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DEPARTMENT OF PHYSICS
SCHOOL OF SCIENCES AND HEALTH PROFESSIONS
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

TECHNICAL REPORT PTR-82-17

PROPAGATION OF SOUND THROUGH THE EARTH'S ATMOSPHERE

By

Francis Badavi
Roger Meredith

and

Jacob Becher, Principal Investigator

Progress Report
For the period July 1 to December 1982

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

Under
Research Grant NAG1-234
Harlan K. Holmes, Technical Monitor
Technology Utilization and Applications Division

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Submitted by the
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P.O. Box 6369
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PROPAGATION OF SOUND THROUGH EARTH'S ATMOSPHERE

By

Francis F. Badavi[1] and Jacob Becher[2]

SUMMARY

This report summarizes the work performed under research grant NAG1-234, during the period of July 1 - December 30, 1982 in the specific area of detection of infrasound generated by Clear Air Turbulence.

Detection of Infrasound Generated By Clear Air Turbulence

Introduction

The purpose of the present work is to establish a possible correlation between atmospheric turbulence and generation of low frequency infrasound waves (frequency -0.1 -10 Hz).

Once the correlation of these infrasound waves has been established, the detection of infrasound could be used as an effective method of atmospheric turbulence detection and storm prediction.

The previous progress reports (research grant NAG1-142, July and December 1981, and NAG1-234 June 1982), had described the technical and instrumentational procedures and criteria employed for the present work.

The present report will be mainly concerned with the analysis of artificially produced infrasound and the response of the data acquisition system. These will be carried out under two headings:

1. System response to infransonic pure-tone; and
2. System response to helicopter noise.

[1]Graduate Research Assistant, Department of Physics, Old Dominion University, Norfolk, Virginia 23508.

[2]Associate Professor, Department of Physics, Old Dominion University, Norfolk, Virginia 23508.

System Response to Infrasonic Pure-Tone

To test the effect of local wind variations on the data-acquisition system, a Bass-Reflex speaker was designed and built to operate in the infrasonic region (output 104 dB @ 1-m; Helmholtz Resonance frequency @ 9.868 Hz). Figure 1 shows the location of the microphone array in relation to the Landing Loads Facility (Bldg.-1262, LaRC).

In the actual field test, the speaker, with an accompanying electronics and power amplifier (Crown-DC300 @ 300 Watts/channel), was placed in a van and taken to three predetermined locations to study the wind effect.

The analysis of the recorded results showed that the microphones could not be left exposed in the field and had to be placed in a protective container, with a wind screen separating the ambient air from microphone diaphragm. To lower the effect of wind shear on the container wall, a coarse fiberglass cloth was employed to cover the top of the container with two layers of soft foam providing seismic isolation. Finally the entire assembly was buried such that the upper surface of the container was level with the ground. Figure 2 shows the position of the container with respect to ground level. This method virtually eliminated the effect of wind shear on the entire assembly.

Figure 3 is a typical noise response of the system before and after the modification. The upper line is the system's noise response with exposed microphone and the lower line is the response after the wind damping container was employed. By the application of this method a considerable amount of drop in response to wind was achieved, and the wind leakage into the system was at an acceptable level.

System Response to Helicopter Noise

The infrasonic signatures generated by the main blade slap rate of a helicopter is a convenient source of artificially-produced infrasound.

To test the data-acquisition system sensitivity, a multi-location hovering schedule was set on the afternoon of August 27, 1982. The specific

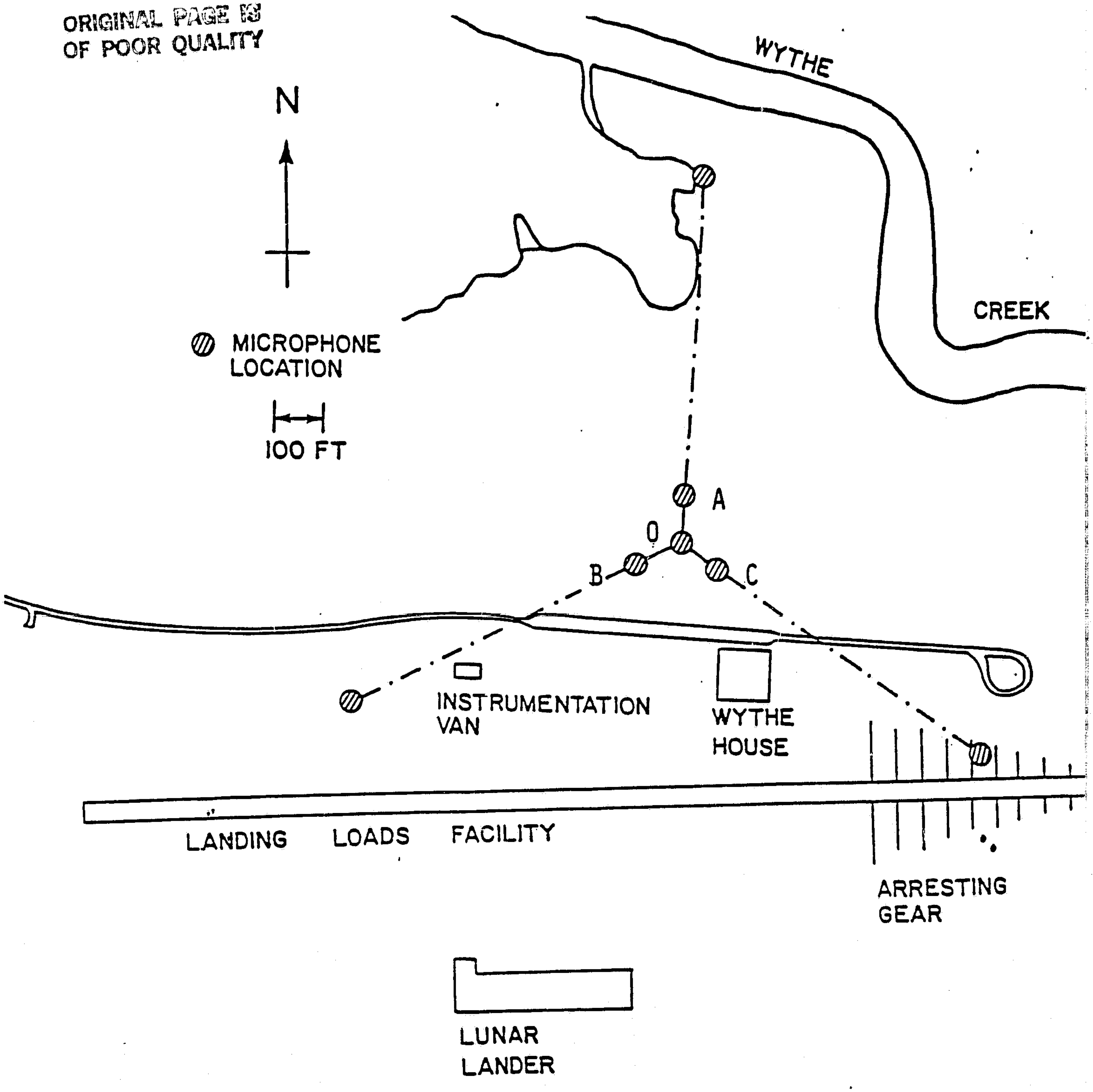

Figure 1. Infrasonic microphone array.

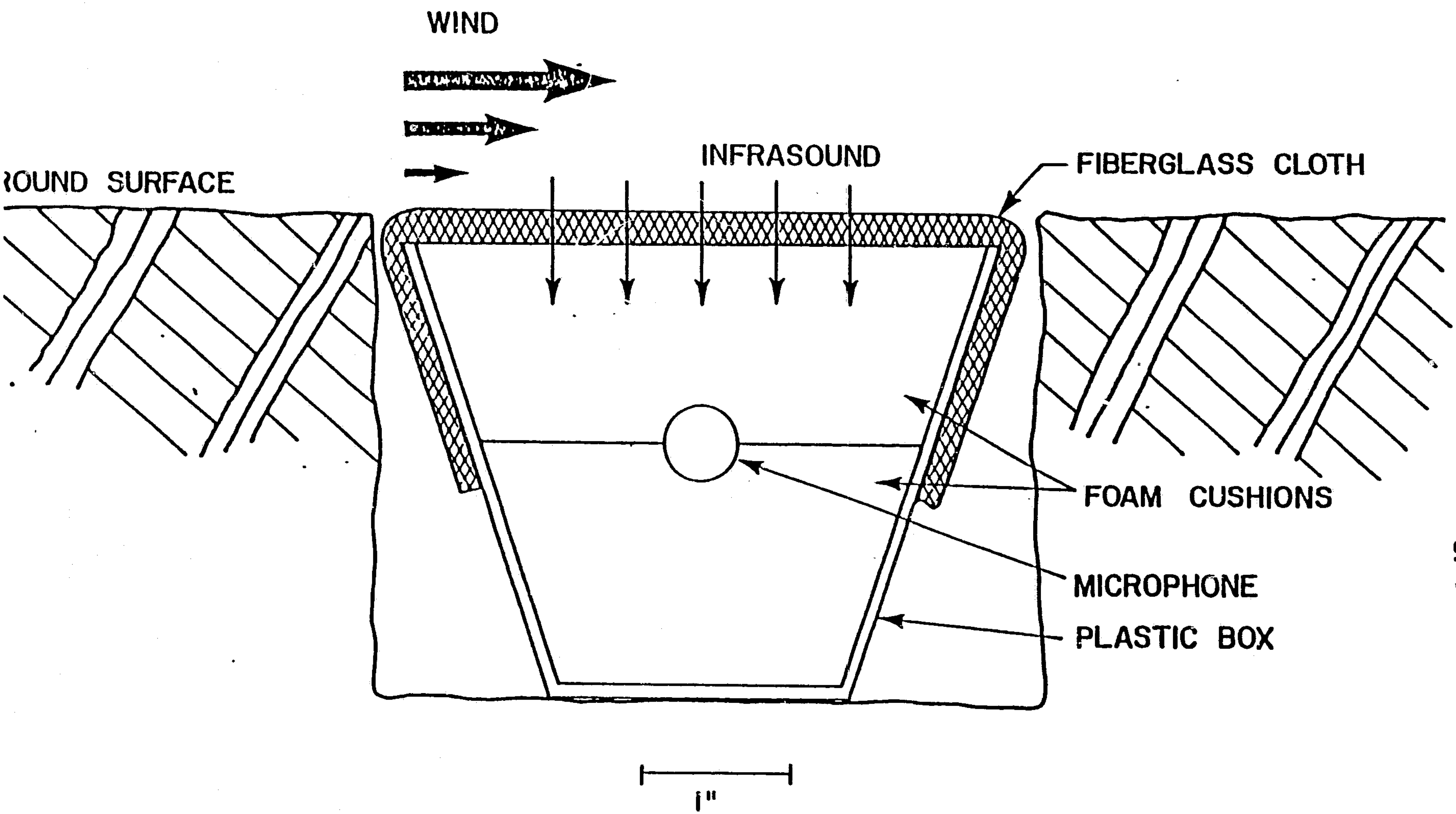

Figure 2. Windscreen details.

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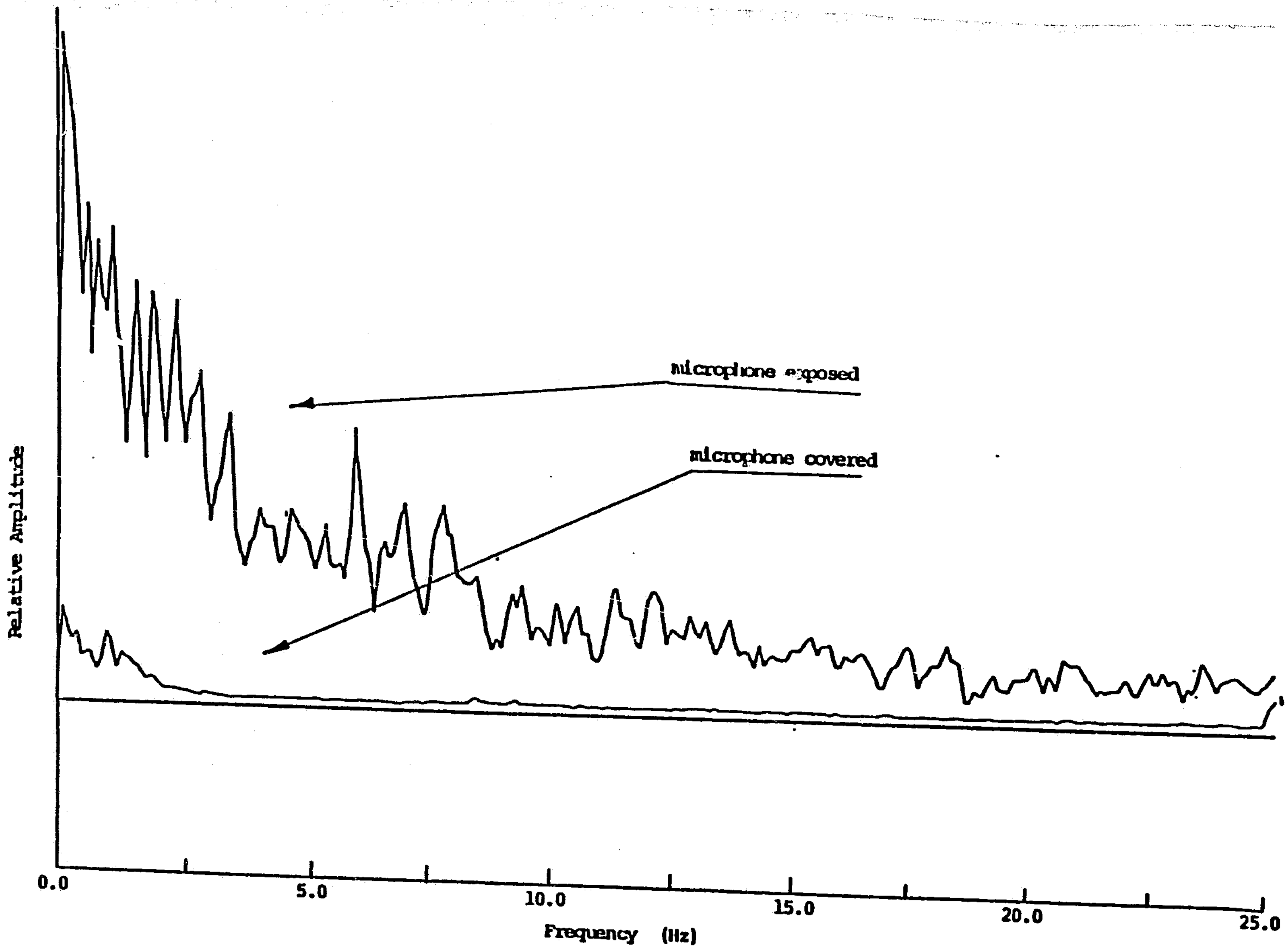

Figure 3. Effect of ambient noise on the microphone w/o wind screen.

helicopter to be used was a Huey 204-B with a blade slap rate of about 10 Hz.

The flight procedure was for the pilot to hover at a predetermined location for approximately 60 seconds, during which time the infrasonic signature was recorded by the operator. Upon completion of data taking, the pilot was instructed to increase his radial distance from the center of the array. This procedure was repeated until a distance was reached where the infrasound was not distinguishable from the background noise.

The purpose of this test was twofold. First, to determine at approximately what radial distance the system's sensitivity was, beyond an acceptable margin, and second, to determine if the system hardware and analysis method, developed for the work, was capable of finding helicopter's direction.

The flight schedule called for the pilot to hover at ten different locations, of which six were radial along a fixed bearing (approximately 3-degrees west of north). The furtherest planned raidal location was approximately 25,000 ft (7500 m) away from the array's center. The other four locations were circumferential at predetermined landmarks along a fixed radius from the array's center.

Table I is a listing of the locations and ranges from the array's center and helicopter's altitude.

This data was later analyzed on a HP 5451-1, Fast Fourier Analyzer computer for the purpose of time and frequency domain spectral analysis.

Figure 4(a-e) show the center microphone's response to different radial distances. The upper diagram is the signal magnitude and the location of fundamental frequency and it's harmonics in frequency domain, and the lower diagram is an expanded display of signal in time-domain (total duration - 1.5 seconds). This diagram was expanded to generate a better time resolution.

As can be seen from figure 4(a-e), the signal is strong at 2,400 ft (720 m), 4,000 ft (1200 m), 8,800 ft (2540 m), and 13,000 ft (3900 m), but

TABLE I. HELICOPTER FLIGHT INFORMATION.

STATION #	LOCATION	RADIAL DISTANCE (METER) FEET	ALTITUDE (METER) FEET
0	POQUOSON TRAILER TRAILERPARK	(720) 2400	(150) 500
1	HOUSING DEVELOPMENT	(1200) 4000	(210) 700
2	HUDGINS ROAD	(2640) 8800	(210) 700
3	RIVER ROAD	(3900) 13000	(210) 700
4	ROBERTS CREEK ENT.	(5400) 18000	(210) 700
5 (CANCELED)	YORK POINT	(7500) 25000	
A	BACK RIVER	(1200) 4000	(180) 600
B	CHAPEL ROAD	(1200) 4000	(180) 600
C	LRC, BLDG 1212	(1200) 4000	(180) 600
X	TEST LOCATION	(1200) 4000	(180) 600

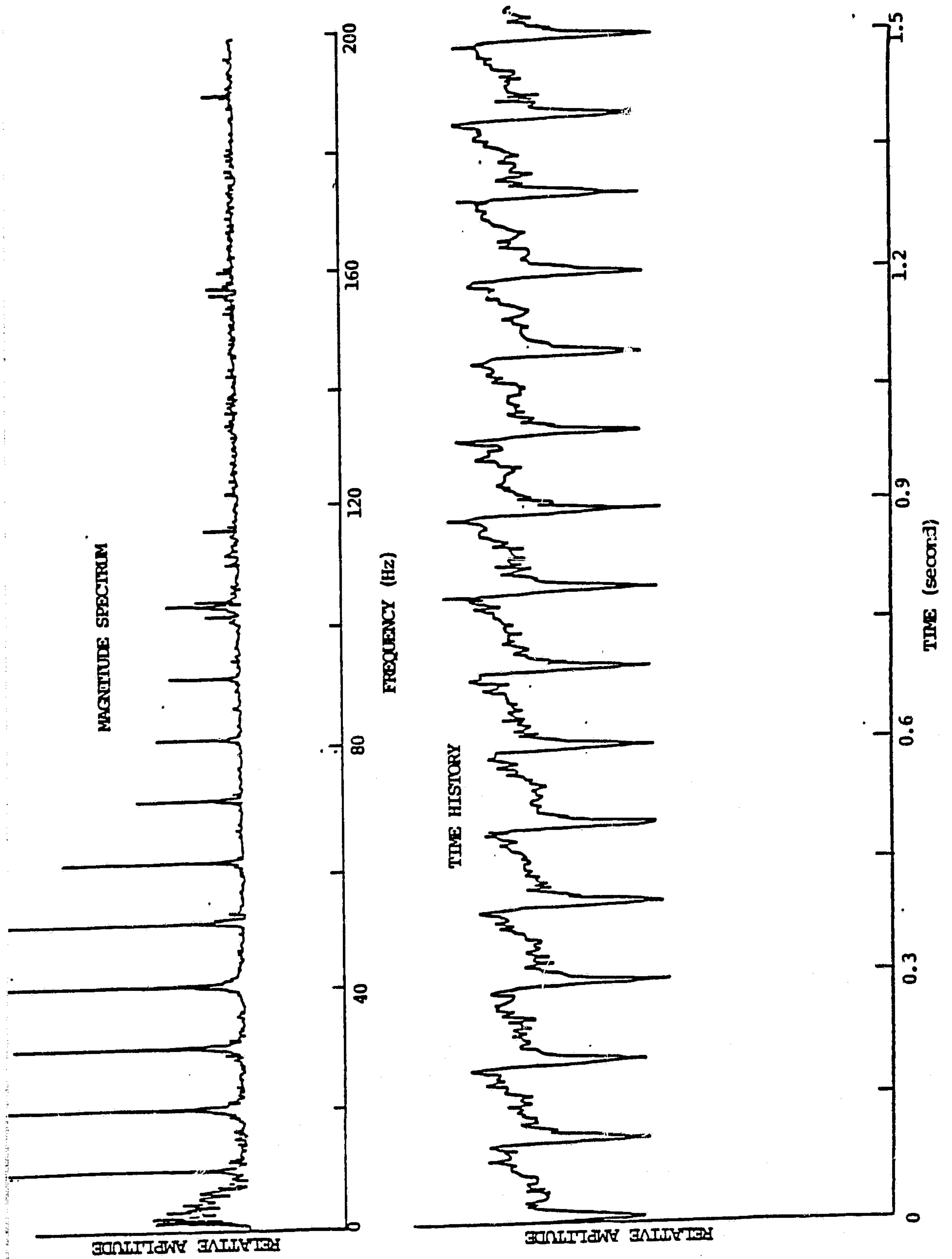

Figure 4(a). Microphone #0, location #0.

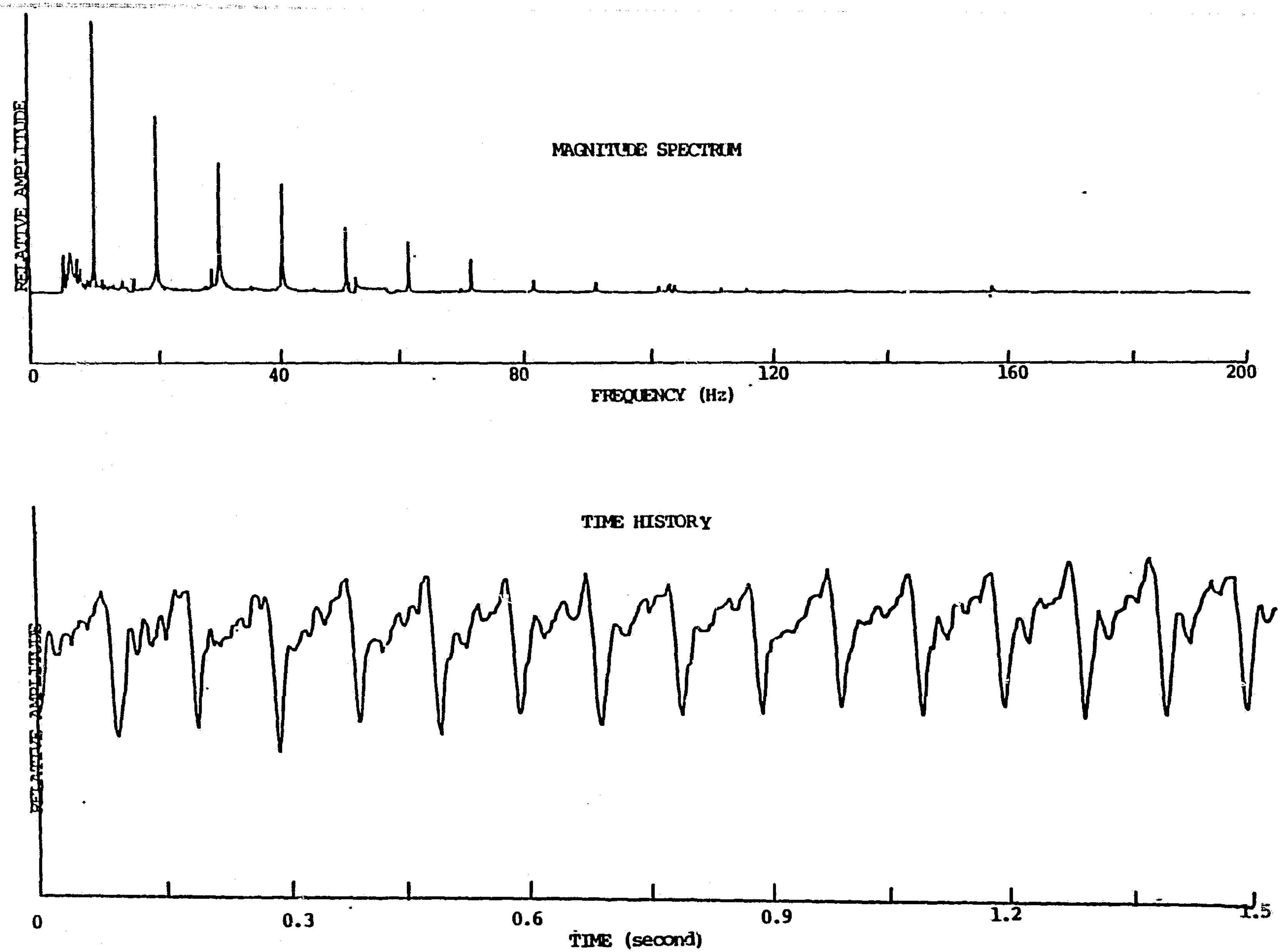

Figure 4(b). Microphone #0, location #1.

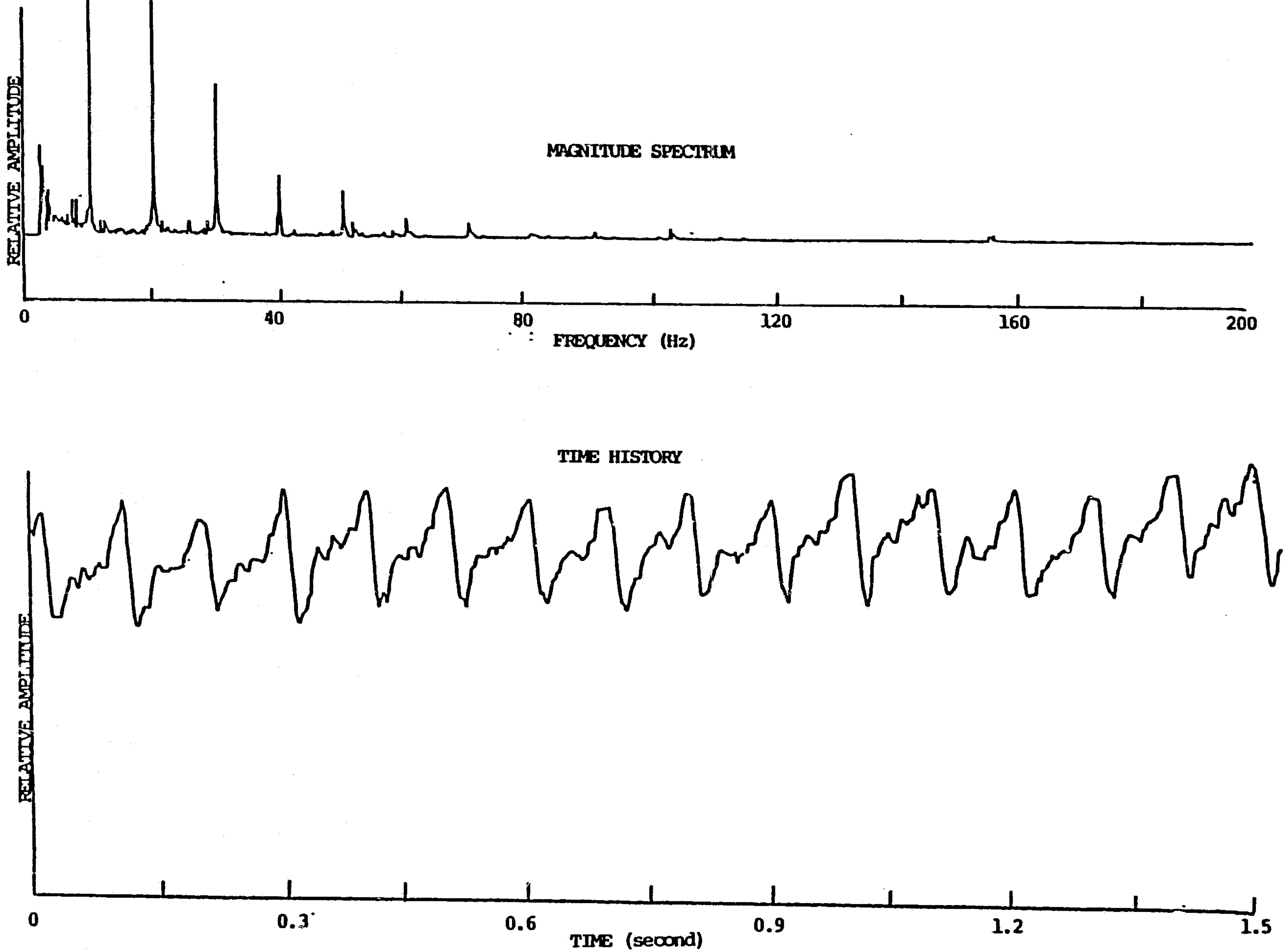

Figure 4(c). Microphone #0, location #2.

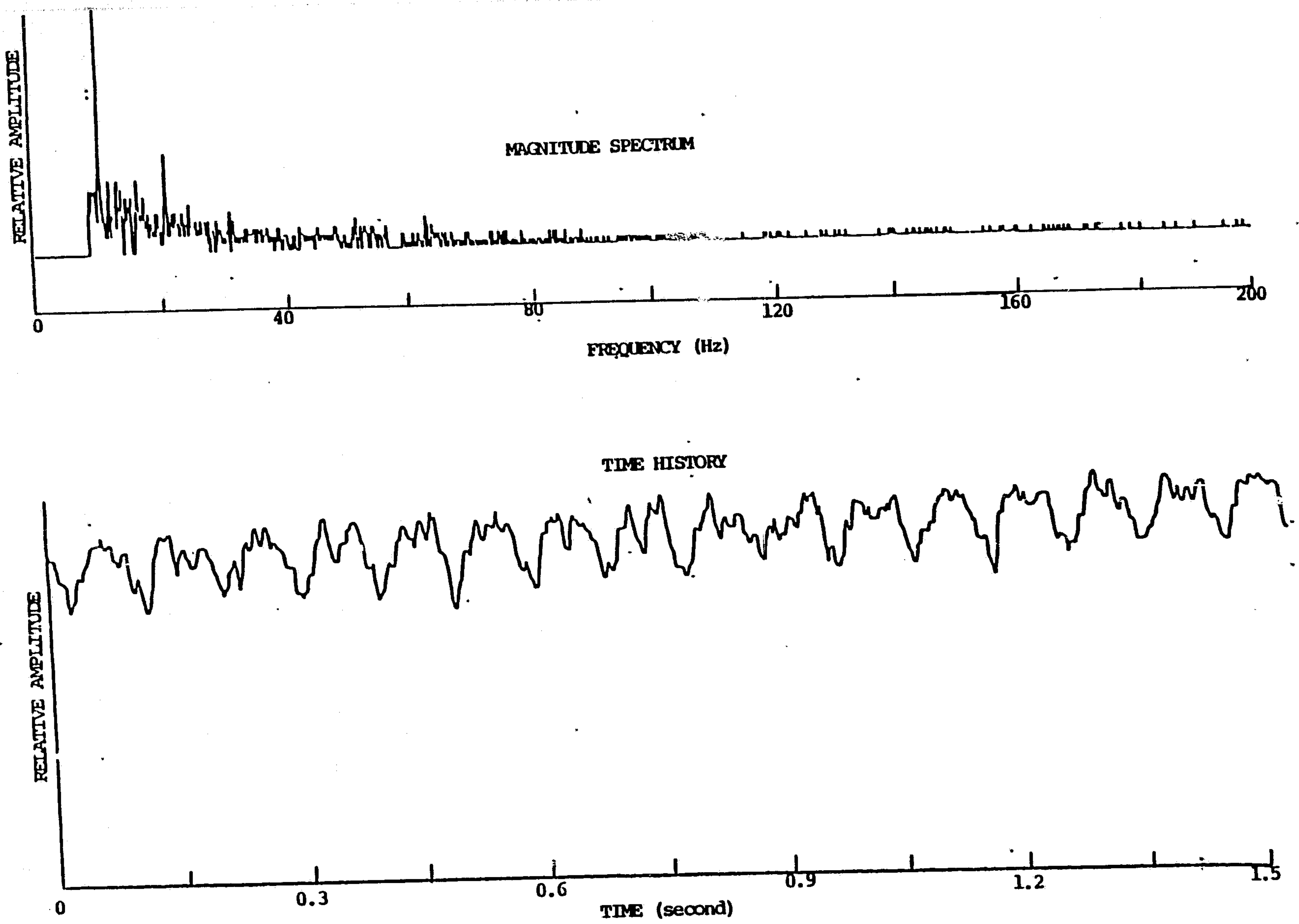

Figure 4(d). Microphone #0, location #3.

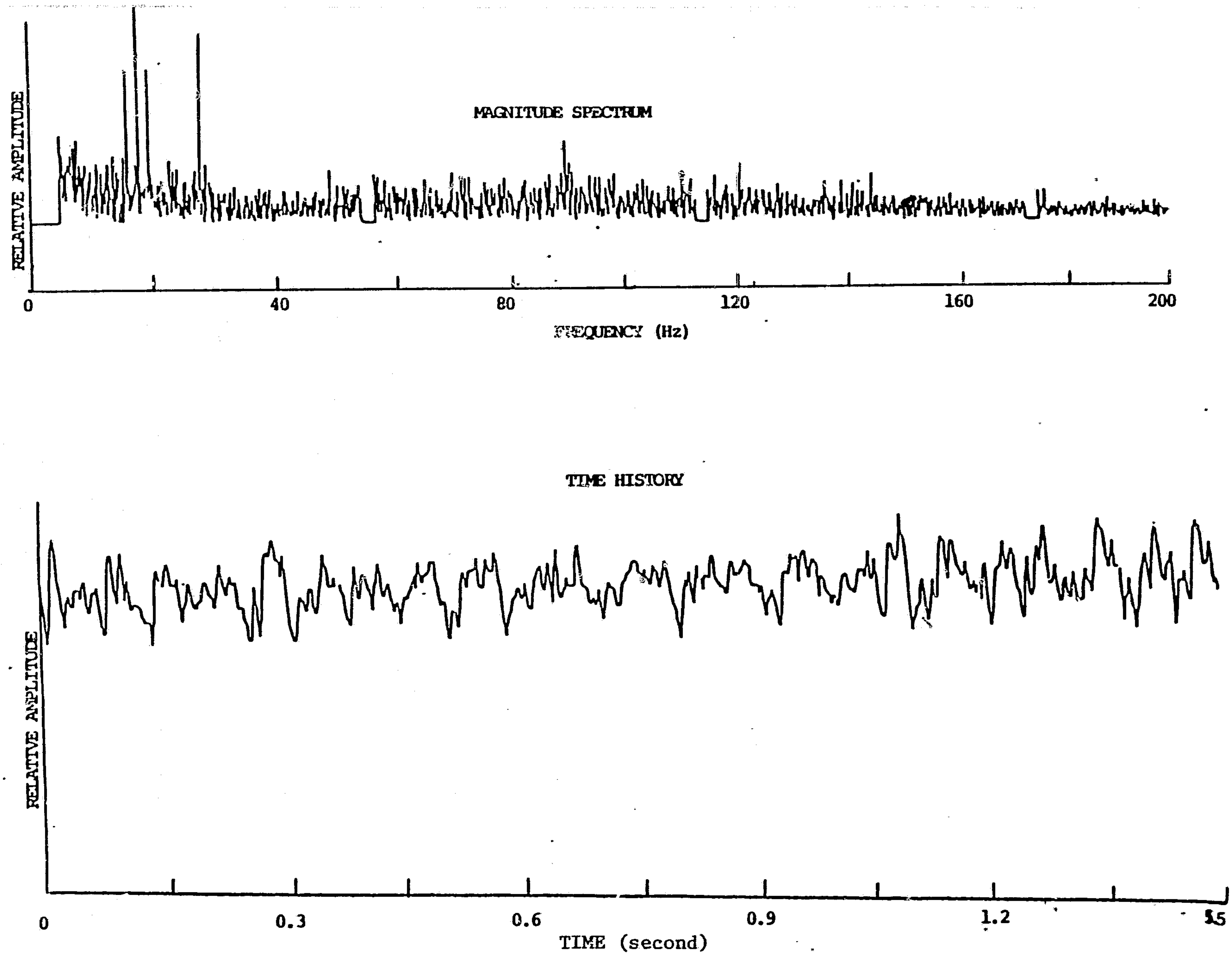

Figure 4(e). Microphone #0, location #4.

at 18,000 ft (5400 m) the spectrum broke down and obscure peaks at 15, 16.5 and 17 Hz were observed. This abnormality is shown in figure 4(e).

Due to this drop in signal to noise ratio it was decided that station #5 at 25,000 ft (7500 m), should not be tried.

At present a clear answer to spectrum breakdown at 18,000 ft (5400 m) has not been fully decided. However, it is possible that some nonlinear phenomenon is contributing to this breakdown.

Because of nonimpulsive behavior of naturally-produced infrasonic signature, it was decided that the time domain cross-correlation technique is not a suitable avenue to follow. On the otherhand, a general purpose, fast Fourier routine appeared to be a more flexible approach.

Based on the conclusion above, cross-power spectrum calculation was performed between the center microphone and microphone A. The purpose of this was to obtain a cross-power magnitude spectrum and find the exact value of a fundamental frequency between two microphones. The exact value of the fundamental frequency made it possible to obtain an expanded cross-power phase spectrum which gave the phase information between two incoming signals.

From the knowledge of phase information it was a simple matter to find the direction of "Signal-Source." This part of the work was carried out by using an algorithm developed on a popular brand desk-top microcomputer.

Figure 5(a-e) show the above stated method. The upper graph is the magnitude of cross power spectrum between center microphone and microphone A, and the center graph is a heavily expanded cross-power phase diagram around the bin that carried the phase-information corresponding to fundamental frequency. Also included is the cross-correlation of the fundamental frequency at bottom with the reference at the center of the abscissa.

As can be seen from figures 5(a-e), the cross-power magnitude dropped very rapidly with increasing radial distance, and at 18,000 ft (5400 m) only the fundamental and the obscure 15, 16 and 17 Hz components were detectable. This problem introduced error in the calculation of signal-source direction finding due to existing weak signal and background noise.

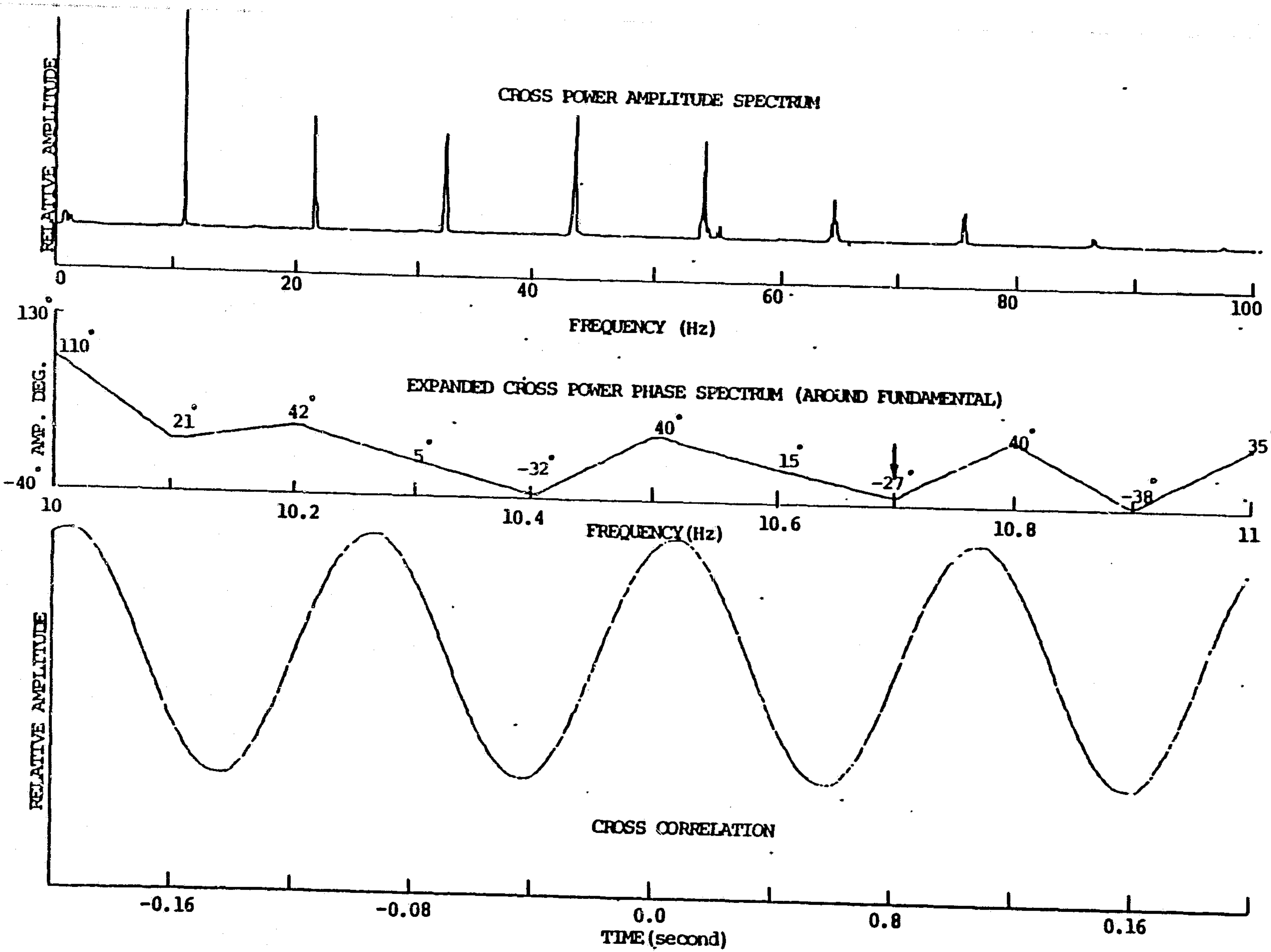

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Figure 5(a). Microphones (0-A), location #0.

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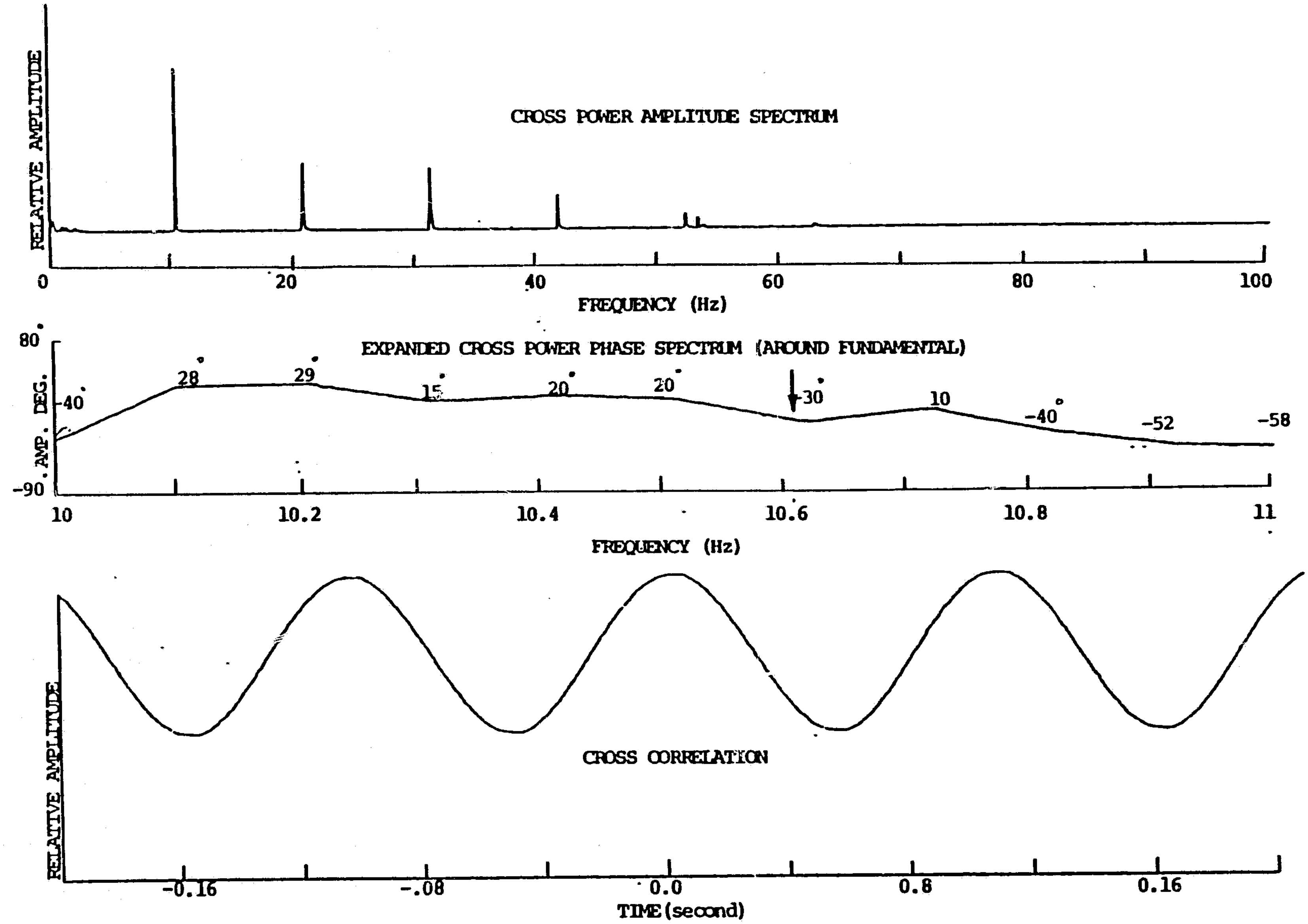

Figure 5(b). Microphone (0-A), location #1.

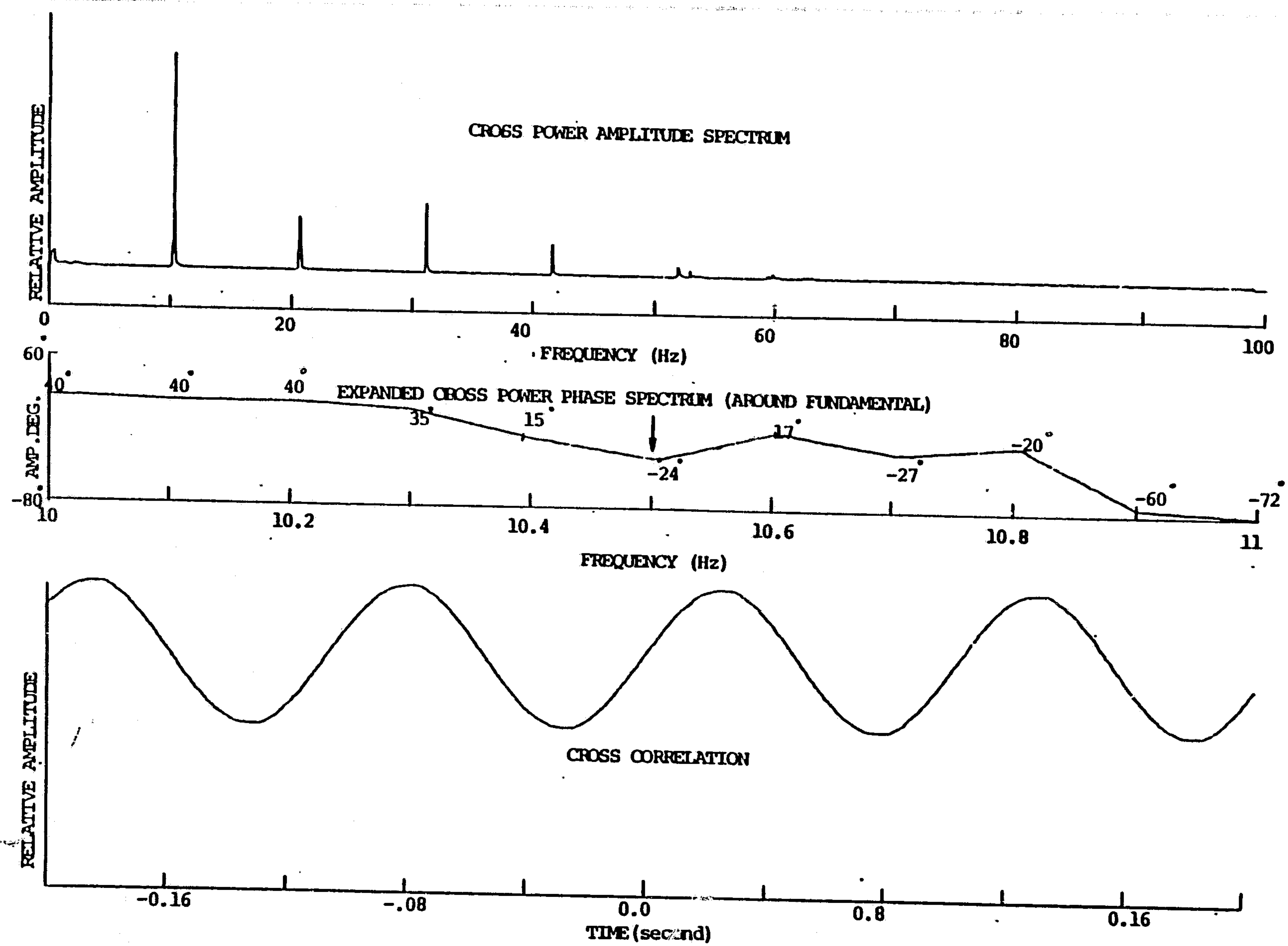

Figure 5(c). Microphones (0-A), location #2.

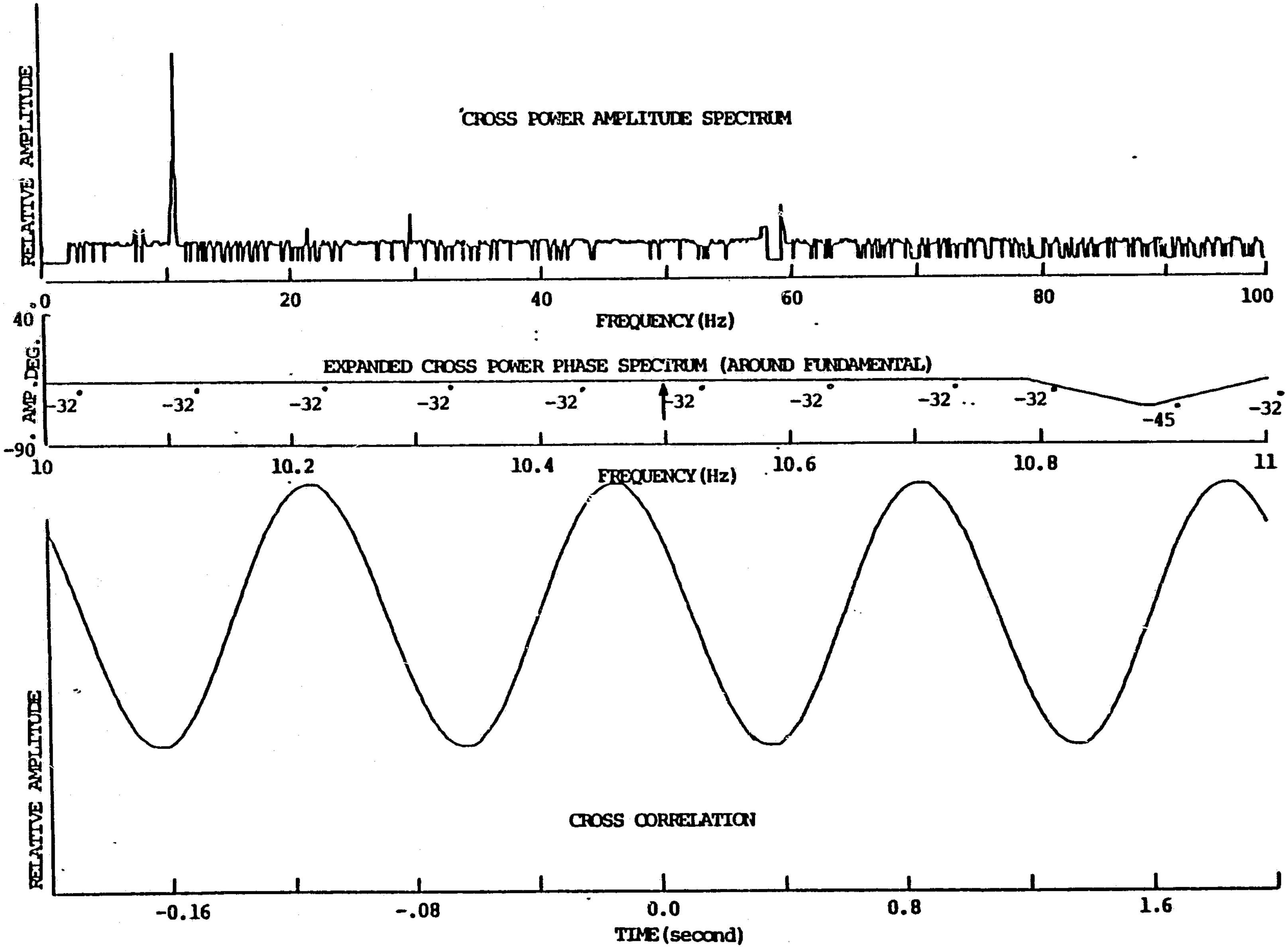

Figure 5(d). Microphones (0-A), location #3.

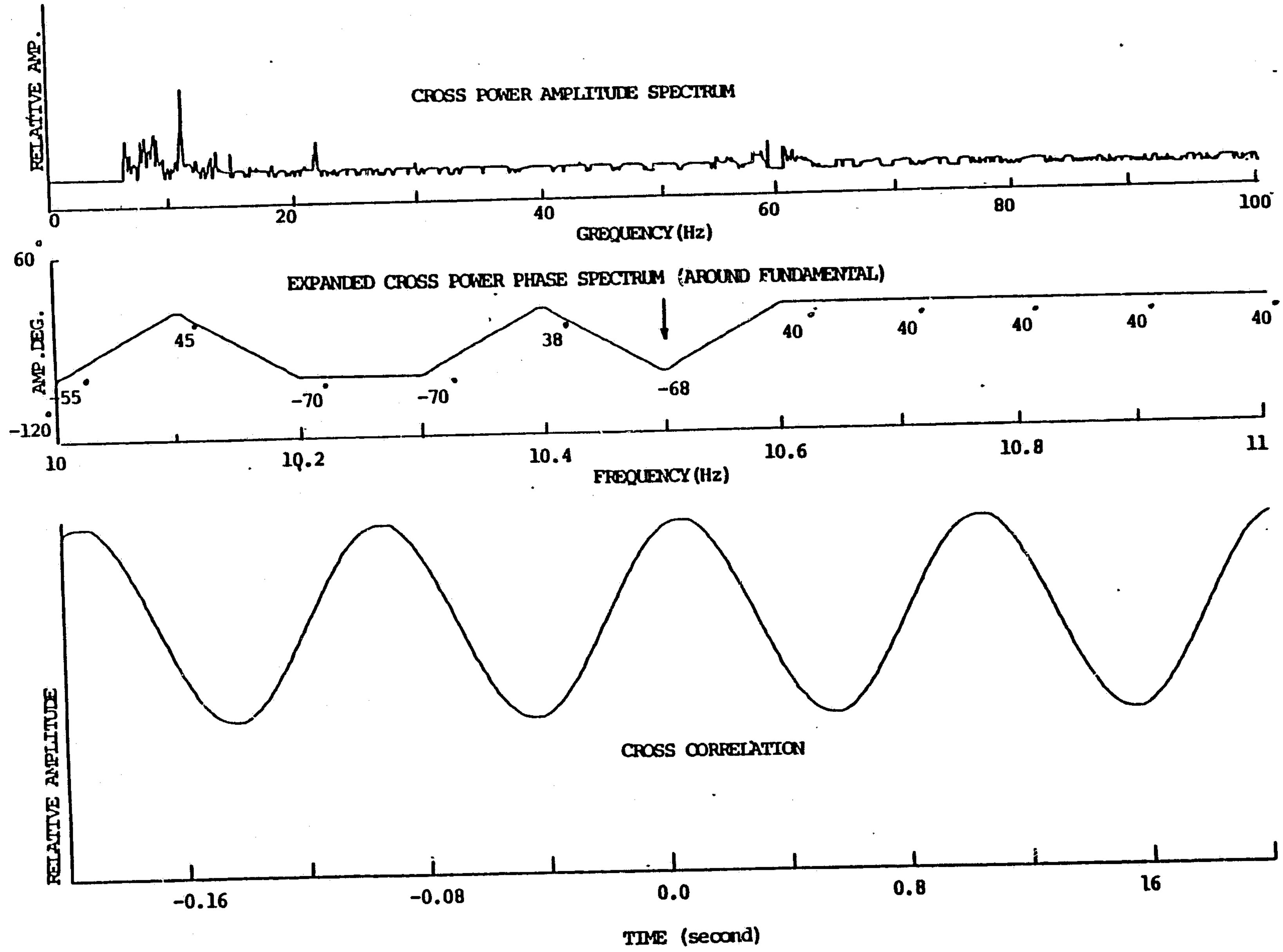

Figure 5(e). Microphones (0-A), location #4.

Table II(a) is the result of the direction finding algorithm for the radial part of the flight. It is obvious that increasing radial distance beyond 18,000 ft (5400 m) induced difficulty in finding a "sharp" direction for the source.

Table II(b) is the same kind of tabular result for the circumferential part of the test. Location x was picked randomly by the pilot, as requested by the system operator, to test out the software capability in finding the proper direction.

Conclusions

The research work at the start of this project was broken down into the following catagories:

1. Analog Instrumentation;
2. Digital Instrumentation: Direction finding Algorithm;
3. Test with known Infrasound: Helicopter and Speaker;
4. Identification of Natural source of Infrasound;
5. Corroboration: Aircraft, Doppler Radar;
6. Second Station (Wallops Island) for triangulation.

At present the first three parts of the project are almost completed, and our accomplishments for the duration of this progress-report have been:

1. Algorithm for signal processing;
2. Novel windscreen; Reducing background noise;
3. Successful test with calibrated infrasound source;
4. Successful test in finding the direction of hovering helicopter.

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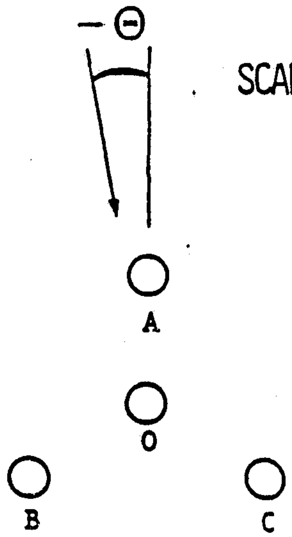
TABLE-II(A). HELICOPTER AZIMUTH REFERRED TO O-A AXIS.

RANGE (FT)	MEASURED AZIMUTH O-A	O-B	O-C
2400	-4°	-6°	-10°
4000	-6°	-8°	-8°
8800	-4°	-6°	-7°
13000	-8°	-10°	-3°
18000	-28°	-13°	-4°



SCALE: OA = 100 FT (33 METER)

TABLE II (B). HELICOTER AZIMUTH REFERRED TO OA AXIS.

	MEASURED AZIMUTH		
RANGE (1200 METER) 4000 FEET	O-A	O-B	O-C
STA - A	90°	83°	96°
STA - B	314°	306°	315°
STA - C	190°	165°	175°
STA - X	241°	241°	239°

SCALE: OA = 100 FT (33 METER)