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TEST STEERED VERTICAL LINE ARRAY (TSVLA) MEASUREMENTS FOR BEARING STAKE SURVEYS (U)

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Warminster, Pennsylvania 18974

1 MARCH 1979

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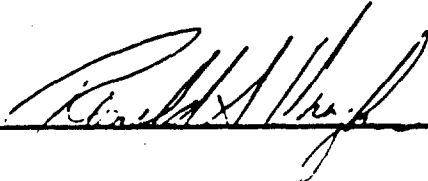
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(C) S U M M A R Y (U)

(C) INTRODUCTION (U)

(C) The project BEARING STAKE surveys were conducted to collect suitable acoustic data necessary to assess performance capabilities of various passive antisubmarine warfare surveillance systems in the Indian Ocean. The acoustic measurements, which were collected at near surface, midwater, and near bottom sensor depths included: propagation loss, omnidirectional ambient sea noise, horizontal and vertical noise directionality, signal vertical arrival angle structure, bottom loss, and various system performance measurements. These measurements were scheduled to be made at five test sites with the following systems: a towed array Ocean Measurements System (OAMS) (five sites), an Australian Long Acoustic Towed Array (LATA) (four sites), an Acoustic Data Capsule (ACODAC) (three sites), a Bottom Mounted Array (BMA) (five sites), a Horizontal Drift Array (HDA) (three sites), and a Vertical Drift Array (VDA) (three sites). This report confines itself to documenting the VDA (hereafter designated in this report as the Test Steered Vertical Line Array (TSVLA)) acoustic results acquired during the BEARING STAKE surveys.

(C) The TSVLA measurements program at NAVAIRDEVCEEN was sponsored by NAVAIR (PMA-264 and AIR-370) to serve as a means of validating the predicted performance of the proposed SVLAD Steered Vertical Line Array DIFAR "A" size passive sonobuoy (AN/SSQ-79) and associated processing algorithms, which are currently being designed/developed to provide an adequate capability in the first bottom bounce range interval to detect, localize, and track the projected low level, low frequency (<640 Hz) signature lines of third generation Soviet submarine threats. Therefore, the TSVLA buoy was designed to be essentially a prototype of the SVLAD sonobuoy with an identical array configuration and operational acoustic frequency band (10 to 640 Hz), but differed in that it contained absolute sensitivity calibration and was unconstrained by physical size limitations.

(U) This report includes a brief description of the TSVLA data collection and processing system, beamforming algorithms and a compilation of the acoustic information (vertical signal and ambient sea noise fields, array noise quieting, and array gain) measured during the BEARING STAKE survey.

(C) D I S C U S S I O N (U)

(C) BACKGROUND (U)

(C) The BEARING STAKE surveys were conducted at five sites in the Indian Ocean in order to collect the necessary acoustic data required to completely assess the performance capabilities of various passive antisubmarine warfare surveillance systems. While acoustic data were collected at near surface, midwater, near bottom sensor depths with a variety of measurement systems (OAMS, LATA, ACODAC, BMA, HDA, and VDA), this report confines itself to documenting the results obtained with the near surface (305 m) TSVLA (VDA) system at the three sites at which it was deployed. Table I lists the coordinates, date, sea state, and water depth of each site. Further details concerning the test locations, other measurement systems, and the overall test objectives and procedures are presented in the BEARING STAKE Technical Specification¹.

Table I (C) TSVLA Test Locations (U)

Bearing Stake Site	TSVLA Area	Date (1977)	Location	Depth (m)	Sea State
3	6	11 Feb	16°59'N 65°10'E	3567	0-1
1B	7	22 Feb	23°15'N 61°33'E	3347	0-1
4	8	21 Mar	4°53'N 52°51'E	5107	0

(C) The SVLAD "A" size passive sonobuoy has been developed to provide an adequate capability in the first bottom bounce range interval to detect, localize, and track the low frequency, low signature line levels of projected third generation Soviet submarine threats. Because the ambient sea noise below 300 to 400 Hz is known to have a high degree of vertical directionality^{2,3,4} with the bulk of the noise arriving at the near horizontal angles, any sensor which allows formation of beam patterns which reject or attenuate this horizontal noise while maintaining peak sensitivity at the bottom bounce signal arrival angles will have the potential to maximize the received signal-to-noise (S/N) ratios (especially when the bottom bounce arrival path is the dominant mode of signal arrival). The SVLAD sensor and recommended processing algorithm, which permits the formation of multiple steered beams, utilizes this concept to achieve the potential to obtain a high degree of array gain for a wide variety of environmental conditions. The TSVLA buoy has been designed to collect the acoustic data necessary to validate the predicted performance of the SVLAD "A" size sonobuoy and associated processing algorithms.

(C) The major physical components of the TSVLA buoy, which is essentially a prototype of the proposed SVLAD sonobuoy, are depicted in figure 1 and details of the array configuration are shown in figure 2. The array consists of 21 omnidirectional hydrophones spaced over a 122 m aperture, with two orthogonal, horizontally oriented velocity hydrophones (DIFAR sensor) located at the array midpoint, at a depth of 305 m. Acoustic signals from each hydrophone channel, which are bandpassed between 10 to 640 Hz, and an associated Automatic Gain Control (AGC) value are simultaneously sampled and held at a 1923 samples per second rate, analog to digital converted, time multiplexed, and transmitted from the test buoy to an aircraft and/or ship, where the digital data is recorded on a high density digital tape recorder. Time code, compass information giving DIFAR sensor orientation with respect to magnetic North, and a unique 14 bit Barker code word used in data synchronization during demultiplexing, are also time multiplexed into the serial data stream at a 961.5 samples per second rate. Details of the TSVLA system's mechanical and electronic design can be obtained from manufacturer's (Hazeltine Corporation) progress reports⁵.

(C) PROCESSING AND BEAMFORMING (U)

(C) The TSVLA acoustic data are processed through a series of computer programs which read five minute segments of data from tape, edit and time demultiplex the digital samples, frequency analyze the data using digital filter and Fast Fourier Transformation (FFT) algorithms, and finally, beamform and display the resulting spectra. Details of the processing logic and algorithms are described in previous report⁶. The pertinent analysis parameters resulting from the processing scheme utilized are summarized in table II. From this table it is seen that the data is divided into six octaves which have stepwise constant analysis bandwidths, varying from 1.878 Hz in octave six (320 to 640 Hz) and progressively decreasing to 0.0587 Hz in octave 1 (10 to 20 Hz). Each octave is divided into 171 frequency bins and each frequency bin is described by a real and imaginary coefficient. These data samples therefore contain the necessary amplitude and phase information required to perform frequency domain beamforming in subsequent processing programs.

Table II (C) TSVLA Analysis Parameters

Oct. No.	Freq. Band (Hz)	Analysis Bandwidth (Hz)	No. of Samples	Sample Time (Sec.)
1	10-20	.0587	18	17.04
2	20-40	.1174	36	8.52
3	40-80	.2348	72	4.26
4	80-160	.4695	144	2.13
5	160-320	.9390	288	1.06
6	320-640	1.878	576	.532

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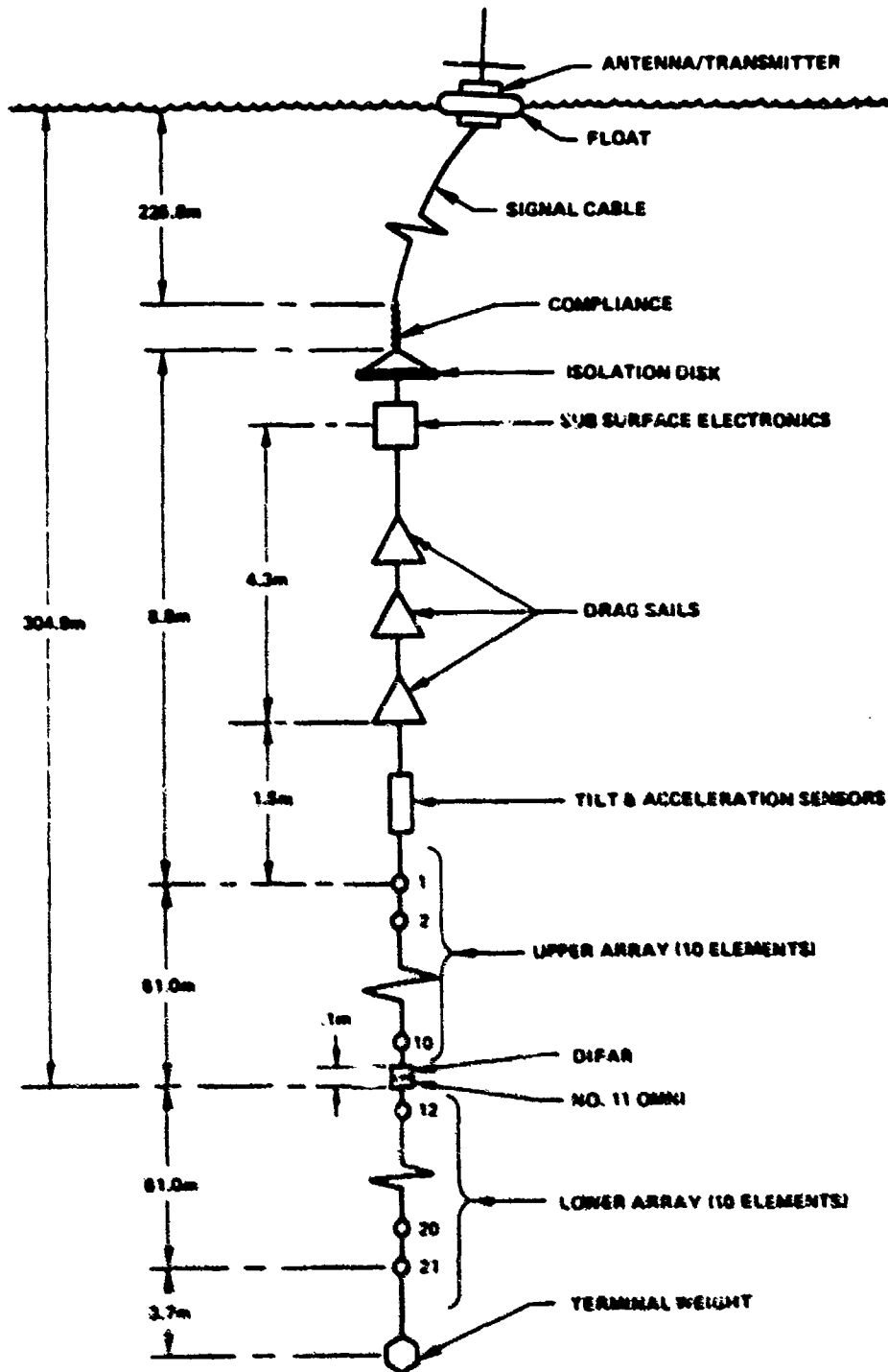


Figure 1 (U) TSVLA System Components

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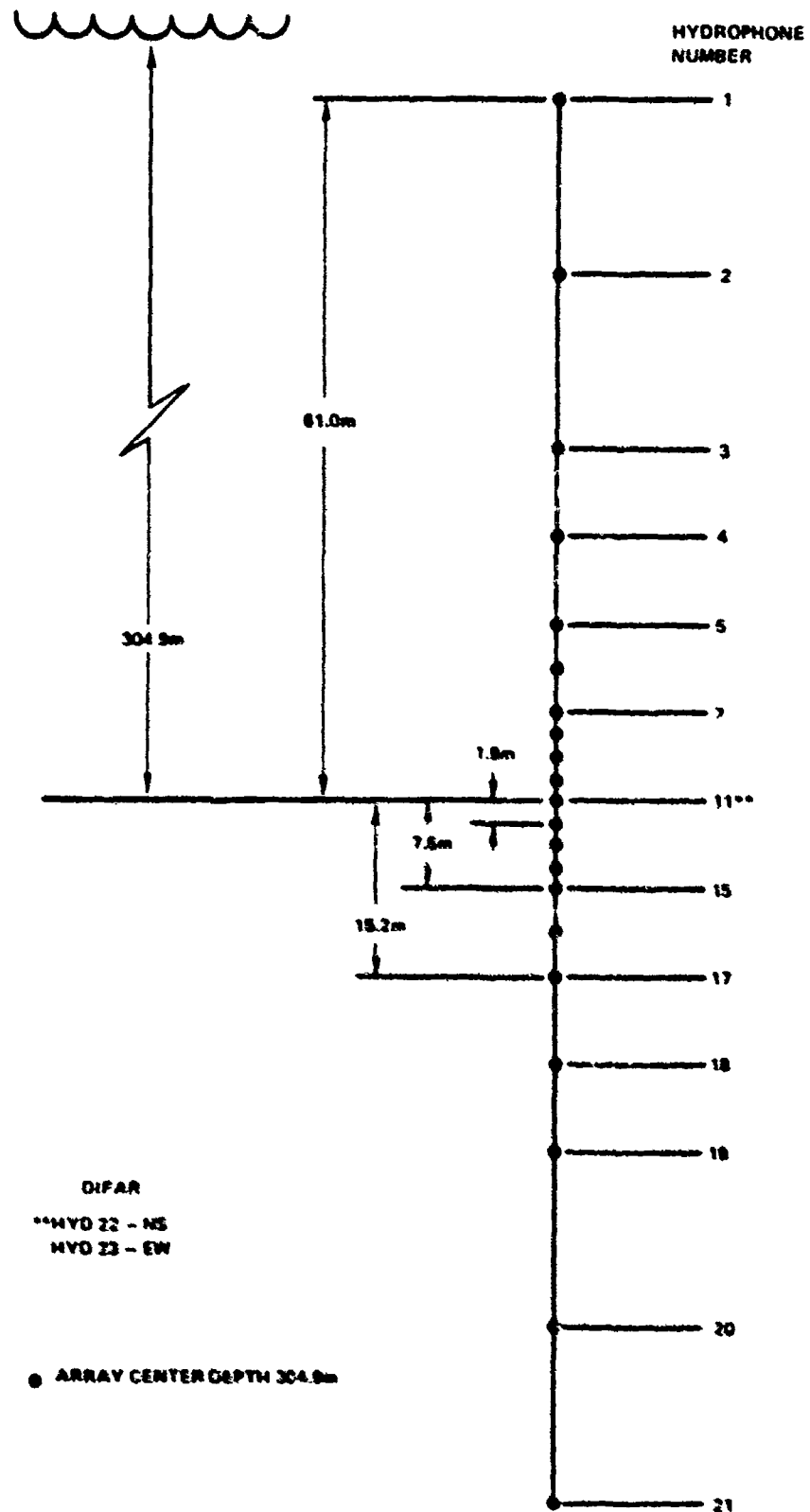


Figure 2 (C) TSVTA Configuration (")

(U) The frequency analyzed data are processed through three beamforming algorithms, namely: conventional time delay beamforming, SVLAD "A" size beamforming, and a simplified sensor beamforming routine.

(C) The conventional beamforming algorithm was implemented to provide collateral acoustic data required to interpret any anomalies in the SVLAD "A" size beamforming results. This routine uses nine element equally spaced subarrays to generate 15 time delay steered beams with 1 dB main lobe crossover points and 25 Dolph-Chebyshev side lobe suppression. From figure 2 it is readily apparent that four equally spaced nine element subarrays can be formed having spacings of 1.9, 3.8, 7.6 and 15.2 m. The 15 steering angles and their corresponding 3 dB down beamwidths (at $0.5S/\lambda$) are listed in table III, while the relationships between the four, nine element subarray's frequency coverage and corresponding S/λ ratios (spacing to wavelength ratios) over the frequency range of each subarray are shown in table IV. Within each frequency band, the beams formed are well behaved and have no grating lobes (except in the 400 to 640 Hz region of band 4). Examples of the beam pattern response at each steering angle at the band edge frequencies (0.25 and 0.5 S/λ) are shown in figures 3 through 10. In addition to the spectra plots of each steered beam, an averaged omnidirectional hydrophone spectrum (all 21 hydrophones), and directionality curves at eight frequencies (beam power output spectrum level versus steering angle) are also computed and displayed by this computer program. Typical examples of the beamformed output reduced to report size are shown in figures 11 and 12. The 25 dB side lobe suppression used during processing was selected because it was consistent with the SVLAD "A" size sonobuoy processing algorithm described in the following paragraph. Since noise fields with directionalities of near 25 dB were observed (Area 7), selected segments of data were also processed with 35 dB side lobe suppression to obtain a true measure of the noise (not side lobe limited). However, this increased side lobe suppression results in correspondingly wider main lobe beamwidths and hence less angular resolution, as indicated by the increase in 3 dB down beamwidths listed in table III.

Table III (C) Conventional Beamforming Parameters (U)

Steering Angle (Deg.)	(25 dB Sidelobes) 3 dB Beamwidths (Deg.)	(35 dB Sidelobes) 3 dB Beamwidths (Deg.)
0.0	13.6	15.4
+8.0	13.7	15.5
±16.3	14.1	16.1
±25.0	15.0	17.0
±34.1	16.5	18.7
±44.0	19.2	21.8
±57.0	27.0	31.6
±78.0	30.6	32.4

Table IV (C) Conventional Beamforming Frequency Bands (U)

Band	Freq. Range (Hz)	Spacing (m)	S/ λ Range
1	10-50	15.2	.1 — .5
2	50-100	7.6	.25 — .5
3	100-200	3.8	.25 — .5
4	200-640	1.9	.25 — .8

(C) The SVLAD "A" size sonobuoy beamforming routine conforms to the beamforming algorithm recommended by the Hazeltine Corporation⁷ based on theoretical studies, which specifies five steered beams (+12°, -28.3°, -36.6°, -45°, and -60° (where negative indicates angles referenced from the horizontal toward the ocean bottom) with 25 dB side lobe suppression for all frequencies between 20 to 640 Hz. For the 10 to 20 Hz octave a three and five element subarray configuration is used to generate a fixed (unsteered) vertically oriented horizontal nulled dipole like beam pattern. From table V, which lists a summary of the pertinent SVLAD "A" size sonobuoy beamforming parameters, it is seen that the acoustic data is divided into six octaves, each of which is further subdivided into two sections. The hydrophone spacing can be a function of steering angle as well as frequency; therefore, two sets of spacing to wavelength ratios are listed, (S/ λ)₁ for the +12° and -28.3° steering, and (S/ λ)₂ for the -36.6°, -45°, and -60° steering angles. For example, in octave 4, section 1, all steering angles use the same spacing (7.6 m), whereas in section 2, only the 12° and -28.3° steering angles utilize the 7.6 m spacing. The -36.6°, -45°, and -60° beams use a 3.6 m spacing. The effect of this switching of array configuration is to control the formation and direction of maximum response of the grating lobe. Examination of the beam response patterns show that while grating lobes are formed at frequencies which have S/ λ ratios greater than 0.5, their direction of maximum response is never at or near the horizontal ($\pm 30^\circ$): in this frequency region the beam patterns will continue to reject horizontal ambient sea noise, in addition to permitting possible signal detection on the grating lobe. A typical example of this condition is illustrated in figure 13 for the -28.3° steered beam at S/ λ ratios of 0.32 (lower band edge), 0.5, and 0.8 (upper band edge). During SVLAD "A" size data processing, the measured spectra of 16 time delay steered beams, four constant phase shift beams, (which were an alternate SVLAD beam forming algorithm) an averaged omnidirectional hydrophone, and the two directional hydrophones (North-South, East-West), in addition to the conventional DIFAR bearings, were calculated and displayed. Each of the 16 time delay beams had 25 dB side lobe suppression and each conformed to the special spacing/frequency/steering angle relationships specified in table V. The steering angles used were 0, ± 7 , ± 14 , ± 21 , ± 28.3 , ± 36.6 , ± 45 , ± 60 , and -70 degrees. The additional beams were included to allow the flexibility to examine alternate beam subsets and thus insure that the proposed five beam configuration is optimum. Examples of the typical output format are shown in figures 14 and 15.

Table V (C) SVLAD Beamforming Parameters (U)

Octave	1		2		3		4		5		6	
	1	2	1	2	1	2	1	2	1	2	1	2
Section	10 - 16 - 20	20 - 32 - 40	40 - 64 - 80	80 - 128 - 160	160 - 256 - 320	320 - 512 - 640						
Freq (Hz)	3	5	9	9	9	9	9	9	9	9	9	9
No. Elements	61.0	30.5	15.2	15.2	15.2	15.2	7.6	7.6	3.6	3.6	1.9	1.9
Spacing ₁ (M)	.4-.64	.23-.4	.2-.32	.32-.4	.4-.64	.64-.8	.4-.84	.64-.8	.4-.64	.64-.8	.4-.64	.64-.8
(S/λ) ₁	61.0	30.5	15.2	15.2	15.2	7.6	7.6	3.6	3.6	1.9	1.9	1.9
Spacing ₂ (M)	.4-.64	.32-.4	.2-.32	.32-.4	.4-.64	.32-.4	.4-.64	.32-.4	.4-.64	.32-.4	.4-.64	.64-.8
(S/λ) ₂	+120°, -28.30°, -36.60°, -450°, -600°											
Steering	Unsteered											

Spacing₁ = Spacing used for steering angles ≤ |±28.30°|
 (S/λ)₁ = Spacing to wavelength ratio for steering angles ≤ |±28.30°|
 Spacing₂ = Spacing used for steering angles > |±28.30°|
 (S/λ)₂ = Spacing to wavelength ratio for steering > |±28.30°|

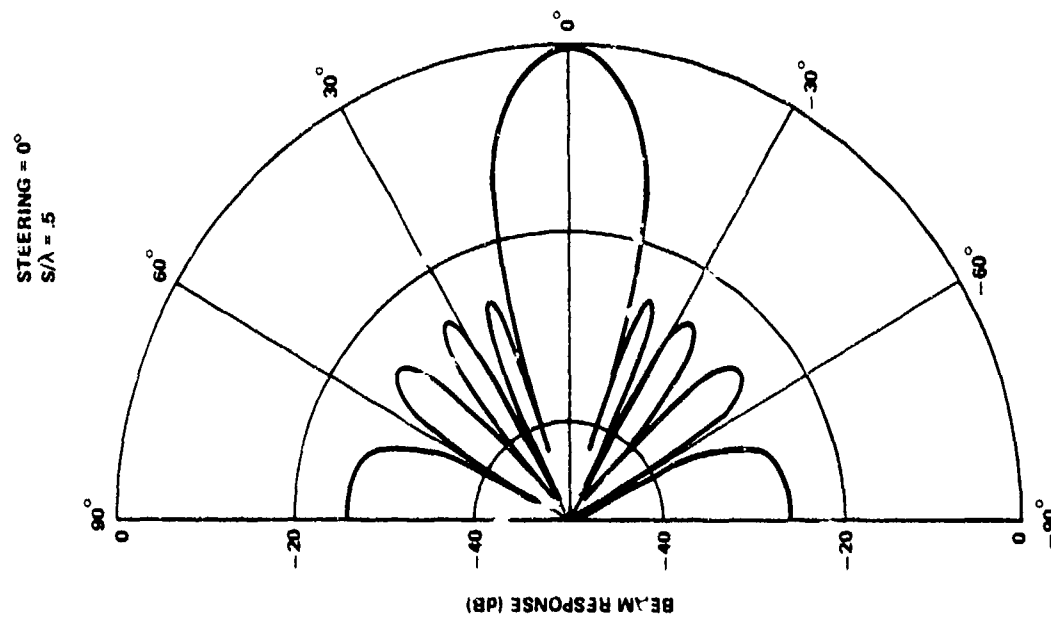
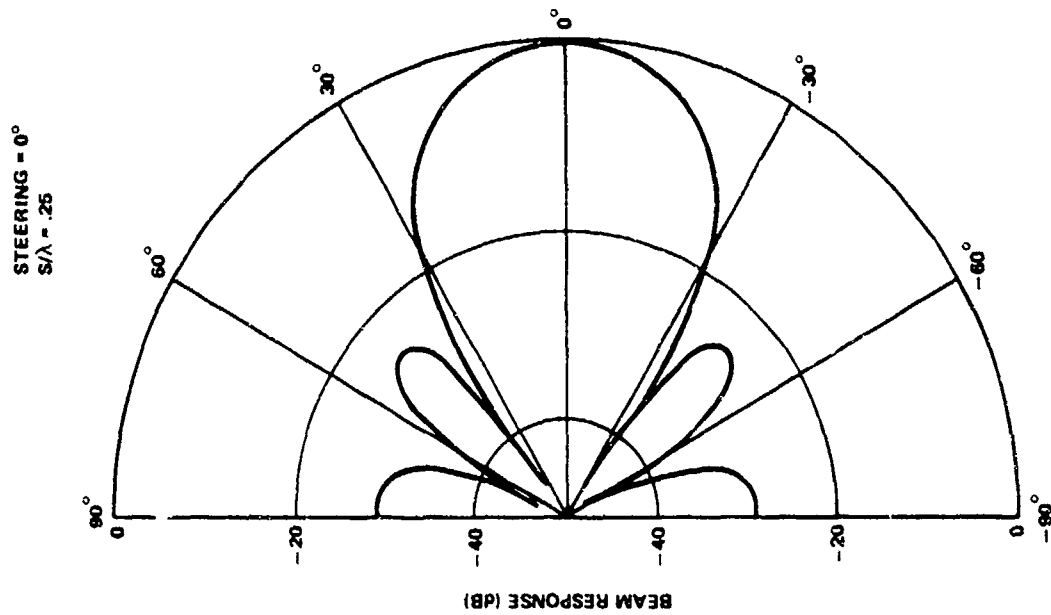


Figure 3 (C) TSVLA Beam Response Patterns (U)

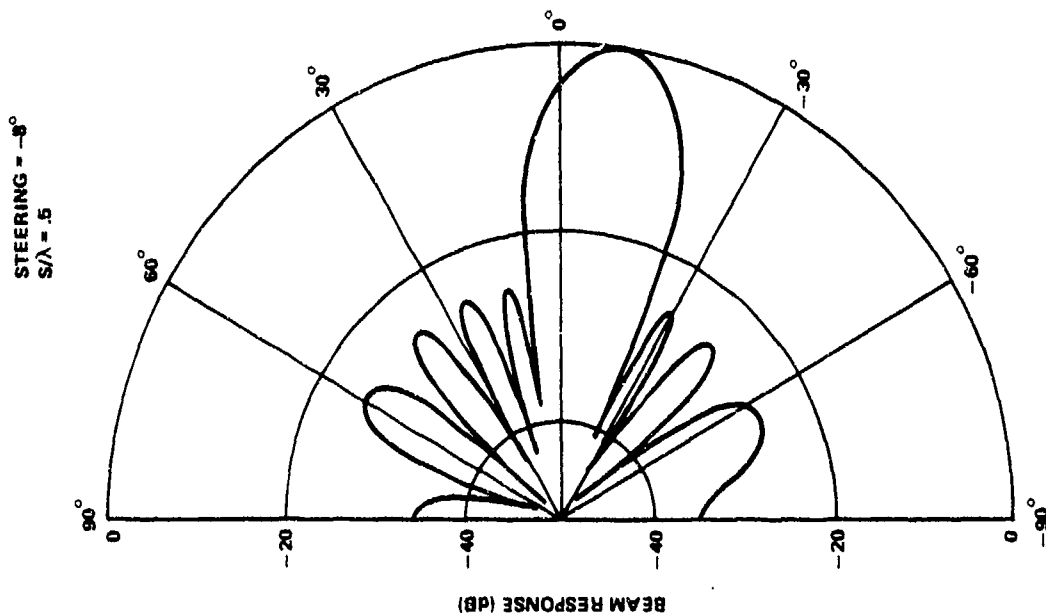
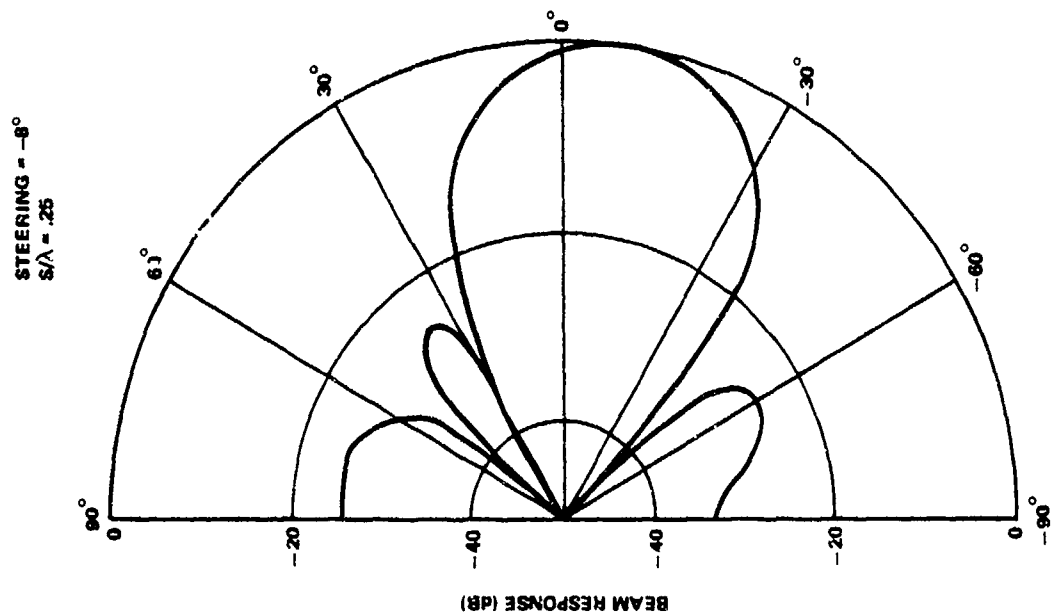


Figure 4 (C) TSVLA Beam Response Patterns (U)

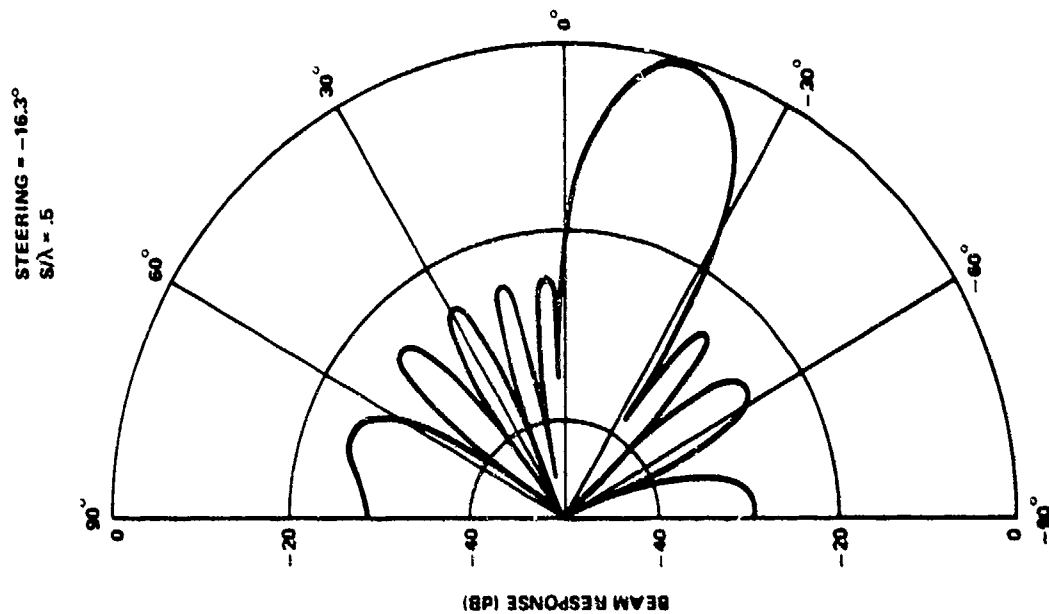
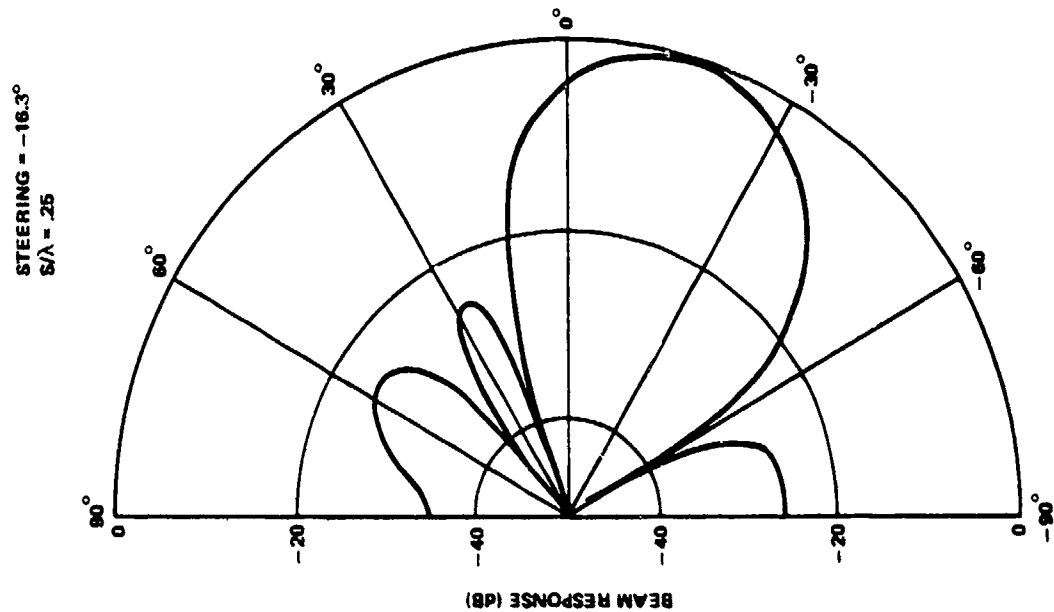


Figure 5 (C) TSVLA Beam Response Patterns (U)

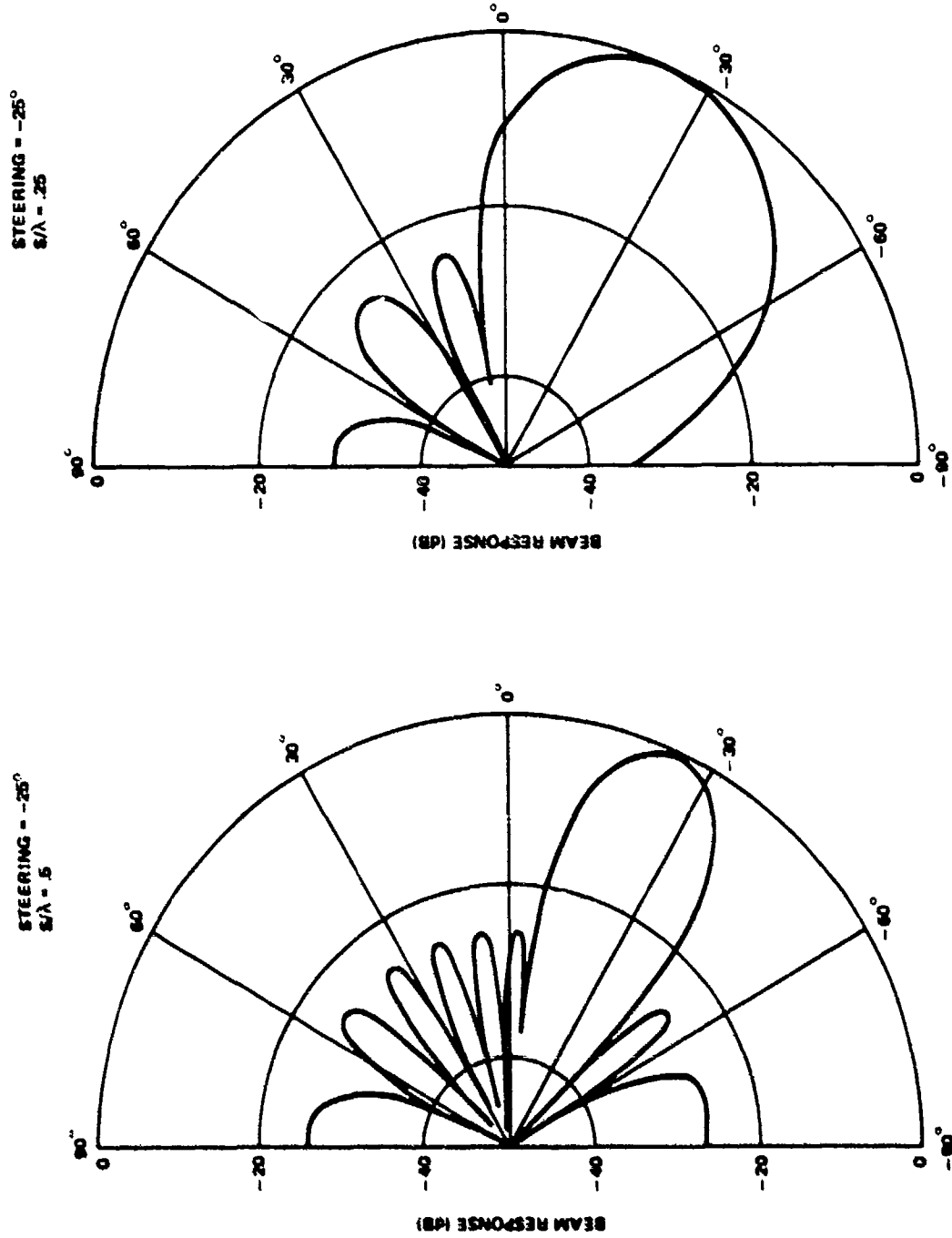


Figure 6 (C) TSVLA Beam Response Patterns (U)

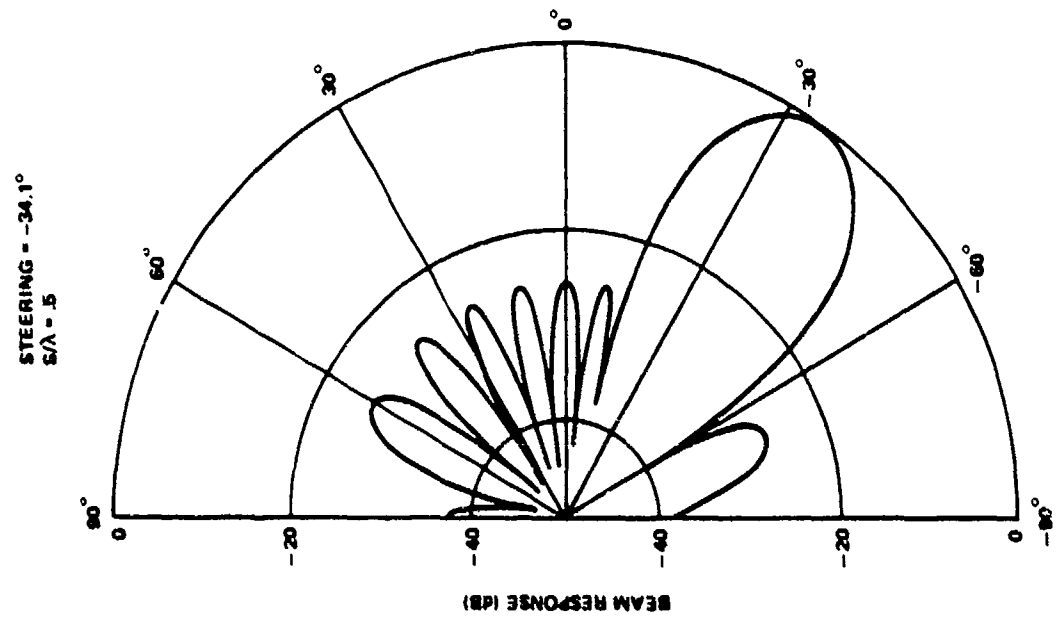
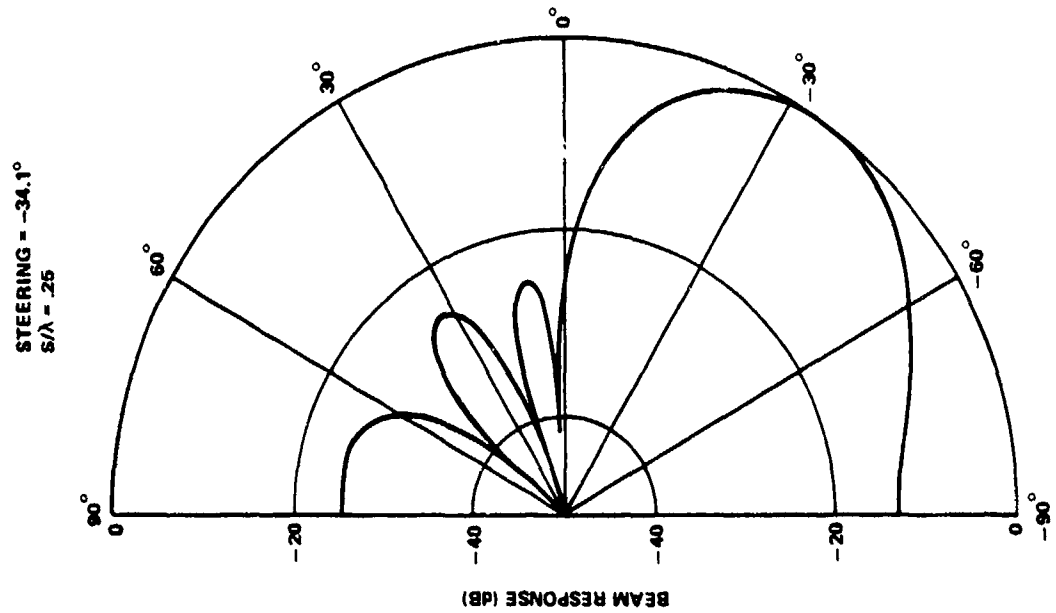


Figure 7 (C) TSVLA Beam Response Patterns (U)

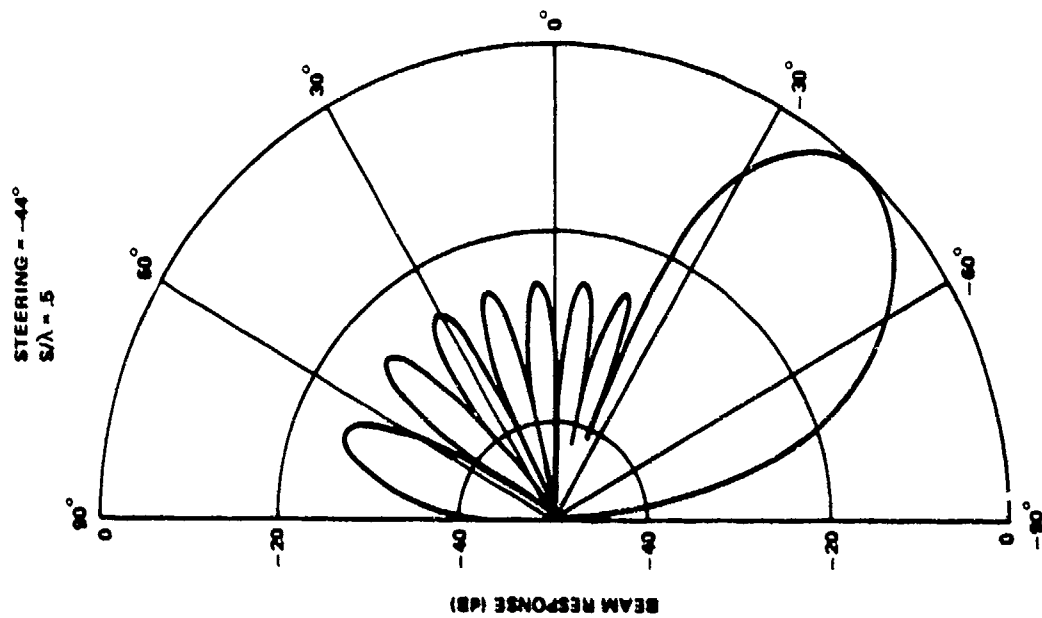
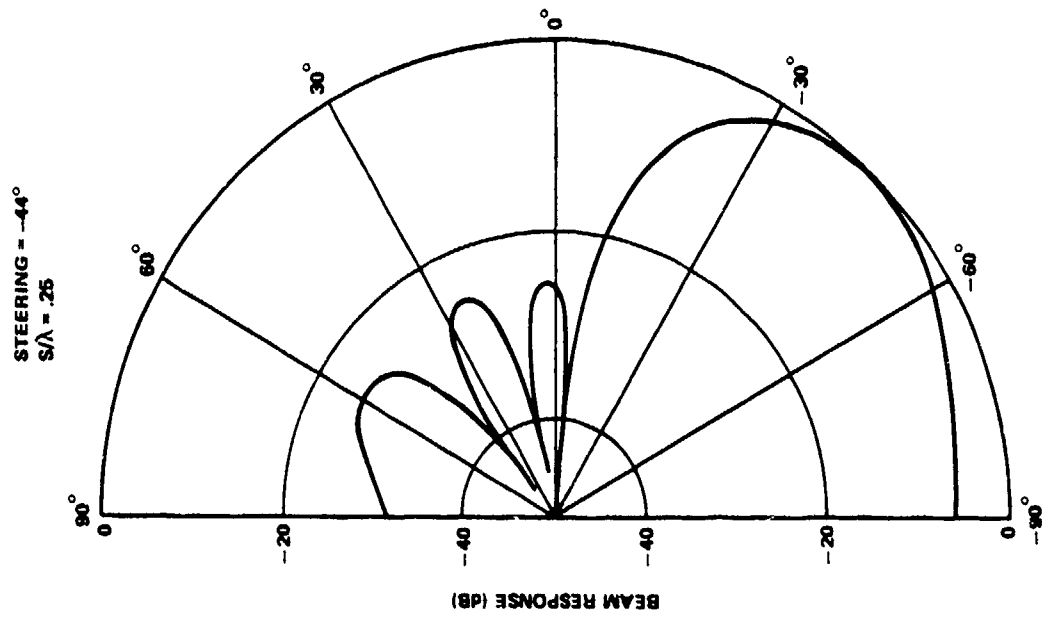


Figure 8 (C) TSVLA Beam Response Patterns (U)

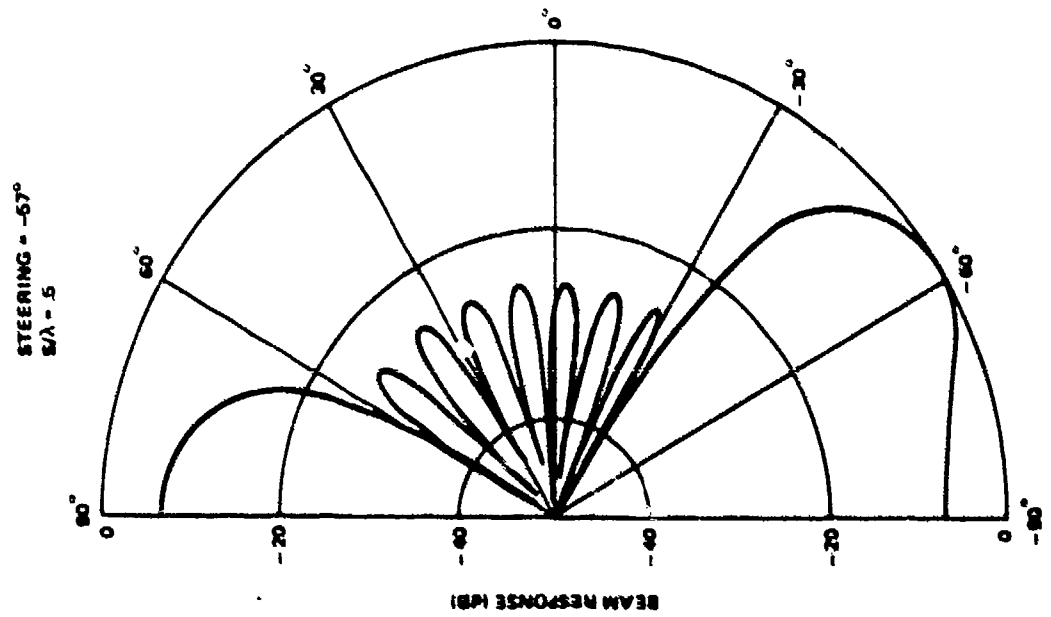
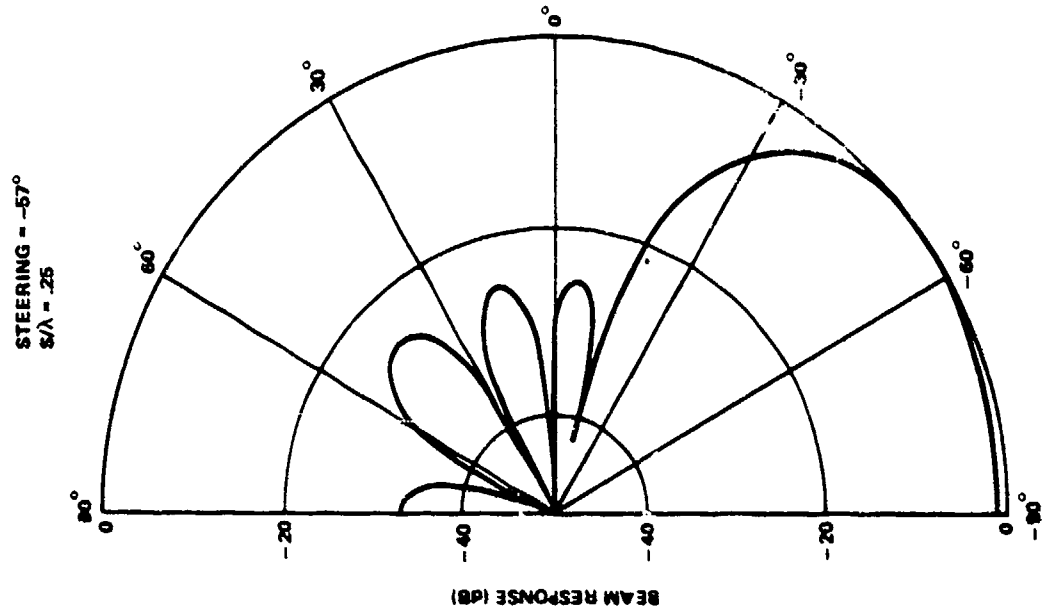


Figure 9 (C) TSVLA Beam Response Patterns (U)

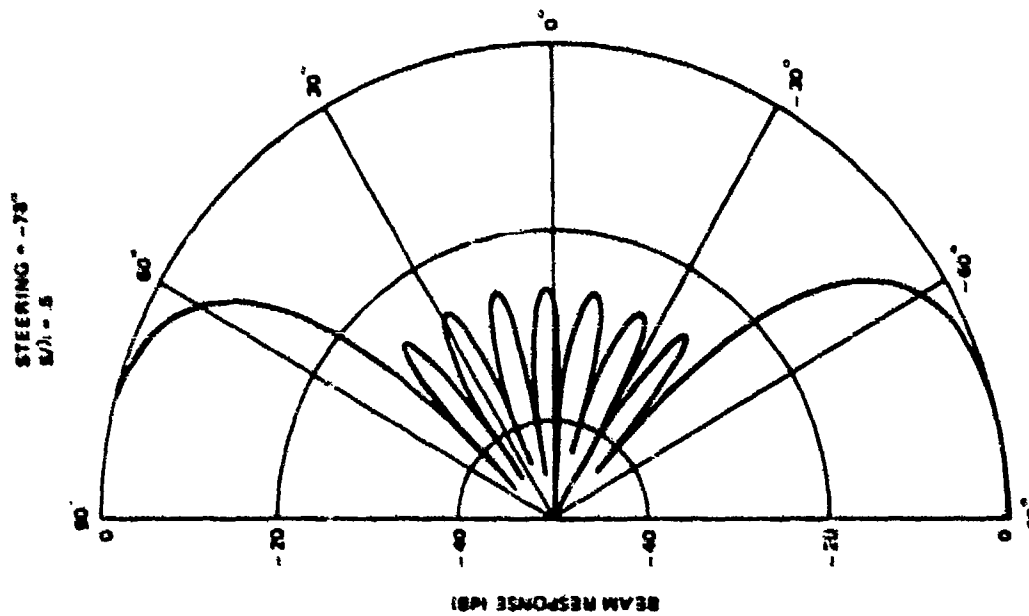
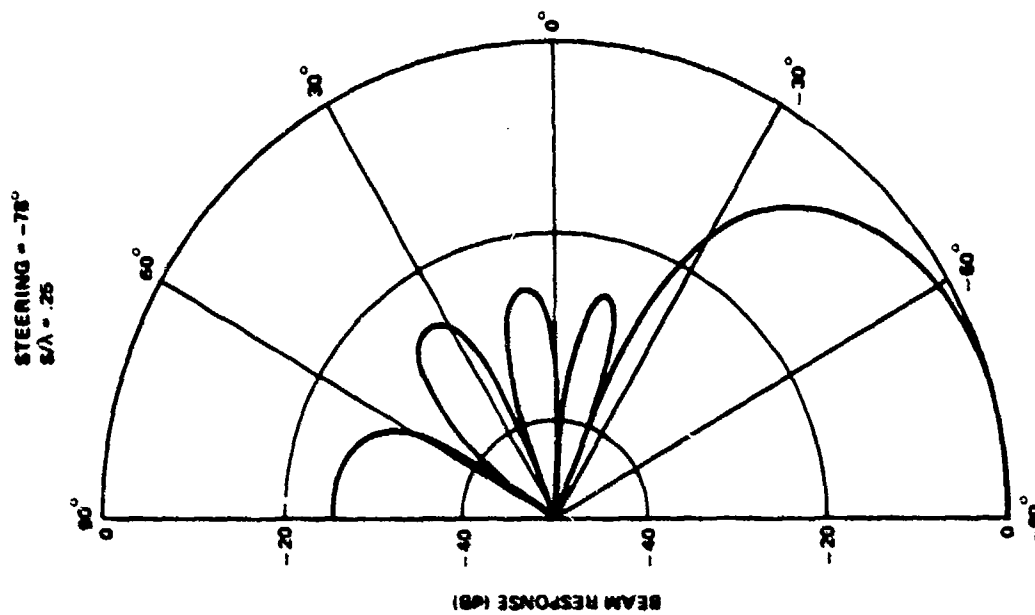


Figure 10 (C) TSVLA Beam Response Patterns (U)

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TRACK - 4 SEG - 228 IVSN - 7303 DATE - 02/11/76

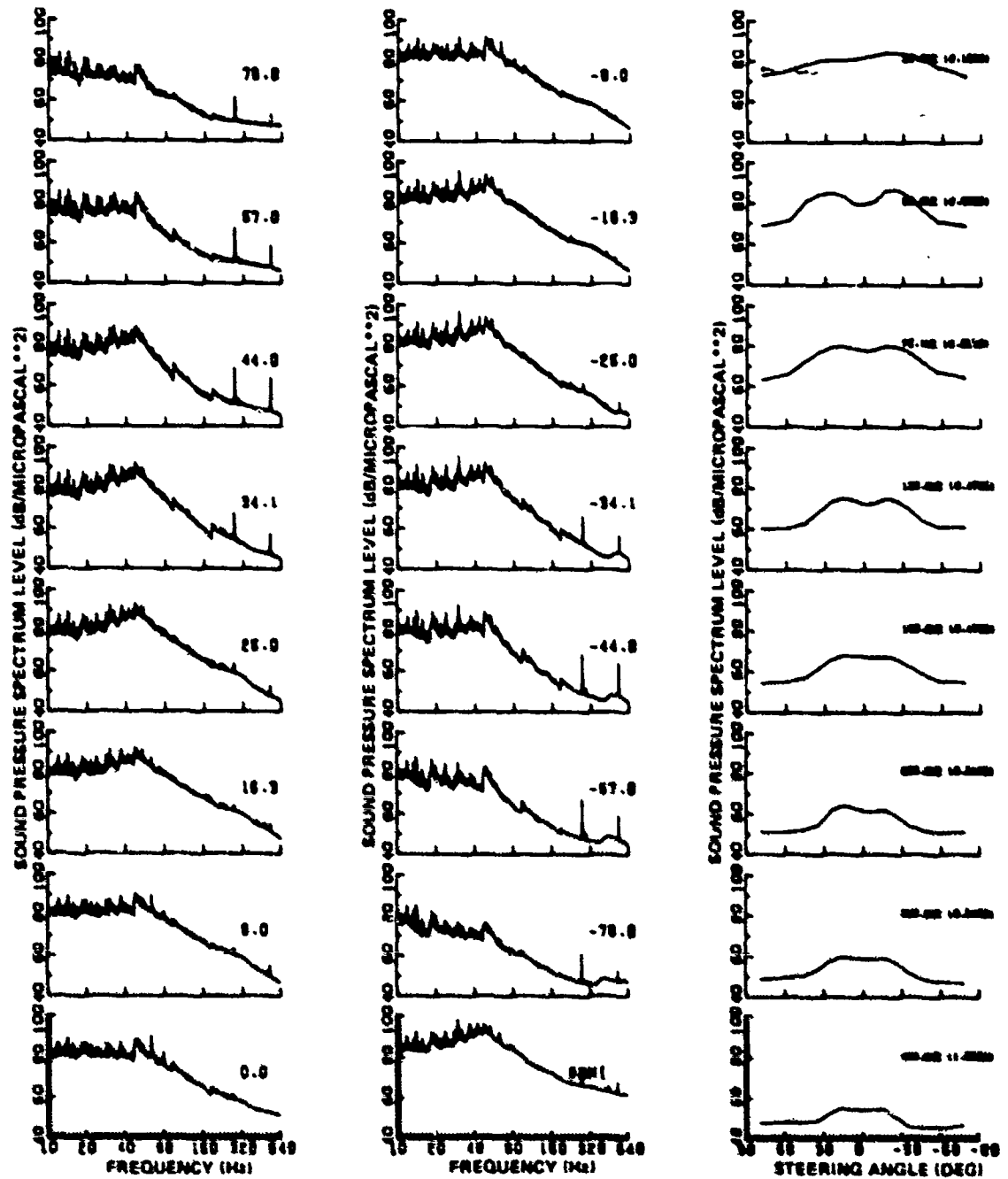


Figure 11 (C) Typical Conventional Beamforming Output (U)

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SVLA BEAM POWER PLOTS

TIME = 17.18

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TRACK = 2 SEG = 231 IVSN = 7308 DATE = 02/11/77

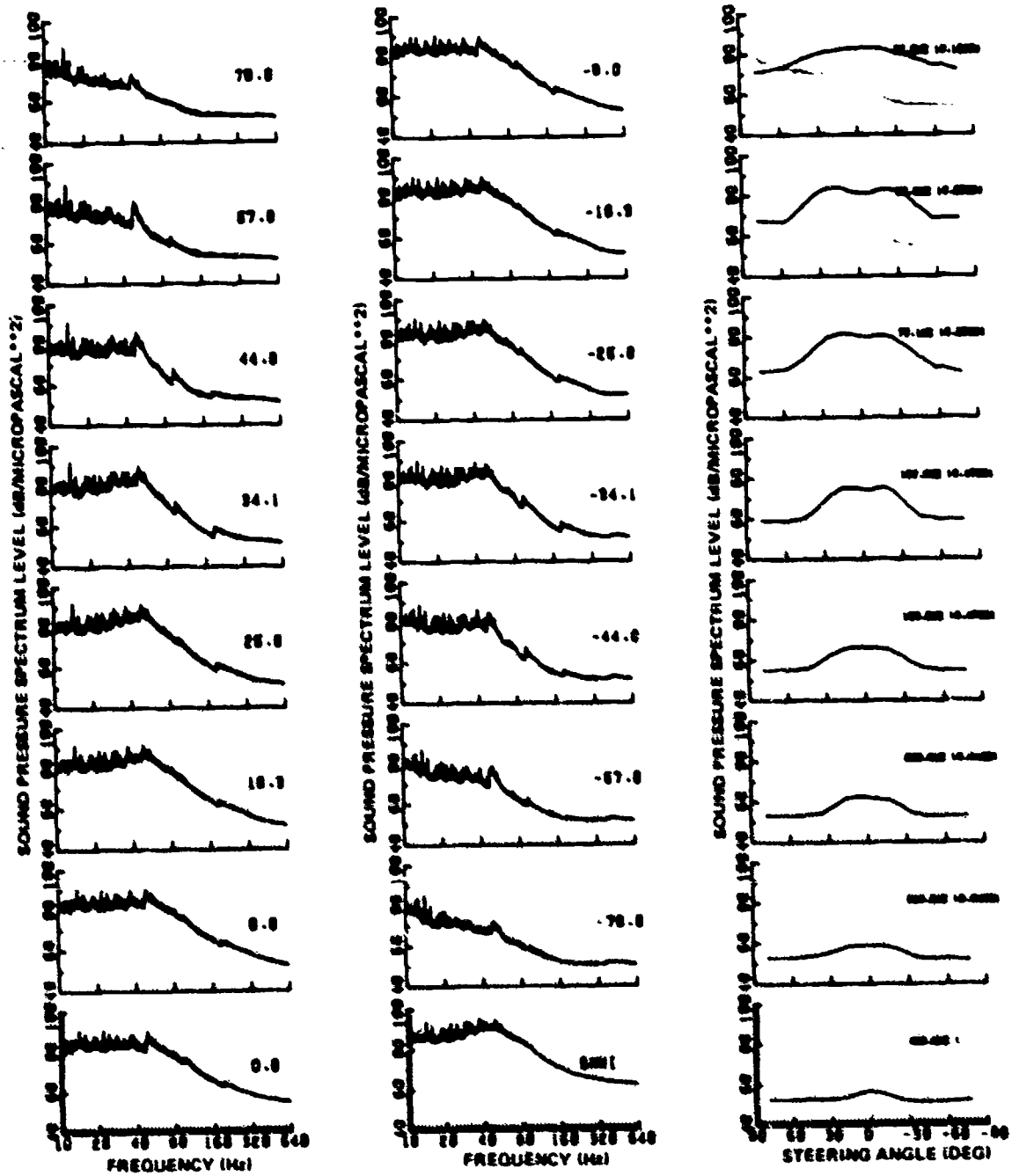


Figure 12 (C) Typical Conventional Beamforming Output (U)

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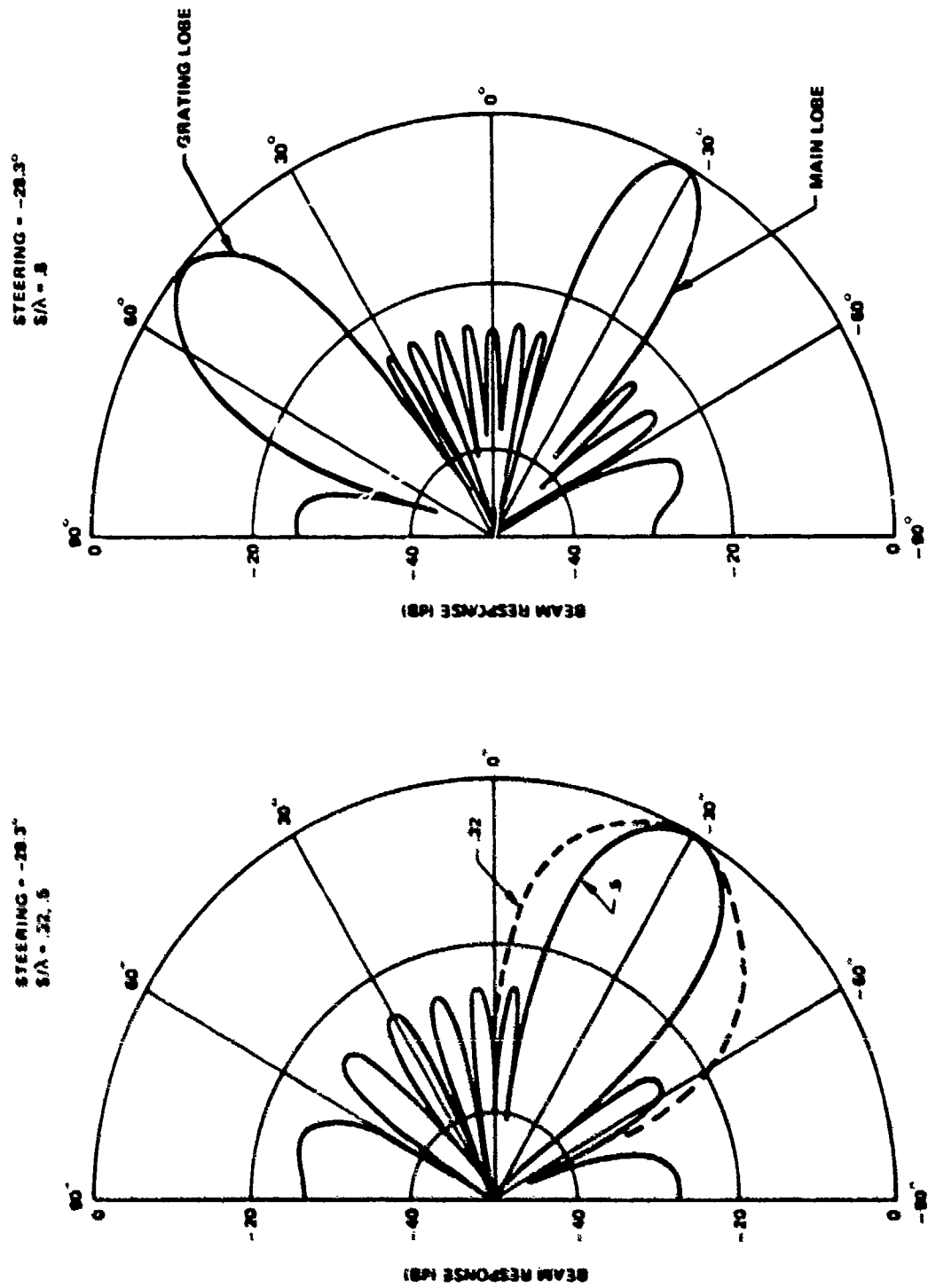
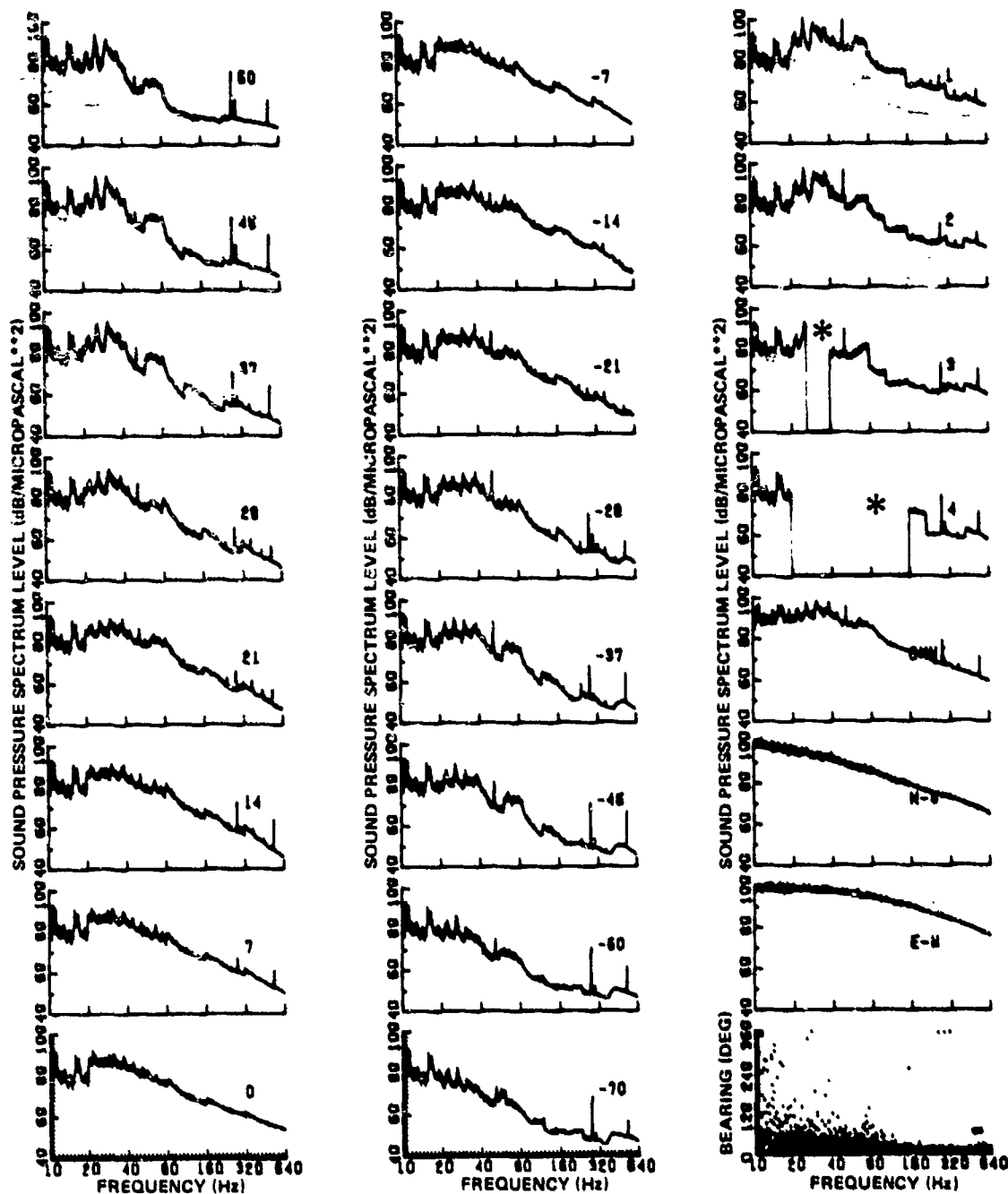


Figure 13 (C) SVLA Beam Patterns (U)

SVLA BEAM POWER PLOTS

TIME = 11.10

AREA = 6 TEST = 1 TAPE = 3
TRACK = 7 SEG = 223 IVSN = 7286 DATE = 02/11/76



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Figure 14 (C) Typical SVLAD Beamforming Output (U)

SVLA BEAM POWER PLOTS

AREA = 6 TEST = 1 TAPE = 5

TRACK = 6 SEG = 225 IVSN = 7300 DATE = 02/11/76

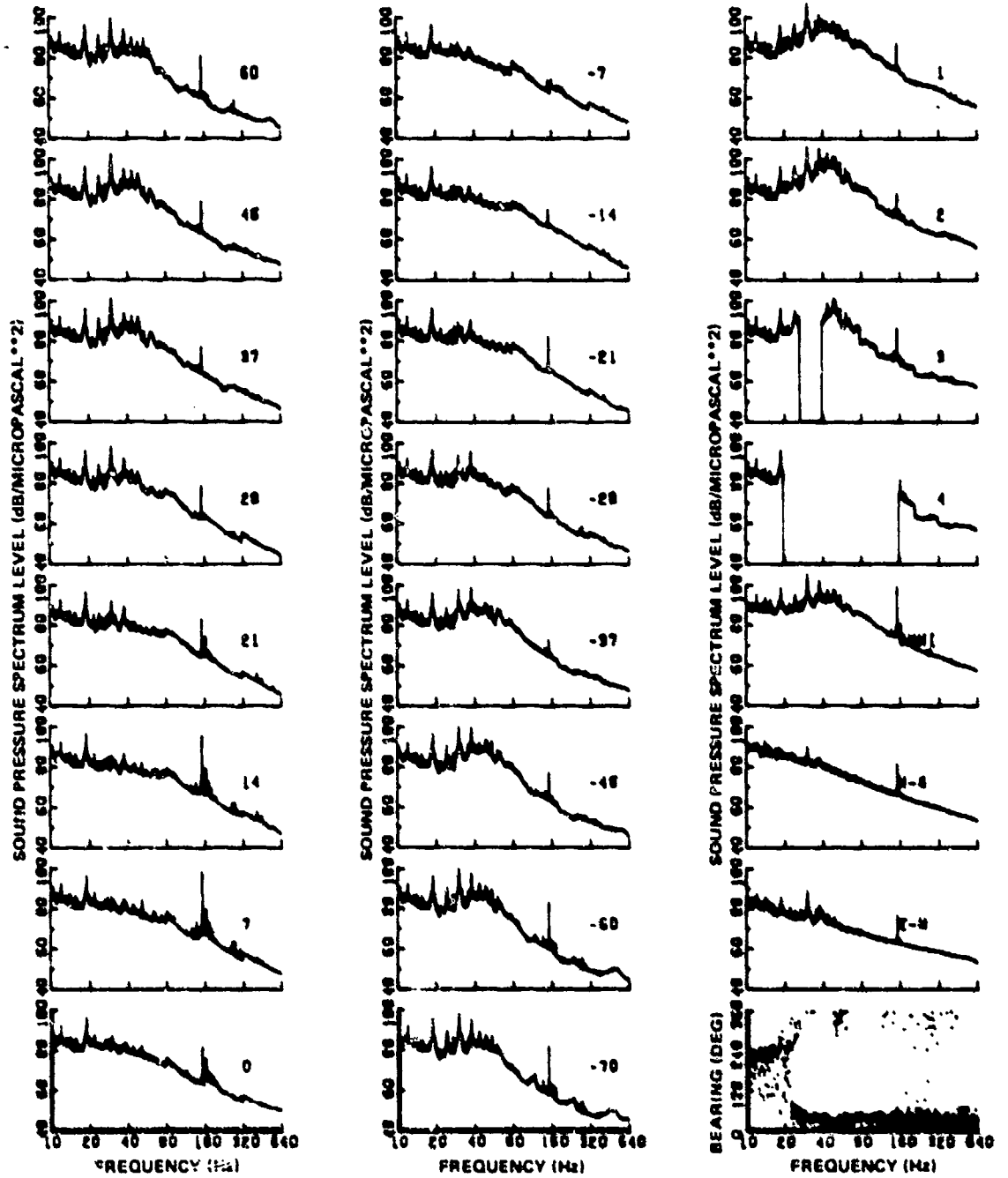


Figure 15 (C) Typical SVLAD Beamforming Output (U)

(C) The special beamforming routine processed the data to examine a number of simplified sensor configurations, namely: differenced omni (two elements), summed omni (two elements), second order differenced omni (three elements), downward pointed cardioid (five elements), in addition to the desired VLAD (AN/SSQ-77) passive sonobuoy sensor. The VLAD sensor, which is currently undergoing technical evaluation, is designed to operate against second generation targets utilizing existing aircraft avionics. These array configurations were processed to insure that a simplified sensor or processing algorithm would not provide performance equal to or nearly equal to the CVLAD sonobuoy. Other than for the VLAD sensor, these alternate configurations will not be considered in this report. Figure 16 shows a typical example of the output format.

(C) RESULTS - AREA 6 (U)

(C) In Area 6 (BEARING STAKE Site 3 - Arabian Basin), approximately 12 hours of usable continuous acoustic data were collected on one TSVLA system between 0630Z and 1830Z on 11 February 1977. Shortly after 0730Z, the digital data stream progressively deteriorated, with increasing numbers of synchronization and/or parity errors. The system was deployed from the USNS WILKES at 16°59' N, 65°10' E at 0350Z, and drifted at a 0.27 kn rate on a 230° bearing throughout the exercise (assuming linear drift between launch and retrieval). At 0800Z, the USNS WILKES commenced projector operations, providing alternate sets of four multitone CW projector signals during three hour periods at successive 1 nmi range intervals. The projector was operated at a 122 m depth using frequency sets of either 55, 67, 155.4, and 165.3 Hz or 290.2, 350, 544.6, and 559.6 Hz. Because of the operational constraints imposed by the projector towing schedule, drift of source and receiver, and buoy signal deterioration after 12 hours, the available TSVLA signal data were limited to ranges between 3 and 5.9 nmi, and hence did not fulfill the prime objective of the TSVLA program (detection performance throughout the first bottom bounce ranges). However, useful ambient noise directionality and vertical signal arrival angle measurements (in addition to performance measurements in the restricted 3 to 5.9 nmi range interval), suitable for partial model and system validation were acquired. While the hydrophone channels are calibrated and matched in sensitivity to within 1 dB during buoy fabrication, post processing perusal of the analyzed data disclosed that there existed considerable mismatch in calibration with as much as 10 dB level offsets in the measured spectra of individual hydrophone channels. Using a procedure previously described⁶, the ambient sea noise was used to generate the necessary amplitude correction factors required to match the channel sensitivities closely. Examination of the beampower output for strong spectral lines (20 to 30 dB S/N on the omni) confirmed that this procedure successfully compensated for the electronic mismatches and permitted close to 25 dB (or 35 dB) side lobe suppression during beamforming. Figure 17 shows the representative sound speed profiles, which were derived from shallow measurements (< 2000 m) mated with deep historic data.

(C) Summaries of the measured ambient sea noise vertical directionalities, in the form of conventional beampower output versus steering angle as a function of time, are shown in figures 18 through 21 for the peak angular resolution frequencies of 50, 100, 200, and 400 Hz. From a cursory examination of

SVD SENSOR ARRAY PLOTS

AREA = 6 TEST = 1 TAPE = 2
TRACK = 4 SEG = 220 IVSN = 7296 DATE = 02/11/76

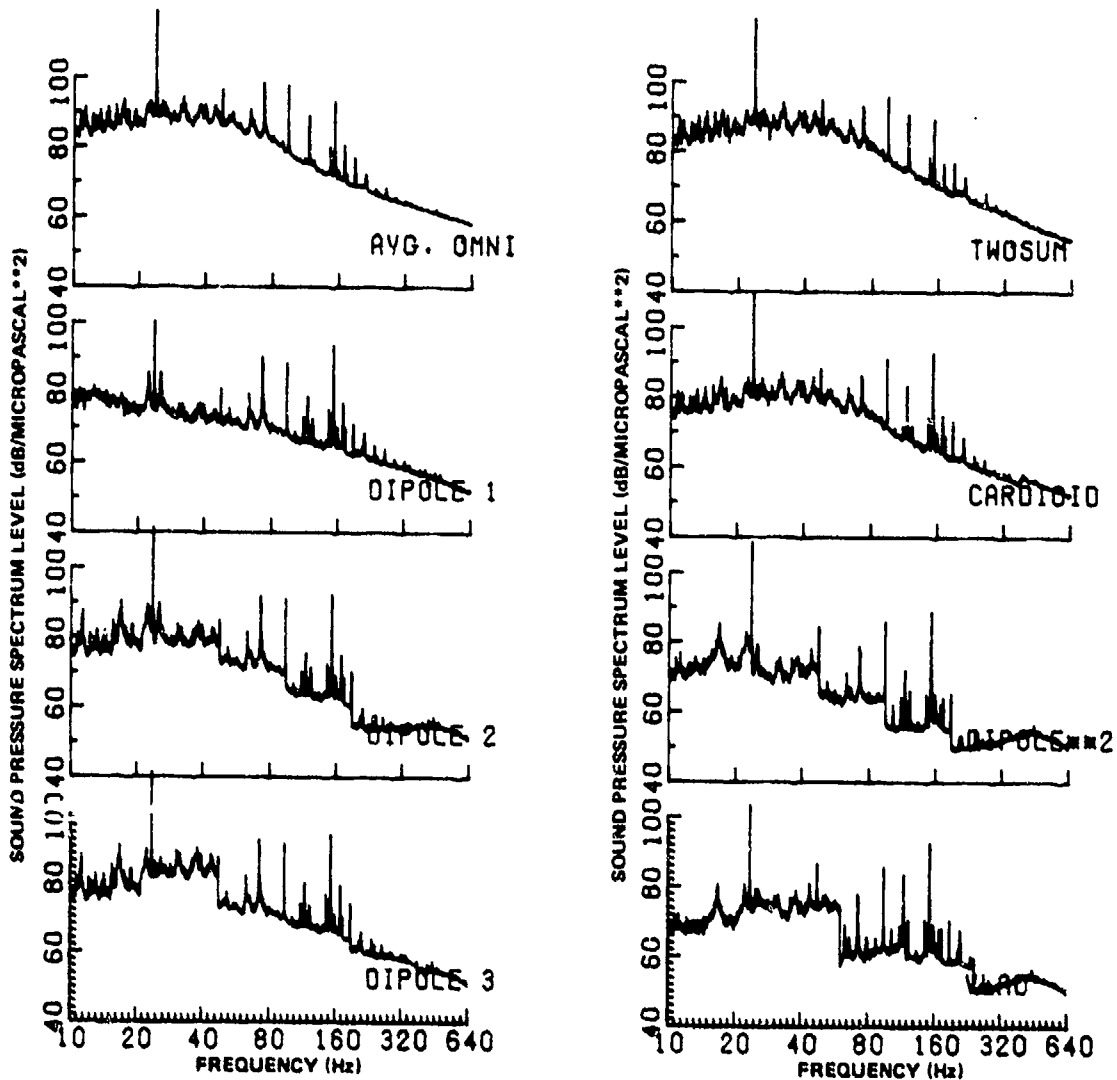


Figure 16 (C) Special Sensor Beamforming Outputs (U)

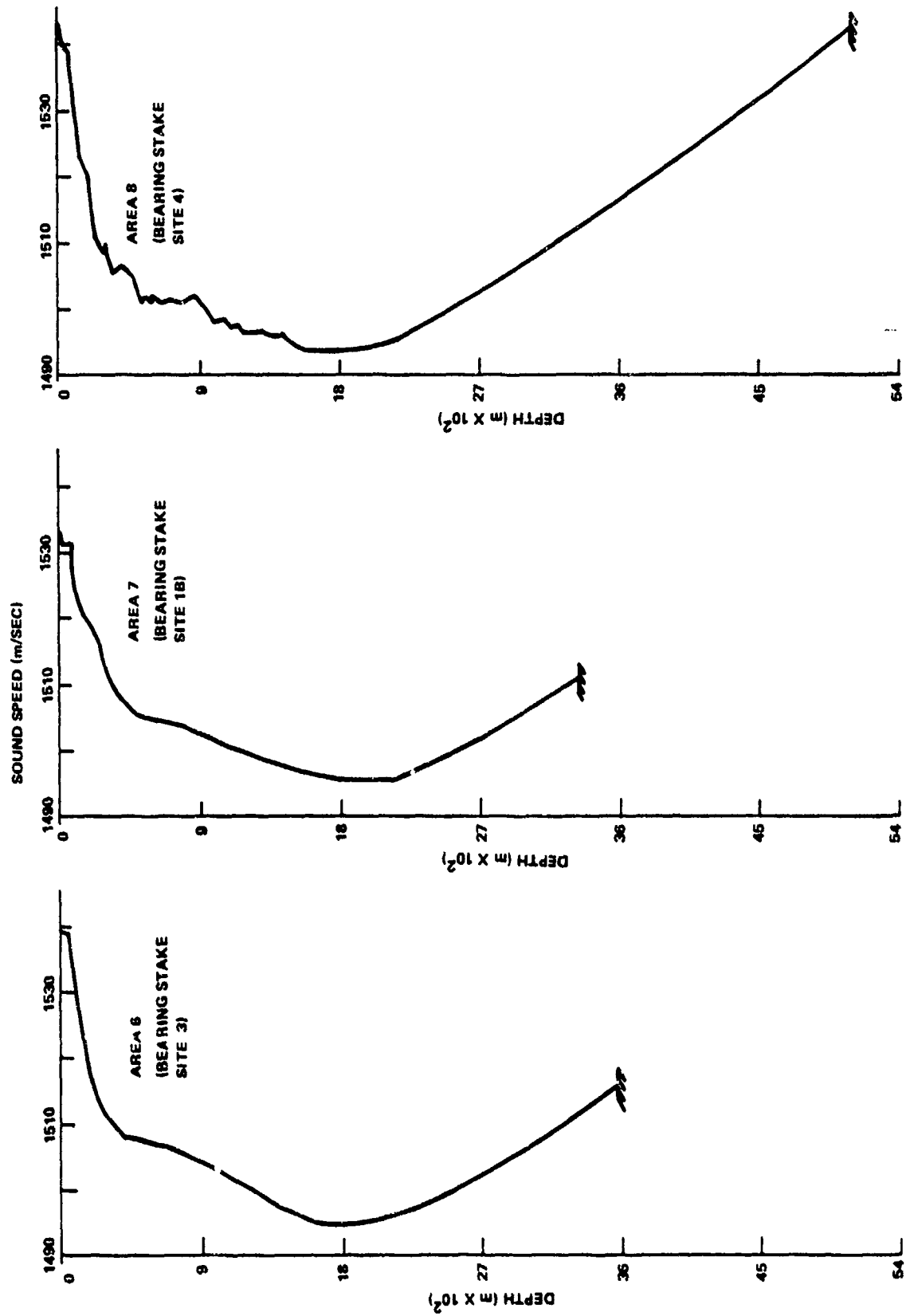


Figure 17 (C) Representative Sound Speed Profiles (U)

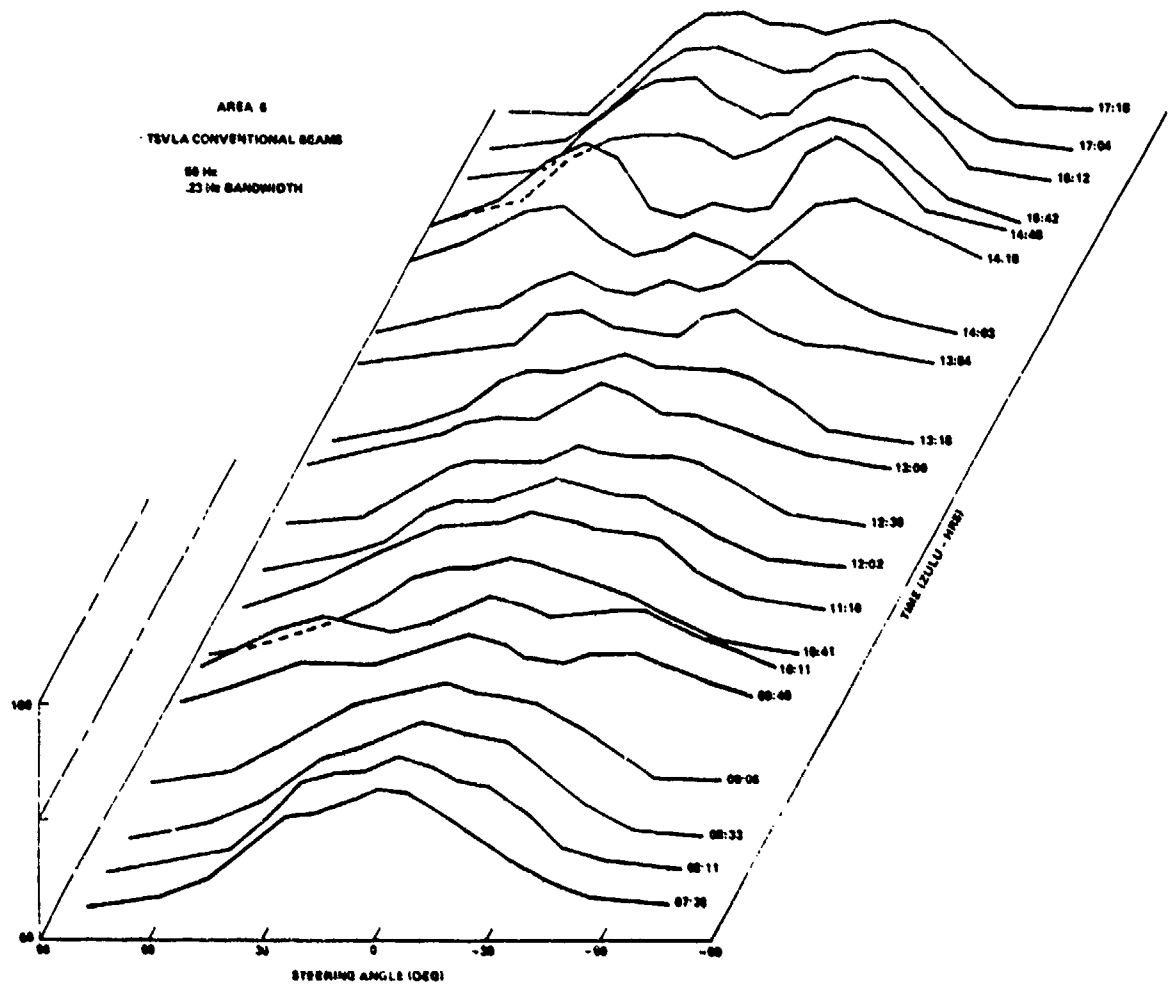


Figure 18 (C) Measured Noise Directionality (U)

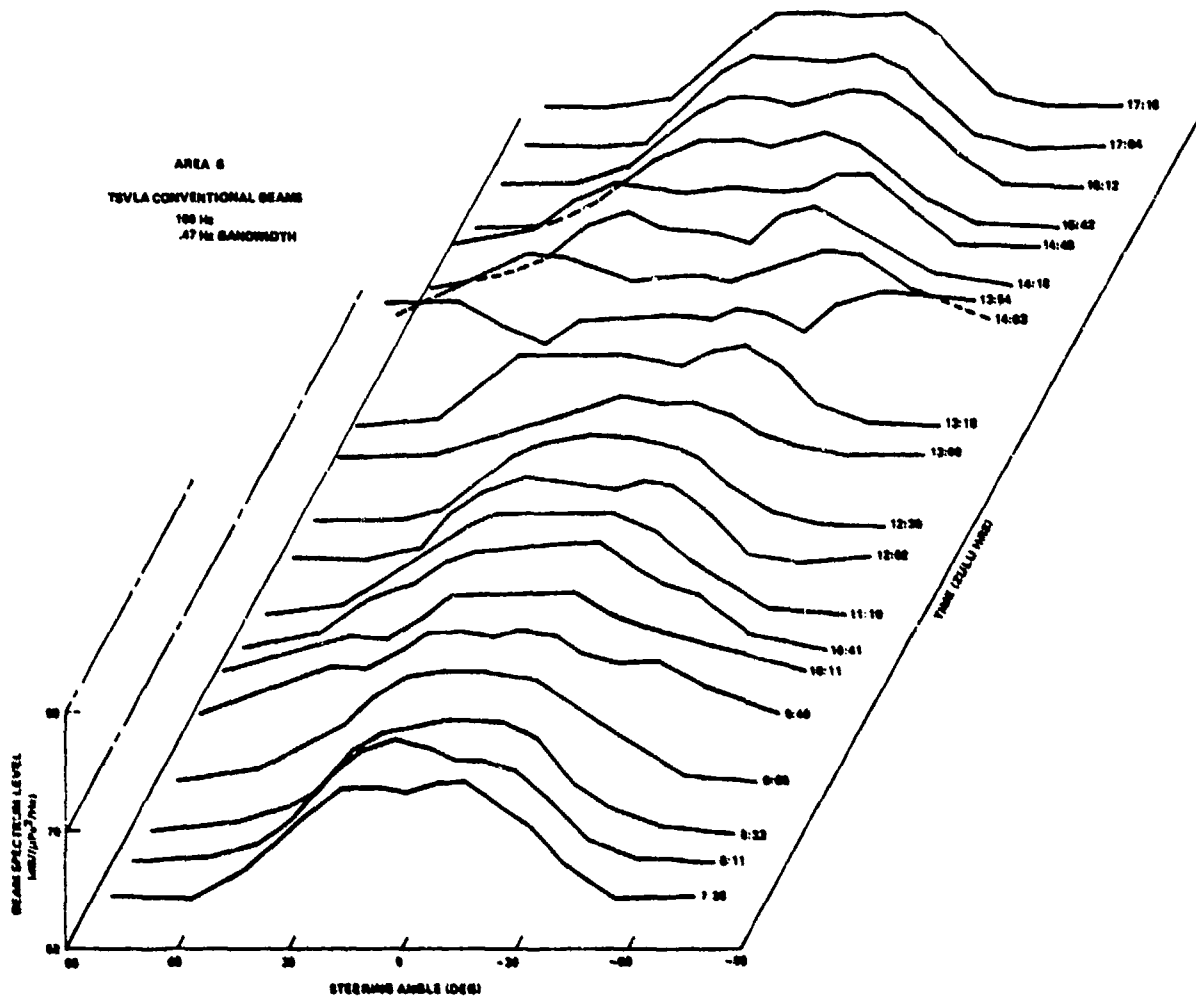


Figure 19 (C) Measured Noise Directionality (U)

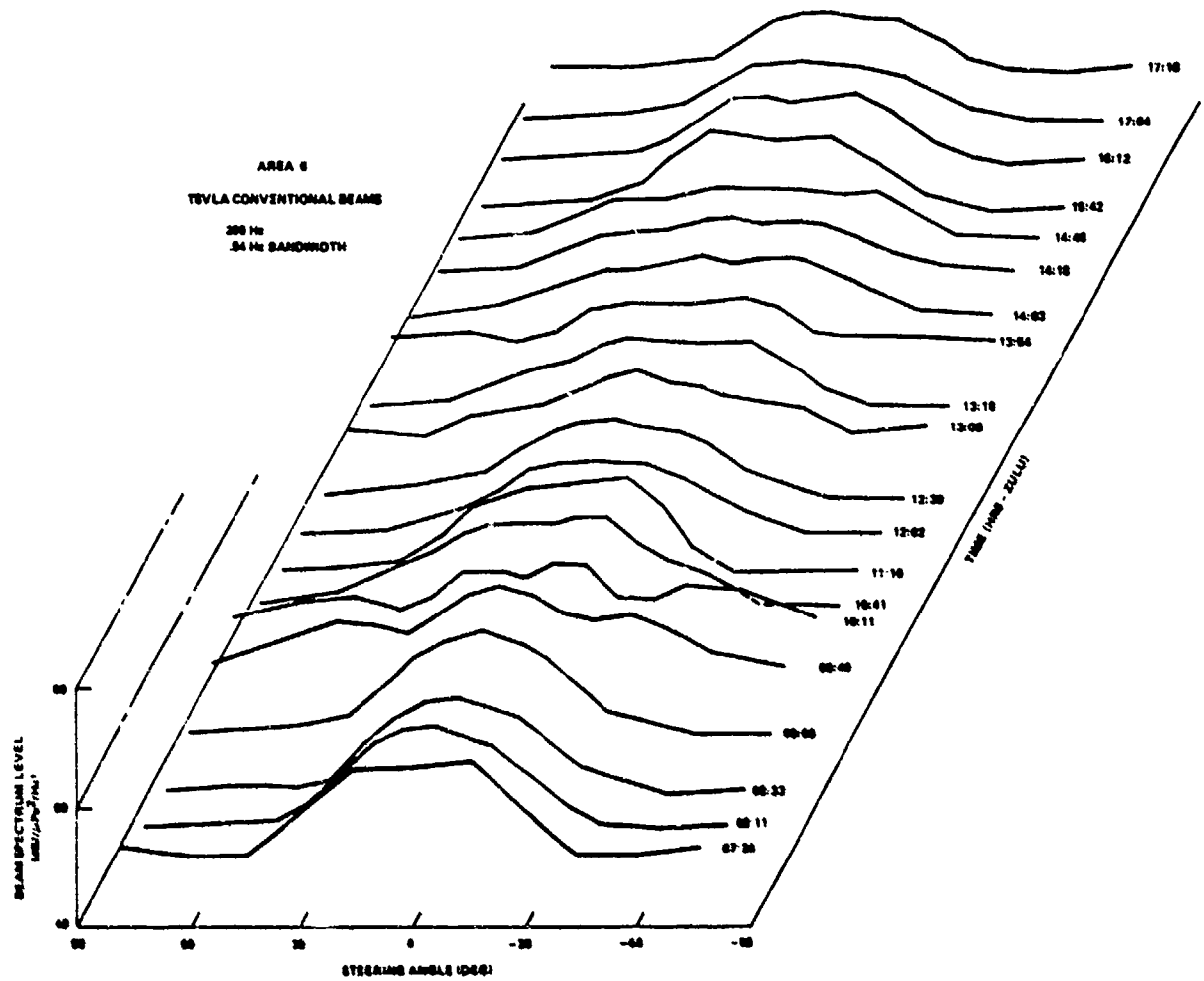


Figure 20 (C) Measured Noise Directionality (U)

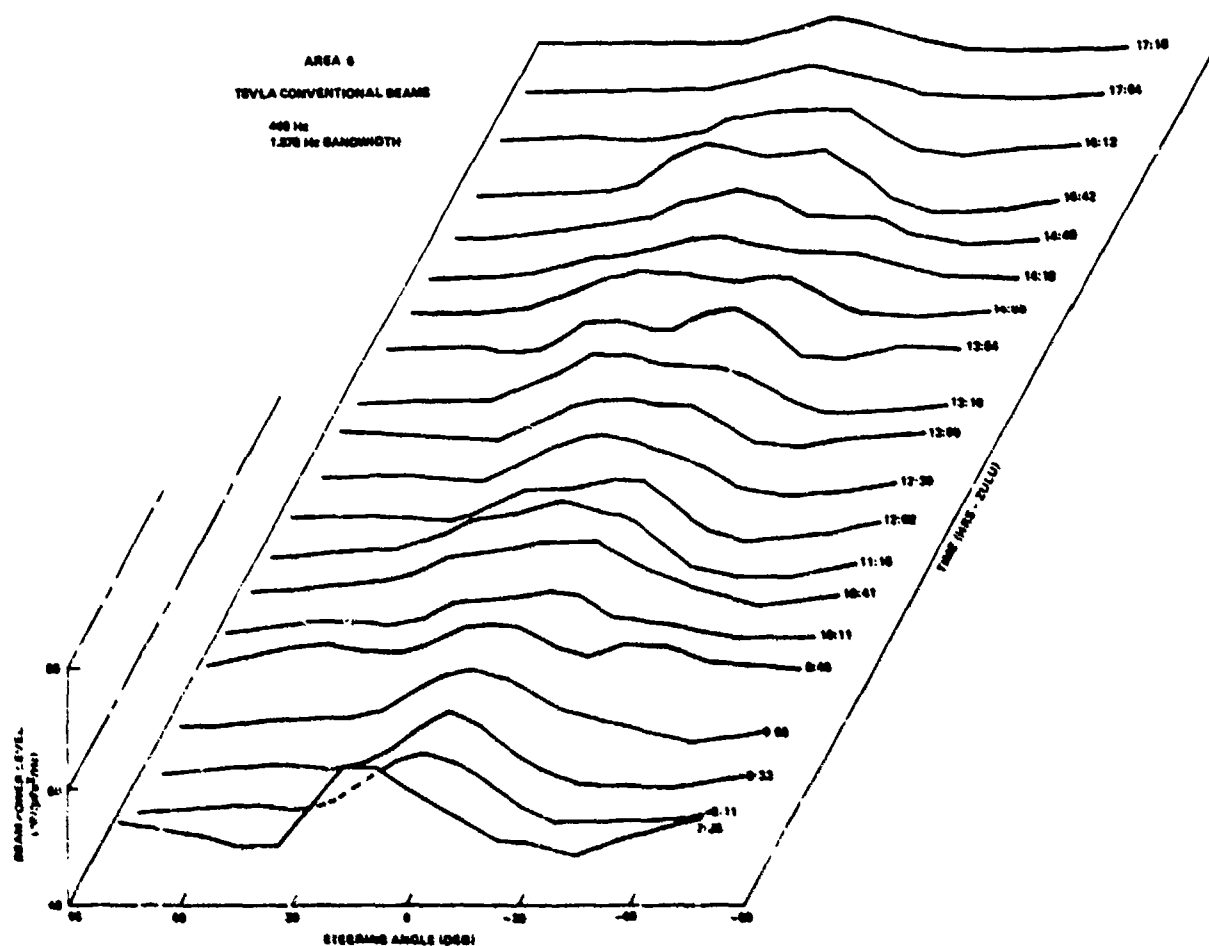


Figure 21 (C) Measured Noise Directionality (U)

(U) this data, large variations in the measured directionalities with time are readily apparent, particularly at the lower frequencies. These variations are due to the presence of local shipping traffic. In specific, in the vicinity of 1000Z (940Z and 1011Z), a large tanker was observed to pass within 4 nmi of the test buoy, producing the first bottom bounce signal arrivals which are present at all frequencies on the $\pm 44^\circ$ and $\pm 57^\circ$ beams. A similar more pronounced effect, due to one or more ships passing very close to the buoy, is also evident, particularly at low frequencies, in the time interval between 1319Z and 1448Z. During this period, high level dominant bottom bounce arrivals are visible on the $\pm 34.1^\circ$, $\pm 44^\circ$, and $\pm 57^\circ$ beams. Although all data segments appear to be influenced somewhat by local shipping, a typical distant shipping noise sample (uncorrupted by local shipping traffic) is perhaps best represented by the 0833Z time segment, which shows directionalities of 18 dB at 50 and 100 Hz, 16 dB at 200 Hz, and 10 dB at 400 Hz. At low frequencies the bulk of the noise energy (approximate 3 dB down points) arrives between $\pm 21^\circ$ of the horizontal, between $\pm 18^\circ$ at 200 Hz, and between $\pm 11^\circ$ at 400 Hz. The 400 Hz curve is also asymmetric, with 3 or 4 dB more noise intensity arriving from the surface (high positive angles) than from the bottom. Reprocessing of selected data segments with 35 dB side lobe coefficients yielded essentially identical directionalities, confirming that the 25 dB measurements are not side lobe limited. Model predictions have not been computed, since bottom loss measurements, a critical model input parameter, are not yet available.

(C) The measured signal arrival angle structures for the two high source level frequencies of 155.4 and 290.2 Hz are shown in figures 22 and 23. The lower source levels used at the other projector frequencies did not permit detection and signal level measurements on enough beams to generate well defined arrival angle curves. In figures 22 and 23 the curves, which are offset for clarity, show the relative beam signal power level output versus steering angle over the 3 and 5.9 nmi range interval. The associated predicted arrival angle structure, based on ray theory modeling, is presented in figure 24: each of the bottom bounce arrival curves shown represents a pair of propagation paths. The squares affixed to each measured curve in figures 22 and 23 correspond to the predicted arrival angles of the direct and first bottom bounce propagation path at each range. There is generally excellent agreement between the measured and predicted data. Furthermore, the ratio between the direct to bottom bounce signal levels is consistent with the measurements, showing rapidly decreasing direct path signal level beyond 3 or 4 nmi. It should be noted that while there are inconsistencies in the direct path levels with range (i.e., at 290 Hz, the 3.4 nmi data shows dominant direct; at 3 nmi the first bottom is dominant), the data shown includes significant temporal as well as spatial variations. Measurements made at nearly the same range are not necessarily sequential time intervals and are not necessarily at the same location.

(C) Because of the limited range interval, the variability of the vertical directionality and omnidirectional levels with time, and the slowly drifting source and receiver conditions, meaningful absolute sensor detection performance against third generation threat levels cannot be established. However, as an alternate, estimates of the expected array gain potential at all

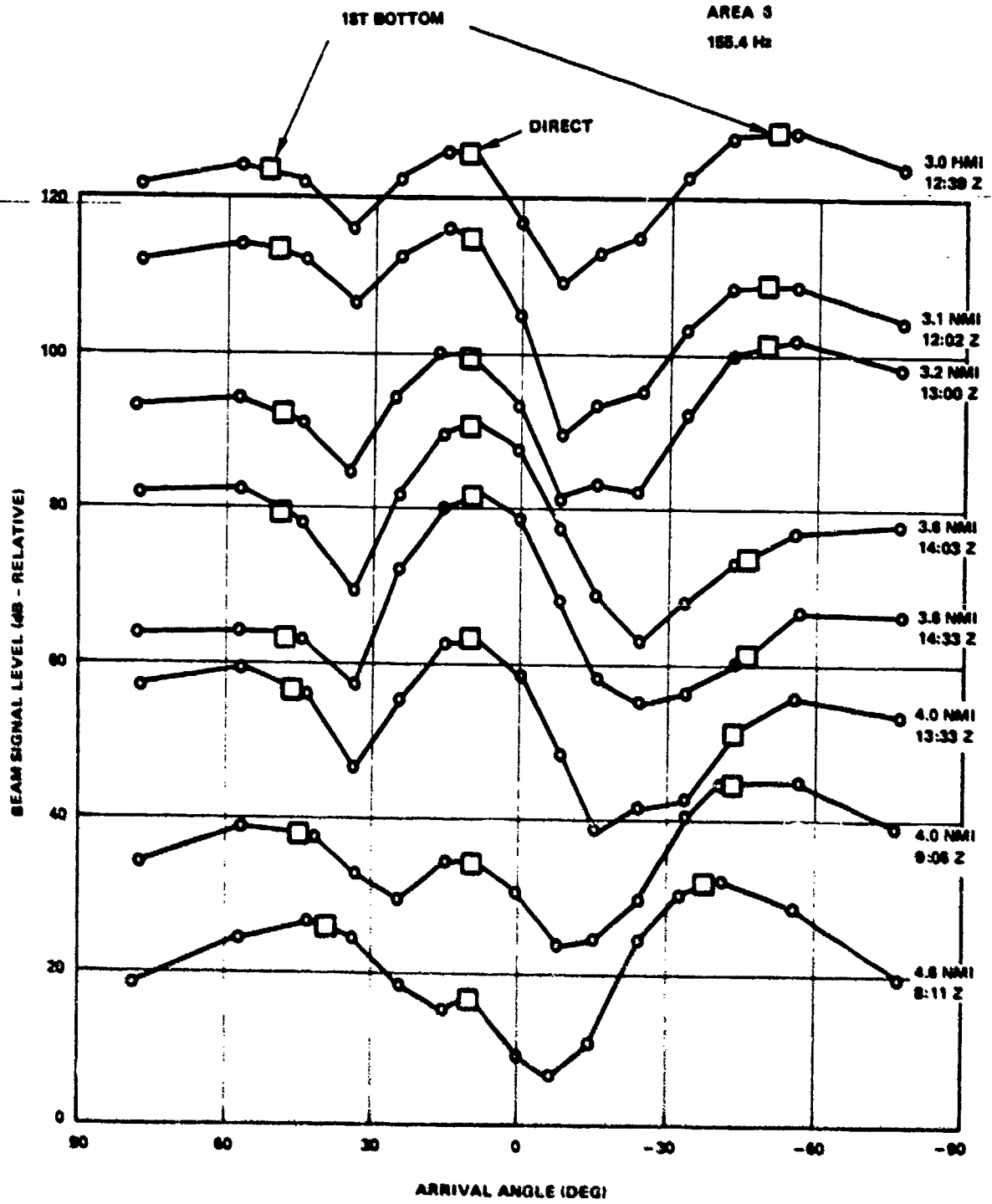


Figure 22 (C) Measured Signal Arrival Angles (U)

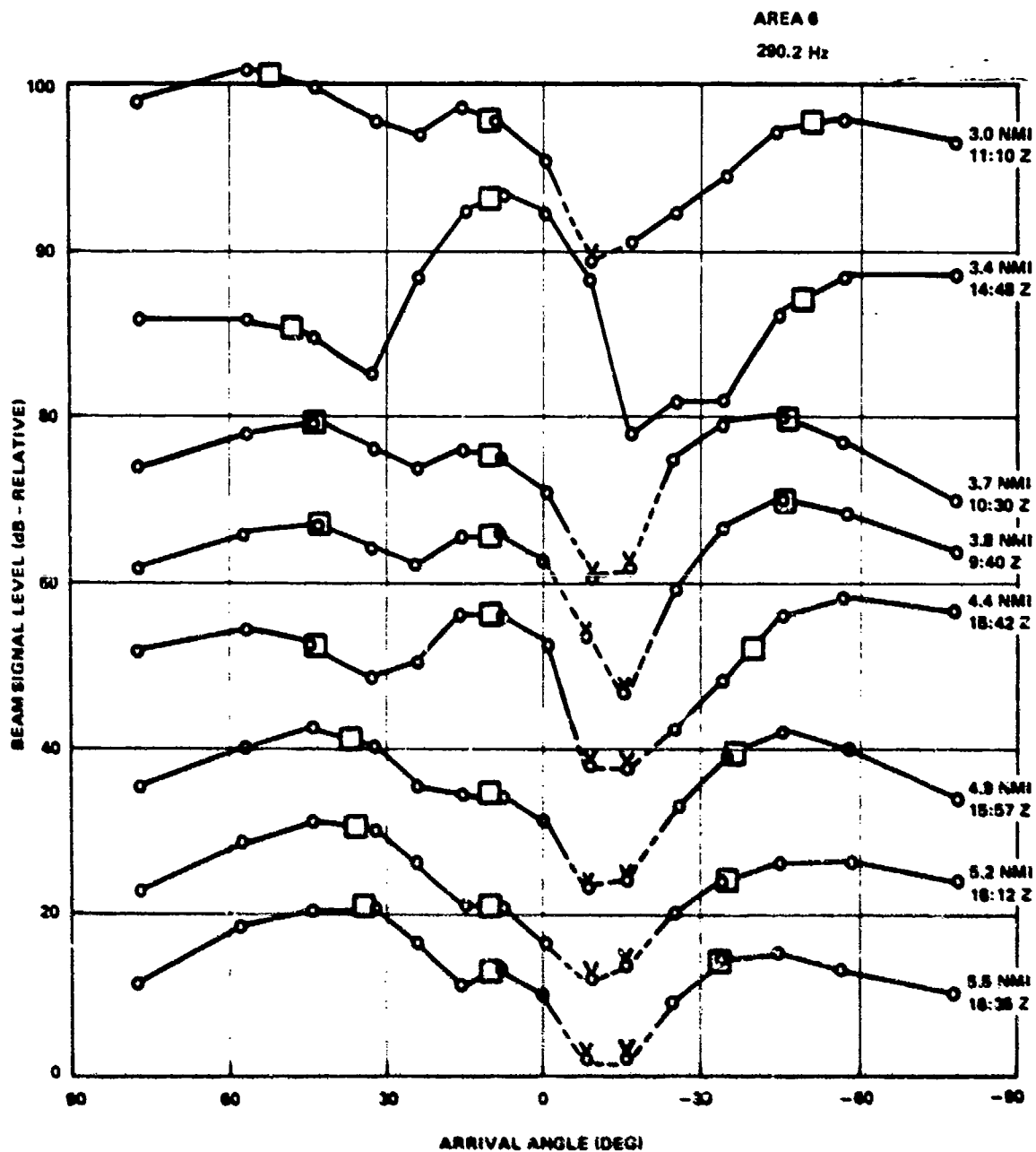


Figure 23 (C) Measured Signal Arrival Angles (U)

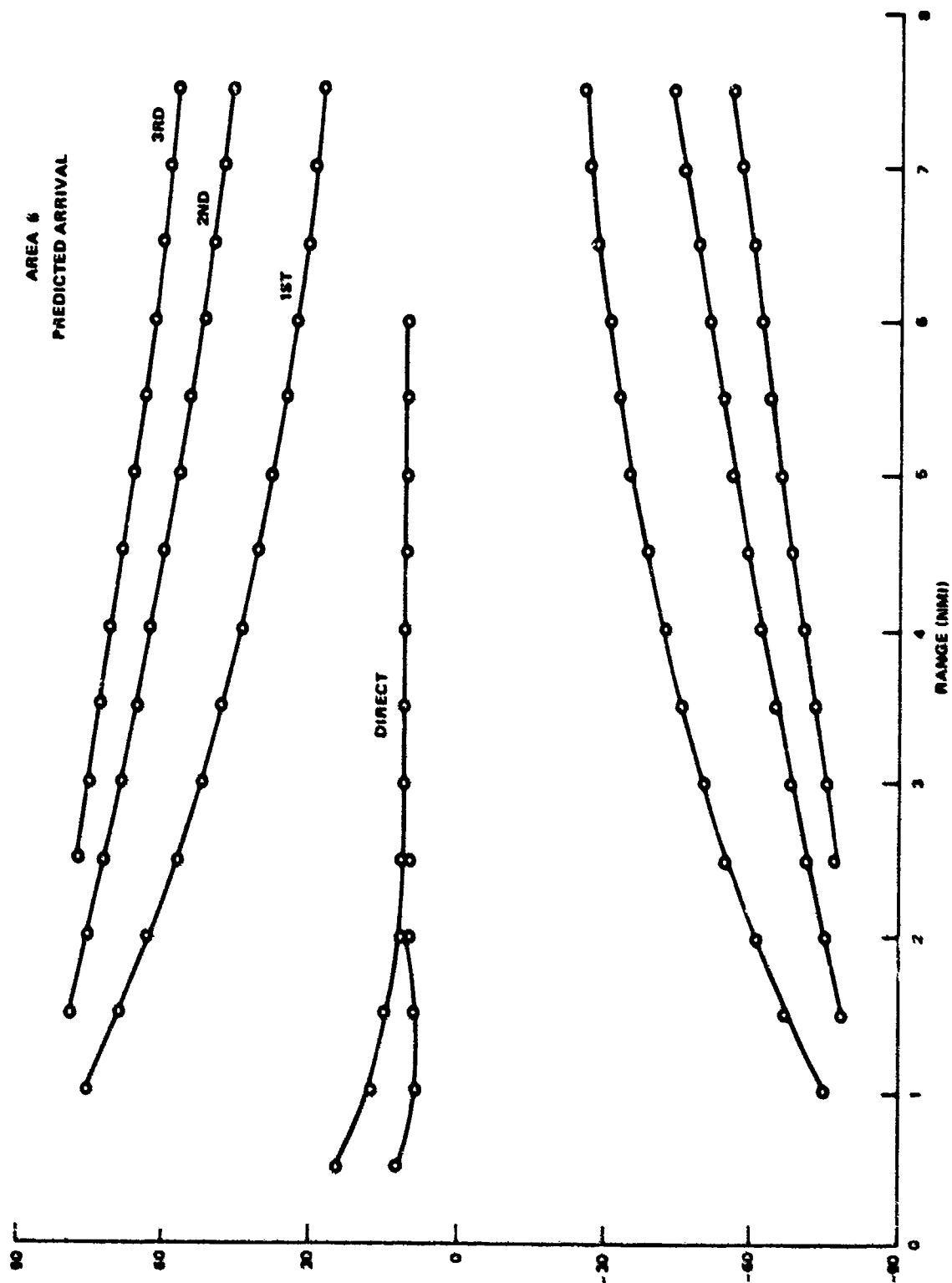


Figure 24 (U) Predicted Signal Arrival Angles (U)

- (C) frequencies, in terms of measured noise gain are presented, along with the available measured array gain at the projector frequencies for the SVLAD five beam and VLAD sensor configurations.

(C) While the actual array gain at any frequency will be a function of signal arrival angle, beam response pattern, and relative intensities between the individual propagation paths, an estimate of array gain potential is strongly reflected in the sensor noise gains. Figures 25 and 26 show the measured noise outputs of the SVLAD ($+14^\circ$, -28° , and -45° beams) and VLAD sensors relative to the averaged omnidirectional hydrophone output. These figures show data taken at 0833Z (no local surface traffic), 1011Z (large tanker at 4 nmi), 1354Z (merchant traffic at less than 4 nmi), and 1824Z (low frequency interference). For time periods which had little or no surface traffic, the SVLAD sensor generally provided 20 dB or more noise gain (-45° beam, 40 to 400 Hz) and the VLAD sensor generally had 6 to 8 dB less gain (except in the 64 to 80 Hz band, where it provided 2 to 5 dB more noise gain). As expected, during local shipping traffic time periods when high angle bottom bounce interference is present, the measured noise gains decreased, with the SVLAD beams providing approximately 12 dB of gain (-28° beam) and the VLAD 5 or 6 dB less.

(C) In figures 27 and 28, the measured array gains (maximum five beam S/N - averaged omnidirectional S/N) are plotted versus time, with the corresponding ranges superimposed on the time axis. Also appended to each graph are shaded bars, which designate the time periods during which the data was heavily corrupted by local shipping noise. The special symbol (^) affixed to specific data points denote measurements on which no signal was detected on the averaged omni hydrophones. In these cases a -10 dB S/N ratio was assumed: the actual array gain is probably equal to or greater than the value shown. The special symbol (') affixed to specific data points is used to indicate five beam measurements which had significantly greater S/N readings on the corresponding positive beams. The positive beam measurement is indicated by a (+). At 55Hz, gains between +8 to +20 dB were generally measured: gain measurements made during heavy local shipping conditions decreased to between 0 to 3 dB. At 155.4 and 165.3 Hz, gains between 8 to 18 dB were generally measured. At 165 Hz between 0800Z and 0900Z, the corresponding positive steered beams ($+28.3^\circ$, $+36.6^\circ$, $+45^\circ$, and 60°) yielded gain 10 dB higher than the negative steered beams. Similar effects have previously been observed on other TSVLA data and have been attributed to multipath phase interference of the pair of ray paths comprising the first bottom bounce propagation path. At these frequencies the gain also decreased during the heavy local shipping conditions to between 4 and 8 dB. At 290.2, 305.2, 544.6 and 559 Hz, the SVLAD five beam configuration provided between 7 to 14 dB of array gain and decreased during heavy local shipping time periods to between 0 and 9 dB.

(C) A summary of the VLAD performance relative to the SVLAD five beam sensor is shown in figure 29. The points plotted are the gain differences between the two sensors (Δ Gain = SVLAD S/N - VLAD S/N). The special symbol (^) denotes measurements on which the signal was not detected on the VLAD sensor: in these cases a -10 dB S/N was assumed. At 544.6 and 559.6 Hz, the VLAD sensor configuration could not be duplicated with the TSVLA array hydrophone spacings. The SVLAD five beam sensor generally provided 3 to 12 dB higher S/N readings than the VLAD sensor, but optimization of the SVLAD sensor, by selecting alternate or additional steering angles would further increase this performance difference.

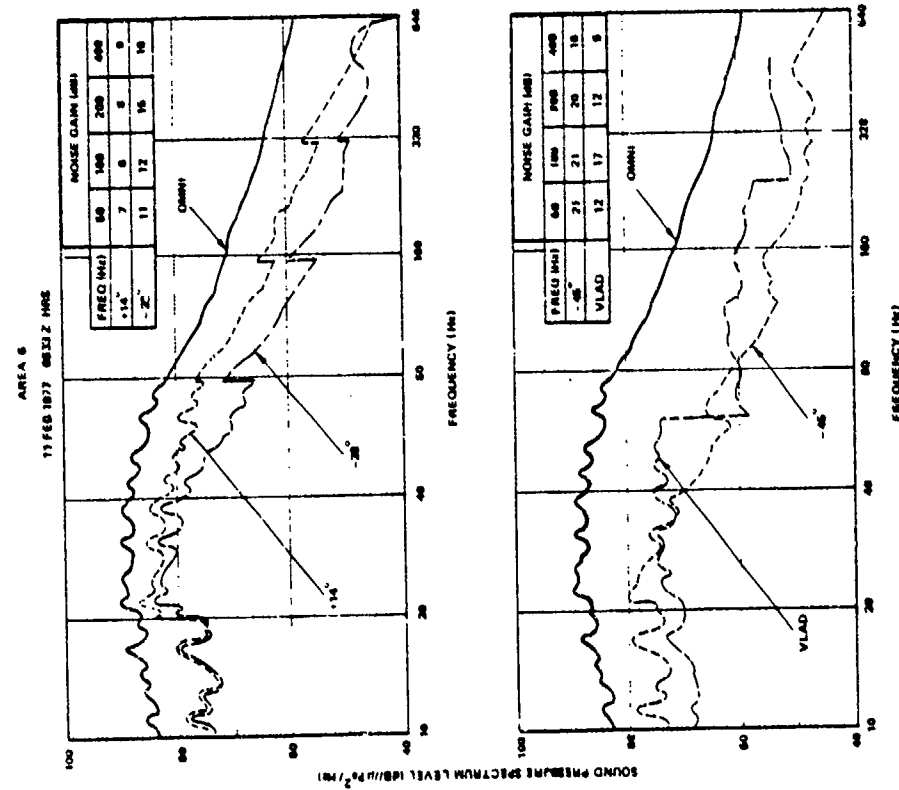
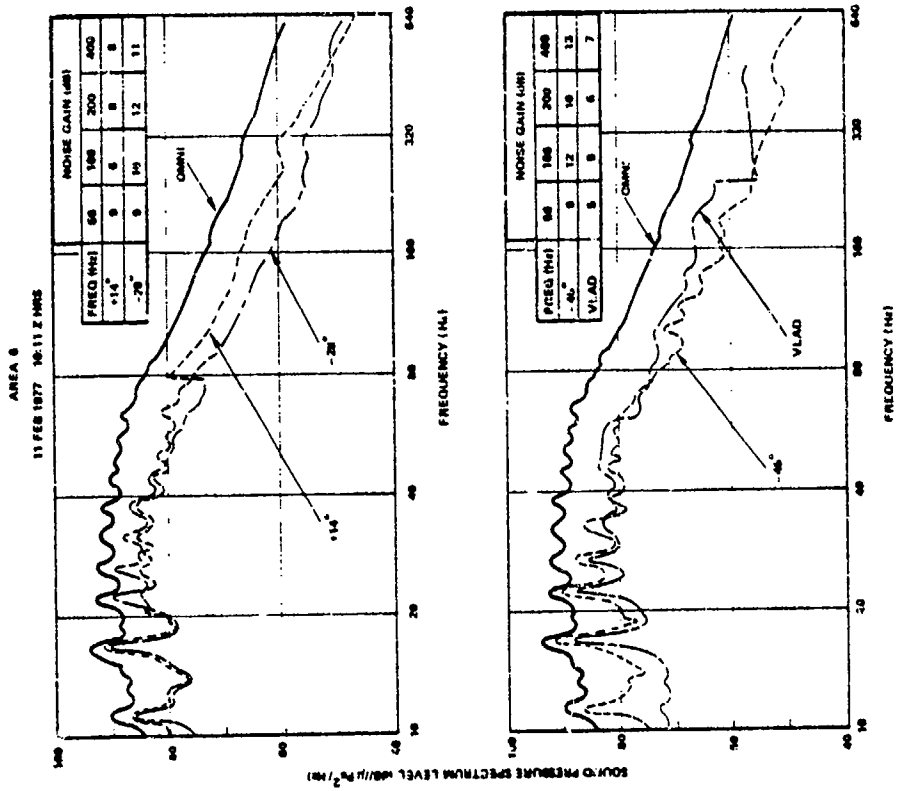


Figure 25 (C) Noise Gain (U)

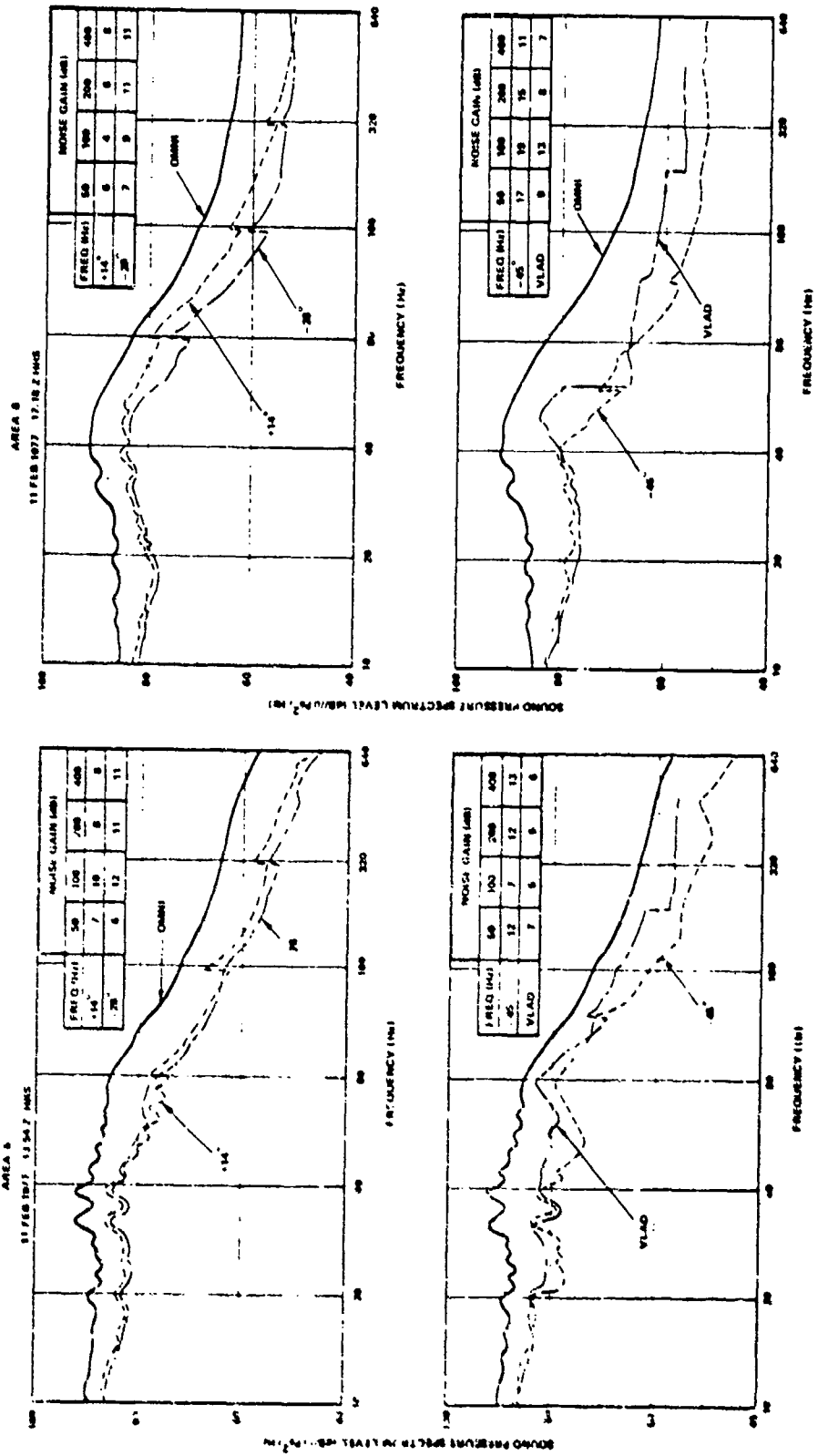


Figure 26 (C) Noise Gain (U)

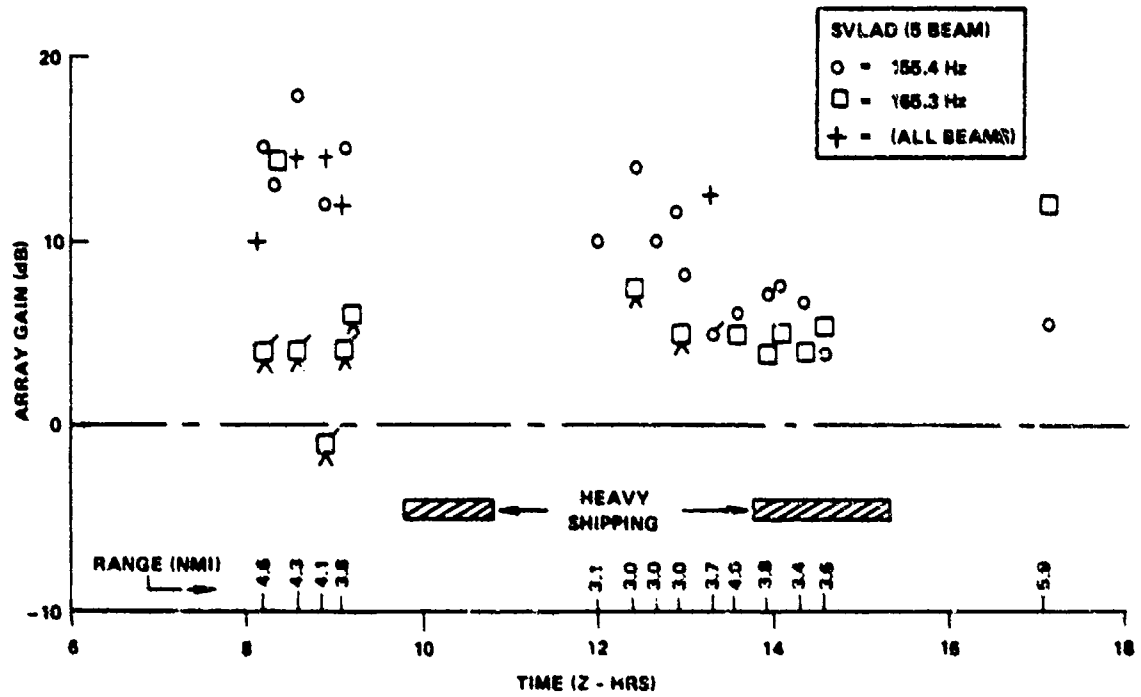
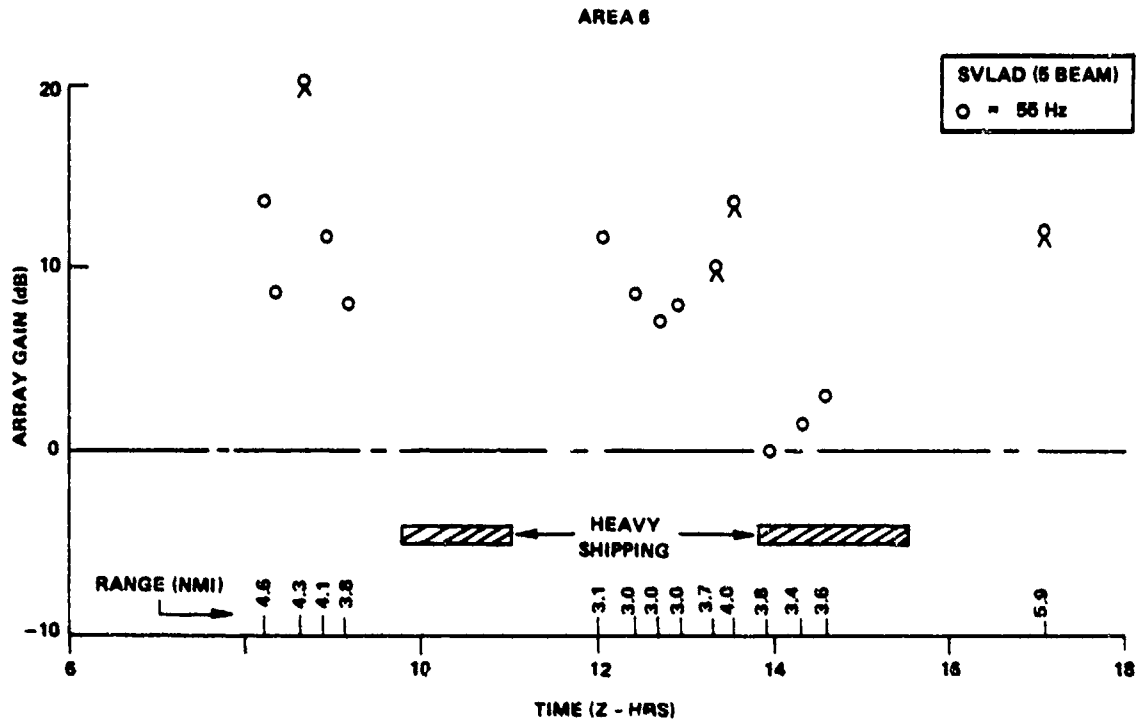


Figure 27 (C) Measured Array Gain-Area 7 (1')

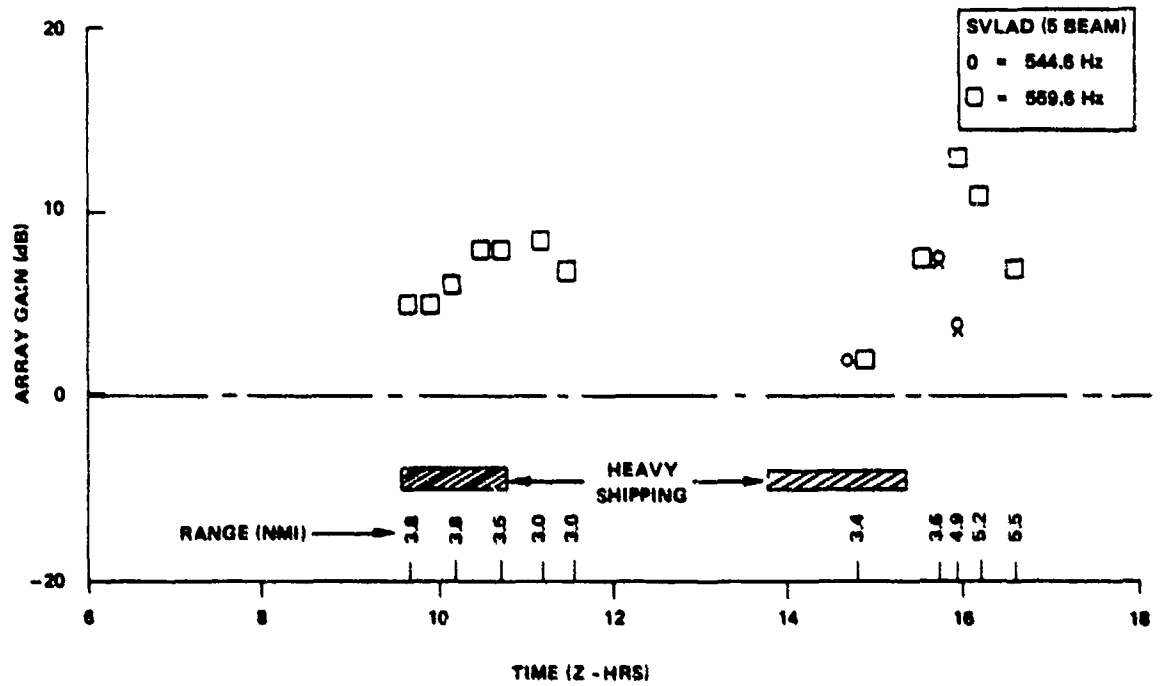
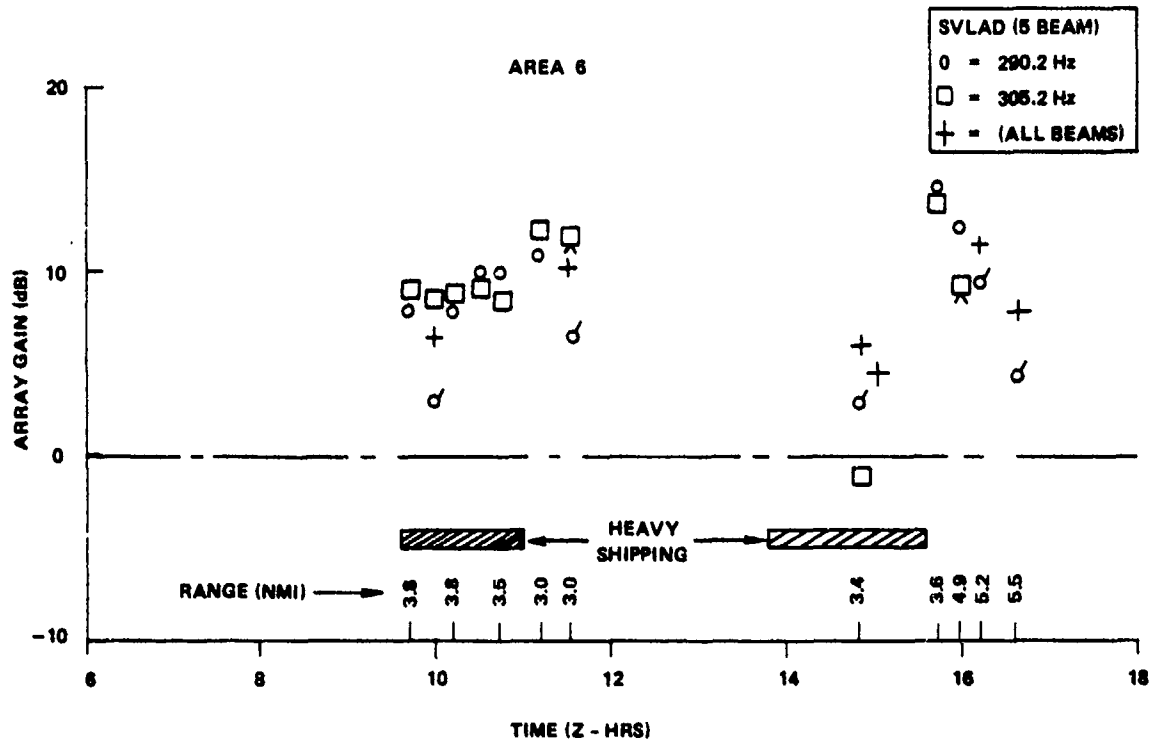


Figure 28 (C) Measured Array Gain-Area 7 (U)

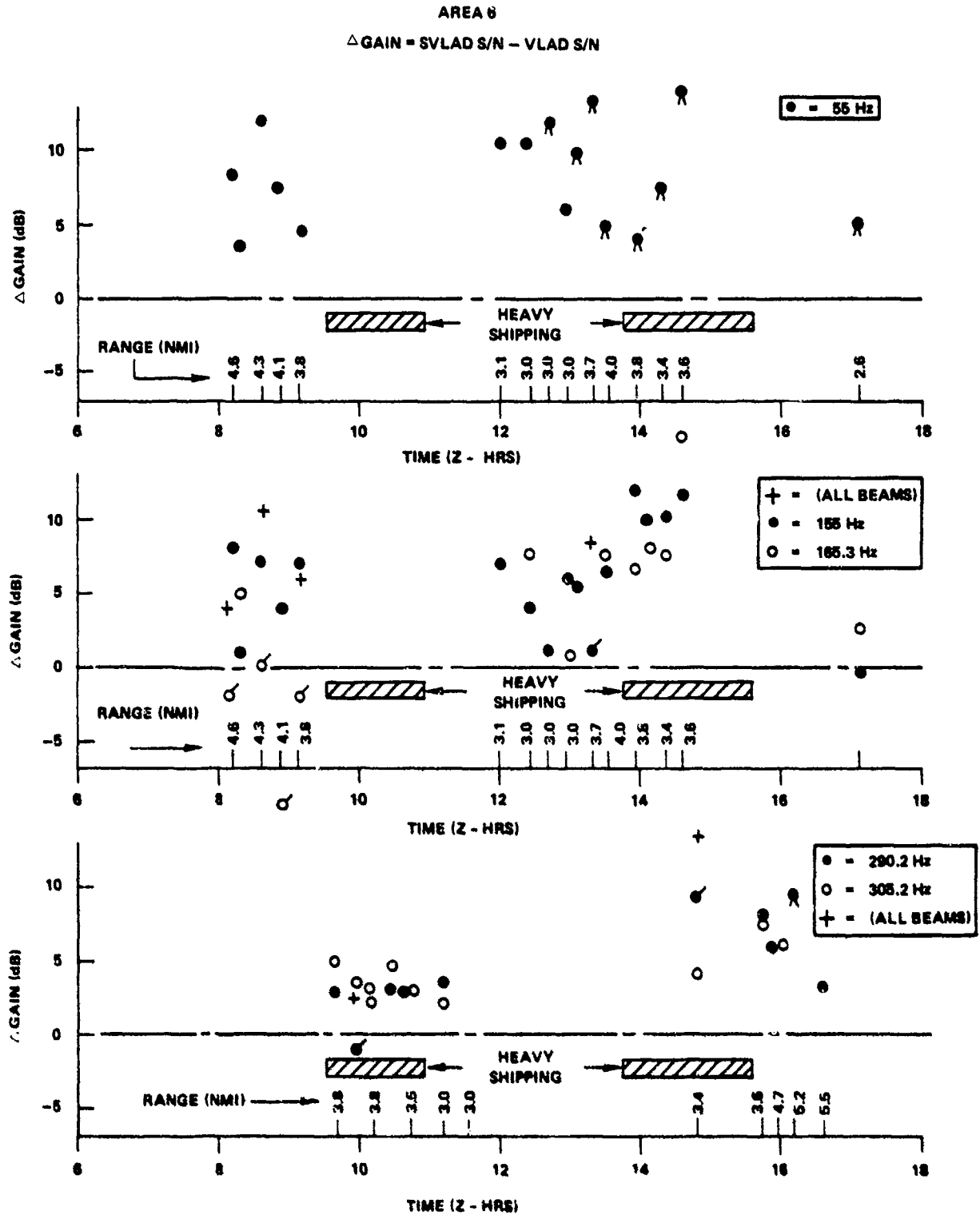


Figure 29 (C) Comparison of SVLAD and VLAD Sensor Performance (U)

(C) Also, for the high density local merchant traffic conditions observed in this area (or for fleet or convoy related conditions) where there exists high degrees of azimuthal noise directionality, there is the potential to achieve with SVLAD significant azimuthal noise gain through steered cardioid beamforming (DIFAR sensor). Computer algorithms to investigate these possibilities have not yet been implemented. For the Area 6 TSVLA data, only intermittent measured results of this nature are possible due to the electronic failure of the directional DIFAR channels.

(C) RESULTS - AREA 7 (U)

(C) Although three TSVLA systems were deployed from the USNS WILKES in Area 7 (BEARING STAKE Site 1B - Oman Basin), only six usable data segments between 1400Z and 1900Z on 22 May 1977 were obtained. During deployment of the first system, an antitampering device fired during deployment severing the signal cable and sending the array and subsurface electronics package to the bottom. While the second system was deployed successfully, the transmitter immediately lost modulation and no data was obtained. The last system was deployed at 23°25' N, 61°33' E at 0830Z and drifted at a 0.4 kn rate (assuming linear drift between launch and retrieval) on a 305° bearing. The data stream contained numerous parity errors due to intermittent modulation and/or interfering signals at or near the buoy transmitter frequency. This data was recorded from 0850Z to 2135Z at which time the transmitter lost all modulation. Careful examination of these tapes revealed that there were six time periods with sufficiently low parity errors to permit processing and beamforming. While all hydrophone channels were operable and the channels were matched in sensitivity to within 1 dB, the absolute calibration was incorrect since the spectrum levels measured were unrealistically high (120 dB// $\mu\text{Pa}^2/\text{Hz}$ at 50 Hz). Hydrophone channel matching gain correction factors, based on the measured ambient noise levels, were derived and applied to the data prior to beamforming to minimize side lobe degradation. The representative sound speed profile, based on shallow measurements and deep historic data, is shown in figure 17. This limited data base permitted only an examination of the measured noise directionality, signal arrival angle structure at ranges of 1.6 to 2.0 nmi, and performance estimates based on measured noise gain.

(C) The measured vertical noise directionalities using 35 dB side lobe suppression are shown in figures 30 through 33 for 50, 100, 200, and 400 Hz. At each frequency the directionalities are generally consistent over all data segments, showing 30 to 32 dB of directionality at 50 and 100 Hz, 22 to 23 dB at 200 Hz, and approximately 18 dB at 400 Hz. In all cases the bulk of the energy arrived between $\pm 25^\circ$ of the horizontal.

(C) The available high level projector signal data at 155 Hz and 290 Hz are shown in figure 34 for the 1.6 and 2.0 nmi ranges, along with a 140 Hz signal projected by the USNS KINGSPORT at a 9 nmi range during Test 6. The observed signal arrival angles do not agree with the predicted arrival angle structure shown in figure 35. The predicted direct and first bottom bounce signal arrival angles are indicated by squares affixed to the measured curves shown in figure 34. Although the reason for this radical disagreement is not known, it appears most likely to be due to a range error. While the projector signals

AREA 7
TSVLA CONVENTIONAL BEAMS
50 Hz

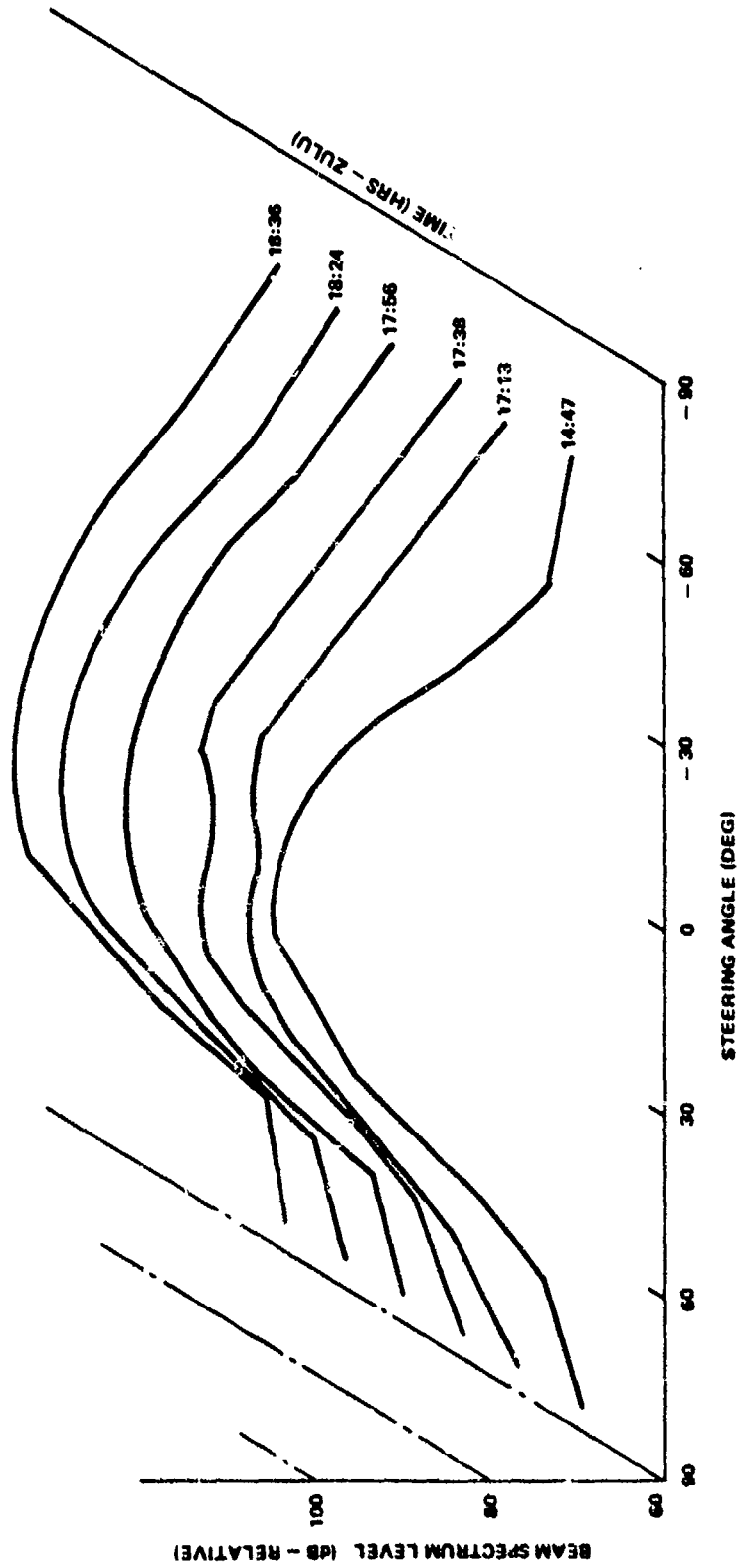


Figure 30 (C) Measured Noise Directionality (U)

AREA 7
TSVLA CONVENTIONAL BEAMS
100 Hz

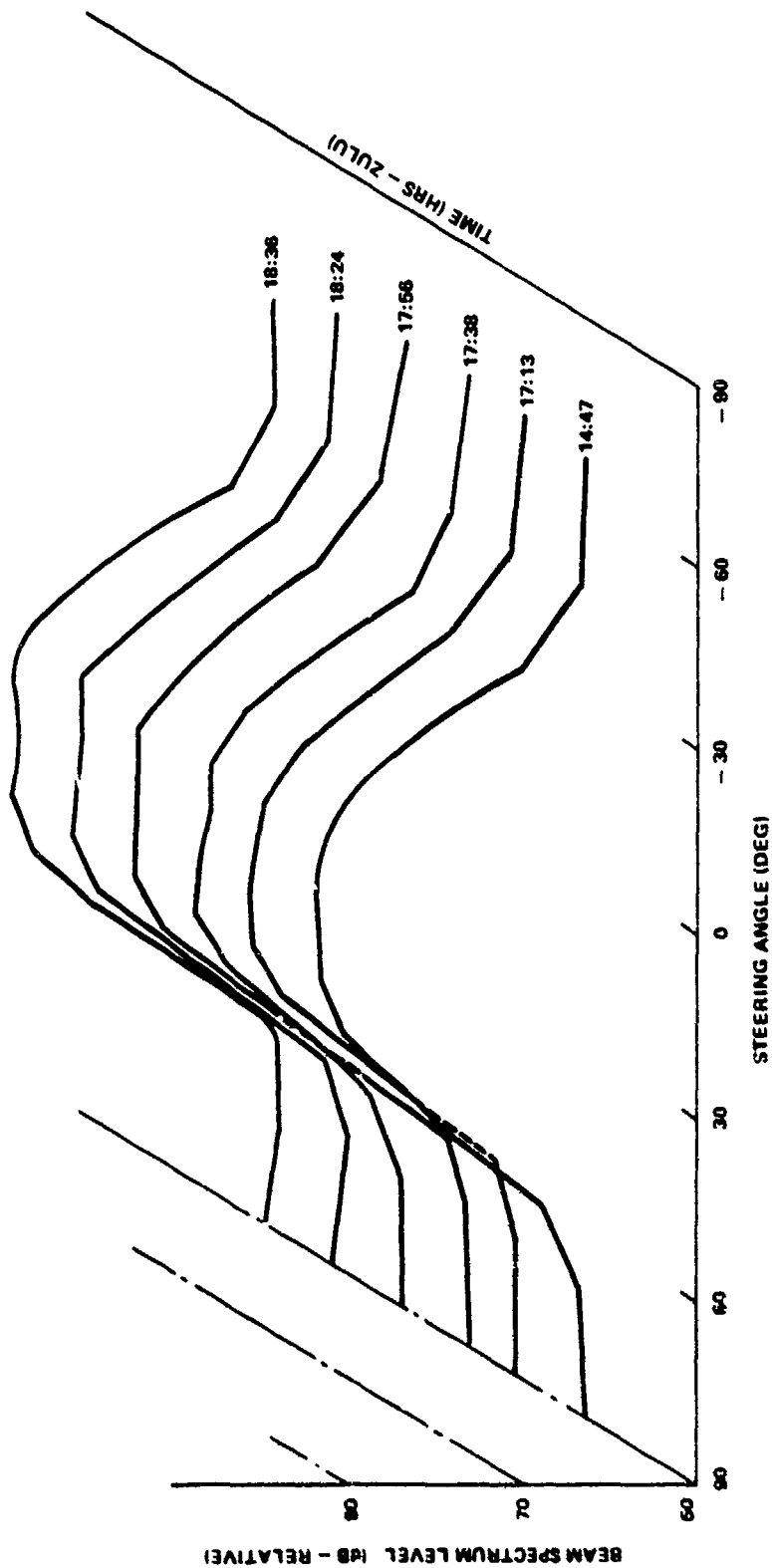


Figure 31 (C) Measured Noise Directionality (U)

AREA 7
TSVLA CONVENTIONAL BEAMS
200 Hz

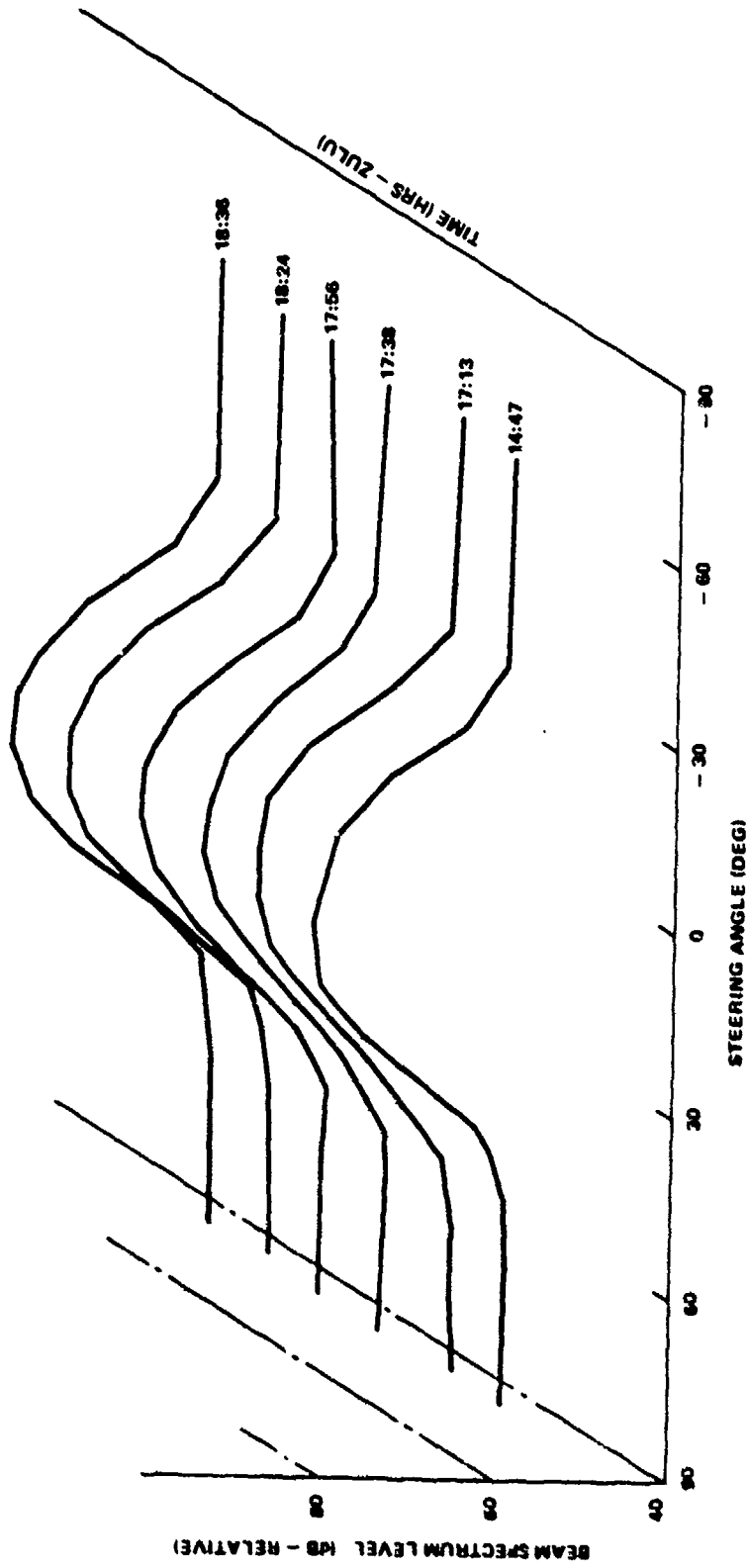


Figure 32 (C) Measured Noise Directionality (U)

AREA 7
TSVLA CONVENTIONAL BEAMS
600 Hz

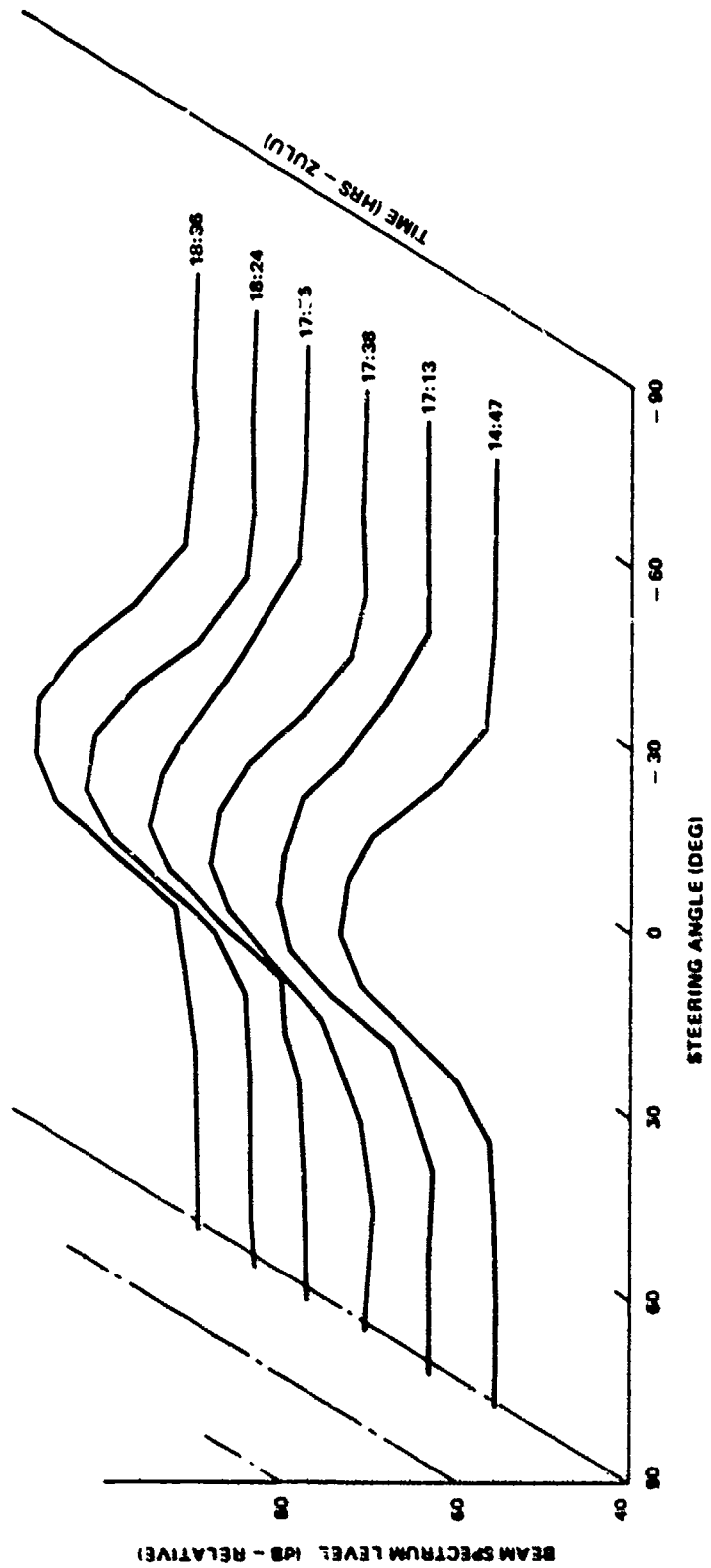


Figure 33 (C) Measured Noise Directionality (U)

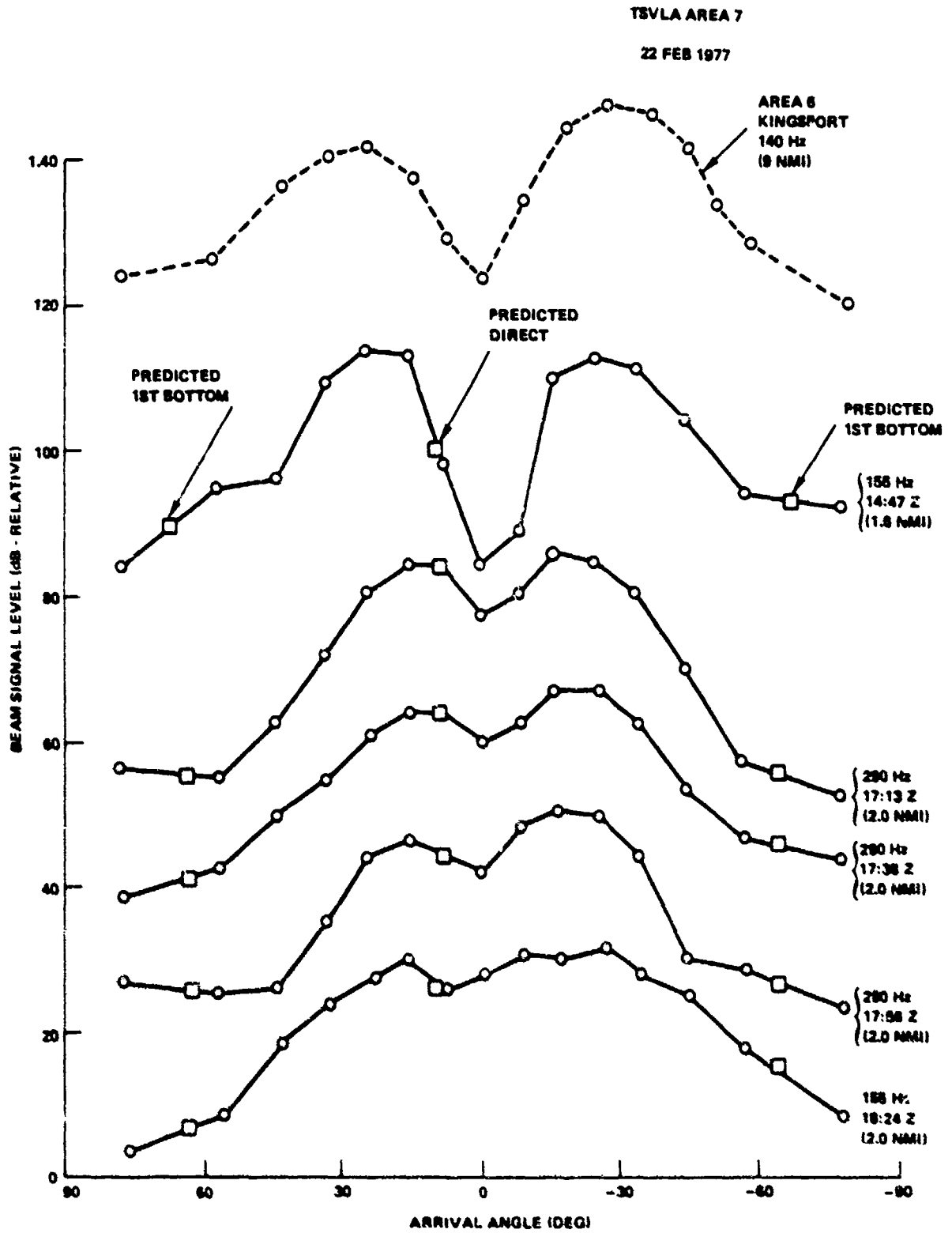


Figure 34 (C) Measured Signal Arrival Angles (U)

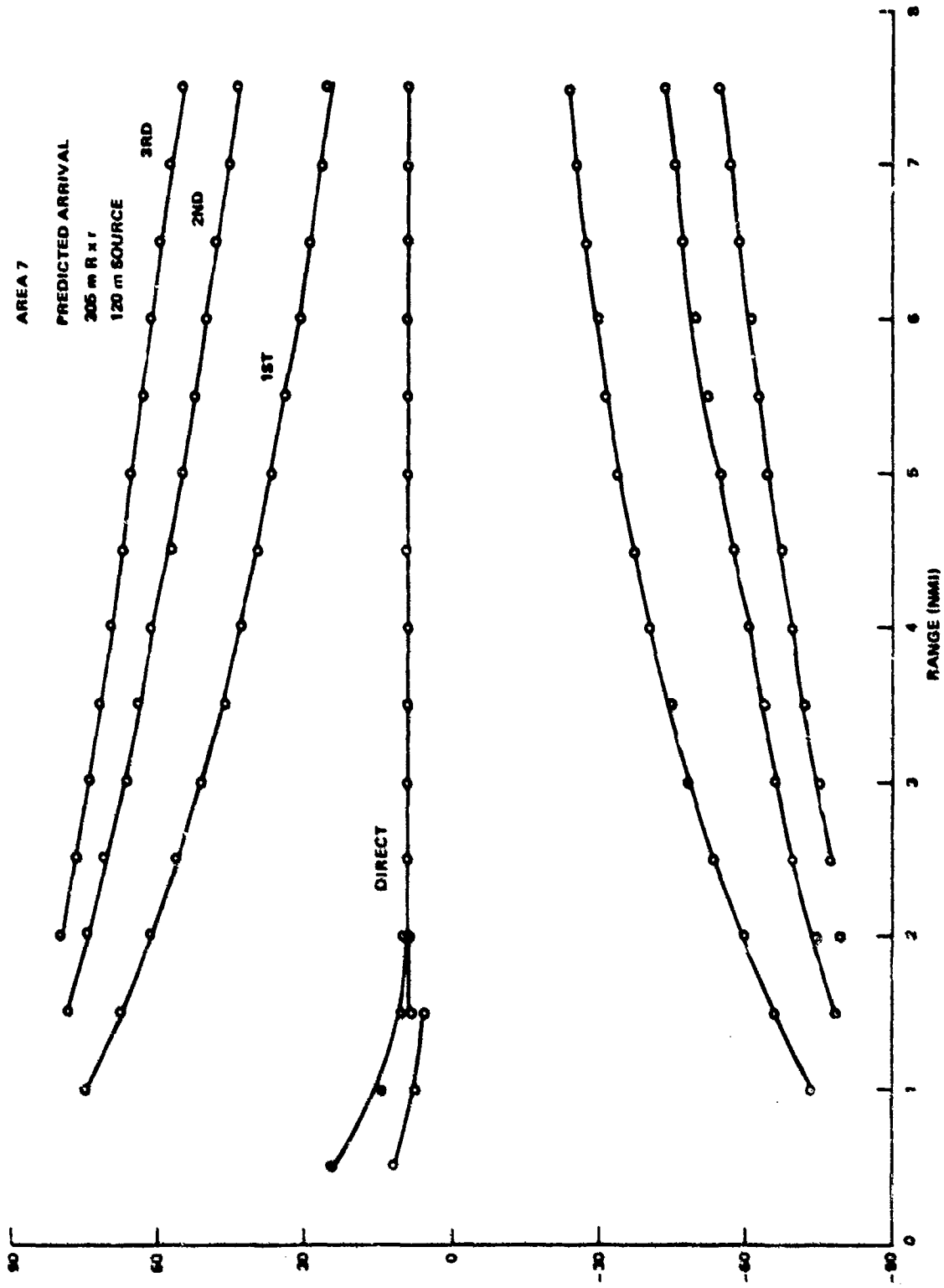


Figure 35 (U) Predicted Signal Arrival Angles

(C) present are consistent with the USNS WILKES projector logs and the corresponding navigation fixes appear to be reasonable, for the given test geometry (range, ocean, receiver, and projector depths) the measured arrival angles are impossible to obtain. However, the measured data are consistent with predictions for an 8 or 9 nmi projector range; a near identical 140 Hz signal arrival curve was measured in area 6 (dashed curve, figure 34) at approximately a 9 nmi range under similar sound speed and test geometry conditions.

(C) An estimate of the array gain potential, in terms of the measured noise gain is shown in figure 36 for the $+14^\circ$, -21° , and -45° conventional beams (25 dB side lobe levels) and the VLAD sensor configuration. The -45° beam provides in excess of 20 dB (~ 25 dB between 60 to 200 Hz) of noise gain at all frequencies and the VLAD 6 to 10 dB less (except between 64 to 80 Hz). The SVLAD processing algorithms could be readily optimized in this area by increasing the beam pattern side lobe suppression for high steering angles to take full advantage of the high vertical noise directionality.

(U) RESULTS - AREA 8

(U) In area 8 (BEARING STAKE Site 4), no usable TSVLA acoustic data were obtained. During late March 1977 in the vicinity of $4^\circ 53'$ N latitude and $52^\circ 51'$ E longitude four TSVLA buoy systems were deployed. During deployment of the first buoy, an antitamper cable cutting device fired and the array and subsurface electronic package was lost. The second array sank. The third array also sank, but was retrieved via a tether line. These latter two units had insufficient buoyancy, caused by the additional system weight resulting from design modifications incorporated in the latest buoys manufactured. The fourth buoy was deployed successfully (although somewhat roughly) and a number of hours of high parity error data were recorded. While a few segments of sufficient length with minimal parity errors were available on one tape, examination of the processed data revealed that the hydrophone samples were frequently clipped in the buoy quantize and thus, the results were unusable.

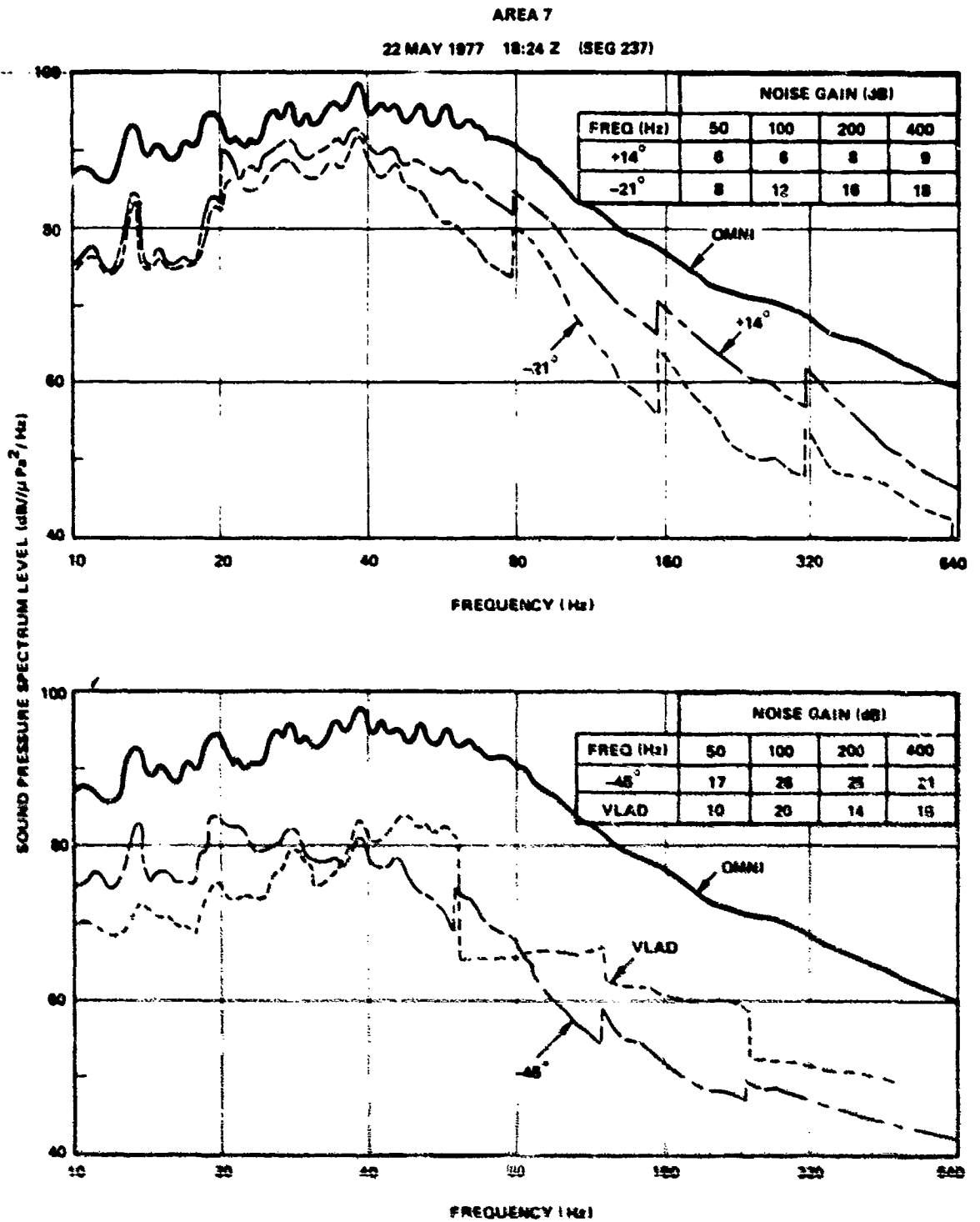


Figure 36 (C) Measured Noise Gain (U)

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(U) A C K N O W L E D G M E N T S

(U) The author wishes to commend the numerous military and civilian personnel and the various organizations whose participation and efforts were invaluable in performing the collection and processing of the TSVLA data. I am particularly indebted to the following personnel who provided collateral data and who have graciously contributed their work or ideas; Mr. A. Horbach, NAVAIRDEVGEN; Mr. R. Scudder, Western Electric Company; Mr. D. Fenner, NORDA; Mr. E. Hamilton, NOSC; and Mr. S. Mitchell, ARL/University of Texas.

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Report Number	Personal Author	Title	Publication Source (Originator)	Pub. Date	Current Availability	Class.
Unavailable	Penrod, C. S., et al.	MOORED SURVEILLANCE SYSTEM FIELD VALIDATION TEST SENSOR PERFORMANCE ANALYSIS. VOLUME I. DATA COLLECTION AND MEASUREMENT SYSTEM DESCRIPTION	University of Texas, Applied Research Laboratories	781231	ADC018009	C
Unavailable	Watkins, S. L., et al.	MOORED SURVEILLANCE SYSTEM FIELD VALIDATION TEST SENSOR PERFORMANCE ANALYSIS. VOLUME III. VERNIER RESOLUTION DATA PRODUCTS	University of Texas, Applied Research Laboratories	781231	ADC018373	C
Unavailable	Watkins, S. L., et al.	MOORED SURVEILLANCE SYSTEM FIELD VALIDATION TEST SENSOR PERFORMANCE ANALYSIS. VOLUME II. STANDARD RESOLUTION DATA PRODUCTS	University of Texas, Applied Research Laboratories	781231	ADC018374	C
NORDATN44	Bucca, P. J.	ENVIRONMENTAL VARIABILITY DURING THE CHURCH STROKE II CRUISE FIVE EXERCISE (U)	Naval Ocean R&D Activity	790201	ADC020353; NS; AU; ND	C
NADC7820830	Balonis, R. M.	TEST STEERED VERTICAL LINE ARRAY (TSVLA) MEASUREMENTS FOR BEARING STAKE SURVEYS (U)	Naval Air Systems Command	790301	ADC018003; NS; ND	C
USIControl674779	Williams, W., et al.	REPORT OF THE LRAPP EXERCISE PLANNING WORKSHOP TRACOR INC ROCKVILLE MD 16 - 17 OCTOBER 1978 (U)	Underwater Systems, Inc.	790302	NS; ND	C
NOSCTR357	Hamilton, E. L., et al.	GEOACOUSTIC MODELS OF THE SEAFLOOR: GULF OF OMAN, ARABIAN SEA, AND SOMALI BASIN (U)	Naval Ocean Systems Center	790615	ND	C
Unavailable	Unavailable	RAPIDLY DEPLOYABLE SURVEILLANCE SYST (RDSS) ACOUSTIC VALIDATION TEST (AVT) EXERCISE PLAN (U)	Naval Electronic Systems Command	790625	AU	C
LRAPPRC79027	Brunson, B. A., et al.	GULF OF MEXICO AND CARIBBEAN SEA DATA AND MODEL BASE REPORT (U)	Tracor, Inc.	790701	ADC019153; NS; ND	C
Unavailable	Unavailable	BEARING STAKE BMS DATA QUALITY ASSESSMENT REPORT (U)	University of Texas, Applied Research Laboratories	790705	AU	C
PME12430	Unavailable	RAPIDLY DEPLOYABLE SURVEILLANCE SYSTEM (RDSS) ACOUSTIC VALIDATION TEST (AVT) DATA REDUCTION AND ANALYSIS PLAN (U)	Naval Electronic Systems Command	790815	NS; AU	C
Unavailable	Unavailable	RAPIDLY DEPLOYABLE SURVEILLANCE SYSTEM (RDSS) ACOUSTIC VALIDATION TEST (AVT) EXERCISE PLAN (U)	Naval Electronic Systems Command	790917	AU	C
NOSCTR467	Pedersen, M. A., et al.	PROPAGATION LOSS ASSESSMENT OF THE BEARING STAKE EXERCISE (U)	Naval Ocean Systems Center	790928	ADC020845; NS; AU; ND	C
NOSCTR466	Anderson, A. L., et al.	BEARING STAKE ACOUSTIC ASSESSMENT (U)	Naval Ocean Systems Center	790928	ADC020797; NS; AU; ND	C