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VELA NETWORK EVALUA[illegible]N AND AUTOMATIC PROCESSING RESEARCH

QUARTERLY REPORT NO. 1

15 JULY 1975 TO 15 OCTOBER 1975

TEXAS INSTRUMENTS INCORPORATED
Equipment Group
Post Office Box 6015
Dallas, Texas 7522[illegible]

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

15 October 1975

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. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This first quarterly report summarizes progress under the VELA Network and Automatic Processing Research Program, Contract Number F08606-76-C-0011, during the period 15 July 1975 to 15 October 1975. Work in the following areas is summarized:

- Array and network evaluation
- Signal detection methods

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20. continued

- Signal estimation techniques, and
- Discrimination.

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SECTION I

INTRODUCTION AND SUMMARY

This first quarterly report summarizes the progress made during the period 15 July 1975 to 15 October 1975 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.

Experimental plans have been drawn up and approved for the ILPA, SRO, and network evaluation tasks. Software modifications have begun and will be completed in the next quarter. Analysis will begin when field data are received (now scheduled to be the second quarter for SRO data and the third quarter for ILPA data).

Evaluation of the automatic power and Fisher detectors using KSRS data continued (this task is an extension of work done on a previous contract). A new prefilter, based on actual signal and noise spectra was implemented. Preliminary results suggest that some lowering of the false alarm rate may be achieved. During the second quarter additional testing of this prefilter will be done and the projected receipt of new data will allow expansion of the data base used to estimate the detectors' performances.

The program NETWORTH, which will be used to estimate the performance of a global network of KSRS-like arrays was modified and catalogued during the first quarter. Network performance estimates will be made during the next quarter.

Preliminary results from the adaptive beamforming (ABF) detector study, using KSRS short-period data, are very encouraging. For the one signal studied, the best ABF output had 6 dB higher signal-to-noise ratio than the best beam output. In addition the ABF processor significantly attenuated the P-coda, thus allowing for considerably easier identification of secondary phases (PcP, PP). This feature may be useful in identifying pP for earthquakes (the signal studied was a presumed explosion).

Work on the study to cascade long-period processing has begun. Initially, three component adaptive (TCA) processing and matched filtering will be cascaded. Most of the effort in the first quarter involved software development. Second quarter effort will include both software development and initial processing.

The task to upgrade the TCA processor is well under way. Software modifications have been completed and a significant amount of data processing has been done. Processing and analysis will be completed during the second quarter and a technical report will be submitted in the third quarter.

Work during the first quarter on the dispersion-related filter consisted of selecting and formating a data base, defining the filter implementation approach and beginning the necessary software development. During the second quarter software development will be completed and processing and analysis will begin.

Development of the interactive discrimination package for the PDP-15 has been initiated. Necessary modifications to the existing software are being defined and a data base has been selected for processing. In addition, some advanced processing concepts are being developed and tested; these will be included in the discrimination package at a later date if they prove successful. Work will continue on these three areas during the second quarter.

Software development necessary to support the higher mode study was essentially completed during the first quarter. Second quarter effort will be directed towards selecting, formating, and processing appropriate first-zone LSRM data.

SECTION II

ARRAY AND NETWORK EVALUATION

A. ILPA AND SRO EVALUATION

1. Current Status

During the last quarter, experimental plans were drawn up for the evaluation of the Iranian Long Period Array (ILPA), the Seismic Research Observatories (SRO), and a long-period network consisting of ILPA, ALPA, NORSAR, LASA, and KSRS. Work has started on modification of existing software to create a program capable of editing the SRO long-period data and outputing the edits in the VLPE edit format. In this way, it will be possible to process the SRO long-period data without further software modifications.

2. Future Plans

During the next quarter, we expect to begin receiving data from some of the SRO stations. Once data begins arriving, both short-period data analysis (on the PDP-15) and long-period data analysis (on the IBM 360/44) will commence. Our first effort will be to formulate an optimum processing scheme to maximize the amount of data handled. When the format of the ILPA data is known, modifications to the ALPA edit program will be made.

Work on the long-period network evaluation will be delayed until the final quarter of the contract, when the necessary ILPA data will be available.

B. AUTOMATIC SIGNAL DETECTOR EVALUATION

1. Current Status

While awaiting new KSRS data tapes (expected in October 1975), work on the automatic detectors during the first quarter consisted of comparing the detectors' false alarm rates for the newly designed prefilter (designed on the basis of single-sensor signal and noise power spectra) and the previous bandpass prefilter. For the two noise samples tested, false alarm rates were lower with the new prefilter than with the previously implemented bandpass filter for the conventional power detector. However, for the Fisher detector, the new filter yielded more false alarms for one noise sample and less for the other than the previous bandpass filter. The new filter needs further tests on both noise and signals.

Noise characteristics for the KSRS short-period array change significantly from the lower frequency band to the higher frequency band. In the immediate future, a noise whitening filter will be tested with noise samples and signals.

2. Future Plans

Work on comparing the bandpass and Fisher detector performances for various types of prefilters will be continued. When new data becomes available, the previous signal and noise data base will be expanded so that more reliable estimates of the detectors' performances can be made.

SECTION III

SIGNAL DETECTION METHODS

A. NETWORK CAPABILITY

1. Current Status

An extensive review of the program NETWORTH, which will be used to estimate the detection capability of a global network of KSRS-like arrays, was completed. This review included both checking the coding (one minor error was found) and running the program several times to obtain an understanding of the effect of certain program parameters. In addition, some modifications which should improve the flexibility of the program have been identified.

2. Future Plans

We expect to obtain the specifications for the network stations from the project officer in the near future and to begin evaluating the capability of this network during the second quarter.

B. ADAPTIVE BEAMFORMING DETECTOR

1. Current Status

This task is a study of detection performance for the time-domain adaptive beamforming system at KSRS short-period array. During this quarter, effort was concentrated on prefilter design and the investigation of noise reduction achieved by the ABF system. Signal degradation by the ABF filter was also investigated by use of a strong event from Novaya Zemlya.

On the basis of four events and noise samples from the preliminary KSRS short-period array evaluation, a time-domain filter was designed. The filter was computed by taking the ratio of average signal amplitude to the average noise power. Figure III-1 shows the frequency response for the filter.

Processing of a half hour noise sample (starting at 1500 on day 312 of 1974) was performed with a number of adaptive filter lengths (31, 15, and 9) for the adaptive convergence rates 0.05, 0.1, 0.3, and 0.5. For prefiltered input data the maximum ABF noise reduction relative to beamsteering among the various filter lengths and convergence rates was between 2 and 3 dB. The same noise sample was processed without prefiltering with a 31-point adaptive filter; noise reduction relative to beamsteering was 9.5 dB at $\mu = 0.5$. This result indicated that the ABF system was more effective in the lower frequency band.

For P-wave signals, processing was performed using a strong event from Novaya Zemlya (PDE: origin time 306/04.59.57, $m_b = 6.7$, and depth = 0). Without prefiltering, the ABF noise reduction relative to beamsteering before the P-arrival was 11.7 dB and signal degradation based on peak-to-peak values was 0.4 dB, resulting in an 11.3 dB improvement over the beamsteer processor. Figure III-2 illustrates the beamsteer and adaptive filter outputs for the events. For the high convergence rate ($\mu = 0.5$) the P-coda has been removed by the adaptive filter which suggests that the P-coda may be comprised primarily of scattered energy. Note the increased clarity of secondary phases on the ABF output.

The same processing was repeated with prefiltering, and the ABF noise reduction relative to beamsteering was 2.2 dB and signal degradation 0.5 dB, resulting in a 1.7 dB gain relative to the beamsteer processor.

The detectors' performances with the prefiltered and unfiltered data were computed: signal-to-noise ratios were measured by taking the signal p-p amplitude to noise RMS values. The results are compared in Table III-1.

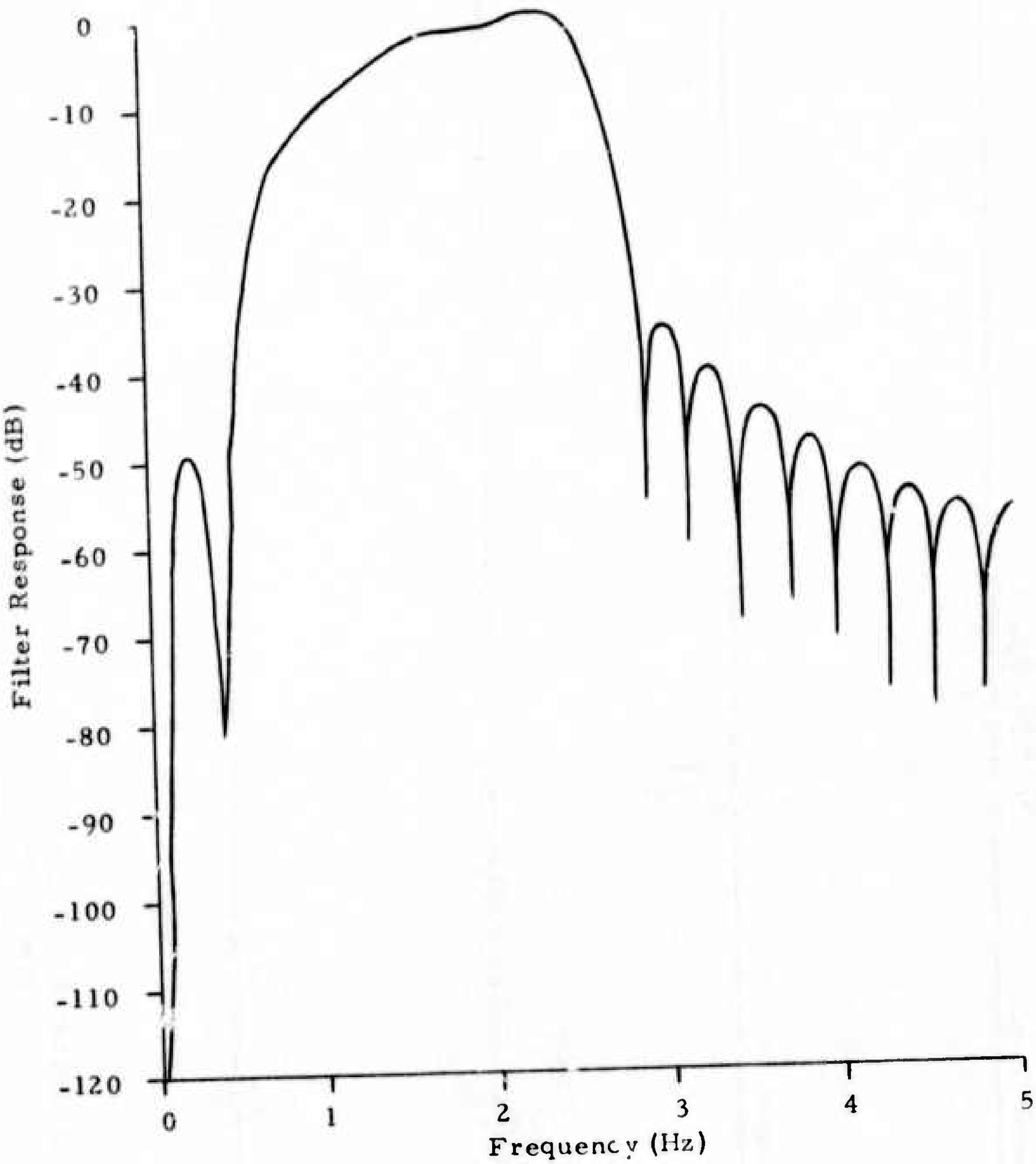

FIGURE III-1

FILTER FREQUENCY RESPONSE

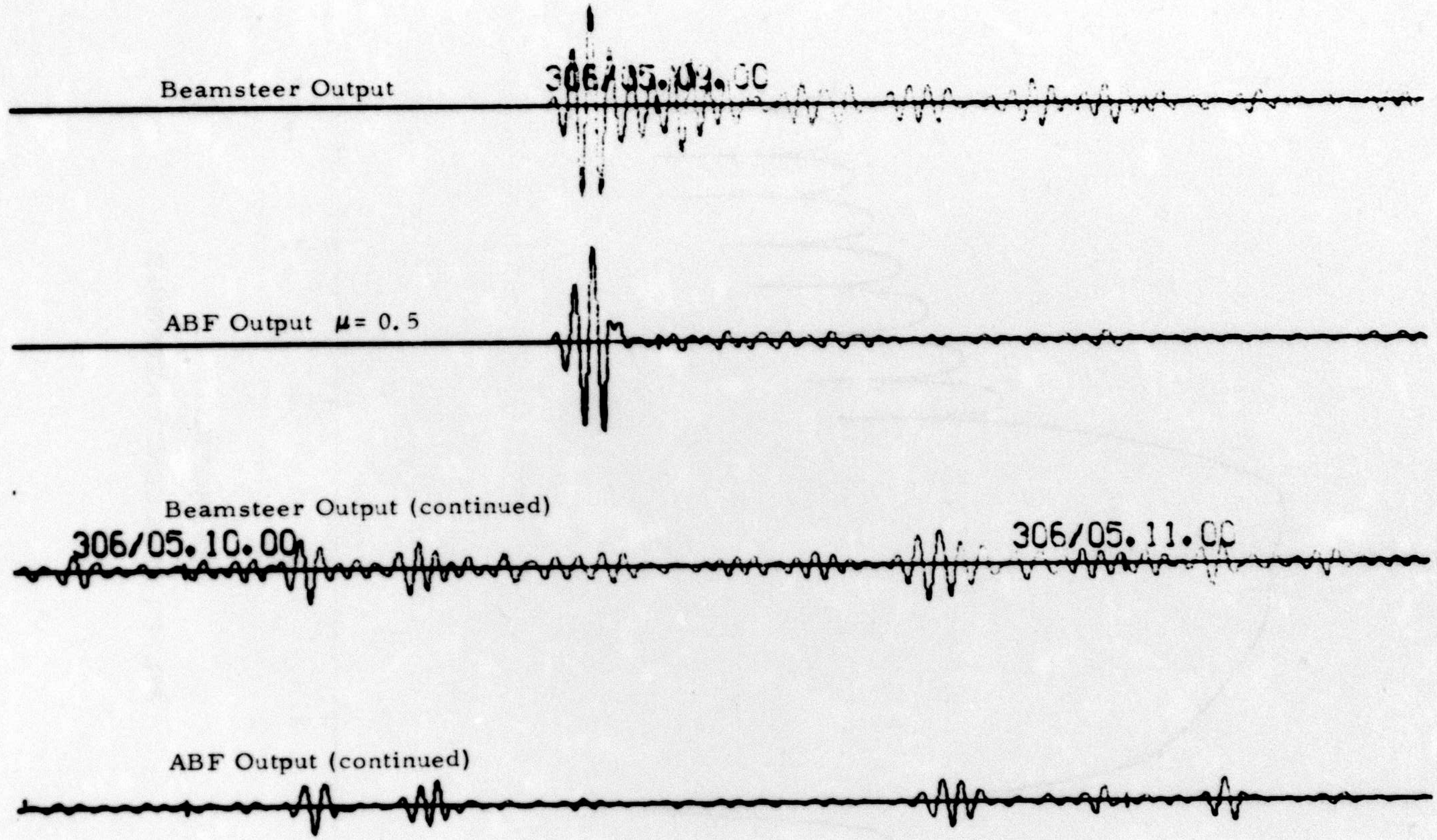

FIGURE III-2

BEAMSTEER AND ABF BEAM OUTPUTS FOR NOVEMBER 2, 1974 EVENT FROM NOVAYA ZEMLYA

TABLE III-1

SIGNAL-TO-NOISE RATIOS (dB)

	Adaptive Processor	Beamsteer Processor
Prefiltered Data	71.1	69.6
Unfiltered Data	75.7	64.5

These results indicate that the best SNR is obtained for the beamsteer processor with prefiltering while the best SNR is obtained for the ABF without prefiltering. The better ABF processor yields a very significant 6.1 dB higher SNR than the better beamsteer processor. This is because the ABF reduces the noise without significantly attenuating the signal, whereas the prefilter in fact reduces the amplitude of the signal (recall that the prefilter is a S/N type filter and is not constrained to pass the signal without attenuation).

These initial results are encouraging in that they suggest a significant improvement in SNR may be possible using a high convergence rate ABF processor.

2. Future Plans

The initial results suggested that prefiltering the input data might not be needed to obtain an optimum signal-to-noise ratio for the ABF processor. In the immediate future, further analysis on weak events will be performed. A new prefilter will be designed on the basis of signal and noise beam spectra.

SECTION IV
SIGNAL ESTIMATION TECHNIQUES

A. CASCADING STUDIES

1. Current Status

This study is directed towards determining what gains are achievable by cascading long-period three component processing techniques. Initial studies will use the three component adaptive (TCA) processor in cascade with matched filtering.

Software development for this task is under way. A 'control' program is being written which will have specific processing techniques as subroutines. The program is being structured to allow the analyst to vary the order in which the processing techniques are applied.

2. Future Plans

During the second quarter software development will be completed and an evaluation of the TCA-matched filter combination begun. This evaluation will continue during the third quarter. Later in the program additional techniques will be studied.

B. THE THREE COMPONENT ADAPTIVE PROCESSOR

1. Current Status

During the quarter just ended, the upgrade of the three component adaptive (TCA) processor was programmed into previously existing software. Data sets (single site) for two seismic regions, southern Kamchatka and central Asia, were selected and quality checked. Limits on Love wave arrival azimuth, beyond which all energy is rejected, have been empirically determined for both events from both regions. Estimates of optimum signal-to-noise ratio improvements to be expected from the TCA processor have been made. All events from the southern Kamchatka region have been processed by both the old and upgrade versions of the TCA processor in order to determine detection threshold improvements. Twenty noise samples have been processed to estimate the false alarm rate of the method.

2. Future Plans

During the next quarter, the single-site data set from central Asia will be processed by this method and the results evaluated. Beamsteered data from one of these regions will also be processed. All results will then be evaluated and a report will be written.

C. DISPERSION RELATION FILTER

1. Current Status

A data base of 21 Sinkiang seismic event signals recorded at ALPA has been chosen for initial evaluation of the dispersion relation filter. The matched filter behavior of these events is well known from previous studies.

Synthetic data generation software for testing and analysis purposes, and spectral analysis software to determine the regional dispersion characteristics have been developed.

The filter implementation has been conceived. Initial theoretical analysis indicates a possible noise rejection on the order of 7 dB over conventional bandpass filtering may be possible.

2. Future Plans

Spectral analysis will be performed on the stronger Sinkiang signals. The filter design will be based on the regional dispersion characteristics. The filter implementation software will be developed and tested with both synthetic and real data. The amount of signal enhancement will be analyzed by burying high SNR signals in various levels of real seismic noise. Finally, the filter will be applied to the weaker Sinkiang signals, the filtering effects will be analyzed, and a report will be written.

SECTION V
DISCRIMINATION

A. PDP-15 DISCRIMINATION PACKAGE

1. Current Status

A data base of 85 NORSAR recorded short-period events is being collected for discrimination evaluation. These include 35 presumed explosions and 50 earthquakes, recorded at NORSAR at 20 Hz sampling rate. A matrix plot program was developed to visually edit plots of all sensors to eliminate dead, noisy, or polarity reversed channels. The program can also be used to time the earliest indicated first motion of the signal. The above events are currently being compiled, tabled, and edited.

2. Future Plans

A program will be written to Wiener filter, and de-reverberate the spectrum of NORSAR recorded events by Generalized Linear Filtering. This method beamforms the logarithm of the spectrum and its effectiveness is based on the degree to which coda and noise fluctuations are uncorrelated between channels. The purpose is to minimize coda interference before performing spectrum and cepstrum analysis.

B. HIGHER MODE STUDIES

1. Current Status

Effort on the study of higher mode surface waves as applied to the discrimination problem was directed toward software development during this quarter. The programs developed so far calculate amplitude of surface wave arrivals from the data, and find the response of a layered earth model to a point source.

Spectra of higher modes can be found in two ways - by narrow-band filtering, or by a moving window maximum entropy spectrum analysis. The software to make both of these calculations using the TS44 operating system, currently the fastest at the SDAC, has been developed and checked out on data from LRSM stations in the format in which it will be ultimately available. Examination of these data has suggested the presence of higher mode surface waves.

The program to calculate earth response was available at the beginning of the contract and required only a few alterations in format and execution order to be applicable to this problem. These changes have been made, and work begun on relating arrivals found by the spectral estimation programs to those predicted by the earth response program.

2. Future Plans

During the next quarter effort will be concentrated on collecting a data base suitable for analysis, and on beginning to process this data base.