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FREQUENCY-WAVE NUMBER ANALYSIS OF  
SIGNALS AND NOISE RECORDED AT THE  
UBO VERTICAL ARRAY

14 November 1967

Prepared For  
AIR FORCE TECHNICAL APPLICATIONS CENTER  
Washington, D. C.

By  
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TELEDYNE, INC.

Under  
Project VELA UNIFORM

Sponsored By

ADVANCED RESEARCH PROJECTS AGENCY  
Nuclear Test & Detection Office  
ARPA Order No. 624

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FREQUENCY-WAVE NUMBER ANALYSIS OF  
SIGNALS AND NOISE RECORDED AT THE  
UBO VERTICAL ARRAY

SEISMIC DATA LABORATORY REPORT NO.201

AFTAC Project No.: VELA T/6702  
Project Title: Seismic Data Laboratory  
ARPA Order No.: 624  
ARPA Program Code No.: 5810  
Name of Contractor: TELEDYNE, INC.  
Contract No.: F 33657-67-C-1313  
Date of Contract: 2 March 1967  
Amount of Contract: \$ 1,736,617  
Contract Expiration Date: 1 March 1968  
Project Manager: William C. Dean  
(703) 836-7644

P. O. Box 334, Alexandria, Virginia

AVAILABILITY

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This research was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office, under Project VELA-UNIFORM and accomplished under the technical direction of the Air Force Technical Applications Center under Contract F 33657-67-C-1313.

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## ABSTRACT

A Fiji earthquake recorded on 30 December 1966, on a vertical-component vertical array, was analyzed by means of frequency-wave number power spectrum. The distance of the teleseismic event was approximately  $85^{\circ}$ . The ambient noise preceding the signal appeared to be predominately composed of Rayleigh Waves. The signal appeared as expected, but the apparent up-going velocity was about 10-15% lower than the down-going velocity. By imaging the vertical array about the earth's surface the response was sharpened, from .75 cps to 1.75 cps. The coda appeared to display considerable non-linear conversion or scattering phenomena above 1.00 cps. The imaged response of the coda compared with the peak signal indicated substantial energy conversions at high frequencies and energy losses that were larger at higher frequencies.

## INTRODUCTION

This is one of a series of observations of teleseismic signals and noise at vertical array sites. The purpose is to compare the f-k spectrum of noise preceding the signal and the signal-generated noise following the signal, with a teleseismic signal. Another objective is to note any anomalous characteristics of the signal which may significantly affect the design of vertical array filters.

Other reports on observations of f-k spectra are SDL reports Number 196 and 197 by the author.

## PROCEDURE

The Uinta Basin Observatory (UBO) vertical array site is in a quiet ambient seismic noise environment located in an inter-mountain basin in Utah. The average structure as observed by an ultrasonic well survey of the compressional velocity is primarily a nearly uniform gradient between 3 km/sec and 6 km/sec at 5.7 km depth. For the deepest sensor (2.71 km), the theoretical uphole time is .716 sec., indicating an average velocity of 3.8 km/sec.

The Fiji Island event which was analyzed was recorded on 30 December 1966. The USCGGS depth of focus was 658 km, magnitude 5.0, and approximate distance of propagation was  $85^{\circ}$ .

The sensor depths are 1.13, 1.49, 1.80, 2.11, 2.47, and 2.71 km. The sample of noise before the signal consisted of 2048 points sampled at the rate of 20 points per second. Samples of 128 points and 256 points were taken about the largest pulse characterizing the P wave received from the Fiji earthquake event. The coda following the signal was sampled with 1024 points immediately following the signal window.

The SDL program for computing f-k spectra makes use of the fast Fourier transform to compute average power as a function of frequency and wave number. Averages were based on time integration with approximately 4 degrees of freedom per estimate for the noise sample of 1024 points and 8 degrees of freedom for the ambient noise sample of 2048 points.

## RESULTS

The f-k spectrum of the ambient noise preceding the signal is shown on Figure 1. The principal noise peak occurs at .16 cps with the high frequency noise nearly centered about the  $k=0$  axis. This suggests that the ambient noise consists predominantly of energy in trapped modes. The slight asymmetry in the wave number pattern suggests a net flow of energy downwards, possibly due to beds dipping roughly  $5^\circ$ . The asymmetry is more evident in the 1.85 cps peak. There is no substantial evidence of reflected P-pulses, although such a component may be obscured by the array response. The main peak of the signal is shown on Figure 2 and 3. The apparent down-going velocity is 4.51 km/sec and apparent up-going velocity is 4.0 km/sec. This anomaly may be due to reflection from a slightly tilted earth's surface, or to dipping beds or other structural complexities. The spectrum shown in Figure 3 is based on a 256-point sample of the peak pulse as compared to a 128-point sample in Figure 2. The anomalous relative velocities of the up-going and down-going peaks are retained and any small difference between the two can easily be attributed to array response, which depends on sample length.

The f-k analysis of the signal coda is shown on Figure 4. It differs from both the signal peak and noise preceding the signal by the striking asymmetry in the 1.0 to 1.75 cps band indicating a net upflow of energy and an abundance of

conversion phenomena, as compared to the near f-k symmetry shown for the preceding samples. The apparent down-going velocity of body waves in the coda is 4.8 km/sec and that of the up-going waves is 4 km/sec which is similar to the peak signal. The relative up and down peak amplitudes and peak frequency in the coda are approximately the same as that of the peak pulse.

In Figures 5, 6, and 7, the array is mirror-imaged in order to attenuate the effects of conversions and produce a wavenumber pattern which is necessarily symmetrical about the frequency axis. This operation will emphasize any reflected pulses by aligning the up-going and down-going pulses. Rayleigh waves would be emphasized as peaks along the frequency axis, and reflected pulses as peaks along the angular sectors, the angle depending on the vertical phase velocity. One problem with the UBO array is that there is no surface instrument. Due to the resulting large sample gap about the surface, the impulse response of the array has large side lobes as indicated on Figure 5, the f-k plot of the ambient noise preceding the signal. In this case the cylindrical pattern and side lobes correspond to those shown for the array response, which suggests the apparent predominance of Rayleigh noise and possible absence of reflected pulses in the ambient noise field. The f-k spectrum of the peak pulse of the Fiji signal on Figure 6 shows a much broader spectrum of the reflected P-pulse with peaks at .75 cps, a broad peak from 1.0 to 1.5 cps and 1.75 cps. For the signal coda, shown in Figure 7, energy in the reflected pulses is shifted toward lower frequency, and some dispersion may be indicated by the bending in the trend of the peaks in the sector indicating reflected P-pulses.

This suggests a possible mechanism for the greater energy loss at higher frequencies observed in the coda as surface scattering by conversion to trapped modes.

#### REFERENCES

- Sax, R. L., 1967, Frequency-Wavenumber Analysis of Signals and Noise Recorded at The Vertical Array at Apache, Oklahoma, SDL Report #196.
- Sax, R. L., 1967, Stability of Frequency-Wavenumber Noise Spectra at UBO, SDL Report #197.

VFKSPTRM

SEISMOGRAM NO. = 18141 NO. OF CHANNEL = 6  
 SAMPLING RATE = 80.00 SAMPLING POINTS = 1 TOTAL POINTS = 2048  
 THE NUMBER OF SMOOTHING TIME = 4

CHANNEL ID	SCALE FACTOR	DEPTH	SYMBOL
UW6	1.00	1.130	U 6
UW5	1.00	1.490	U - 5
UW4	1.00	1.800	U - 4
UW3	1.00	2.110	10 - 3
UW2	1.00	2.470	10 - 21
UW1	1.00	2.710	24 - 27

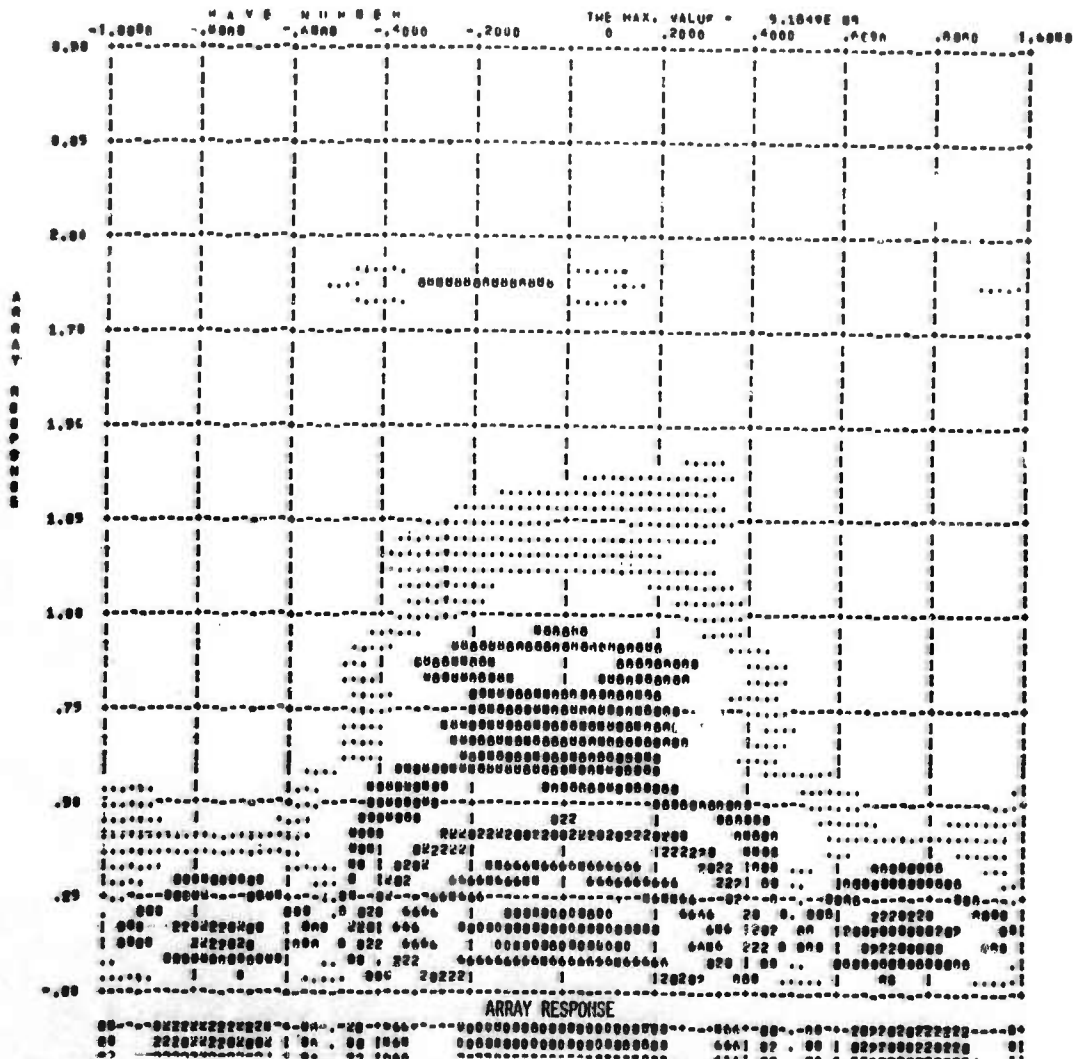


Figure 1. Noise Preceding Fiji Signal,  
 UBO Vertical Array

VFKSPTRM

CHANNEL NO. = 1014  
 NO. OF CHANNEL = 6  
 SAMPLING RATE = 20.00 HANLING POINT = 1 TOTAL POINTS = 2048  
 THE NUMBER OF SHOWING TIME = 4

CHANNEL ID	SCALE FACTOR	DEPTH		
UM6	1.00	1.130	U 0	0
UM5	1.00	1.490	0 - J	0
UM4	1.00	1.800	0 - V	0
UM3	1.00	2.110	12 - 17	2
UM2	1.00	2.470	10 - 21	0
UM1	1.00	2.710	24 - 27	.

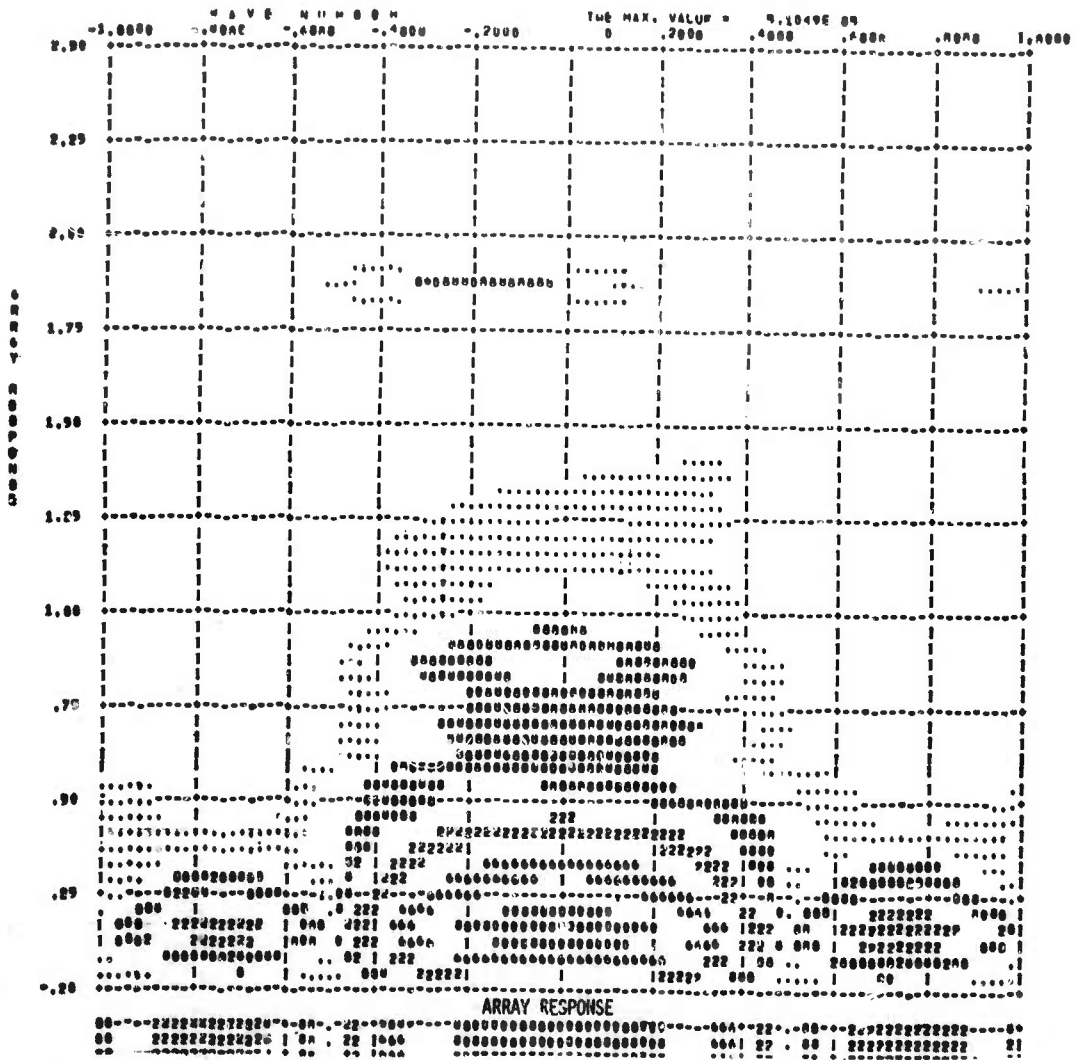


Figure 1. Noise Preceding Fiji Signal, UBO Vertical Array





VFKSPTRM

OBSERVATION NO. = 3013 NO. OF CHANNELS = 6  
 SAMPLE RATE = 20.00 STARTING POINT = 4000 TOTAL PRINTS = 1074  
 TIME BETWEEN UP SHORTWAVE TIME = 3

CHANNEL ID	SCALE FACTOR	DEPTH	UNIT	SYMBOL
UW0	1.00	1.150	U 0	
UW0	1.00	1.450	0 - 3	0
UW0	1.00	1.800	0 - 0	0
UW3	1.00	2.110	12 - 15	2
UW2	1.00	2.470	10 - 21	0
UW1	1.00	2.710	14 - 21	.

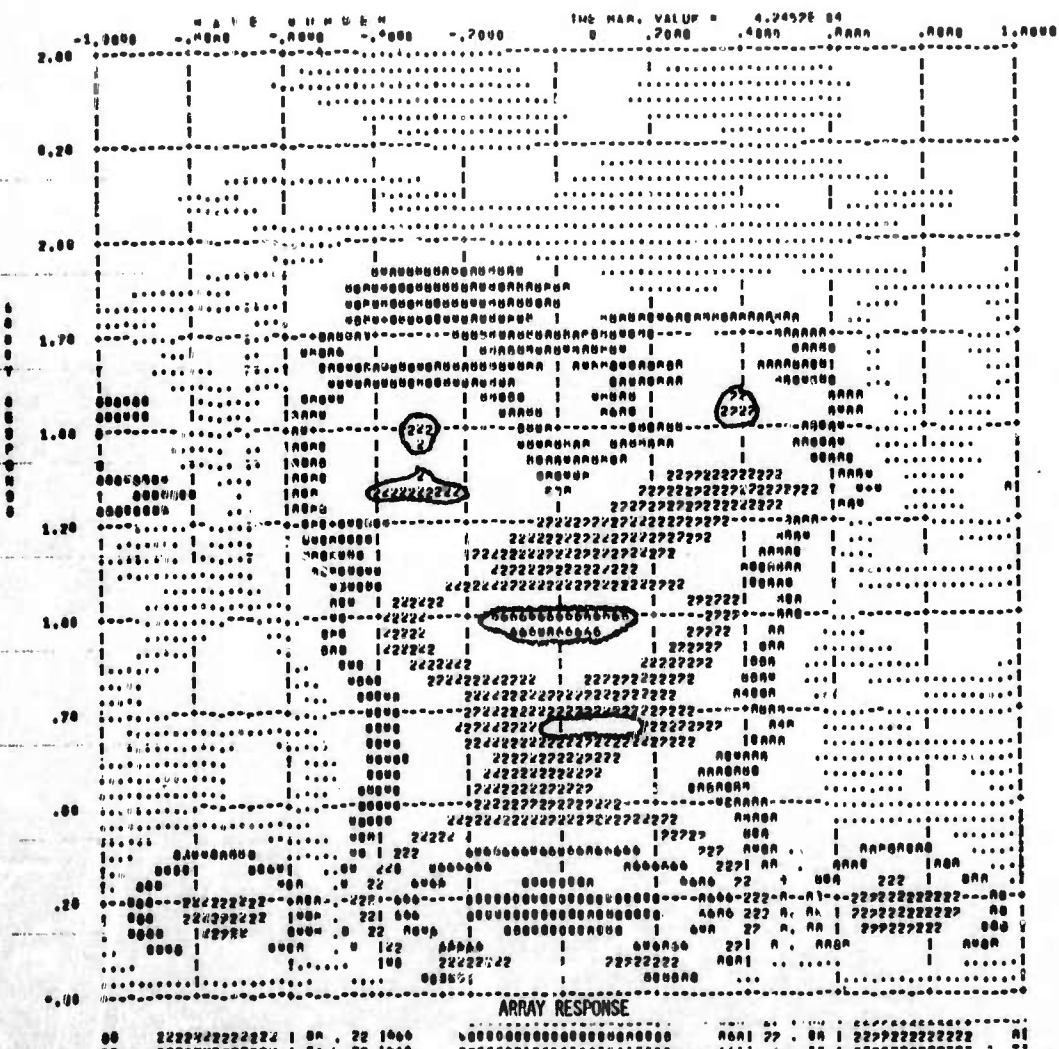


Figure 4. Coda of Fiji Signal, UBO Vertical Array

VFKSPTRM

SCHEMATIC NO. = 10141

NO. OF CHANNELS = 12

AMPLITUDE GAIN = 20.00

STANDARD POINTS = 1

TOTAL POINTS = 2048

THE NUMBER OF S-DRAWING LINES = 4

UNITARY ID	SCALE FACTOR	DEPTH	UNIT	SYMBOL
U01	1.00	-2.710		
U02	1.00	-2.470		
U03	1.00	-2.110	U - 1	0
U04	1.00	-1.800	U - 7	4
U05	1.00	-1.400	12 - 12	2
U06	1.00	1.110	10 - 01	0
U07	1.00	1.400	14 - 01	.
U08	1.00	1.800		
U09	1.00	2.110		
U10	1.00	2.470		
U11	1.00	2.710		

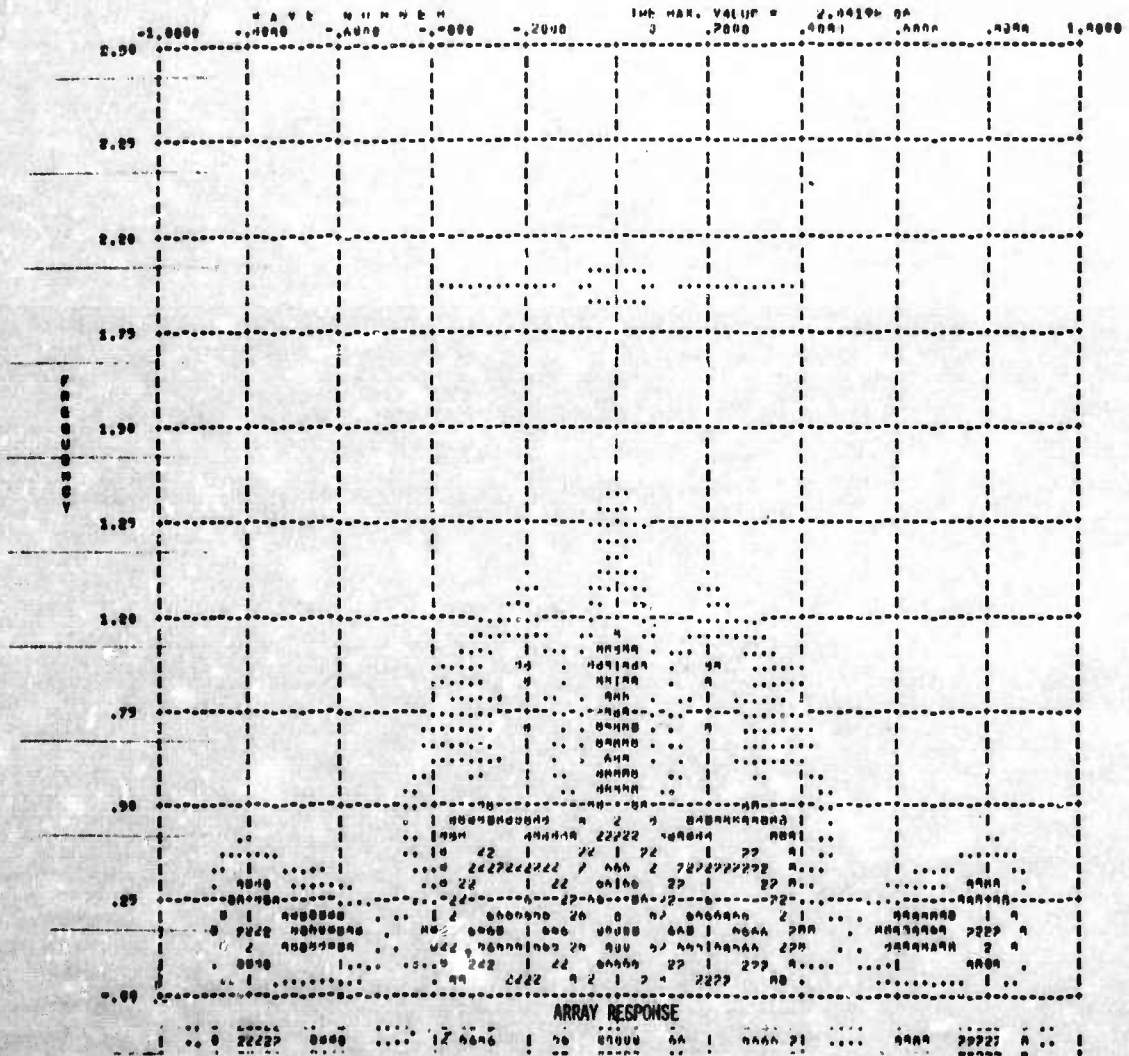


Figure 5. Noise Preceding Fiji Signal, Imaged, UBO Vertical Array

VFKSPTRM

ORIGINATOR NO. = 14141 NO. OF CHANNELS = 12  
 SAMPLE RATE = 20.00 STARTING POINT = 3000 TOTAL DURATION = 300  
 THE NUMBER OF SHOWING TIME = 0

CHANNEL ID	SCALE FACTOR	DEPTH	U M	SYMBOL
U01	1.00	-2.710		
U02	1.00	-2.470	U M	
U03	1.00	-2.110	0 - 3	0
U04	1.00	-1.800	0 - 4	0
U05	1.00	-1.490	12 - 13	0
U06	1.00	-1.130	10 - 21	0
U07	1.00	1.130	14 - 27	
U08	1.00	1.490		
U09	1.00	1.800		
U10	1.00	2.110		
U11	1.00	2.470		
U12	1.00	2.710		

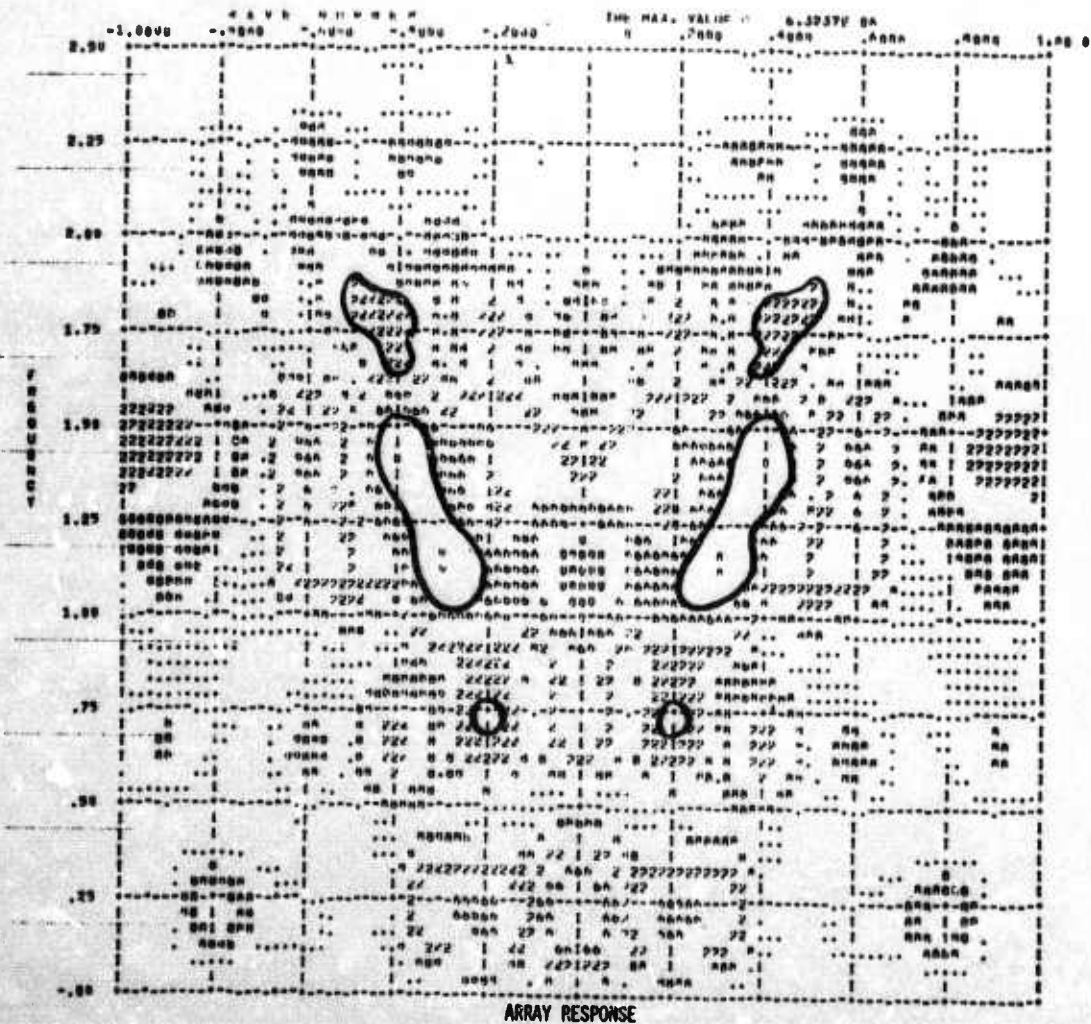


Figure 6. Fiji Signal, Imaged, UBO Vertical Array



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1. ORIGINATING ACTIVITY (Corporate author) TELEDYNE, INC. ALEXANDRIA, VIRGINIA		2a. REPORT SECURITY CLASSIFICATION Unclassified	
		2b. GROUP ---	
3. REPORT TITLE FREQUENCY-WAVE NUMBER ANALYSIS OF SIGNALS & NOISE RECORDED AT THE UBO VERTICAL ARRAY			
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Scientific			
5. AUTHOR(S) (Last name, first name, initial)  Sax, Robert L.			
6. REPORT DATE 14 November 1967		7a. TOTAL NO. OF PAGES 15	7b. NO. OF REFS 2
8a. CONTRACT OR GRANT NO. F 33657-67-C-1313		8a. ORIGINATOR'S REPORT NUMBER(S)  201	
b. PROJECT NO. VELA T/6702			
c. ARPA Order No. 624		9a. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)  ---	
d. ARPA Program Code No. 5810			
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11. SUPPLEMENTARY NOTES  ---		12. SPONSORING MILITARY ACTIVITY ADVANCED RESEARCH PROJECTS AGENCY NUCLEAR TEST DETECTION OFFICE WASHINGTON, D. C.	
13. ABSTRACT A Fiji earthquake recorded on 30 December 1966, on a vertical- component vertical array, was analyzed by means of frequency-wave number power spectrum. The distance of the teleseismic event was approximately 85°. The ambient noise preceding the signal appeared to be predominately composed of Rayleigh Waves. The signal appeared as expected, but the apparent up-going velocity was about 10-15% lower than the down-going velocity. By imaging the vertical array about the earth's surface the response was sharpened, from .75 cps to 1.75 cps. The coda appeared to display considerable non-linear conversion or scattering phenomena above 1.00 cps. The imaged re- sponse of the coda compared with the peak signal indicated substan- tial energy conversions at high frequencies and energy losses that were larger at higher frequencies.			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Earthquake P-pulse						
Seismic Noise						
Earthquake P-coda						
Vertical Array						
Teleseismic Signals						
Frequency-Wavenumber Spectra						

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