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**VELA NETWORK EVALUATION AND AUTOMATIC PROCESSING RESEARCH**

**QUARTERLY REPORT NO. 3**

**10 JANUARY 1976 TO 10 APRIL 1976**

**TEXAS INSTRUMENTS INCORPORATED**  
Equipment Group  
Post Office Box 6015  
Dallas, Texas 75222

Contract No. F08606-76-C-0011  
Amount of Contract: \$440,000  
Beginning 15 July 1975  
Ending 30 September 1976

Prepared for  
**AIR FORCE TECHNICAL APPLICATIONS CENTER**  
Alexandria, Virginia 22314

Sponsored by  
**ADVANCED RESEARCH PROJECTS AGENCY**  
Nuclear Monitoring Research Office  
ARPA Program Code No. 6F10  
ARPA Order No. 2551

10 April 1976

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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 Number F08606-76-C-0011.

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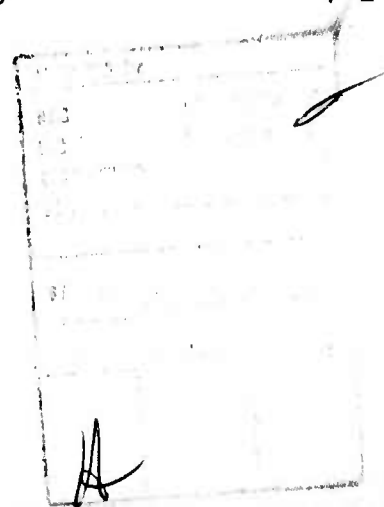
20. continued

- ~~Signal~~ estimation techniques, *and*
- ~~Discrimination.~~



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## SECTION I INTRODUCTION AND SUMMARY

This third quarterly report summarizes the progress made during the period 10 January 1976 to 10 April 1976 in the VELA Network Evaluation and Automatic Processing Research program being carried out by Texas Instruments Incorporated at the Seismic Data Analysis Center (SDAC) in Alexandria, Virginia. The four program tasks are:

- Array and network evaluation
- Signal detection methods
- Signal estimation techniques
- Discrimination.

During the last quarter, processing and analysis of long-period and short-period data from the Albuquerque, Guam, and Mashhad SRO stations was initiated, with the goal of establishing the noise characteristics and signal detection and discrimination capabilities of each. The quality of the SRO data sampled has been in general excellent, with few long-period transients and no spikes observed. Software modifications were completed for the ILPA evaluation, and this evaluation will begin when the data are available. Work has started on the program to transfer ILPA data to the mass storage center.

Evaluation of the automatic power and Fisher detectors using KSRS short-period data was continued. Detection probabilities using 37 Eurasian events recorded in November 1974 were obtained for several pre-filters with 0.8 and 1.6 second integration gates. For optimum detection with the Fisher and the conventional power detectors, a single sensor prefilter (1.5 to 2.5 Hz) has been determined. During the next quarter, detection



probabilities for three regions will be examined using February 1976 (winter season) data.

A modified version of the program NETWORKH has been used to evaluate the effect of certain physical parameters on network detection capability. This study, which was completed during the last quarter, indicates that the station detection threshold and the station reliability are the primary determinants to network performance. The value of the signal amplitude variance had significant effect upon the individual station capability but little effect upon the total network detection capability. Finally, an evaluation of the individual stations comprising the baseline network used in the study yielded a ranking of their detection capability.

For the adaptive beamforming (ABF) detector study using KSRS short-period data, estimation of the detection probability using the beamsteer and ABF detectors was accomplished for 38 Eurasian events recorded in November 1974. Preliminary results suggest that the ABF yields about a 2 dB improvement over beamsteering. Currently, a simulation of burying a scaled signal in a given noise sample is being undertaken. This is part of an effort to improve the ABF capabilities for weak signals.

A program has been written to design and apply a Wiener filter to long-period signals buried in noise as part of the cascading study. Statistically reliable noise and signal power spectra have been found in the course of this study, and the signal-to-noise ratio gain achieved exceeds that of a simple bandpass filter by as much as 3 dB for a realistic case. A more rapidly adapting version of the three component adaptive filter has also been developed. It is now being tested on several events.

During the last quarter, a programming error was found in the upgraded version of the three component adaptive processor (TCA). All relevant data were re-processed to correct the evaluation of the TCA. No significant changes, though, were found in the evaluation results.

The dispersion relation filter is nearing completion. A time variant Wiener filter algorithm and utilization of a variable bandwidth along the dispersion curve have been incorporated into the program. This Wiener filter is being tested on synthetic chirp waveforms and actual signals buried in seismic noise. The filter appears to work reasonably well on chirp waveforms. Also, the choice of the expected signal-to-noise ratio as a Wiener filter design parameter has been found to be rather critical.

A Short-Period Earthquake/Explosion Discriminator (SPEED) processing module has been integrated into the Interactive Seismic Processing System (ISPS) graphics capability on the PDP-15 computer. A demonstration of SPEED was completed, which showed capability for on-line cepstrum analysis and variable frequency magnitude (VFM) measurement. These capabilities were demonstrated on a presumed explosion from Kazakh and an earthquake from Iran using NORSAR seismic data. The results strongly suggest that it is possible to carry out the discrimination processing with a single analyst, keeping up with the anticipated data flow of 25 to 50 events per day of an operating surveillance system. The SPEED demonstration showed that cepstrum analysis could be done to reduce false identification of earthquakes (as explosions) to an acceptably low rate and that this could be followed by VFM processing which has been shown to have about as much discrimination capability as  $M_s$  versus  $m_b$ .

Higher mode Love waves with periods between 5 and 10 seconds have been examined during the last quarter. Studies of these waves generated from two Nevada explosions have confirmed that the energy attenuation coefficients for the source-station (SDCS) paths are relatively high. Because of this 'anomalous' attenuation, accurate measurements must be made in order to have the proper correction. Also, the three component adaptive filter was used to separate higher mode arrivals from two presumed explosions and an

earthquake. No depth discrimination capability was found by fitting these higher mode spectra with a theoretical model.

SECTION II  
ARRAY AND NETWORK EVALUATION

A. ILPA AND SRO EVALUATION

1. Current Status

During the past quarter, data began arriving from three of the Seismic Research Observatories (SRO's). These reporting SRO's are Albuquerque, New Mexico, Guam, and Mashhad, Iran. Processing and analysis of long-period and short-period data from these SRO's has been initiated, with the goal of establishing the noise characteristics and signal detection and discrimination capability of each SRO. From the limited data base processed to date, several preliminary results have been found.

- Short-period RMS noise as recorded at Albuquerque averages about  $0.4 \text{ m}\mu$  (12 daily samples).
- Short-period RMS noise as recorded at Guam averages about  $30 \text{ m}\mu$ , presumably due to wave activity (12 daily samples).
- Long-period RMS noise as recorded at Albuquerque averages about  $9 \text{ m}\mu$  (14 daily samples).

The following preliminary detection capability results are based on a suite of events with epicentral distances predominantly between  $60^\circ$  and  $103^\circ$  for short-period data and between  $60^\circ$  and  $120^\circ$  for long-period data.

- Considering only those events for which the short-period detector permitted data to be recorded, the short-period 50 percent detection threshold at Albuquerque is at approximately  $m_b = 4.4$ .

- Considering all events in the data base, where those for which data was not recorded are counted as non-detections, the short-period 50 percent detection threshold at Albuquerque is at approximately  $m_b = 4.8$ .
- Considering all events in the data base, the long-period 50 percent detection threshold at Albuquerque is at approximately  $m_b = 4.6$ .

The quality of the SRO data sampled has been in general excellent. On some samples of Albuquerque data, long-period transients (glitches) have been observed on the north-south component. These have been tentatively attributed to thermal effects by personnel at the Albuquerque Seismological Center. No spikes have been observed on data from any of the three SRO's sampled to date.

For the ILPA evaluation, the Alaskan Long-Period Array edit program was modified to adapt it to the Iranian Long-Period Array satellite format. The output of this modified program will be compatible with the rest of the long-period array processing package, making possible a complete (noise and signal) evaluation of ILPA.

Testing and debugging of the ILPA edit program have been delayed by lack of test data.

Finally, work has been started on the program to transfer ILPA data to the mass storage center.

## 2. Future Plans

During the next quarter, processing and analysis of both long-period and short-period data recorded at the previously mentioned SRO's will continue, building up a large data base of signal and noise samples. As other SRO's begin to report data, they will be included in the processing and analysis scheme.

When data becomes available, the ILPA edit program will be tested and debugged. When this is completed, evaluation of the noise characteristics and signal detection capability will be started.

Also, work will continue on the ILPA data transfer program. Much of the time will be spent learning the data language necessary for the program.

## B. AUTOMATIC SIGNAL DETECTOR EVALUATION

### 1. Current Status

Major accomplishments for work on the optimum automatic signal detector evaluation include the following:

- Detection probabilities using 37 Eurasian events recorded in November 1974 were obtained for several prefilters with 0.8 and 1.6 second integration gates. Only  $270^{\circ}$  and  $300^{\circ}$  azimuths with the same 15 km/sec velocity were used for the detector beams. Figure II-1 shows the  $m_b$  distribution (the upper part) for the events, and the maximum likelihood estimated detection probability curve (the lower part) for the 0.8 second integration gate Fisher detector result (note - OPTSS stands for optimum detection prefilter designed from single-sensor data). Complete results of the detection probability from the event ensemble are given in Table II-1 for the various prefilters. For optimum detection with the Fisher and the conventional power detectors, the OPTSS prefilter has been selected for further study.
- The detector response pattern was studied using an event from Greece. The Fisher and conventional power detector outputs

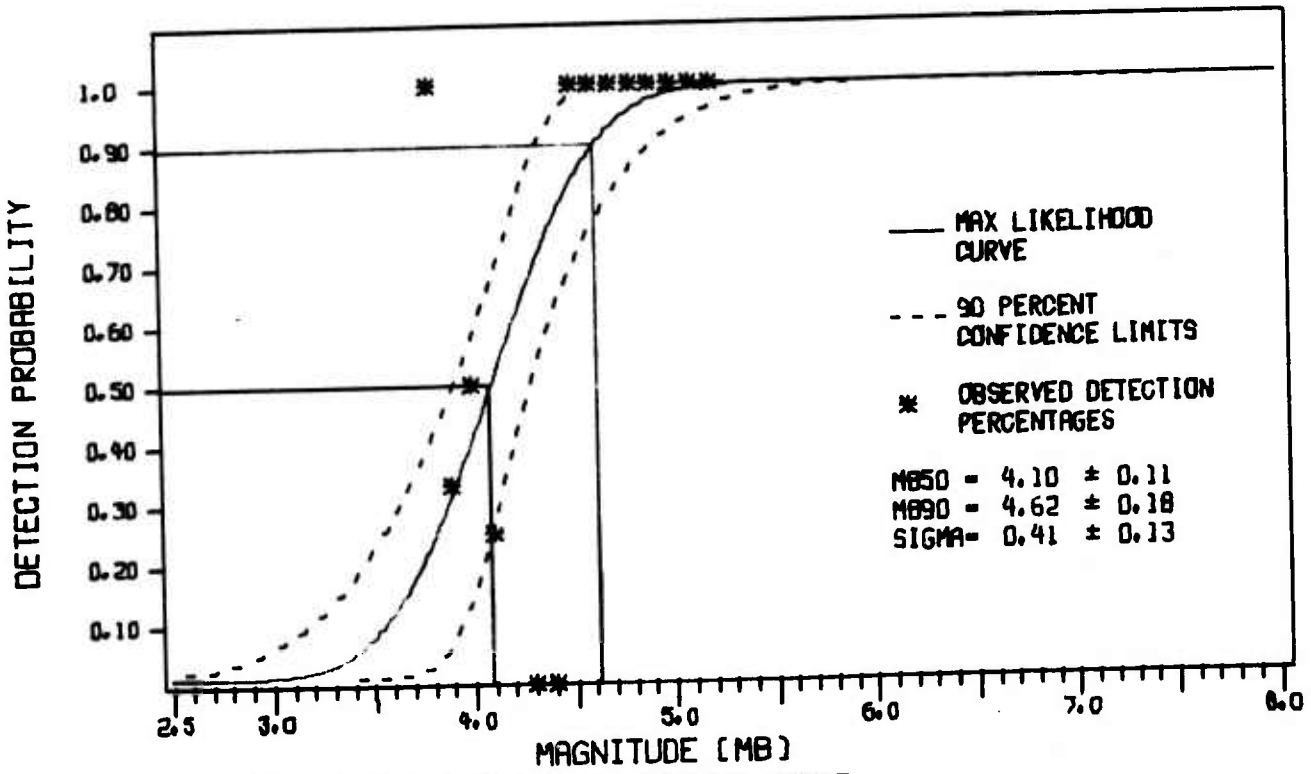
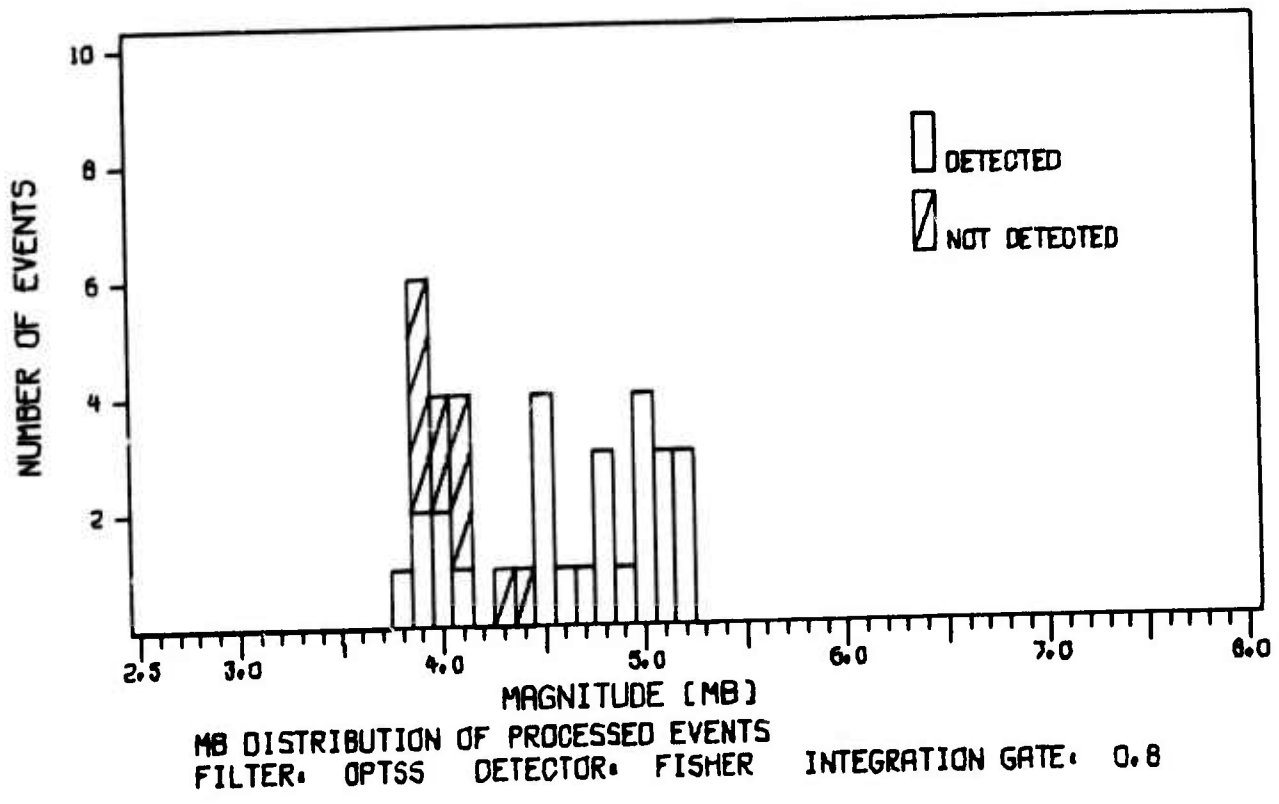


FIGURE II-1

THE MAXIMUM LIKELIHOOD ESTIMATED DETECTION PROBABILITY CURVE FOR 37 EURASIAN EVENTS USING THE FISHER DETECTOR

TABLE II-1

MAXIMUM LIKELIHOOD ESTIMATES OF DETECTION PROBABILITIES FOR  
 FISHER AND CONVENTIONAL POWER DETECTORS AT KRSR SHORT-PERIOD ARRAYS  
 (ON THE BASIS OF 37 EURASIAN EVENTS IN NOVEMBER 1974)

Prefilter	Integration Gate (sec)	Fisher Detector			Conventional Power Detector		
		$m_b^{.50}$	$m_b^{.90}$	$\sigma$	$m_b^{.50}$	$m_b^{.90}$	$\sigma$
Low Passband (0.5-1.1 Hz)	0.8	4.78 ± 0.20	5.81 ± 0.52	0.80 ± 0.31	4.26 ± 0.19	5.28 ± 0.38	0.80 ± 0.31
	1.6	4.51 ± 0.16	5.45 ± 0.38	0.73 ± 0.26	4.45 ± 0.18	5.48 ± 0.42	0.80 ± 0.31
Wide Passband (0.5-3.5 Hz)	0.8	4.40 ± 0.14	5.19 ± 0.28	0.62 ± 0.20	3.75 ± 0.32	4.78 ± 0.30	0.80 ± 0.37
	1.6	4.24 ± 0.14	4.94 ± 0.22	0.55 ± 0.17	3.98 ± 0.24	5.00 ± 0.33	0.80 ± 0.34
Optimum: Array Beam (1.0-2.8 Hz)	0.8	4.12 ± 0.21	5.15 ± 0.36	0.80 ± 0.32	4.09 ± 0.13	4.70 ± 0.19	0.48 ± 0.16
	1.6	4.17 ± 0.15	4.95 ± 0.25	0.60 ± 0.20	4.25 ± 0.10	4.69 ± 0.16	0.34 ± 0.10
Optimum: Single Sensor (1.5-2.5 Hz)	0.8	4.10 ± 0.11	4.62 ± 0.18	0.41 ± 0.13	4.02 ± 0.16	4.70 ± 0.21	0.53 ± 0.19
	1.6	4.07 ± 0.21	5.03 ± 0.31	0.75 ± 0.29	4.01 ± 0.17	4.74 ± 0.22	0.57 ± 0.21



were obtained for 20 km/sec, 15 km/sec, and 10 km/sec velocities of propagation and several azimuths.

The response pattern was examined for detector output loss if a limited number of beams were used to cover a large area of interest. Preliminary results suggest that the Fisher detector yields a larger loss than the conventional power detector.

## 2. Future Plans

During the next quarter, detection probabilities for three regions will be examined using February 1976 (winter season) data. Detection performance using single sensor data will also be studied.

SECTION III  
SIGNAL DETECTION METHODS

A. NETWORK CAPABILITY

1. Current Status

A modified version of the program NETWORTH has been used to evaluate the effect of certain physical parameters on network detection capability. This study, which was completed during the last quarter, indicates that the station detection threshold and the station reliability are the primary determinants to network performance. The value of the signal amplitude variance had significant effect upon the individual station capability but little effect upon the total network detection capability; a decrease in detection capability at one station was generally compensated by an increase at another station. Finally, an evaluation of the individual stations comprising the baseline network used in the study yielded a ranking of their detection capability.

2. Future Plans

The report on this evaluation of the program NETWORTH has been written and is currently being reviewed prior to typing.

B. ADAPTIVE BEAMFORMING DETECTOR

1. Current Status

Estimation of the detection probability for 38 Eurasian events recorded in November 1974 using the beamsteer and ABF detectors were computed with the maximum likelihood method. Table III-1 shows the Gaussian

TABLE III-1  
 MAXIMUM LIKELIHOOD ESTIMATES OF DETECTION PROBABILITIES FOR  
 DELAY-AND-SUM AND ABF BEAMFORMINGS (ON THE BASIS  
 OF 38 EURASIAN EVENTS IN NOVEMBER 1974)

Prefilter	Delay-And-Sum			ABF		
	$m_b$ 50	$m_b$ 90	$\sigma$	$m_b$ 50	$m_b$ 90	$\sigma$
Optimum: Single Sensor (1.5-2.5 Hz)	$4.35 \pm 0.11$	$4.90 \pm 0.18$	$0.43 \pm 0.11$	$4.24 \pm 0.14$	$5.01 \pm 0.25$	$0.60 \pm 0.19$
Optimum: Array Beam (1.0-2.8 Hz)	$4.35 \pm 0.11$	$4.90 \pm 0.18$	$0.43 \pm 0.11$	$4.25 \pm 0.13$	$4.93 \pm 0.22$	$0.53 \pm 0.16$

parameters of the detection probabilities from the beamforming and ABF results. The criteria for detection was that the signal amplitude was at least 1.5 times higher than the noise. These preliminary results suggest that the ABF yields about a 2 dB improvement over beamsteering.

Also, during the last quarter, the array beamforming response pattern was examined. Signal-to-noise ratios were computed by beamforming an event from Greece with 20 km/sec, 15 km/sec, and 10 km/sec velocities for various azimuths. The results of this analysis will be discussed in the next monthly report.

## 2. Future Plans

Currently, a simulation of burying a scaled signal in a given noise sample is being undertaken. In the future, detection of weak signals will be examined by (1) stopping ABF updating upon detection by the Fisher detector, and by (2) using low ABF convergence rates ( $\sim 0.05$ ).

## SECTION IV

### SIGNAL ESTIMATION TECHNIQUES

#### A. CASCADING STUDIES

##### 1. Current Status

A program has been written to design and apply a Wiener filter to long-period signals buried in noise. Statistically reliable noise and signal power spectra have been found in the course of this study, and the S/N ratio gain achieved exceeds that of a simple bandpass filter by as much as 3 dB for a realistic case.

A more rapidly adapting version of the three component adaptive filter has been developed. It is now being tested on several events.

##### 2. Future Plans

The effect of signal-noise correlation on the Wiener filter is going to be investigated; the problem is modeling this correlation. Also, an averaged matched filter waveform will be found, and its performance and that of the three component adaptive filter will be tested alone and in various combinations.

#### B. THE THREE COMPONENT ADAPTIVE PROCESSOR

##### 1. Current Status

During the last quarter, a programming error was found in the upgraded version of the three component adaptive processor (TCA). All relevant data were re-processed to correct the evaluation of the TCA.

However, no significant changes in the evaluation results were found. The final conclusions of the evaluation are:

- The most effective form of the upgraded Love wave TCA processor contains rotation of the Love wave frequency components about the vertical axis to the transverse component with an accept-reject limit placed on the Love wave arrival azimuth.
- At 12 dB true signal-to-noise ratio, we can expect 7-9 dB gain for Rayleigh waves and 6-7 dB gain for Love waves from the original TCA processor when applied to single-site data.
- At 12 dB true signal-to-noise ratio, we can expect about 9 dB gain for Love waves from the upgraded TCA processor when applied to single-site data.
- Only low or negative gains can be expected from either version of the TCA processor when applied to beam data.
- Application of the original TCA processor to single-site data lowered the 50 percent Rayleigh wave detection threshold by about 0.25-0.40  $m_b$  units and the 50 percent Love wave detection threshold by about 0.15  $m_b$  units.
- Application of the upgraded TCA processor to single-site data lowered the 50 percent Love wave detection threshold by about 0.35  $m_b$  units.
- Application of the original TCA processor to beam data lowered the 50 percent Rayleigh wave detection threshold by about 0.15  $m_b$  units. Essentially no change occurred in the 50 percent Love wave detection threshold.

- Application of the upgraded TCA processor to beam data yielded essentially no change in the 50 percent Love wave detection threshold.

## 2. Future Plans

The report on the evaluation of the upgraded TCA processor has been written and is currently being reviewed prior to typing.

## C. DISPERSION RELATION FILTER

### 1. Current Status

The dispersion relation filter is nearing completion. A time variant Wiener filter algorithm and utilization of a variable bandwidth along the dispersion curve have been incorporated into the program. This Wiener filter is being tested on synthetic chirp waveforms and actual signals buried in seismic noise. The filter appears to work reasonably well on chirp waveforms. The choice of the expected signal-to-noise ratio as a Wiener filter design parameter is rather critical.

The filter, to some extent, is capable of resolving signal estimates down to a -6 dB signal-to-noise ratio. However, it can also generate false signal estimates in the form of partial chirp waveforms from pure noise which are difficult to discern from resolved signals up to +6 dB signal-to-noise ratio.

### 2. Future Plans

Testing of the Wiener filter will be continued, and an attempt will be made to solve the false estimate problem. It is expected that the major portion of the technical report for this task will be written during the next quarter.

## SECTION V DISCRIMINATION

### A. PDP-15 DISCRIMINATION PACKAGE

#### 1. Current Status

A Short-Period Earthquake/Explosion Discriminator (SPEED) processing module has been integrated into the Interactive Seismic Processing System (ISPS) graphics capability on the PDP-15 computer. A demonstration of SPEED was completed, which showed capability for on-line cepstrum analysis and variable frequency magnitude (VFM) measurement. These capabilities were demonstrated on a presumed explosion from Kazakh and an earthquake from Iran using NORSAR seismic data. The results strongly suggest that it is possible to carry out the discrimination processing with a single analyst, keeping up with the anticipated data flow of 25 to 50 events per day of an operating surveillance system. Allowing a utilization of 50% of computer capacity, the processing time per event for all routine event classification processing should be on the order of 15 minutes. Specific algorithms should therefore consume no more than several minutes per event. The SPEED demonstration showed that cepstrum analysis could be done to reduce false identification of earthquakes (as explosions) to an acceptably low rate and that this could be followed by VFM processing which has been shown to have about as much discrimination capability as  $M_s$  versus  $m_b$ .

One of the major problems in designing a practical interactive discrimination processor is the reduction of data channels to one or several channels per event (post DAP processing). The approach followed and demonstrated was to apply complex cepstrum beamforming to all of the NORSAR



channels to produce a single event channel which was corrected for system response. This was done in such a way that the analyst could choose an event channel corrected to ground displacement, ground acceleration, or the uncorrected seismic response. Since the low frequency response of the displacement wavelet is greatly different from that of the pP operator, the best results appear to be obtained by choosing the channel corrected to ground displacement.

## 2. Future Plans

SPEED is being modified to include an absorption correction to the spectrum used for VFM. Also, the deconvolution program which separates the seismogram into direct P and echo pP wavelets is being modified for the case of a filtered echo. Physically, this would represent a scattered or multiple echo. Work is proceeding to make the post DAP data reduction an efficient batch process suitable for production usage. A small data base will be processed with SPEED to evaluate the effectiveness for event discrimination.

## B. HIGHER MODE STUDIES

### 1. Current Status

Higher mode Love waves with periods between 5 and 10 seconds have been examined during the last quarter. Studies of these waves generated from two Nevada explosions have confirmed that the energy attenuation coefficients for the source-station (SDCS) paths are relatively high. Because of this 'anomalous' attenuation, accurate measurements must be made in order to have the proper correction. This may not be possible, though, with the limited number of stations available.

The three component adaptive filter was used to separate higher mode arrivals from two presumed explosions and an earthquake. No depth

discrimination capability was found by fitting these higher mode spectra with a theoretical model. This fitting process was hampered by the narrow azimuthal distribution of the SDCS stations in relation to the events available for analysis.

## 2. Future Plans

It is recommended that future studies for this task involve the possibility of studying Eurasian events recorded at Eurasian stations. This should reduce the problems associated with attenuation determination and azimuthal distribution of stations.