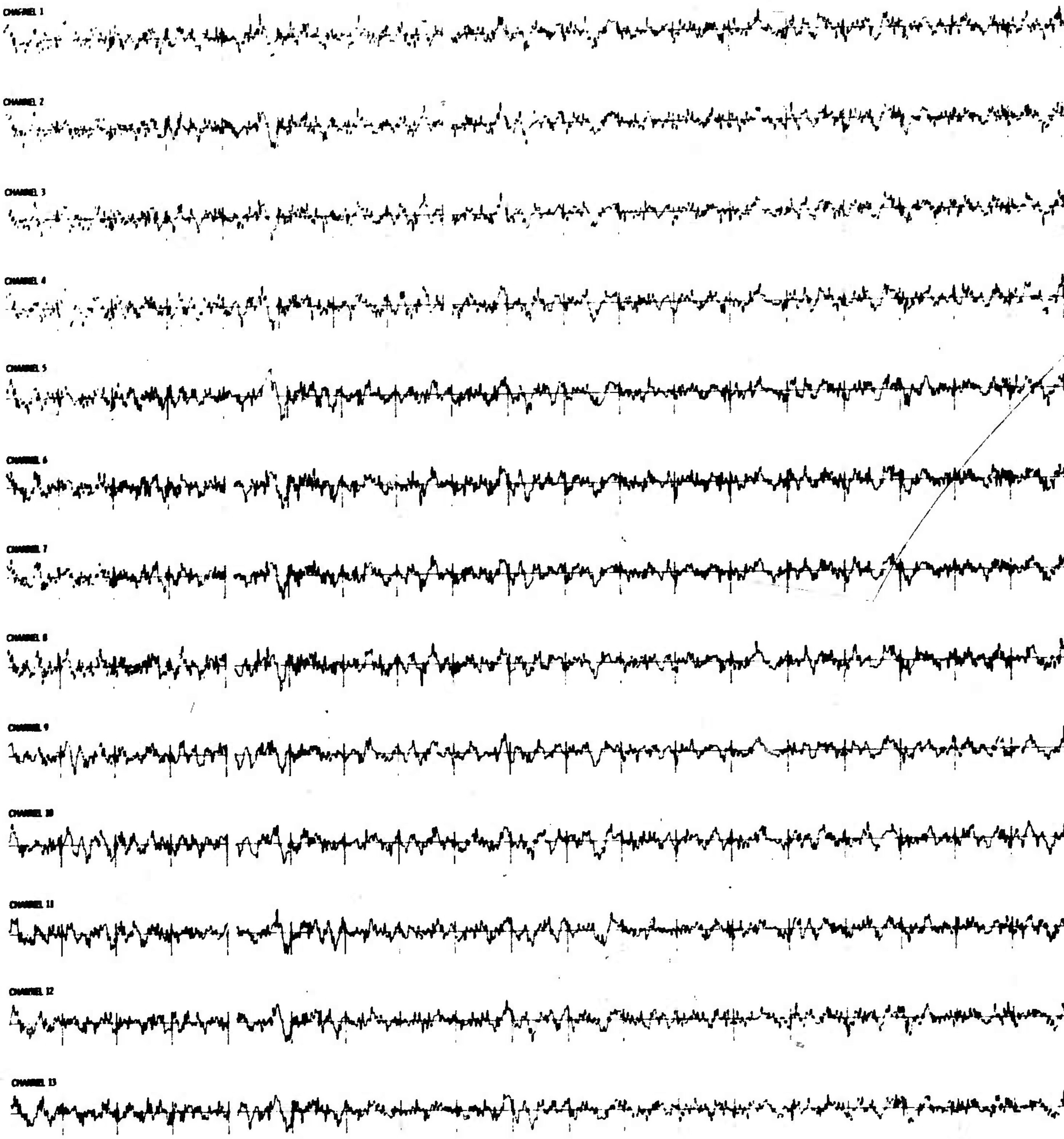


Figure IV-3. Improvement of Adaptive Output Over Beamsteer for Points 1792 through 2304 as a Function of T.


CHANNEL 1
CHANNEL 2
CHANNEL 3
CHANNEL 4
CHANNEL 5
CHANNEL 6
CHANNEL 7
CHANNEL 8
CHANNEL 9
CHANNEL 10
CHANNEL 11
CHANNEL 12
CHANNEL 13

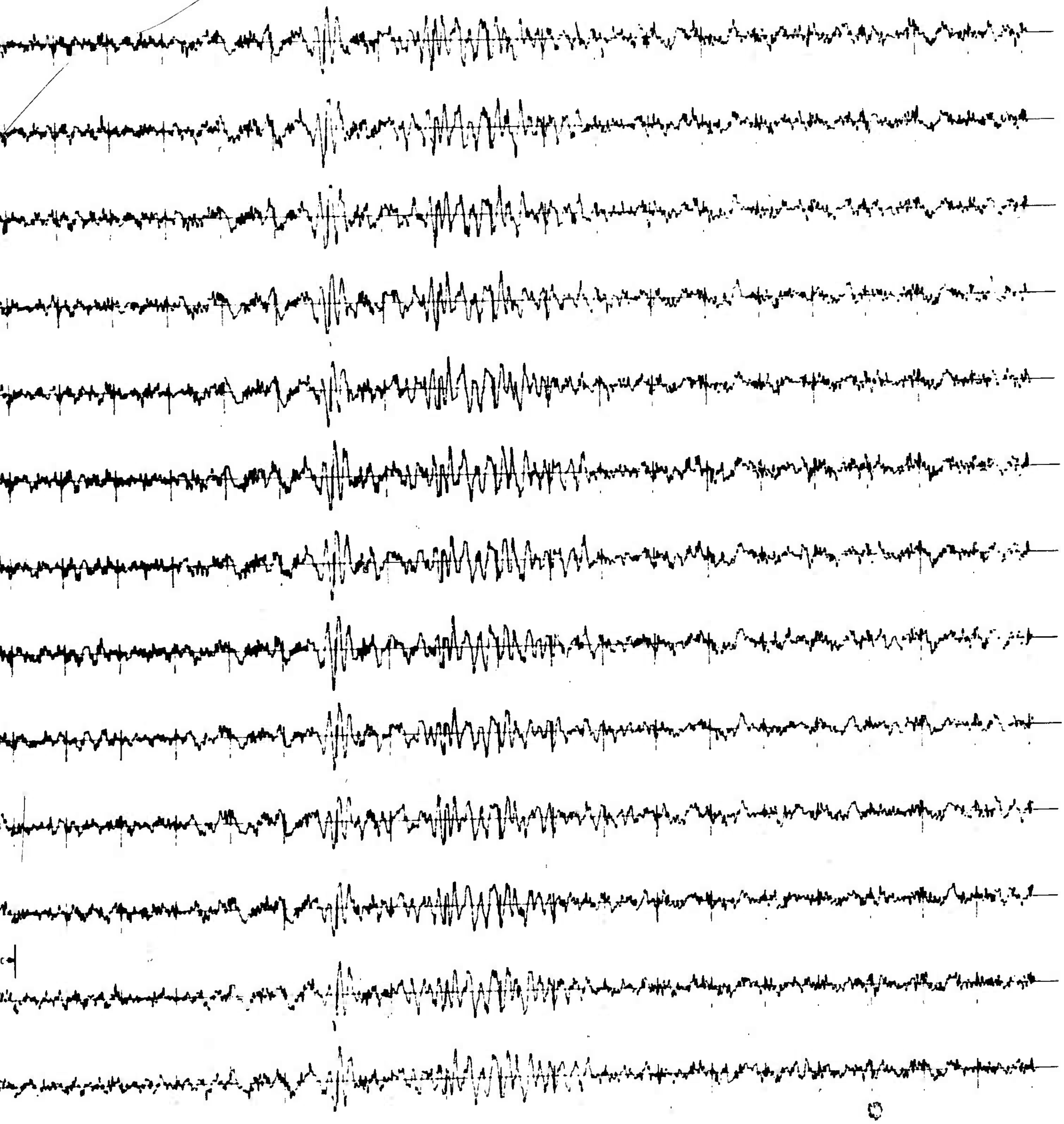


Figure IV-4. Noise Sample 1014 With 20 km/sec Signal Added at S/N = 4

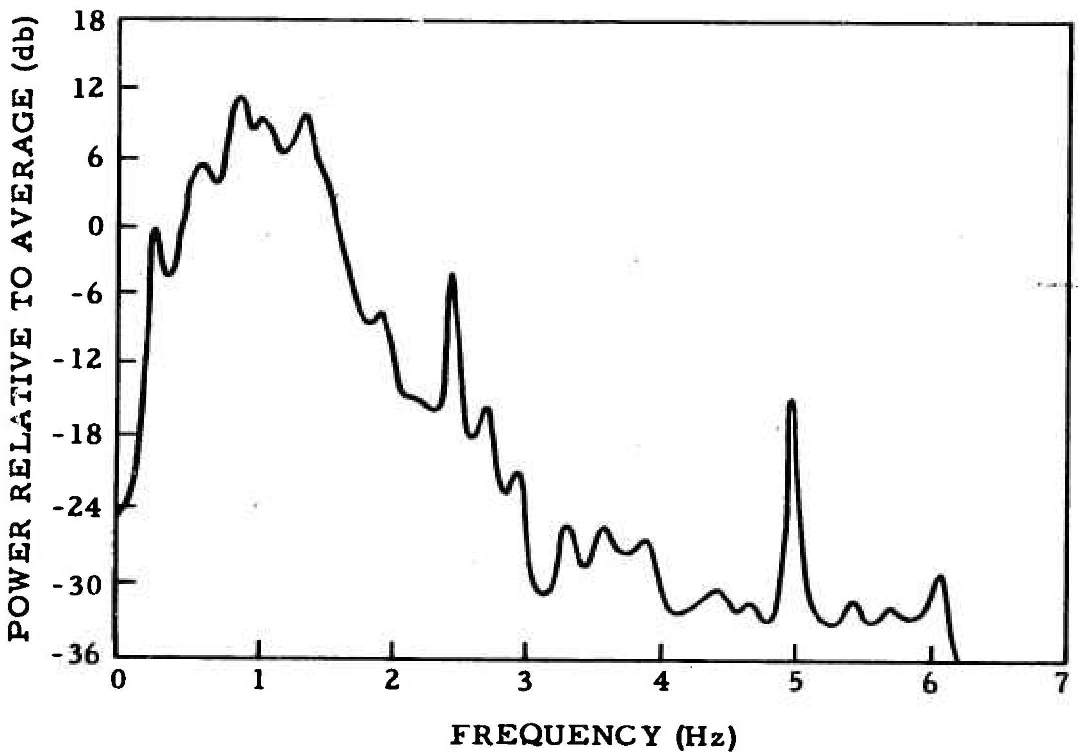
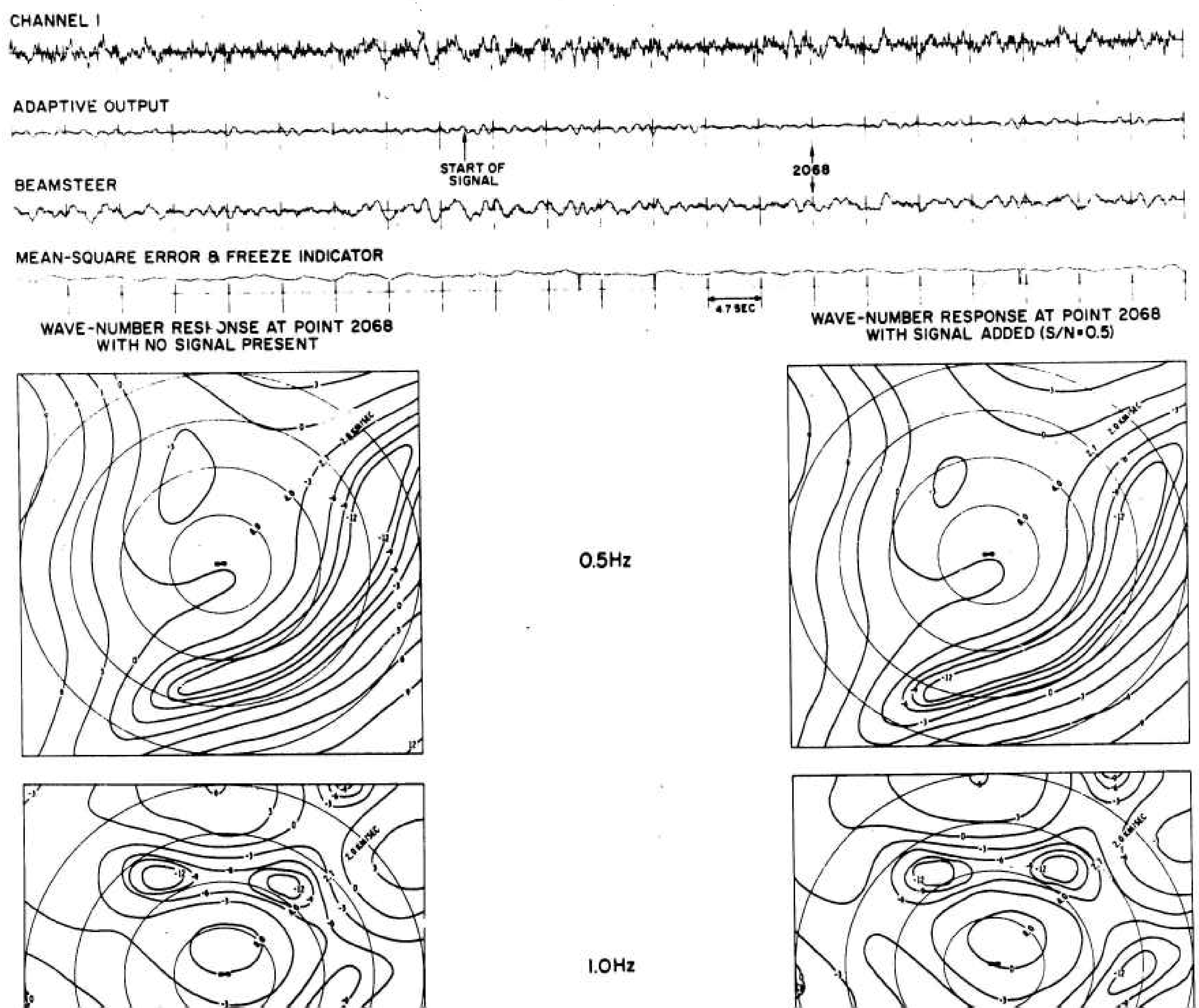


Figure IV-5. Power Spectrum of Channel 1 of the Signal Data


CHANNEL 1
ADAPTIVE OUTPUT
START OF SIGNAL
2068
BEAMSTEER
MEAN-SQUARE ERROR & FREEZE INDICATOR
4.7 SEC
WAVE-NUMBER RESPONSE AT POINT 2068 WITH NO SIGNAL PRESENT
WAVE-NUMBER RESPONSE AT POINT 2068 WITH SIGNAL ADDED (S/N=0.5)
0.5Hz
1.0Hz

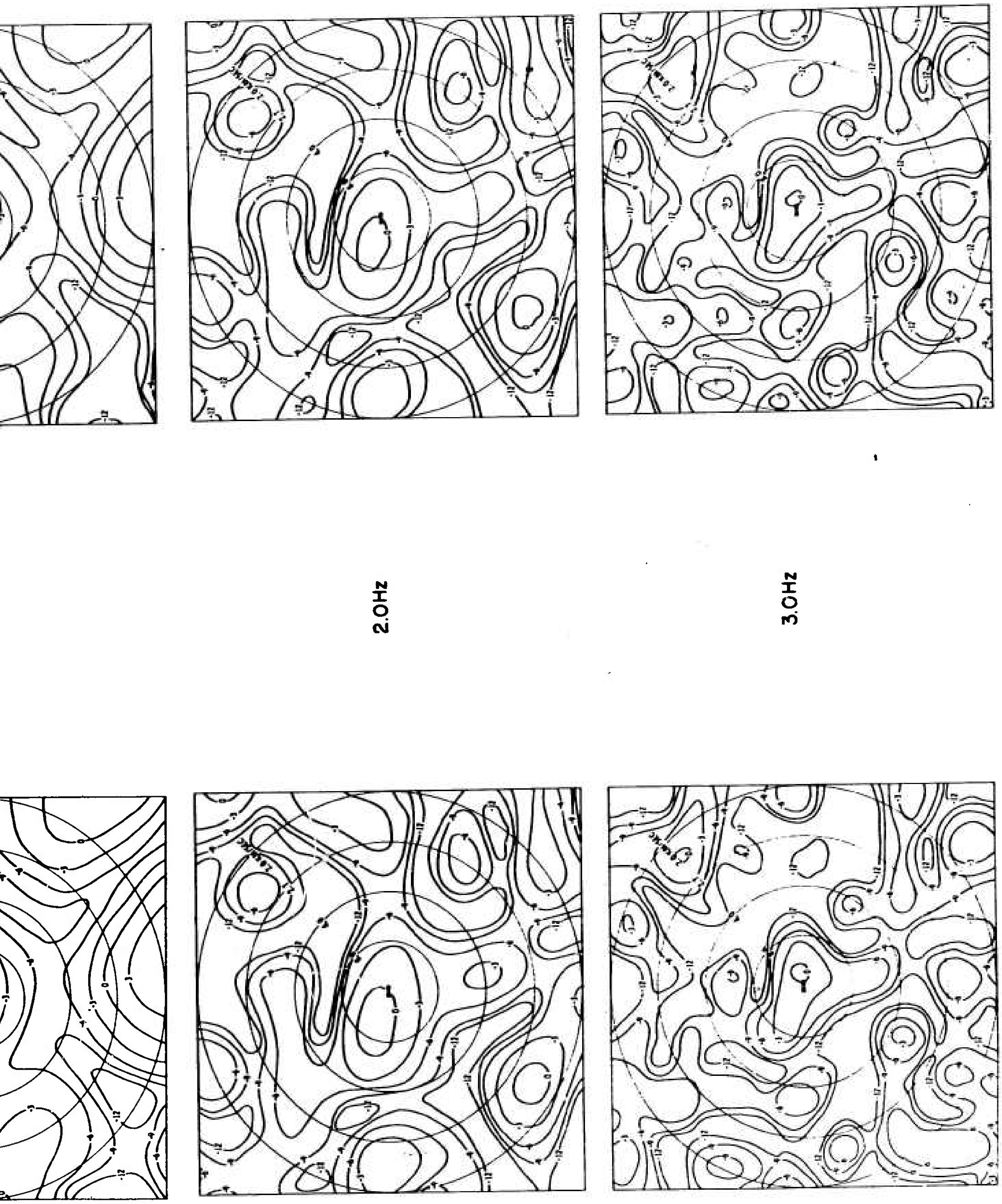
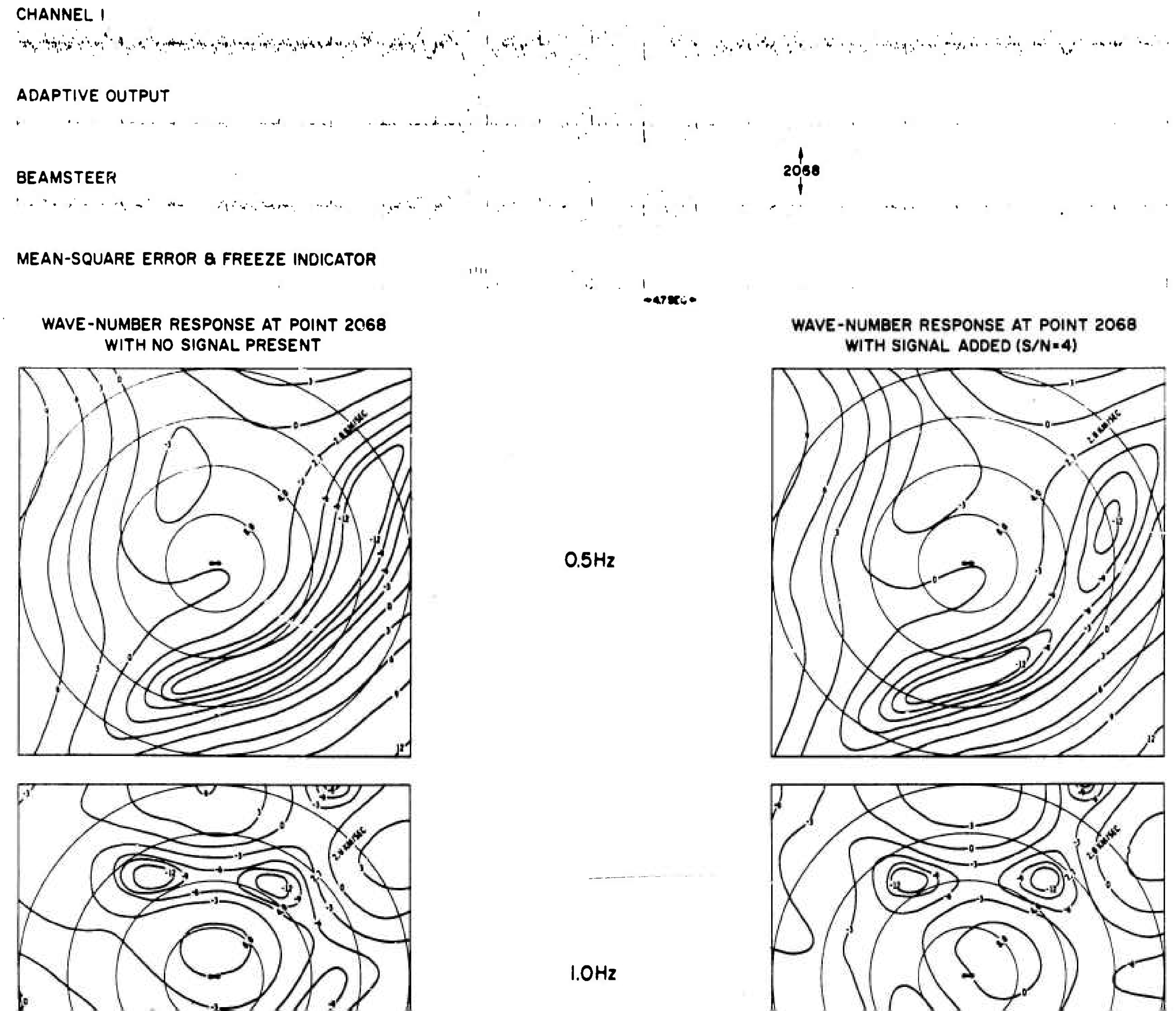


Figure IV-6. Adaptive Processing Results for Signal Plus Noise Data, S/N = 0.5


CHANNEL I
ADAPTIVE OUTPUT
BEAMSTEER
2068
MEAN-SQUARE ERROR & FREEZE INDICATOR
WAVE-NUMBER RESPONSE AT POINT 2068
WITH NO SIGNAL PRESENT
WAVE-NUMBER RESPONSE AT POINT 2068
WITH SIGNAL ADDED (S/N=4)
0.5Hz
1.0Hz

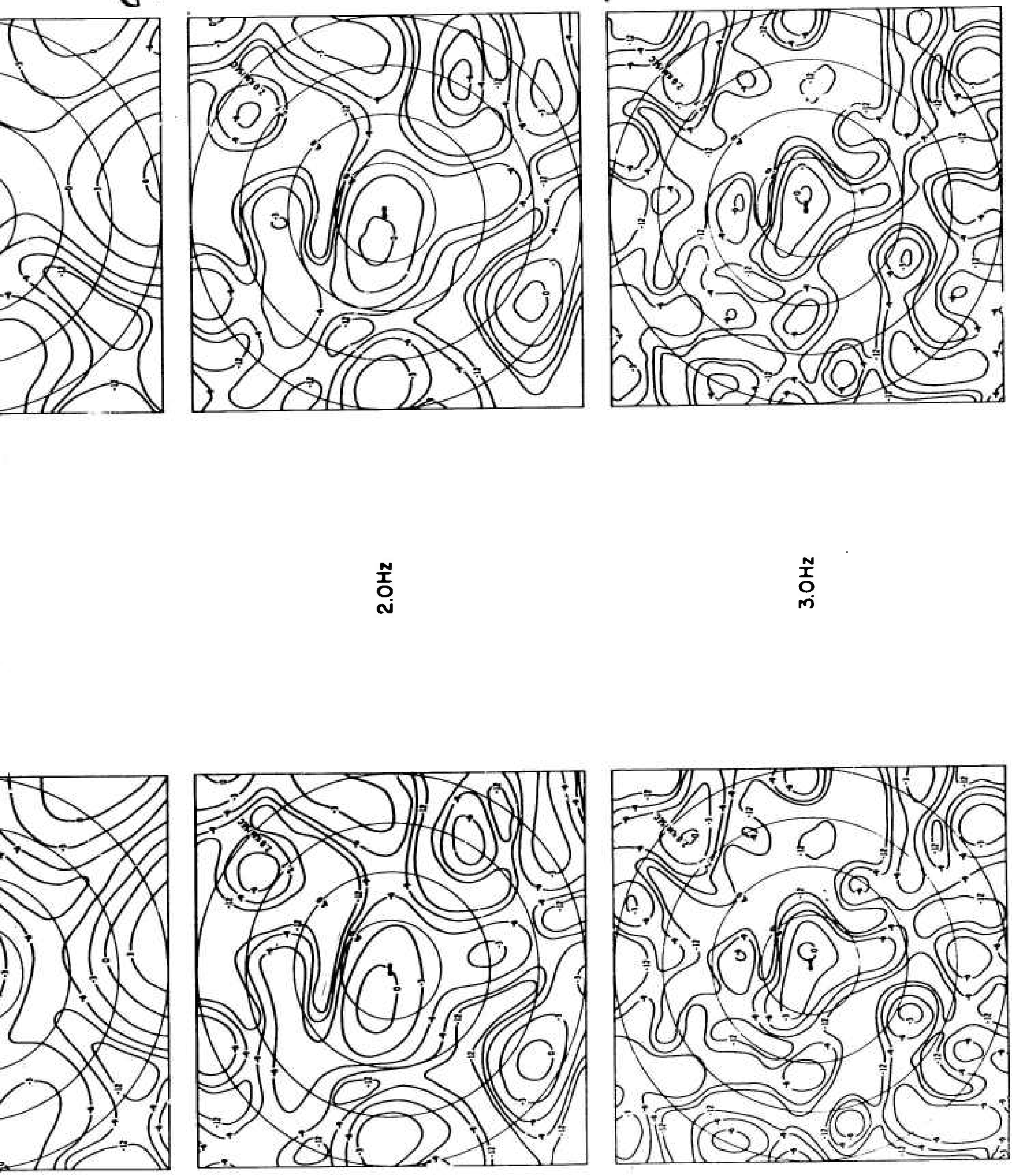


Figure IV-7. Adaptive Processing Results for Signal Plus Noise Data, S/N = 4

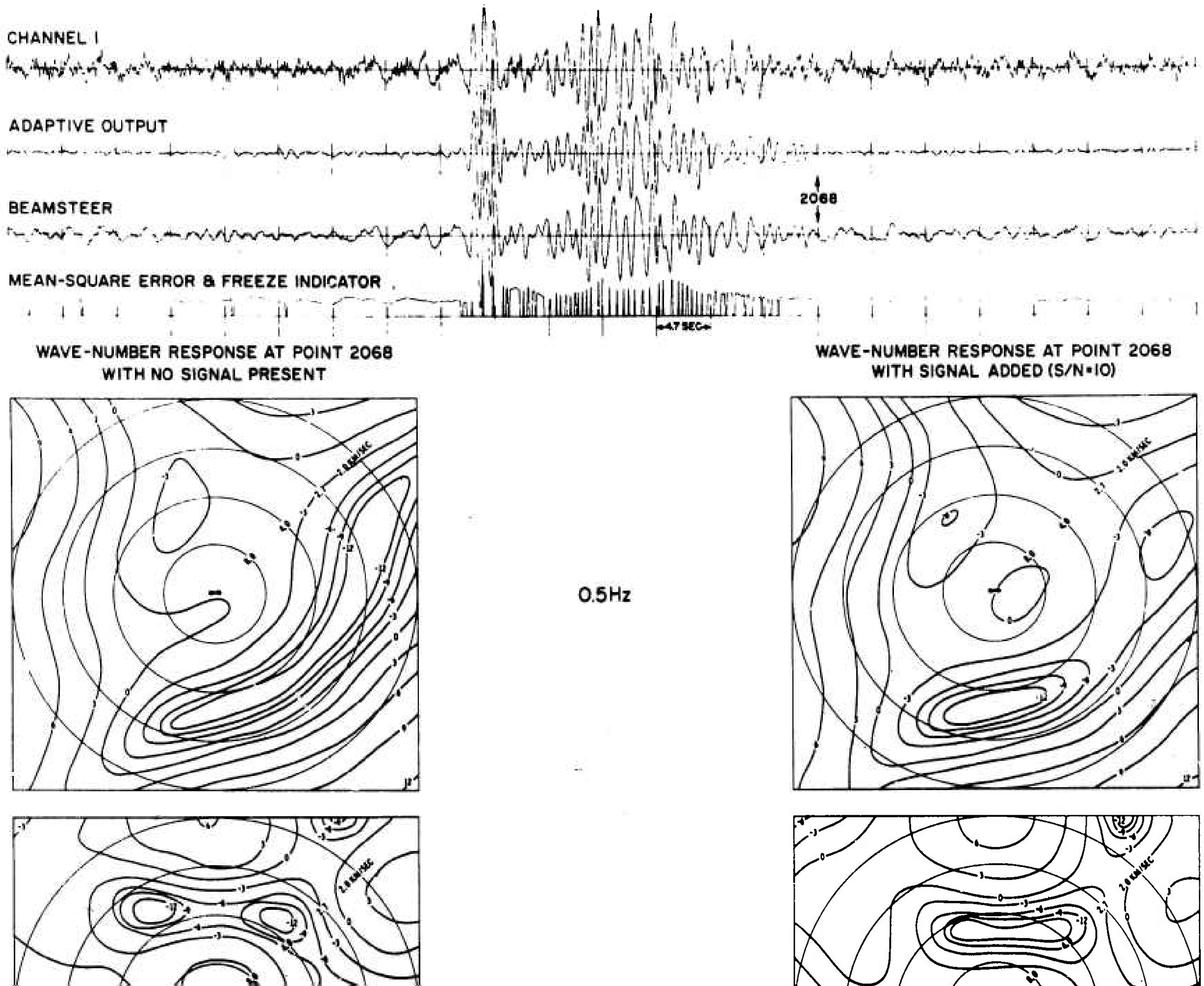

CHANNEL I
ADAPTIVE OUTPUT
2068
BEAMSTEER
MEAN-SQUARE ERROR & FREEZE INDICATOR
4.7 SEC
WAVE-NUMBER RESPONSE AT POINT 2068
WITH NO SIGNAL PRESENT
WAVE-NUMBER RESPONSE AT POINT 2068
WITH SIGNAL ADDED (S/N=10)
0.5Hz

Figure IV-8. Adaptive Processing Results for Signal Plus Noise Data, S/N = 10

BLANK PAGE

and the MSE and freeze indicator are shown at the top. The lower portion of these figures show the wavenumber response of the filter after the signal and at the same point when no signal was present.

Examination of these response plots shows that none of the cases processed produced sufficient filter distortion to create a problem in on-line processing.

To further investigate the adaption of the filters to signals, the filters resulting after the signals were processed (point 2068) were applied in a fixed mode to the signal only data. Had the filters adapted to the signal, reprocessing with these filters would result in signal attenuation. The results of this fixed filtering of the signal are shown in Figure IV-9. Filters resulting from the S/N = 0.5, 4, and 10 cases were each applied to the signal and the attenuation was 0.4 db, 0.7 db, and 0.2 db respectively. This further indicates that signals can be handled in such a manner that they will not be a problem for on-line adaptive processing.

It could be questioned whether the ability of the adaptive filter to pass signals actually resulted from the signal detection and filter freezing techniques. The small convergence rate combined with the short length of the signal possibly prevented filter adaption to the signal. To answer this question the S/N = 4 data were processed without filter freezing. Figure IV-10 shows the wavenumber response of the filter at 1 Hz after the signal is past-compared to the response of the filter that was frozen in the signal.

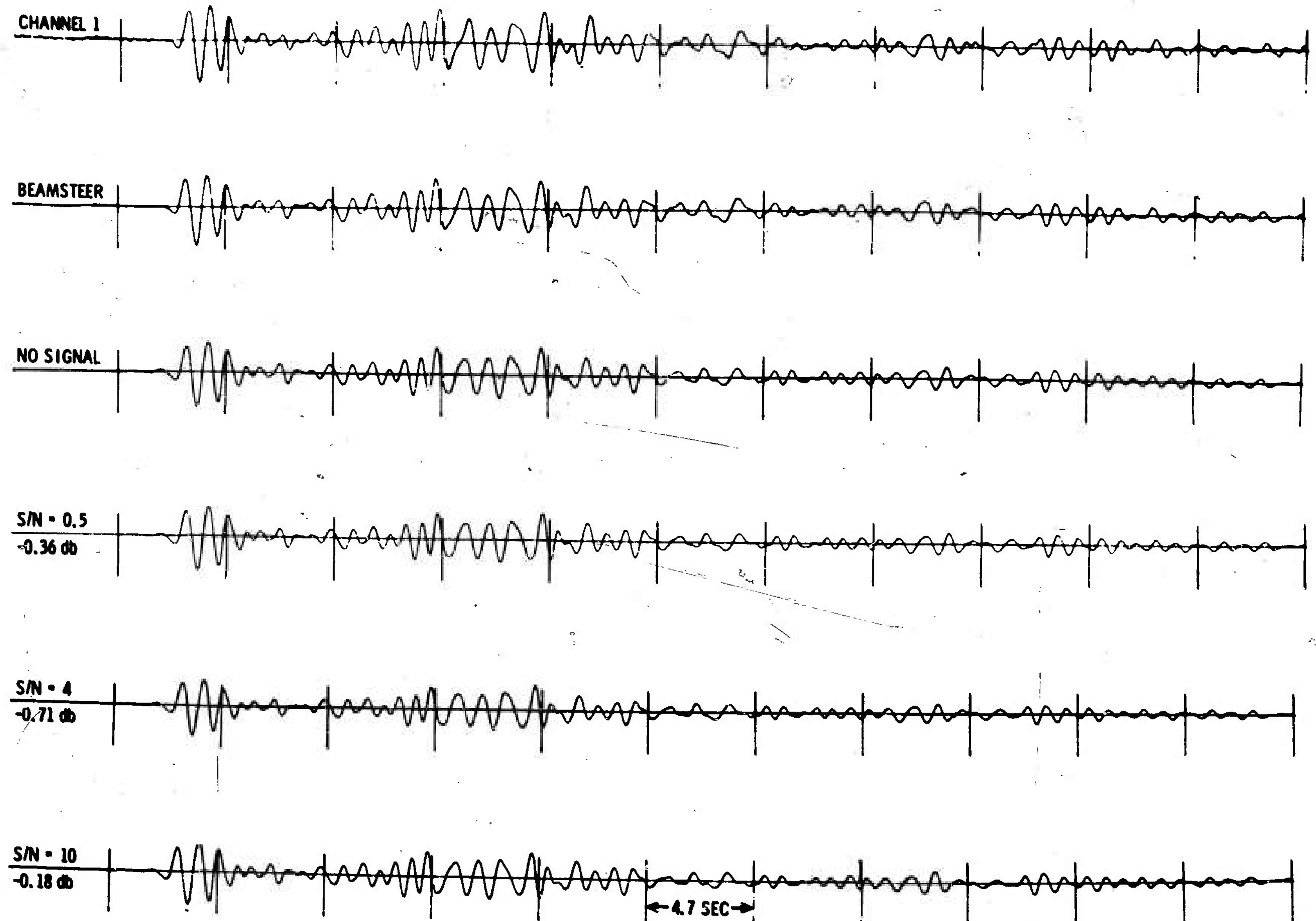


Figure IV-9. Fixed Filtering of Signal Data with Adaptively Designed Filters Taken Immediately After Signal Passage

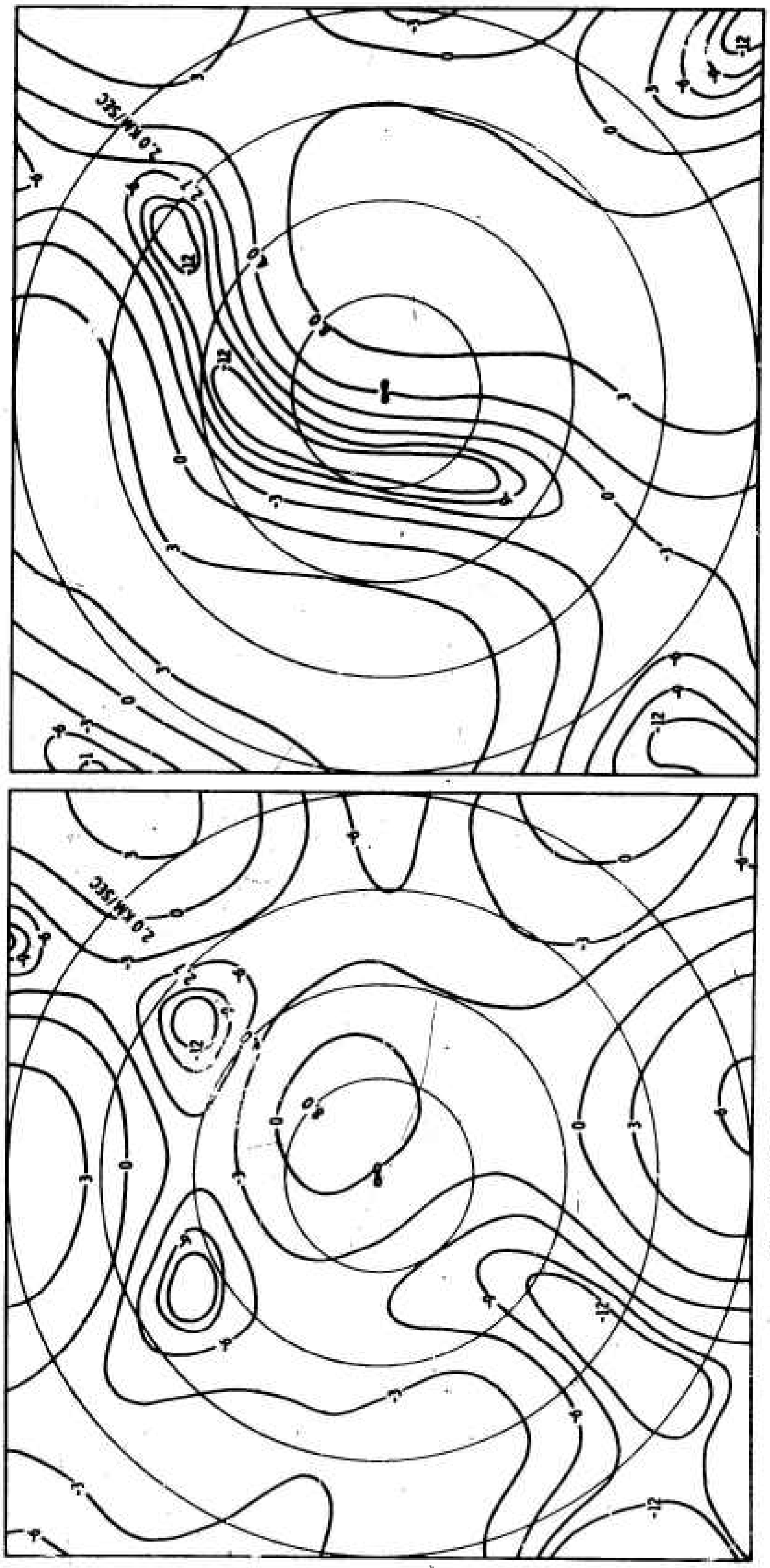


Figure IV-10. Wavenumber Responses at Point 2068 with and without Freezing, S/N = 4, f = 1.0 Hz

The non-frozen filter is seen to be strongly adapted to reject a signal from the northwest with a 20 km/sec velocity. Thus, one can conclude that the signal detection and freezing techniques used here are responsible for the ability of the filters to pass signals without adapting to them.

In actual on-line processing the convergence parameter would probably be smaller than the 5% value used here. Thus, since the signal problem increases with larger convergence rates, the signal problem in an actual on-line situation is expected to be even smaller than indicated here.

SECTION V

DATA QUALITY PROBLEM

A. STATEMENT OF THE PROBLEM

Three common problems come to mind regarding the quality of data encountered in on-line processing. The first possibility is of a channel going bad (dead or noisy); the second possibility is of a previously bad channel regaining proper operation; and the third possibility is of spikes in the data.

The problem of spikes can presumably be easily solved by a spike detection and data interpolation technique. This problem was, therefore, not dealt with in this study. The problem of channel addition has been previously covered.[5] Results there indicated a smooth transition from the optimum NC-1 channel filter to the optimum NC channel filter. This presents no problem to on-line adaptive processing, thus this problem was not studied further here.

The problem of channel deletion, on the other hand, can be serious especially if a channel dies gradually. The adaptive algorithm in this case, in its attempt to minimize filter output, will weigh the decaying channel more heavily. When the channel is finally considered dead we are faced with the problem of distributing these large weights. Redistribution of large filter weights is bound to cause a transient increase in the filter output. Even in the event of a channel going dead instantaneously, the redistribution of filter weights could cause slight temporary damage to the filter performance. Thus, the problem addressed here is to devise a technique for on-line quality control and to measure the effects of bad data on a simulated on-line processor employing this technique.

B. DATA QUALITY CONTROL ALGORITHM

A subroutine was added to the on-line processor simulation program to examine the raw data, $X_{i,t}$, for dead or noisy channels. A channel was considered bad if its rms value over some interval, N points long, was less than or greater than one of two fractions of the average rms value across channels. In equation form the criterion for channel deletion was

$$\left[\frac{1}{N}\sum_{n=0}^{N} X^2_{i,t+n}\right]^{1/2} \begin{matrix} < XMIN \\ \text{or} \\ > XMAX \end{matrix} \left[\frac{1}{NC}\sum_{i=1}^{NC}\left[\frac{1}{N}\sum_{n=o}^{N} X^2_{i,t+n}\right]^{1/2}\right] \quad (5\text{-}1)$$

Whenever either of the above conditions existed, the data for channel i was zeroed and the $(\overline{X}_t - X_{i,t})$ term for that channel zeroed also.

When the adaptive processor encountered this zeroed data the filter weights for that channel were equally distributed between the remaining NC-1 channels and the dead channel filter weights zeroed as follows:

$$F^t_{i,j} = F^t_{i,j} + \frac{1}{NC-1} F^t_{NZ,j} \qquad i \neq NZ \qquad (5\text{-}2)$$

$$F^t_{i,j} = O \qquad i = NZ$$

where NZ is the number of the zeroed channel.

C. DETERMINATION OF PARAMETERS

The first problem to be solved in implementing the data quality control feature in simulated on-line processing is to determine the range of suitable values for XMIN and XMAX in Equation 5-1. Selection of values for these parameters involves a trade-off between two factors. In selection of XMIN for example, one would like to make XMIN relatively large to avoid filter concentration on a slowly decaying channel. Filter concentration on such a channel would result in reduced filter performance prior to deletion of the channel as well as a large transient on the filter output immediately following channel deletion. However, there is the false alarm (deletion of good channels) factor which requires a small XMIN value.

The XMIN value representing a trade-off between these factors was determined experimentally by processing noise sample 1014 repeatedly with gradually increasing XMIN values. At XMIN values above 0.3 channels were erroneously determined to be dead. The false alarm rate increased very rapidly with increasing XMIN to a point around 0.4 where the false alarms and subsequent distributions of filter coefficients caused the adaptive algorithm to become unstable and the filter output to diverge.

A similar trade-off between quality control effectiveness and false alarm rates exists in selection of XMAX. The noise data was processed repeatedly with XMAX values starting at 2.0 and gradually decreasing. In this case false alarms began at about 1.8 and instability of the adaptive algorithm occurred around 1.6.

Figure V-1 summarizes the results of the processing to determine acceptable XMIN, XMAX values. In this figure the false alarm rate is plotted as a function of XMIN and XMAX. Values of these parameters for subsequent simulated on-line processing were chosen as 0.3 and 1.8 respectively.

D. DEAD CHANNEL DATA PROCESSING

Channel 1 of noise sample 1014 was zeroed from point 1280 to the end of the sample. The data was then adaptively processed beginning with the previously mentioned filter designed from a noise ensemble. The convergence rate was 5% of maximum and the XMIN, XMAX values were 0.3 and 1.8 respectively.

Figure V-2 shows the dead channel, beamsteer, filter output and MSE indicator for this case. Also shown in the figure are the wavenumber responses of the filter just before and after the beginning of the dead segment. The wavenumber plots show that the effect of the channel deletion on the filter was not significant. In terms of the rms value of the filter output for the 256 points following the channel deletion the dead channel case was only 0.2 db above the 13 channel case.

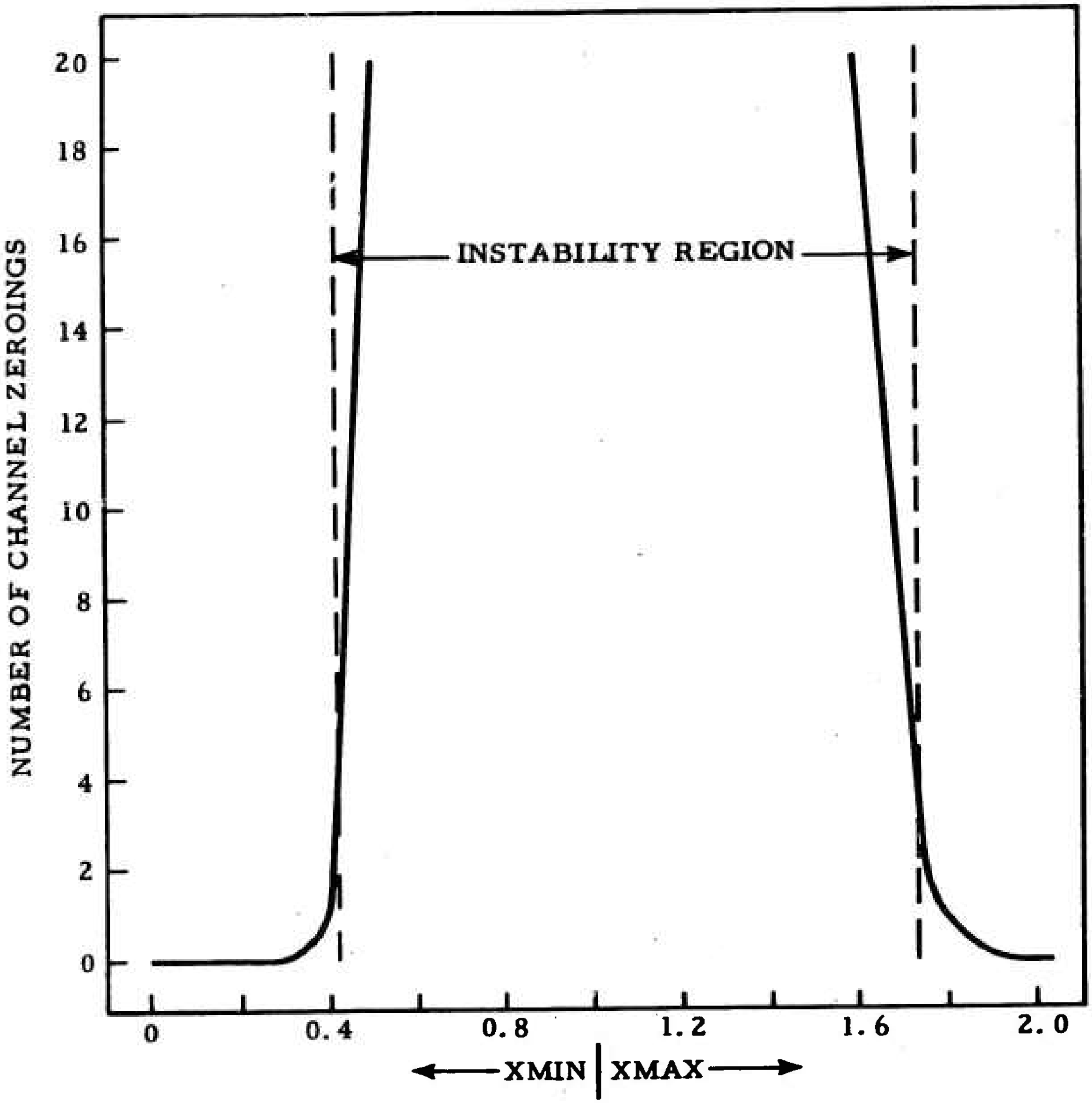
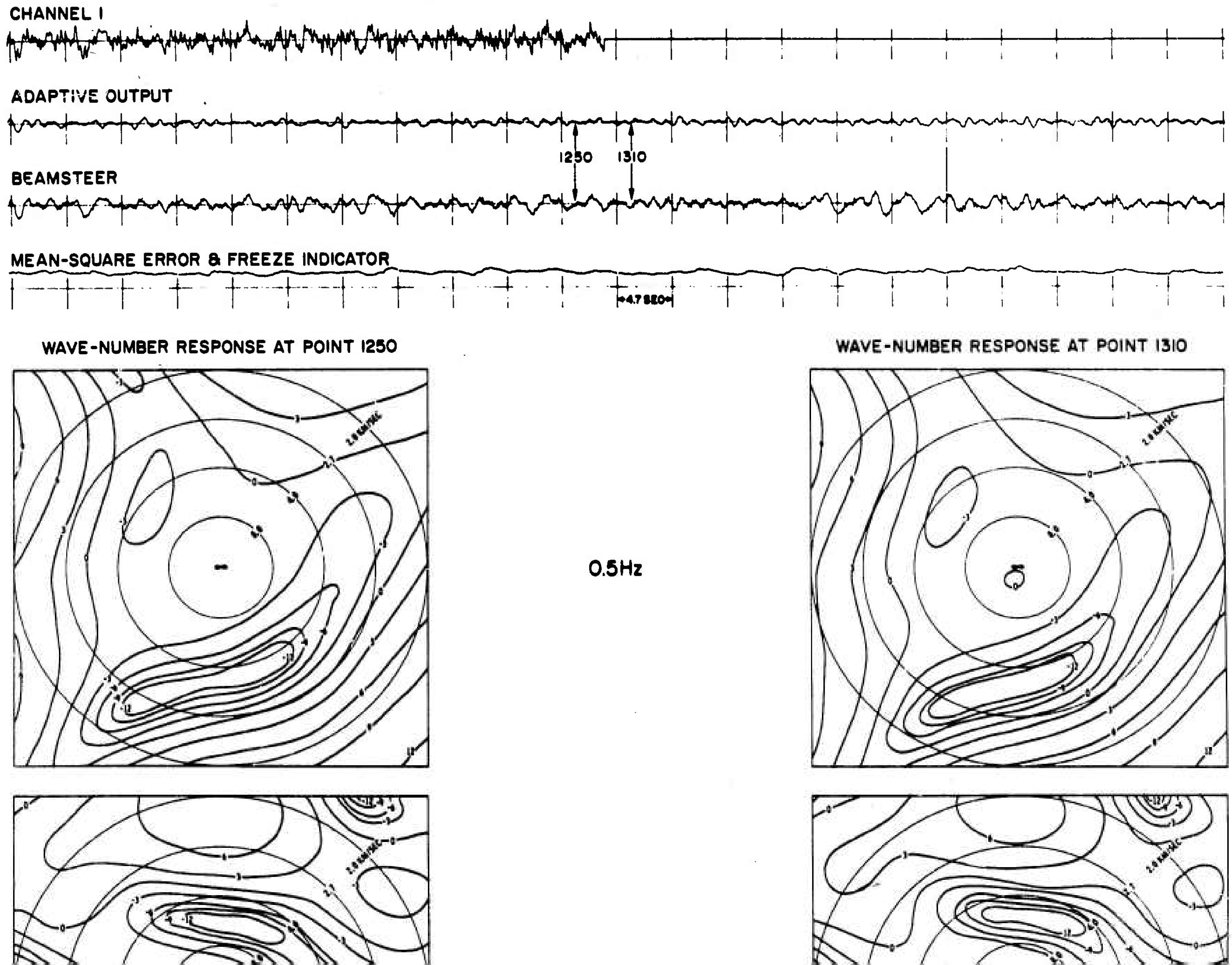


Figure V-1. Number of Bad Channel False Alarms as a Function of Threshold Values



CHANNEL I
ADAPTIVE OUTPUT
1250
1310
BEAMSTEER
MEAN-SQUARE ERROR & FREEZE INDICATOR
4.7 SEC
WAVE-NUMBER RESPONSE AT POINT 1250
0.5Hz
WAVE-NUMBER RESPONSE AT POINT 1310

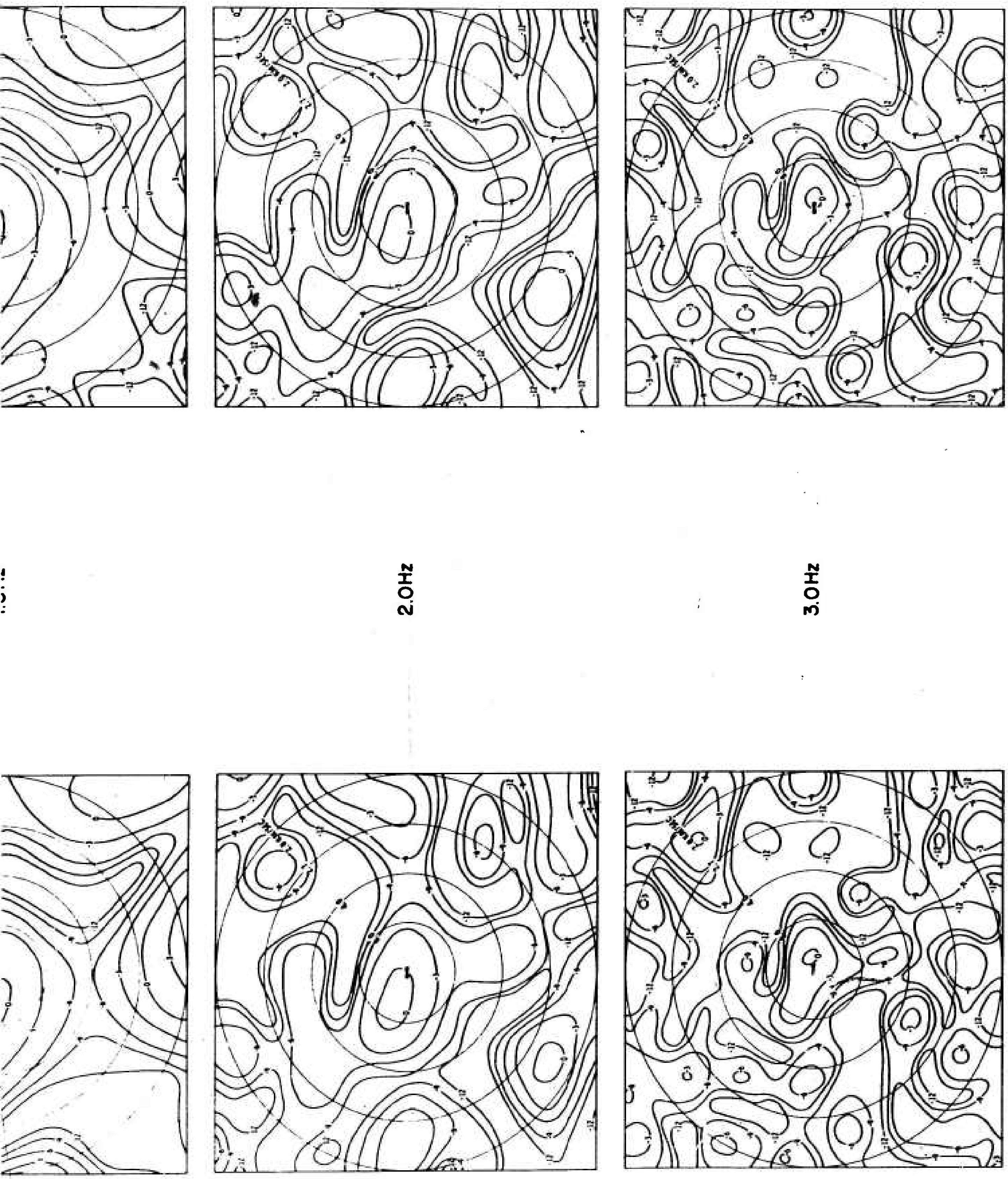


Figure V-2. Adaptive Processing Results for Dead Channel Case

Previous work on the channel deletion problem[5] indicated transients in the filter output of about 3 db. Two differences existed between these experiments. The channel deleted in the first experiment was on the extreme edge of the array while the deleted channel here was at the center of the array. Secondly, the convergence rate used in the previous experiment was not reported, but it is probably much smaller than the 5% of maximum used here. Either or both of these differences may be responsible for the smaller transients in the present study. Further work would be required to pinpoint the explanation exactly.

BLANK PAGE

SECTION VI
ADAPTIVE BEAMSTEER PROBLEM

A. STATEMENT OF THE PROBLEM

It is generally not possible to model the signal for an adaptive beamsteer processor exactly except in the infinite velocity case. For other velocities the move-out of the signal across the array will not correspond to an even multiple of the digital sampling interval for all instruments in the array. The signal model must, therefore, approximate the actual signal to the nearest sample point. The maximum-likelihood adaptive filter is constrained to pass any signal unattenuated which fits the signal model. However, in the case of the directional adaptive beam where the signal and signal model differ, some signal attenuation could conceivably occur. The degree of this attenuation was measured in this experiment.

B. PROCESSING PROCEDURE

This experiment could have been accomplished by time shifting and processing signal data. However, it can be shown that the same result can be achieved in an easier manner by modifying the calculation techniques for computation of filter wavenumber responses.

If the adaptive beamsteer is to be formed for velocity v_y, (for simplicity $v_x = 0$) the arrival time of the signal on channel i, t_i, relative to the arrival at the center of the array is

$$t_i = \frac{y_i - y_c}{v_y} \qquad (6-1)$$

where y_i is the y coordinate of channel i

y_c is the y coordinate of the center instrument.

The signal model arrival time t_i^m approximates t_i to the nearest sample point. Thus, the error in the signal model for channel i is

$$\epsilon_i(t) = t_i^m - t_i \quad . \tag{6-2}$$

This error which is expressed as a time error is equivalent to a positional error $\epsilon_i(y)$ which can be found from $\epsilon_i(t)$ by

$$\epsilon_i(\vec{r}) = v_y \epsilon_i(t) \quad . \tag{6-3}$$

The wavenumber response of a filter is given by

$$\rho(f,k) = \sum_{i=1}^{NC} \phi_i(f) \, e^{-2\pi jk \cdot \vec{r}_i} \quad . \tag{6-4}$$

where $\vec{r}_i$ is the bector location of the r^{th} sensor relative to some arbitrary reference

The errors caused by the approximate signal model can therefore be observed by computing

$$\rho(f,k) = \sum_{i=1}^{NC} \phi_i(f) \, e^{-2\pi jk \cdot (\vec{r}_i + \epsilon_i(\vec{r}))} \tag{6-5}$$

and comparing this with Equation 6-4.

C. PROCESSING RESULTS

Signal models and their associated errors were calculated for beamsteers aimed at velocities of 10, 20, and 30 km/sec from the north (y direction). These parameters were then introduced into the calculation of the wavenumber response of the ensemble filter used as the initial filter for processing in the previous sections. The results of these calculations are shown in Figures VI-1 through VI-4. These figures are for the frequencies 0.5, 1, 2, and 3 Hz respectively. In each figure the plot in the upper left-hand corner is the response of the filter when the signal and signal model correspond exactly, (infinite velocity case). The remaining three plots on each page show how the response changes due to signal model errors when the beam is centered on signals arriving at 30, 20, and 10 km/sec.

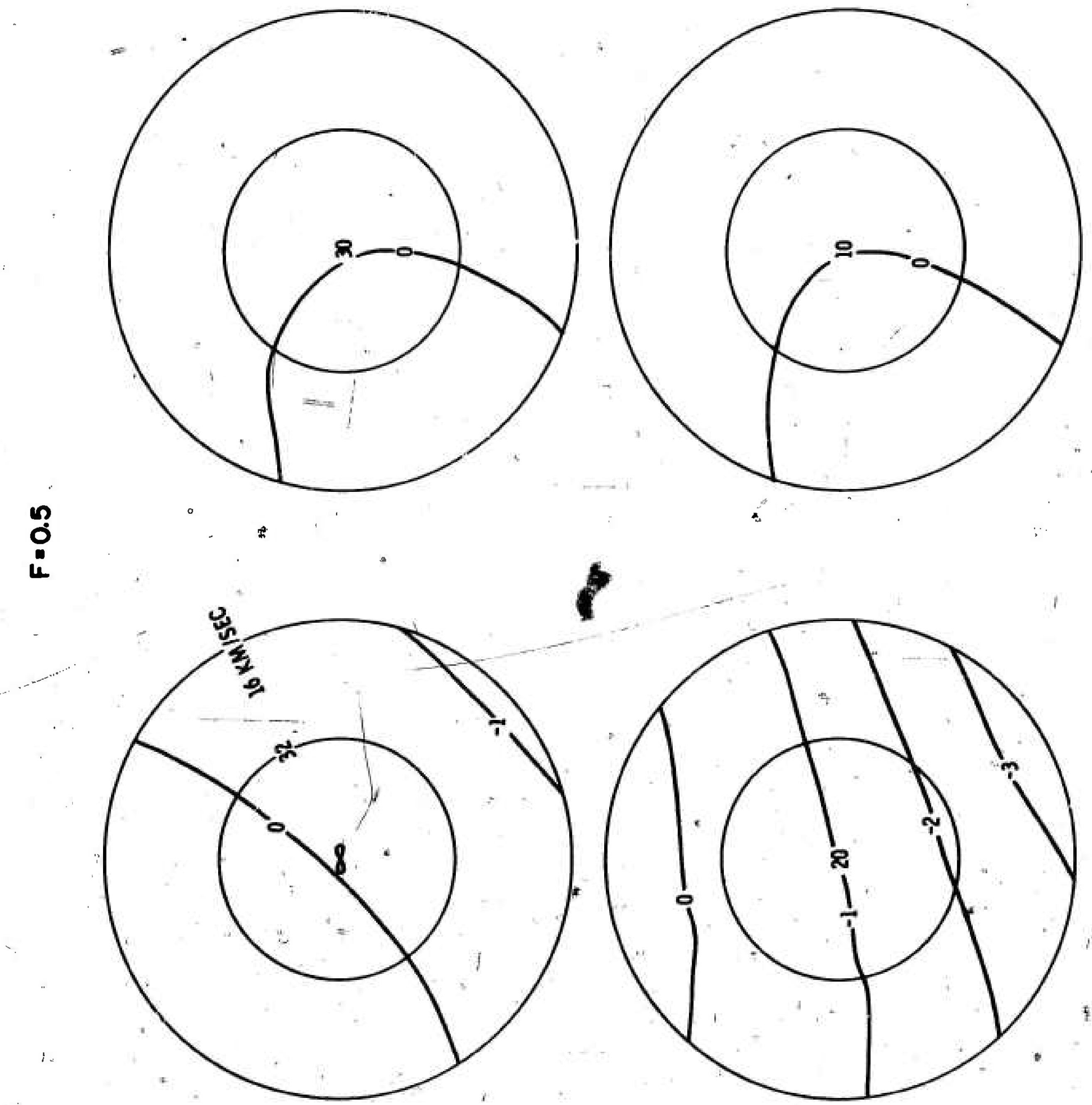


Figure VI-1. Wavenumber Responses of Adaptive Beamsteers, f = 0.5 Hz

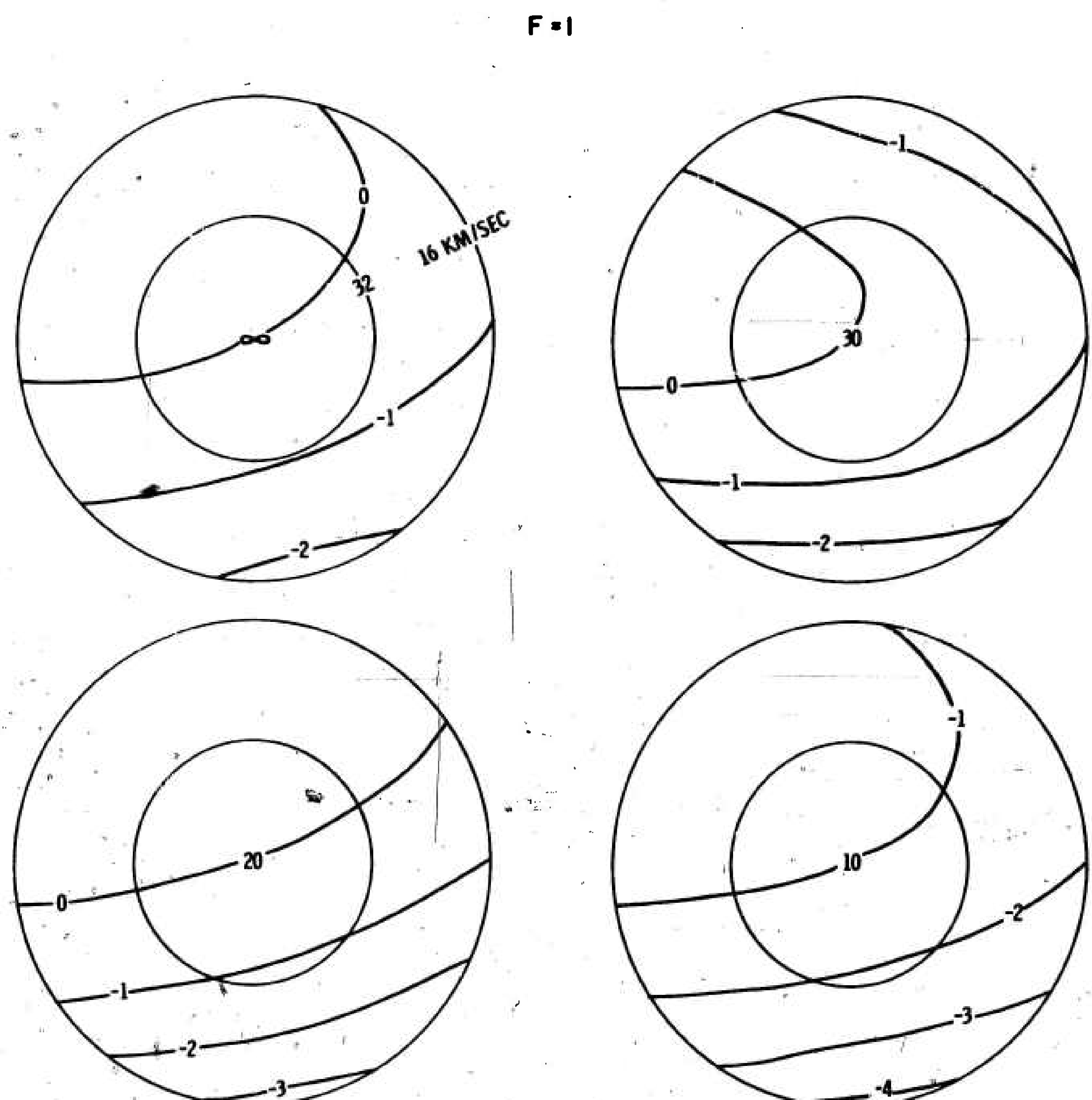


Figure VI-2. Wavenumber Responses of Adaptive Beamsteers, f = 1.0 Hz

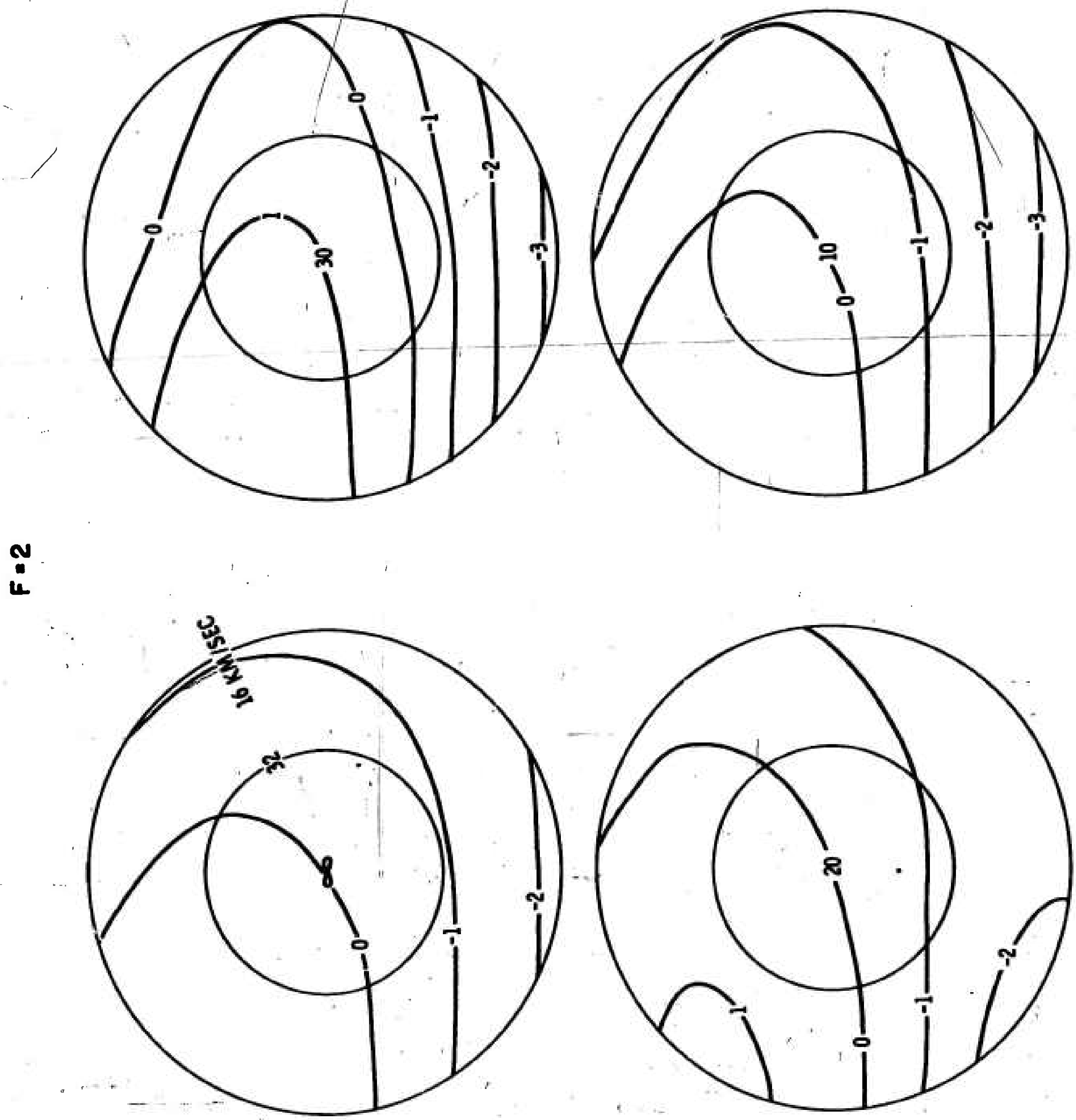


Figure VI-3. Wavenumber Responses of Adaptive Beamsteers, f = 2.0 Hz

F=3

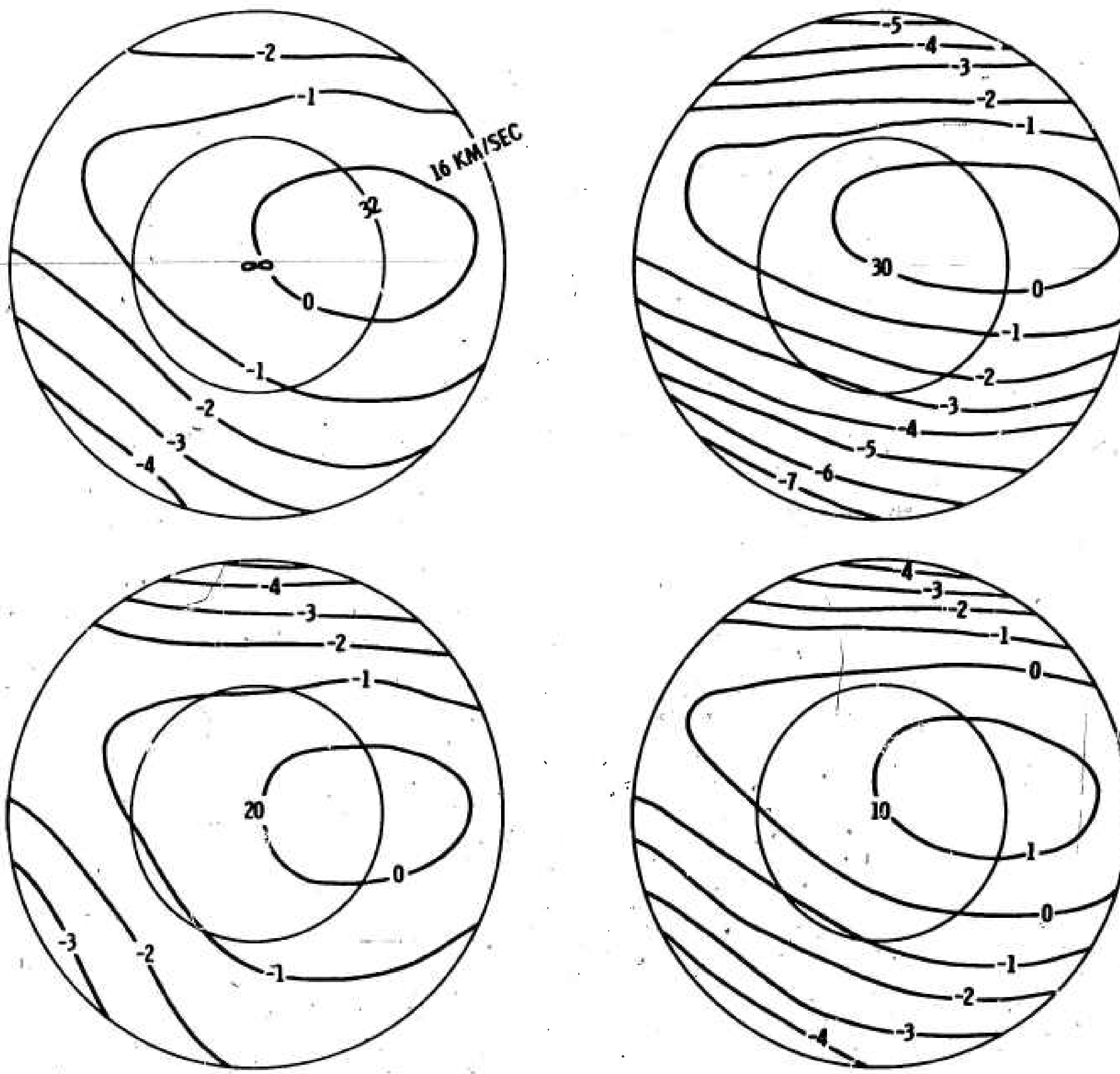


Figure VI-4. Wavenumber Responses of Adaptive Beamsteers, f = 3.0 Hz

These figures show that if the signal arrives exactly in the center of the beam, then the attenuation will be 1 db or less. However, for signals off-center from the beam, attenuation as large as 3 db could result at certain frequencies.

At most velocity-frequency combinations where the signal is relatively close to the beam center, the attenuation resulting from signal model errors is not significant.

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

As a result of the experiments reported here there appears to be no problems associated with adaptive on-line processing which cannot be satisfactorily overcome by relatively simple procedures.

The signal problem is severe if preventive measures are not taken. However, the preventive measures required are simple and quite effective. If a more effective solution than the one used here is needed, some type of optimum signal detection scheme is suggested.

Relatively simple procedures also appear to be effective in performing the data quality control function required for on-line processing. The transients introduced into the filter output as a result of zeroing a bad channel are small. The size of the transient appears to be related to location of the channel in the array, size of the convergence rate, and the coherence of the data. Further study of these factors is recommended. The output transient could probably be lessened if, rather than distributing the filter coefficients evenly, they were distributed in a more optimal manner. Two possibilities would be to distribute the weights of the deleted channel more heavily among its closer surrounding elements or to distribute the weights in proportion to the weights already existing on each of the channels.

Finally, signal attenuation resulting from signal model approximation to the nearest sample point in adaptive beamsteer processors is 1 db or less for signals near the center of the adaptive beam for frequencies ranging from 0.5 to 3.0 Hz.

SECTION VIII

REFERENCES

1. Texas Instruments Incorporated, 1967: Adaptive Filtering of Seismic Array Data, Advanced Array Research Spec. Rpt. No. 1, Contract F33657-67-C-0708-P001, 18 Sept.

2. Texas Instruments Incorporated, 1968: Prediction Error and Adaptive Maximum-Likelihood Processing, Advanced Array Research Spec. Rpt. No. 10, Contract F33657-67-C-0708-P001, 28 Feb.

3. Texas Instruments Incorporated, 1968: Theoretical Considerations in Adaptive Processing, Advanced Array Research Spec. Rpt. No. 13, Contract F33657-67-C-0708-P001, 28 Feb.

4. Texas Instruments Incorporated, 1970: Convergence of Time-Domain Adaptive Maximum-Likelihood Filters for Stationary Data, Tech. Rpt. No. 3, Seismic Array Processing Techniques, Contract F33657-70-C-0100, 26 Feb.

5. Texas Instruments Incorporated, 1969: Problems in Automating Multichannel Adaptive Processing, Advanced Array Research Spec. Rpt. No. 5, Contract F33657-68-C-0867, 31 Mar.

6. Texas Instruments Incorporated, 1968: Advanced Array Research Final Report, AFTAC Contract F33657-67-C-0708-P001, 15 Feb.

7. Widrow, Bernard, 1966: Adaptive Filters I: Fundamentals, Stanford Electronics Laboratories, Stanford University, Tech. Rpt. 6764-6, Contracts DA-01-021AMC-90015(Y) and NOBsr-95036, Dec.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Texas Instruments Incorporated
Services Group
P.O. Box 5621, Dallas, Texas 75222

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
____

3. REPORT TITLE
SIMULATION OF ADAPTIVE ON-LINE MAXIMUM-LIKELIHOOD PROCESSING — SEISMIC ARRAY PROCESSING TECHNIQUES TECH. RPT. NO. 11

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical

5. AUTHOR(S) (First name, middle initial, last name)
Ronald J. Holyer

6. REPORT DATE
20 August 1970

7a. TOTAL NO. OF PAGES
44

7b. NO. OF REFS
7

8a. CONTRACT OR GRANT NO.
F33657-70-C-0100

b. PROJECT NO.
VELA/T/0701/B/ASD

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
____

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
____

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of Chief, AFTAC.

11. SUPPLEMENTARY NOTES
ARPA Order No. 624

12. SPONSORING MILITARY ACTIVITY
Advanced Research Projects Agency
Department of Defense
The Pentagon, Washington, D.C. 20301

13. ABSTRACT

On-line adaptive maximum-likelihood processing has been simulated on the IBM S/360 computer to investigate some of the problems associated with on-line processing. The problems considered were the presence of signals in the data, dead or noisy channels, and signal model errors in adaptive beamsteers. Experimental results indicate that relatively simple techniques are effective in reducing the detrimental effects of these on-line problems to an insignificant level.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Multichannel Adaptive Processing						
Maximum-Likelihood Filters						
On-Line Processing						