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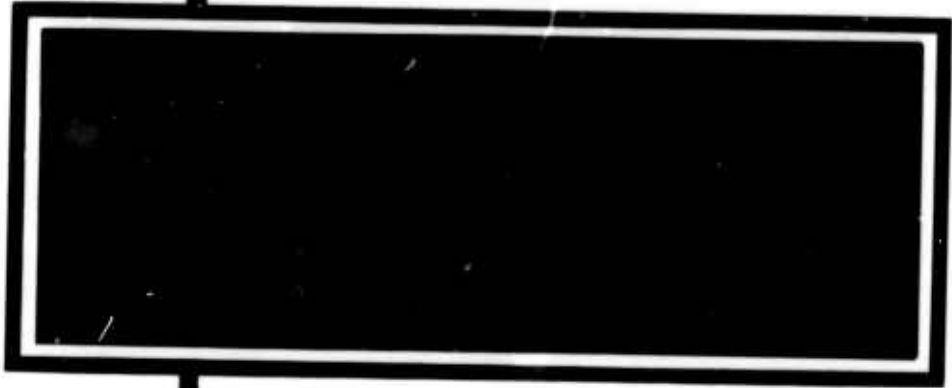
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TEXAS INSTRUMENTS  
SCIENCE SERVICES DIVISION



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**ADVANCED ARRAY RESEARCH**  
Quarterly Report No. 1  
15 February 1968 through 31 May 1968

George Hair, Program Manager  
Area Code 214, 238-3473

**TEXAS INSTRUMENTS INCORPORATED**  
Science Services Division  
P.O. Box 5621  
Dallas, Texas 75222

Contract No. F33657-68-C-0867  
Beginning 15 February 1968  
Ending 14 February 1969

Prepared for

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

Sponsored by  
**ADVANCED RESEARCH PROJECTS AGENCY**  
Nuclear Test Detection Office  
ARPA Order No. 624  
AFTAC Project No. VT/7701

7 June 1968



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*Wash., D.C. 20333*



# TEXAS INSTRUMENTS

INCORPORATED

SCIENCE SERVICES DIVISION

7 June 1968

Air Force Technical Applications Center  
VELA Seismological Center  
Headquarters, USAF  
300 N. Washington Street  
Alexandria, Virginia 22314

Attention: Major Carroll F. Lam

Subject: Quarterly Report No. 1 for period 15 February 1968  
through 31 May 1968

Identification: AFTAC Project No.: VT/7701  
Project Title: Advanced Array Research  
ARPA Order No.: 624  
ARPA Program Code No.: 7F10  
Name of Contractor: Texas Instruments Incorporated  
Contract Number: F33657-68-C-0867  
Effective Date of Contract: 15 February 1968  
Amount of Contract: \$341,000  
Contract Expiration Date: 14 February 1969  
Project Manager: George Hair  
Area Code 214, 238-3473

## TECHNICAL STATUS

Major accomplishments and problems encountered during the first quarter and plans for the second quarter are reviewed by task.

### Task A - Research on Adaptive Processing Technique

The effect of oversampling on the adaptive prediction error filter was studied using independent channels of white noise data with different degrees of oversampling. False gain is found if the data is oversampled and is

dependent on the degree of oversampling, number of channels used in predicting, filter length, and the value of the convergent parameter. Two adaptive schemes were used in this work: (1) constant convergent parameter  $k_g$ ; (2) variable convergent parameter  $b_j = b/X_j^T X_j$  where  $X_j$  is the total vector used in predicting at the  $j^{\text{th}}$  point in time. Both schemes were used for three degrees of oversampling to produce mean square error curves versus convergent parameter on the following filter configurations:

| <u>Channels</u> | <u>Length of Filter</u> |
|-----------------|-------------------------|
| 1               | 21                      |
| 1               | 35                      |
| 7               | 3                       |
| 7               | 5                       |

Attempts to obtain theoretical expressions to describe mean square error as a function of the various influences have not been successful. However, the data can be used to grossly estimate the values of convergence parameters to use in various situations to avoid serious reductions in mean-square-error due to oversampling. A special technical report on the effect of oversampling is in preparation.

Specification of an 870A adaptive processing program is essentially completed. A detailed flow chart, overlay of simultaneous processing, and program writeup have been established in addition to the mathematical specification.

Conversion of the 7044 programs to the IBM 360 has been completed. These programs are adaptive prediction error and adaptive maximum likelihood filtering routines.

During the next quarter, the 870A program will be coded, checked out and used extensively to investigate ways in which to solve those practical problems expected to arise with on-line implementation of adaptive

filtering. The program will be flexible enough so that it will also be used to experiment with variations of the adaptive algorithm and to verify and demonstrate results of other theoretical studies in adaptive processing.

Task B - Evaluation of the Expanded SP Array at TFO

Task C - Evaluation of the Seven Element Long-Period Array at TFO

Tasks B and C have just become active within the past month since the new 37-element SP array and the new 7-element LP array at TFO were not yet operational. The Digital Field System (DFS) to be used to record data at TFO for these tasks has been modified, at Texas Instruments' expense, to permit recording at lower tape speeds and sampling rates. This capability is required to permit recording of LP data with a minimum of redundant sampling and to continuously record both SP and LP data for the desired long data samples.

The modifications permit recording at the additional tape speeds of  $1 \frac{7}{8}$  and  $15/16$  ips, providing a capability to record data samples up to 8 hrs, 20 min on a single 2500 ft reel in the 31-channel mode, and samples up to 4 hrs, 10 min in the 62-channel mode, all at a 0.096 sec sampling interval.

In addition, Texas Instruments has provided a set of 62 anti-alias filters for use with the new sampling rate. These are active dual three-pole filters with a response 6 db down at the corner frequency of 4.5 Hz, and a roll-off rate of approximately 35 db/octave.

Arrangements have been made for the recording program, which is presently scheduled for a three week effort beginning on 30 May and ending on 20 June. The DFS arrived on-site May 26 and began interfacing with the TFO station on May 27. Tapes will be mailed to Dallas during the recording program for quality checking.

The recording program will be completed early in the second project quarter and the process of selecting, editing and preparing a library of signal and noise samples will be completed by the middle of the quarter. Data processing and analysis toward evaluations of both arrays will begin at that time.

Task D - Norway Large Aperture Array Signal and Noise Analysis

This task is scheduled to begin late in the second project quarter and therefore has been inactive.

Task E - Analysis of WMO Vertical and Horizontal Component Ambient Noise

Analysis has begun of the Wichita Mountains Seismological Observatory (WMSO) noise sample. The noise sample was recorded on September 16, 1967 from 01:45:10 to 02:15:00 GCT time, with a 24 millisecond sample period, making the total length around 75,000 points.

From visual analysis of the playbacks, several types of noise other than ambient seismic noise have been found. These are:

1. Single spike
2. Cross channel spikes
3. Acoustic
4. Ground wave

The first two are definitely instrument noise. The last two come from artillery firing on the Fort Sill reservation and will be discussed in detail later.

A high-resolution maximum-entropy power-density spectrum was computed from the 75,000 point noise sample for seismometer U-4 because it is free of non-seismic noise. The spectrum was obtained from an autocorrelation with lags computed out to  $\pm 250$ . The 2 Hz noise peak found in previous WMO analysis shows clearly here.

A definite pattern is observed in the noise sample. A considerable amount of transverse wave energy appearing on the (buried) vertical seismometers is followed by longitudinal wave energy appearing on the (surface) horizontal seismometers. Based on differences in arrival times at the various seismometers, direction of propagation and speed were determined for both waves for a number of such events. They originate within the azimuth range of  $N 68^{\circ} E$  to  $N 80^{\circ} E$  and have propagation speeds between 2.42 km/sec and 2.79 km/sec for the transverse wave; 0.42 km/sec and 0.44 km/sec for the longitudinal wave. Apparently, they are the ground and acoustic wave from artillery firing on Fort Sill range. The difference in arrival time between the ground and acoustic wave was measured as 19 seconds and the energy source was estimated at 10 km,  $N 74^{\circ} E$  from the center seismometer of the array. This corresponds to an impact area on the Fort Sill firing range.

In order to eliminate or reduce the non-seismic noise, an automatic error detection and correction process is needed. Various prediction (interpolation) error filters have been designed and applied to the noise sample and the outputs analyzed for error indication. Results show that the prediction (interpolation) error of these filters increases very fast as the filter length increases. Thus, no more than 10 points were used in the error detection filter. The mean square error of a 6-point one-sided prediction filter is around -35 db and the mean square error of the same length two-sided interpolation filter is around -55 db, where 0 db is the average input power.

The errors are also corrected by a prediction filter which may or may not be the same filter used for error detection. After the first error point is replaced by the predicted value, this point is used in the prediction of the next point as if it is the true value. This is worse than using the old statistics to predict two points ahead, because the filter is no longer

optimum. The performance of prediction goes down rapidly as the number of consecutive error points goes up. Experiments show that the mean square error exceeds 10% of the average input power for four or more consecutive error points.

This error correcting technique can be improved by using both forward and backward prediction. The outputs are then weighted and combined to serve as the estimated value. Study on the optimum weighting function (minimum mean-square-error criterion) shows it is approximately a cosine function.

This task has been temporarily suspended pending availability of the new TIAC 870A computer. When it is resumed, the noise sample will be run through the automatic error detection and correction procedure, the line spectra and spectral matrices will be computed and analyzed.

Task F - Investigation of the Feasibility and Value of On-Line Wavenumber Spectra Computation and Display

This task is scheduled to begin late in the second project quarter and therefore has been inactive, except to monitor the research being conducted on high-resolution frequency-wavenumber spectra on Contract No. AF 33(657)-16678, Large-Array Signal and Noise Analysis.

Task G - Study of Minimum Phase Equalization

This task is scheduled to begin late in the second project quarter and therefore has been inactive.

Task H - Special Problems

A special research program has been planned during the first quarter to develop and evaluate, for at least one array station, a technique for estimating the advisability and optimum method of expanding existing array stations. This technique will require a good understanding of the space-time characteristics of the noise field at the selected station since the

first step will be to model the noise field. A station especially well suited to an initial investigation of such a technique (the noise field is relatively simple and time stationary) has been selected. Noise and signal data collected at this station under another contract is presently being analyzed under that contract. When the analysis has proceeded to the point that the noise field can be modeled, the special problem will begin. The following describes the analysis now underway on this data.

Fifteen noise samples (approximately 4 min in length) selected from a 30 day period were transferred from field tapes to IBM tapes compatible with the 360/50 system. Cross-power matrices were generated for each of the noise samples for the frequency band 0 - 5.283 Hz at a frequency increment of 0.0412 Hz. Prediction filters were designed and applied to an average cross-power matrix computed from the 15 noise samples. Results showed very high coherence in the area of .25 - .85 Hz and 1.15 - 2.1 Hz.

Wavenumber spectra were computed from two of the individual noise samples at 0.25, 0.5, 0.75, 1.0, 1.25, 1.5, 1.75, and 2.0 Hz. At frequencies below 1.0 Hz, a velocity for the coherent energy could not be accurately determined. However, at higher frequencies, velocities of well defined noise lobes could be measured fairly accurately.

At 1.5 Hz, most of the coherent energy appears to be concentrated in a single source from the southwest with an apparent velocity of approximately 2.65 km/sec.

Wiener filters have been designed and evaluated on the average cross power matrix. The cross power matrix was not normalized in the design, but an equal signal-to-noise ratio was used for each channel.

The following study has been recommended by John Burg to determine how well the measured noise field can be theoretically modeled.

From an average cross power matrix for the single frequency of 1.5 Hz the following will be performed.

1. Normalize the noise matrix
2. Compute conventional and high-resolution wavenumber spectra
3. Design and evaluate an MCF
4. Compute the wavenumber response of the MCF

In an effort to approximate the measured noise field with theoretical models, a cross power matrix will be generated which will consist of:

1. One direction noise source (94.5%) - from the southwest with a velocity of 2.65 km/sec
2. Isotropic noise (velocity of surface mode energy) - 5%
3. Random noise - 0.5%

Similarly, the following will be computed from the theoretical matrix:

1. Conventional and high-resolution wavenumber spectra
2. Design and evaluate an MCF
3. Compute the wavenumber response of the MCF

The two designed MCF's may also be cross applied to the noise matrix. The RMS values output by the two MCF's will be compared.

Adjustments in the percent of each noise model may then be made and a new filter designed and evaluated.

FINANCIAL STATUS

Financial status as of 1 May 1968 was reported on the Alternate Management Summary Report submitted 20 May 1968.

ACTION REQUIRED BY AFTAC

None.

Very truly yours,

TEXAS INSTRUMENTS INCORPORATED



George Hair  
Program Manager

GH:se

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10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES

ARPA Order No. 624  
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Advanced Research Projects Agency  
Department of Defense  
The Pentagon, Washington, D.C. 20301

13. ABSTRACT

Progress is reported for those tasks active during the first quarter: Research on Adaptive Processing Techniques, Evaluation of the Expanded SP Array at TFO, Evaluation of the 7-Element LP Array at TFO, Analysis of WMO Vertical and Horizontal Component Ambient Noise. Plans for the second quarter are reported for these and other tasks scheduled to begin during the second quarter.

**KEY WORDS**

**LINK A**

**LINK B**

**LINK C**

**ROLE**

**WT**

**ROLE**

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Adaptive processing techniques  
Noise field modeling  
Expanded short-period TFO array  
Long-Period TFO array  
Ambient seismic noise