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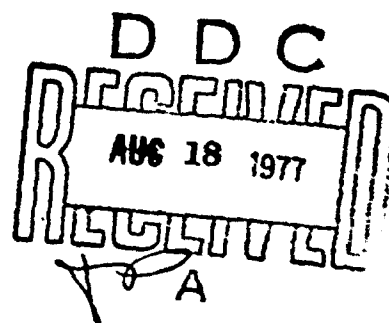


REAL-WORLD MEASUREMENTS OF MSS ACODAC
HYDROPHONE RESPONSE PATTERNS (U)

Thomas B. Gabrielson
Aero Electronic Technology Department
NAVAL AIR DEVELOPMENT CENTER
Warminster, Pennsylvania 18974

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) (C) One of the experiments performed during the Moored Surveillance System - Field Validation Test (MSS-FVT) was designed to evaluate the real-world beam pattern capabilities of deep ocean DIFAR-like sensors. While beam patterns can be readily measured under controlled conditions, the intent of this analysis was to examine the problem of beamforming in an actual ocean envi- ronment. This report examines the simple cardioid beams computer-formed from the outputs of these near-bottom mounted hydrophones.		

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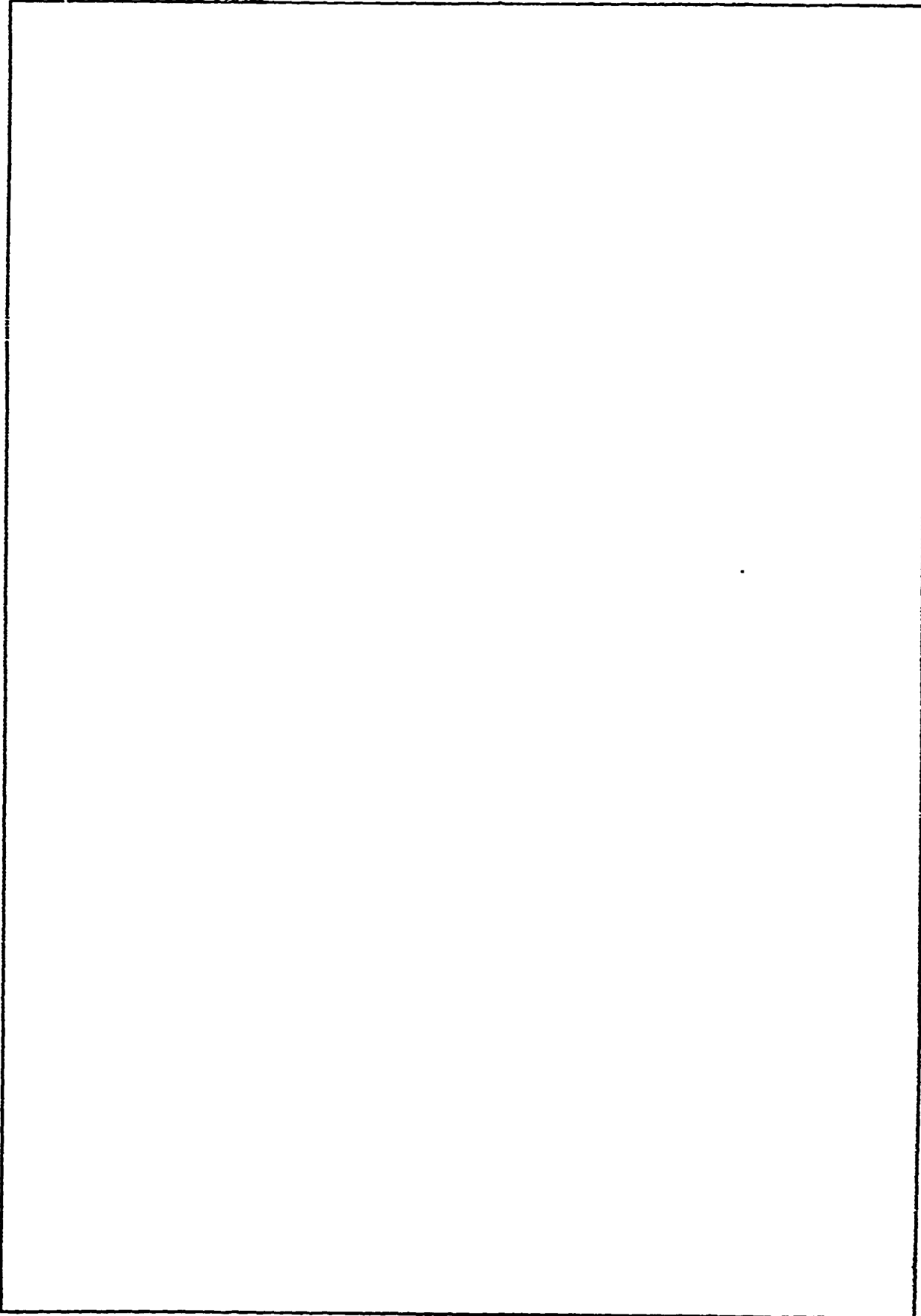
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CONFIDENTIAL**S U M M A R Y****INTRODUCTION**

(C) A portion of the MSS-FVT, conducted in the western North Atlantic during November 1975, was directed toward an evaluation of a candidate MSS sensor array for near-bottom use. The array consisted of two DIFAR hydrophone sets, one situated 20 feet directly above the other. Two configurations were obtained using these sensors: one was simply the lower DIFAR set, and the other was created by electrically subtracting each of the corresponding outputs in the upper and lower sets. This subtraction was performed in order to create a response null in the horizontal plane. As a result, the relative level of long range noise arriving at the sensor at angles close to horizontal should be reduced. This, in turn, should improve the received signal-to-noise ratio (SNR) for short range sources.

(C) The objective of the real world beam pattern portion of the FVT data analysis, conducted under Task Area XOS060000, Work Unit RH201, was to measure the quality and characteristics of horizontal cardioid beam patterns formed from actual deep ocean sensor outputs. The analyses included in this report cover two situations: one in which the formed beam was rotated through 360 degrees on its vertical axis with the source projector's location fixed, and the other in which the beam was formed in a single direction while the source projector was towed around the sensor. After beamforming by digital computer processing, the results were examined for beamwidth and relative response front-to-back ratio. (An ideal cardioid would have a 3 dB beamwidth of 130 degrees and an infinite front-to-back ratio.)

RESULTS

(C) The experiment in which the source was moved around a stationary beam failed to provide useful data. In spite of the relatively uniform range of the projector at each position around the sensor, the wide variation of the received signal level overshadowed the directional response of the beams. These gross variations in signal level may have been caused by the sloping ocean floor and the wide variation in temperature of the near-surface water at the test site.

(C) The rotated-beam analysis produced a well shaped beam with a front-to-back power response ratio greater than 15 dB for the 335 Hz projector frequency received by the single DIFAR sensor. The front-to-back ratio was 5 dB lower for the beam formed on the differenced sensor output. In addition, the beams formed on the 70 Hz projector frequency were substantially broader than the 130 degree beamwidth (between -3 dB power points) of a true cardioid beam. Front-to-back ratios for the 70 Hz beams were 5 dB or less. The poor quality of the 70 Hz beams resulted from the presence of a strong, interfering source of broadband noise in the field, presumably at short range, and the low SNR of the received signal.

CONCLUSIONS

(C) This analysis was designed to assess and compare the cardioid beams of the two sensor configurations based on the beamwidths and null depths (front-to-back ratios) of the response patterns. The resulting data show no significant difference between the performance of the single and the differenced sensors.

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(U) The environment of the test itself - the highly variable thermal conditions, the topography of the sea floor at the site, and the presence of at least one interfering source - made interpretation of the results little more than speculation. Further analysis would probably involve sophisticated modelling and processing techniques and might, ultimately, be of limited practicality because of the number of unknowns.

DESIGN OF THE EXPERIMENT

(C) From 0430Z on 18 November 1975, until 1006Z on 19 November 1975, the R/V CHAIN and the CFAV KAPUSKASING circled two sensor/recorder units at a range of approximately nine nautical miles. During these circuits, each ship projected three discrete-frequency acoustic signals. Each sensor/recorder unit included an array of two DIFAR hydrophone sets and an Acoustic Data Capsule (ACODAC - used to record the sensor outputs) moored to the ocean floor. The two DIFAR hydrophone sets were electrically connected to form the differenced sensor outputs and one set was also used by itself as an ordinary DIFAR configuration.

(C) The useful portion of this exercise for evaluating the cardioid beam characteristics of the sensors was limited to R/V CHAIN's tow around the ACODAC, serial number 2A5. This segment extended from 0430Z to 1900Z on 18 November. Reasons for this reduction in usable data were: first, the levels of KAPUSKASING's projector lines were generally too low to be detected; and, second, the other ACODAC was inoperative during the time of CHAIN's tow around it. In addition, one of CHAIN's three projector frequencies, 588 Hz, was set 13 dB lower than scheduled, thus making its level at the sensor unusably low.

(U) CHAIN's usable tow was executed by holding position for forty minutes at each of eight stations spaced 45 degrees around the ACODAC at constant range. The projector was on throughout the tow, and at each station a 2000 meter bathythermograph was taken. The intent of this maneuver was to provide a constant source level and similar propagation path at several locations around the ACODAC.

THE PROCESSING SYSTEM

(C) The real world beam pattern data of the MSS-FVT was analyzed using two separate processing units: a combination signal conditioner/Analog-to-Digital Converter (ADC), and the NAVAIRDEVCON central computer facility.

(U) Three parallel channels of variable attenuation (for channel balance), low-pass filtering at 500 Hz and 40 dB/octave, and 2.5 dB amplification composed the signal conditioner. The ADC was a thirteen bit converter preceded by a three channel multiplexer. For the purpose of this analysis, the converter sampled at 2048 Hz/channel, which was well within its 3300 Hz/channel capability for three input channels. Finally, a minicomputer system wrote the sampled data on a nine track, 800 BPI digital tape in 16-bit words.

(C) The digital tape was then input to the NAVAIRDEVCON CDC 6600/CYBER computer which performed the subsequent analyses. First, the data words were converted from 16 to 60-bit length for compatibility with the 6600/CYBER. Further processing stages were dependent on the type of output desired but generally included

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- (C) Fast Fourier Transform (FFT) processing and a cardioid beamforming algorithm. The 4096 point FFT produced a frequency resolution of 0.5 Hz with the 2048 Hz sampling rate.

D A T A A N A L Y S I S**CASE OF MOVING BEAM/STATIONARY SOURCE**

(C) Most of the data on cardioid beam performance was obtained by selecting one of the intervals of fixed projector position and computer-rotating the beams produced by both sensor configurations through 360 degrees in the horizontal plane. The resulting beam shapes for both the 70 Hz and 335 Hz projector frequencies are shown in figures 1 through 4.

(C) The 335 Hz beams are well formed but the 70 Hz beams show very little directivity and bearing errors of 20 to 40 degrees. One reason for this poor shape was the presence of a nearby source of low frequency, broadband noise (possibly a merchant ship) on a bearing differing from that of the projector ship. This source was discovered when beams were formed on frequencies close to that of the 70 Hz projector line (see figures 5 and 6). These "noise-field" beams show strong horizontal directionality in the noise field which was confirmed through an independent beamforming system operating on the same data. The presence of this noise source precludes drawing reliable conclusions about the sensor beam characteristics at 70 Hz.

(C) The second factor which degraded the 70 Hz cardioid beam was the low, received SNR. This effect is illustrated in figure 7 which shows the influence of signal-to-noise ratio on the shape of an ideal cardioid response pattern. For example, an SNR of 3 dB (referred to whatever bandwidth the processor itself uses - 0.5 Hz in this case) would corrupt a true cardioid to look much the same as the single DIFAR 70 Hz beam (figure 1). Measurements made of SNR for the same time period as the beamforming analysis have shown that it was roughly 3 dB.

(U) The 335 Hz beam pattern was not influenced by either of the effects mentioned above since the received SNR was relatively high (greater than 10 dB for the single sensor, slightly less for the differenced sensor) and there were no significant sources of noise at that frequency in the area.

(C) The SSN GREENLING, with its projector on, passed within five nautical miles of the sensors during the time interval of this experiment, however, the frequencies were such that the interference did not seem to be significant.

CASE OF STATIONARY BEAM/MOVING SOURCE

(C) In an attempt to include more environmental parameters in the investigation of sensor beam patterns, the eight stationary periods during the circular tow were considered. Each period was processed (five minutes per position) to examine the effects of a source moving physically around a beam pointed in a single direction. Before any beamforming was done, the received signal level at both 70 and 335 Hz revealed variations on the order of 40:1 (ratio of intensities) around the circle even after correction for the minor range differences. This signal variation, coupled with the presence of the source of noise mentioned in the last section, would make any attempt at beamforming unrealistic.

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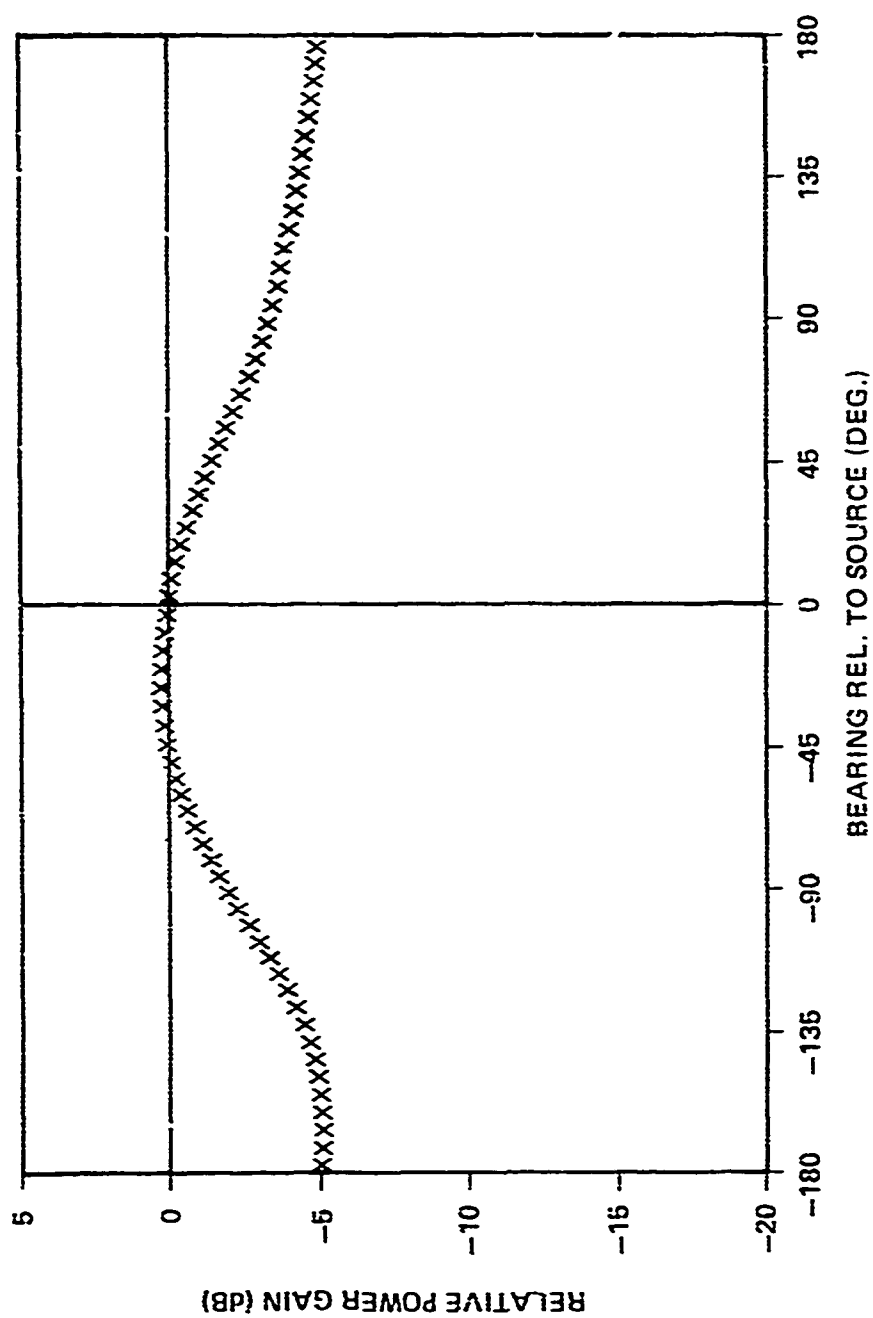


FIGURE 1 - (C) Single Sensor Beam Formed on the 70 Hz Projector Line (U).

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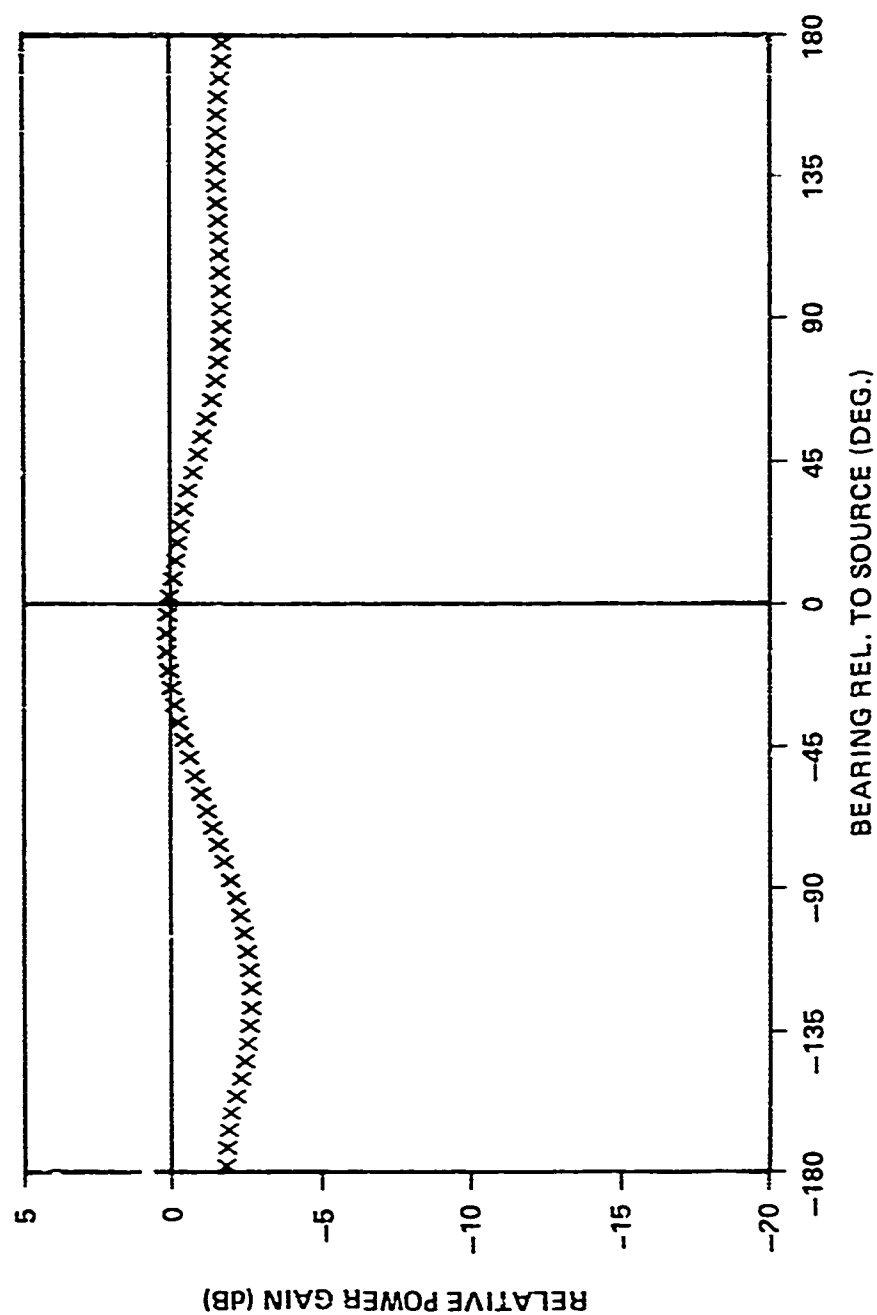


FIGURE 2 - (C) Differenced Sensor Beam Formed on the 70 Hz Projector Line (U).

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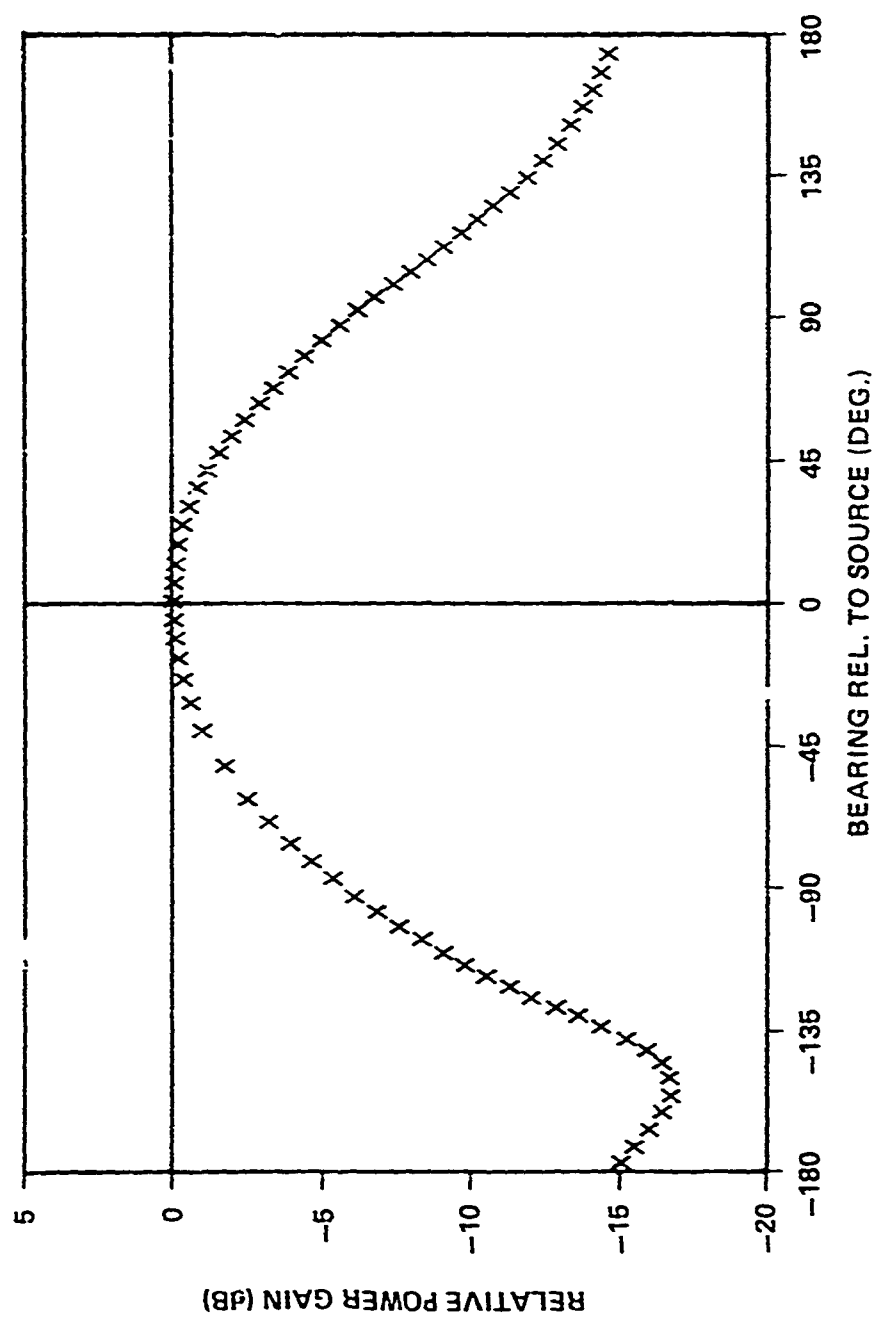


FIGURE 3 - (C) Single Sensor Beam Formed on the 335 Hz Projector Line (U).

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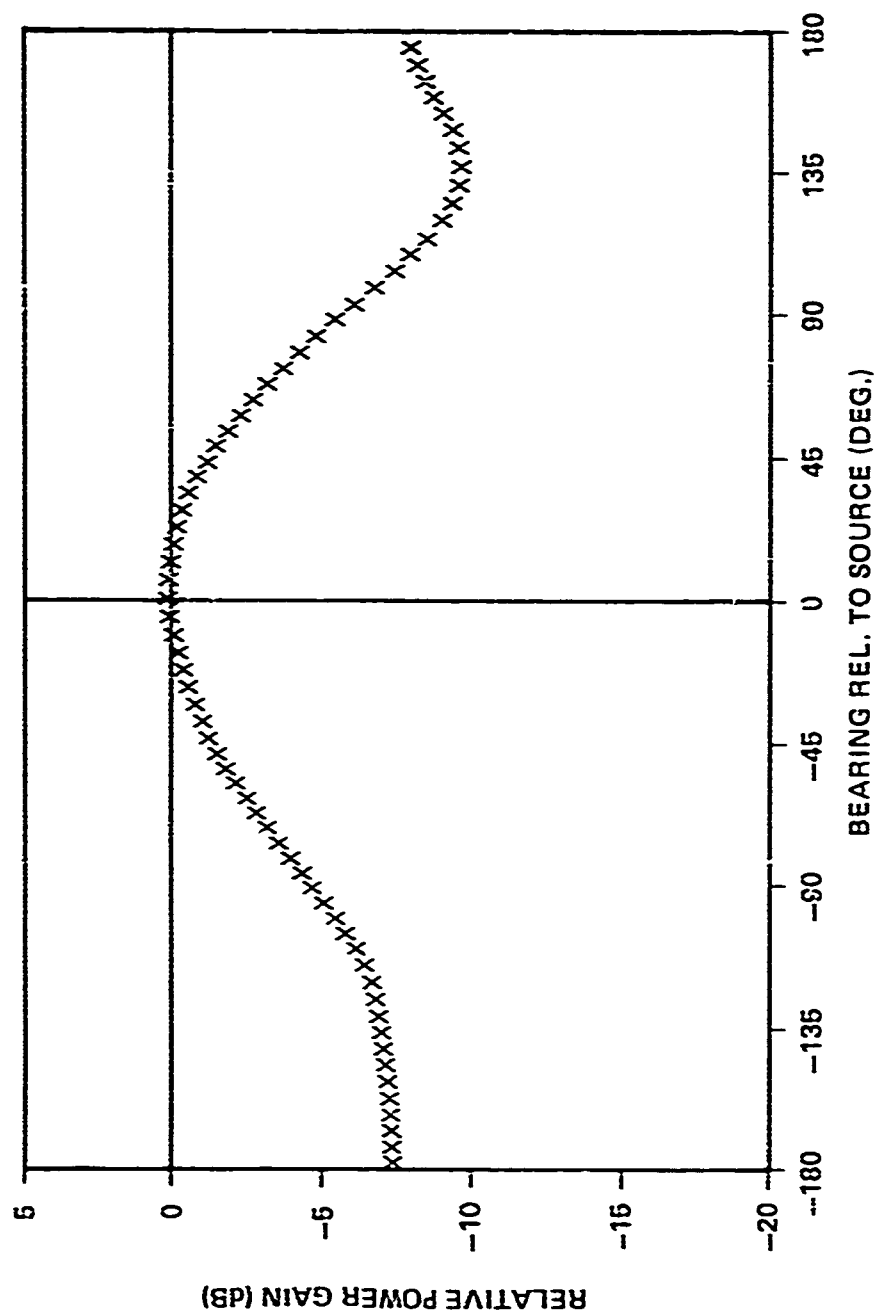


FIGURE 4 - (C) Differenced Sensor Beam Formed on the 335 Hz Projector Line (U).

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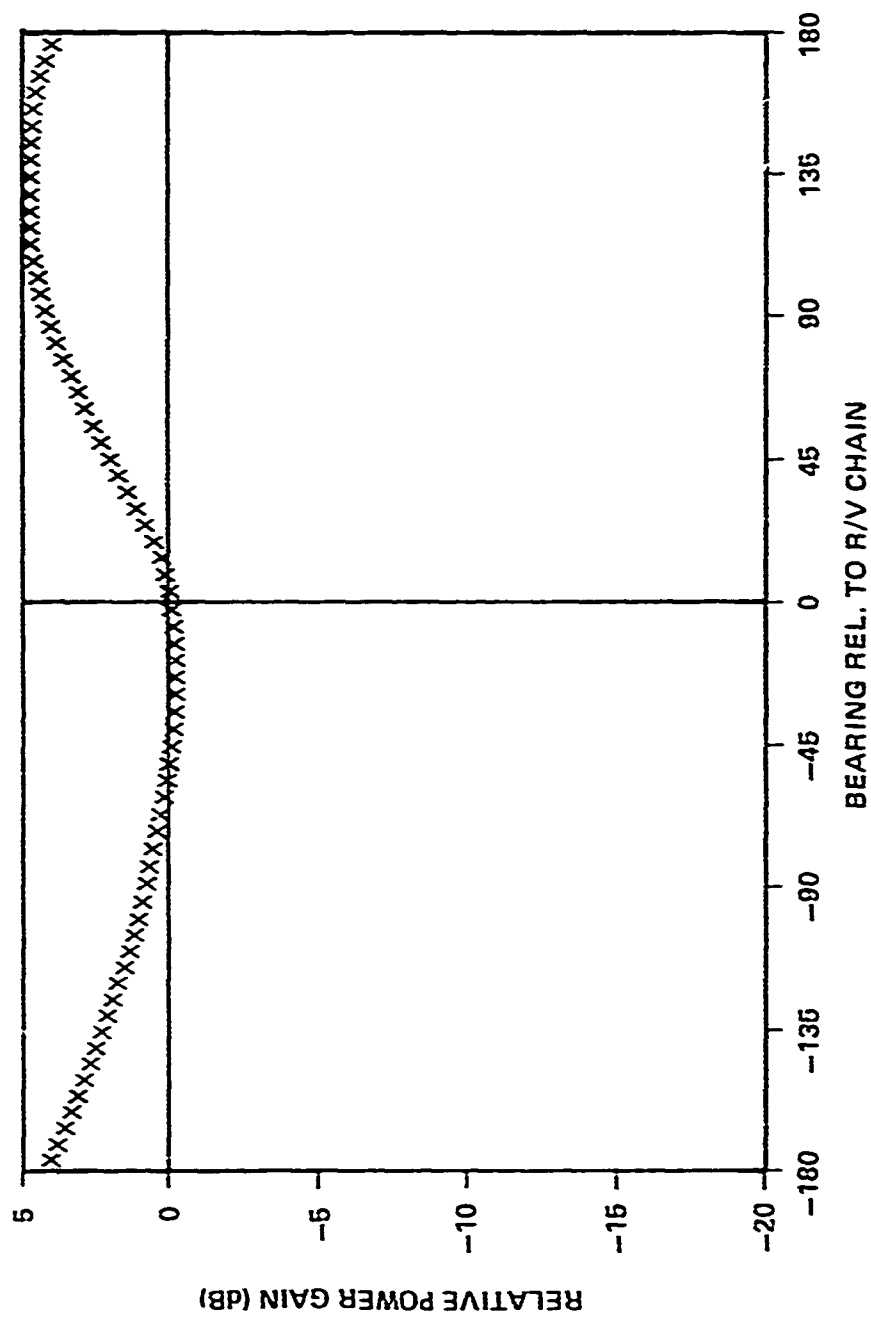


FIGURE 5 - (C) Single Sensor Beam Formed at 66 Hz (U).

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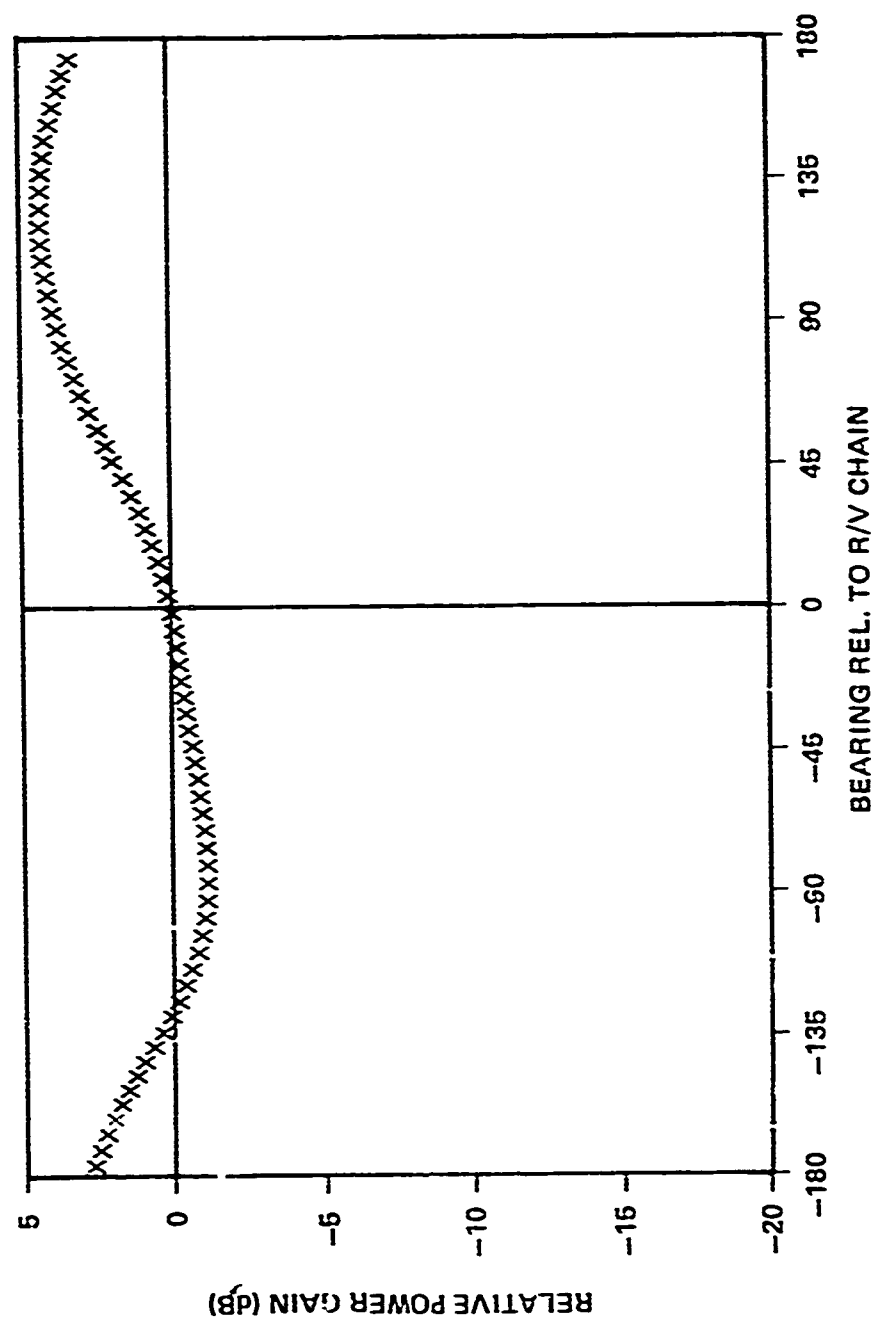


FIGURE 6 - (C) Single Sensor Beam Formed at 74 Hz (U).

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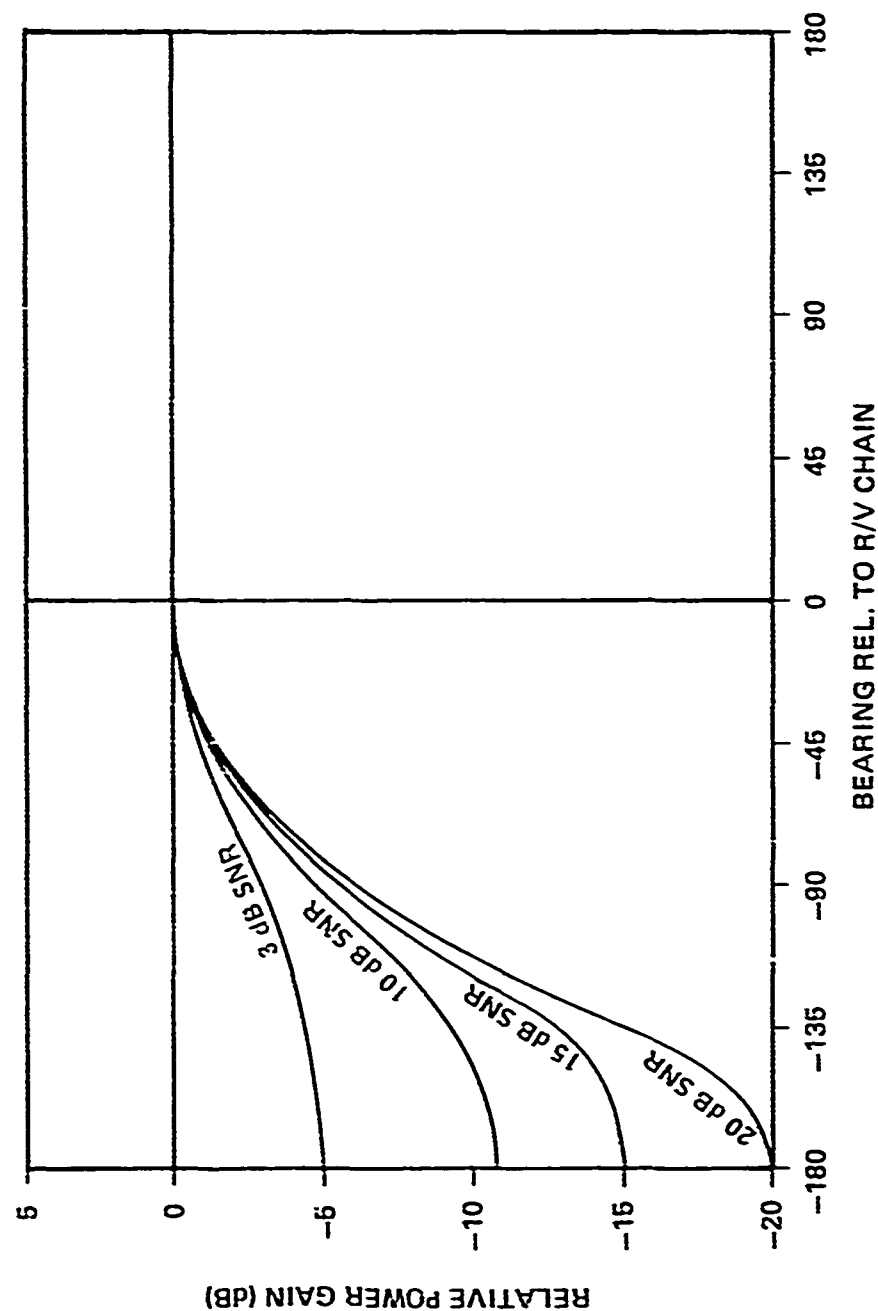


FIGURE 7 - (U) Influence of Signal-to-Noise Ratio (SNR) on Cardfold Beam Shape.

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(C) One reason for the wide variation in received signal level around the circle could have been the bottom slope at the test site. Bottom-mounted systems are sensitive to bottom slope in that more non-bottom bounce energy can come from the downslope direction than from upslope. Whether the slope at this site was enough to affect performance has not been determined but the data shows the highest received intensity in the downslope direction.

(U) The near-surface temperature structure of the water may supply another explanation. Bathythermograph measurements made from the R/V CHAIN show that one location had a substantially lower near-surface temperature maximum than any of the others. A greater depth excess in the sound velocity profile is thus produced which can result in a decrease in propagation loss for this particular sensor depth. Again, the quantitative effects of an increase in depth have not been investigated but the data does show a substantially higher received level for this projector location than for the two adjacent locations.

COMPARISON BETWEEN SINGLE AND DIFFERENCED SENSOR PERFORMANCE

(C) None of the real world beam pattern analyses produced evidence to support the superiority of the differenced sensor over the single sensor. On the contrary, when there was a noticeable difference in sensor performance it favored the single sensor.

(U) While the number of variables in this experiment cannot readily be reduced to manageable size, some explanations for the lack of difference between sensors may be proposed.

(U) First, the noise was not all long distance shipping noise. The presence of the merchant ship (?) at relatively short range and the submarine with its projector added a significant short range component to the noise field. The differenced sensor was designed to reduce long range noise only.

(C) Second, the array may have been tilted. The current meter, located only 20 feet from the ocean floor, indicated currents in excess of 0.5 knots. Because the ACODAC itself, the source of greatest hydrodynamic drag, was located 100 feet from the floor, there may have been some significant array tilt. If the differenced sensor array was tilted, the null in the vertical response pattern would no longer be horizontal and the rejection of long range noise would be degraded. This would result in a drop in SNR. The vertical/response patterns at 70 Hz and 335 Hz (figures 8 and 9) show the small amount of tilt (particularly at 335 Hz) necessary to significantly modify the horizontal response.

(C) Finally, if the two DIFAR units making up the array were tilted with respect to each other, the horizontal null would be degraded, filling in rapidly with the first few degrees of offset.

DATA VALIDITY TESTS

(U) Prior to processing the ACODAC data, the procedures summarized below were used to evaluate and minimize the processor's contribution to error in the data.

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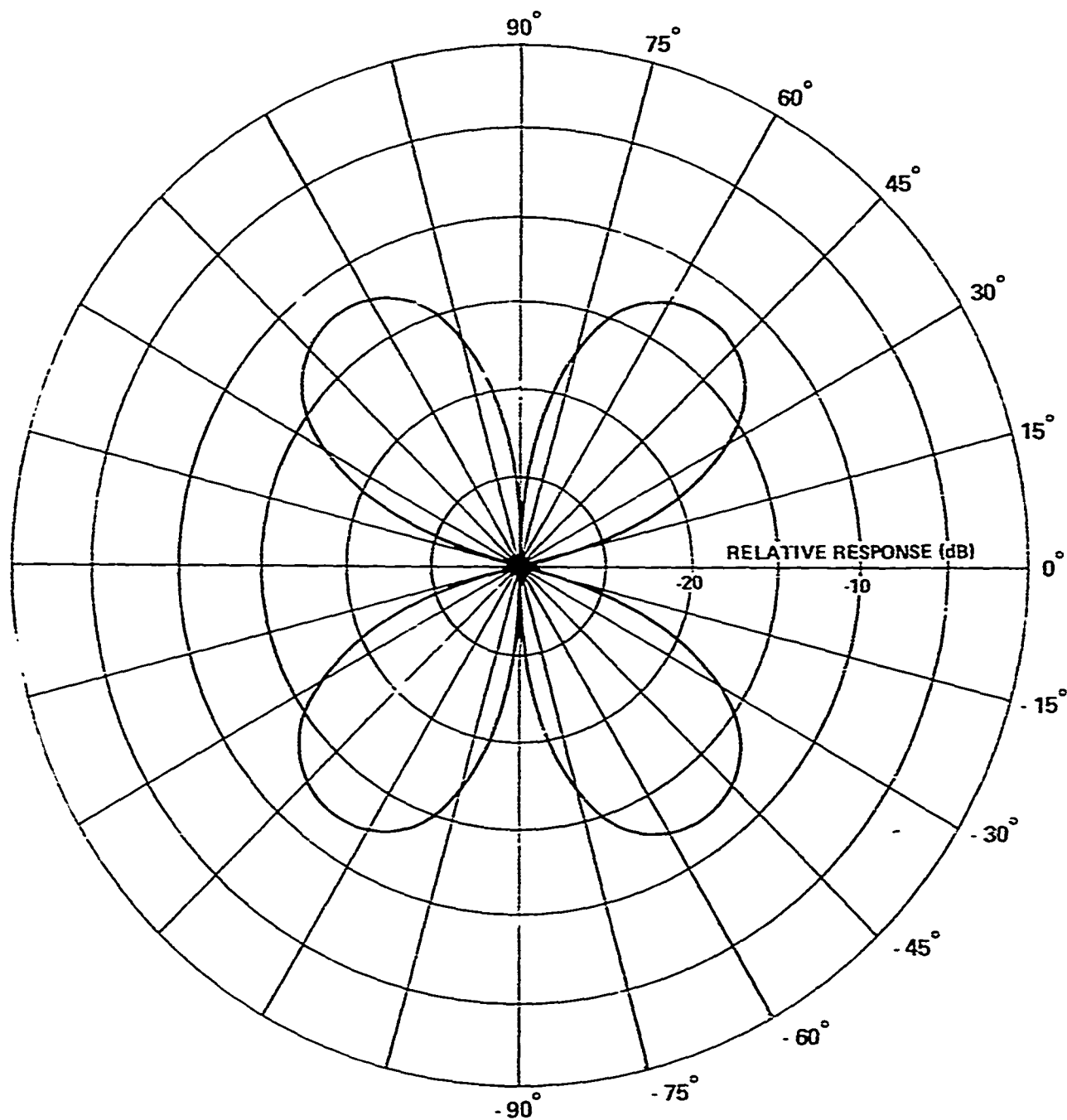


FIGURE 8 - (C) Differenced Sensor Vertical Response at 70 Hz Relative to the Beam Axis Response of a Single DIFAR Hydrophone (U).

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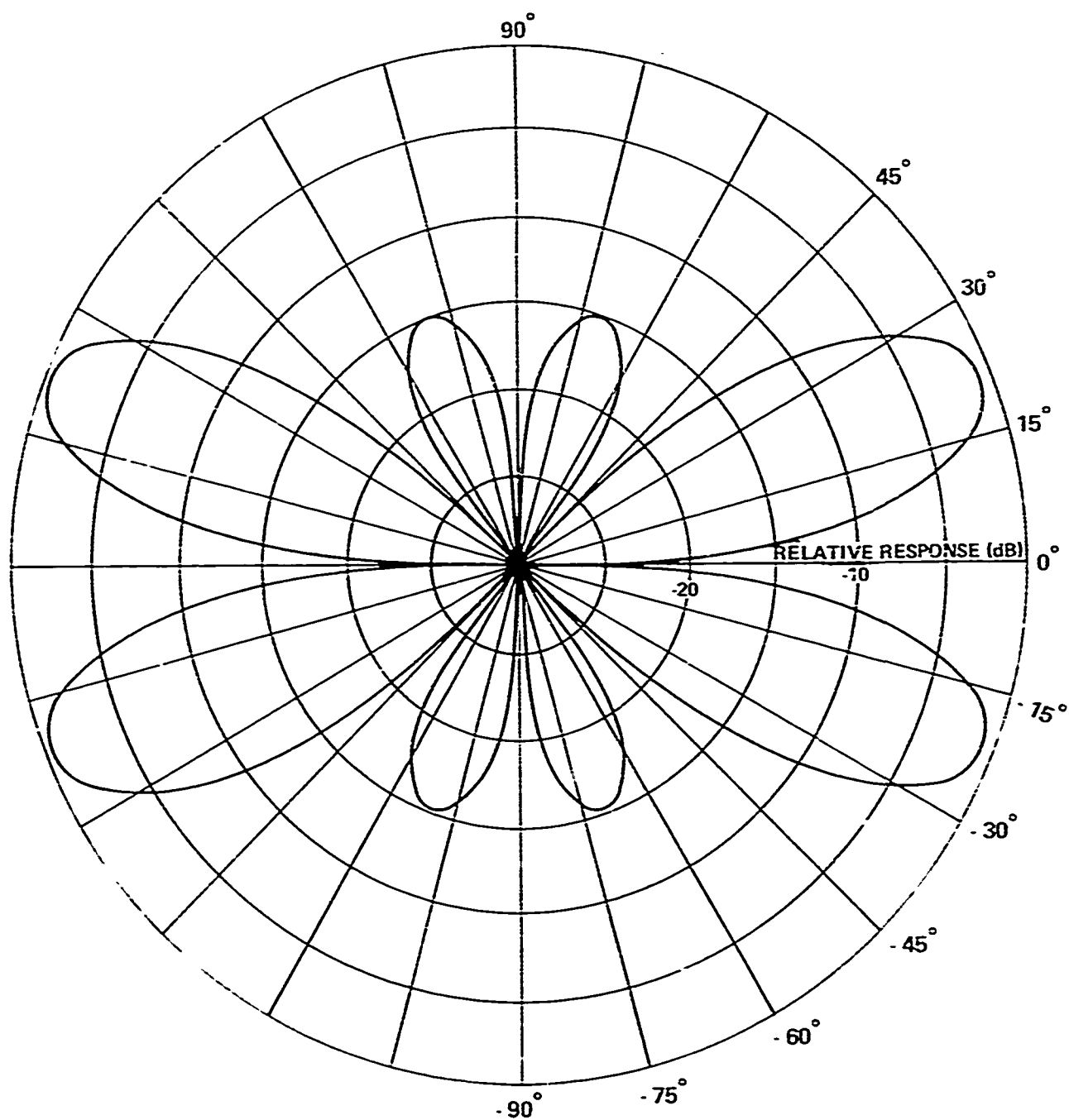


FIGURE 9 - (C) Differenced Sensor Vertical Response at 335 Hz Relative to the Beam Axis Response of a Single DIFAR Hydrophone (U).

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(C) Preliminary set-up of the signal conditioner involved matching the frequency responses of the three channels across the band of interest (approximately 50 to 400 Hz). Using a sweep frequency signal generator as input and adjusting the attenuators and filters for minimum output signal difference between pairs of channels, the channels were balanced to within 0.1 dB. In addition, the tape recorder reproduce amplifiers were set with the ACODAC tone calibration signal (on the data tape itself). Here, the best balance possible was ± 1 dB - the limiting source of error in channel balance through the entire system. A study of the effects of a 1 dB channel imbalance showed that the bearing would be correct within five degrees and that the 3 dB (power) beamwidth of the cardioid pattern would increase by no more than five percent (one channel 1 dB high, another channel 1 dB low).

(U) Once the signal conditioner channels were balanced, two tests were run to check out the entire processing system. First, the inputs to the signal conditioner were shorted and a short segment of "data" was processed to evaluate system noise and DC offset voltages. The resultant offset was not high enough to significantly affect the dynamic range of the ADC. The noise was generally limited to the lower four bits.

(C) The second involved paralleling the three signal conditioner inputs and applying a 300 Hz sine wave (2 volts peak-to-peak) to test channel balance and to verify the operation of the beamforming algorithm. Processing of this data proved that the RMS channel levels were all within 0.1 dB of each other and the computed bearing was consistently within a degree of forty-five degrees. (The computed bearing should be forty-five degrees when the level of the north-south channel equals the level of the east-west channel.)

(C) In order to insure that the frequency bins processed by the beamformer actually contained the projector lines, spectral data from an FFT of the omni channel was searched manually. In this way, the locations of two of the projector lines from the R/V CHAIN were found. The absence of the 588 Hz line and the lines from CFAV KAPUSKASING's projector indicated that their levels were not high enough for processing.

(C) Once beamforming on the projector frequencies was completed (in the source-stationary case), additional beams were formed on frequencies which bracketed the projector lines. When these beams were produced near the 70 Hz line (see figures 5 and 6), the interfering noise source's presence and approximate bearing were discovered. The region around 335 Hz showed no such horizontal directionality in the noise field (see figures 10 and 11).

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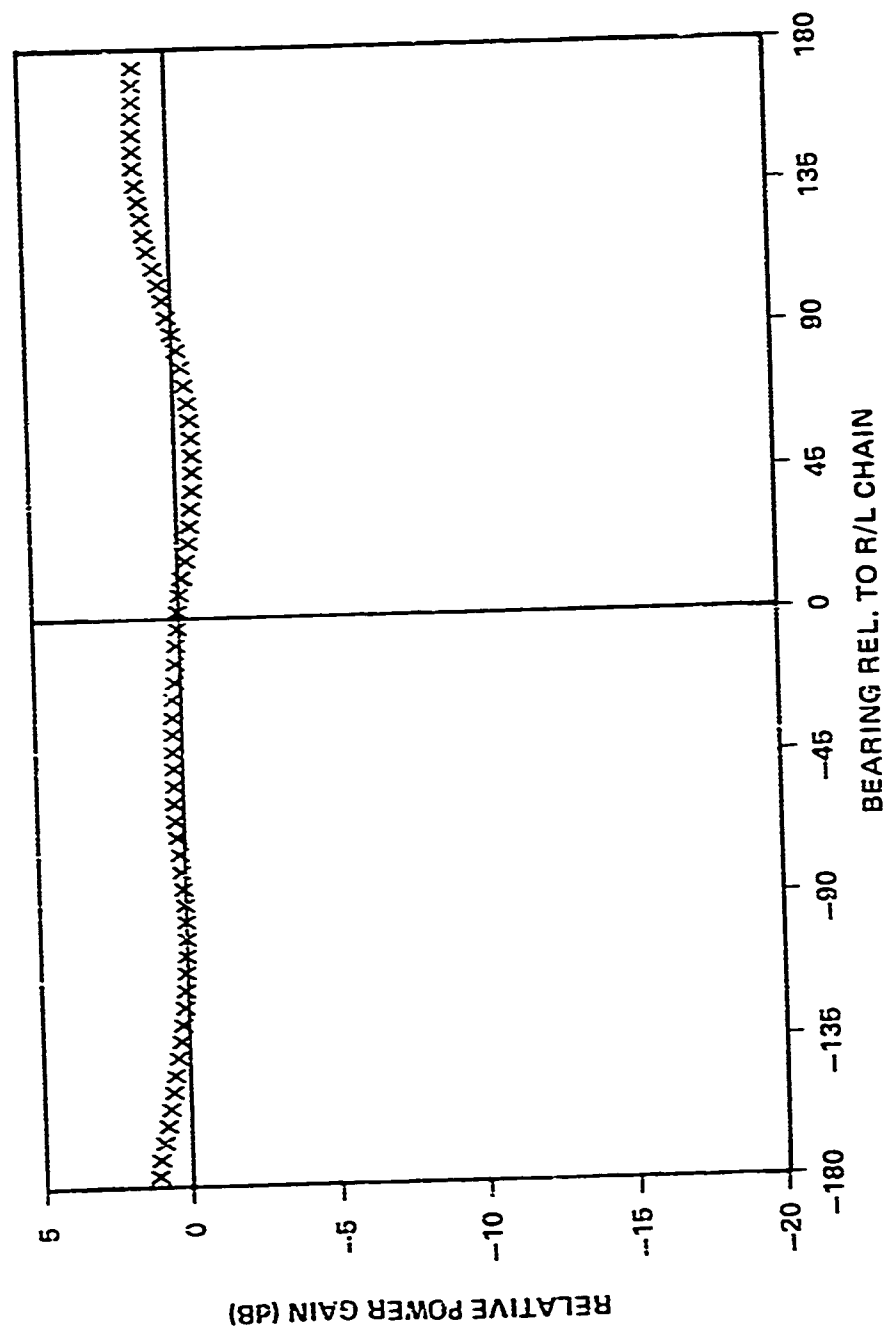


FIGURE 10 - (C) Single Sensor Beam Formed at 329 Hz (U).

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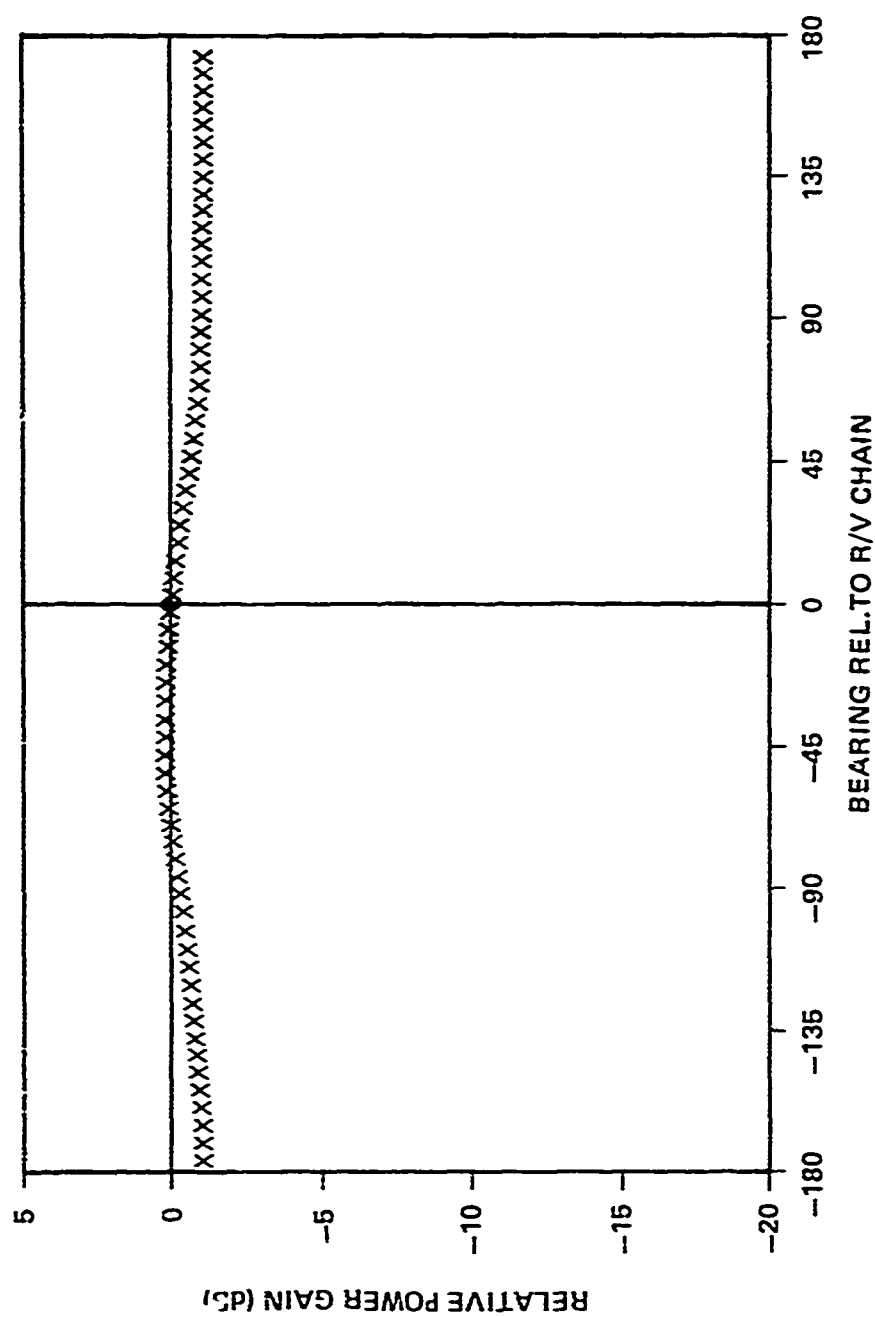


FIGURE 11 - (C) Single Sensor Beam Formed at 341 Hz (U).

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Unavailable	Unavailable	MSS CONFIGURED ACODAC SYSTEMS PRELIMINARY TEST REPORT-BEARING STAKE (U)	Sanders Associates, Inc.	761111	AU	C
ARL-TR-76-52	Watkins, S. L.	MOORED SURVEILLANCE SYSTEM FIELD VALIDATION TEST AMBIENT SOUNDFIELD AND PROPAGATION MEASUREMENTS FOR NEAR-BOTTOM SENSORS AT SITE A3 (U)	University of Texas, Applied Research Laboratories	761201	ND	C
Unavailable	Unavailable	REAL-WORLD MEASUREMENTS OF MSS ACODAC HYDROPHONE RESPONSE PATTERNS (U) PHASE REPORT - PRELIM DRAFT	Naval Air Development Center	761222	AU <i>ADC 010980</i>	C
XONICS TR109OSD	Morey, C. F.	EFFECT OF ARRAY TILT ON BEAM NOISE, SIGNAL-TO-NOISE RATIO, AND DETECTION OPPORTUNITY	Xonics, Inc.	770101	NS; ND <i>ADC 010980</i>	C
NRL-7996	Andriani, C. R., et al.	ACOUSTIC PROPAGATION IN THE LABRADOR SEA	Naval Research Laboratory	770308	ND	C
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