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TECHNICAL MEMORANDUM

NEARFIELD AND FARFIELD RESULTS WITH INOPERATIVE STAVES AND A SONAR DOME FOR THE AN/SQS-26

by
J. D. Morell and R. E. Douglass

Submitted to

Commander, Naval Ship Systems Command
Department of the Navy
Attn: Code 1631

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ABSTRACT

This memorandum presents some computed results of the effects of inoperative staves in the presence of a dome on the nearfield and farfield patterns of the AN/SQS-26. Self and mutual stave impedances are given. The results are obtained from equations describing a two-dimensional model composed of a cylindrical baffle (transducer) with radiating strips (staves) enclosed in a thin, concentric shell (dome).

The results show that for both the Track and Bottom Bounce Beams the dome increases the peak pressure in the nearfield as compared to that of a bare transducer. The inoperative staves produce additional non-uniformity of intensity across the major lobe in the farfield pattern of the Bottom Bounce (45°) Beam. The dome increases the level of the side lobe structure, further degrading the farfield pattern. The dome causes an increase in the magnitude of most stave impedances but reduces the real part of self impedance.

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I. INTRODUCTION

Failure of transducer elements, preamplifiers, and power amplifiers will cause portions of a transducer array to become inoperative. Although a limited number of such events will cause degradation of the performance of the array, the array will still function. Evaluation of this degradation will be of benefit in determining the tolerable level of failure. In conjunction with reliability data, this knowledge will be useful in establishing long-term maintenance requirements and schedules.

The analysis of self and mutual stave impedance is a first step in a program to determine the influence of the sonar dome on element interaction coefficients. Determination of the effects of the dome on the radiation load is required for element design and performance predictions. The two-dimensional, analytical model considered in this report yields results for the effects of the dome on stave interactions. Other analytical models, including some three-dimensional configurations now under consideration, may yield to analysis and provide improved methods for evaluating the interactions between transducers, dome, and sea.

A recent memorandum [1] presented an analysis of the effects of inoperative staves on farfield patterns of the Track Beam of the AN/SQS-26 sonar. This memorandum presents and discusses (a) the nearfield results for the Track Beam; (b) the nearfield and farfield results for the Bottom Bounce (45°) Beam; and (c) the results from a self and mutual stave impedance analysis.

The analytical model used to obtain the results in Sections A and B consists of an infinite cylindrical baffle (transducer) with radiating strips (staves) enclosed by a thin, concentric shell (dome). The behavior of the fluid is governed by the scalar wave equation, which for harmonic time dependence reduces to Helmholtz's Equation [2]. The motion of the shell is described by a set of differential equations obtained by W. Flügge [3].

A complete development of the solution describing the sound pressure field produced by the analytical model is presented in Reference 4. The modifications of the equations to include asymmetric arrays were presented in Reference 1. The equations were coded for a UNIVAC 1108 computer and numerical results were obtained using parameters appropriate to the AN/SQS-26. Since the analytical model used in this analysis is two dimensional, only the zero tilt angle modes were analyzed.

The self and mutual stave impedance study uses the expressions for the nearfield pressure field presented in Reference 5. Development of expressions for stave impedance is shown in Section C.

II. DISCUSSION

A. EFFECTS OF INOPERATIVE STAVES ON THE NEARFIELD OF THE TRACK BEAM

The farfield patterns for the Track Beam are presented in Reference 1. This section contains the nearfield patterns for six of the Track Beam configurations. The cases without and with a dome, with all staves active are shown first, followed by the remaining four cases, which have three (12.5%) and six (25%) of the staves inoperative. The inoperative staves are in "pseudo-random" locations, chosen to match those used in Reference 1. The other parameters used in the numerical computations are appropriate for the AN/SQS-26.

The peak pressure, P_m, is defined as

$$P_m = 20 \log_{10} \frac{|p \max|}{|p \max \text{ ref}|} ,$$

where $|p \max|$ is the greatest pressure magnitude in the nearfield pattern, and $|p \max \text{ ref}|$ is the greatest pressure magnitude in the nearfield of a reference pattern. The average pressure on the active portion of the transducer, P_{avg}, is given by

$$P_{avg} = 20 \log_{10} \frac{|p| \text{avg}}{|p| \text{avg ref}} ,$$

where

$|p|$ avg $= \dfrac{\int |p| dA}{A}$, and, by definition,

$|p|$ is the magnitude of the nearfield pressure,

A is the area of the active portion, and

$|p|$ avg ref is $|p|$ avg for a reference array.

These two quantities, P_m and P_{avg}, will be used to discuss nearfield results. A summary of P_m and P_{avg} for the Track Beam is given in Table I, below.

TABLE I

NEARFIELD PEAK PRESSURE AND AVERAGE PRESSURE
FOR THE TRACK BEAM (REFERENCED ARRAY 0000, NO DOME)

		Array Number as shown in Figures 1-6		
		0000	3200	6200
P_m	No Dome	0.0 dB	+0.1 dB	-0.2 dB
	Dome	+0.3 dB	+0.9 dB	-0.1 dB
P_{avg}	No Dome	0.0 dB	-0.4 dB	-0.8 dB
	Dome	+1.1 dB	-0.9 dB	+0.3 dB

For the arrays shown in Table I, the peak pressure, P_m, is increased as much as 0.8 dB by the addition of the dome. The average pressure, P_{avg}, for the cases without a dome decreases as the number of inactive staves increase. The dome produces an increase in the average pressure for Arrays 0000 and 6200 but causes a reduction of P_{avg} for Array 3200.

A study of Figs. 1-6 reveals two effects produced by the addition of a dome. First, the dome increases the level of the center of the pattern, producing an increase in peak pressure, P_m. Since the acoustic pressure is negative in one half-cycle, the greater peak pressure can result in local cavitation. Second, the dome increases the non-uniformity of the nearfield pressure amplitude. This non-uniformity in the nearfield will affect the farfield, broadening the main lobe and increasing side lobe levels.

B. EFFECTS OF INOPERATIVE STAVES ON THE NEARFIELD AND FARFIELD OF THE BOTTOM BOUNCE (45°) BEAM

The results for the Bottom Bounce (45°) Beam were obtained from the analytic model described in Reference 1. The physical parameters used in the calculations are appropriate to the AN/SQS-26. Three stave configurations are shown, the case with no inoperative staves and cases with three and six inoperative

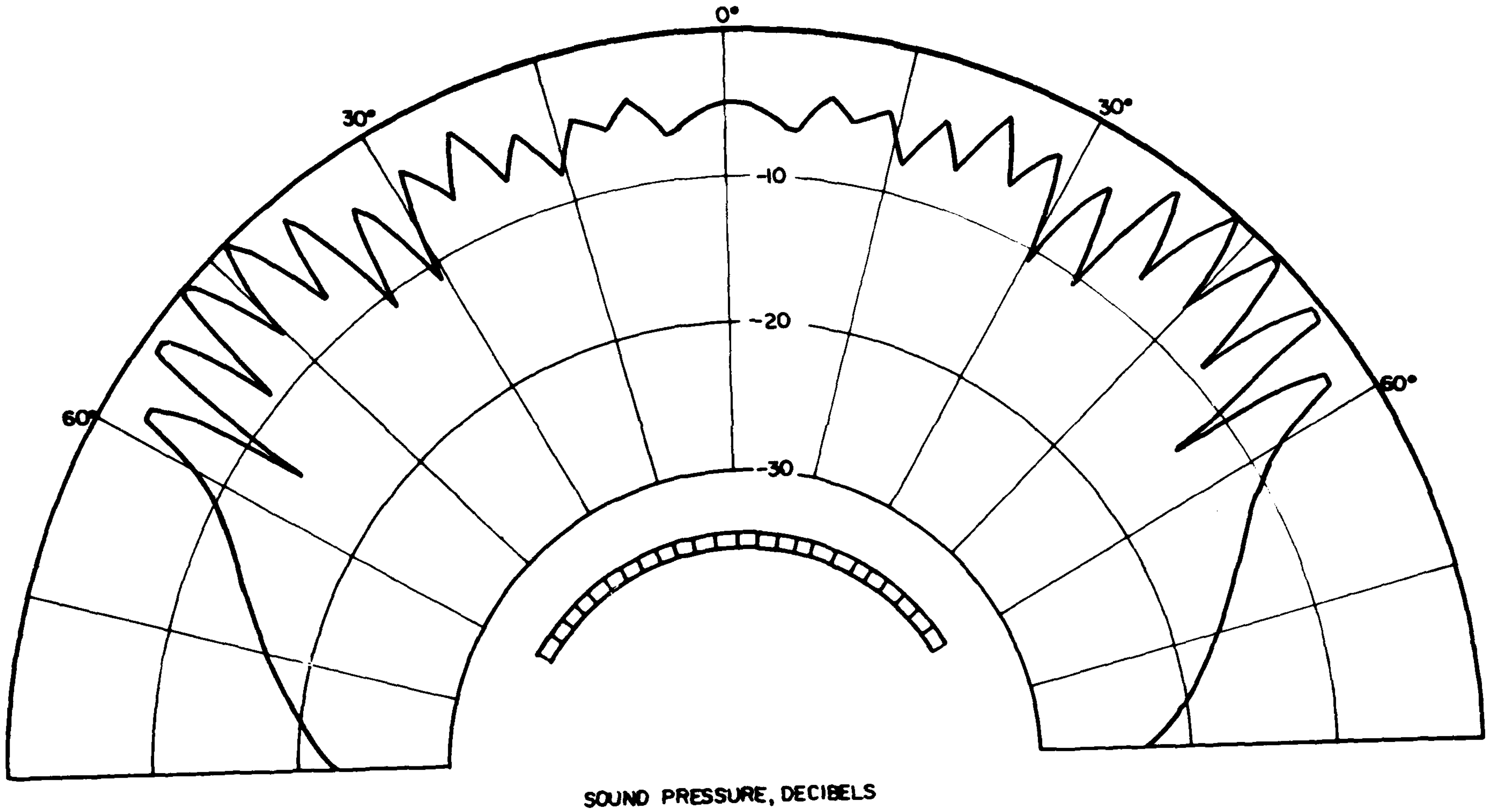

FIG. 1 - NEARFIELD PATTERN FOR ARRAY 0000 (WITHOUT DOME)

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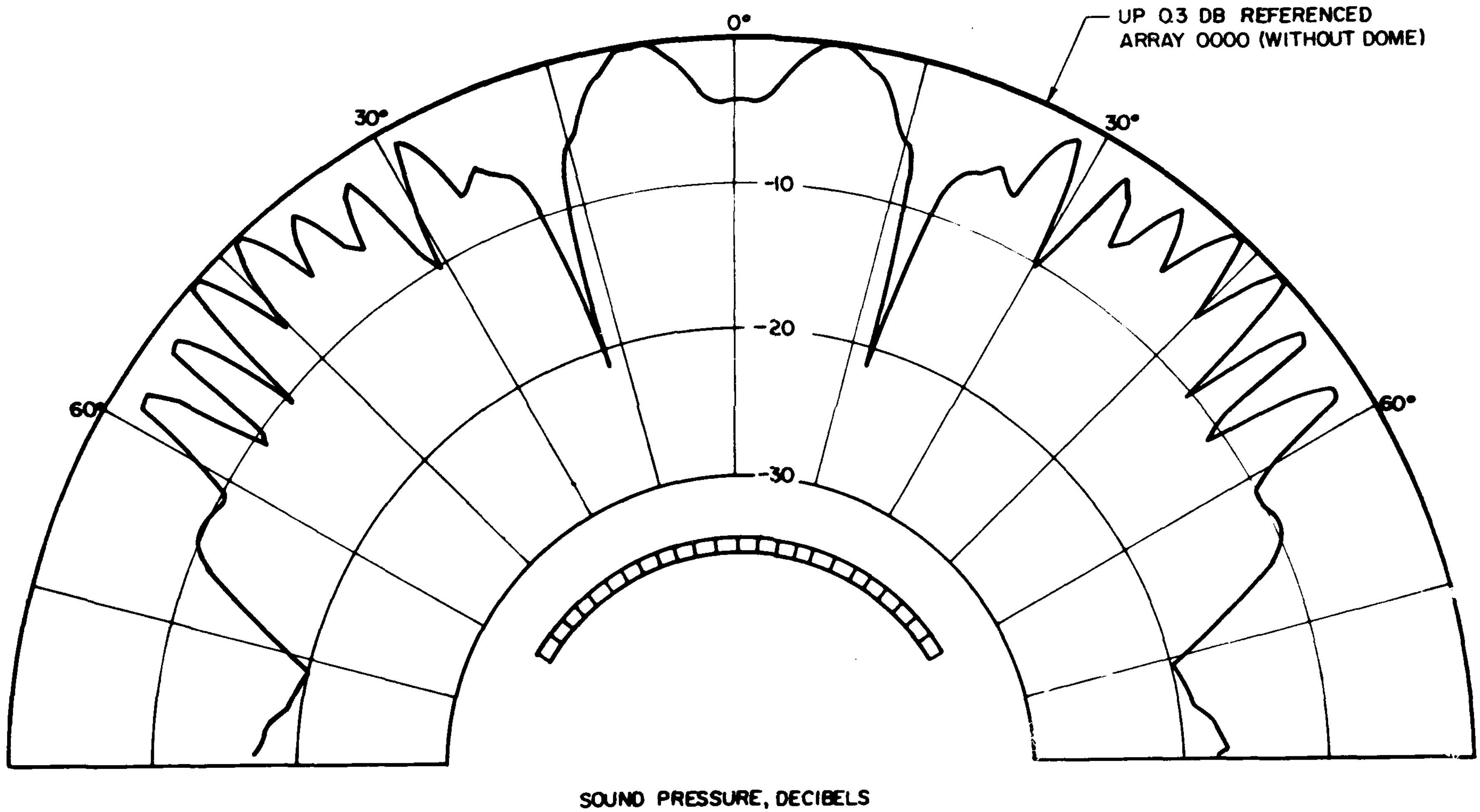

FIG. 2 – NEARFIELD PATTERN FOR ARRAY 0000 (WITH DOME)

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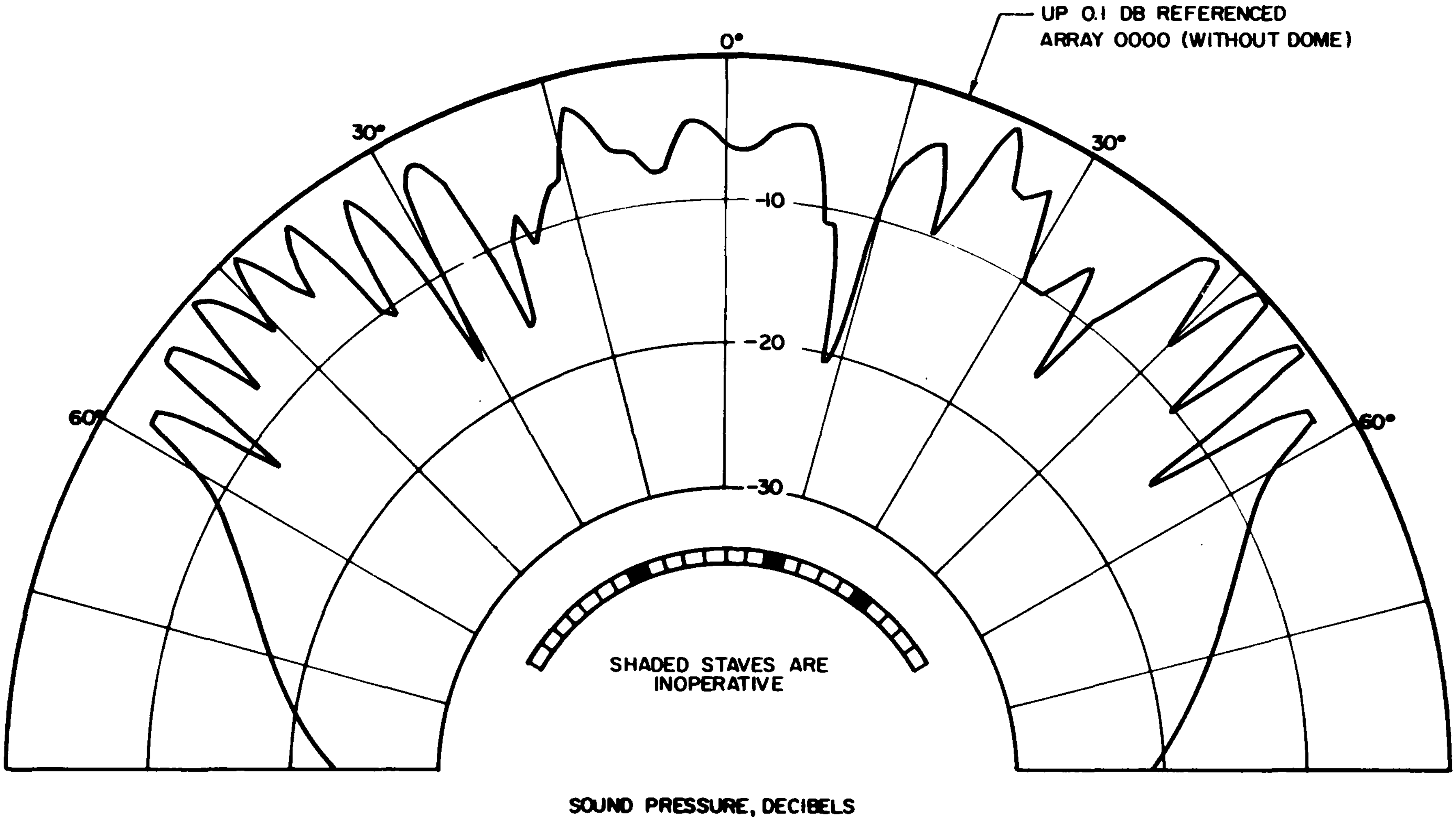

FIG. 3 — NEARFIELD PATTERN FOR ARRAY 3200 (WITHOUT DOME)

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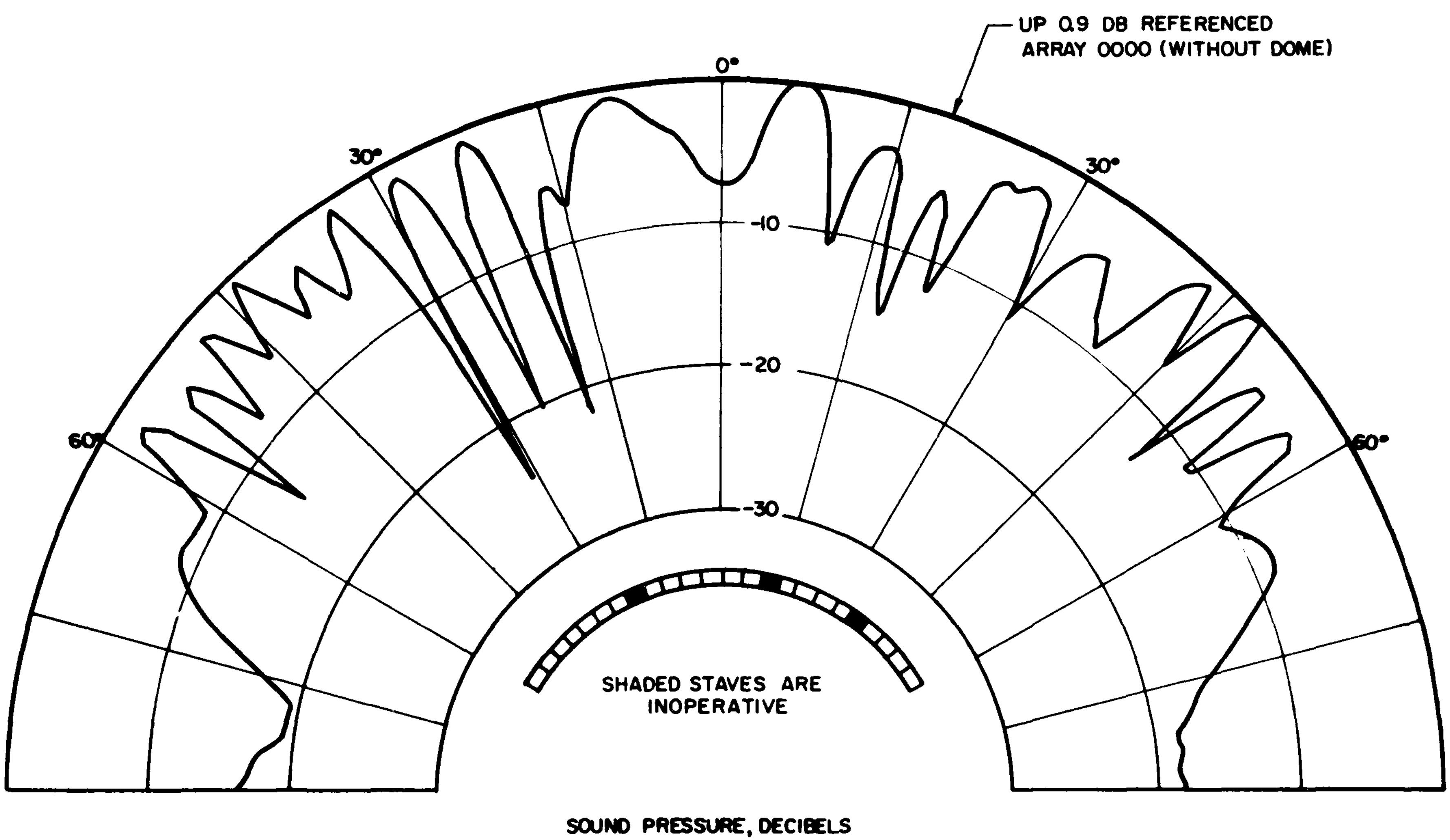

FIG. 4—NEARFIELD PATTERN FOR ARRAY 3200 (WITH DOME)

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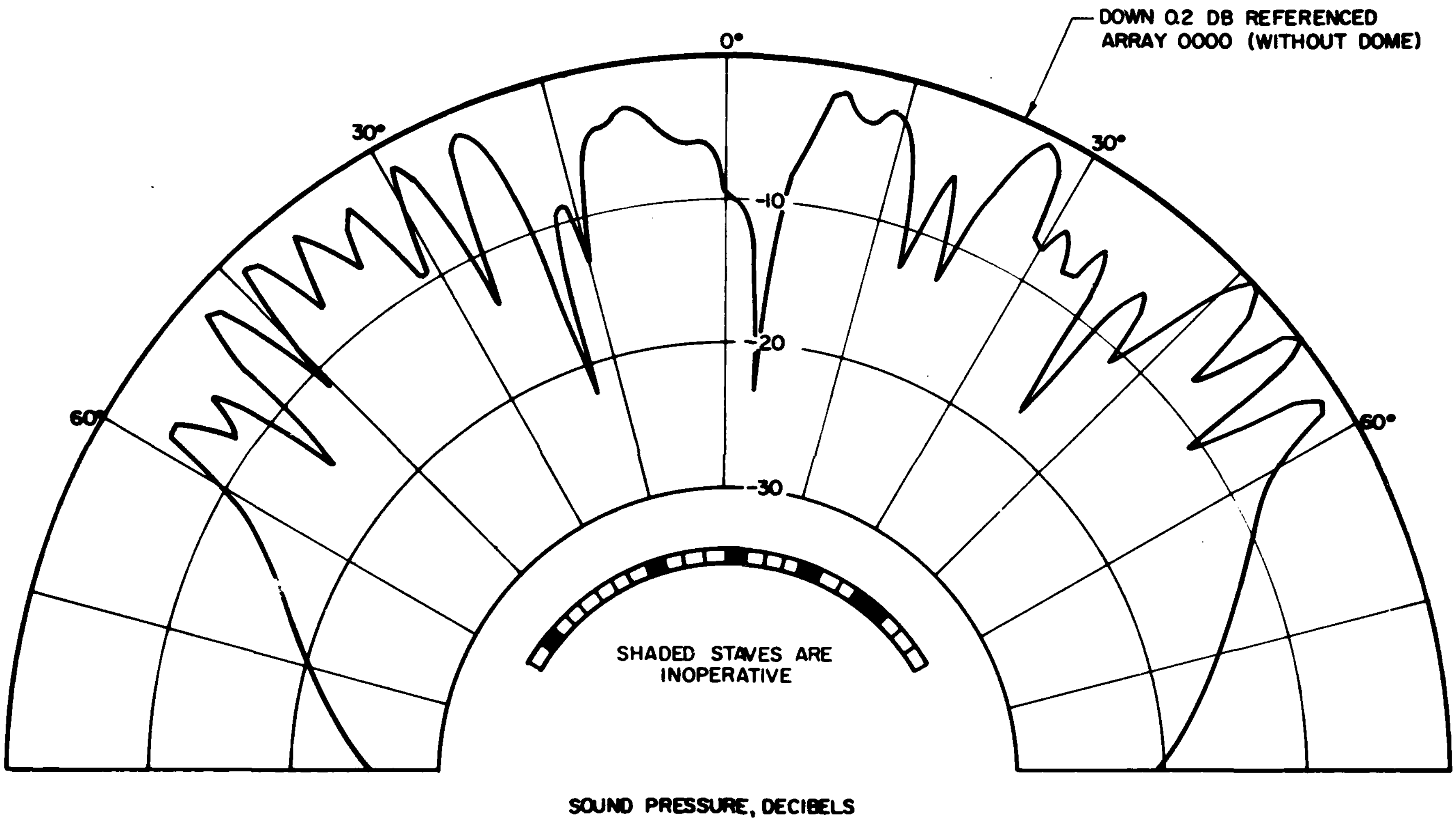

FIG. 5 — NEARFIELD PATTERN FOR ARRAY 6200 (WITHOUT DOME)

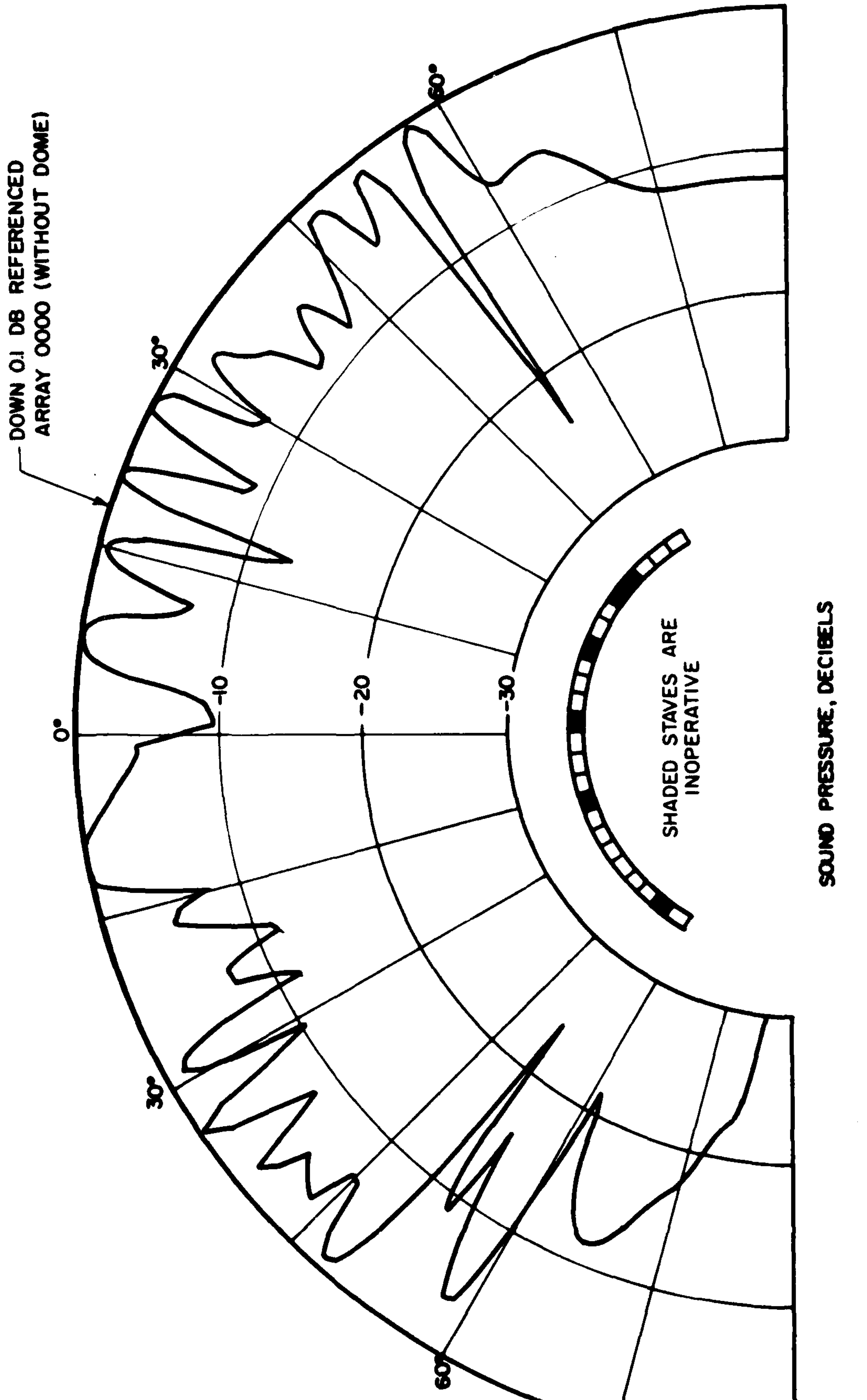

FIG. 6 – NEARFIELD PATTERN FOR ARRAY 6200 (WITH DOME)

TRACOR, INC. DWG. A6-55-23
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staves. The inoperative staves assume the same pseudo-random locations as those used to obtain the results in Section A. Near-field and farfield results with and without a dome are presented.

The 45° beam is formed with twenty-two staves. The phasings used to form this beam are shown in Table II. Each active stave in the array has unity velocity amplitude, whereas each inoperative stave has zero velocity amplitude.

TABLE II

SYSTEM PHASINGS FOR THE BOTTOM BOUNCE (45°) BEAM

Stave No.	R1 L1	R2 L2	R3 L3	R4 L4	R5 L5	R6 L6	R7 L7	R8 L8	R9 L9	R10 L10	R11 L11
Phase	0°	350°	335°	312°	281°	241°	193°	141°	81°	14°	304°

The peak pressure, P_m, and average pressure, P_{avg}, for the 45° beam arrays are shown in Table III.

TABLE III

PEAK PRESSURE AND AVERAGE PRESSURE FOR THE BOTTOM BOUNCE (45°) BEAM (REFERENCED ARRAY 0045, NO DOME)

		Array Number as shown in Figs. 7-12		
		0045	3245	6245
P_m	No Dome	0.0 dB	+1.5 dB	+2.0 dB
	Dome	+0.9 dB	+3.0 dB	+3.3 dB
P_{avg}	No Dome	0.0 dB	-0.5 dB	-0.3 dB
	Dome	-5.7 dB	-2.3 dB	-0.6 dB

Results in Table III show increasing peak pressure, P_m, as the number of inoperative staves becomes greater. The dome produces an additional increase in the peak pressure. The arrays with inoperative staves display lower average pressures, P_{avg}, and the addition of the dome reduces average pressure even more. However, the effect of the dome on the average pressure becomes less pronounced as the number of inoperative staves is increased, decreasing the average pressure 5.7 dB for array 0045, 1.8 dB for array 3245, and only 0.3 dB for array 6245.

Figures 7-12 display the nearfield pressure patterns for the 45° beam. In each of the arrays, the dome increases the level at the center of the pattern. The smoothing effect observed in the results with a dome for the Track Beam does not occur in Figs. 7-12. The effect of the dome, which is most pronounced in array 6245 (Figs. 11 and 12), is to roughen the pattern. Note that there are three nulls in the nearfield pattern shown in Fig. 11, while the same array with a dome has six nulls in the nearfield pattern, as shown in Fig. 12.

The farfield directivity patterns for the 45° beam are shown in Figs. 13-18. It can be seen in these figures that the major lobe of the 45° beam has a sub-structure with three lobes. The pattern in Fig. 13, Array 0045 (without dome), has maximum intensity in the outer lobes of the major lobe sub-structure. The pattern for the same array with a dome, Fig. 14, has maximum response in the center lobe, while the outer lobes are down 2.0 dB. Thus, the dome shifted the position of the major response. The intensity level across the 45° major lobe is not uniform for the array without a dome, and the dome increases these variations another 2.0 dB. Figures 15 and 16 are patterns for an array with three inoperative staves. The inoperative staves produce an increased level in the side lobe structure (compare Figs. 13 and 15). Parts of the side lobe structure shown in Fig. 16 are increased an additional 2.0 dB by the dome, as compared with Fig. 15 (without dome). The side lobe structures in Figs. 17 and 18, patterns for an array with six inoperative staves, are higher than those for the two previous arrays. Again, the dome produces an additional increase in the intensity of the side lobe structure.

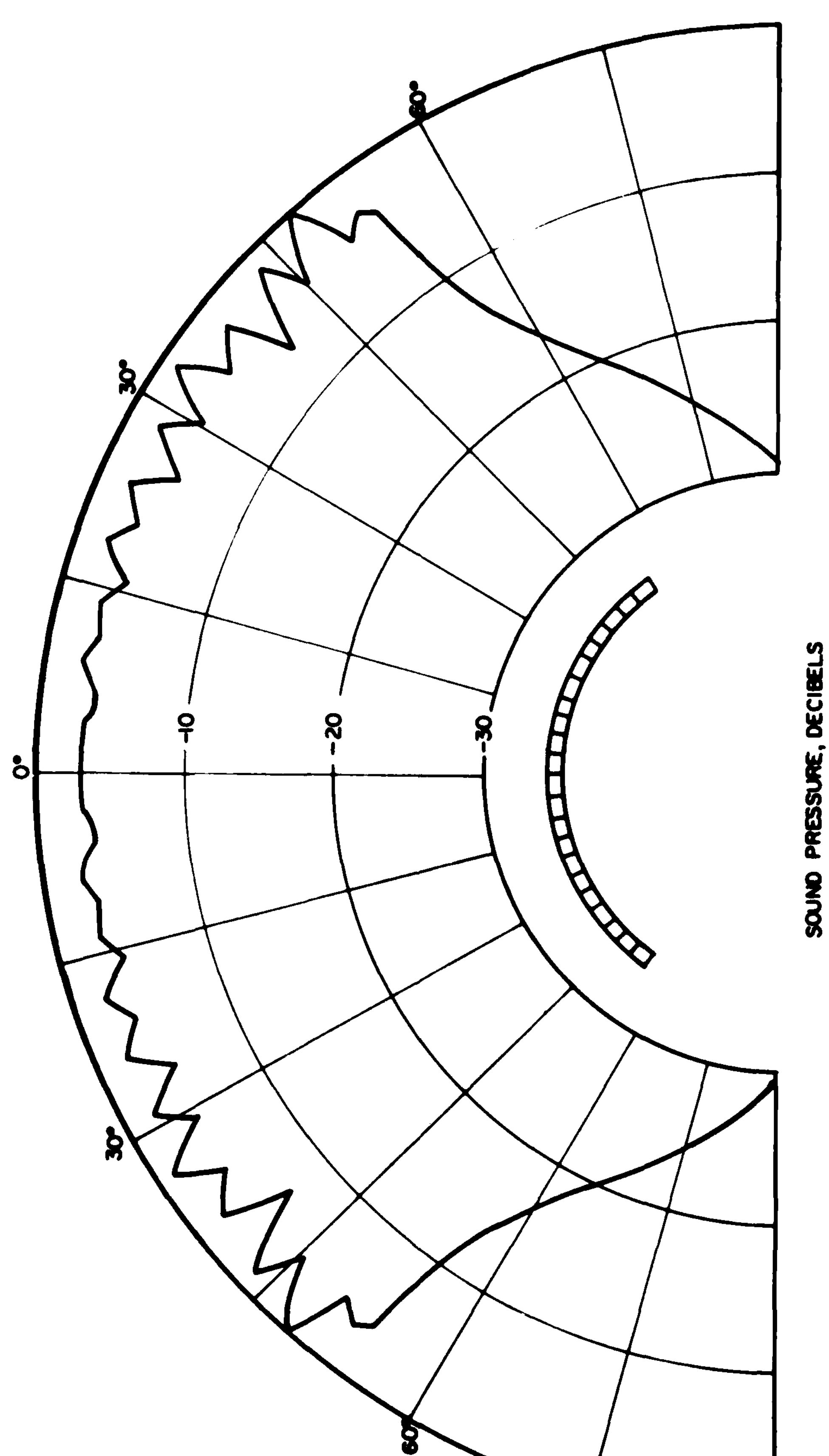

FIG.7 — NEARFIELD PATTERN FOR ARRAY 0045 (WITHOUT DOME)

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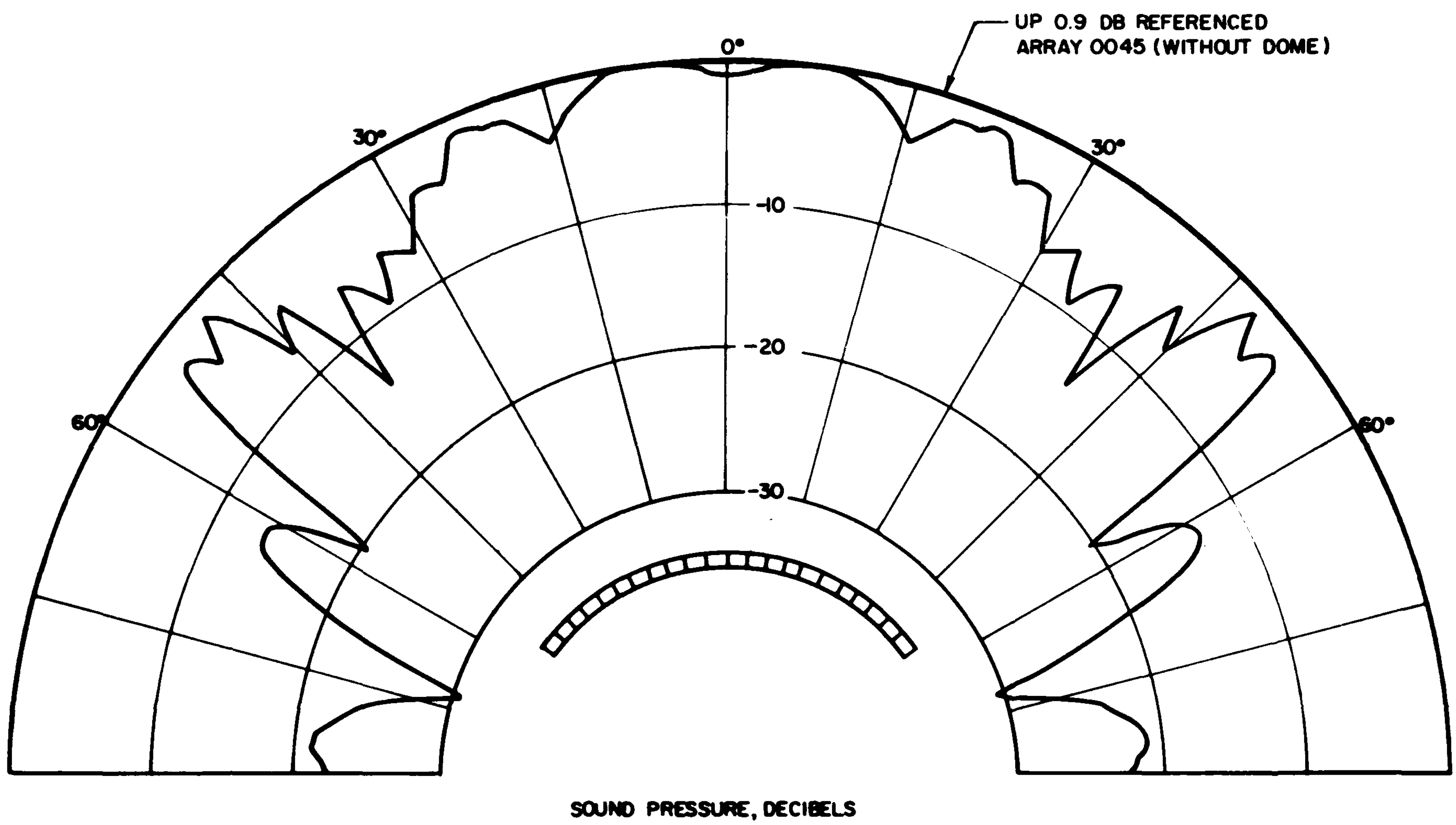

FIG. 8 - NEARFIELD PATTERN FOR ARRAY 0045 (WITH DOME)

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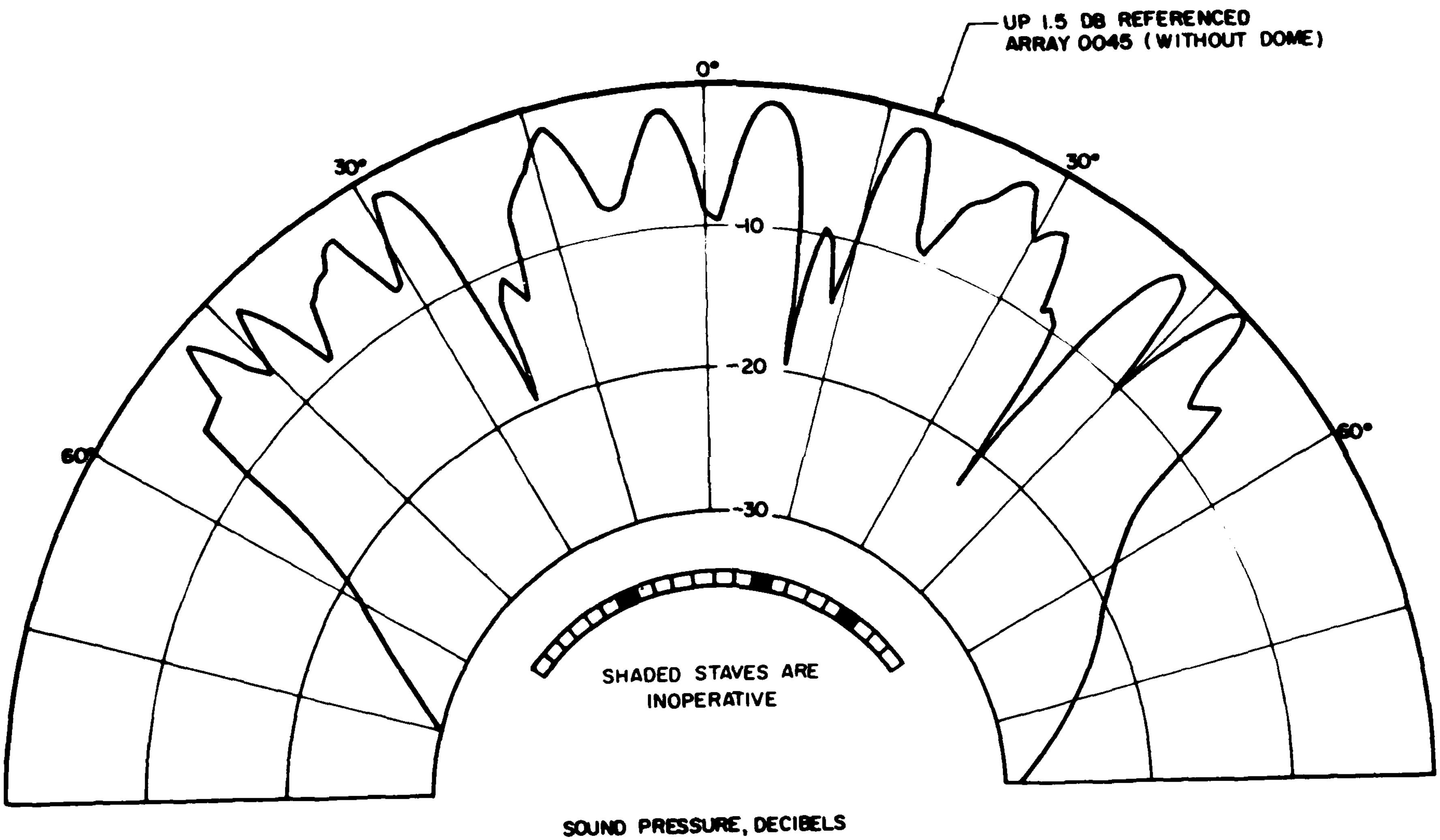

FIG. 9- NEARFIELD PATTERN FOR ARRAY 3245 (WITHOUT DOME)

TRACOR, INC.
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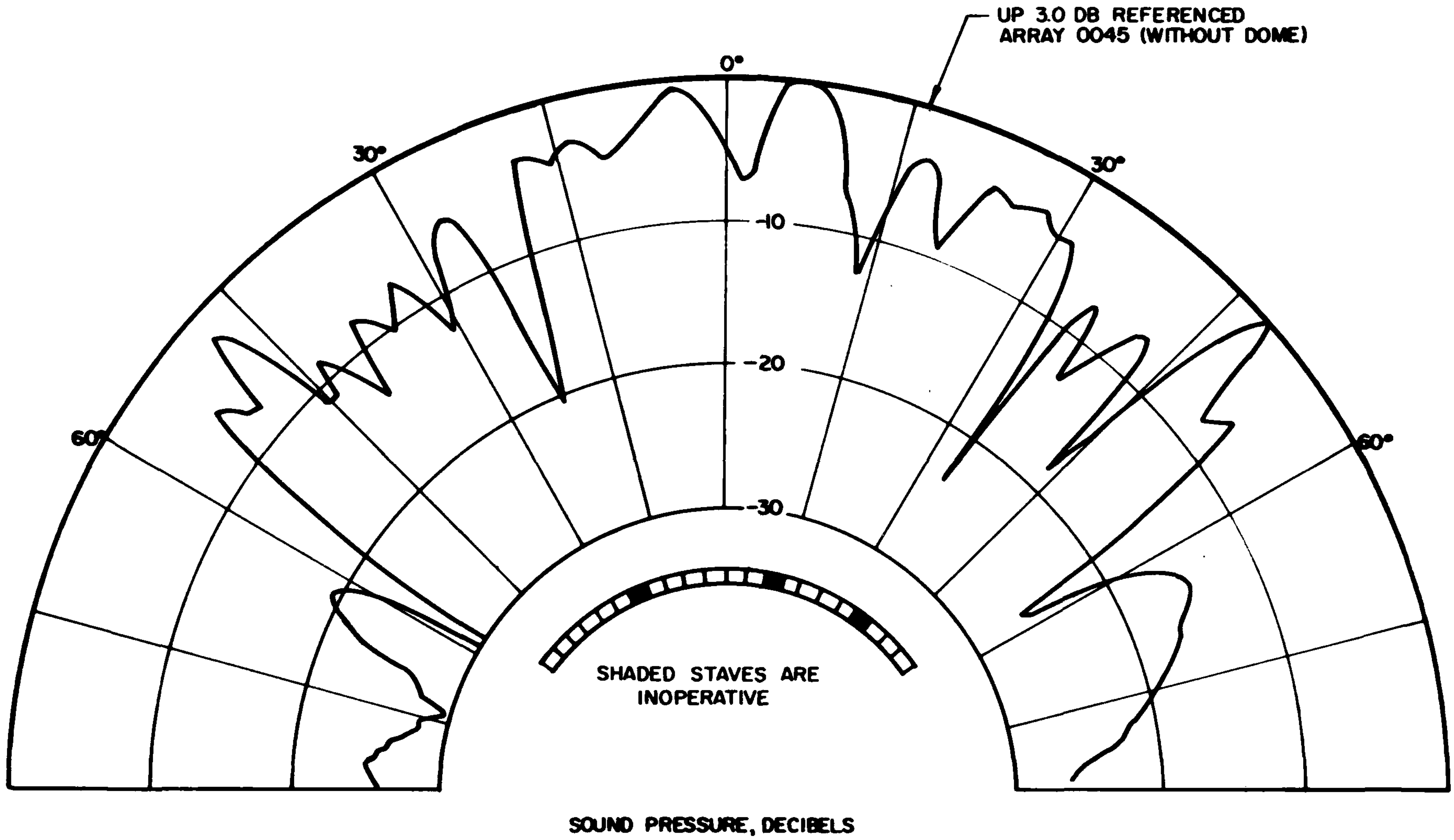

FIG.10—NEARFIELD PATTERN FOR ARRAY 3245 (WITH DOME)

TRACOR, INC. DWG. AS-55-27
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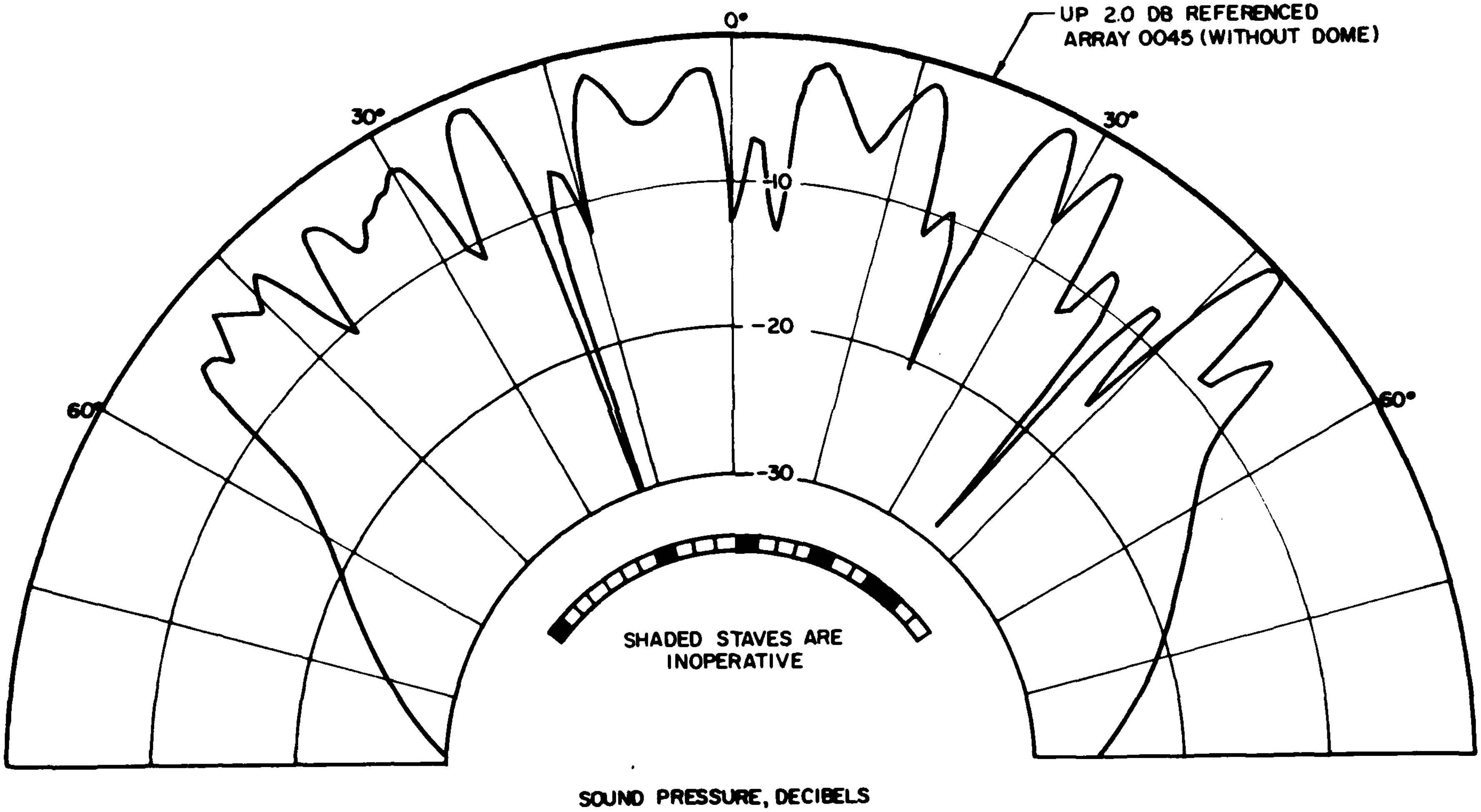

FIG. 11 - NEARFIELD PATTERN FOR ARRAY 6245 (WITHOUT DOME)

TRACOR, INC. DWG. A6-55-28
AUSTIN, TEXAS 2-16-67 MORRELL/SL

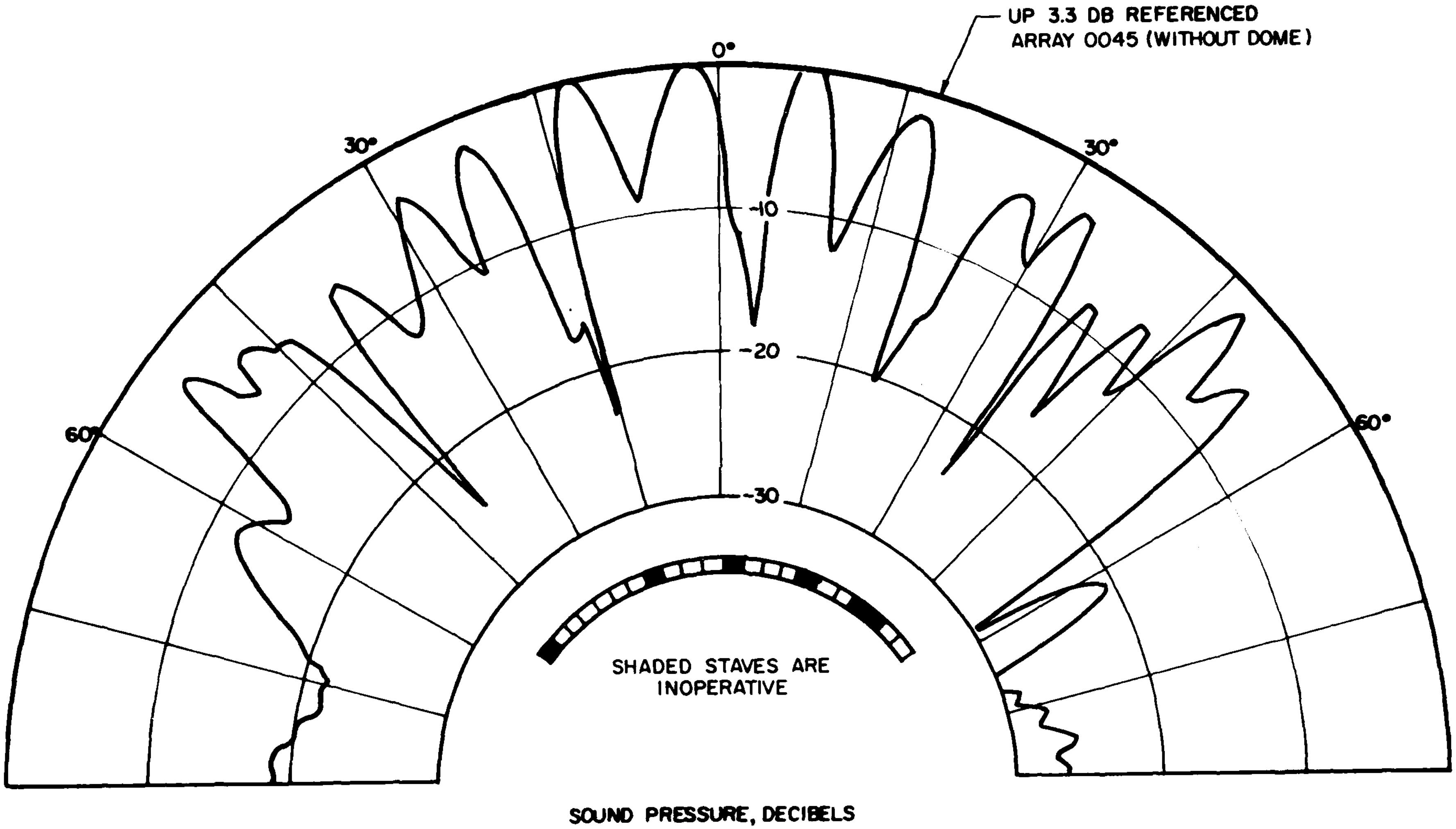

FIG. 12 - NEARFIELD PATTERN FOR ARRAY 6245 (WITH DOME)

TRACOR, INC. DWG. A6-55-29
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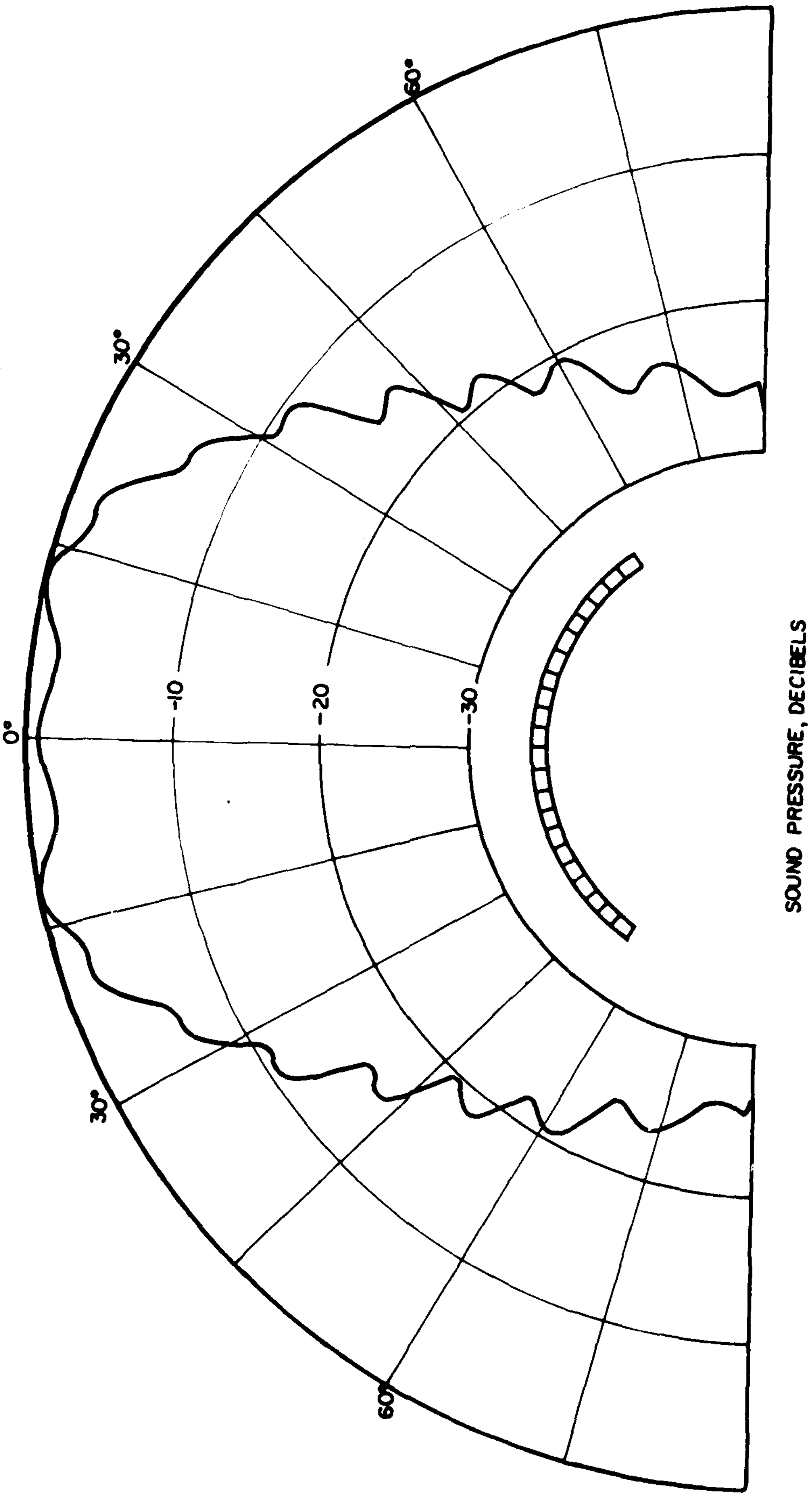

FIG.13 - DIRECTIVITY PATTERN FOR ARRAY 0045 (WITHOUT DOME)

TRACOR, INC. DWG A6-55-30
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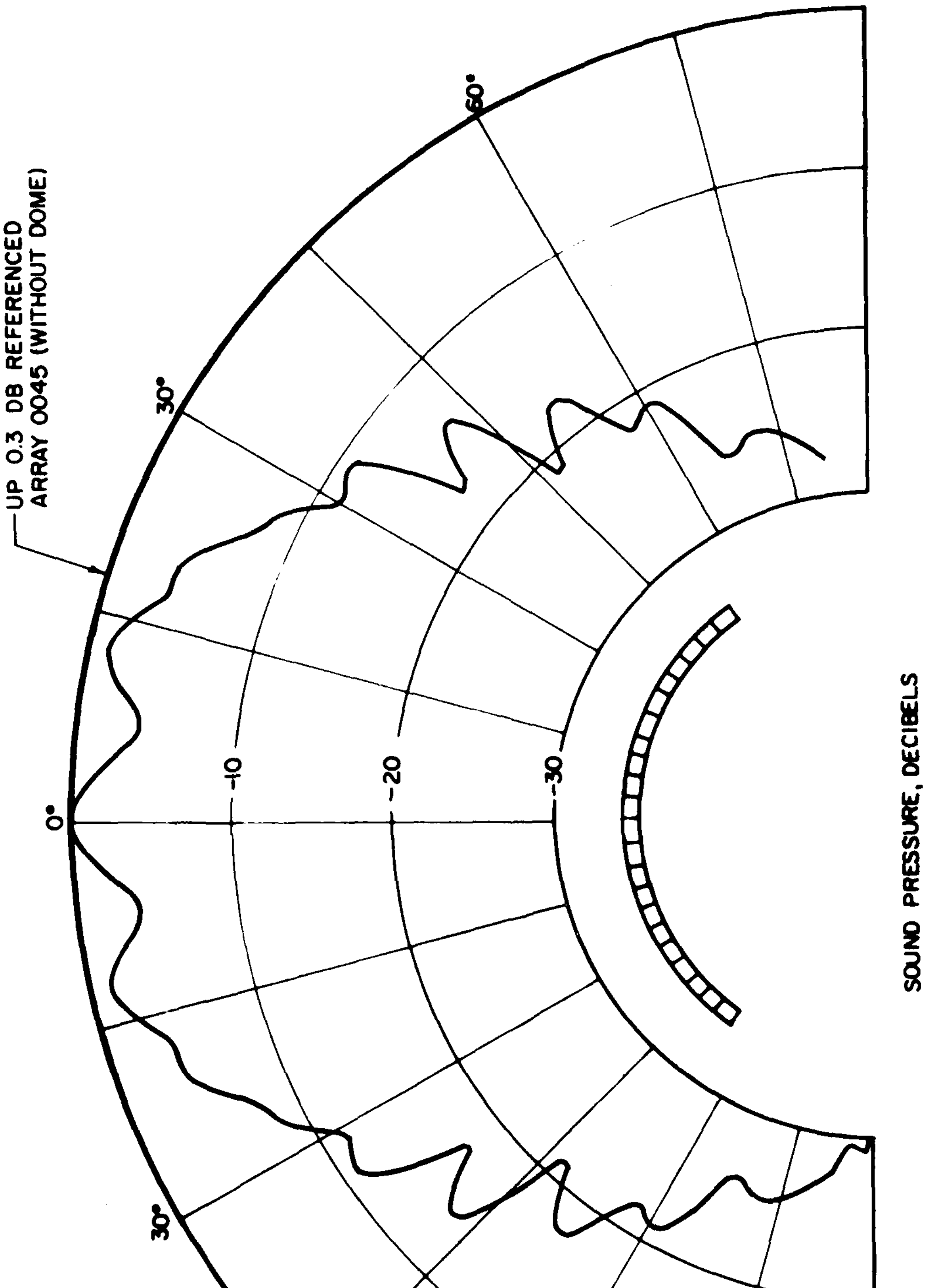

FIG.14 - DIRECTIVITY PATTERN FOR ARRAY 0045 (WITH DOME)

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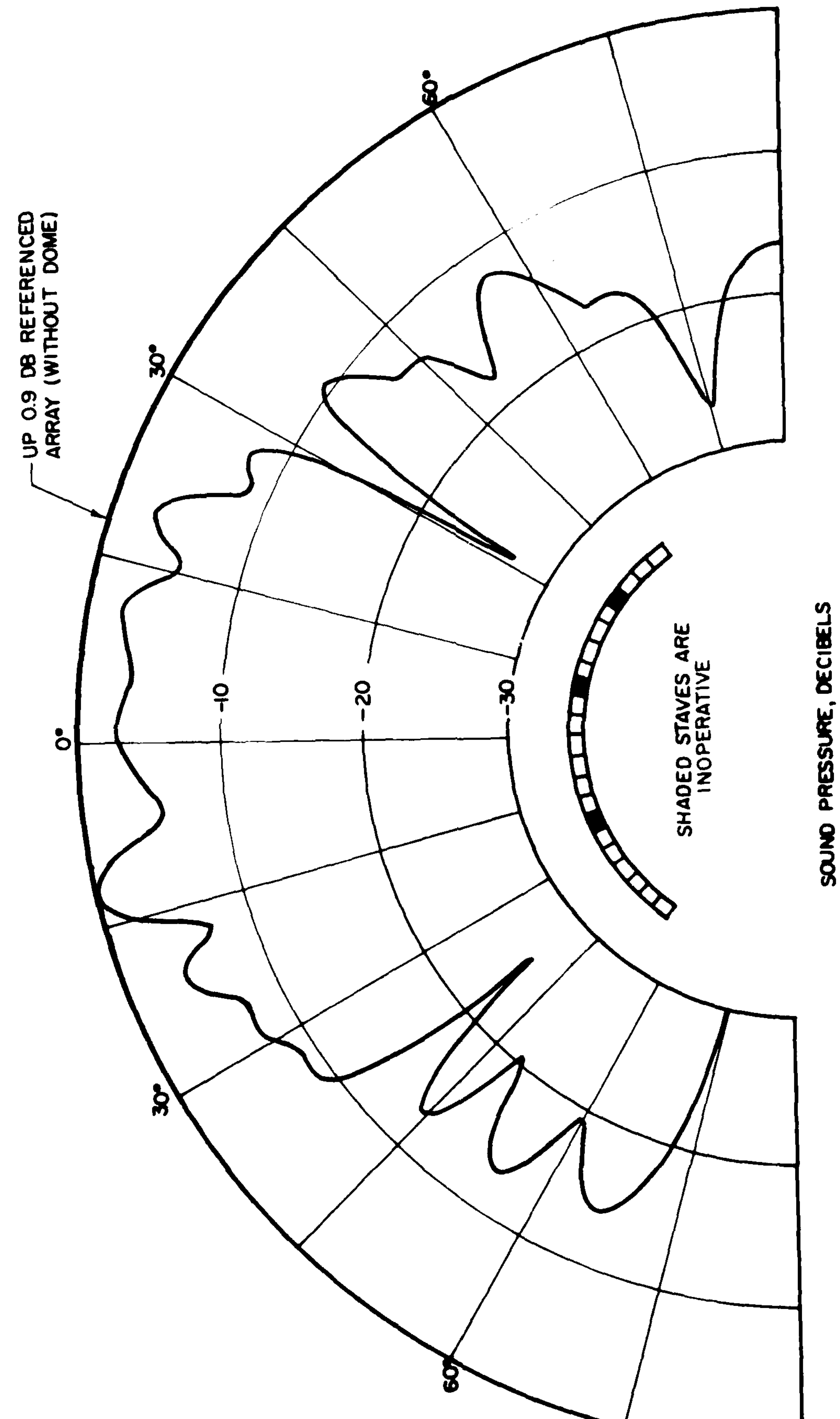

FIG. 15 - DIRECTIVITY PATTERN FOR ARRAY 3245 (WITHOUT DOME)

TRACOR, INC. DWG. A6-55-32
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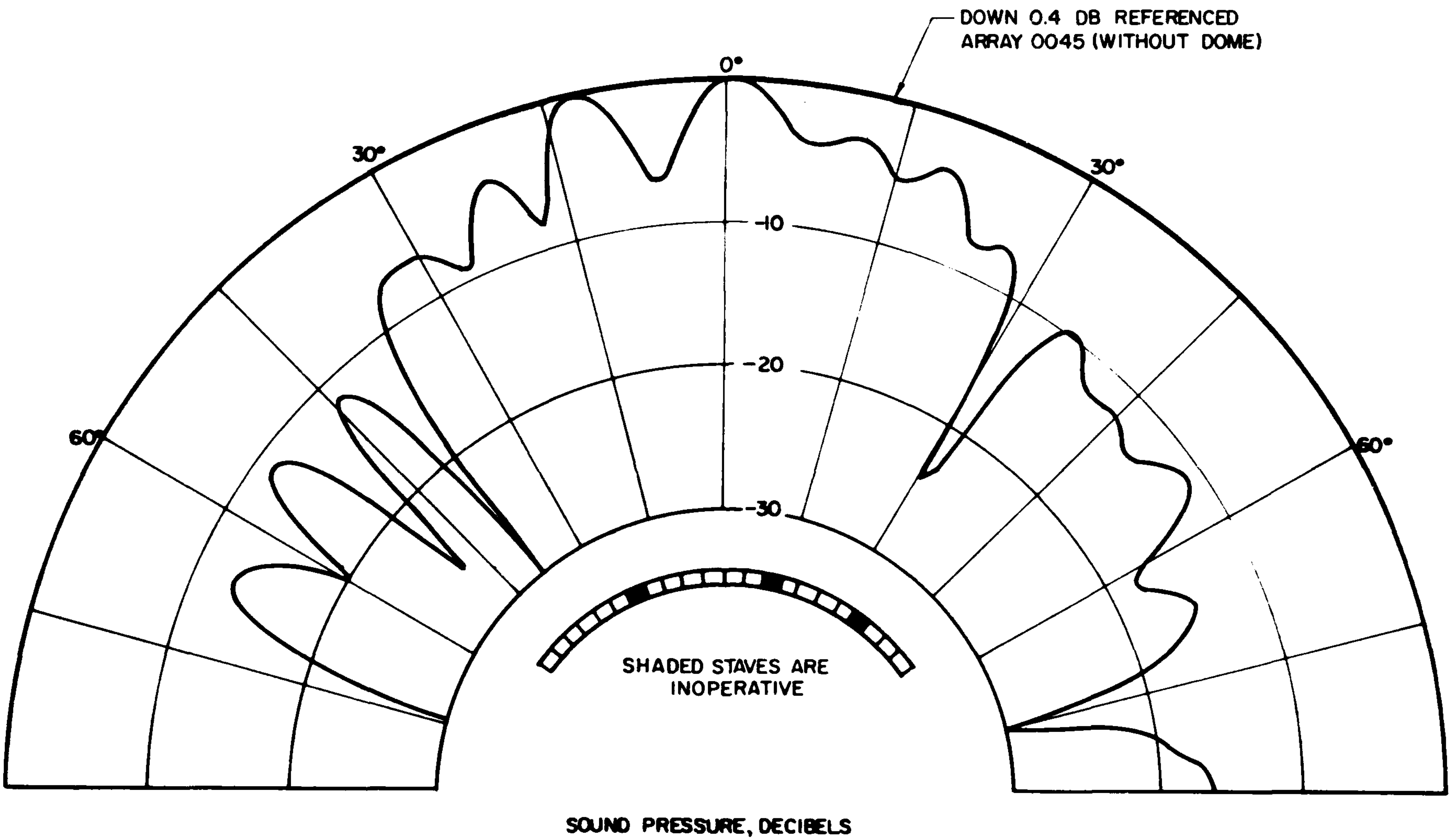

FIG. 16 – DIRECTIVITY PATTERN FOR ARRAY 3245 (WITH DOME)

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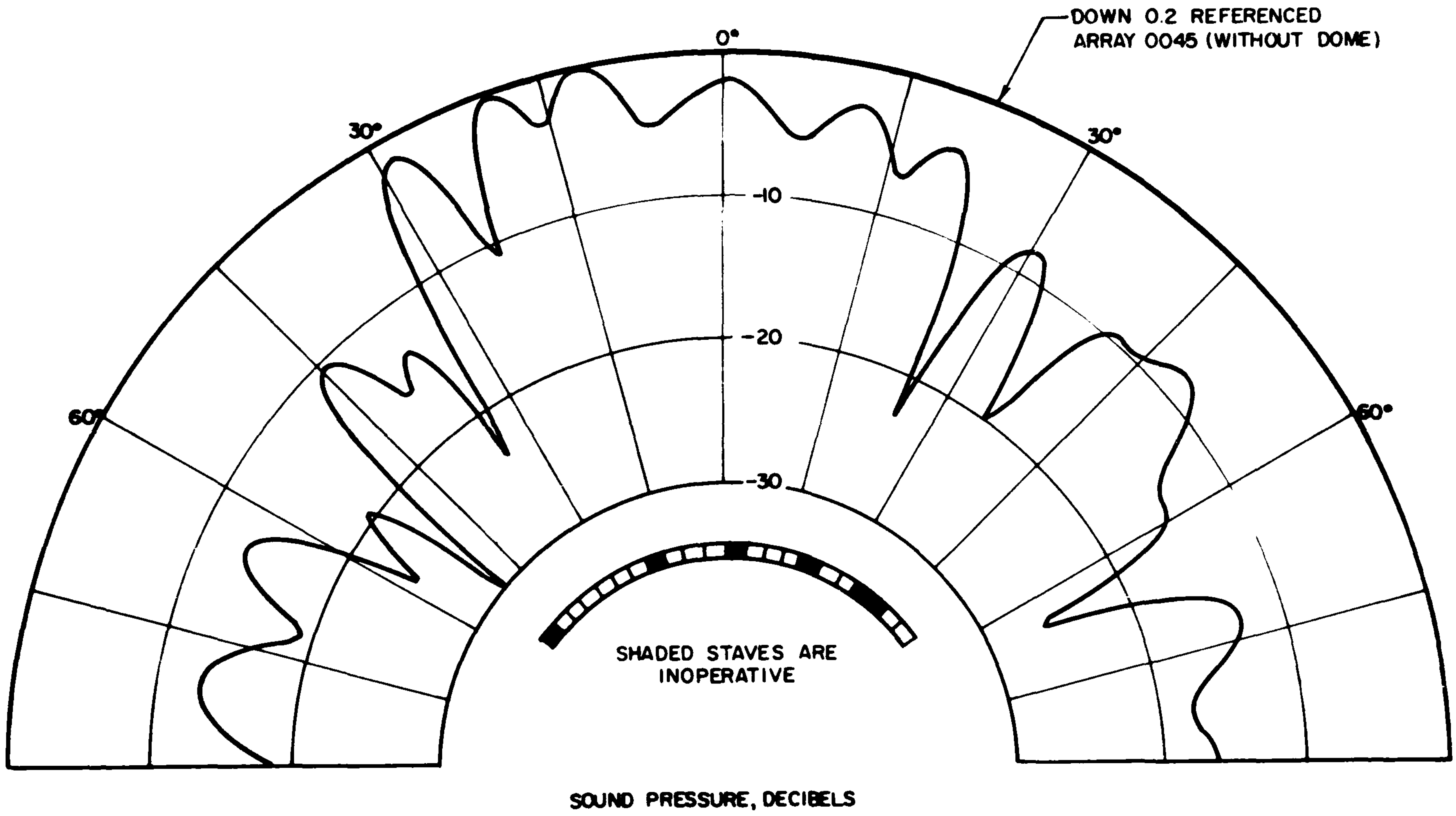

FIG. 17 – DIRECTIVITY PATTERN FOR ARRAY 6245 (WITHOUT DOME)

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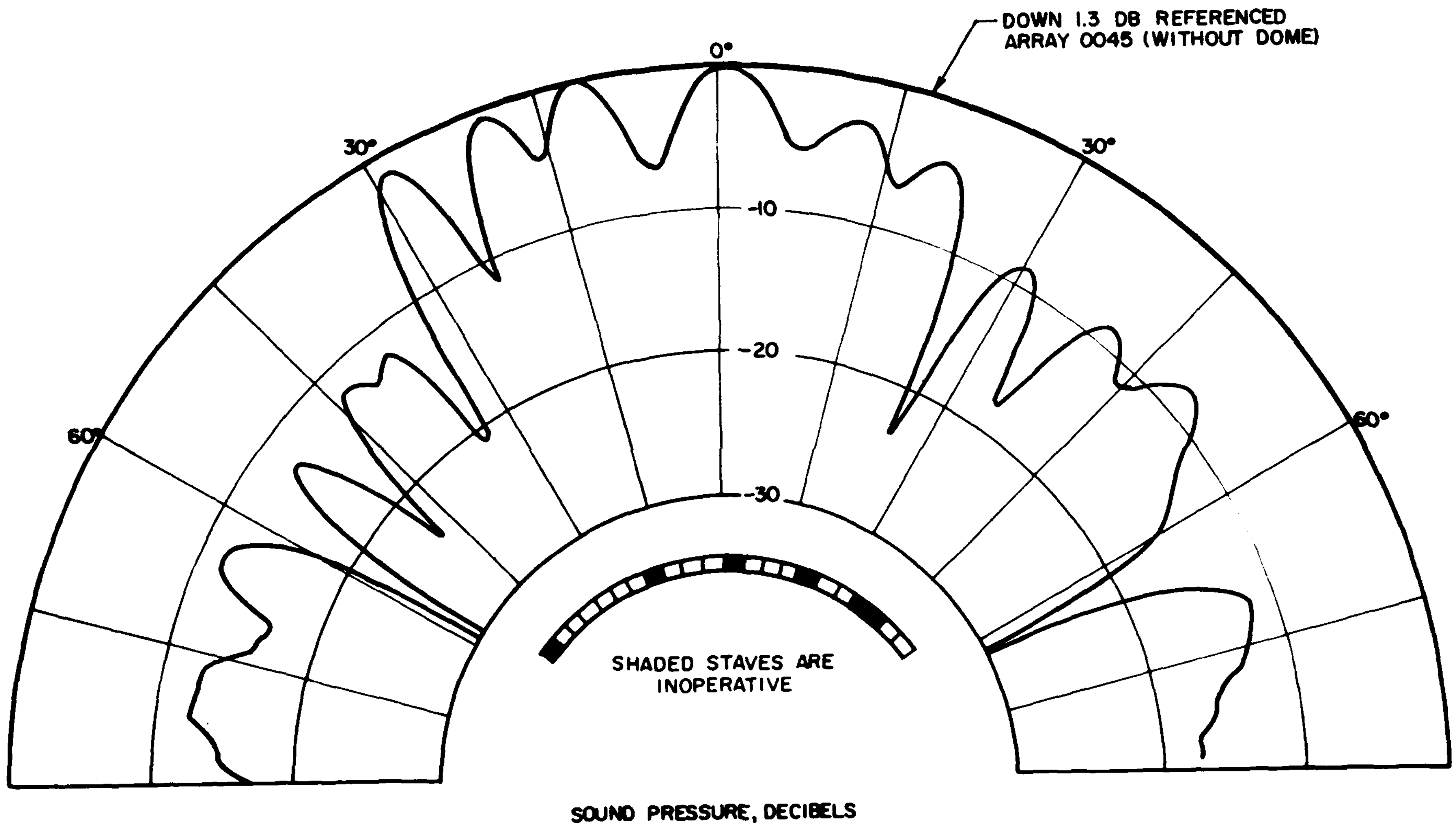

FIG.18 – DIRECTIVITY PATTERN FOR ARRAY 6245 (WITH DOME)

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However, this increase is less pronounced for Array 6245 (with six inactive staves) than for Array 0045 (with all staves active) or Array 3245 (with three inactive staves).

The Directivity Index and Major Lobe Width for the 45° beam are presented in Table IV, below. The Major Lobe Width is determined by the angular separation of the 6 dB down points in the farfield patterns. The major lobe of the Bottom Bounce Beam is narrowed by the dome. However, data for the Track Beam [1] shows a slight broadening of the major lobe as a result of the addition of the dome. The Directivity Index for the arrays shown in Table IV demonstrates no predictable behavior. The Directivity Index for the array with no inoperative staves is increased by the dome, but the dome reduces the Directivity Index of the arrays with inoperative staves.

TABLE IV

FARFIELD CHARACTERISTICS OF THE BOTTOM BOUNCE (45°) BEAM

		Array Numbers as shown in Figs. 13-18		
		0045	3245	6245
Directivity Index	No Dome Dome	9.8 dB 11.0 dB	11.3 dB 10.9 dB	10.6 dB 10.3 dB
Major Lobe Width	No Dome Dome	47.0° 45.0°	47.0° 46.5°	54.5° 54.5°

C. EFFECTS OF THE DOME ON SELF AND MUTUAL STAVE IMPEDANCE

The self and mutual impedances of rectangular elements in a cylindrical baffle have been evaluated in the absence of a dome [6,7,8]. Although an analysis, similar to the one in Reference 6, of self and mutual element impedances with a concentric shell (dome) has been performed, evaluations of the resulting equations are not yet tractable.

However, evaluation of self and mutual impedances of infinite strips (staves) on a cylindrical baffle is practical for cases with and without a dome. The case without a concentric shell has been investigated by others [7,9]. A brief description follows of the development of the expressions used in this memorandum to evaluate the impedances.

Equations describing the nearfield pressure for the two-dimensional model were presented in Appendix A of Reference 6. Reference 4 contains the detailed development of the equations describing the acoustic pressure field. The expression for the nearfield pressure at the surface of the baffle (transducer) is given by

$$p = \sum_{n=0}^{\infty} \left\{ \frac{H_n(ka) + h\gamma_n H_n'(kb)[J_n'(kb)N_n(ka) - J_n(ka)N_n'(kb)]}{H_n'(ka) + h\gamma_n H_n'(kb)[J_n'(kb)N_n'(ka) - J_n'(ka)N_n'(kb)]} \right\} \quad (1)$$

$$\cdot\ \delta_n \cos n\theta\, e^{-i\omega t} ,$$

where

$$\gamma_n = \frac{\pi b}{2\rho c^2} \left\{ \rho_s \omega^2 - \frac{E_s}{b^2}\left[1 + \frac{h^2}{12b^2}(n^4 - 2n^2 + 1)\right] - \frac{E_s^2 n^2}{b^2(b^2\omega^2\rho_s - E_s n^2)} \right\}, \quad (2)$$

and where

a = radius of cylindrical baffle (transducer),

b = mean radius of concentric shell (dome),

ρ = density of fluid (water)

ρ_s = density of shell material (steel),

E_s = modulus of shell material,

h = thickness of shell,

k = wave number, ω/c,

c = speed of sound in fluid,

ω = frequency of transmission,

J_n = Bessel Function of order n,

N_n = Neumann Function of order n,

H_n = Hankel Function of the first kind $[=J_n + iN_n]$, of order n,

$'$ = derivative with respect to the argument, and

δ_n = constant to be evaluated by the velocity condition.

The boundary condition to be used is a single strip (stave) with unity velocity amplitude. The stave has an angular width of 2φ and is centered at $\theta=0$, where θ determines the angular position of any point on the surface of the array. This condition yields

$$\delta_n \begin{cases} = i\rho c \dfrac{2\varphi}{\pi} \dfrac{\sin n\varphi}{n\varphi} & n \neq 0 \\ = i\rho c \dfrac{\varphi}{\pi} & n=0 \end{cases} \tag{3}$$

Substituting Eq. (3) in Eq. (1) yields the form

$$p = i\rho c \left\{ C_o \frac{\varphi}{\pi} + \sum_{n=1}^{\infty} C_n \frac{2\varphi}{\pi} \frac{\sin n\varphi}{n\varphi} \cos n\theta \right\} e^{-i\omega t} , \tag{4}$$

where C_j is the collection of terms inside the braces in Eq. (1). The mutual impedance between the i^{th} and j^{th} stave is defined by

$$Y_{ij} = \frac{1}{v_i} \int_{A_j} p_i \, dA_j , \tag{5}$$

where p_i is the nearfield pressure at the j^{th} stave as a result of the motion of the i^{th} stave, v_i is the velocity of the i^{th} stave, and A_j is the area of the j^{th} stave. The staves in the analytic model are of infinite length, so the results are evaluated per unit length of stave. For the j^{th} stave (centered at $\theta = \theta_j$) Eq. (5) reduces to*

$$Y_j = \int_{\theta_j-\varphi}^{\theta_j+\varphi} i\rho c \left[C_o \frac{\varphi}{\pi} + \sum_{n=1}^{\infty} C_n \frac{2\varphi}{\pi} \frac{\sin n\varphi}{n\varphi} \cos n\theta\right] a d\theta \ . \qquad (6)$$

Evaluation of the integral yields

$$Y_j = i\rho c \left\{C_o \frac{2a\varphi^2}{\pi} + \sum_{n=1}^{\infty} C_n \frac{\sin n\varphi^2}{n\varphi} \cos n\theta_j\right\} \ . \qquad (7)$$

Parameters appropriate to the AN/SQS-26 were used in Eq. (7) to determine the self and mutual stave impedances. The stave impedances are normalized to ρcA and separated into real and imaginary parts as presented in Table V. The "j" in Table V corresponds to the center-to-center spacing of the staves defined by

$$\theta_j = j(2\varphi). \qquad (8)$$

Thus j=0 is the case for self impedance; j=1 is for the case of mutual impedance for adjacent staves, j=2 for the case with one intervening stave, and j=23 for the case with 22 intervening staves.

A survey of Table V shows some negative resistive components of impedance. This result has been observed in other analyses [6,7, 8,9]. Comparison of the results with and without a dome reveals the following:

1. The dome reduces the real part and increases the reactive part of self impedance (j=0).
2. Adding the dome increases the magnitude of most of the mutual impedances (Y_j).
3. The effects of the dome on individual staves are mixed, i.e., there are various permutations of increased real parts, decreased real parts, increased reactive parts, and reduced reactive parts.

*All stave mutual impedances will be relative to stave "0", i.e., the stave located at $\theta=0$.

TABLE V

SELF AND MUTUAL STAVE IMPEDANCE

j	Real Part		Imaginary Part	
	No Dome	Dome	No Dome	Dome
0	+1.033	+0.914	-0.336	-0.560
1	-0.089	-0.146	+0.023	-0.001
2	+0.081	+0.175	-0.016	-0.327
3	-0.096	+0.045	+0.088	+0.124
4	+0.056	+0.005	-0.087	+0.022
5	-0.074	-0.130	+0.041	-0.047
6	+0.038	+0.160	-0.053	-0.020
7	-0.058	-0.161	+0.015	+0.111
8	+0.024	-0.044	+0.034	-0.146
9	-0.046	+0.003	-0.000	+0.116
10	+0.013	-0.069	-0.022	-0.060
11	-0.037	+0.023	-0.008	+0.015
12	+0.005	-0.029	-0.016	-0.008
13	-0.029	-0.010	-0.013	+0.027
14	-0.001	-0.036	-0.013	-0.045
15	-0.024	+0.027	-0.015	+0.043
16	-0.006	-0.078	-0.012	+0.029
17	-0.020	+0.048	-0.016	-0.010
18	-0.009	-0.067	-0.012	+0.004
19	-0.018	+0.024	-0.016	-0.004
20	-0.011	-0.050	-0.012	-0.002
21	-0.016	+0.016	-0.016	+0.003
22	-0.012	-0.049	-0.012	-0.003
23	-0.015	+0.017	-0.015	-0.002

III. CONCLUSIONS

The results of this study support the following conclusions:

A. NEARFIELD OF THE TRACK AND BOTTOM BOUNCE BEAMS

1. Addition of the dome in cases with and without inoperative staves increased the peak pressure.
2. Inoperative staves increased the non-uniformity of the pressure field over the active portion of the array.

Each of these phenomena can contribute to the onset of cavitation in the nearfield or at the face of the transducer.

B. FARFIELD OF THE BOTTOM BOUNCE BEAM

1. The structure of the farfield patterns for the Bottom Bounce 45° beam was altered greatly by inoperative staves.
2. The dome produced increased levels of side lobe structure, and non-uniformity in the level across the width of the major lobe.

The performance of the Bottom Bounce Beam will be degraded by these factors.

C. SELF AND MUTUAL IMPEDANCE

1. Most of the mutual impedance magnitudes increased as the result of the addition of the dome, creating a need for larger instantaneous power levels to achieve the same transducer head velocities.
2. The reduction of the real part of self impedance caused by the dome will result in less energy being transferred into the sea.

Since the impedance at a stave is the sum of the contributions of all active staves, the total effect of the dome can only be found for specific velocity configurations.

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13. ABSTRACT

This memorandum presents some computed results of the effects of inoperative staves in the presence of a dome on the nearfield and farfield patterns of the AN/SQS-26. Self and mutual stave impedances are given. The results are obtained from equations describing a two-dimensional model composed of a cylindrical baffle (transducer) with radiating strips (staves) enclosed in a thin, concentric shell (dome).

The results show that for both the Track and Bottom Bounce Beams the dome increases the peak pressure in the nearfield as compared to that of a bare transducer. The inoperative staves produce additional non-uniformity of intensity across the major lobe in the farfield pattern of the Bottom Bounce (45 deg) Beam. The dome increases the level of the side lobe structure, further degrading the farfield pattern. The dome causes an increase in the magnitude of most stave impedances but reduces the real part of self impedance.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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