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IMPLEMENTATION OF THE PHASE DIFFERENCE TRACE FUNCTION FOR A CIR--ETC(U)
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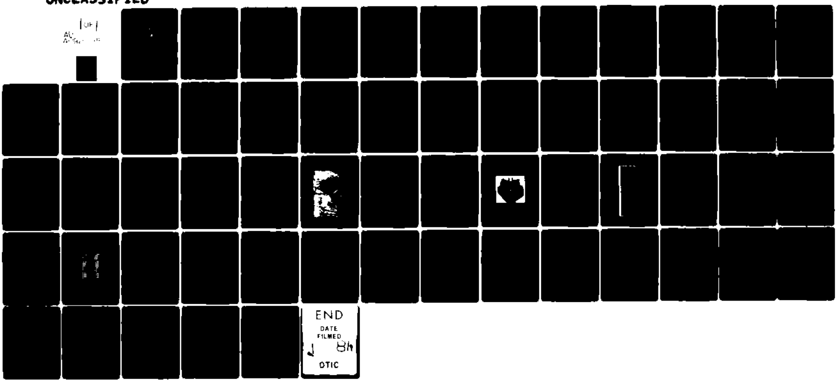

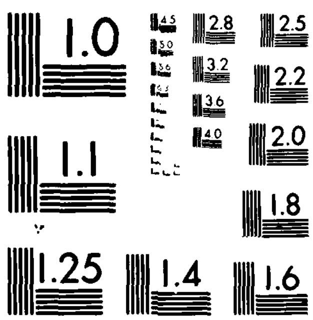

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THESIS

Implemention of the Phase Difference Trace Function for a Circular Array

by

George William Rollings

June 1980

Thesis Advisor: G. L. Sackman

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IMPLEMENTATION OF THE PHASE DIFFERENCE TRACE FUNCTION FOR A CIRCULAR ARRAY

by

George W. Rollings
Lieutenant, United States Navy
B. S., University of Kansas, 1974

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

June 1980

Author: ______________________________

Approved by: ______________________________ Thesis Advisor

______________________________ Second Reader

______________________________ Chairman, Department of Electrical Engineering

______________________________ Dean of Science and Engineering

ABSTRACT

Components necessary for the implementation of the trace function concept in a circular array were designed and constructed. The performance of the degenerate trace function for a narrowband signal in the presence of correlated noise was examined. The results agree with theoretical values and illustrate the threshold effect and phase unwrapping problems. Using a 97.5 cm. diameter array in air, for a population base of ten sets of data, trace function measurements were taken at each of various signal to noise ratios between 28.2dB and -7.8dB. Calculated beamwidths, taken to be twice the standard deviation of the estimated bearing, were as follows: 28.2dB - 1.6° 10.2dB - 2.2°, -1.8dB - 2.3°. The threshold appeared to be in the range of -1.8dB to -4.8dB.

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ACKNOWLEDGEMENTS

I wish to express my deep appreciation to Professor G. L. Sackman, who was a source of continual inspiration, patience and trust throughout the project. He allowed me to learn by guided discovery, resulting in a great deal of self-satisfaction.

I would also like to thank LCDR. Shmuel C. Shelef, Israeli Navy, who was of considerable aid in the initial design stages for the implementation of the trace function concept.

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Last, but not least, I wish to recognize the contribution of my wife, Clare. Without her patience, understanding, interest and assistance, my accomplishment of this project would not have been possible. Such support was as instrumental as any of the required components of this thesis.

I. INTRODUCTION

A. TRACE FUNCTION

The trace function concept[1,2] has been applied by Shelef[3] as an improved solution to the bearing estimation problem of small circular arrays at low frequencies. The phase difference trace function is a discrete plot of phase difference versus element indices for all element pairs. If only the diametrically opposite pairs are used it is called the degenerate case. The geometry for a circular array with incident plane wave is shown in Fig. 1. The analytic degenerate phase difference trace function has been shown, by Sackman and Shelef[1,2,3], to be

$o = (360D/l)\cos\{[360(i-1)/N]-0\}$,where:

o is the phase difference for the ith pair, in degrees

D is the array diameter

l is the wavelength of the frequency of interest

N is the number of elements in the array

i is the index of the element pair $i,i+(N/2)$

This is a cosine wave with phase equal to the direction of propagation of the signal of interest. Hence the bearing of the incoming signal, direction to the source, is 0 ± 180

degrees. A sample trace function is shown in Fig. 2. Since the trace function represents discrete, uniformly sampled values of a periodic waveform, the phase θ can be determined from the phase of the fundamental in the discrete Fourier series expansion of $\Delta\phi_i$.

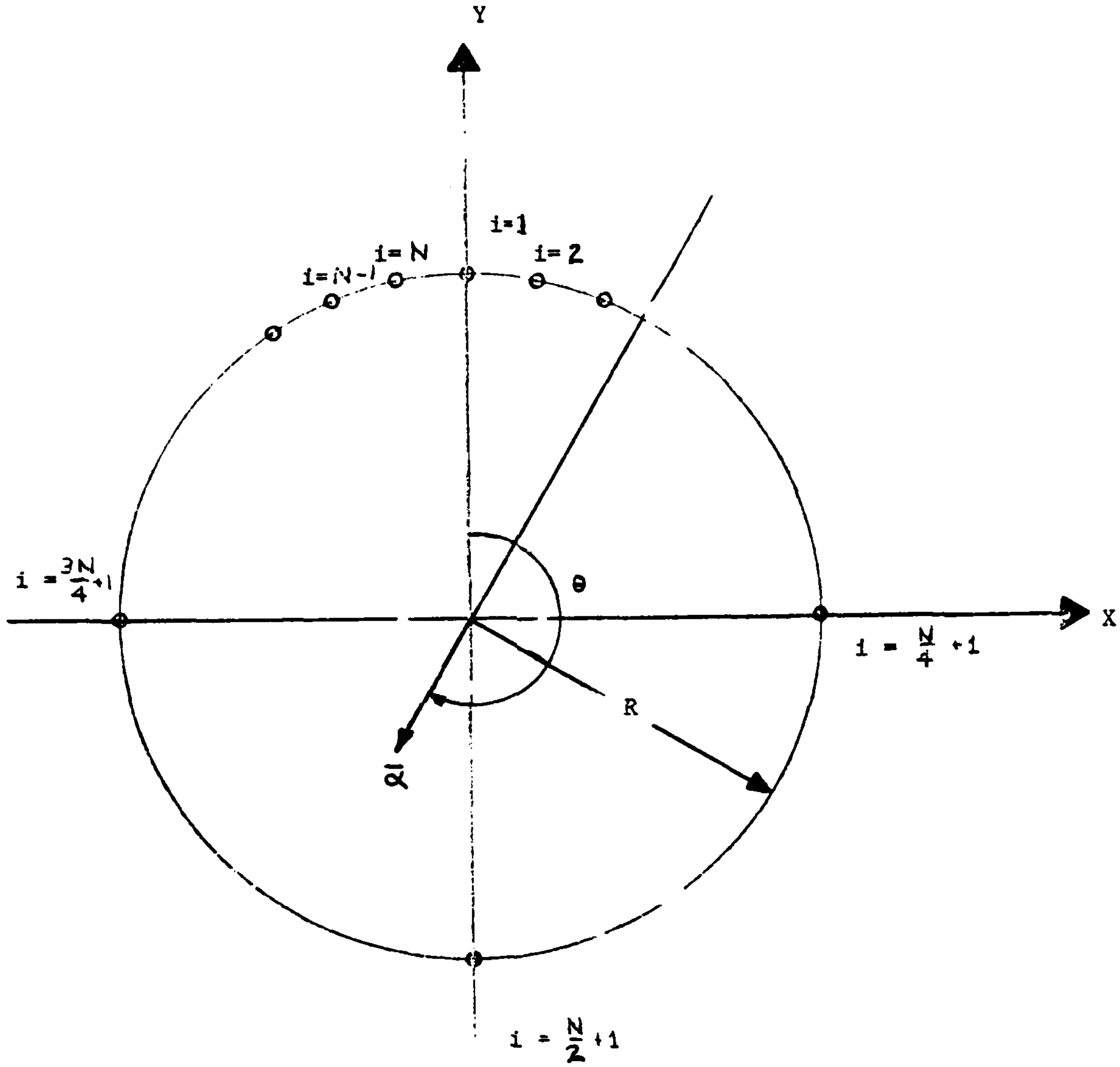


Figure 1 - CIRCULAR ARRAY GEOMETRY

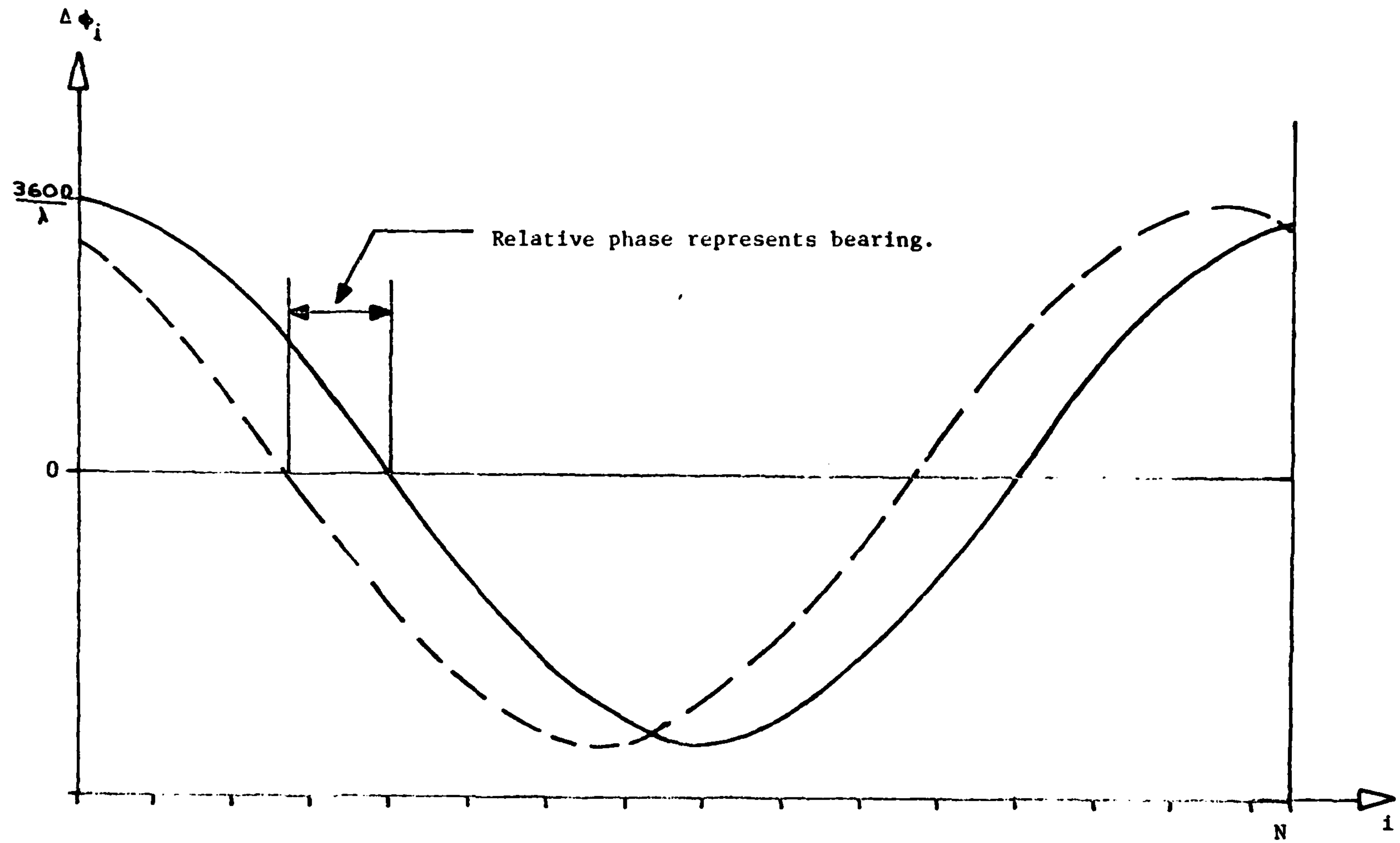


Figure 2 - SAMPLE TRACE FUNCTION

B. OBJECTIVE

The objective of this thesis project was to design and construct the necessary components to implement the trace function concept for a circular array. The desired output of such a system must be the phase difference between any selected pair of elements in an array of diameter, D.

The first consideration in the experimental design was to select air as the medium. Although the simulation done by Shelef[3] assumed a water medium, air avoids the need for watertight integrity and allows a smaller array due to the slower sound velocity in air. In addition, no surface or bottom reflection problems are present in air if an anechoic chamber is used. An air medium also reduces the size of the transducers and hence the bulk of the supporting structure.

The next consideration was to select the component blocks necessary to produce the desired output. The incident tonal is produced by a loudspeaker and received by a microphone. The microphone output requires amplification and filtering to raise the signal voltage and exclude noise outside the frequency band of interest. A phase compensator or shifter is used to correct phase shifts caused by processing components or cabling such that the measured phase difference between any two elements is due only to their physical location in the array and the source direction. Finally a method of measuring this phase difference is required.

In addition to the above electronic components , a supporting structure for the array elements, interconnecting cabling from the array inside the anechoic chamber to the phase measurement device outside the chamber, and chassis to house the electronic components were constructed.

II. DESIGN

A. ARRAY STRUCTURE

A structure to support the microphone elements of the array and perhaps house some of the electronic components was the first item to be designed. This structure supports a maximum of thirty-two elements allowing rotation to simulate different source directions and variation of array diameter. A plywood box with a machined aluminum top was obtained which satisfied these requirements. Penetrations were made for cabling in both the box and metal top. Degree graduations for bearing measurement were machined in the rotatable aluminum top which accommodates thirty-two equally spaced one-half inch diameter radial arms of any desired length. The array base is shown in Fig. 4. The aluminum top is elevated above the plywood box to allow the microphone cabling going through the central sleeve adequate room to pass, without sharp bends, into the contained aluminum chassis. This chassis houses the preamplifiers, filters and battery power supplies. Amplification and filtering are accomplished as near as possible to the microphones to minimize the effect of noise in the cables connecting the array to the phase shifter, which is located outside the anechoic chamber.

The actual number of elements in the array was limited to thirty-two by the initial design. However, the results of the simulation by Shelef[3] indicated that sixteen elements should be sufficient to demonstrate the concept for an array diameter on the order of one wavelength or less. Therefore, only the components necessary for sixteen elements were constructed.

B. MICROPHONES

The requirements for the microphones are as follows: good response in the frequency range of interest, 100Hz to 500Hz, as nearly omnidirectional as possible, and small in size. Subminiature size condenser microphones with FET transistor(Model EM-3) which met all of the above requirements were obtained from Formula International Inc.. The FET amplifier requires a single polarity power supply of 2 to 10VDC. The microphone element is 9.8mm in diameter and 11mm in length. Its frequency response range is 50Hz to 8KHz with omnidirectional spatial response. A summary of the manufacturer's specifications and a measured amplitude spectrum appear in Appendix A, Fig. 5.

C. PREAMPLIFIER/FILTER

The microphone output was assumed to be on the order of 1mV in amplitude and hence requires preamplification to achieve amplitudes on the order of .5V. This level is compatible with most signal processors. In addition, the preamplifier must be of low noise design. To satisfy this requirement the Fairchild uA 739 Dual Low Noise Audio Preamplifier/operational Amplifier was selected. Low noise passive components were also chosen. A 25 turn, 20 Kilohm potentiometer is used in the feedback path to allow voltage gain adjustment up to about 50dB. The frequency compensating network was selected based on the maximum gain. A large input coupling capacitor is required for low impedance at the frequencies of interest. To insure a high input impedance presented to the microphone, a large resistance is shunted to ground at the preamplifier input.

In order to restrict the amplified output to the frequency band of interest and reject input noise at other frequencies, a lowpass filter was needed. Since the desired information was contained in the signal phase the filter phase response was important. A sixth order, unity gain, active Bessel filter was chosen to provide sufficient attenuation outside the passband, small insertion loss and linear phase response. The design procedure used was taken from Garrett[4]. The cutoff frequency was chosen to be 500Hz. The normalized capacitance values are frequency scaled by the equivalent radian frequency, then impedance scaled to be near common component values. The impedance scaling factor was chosen to be a standard component value, making high precision components readily obtainable. To implement the active filter a quad operational amplifier with low input bias current, LM 324A, was selected with the fourth operational amplifier as an output voltage follower to provide extra output drive capability. Since the uA 739 is a dual channel device with excellent channel separation, a printed circuit board was designed to accommodate two preamplifier and filter circuits. The resulting preamplifier and filter schematic is shown in Appendix A, Fig. 6. To allow use of a battery power supply(low noise) for the preamplifier and microphone, separate connections were designed for the power supplies to the preamplifier and filter integrated circuits. The microphone power connection is external to the printed circuit board. The printed circuit board layout is shown actual size in Appendix A, Fig. 7. A microphone is connected to each channel via a length of miniature coaxial cable. The filter output is connected to equipment outside the anechoic chamber via a shielded, twisted pair cable.

D. PHASE SHIFTER AND SWITCHING NETWORK

Since the signal phase is the parameter to be measured, any phase differences due to component tolerances, or unequal cable lengths must be compensated for. To bandlimit any noise entering over the length of the connecting cable a second order, unity gain Bessel filter with cutoff frequency of 500Hz is used as an input stage. The same design procedure was used for this filter as for that of the filter following the preamplifier. To compensate for electronic phase changes, a delay equalizer or phase shifter was designed as described in Millman and Halkias[3]. It provides 60 to 125 degrees shift at 100Hz and 45 to 130 degrees at 500Hz. Again precision, low noise passive components were selected. The LM 324A was chosen as the active element based on its high gain and low offset voltage. One filter/phase shift circuit is required for each microphone. Note that each circuit uses only two of the four available amplifiers on the LM 324A, allowing two channels for each integrated circuit. The schematic for one circuit and the layout for a printed circuit board for sixteen circuits appears in Appendix A, Figs. 8 and 9 respectively. The output of each phase shifter circuit is connected to a switching network so that any pair of elements can be selected.

The switching network design consists of double-pole, single-throw switches, light emitting diodes(LED's) and a circular printed circuit board. The red and green LED's are used to indicate which elements are selected and which of the two signals is the phase reference(Red). Each phase shifter output is routed to a circular circuit board connection, then to a selector switch and finally to the selected output coaxial connector via the circuit board. The schematics and circular printed circuit board are shown in Appendix A, Figs. 10 and 11, respectively.

E. NOISE SOURCE FILTER

A noise source is needed to examine the performance of the array and trace function in the presence of ambient noise. To simulate ambient, deep ocean noise as described in Urick[6], a single pole, low pass characteristic was chosen. The design includes adjustable gain and variable cutoff frequency. The schematic is shown in Appendix A, Fig. 12. The input is pseudo-random noise and the output is connected to a speaker, mounted above the array, via a power amplifier. This configuration causes the noise to be correlated at all elements. Again low noise, passive components and one-fourth of a LM 324A are used.

III. CONSTRUCTION

A. PURPOSE

The purpose of this section is to describe the problems encountered in and the solutions applied to the construction of this project. Varying degrees of ingenuity are present in the solutions. Some are peculiar to the type of project involving a sensing element in one environment, the anechoic chamber, and processor in another, the chamber control room, connected via cabling.

B. MICROPHONE CABLING

This was a problem in that the outside diameter of the miniature coaxial cable used to connect the microphone to the preamplifiers is only 16 gauge. This small size made the microphone connections tedious. Stripping the insulation had to be done by hand with a knife. Once the leads were soldered, individually insulating them from one another was also difficult due to the small size. Some insulating "spaghetti" pre-positioned to slide over the connection seemed the easiest and most compact method. The FET power supply connection was accomplished with 30 gauge wire-wrap and electric wire-wrap gun.

C. CABLE ASSEMBLY

A cable assembly connects the array elements from the filter output, located inside the anechoic chamber, to the phase shifter input filter located outside the chamber. Sixteen signal cables and two power supply cables are required. Cable or conductor size was not a problem in this case. The difficulty was in connecting each signal and ground lead to the filter output of the array end as well as signal, ground and shield on the phase shifter end. Hardwiring both ends was out of the question because the cable assembly had to pass through a bulkhead penetration in the anechoic chamber. It was decided to hardwire the array end and make the phase shifter end disconnectable. Soldering the signal and ground connectors to the preamplifier/filter edge connector pins was facilitated by using female Burndy Hyfen contacts(cat. no.Rc20W 1F45 2, die set N20RT 2). These contacts added reinforcement to the stamped, u-shaped pins which prevented the shorting of leads together except in the case of adjacent connections. An adjacent connector problem was only encountered once with the power supply connections and was solved by insulating them from adjacent pins with 3/16" diameter "spaghetti". On the phase shifter/switching network end of the cable assembly, a removable connector was required having terminals for sixteen signal leads, sixteen ground leads, three power supply leads and a shield termination, or thirty six leads in all. Individual coaxial connectors require individual jacks and are susceptible to errors in connection, Most of the multiple pin cable connectors with sufficient terminals were too large for the anechoic chamber bulkhead penetration. None were immediately available. While discussing this problem with a technician, the idea of using a printed circuit board edge connector was conceived. A rather suitable connector was designed by using a fourty-four pin edge connector for the thirty-six terminals, a double-sided printed circuit board for a male-to-male adapter and a second edge connector mounted on the side of the phase shifter/switching network chassis. The diagram for the female edge connector and printed circuit board connector appear in Appendix A, Figs. 13 and 14 respectively.

D. SWITCHING NETWORK

The problem encountered in wiring the switching network was one of accessibility. A method was needed to connect the circular printed circuit board, attached to the chassis bottom, to the switches and LED's located on the chassis top cover, yet allowing cover removal. Fifty connections are involved, three for each of sixteen switches, one input and two output, and a common power supply and ground for thirty-two LED's. Burndy Hyfen contacts, both male and female, were used to permit removal of the top and provide access to the internal components. Each connector pair required insulation with "spaghetti" to prevent shorting.

E. BATTERY POWER CONSERVATION

In order to conserve battery power, hence maximizing battery lifetime, a switch was installed in the array base structure to allow the batteries to be switched off when not in use. Maximizing battery life reduces the frequency of removing the heavy aluminum top, which requires care, since all microphone cabling passes through it. However, enough length is allowed for this and the battery connections are designed to permit replacement.

IV. TRACE FUNCTION MEASUREMENTS AND CONCLUSIONS

A. TEST CONDITIONS

The phase shifter output signal amplitude was originally designed to be on the order of .5V, to be acceptable by most signal processing equipment, assuming a microphone output amplitude of 1mV. When initial testing began, this was found to be untrue. The actual phase shifter output amplitude in the tests was on the order of 1mV, indicating an error in the assumption of more than two orders of magnitude. However, the spectrum analyzer used to measure phase difference has input sensitivity which responds to amplitudes well below this level. Hence, this considerable error did not present a problem in the experiment. Additional amplification will be required to use this equipment if higher signal amplitudes are needed in the future.

Due to the use of unshielded wire to make connections inside the phase shifter chassis, "crosstalk" and "leakage" between the busses causes the signal input to any switch appears on both channels. Measurements made to examine these effects gave the following results: with a switch off, the signal leaking through to either bus is 60dB below the input signal; with the switch selected to either bus, the signal on the other bus is 30dB below the input signal.

With the array installed in the anechoic chamber, aligned as described in Appendix B, measurements for the degenerate case phase difference trace function were taken. The array was located to the left of the chamber access door, centered under the turning motor apparatus. The noise source speaker was suspended from the turning motor apparatus about 1.5m above the array, but was not rotated during the test period. The noise speaker was oriented to radiate down on the array. This arrangement creates highly correlated noise at all the array elements, since they were equidistant from a single source. The tonal "target" speaker was suspended from the other turning motor apparatus in the diametrically opposite corner, approximately 6m away. This speaker was oriented to radiate horizontally toward the array center. The array was "boresighted" to place the target at 0 degrees bearing, this being along the radial arm of element number one. Array diameter was set at 97.5cm.

Measurements were taken using a Hewlett Packard Model 3582A Spectrum Analyzer. The Hanning Passband was used with RMS averaging of a thirty-two member ensemble. The spectral span was 0Hz to 500Hz. Channel sensitivity was as low as possible without overloading. The periodic noise source in the spectrum analyzer was used to drive the noise source filter with a cutoff frequency of 200Hz. A Wavetek Function Generator was used to generate a 200Hz tonal. Both speakers were driven by Hewlett Packard Model 467A Power Amplifiers. Signal and noise levels were measured in a 1Hz band individually with the other source off. To accumulate a population base for statistical analysis, ten sets of data were taken at various signal-to-noise ratios (SNR's), the bearing estimated for each set, and the sample mean and standard deviation found using a Hewlett Packard Model 32E calculator. Measurements were taken at the following signal-to-noise ratios: +28.2dB, +10.2dB, -1.3dB, -2.8dB, -3.3dB, -4.6dB, and -7.3dB. Sample data for a few of the SNR's, including X-Y plots of magnitude spectra, phase spectra, phase difference trace function with coherence and taken as twice the standard deviation of the estimated bearing. A plot of beamwidth versus SNR, compared to theoretical values appears in Fig. 3.

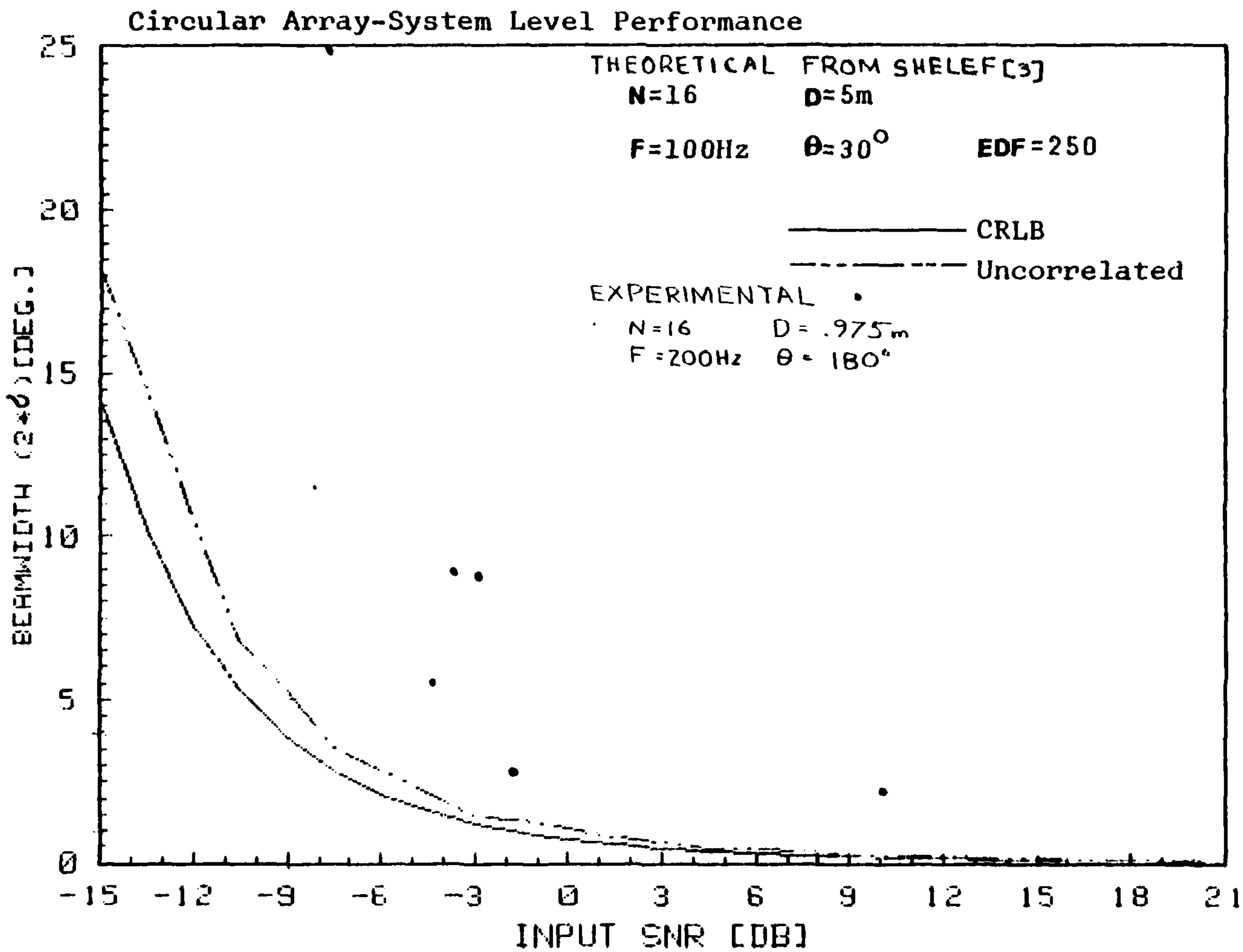


Figure 3 - BEAMWIDTH VERSUS SNR WITH THEORETICAL VALUES

B. CONCLUSIONS

The data illustrates that the degenerate case phase difference trace function concept can be implemented in a sixteen element array. However, due to the small number of data sets, the derived statistics may contain considerable errors. This may account for the small improvement in beamwidth for SNR increase from 10.2dB to 28.2dB and the abnormal behavior of the beamwidth between -1.8dB and -4.8dB. Further investigation is needed to resolve whether the behavior in this region is caused by statistical effects of insufficient samples or something peculiar to this range of SNR. However, even for the case examined, the results compare favorably with simulation values obtained by Shelef[3].

The problem described by Shelef[3] concerning unwrapping the phase also appears to be present for this array. The spectrum analyzer employed in the tests represents phase, in degrees, from -200 to +200, having two regions of 20 degrees overlap. Some of the data was corrected by adding or subtracting 360 degrees in order to make a smooth sinusoidal curve from which to obtain the bearing estimate by the phase of the fundamental Fourier series coefficient. This adjustment was made only to data values when two successive values differed by more than 180 degrees. Both original and corrected data is presented in the samples shown in Appendix C. The unwrapping problem should not occur for array diameters less than one-half wavelength.

The coherence was measured with each phase difference to examine if any trends could be identified. The coherence value is recorded with each phase value on the sample trace function plots. In the bearing estimation, all the samples were used without regard to the associated coherence. The effect of correlated noise on the coherence is shown in the spectra presented, causing a drop in coherence as the signal is degraded. An interesting effect was noted in that the coherence value for the pair of microphones most nearly perpendicular to the target bearing did not decrease steadily, and it rose again to 1.00 for SNR below -4.8dB, whereas the value for all other elements decreases monotonically. The phase difference values for this particular pair however, was virtually unchanged over the range of SNR examined. This may imply correlation between signal and noise for this pair in this range of SNR.

The threshold effect described by Shelef[3] occurs as expected. It would appear in this case to be in the neighborhood of -1.8dB SNR.

Further investigation using the equipment constructed in the course of this thesis would be necessary to reduce the possible sampling errors for the degenerate case and begin examination of the complete trace function for both narrowband and wideband signals. This will probably require a computer interface with the spectrum analyzer to store all the data samples. In addition, a computer controlled switching network would reduce the time necessary to record the data. Two hours were required to make all measurements for a given SNR with the present switch system. Although further work is required, the trace function concept was successfully implemented and appears to have considerable potential as a bearing estimator for small arrays above the signal to noise ratio threshold.

APPENDIX A

DESIGN DIAGRAMS AND SCHEMATICS

This Appendix contains material resulting from the design and construction of this thesis project.

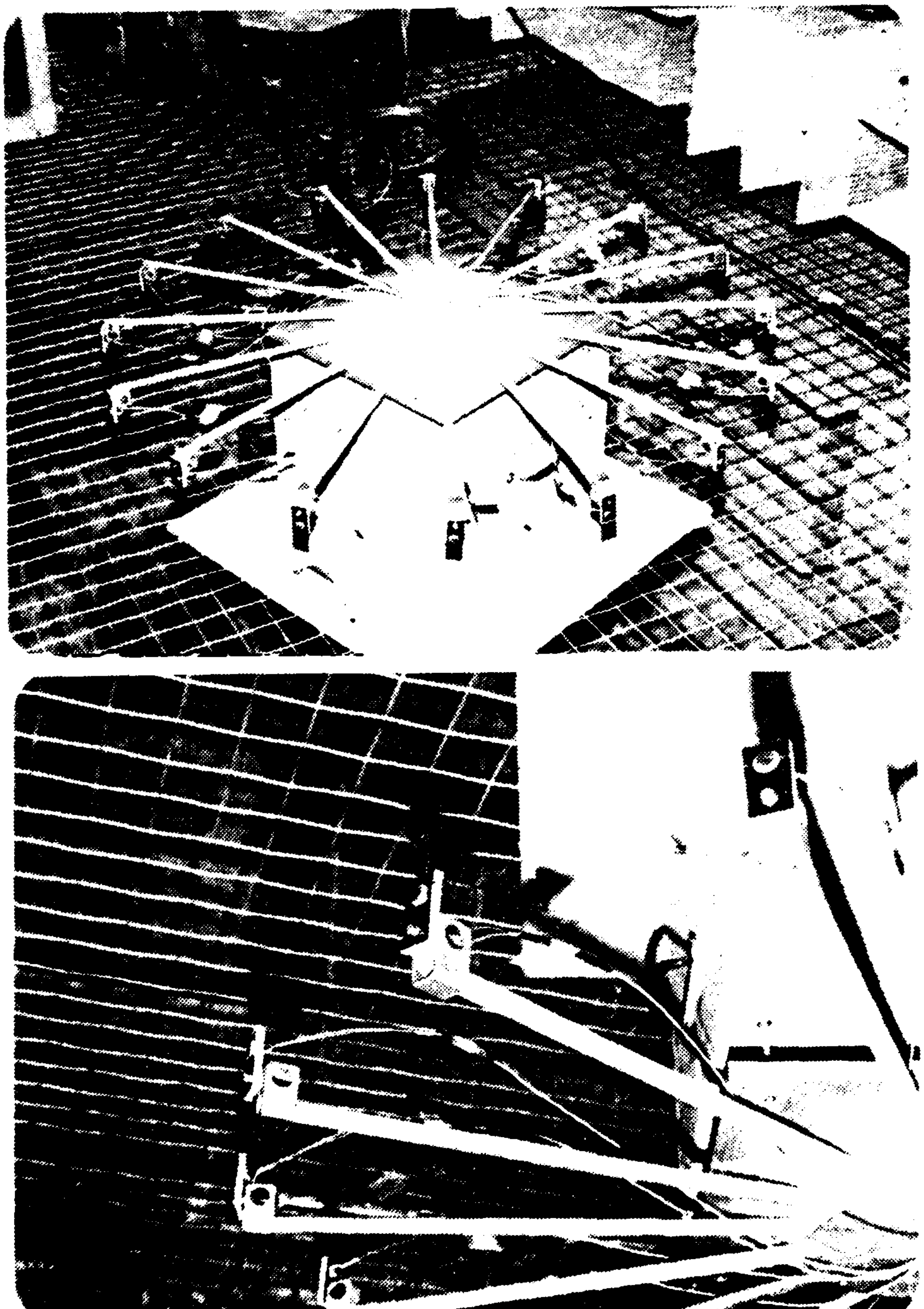


Figure 4 - ARRAY STRUCTURE PHOTOGRAPHS

MANUFACTURER SPECIFICATIONS

SENSITIVITY : -65 ± 3 dB 0dB = 1V/μbar 1KHz

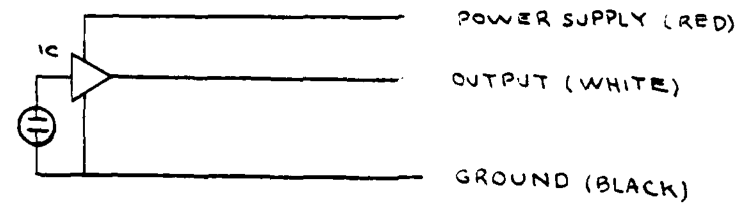
FREQUENCY RESPONSE 50Hz - 8KHz

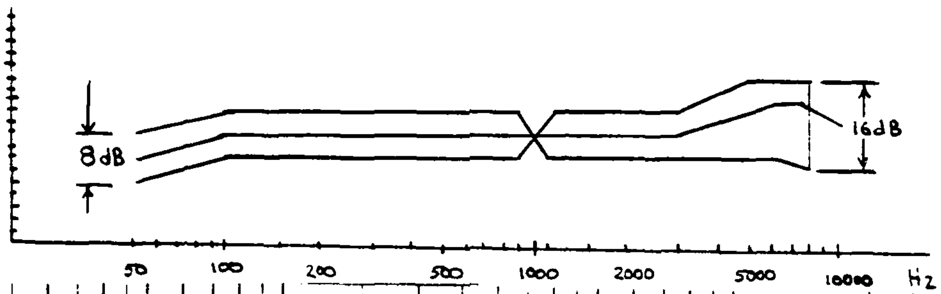
OUTPUT IMPEDANCE 1KΩ MAX

POLAR PATTERN OMNI-DIRECTIONAL

POWER SUPPLY 2-10V

SOUND PRESSURE LEVEL 120 dB MAX





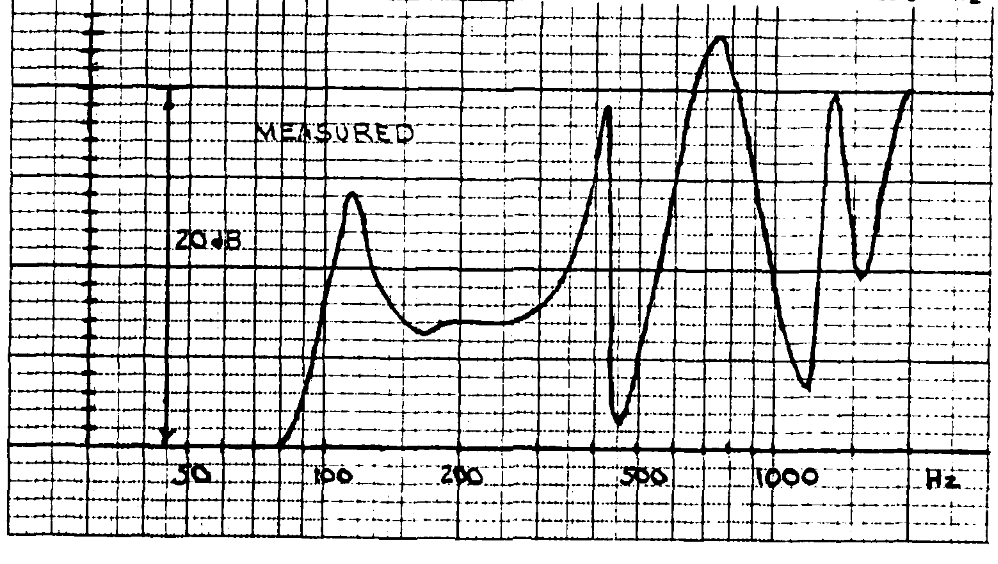


Figure 5 - MICROPHONE SPECIFICATIONS

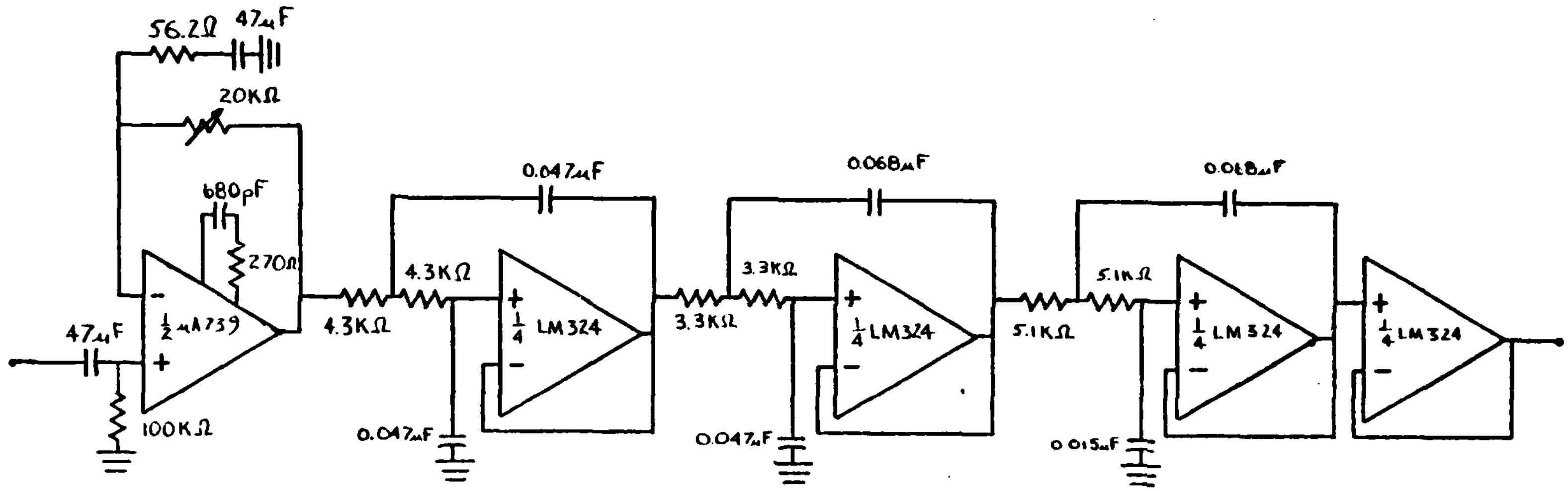


Figure 6 - PREAMPLIFIER/FILTER SCHEMATIC

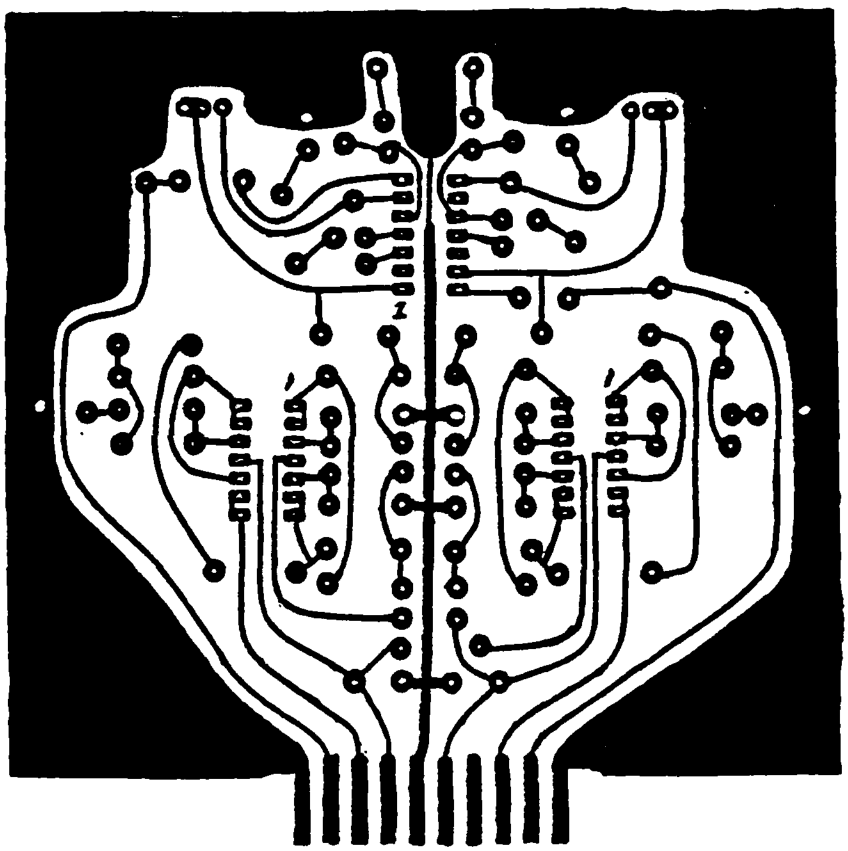


Figure 7 - PREAMPLIFIER/FILTER PRINTED CIRCUIT BOARD

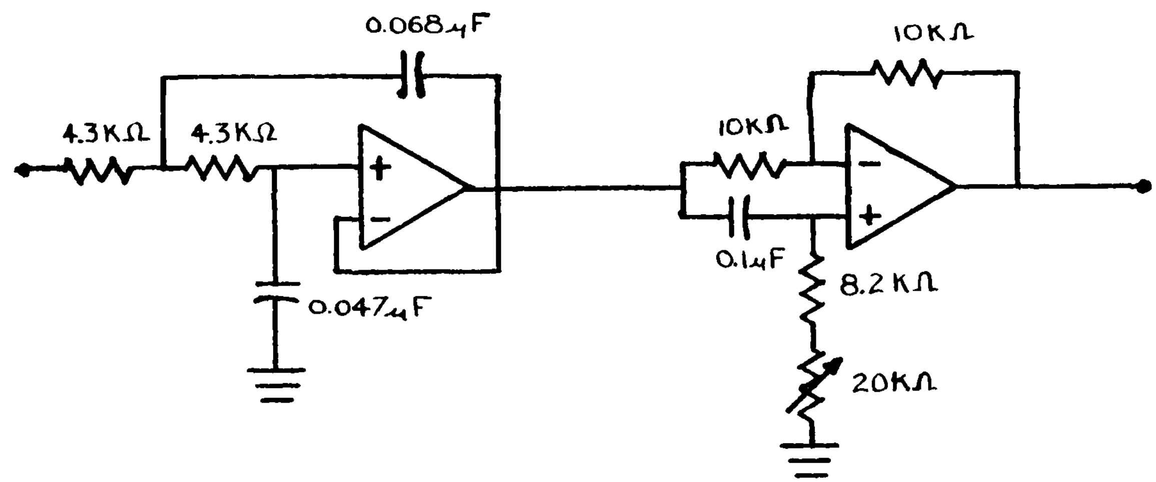


Figure 8 - PHASE SHIFTER SCHEMATIC

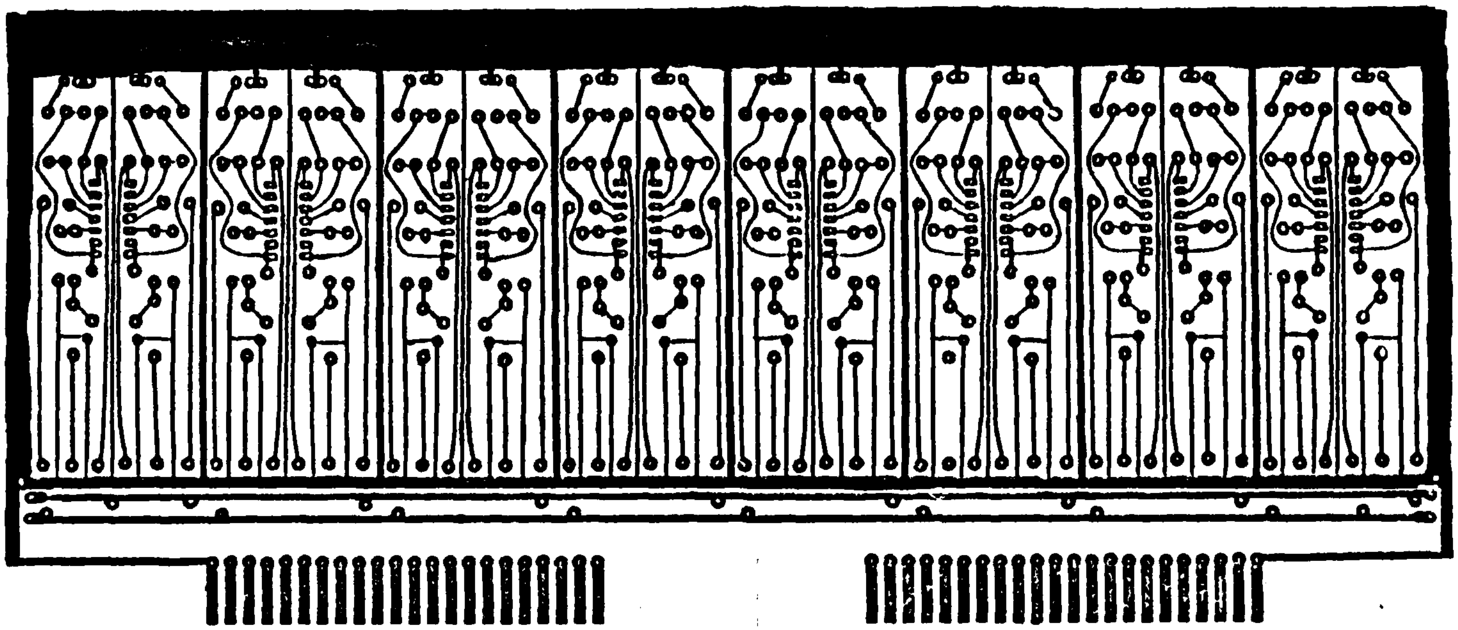


Figure 9 - PHASE SHIFTER PRINTED CIRCUIT BOARD

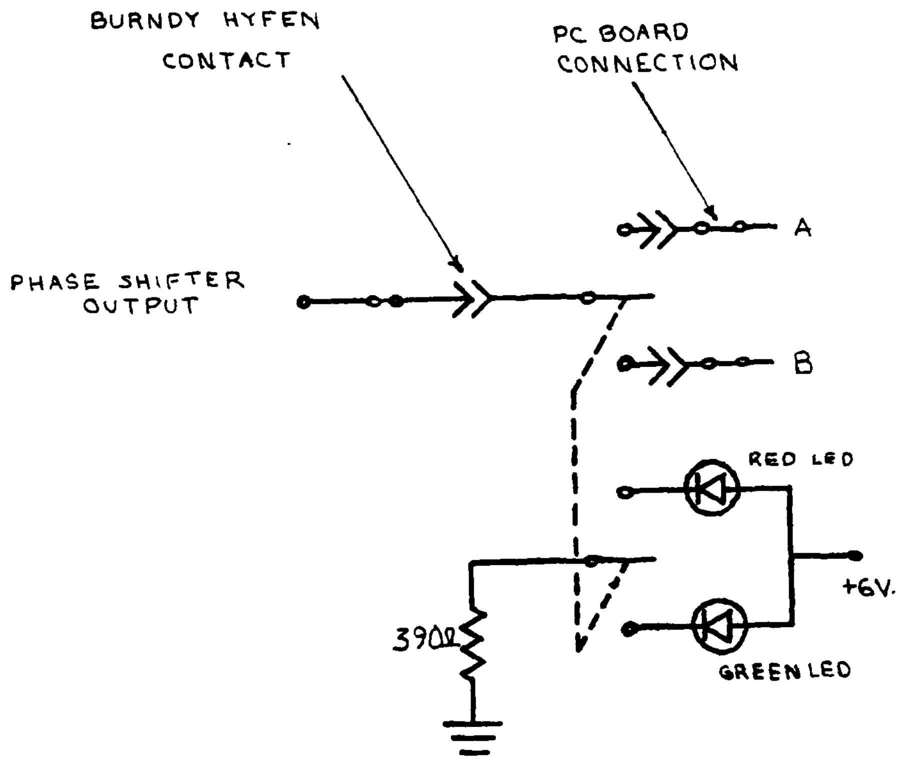


Figure 10 - SWITCHING NETWORK SCHEMATIC

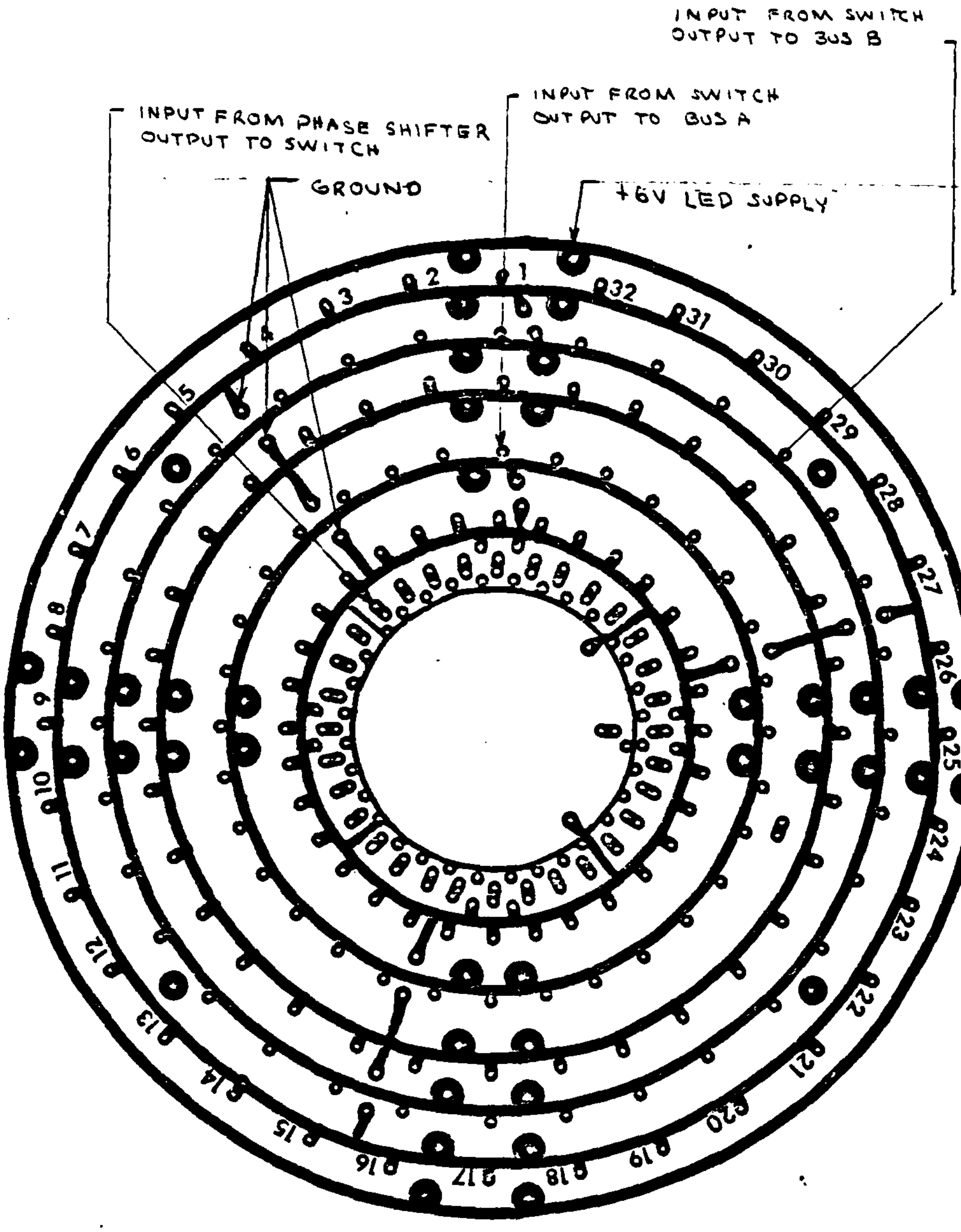


Figure 11 - CIRCULAR PRINTED CIRCUIT BOARD

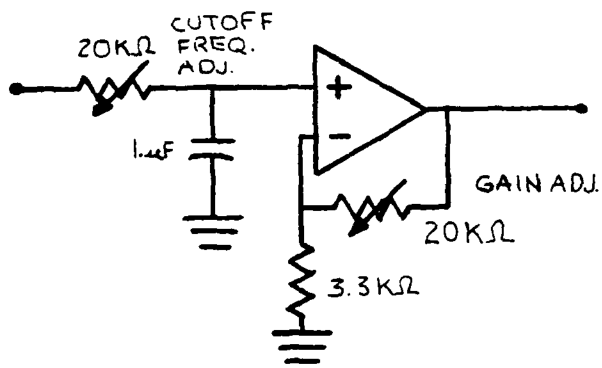


Figure 12 - NOISE SOURCE SCHEMATIC

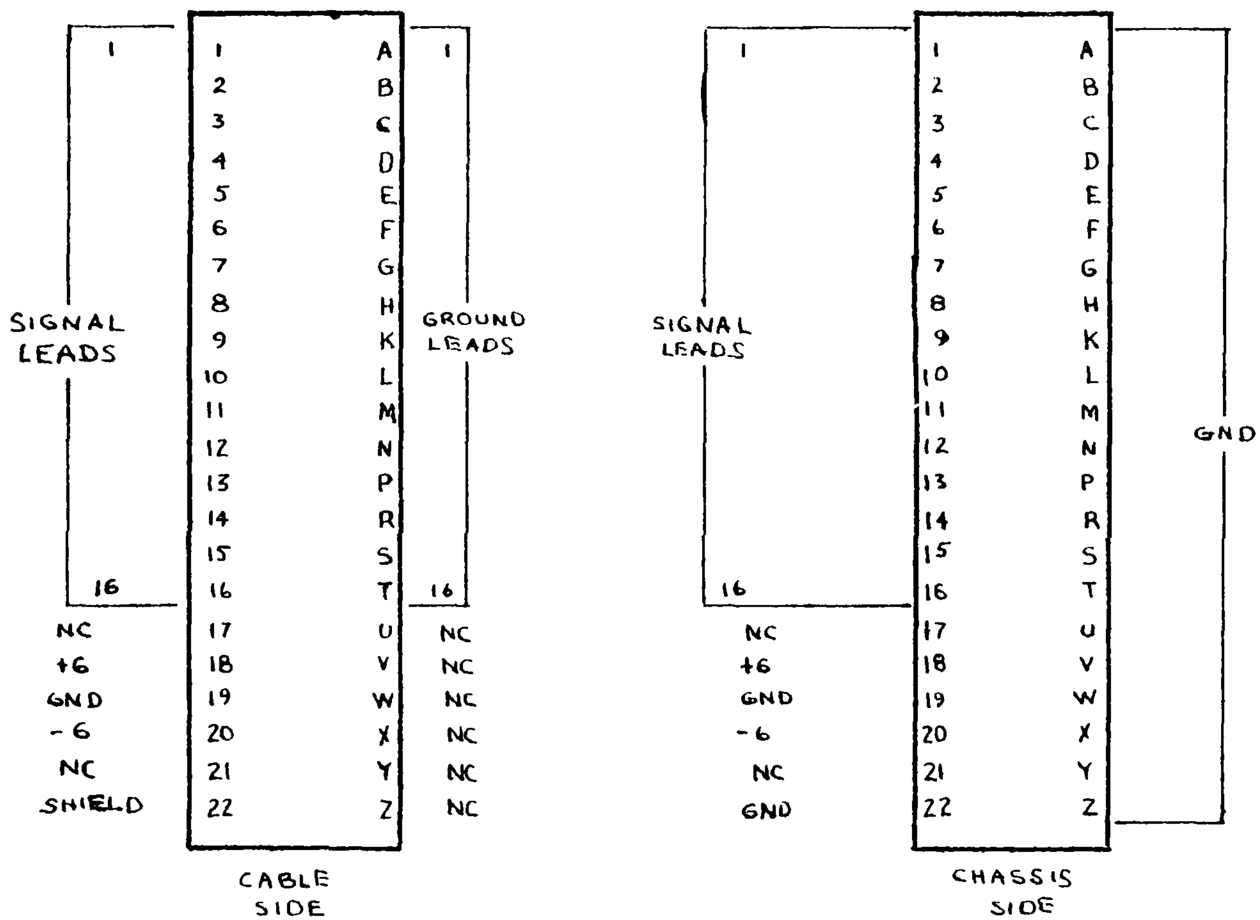


Figure 13 - CABLE ASSEMBLY CONNECTOR SCHEMATIC

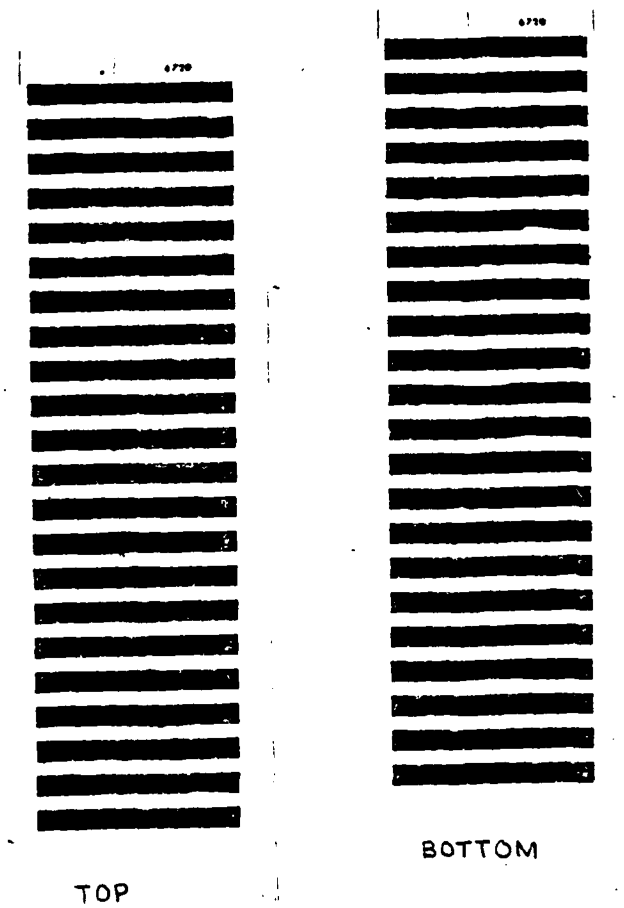


Figure 14 - MALE-TO-MALE PRINTED CIRCUIT BOARD

APPENDIX B

OPERATING PROCEDURES

A. PRINTED CIRCUIT BOARD ALIGNMENT

Following the assembly of the printed circuit board components, preamplifier/filter and phase shifter, they were aligned as follows: preamplifier gains were set at 200Hz upon construction, phase shifter aligned to 45 degrees at 200Hz.

Upon complete assembly and installation in the anechoic chamber, the preamplifier gains were matched to within .1dB at 200Hz. The phase shifter channels were aligned for 0 degrees shift at 200Hz when positioned just beneath element number one and pointing toward the source, with element number one as the phase reference. A separate microphone holder was fabricated for this phase alignment, which removes electronic phase changes.

B. INSTALLATION AND OPERATING PROCEDURES

1. Remove the microphones from the radial arms and the arms from the aluminum top before moving the array base.

2. Lift the array base only by the attached handles. Do NOT use the cable assembly or the aluminum top as a

handhold.

3. Before passing the cable assembly connector through a penetration, especially the anechoic chamber bulkhead penetration, wrap and secure the connector in a cloth or heavy paper to prevent snagging and breaking any of the shield terminations. The male to male edge should be left in the phase shifter edge connector.

4. Energize and de-energize the regulated power supplies used to power the filter, phase shifter and LED's as near as simultaneously as possible. Exact synchronization is not required. The design regulated voltage is ±6V based on LED brightness. Exceeding this voltage may shorten LED lifetime. At no time should ±9V be exceeded.

5. Turn the battery power supplies, located in the array base, off when not in use with installed switch to prolong battery life. The sequencing of the battery and regulated power supplies is not important.

6. The use of a 0 to 50mA range ammeter, inserted in the power supply leads and an independent voltmeter is recommended. The installed panel meters on the regulated supplies are sometimes in error or lack sufficient sensitivity. The voltmeter is useful in setting the power supply voltage while the ammeter can be used to detect improper switching operations if it is over ranged.

7. Do NOT select any more than two elements, one to each signal bus, at a time. Selection of more than one to each signal bus will result in over ranging of the recommended ammeter described above. Such a selection wil cause invalid results and potential equipment damage. Care must be taken not to violate this precaution during switching operations.

8. To properly connect the cable assembly to the phase shifter chassis, match the indexing "1" on each edge

connector. Insure that all power supplies are de energized prior to making this connection.

9. The positive battery power supply voltage may be measured at the microphone. Extreme care must be taken with a probe to avoid shorting the supply to the signal lead or ground. The switch must be on to allow this measurement. It is recommended that the batteries be replaced when the measured voltage falls below 5V.

10. Since the preamplifier gains and phase shifter aligned at 200Hz, use of this equipment at other frequencies may require re alignment. For broadband use alignment at the geometric mean frequency may be advisable. It should be noted that the overall frequency response is almost symmetric about 250Hz. Cables of equal length should be used to connect the phase shifter chassis to any phase measuring equipment to avoid contributing significant phase error to the measurement.

11. Install and operate the equipment, observing the above precautions, as follows: insure all power supplies are de energized, connect the cable assembly to the phase shifter chassis, energize the regulated power supplies then the batteries, select the desired elements and make any desired measurements.

APPENDIX C

SELECTED DATA

This Appendix contains some samples of the data taken using the equipment constructed in this thesis project. It illustrates the degenerate trace function concept for a 97.5cm diameter, sixteen element array operating with a 200Hz target.

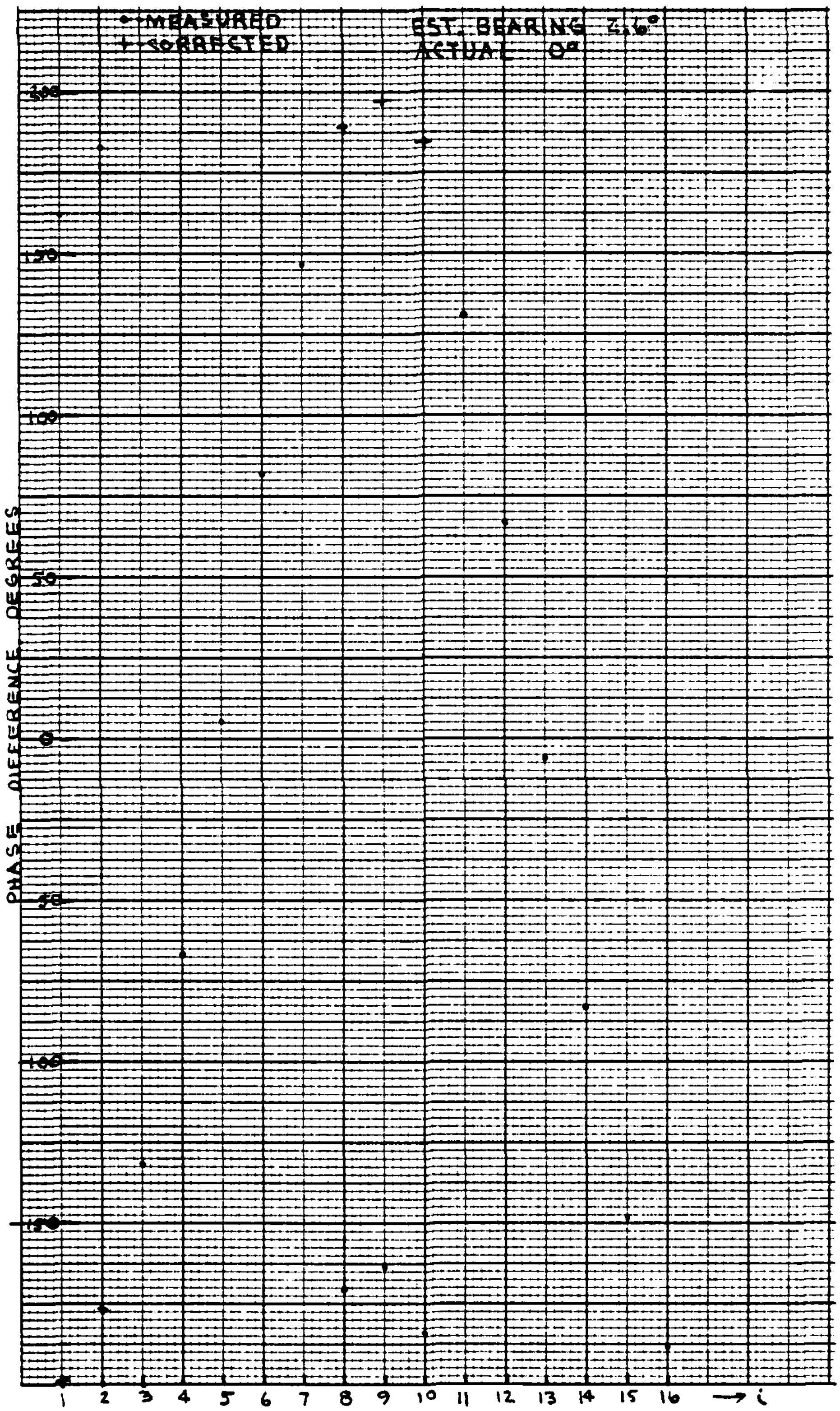


Figure 15 - TRACE FUNCTION, SNR=28.2dB, BEARING=0 DEGREES

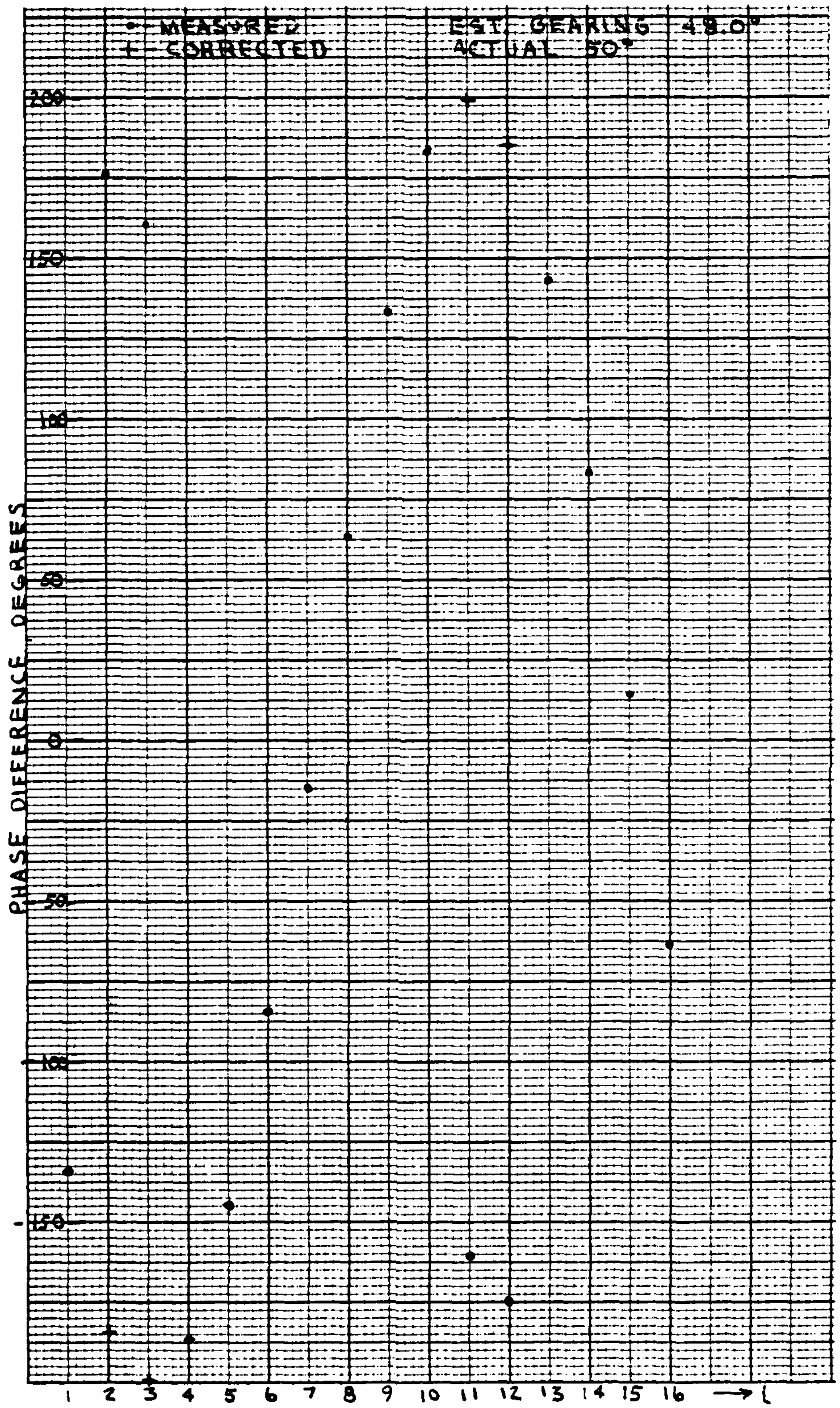


Figure 16 - TRACE FUNCTION, SNR=28.2dB, BEARING=50 DEGREES

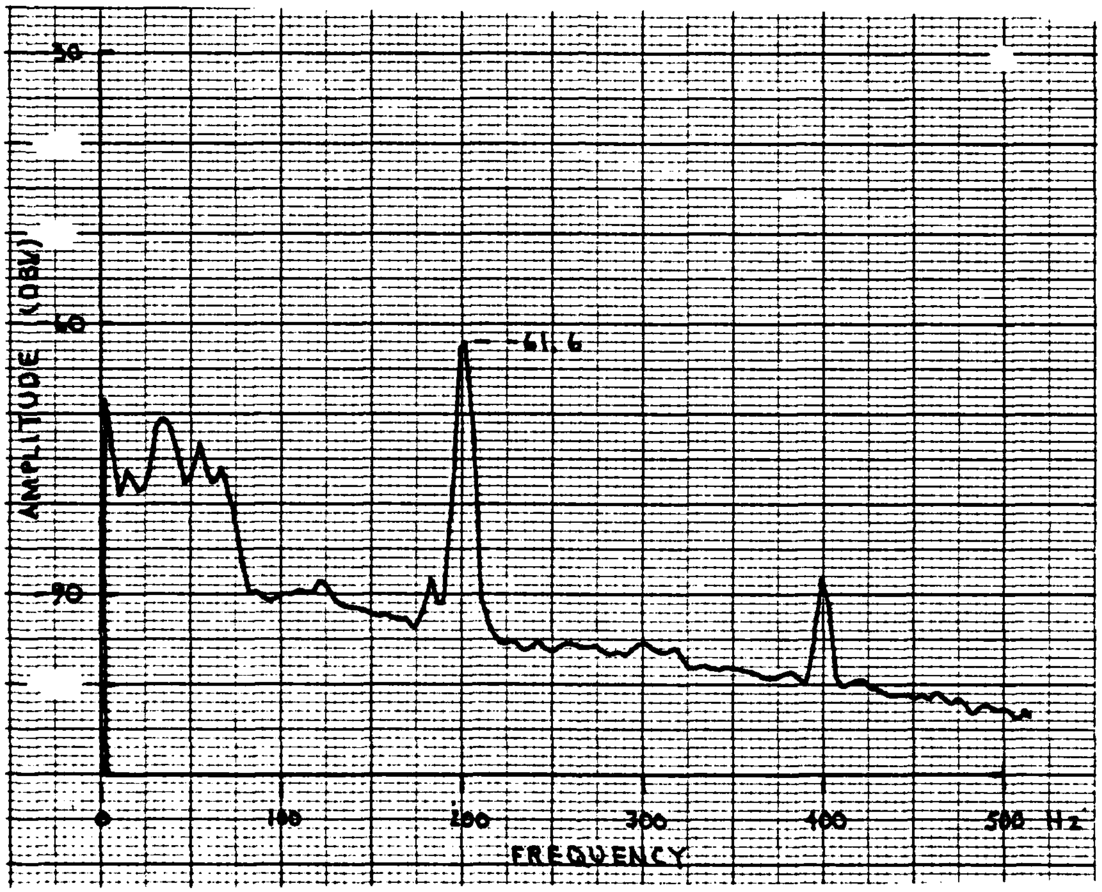


Figure 17 - AMPLITUDE SPECTRUM, SNR=28.2dB

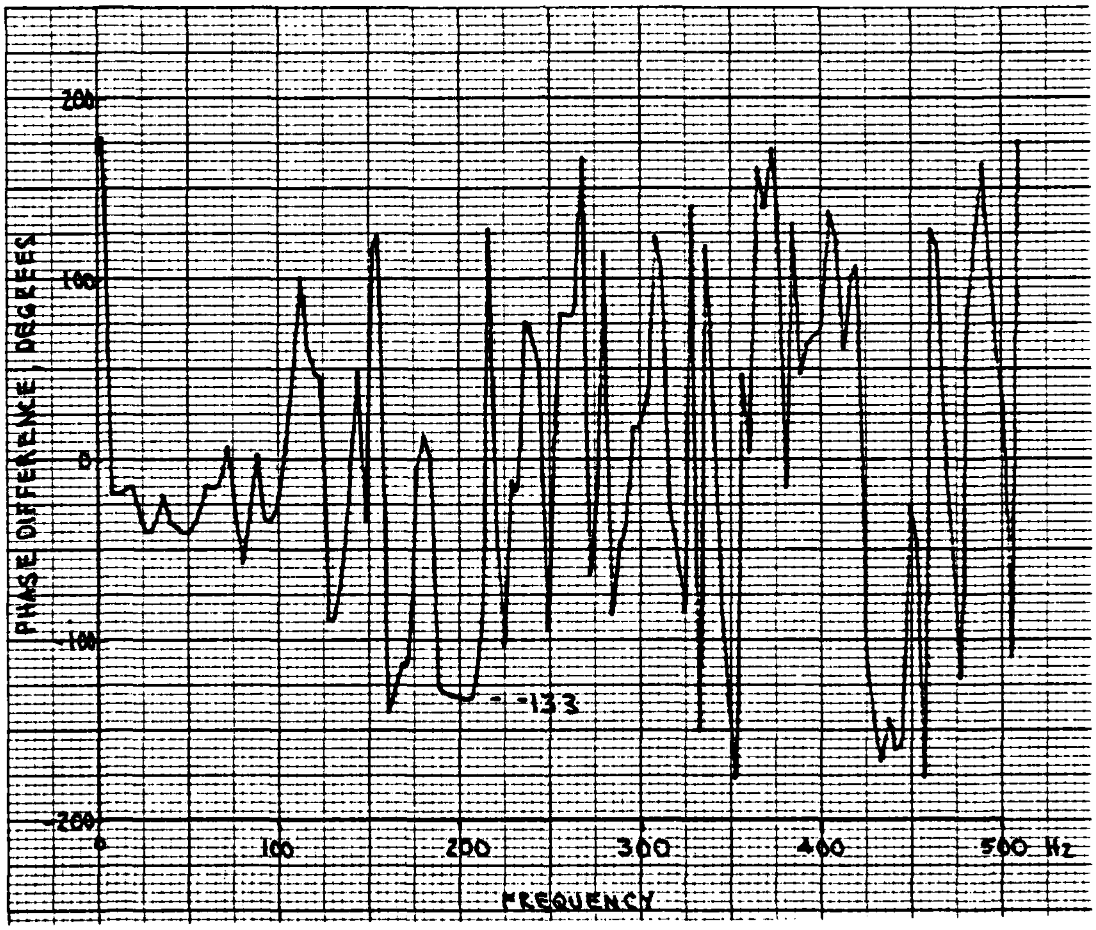


Figure 18 - PHASE DIFFERENCE SPECTRUM, SNR=28.2dB

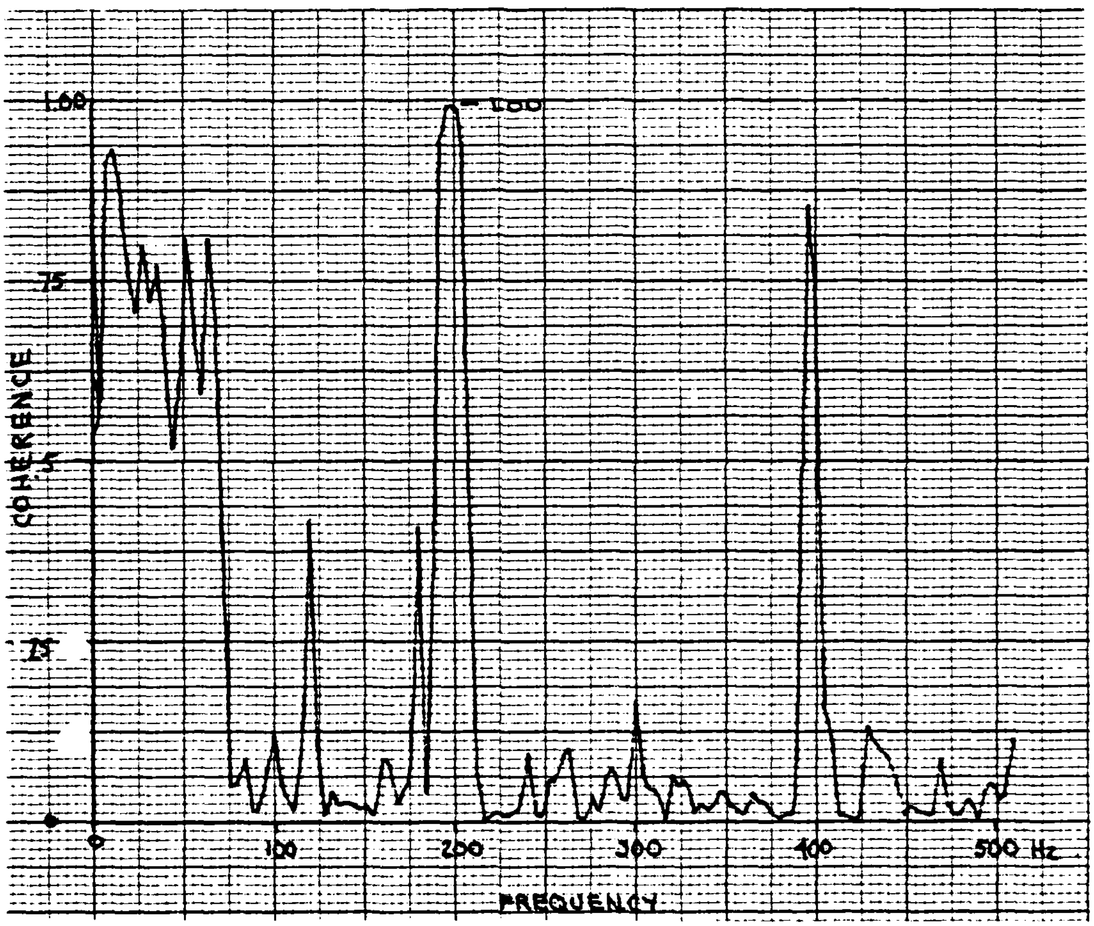


Figure 19 - COHERENCE SPECTRUM, SNR=28.2dB

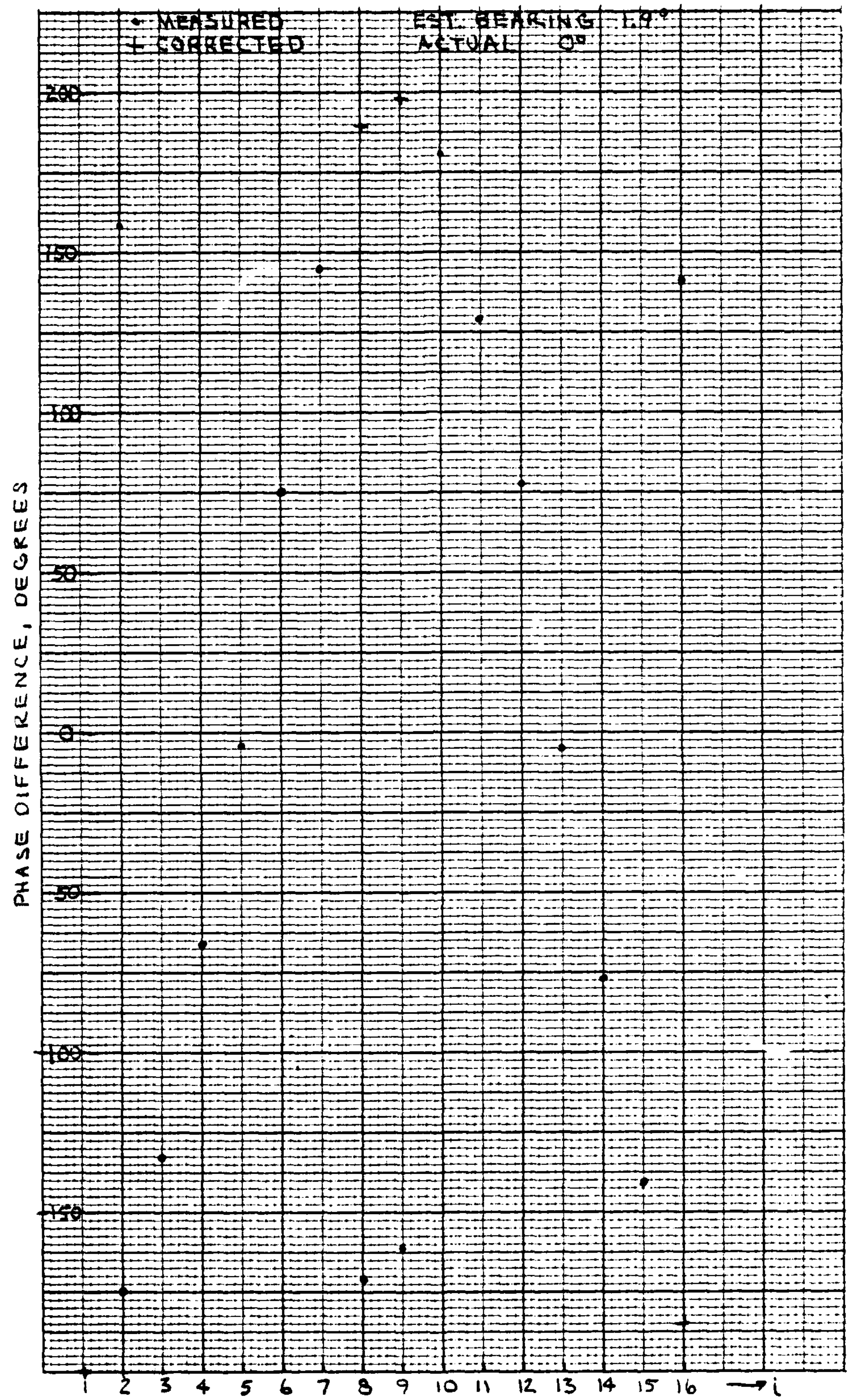


Figure 20 - TRACE FUNCTION, SNR=10.2dB, BEARING=0 DEGREES

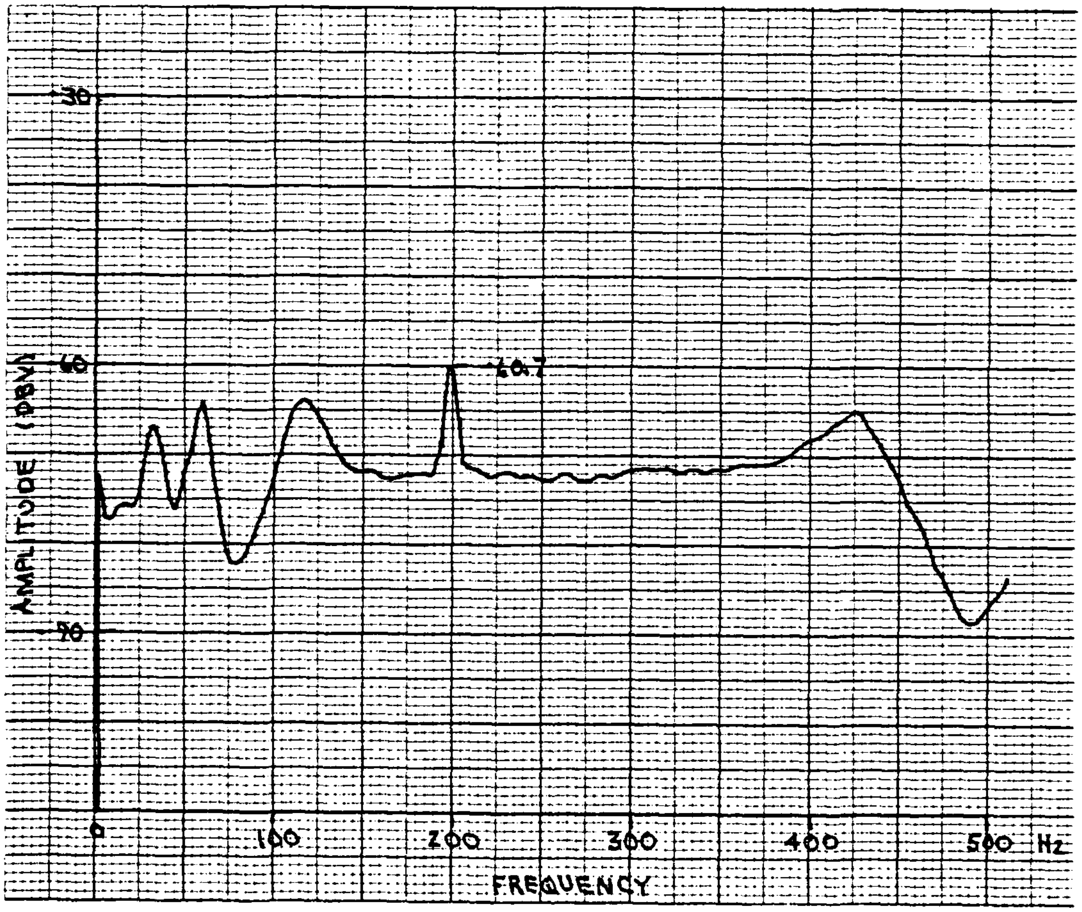


Figure 21 - AMPLITUDE SPECTRUM, SNR=10.2dB

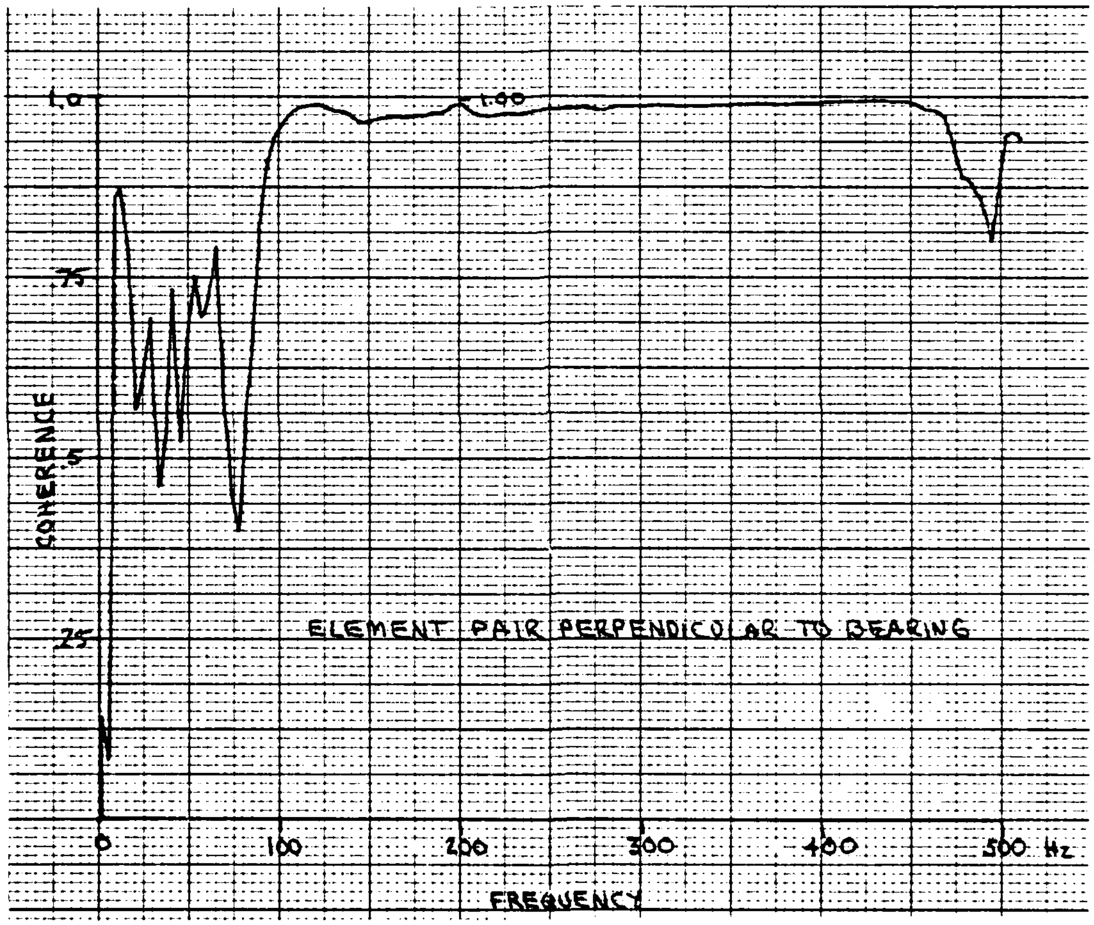


Figure 22 - COHERENCE SPECTRUM, SNR=10.2dB

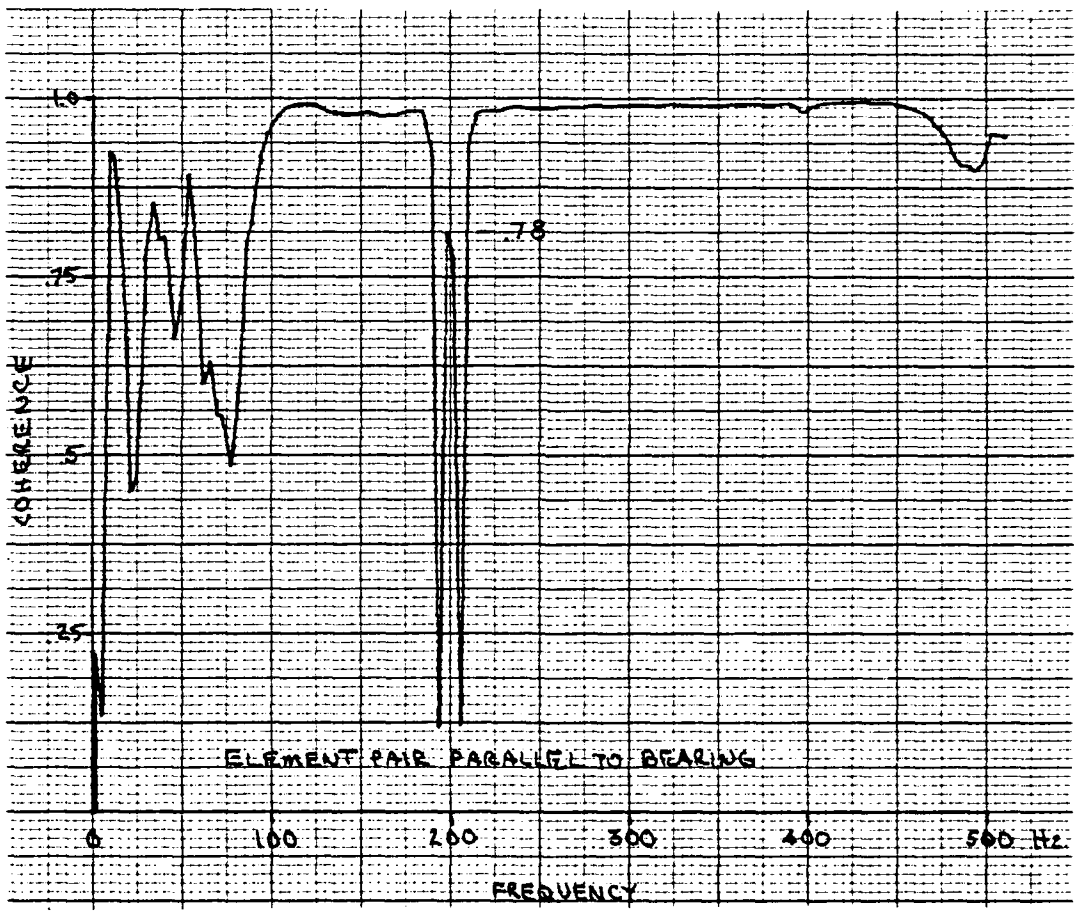


Figure 23 - COHERENCE SPECTRUM, SNR=10.2dB

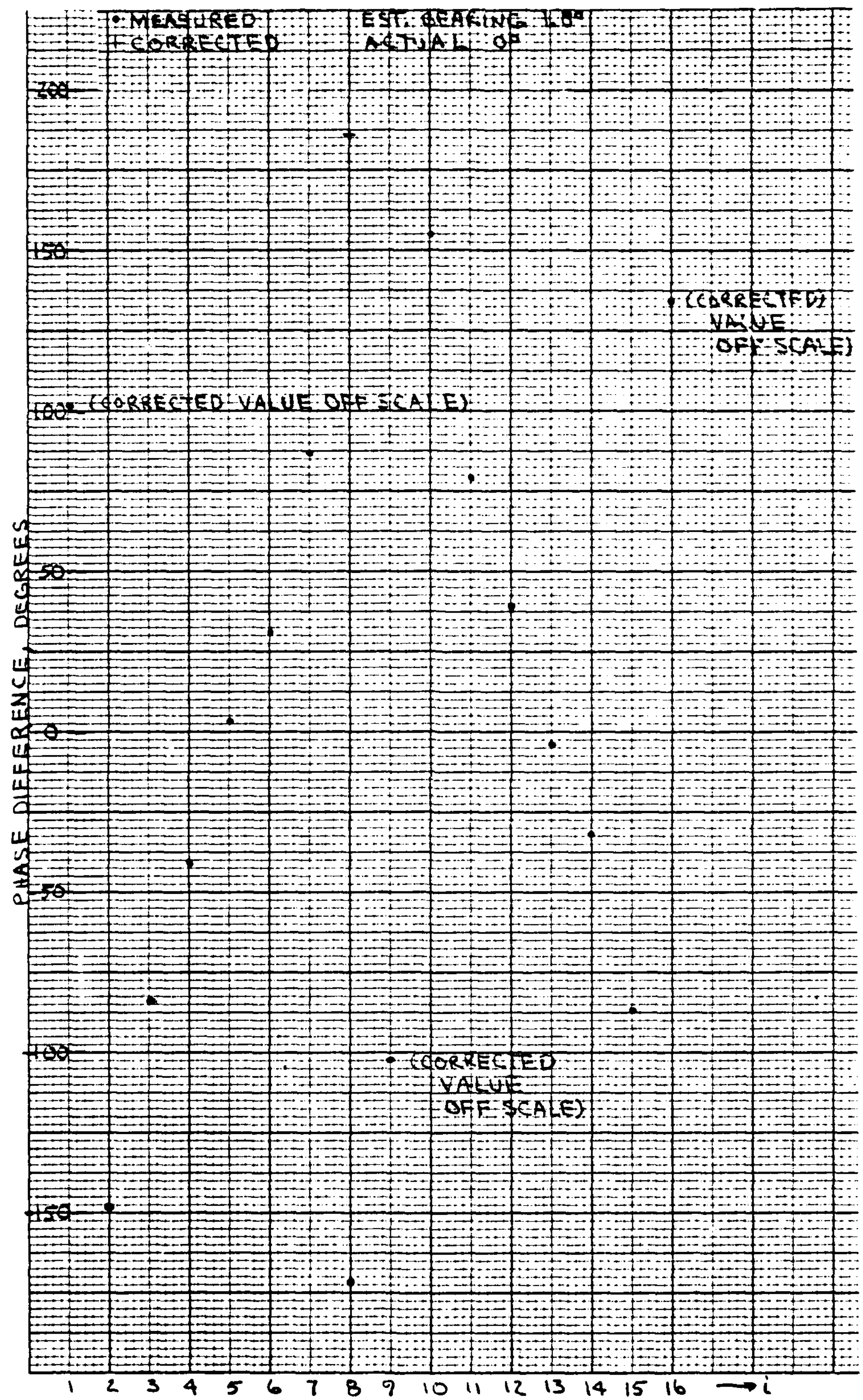


Figure 24 - TRACE FUNCTION, SNR=-1.8dB, BEARING=0 DEGREES

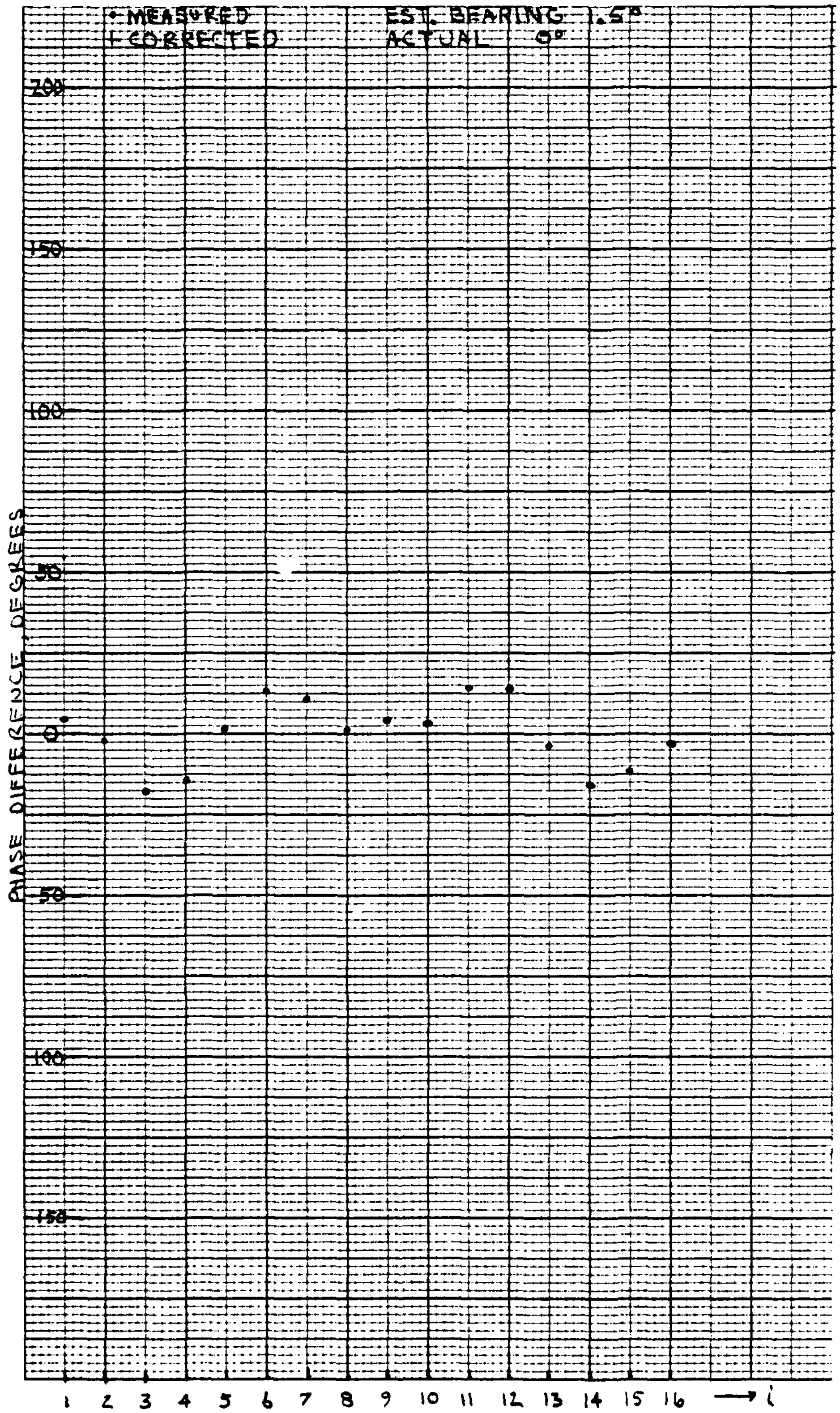


Figure 25 - TRACE FUNCTION, SNR=-7.8dB, BEARING=0 DEGREES

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