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A Improved Version of the NUSC Train of Computer Programs for Transmitting Sonar Array Prediction

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ABSTRACT

The fifth version of the NUSC Transmitting Train of Programs comprises nine computer programs that predict the electrical, mechanical, and acoustical behavior of sonar arrays. Several improvements and necessary changes have been made to the older version of the train of programs resulting in a new version with greater versatility. The nine programs, which have been completely interfaced by tape and drum connections, can now be run together in one computer run. A description of the updated programs is provided and the currently required input data and control cards are given together with samples of the plotted output.

REVIEWED AND APPROVED: 13 August 1971

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ADMINISTRATIVE INFORMATION

The development and documentation of this version of the train of programs were done in fiscal years 1970 and 1971 under the following projects and sponsors:

Project No./Title/Principal Investigator	Navy Subproject and Task No./Program Manager
A-452-00-00 Research on Transducers for Sonars D. T. Porter, Code TD1	SF 11 121 301-14077 G. Moore, NAVSHIPS 901D
G-653-01-00 Mutual Interference Reduction Program R. L. Boivin, Code SA2	S 2202-08663 H. B. Latimer, NAVSHIPS PMS-387
A-231-00-00 Holographic Measurements of Sonar Transducer Array Interactions G. M. Mayer, Code EB2	SF 11 121 303-14074 G. Moore, NAVSHIPS 901D

The author acknowledges the significant contributions of Charles R. Minter, who accomplished the replacement of tape storage by drum storage; Richard MacDonald, who made numerous runs with the program and was largely responsible for its debugging; Andrew A. Lesick, who provided the plotting subroutines used in Programs S1111 and S1478; and Roy D. Clark, who was consulted on many difficult problems throughout the project.

The Technical Reviewer for this report was Dr. Charles H. Sherman, of the Sonar Technology Department (Code TD1), Science and Technology Directorate.

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INTRODUCTION

The Transmitting Train of Programs (TTOP) was designed by the Naval Underwater Systems Center (NUSC) for computation of the electrical, mechanical, and acoustical behavior of arrays of ceramic longitudinal vibrators or flexural disks mounted on plane, cylindrical, or spherical baffles. There have been four previous versions of the train of programs.[1,2,3] Familiarity with these older versions is desirable for a good understanding of this report. Since the time that the fourth version was reported on, several improvements and necessary changes have been made to the train of programs. These improvements include the addition of the General Electric Stress-Strain Histogram Program, the addition of two flexing head models, the substitution of scratch drum area for scratch tapes, use of the Stromberg-Carlson 4060 cathode ray tube plotter, and the addition of CALCOMP plots of electrical impedances, admittances, acoustical transmitting responses, and other array data.

The report describes this improved version of the train of programs and documents the input data and control cards currently required for the NUSC UNIVAC 1108. Appendixes to the report present discussions of flexing head theories, nearfield-farfield source level corrections, use of this train of programs for analyzing receiving arrays, and multielement amplifier capability. Also provided is a comparison of this new version of the train of programs with the four older versions.

Throughout the report, this fifth version of the Transmitting Train of Programs is referred to as TTOP5.

TTOP5 EQUIPMENT REQUIREMENTS

TTOP5 is located on File 1 and 2 of Cur Tape U468 in the NUSC Digital Computing Branch. Program S1625 and its subroutines are on File 2; all other programs are located on File 1. This version was programmed for the NUSC UNIVAC 1108, which has a core storage of 65,536 words and an Executive II monitoring system. However, care was taken to do as much programming as possible in standard FORTRAN statements.

Considerable use is made of scratch drum area in TTOP5. A FASTRAND drum is not required. A modified NTAB table has been assembled (element IOTAB), which assigns unit numbers to scratch drum areas and to three scratch tapes. IOTAB currently reserves 987,136 (decimal) words or 3,610,000 (octal) words of scratch drum storage. This capacity would still be adequate if the maximum array size (without symmetry) were increased from 200 to 400. By appropriately editing IOTAB, TTOP5 could be run with approximately 250,000 (decimal) words of scratch drum storage.

All of the plotting in TTOP5, with the exception of that done in Program S0577B, is accomplished on a Stromberg-Carlson Model 4060 IGS cathode ray tube plotter. (S0577B uses a small CALCOMP plotter.) The plotting commands in TTOP5 are all in the CALCOMP language. A CALCOMP to IGS conversion package is brought in from File 1 of Cur Tape U172 to construct IGS plots from the CALCOMP information produced. The programs in TTOP5 using the IGS plots all contain the command "CALL PLOT (0,0,993)" at the end of each computed plot. This command activates the CALCOMP to IGS conversion package. A user wanting CALCOMP plots instead of IGS plots would have to remove this command, and insert in its place the page advance command "CALL PLOT (12.0,-12.0,-3.)"

A maximum of seven tapes would be needed for a run: A Cur Tape, three scratch tapes, a CALCOMP plotter tape, an IGS plotter tape, and a TPR tape for runs requiring the UNIVAC 1108 to print more than 200 pages.

A user of TTOP5 who has less than the required 987,136 words of scratch drum storage space may reduce the storage required by changing the basic parameter (IQ) that determines the maximum array size permissible, i.e., the statement "PARAMETER IQ = 200" near the beginning of programs S0577A, S1480, and S0577B. If this is not practical, the user should employ the second version of the train of programs. This version, which has been run successfully at several companies in the sonar industry, does not require storage on scratch drum area.[2]

As with previous versions of the train of programs, TTOP5 requires no "overlaying" or "mapping." A comparison of TTOP5 with the older version is provided in Appendix A.

DESCRIPTION OF THE PROGRAMS

There are currently nine separately executable programs in the TTOP5; their order of execution is shown in Fig. 1. For each frequency three programs must be executed. These are S0577A, S0577B, and either S1468 or S1480, depending on the array size. The remaining five programs are used only if needed, and need be executed only once during a given run. The nine programs have been completely interfaced by tape and drum connections. The control and data card order require for a typical run is shown in Fig. 2.

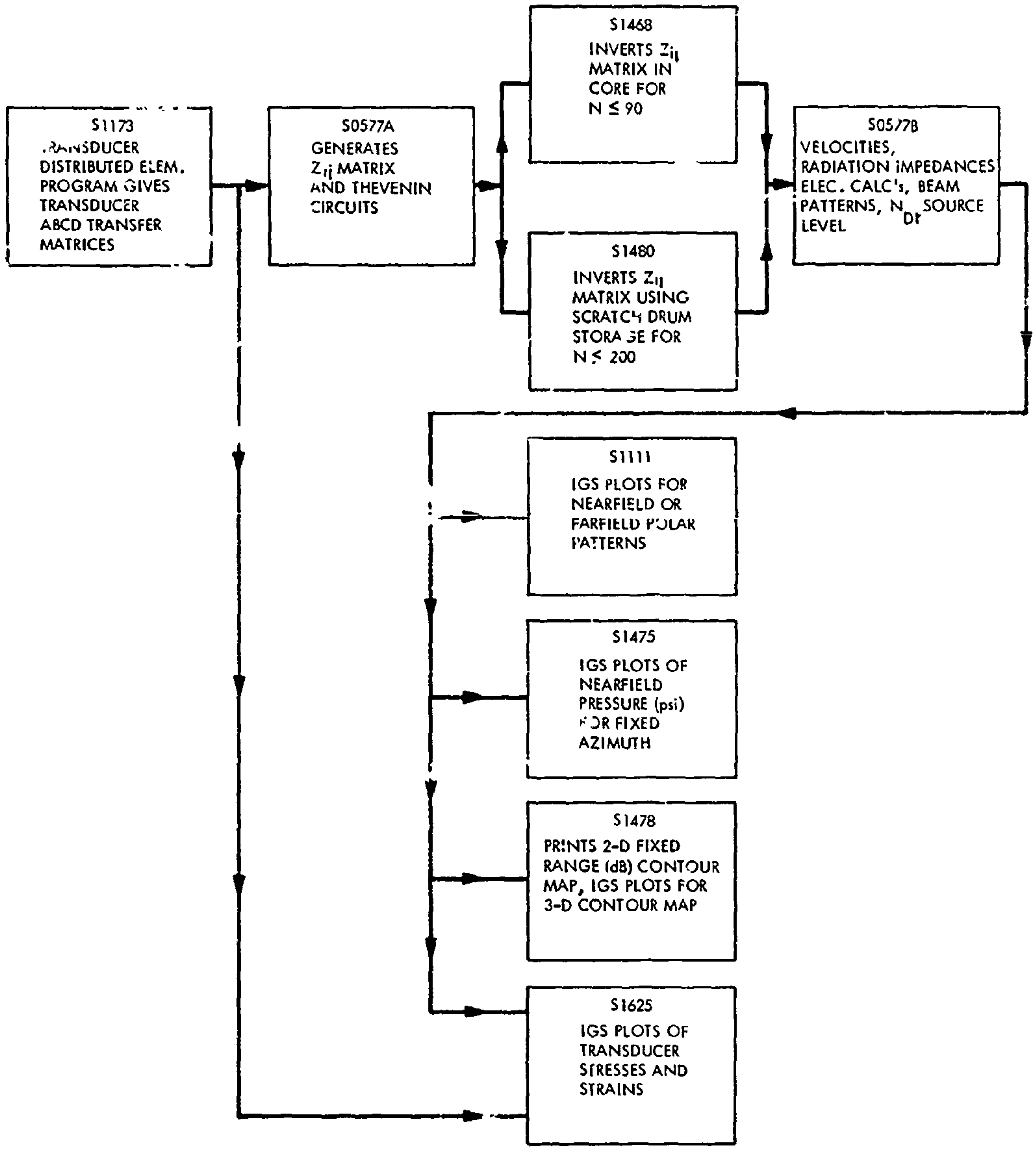


Fig. 1. TTOP5 Order of Program Execution

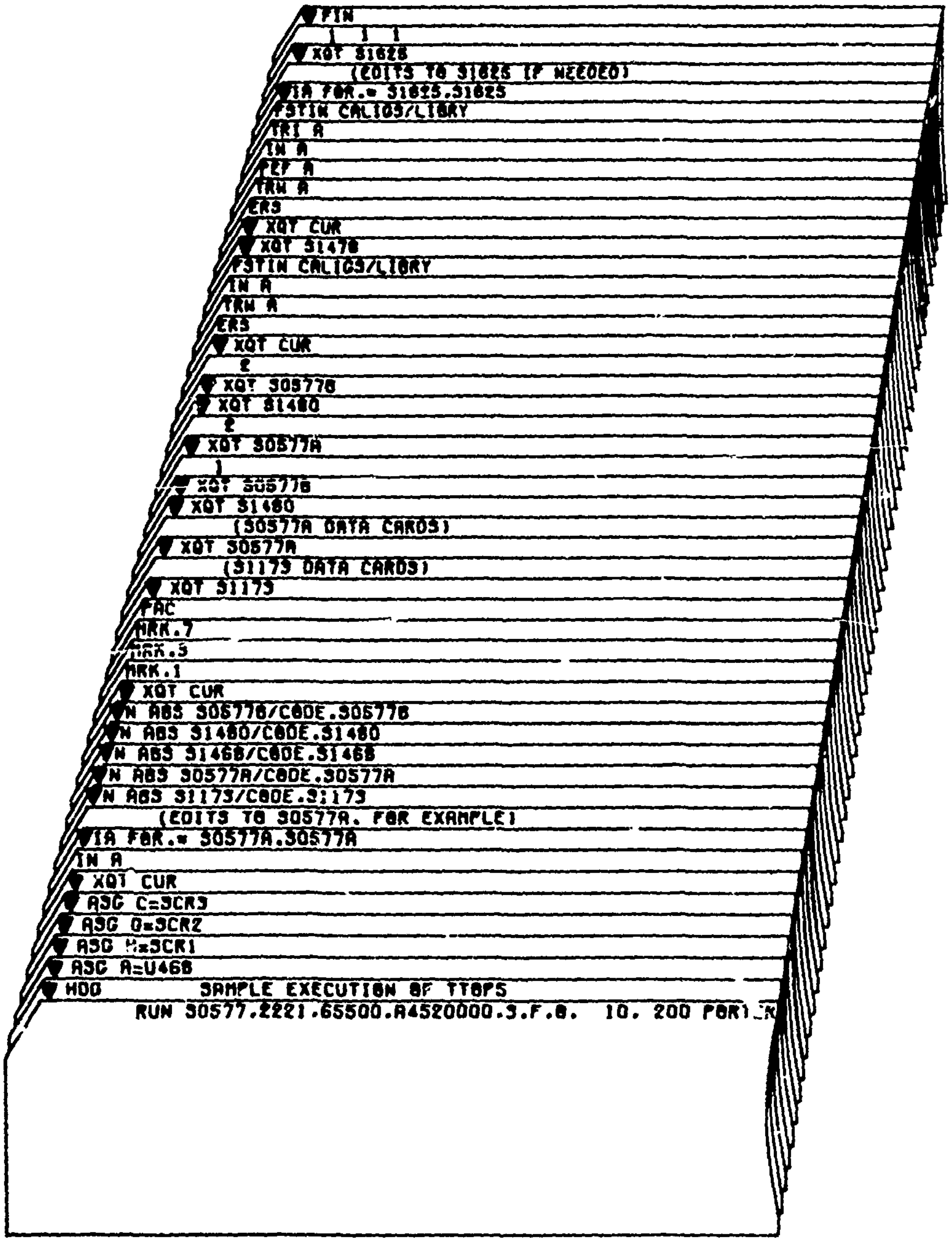
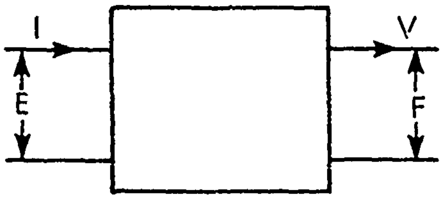


Fig. 2. Control Cards for Typical Run of TTOP5

PROGRAM S1173

This program computes the ABCD transducer transfer matrix for an electric field longitudinal vibrator, using distributed-element analysis.[4] Figure 3 describes the ABCD matrix.



$$E = AF + BV$$
$$I = CF + DV$$

Fig. 3. Two-Port Representation of a Transducer

Program S1173 assumes plane wave motion within the transducer, so that radial motion of the ceramic stack or other parts of the transducer, is not accounted for. Neither is the transducer case directly accounted for; however, if the head can be considered as decoupled from the case, then, for some designs, the case may be regarded as an extension of the tail. Losses in the ceramic stack are accounted for by inputting complex values of the ceramic S, G, and E data. Other mechanical losses are not accounted for in S1173; however, Program S0577A does account for a resistance and compliance of the seal connecting the head to a housing.[2]

If a user wishes to consider an array whose transducers are not identically manufactured, the array can be divided into random subarrays, so that the transducers within a given subarray are identically manufactured. A set of input data for Program S1173 is needed for each subarray. An ABCD matrix is then generated for each subarray and for each frequency considered. If it is desired to evaluate the effects of the interstices between transducers on the array, then it is convenient to consider the transducers as one subarray and the interstices as a second subarray. This can be done if the interstices are modeled by the plane wave distributed-element analysis used by Program S1173. Such an "interstice-transducer" might have several cascaded elements of water, rubber, and metal in its head section, a short, stiff, dummy stress rod, and a short, stiff, dummy ceramic piece with very low values of G and E.

Program S1173 was originally written by the Electronics Division of General Dynamics/Rochester, N.Y., and was released to NUSC. The input data for this program are presented in Table 1.

Table 1

INPUT DATA FOR PROGRAM S1173

Card No.	Format	Data	
1	I4, I2	NRUN	Number of subarrays or separate transducer structures to be analyzed in S1173
		IA	Normally = 0; if = 1, ABCD's will be punched out as well as written on drum
2	13I3	MO	Month numbe:
		DAY	Day number
		YEAR	Year number
		NRINGS	Number of rings in ceramic stack
		N	0
		NES(1)	Number of pieces in tail section
		NES(2)	Number of pieces in tail nut section
		NES(3)	Number of pieces in tail end cap section
		NES(4)	Number of pieces in head end cap section
		NES(5)	Number of pieces in stress rod section
		NES(6)	Number of pieces in head nut section
		NES(7)	Number of pieces in head section
		NTOT	Total number of pieces in above 7 sections
3	1X6F10.2	Starting frequency of first frequency block; frequency increment in first frequency block; second starting frequency; second increment; third starting frequency; third increment	
4	4I3	Number of frequencies in first block, second block, third block; total number of frequencies	
5	I2,5D15.7 (NTOT cards, 1 for each nonceramic piece.)	LTYPE	1 if left and right areas of piece are equal 2 if left and right areas of piece are not equal

Table 1 (Cont'd)

INPUT DATA FOR PROGRAM S1173

Card No.	Format	Data	
5 (Cont'd)		DIST	Length of piece in meters
		RHO	Density of piece in kg/meter^3
		COMP	Reciprocal of Young's modulus in meter^2/newton
		AREA	Left cross-sectional area in meter^2
		AREAR	Right cross-sectional area in meter^2
6	5D15.7	RHOO	Ceramic density in kg/meter^3
		DISTT	Ceramic ring height in meters
		AREAA	Ceramic cross-sectional area in meter^2
		S3333R	Real part of S_{33}^D in meter^2/newton
		S3333	Imaginary part of S_{33}^D
7	5D15.7	G33R	Real part of G_{33} in volt-meter/newton
		G33	Imaginary part of G_{33}
		E33R	Real part of $\epsilon_{33}^T/\epsilon_o$ (dimensionless)
		E33	Imaginary part of $\epsilon_{33}^T/\epsilon_o$

The program assumes that the transducer's tail is on the left and its head is on the right. The distributed-element description of the ceramic and nonceramic pieces is also written on scratch tape for further use by Program S1625 if desired. If S1625 is to be used, each of the seven groups (head, tail, etc.) must have at least one piece in them. No plotting is done in Program S1173.

PROGRAM S0577A

This program is essentially the first half of NUSC Program S0577.[2] For the first frequency for which S0577A is executed, the program reads in, by cards, most of the data describing the array's transducers, amplifiers, passive electrical networks between transducer and amplifier, and beamforming. Tables 2 and 3 describe the card input data required by Program S0577A. For frequencies after the first frequency, S0577A reads in only a "frequency counter" card, indicating which frequency is to be examined. The format is I4, so that for the 12th frequency this card would have a "1" in column 3 and a "2" in column 4. If distributed-element transducer analysis is being used, and the ABCD matrices are being read in by cards (instead of from the S1173 drum), then for each frequency S0577A reads in an ABCD matrix for each subarray within the array (see Card No. 13, Table 3). If lumped-element analysis is being used, the transducer ABCD matrices are generated within S0577A from the lumped-circuit information (Card No. 14a or 14b).

For each frequency S0577A generates a Thevenin equivalent circuit for the transducers, their amplifiers, and the passive electrical sections between the amplifiers and the transducers. The available choices for passive sections and amplifiers are shown in Figs. 4 and 5. Also, for each frequency, S0577A generates an acoustic mutual impedance matrix for the array, taking advantage of two-fold or four-fold symmetry when directed by IA4 (Card No. 9). The Thevenin circuit and mutual impedance matrix are then stored on the scratch drum for future use with Programs S1468 (or S1480) and S0577B.

The acoustic mutual impedance coefficients are computed from formulas for mutual impedances between either circular or rectangular pistons on an infinite, rigid plane. This is, of course, only an approximation for arrays on cylinders or spheres. This approximation becomes more accurate as the cylinder or sphere diameter grows larger relative to the size of the pistons. The approximation is also more accurate for pistons close together than for those far apart. However, if the pistons are far apart, their mutual impedance coefficient will be small, so that the loss in accuracy will generally be negligible. If the baffle is not rigid, it is often possible to simulate the non-rigid interstices by electrically undriven radiators.

Table 2

INPUT DATA FOR PROGRAM S0577A

Card No.	No. of Data Cards	Format	Nearest Numbered FORTRAN Statement	Condition or Note	Input Data
1	1	14	106		0577 in columns 1-4 (Job Identification Card)
2	1	1X7A6	115		Any desired message that will also be printed out
3	1	1X7A6	117		Any desired message that will also be printed out, both by the printer and plotter for programs S0577B and S1625
4	1	20I2	203	Note 4	IM1, IM2,..., up to IM20 (Miscellany)
5	1	20I2	203	Note 5	IW1, IW2,..., up to IW6 (Water Data)
6	1	1X6F10.2	203		Array depth (in feet), water temperature (in °F) salinity (in parts per thousand), and difference between static pressure and acoustic pressure needed for cavitation (in psi)
7	1	20I2	221	Note 7	IP1, IP2,..., up to IP13, (Steering and Pattern Data)
8a	1	1X6F10.2	290	Note 8	(Steering and Pattern Data) Initial ϕ steering angle, initial θ steering angle, increment in ϕ steering angle, increment in θ steering angle, frequency of compensation for phase delay, initial ϕ pattern angle
8b	1	1X6F10.2	290	Note 8	Initial pattern angle, increment in ϕ pattern angle, increment in θ pattern angle, sound velocity for which array is compensated (in feet/second), initial nearfield range (inches), increment in nearfield range (inches)
8c	Variable	4X16F4.2	270	IP9 = 1	Ratios of phases to be used to ideal plane phases
9	1	20I2	315	Note 9	IA1, IA2,..., up to IA12 (Array Data)
10	1-9	2F10.4, 2I5, 3F10.4	426	Note 10 IA1 = 0 (Card No. 9)	(Array Data) Horizontal separation between transducer centers, vertical separation, number of columns, number of rows, starting X-coordinate, and starting Y-coordinate
11	1	1X6F10.2	430	IA5 = 1 (Card No. 9)	Radius of curvature (in inches) of mounting sphere or cylinder; radius of curvature (in inches) of phasing cylinder (if used) (IP12 = 1)
12a	1 or 2	1X6F10.2	436	IM11 = 0 (Card No. 4)	Effective radius of pistons in inches in each separate array (one radius for each separate array)

Table 2 (Cont'd)

INPUT DATA FOR PROGRAM S0577A

Card No.	No. of Data Cards	Format	Nearest Numbered FORTRAN Statement	Condition or Note	Input Data
12b	1, 2, or 3	1X6F10.2	490	IM11 = 1 (Card No. 4)	Height and width of rectangular piston faces (one height and one width (inches) for each subarray)
12c	1	1X6F10.2	492	IM11 = 1 (Card No. 4)	For rectangular piston arrays, (1) the maximum piston center-to-center separation distance (inches) for which the mutual impedances are computed by the rectangle partition method, and (2) the maximum kl of the subdivided pieces of the rectangle
13a	1	20I2	438	Note 13a	IT1, IT2,..., up to IT11 (Transducer Data)
13b	(No. of passive electrical sections) X (No. of subarrays)	1X4I3,6E11.4	547	Note 13b	Passive section number, subarray number, section type, series/parallel tag, values of resistance, inductance, capacitance, loss angle of capacitance (tan δ), cable length (feet), transformer ratio (stepup)
14a	No. of subarrays	1X6E11.4	560	IT9 = 0 IT6 = 0	Transducer data for simplified lumped-element equivalent circuit of Fig. 4a of reference 2: C_b, tan δ, effective coupling coefficient, head mass, tail mass, air resonance at constant voltage drive (F^E_{ra}), for each subarray
14b	Two cards for each subarray	1X6E11.4	560	IT9 = 0 IT6 = 1	Transducer data for expanded lumped-element circuit of Fig. 4b of reference 2: C_b, tan δ, N, C_m, C_{p1}, Head Mass, R_{p1}, C_{p2}, Tail Mass, R_{p2}
14c	One card for each subarray	1X6E11.4	565		Housing Data: Resistance and compliance of seals joining head mass to housing
15a	1	1X8F8.5	524	Note 13a	Velocity profile coefficients, a_n, for flexural disks
15b	1	1X6E11.4	577	IT5 = 3	Rectangular face plate modeled as flexing beam: plate thickness (inches), specific gravity, Young's modulus (psi), Poisson's ratio, edge resistance (kg/sec, per inch of plate circumference), driving ring radius (inches)

Table 2 (Cont'd)

INPUT DATA FOR PROGRAMS S0577A

Card No.	No. of Data Cards	Format	Nearest Numbered FORTRAN Statement	Condition or Note	Input Data
16	1	20I2	550	Note 16	IS1, IS2,..., up to IS10 (amplifier data)
17a	1	11X,5F10.2	605	Note 17a	Open circuit amplifier voltage, amplifier driving current, iteration convergence tolerance, watts of constant power source, volt-amperes of constant volt-ampere source
17b	1	3I5,2F10.2	680	IS1=5or6 (Card No. 16)	Number of signal levels, resistance levels, and reactance levels involved in the black-box amplifier output matrix; expected average load resistance; expected average load reactance
17c	1	1X10F7.2	681	IS1=5or6 (Card No. 16)	Vector of signal levels
17d	1	1X10F7.2	681	IS1=5or6 (Card No. 16)	Vector of resistance levels
17e	1	1X10F7.2	681	IS1=5or6 (Card No. 16)	Vector of reactance levels
17f	Variable	1X10F7.2	681	IS1=5or6 (Card No. 16)	Three-dimensional matrix of black-box amplifier output voltage or current amplitudes
17g	Variable	1X10F7.2	681	IS1=5or6 (Card No. 16)	Three-dimensional matrix of black-box amplifier output voltage or current phases
18.5	1	20I3	801	IA1 = 1 (Card No. 9)	Number of transducer in each subarray (if coordinates are read in by Card Nos. 19, 20, or 21)
19	Variable	1X6F10.2	804	IA1 = 1 (Card No. 9) IA2 = 1	Planar X and Y coordinates (in inches) of N, N/2, or N/4 transducers depending on the degree of symmetry
20	Variable	1X6F10.2	806	IA1 = 1 (Card No. 9) IA2 = 2	Cylindrical ϕ and Z coordinates (in degrees and inches, respectively) of N, N/2, or N/4 transducers
21	Variable	1X6F10.2	808	IA1 = 1 (Card No. 9) IA2 = 3	Spherical ϕ and θ coordinates (in degrees) of N, N/2, or N/4 transducers

Table 2 (Cont'd)

INPUT DATA FOR PROGRAM S0577A

Card No.	No. of Data Cards	Format	Nearest Numbered FORTRAN Statement	Condition or Note	Input Data
22	Variable	1X8F8.5	1304	IA9 = 1 (Card No. 9)	Horizontal shading coefficients
23	Variable	1X8F8.5	1304	IA9 = 1 (Card No. 9)	Vertical shading coefficients
24	1 or 2	1X8F8.5	1320	IA9 = 2 (Card No. 9)	Separate shading coefficient for each subarray (IA3 of them)
25a	Variable	1X8F8.5	1332	IA9 = 3 (Card No. 9)	Individual shading coefficients for N, N/2, or N/4 transducers
25b	Variable	40F2.0	1360	IA9 = 4	Read in "1." for unused elements. (See note for Card No. 9)
26	61	3(E13.6, 11X)	1405	IM19 = 1 (Card No. 4) IA2 $\neq$ 1 (Card No. 9) Note 26	Farfield pressure amplitude table ($P_2(\gamma)$) (See Eq. (7) of reference 1.)
27	1	1X6F10.2	1902		First starting frequency (F1), first frequency increment (DF1), second starting frequency (F2), second frequency increment (DF2), third starting frequency (F3), and third frequency increment (DF3).
28	1	1212	1903		Number of frequencies generated by F1 and DF1, by F2 and DF2, by F3 and DF3, and total number of frequencies
28.5	Two cards for each subarray for each frequency	1X4E13.6	2486	IT9 = 1 IT6 = 0	ABCD matrix for transducer without housing: A(real), A(imaginary), B(real), B(imaginary), C(real), C(imaginary), D(real), D(imaginary)
28.7	2 cards, each time S0577A is executed	1X4E13.6		IT4 = 1 IT5 = 5	Mobility matrix for flexing head. (See Appendix C.) First card has real parts of q_{11}, q_{12}, q_{21}, q_{22}; second card has imaginary parts. Dimensions are seconds/kg

Table 3

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
4	IM1	0	Nothing
		1	Print out real and imaginary parts of the mutual impedance matrix (R, X) before inversion, and print out the inverse of the R matrix.
	IM2	0	Nothing
		1	Print out the $(R+XR^{-1}X)$ and $(R+XR^{-1}X)^{-1}$ matrices.
	IM3	0	Nothing
		1	Print out the $(R+XR^{-1}X)^{-1}$, $(R+XR^{-1}X)^{-1}XR^{-1}$, X, R^{-1}, and $XR^{-1}X$ matrices.
	IM4	0	Nothing
		1	Print out the mutual impedance tables.
	IM5	0	Nothing
		1	Print out the transducer input voltage amplitudes and phases for each transducer and iteration (IS1 = 3, 4, 5, or 6).
	IM6	0	
	IM7	0	The self-radiation impedances are computed for radiators in rigid baffles.
		1	The self-radiation impedances are computed for an approximation to circular pistons at the end of an infinite pipe by $Z/\rho cA = 1 - J_1[2(ka-0.4)]/(ka-0.4) + jS_1[2(ka-0.4)]/(ka-0.4)$.
	IM8	0	Nothing
		1	Print out the farfield pressure amplitude table for $P_2(\gamma)$.
	IM9	0	Nothing
		1	Print out the directionality factor for each transducer and pattern angle used.
	IM10	0	Nothing
		1	Omit printout of radiation data and beam pattern data.

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
4 (Cont'd)	IM11	0 1	Circular pistons or flexural disks. Rectangular or square pistons or flexing heads.
	IM12	0 1	Nothing Failure option (Card No. 4 of S0577B)
	IM13	0 1	Compute a table of mutual impedance coefficients between equivalent area circular pistons for $0 < kd \leq 10$ (subroutine MUTIMP). Repeat for each different pair of subarrays. Do not compute the above tables.
	IM14		At the end of the computations a summary sheet of the most important results is printed out. The number of copies of the summary sheet will be IM14 + 3.
	IM15	7	
	IM16	0 1 2 3 4 5 6 7 8 9 10 11 12 13	No array location plot; if nonzero, following array location CALCOMP plots will be made. Shading coefficients Head velocity magnitudes $R/\rho cA$ $X/\rho cA$ Acoustic powers Electrical input impedance magnitudes Electrical input impedance phases Electrical input powers Average acoustic pressures (psi) over the transducer faces Phases of electrical input signals to amplifiers Peak displacements (meters) of transducer faces Element number Edge velocity/center velocity (flexing bar model)
	IM17	0 1	Nothing Frequency CALCOMP plot of source levels

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
4 (Cont'd)	IM17 (Cont'd)	2	Frequency CALCOMP plot of maximum-to-minimum velocity ratios
		3	Frequency CALCOMP plot of maximum-to-minimum ratio of electrical input impedance magnitudes
		4	Frequency CALCOMP plot of nearfield-farfield correction
	IM18	0	Nothing
		1	CALCOMP impedance plot for transducer no. 1
		2	CALCOMP admittance plot for transducer no. 1
	IM19	0	For arrays on spheres or cylinders, computes the farfield single element pattern by Eq. (8) of ref. 1 (subroutine FFPAT), which is farfield of circular piston on rigid sphere. Do not use if diameter of sphere or cylinder is over 10 wavelengths.
		1	Read in the above single element pattern from Card No. 26 (one pattern for all frequencies considered).
		2	For arrays on spheres or cylinders, computes the farfield single-element pattern by Pa 2 J_1 (ka sin θ)/ (ka sin θ) $e^{-0.44\theta}$. This option is suggested for use when the sphere or cylinder is over 10 wavelengths in diameter.
	IM20	0	Nothing
		1	Two copies of an extra summary sheet are printed out, giving maximum and minimum values for radiation impedance and head velocity over the array, for each array run.
5	IW1	1	Fresh water, density = 62.5
		2	Salt water, density = 64.0
		3	Air load, density = 0.081, sound velocity = 1090. Electrical and mechanical results are valid for air load; acoustical results are not valid.
	IW2	0	
	IW3	1	

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
7	IP1	0	Phase delays generated.
		1	Time delays generated.
		2	All Elements driven in phase.
		3	Electrical phase delays read in from Card No. 2 of S0577B.
		4	Option to vertically steer with resolvers, reading in a set of azimuthal phases from Card No. 3 of S0577B.
	IP2		Number of array runs used for each frequency ($\leq$40) See note for IP8 = 1.
	IP3 IP4		Number of azimuthal pattern angles used ($\leq$183) = (100 times IP3) + IP4.
	IP5 IP6		Number of elevation pattern angles used ($\leq$183) = (100 times IP5) + IP6.
	IP7	0	Array is compensated for actual sound velocity.
		1	Array is compensated for a fictitious sound velocity read in on Card No. 8b.
	IP8	0	Nothing
		1	Patterns are computed for different values of ϕ and θ steering angles for the same set of computed head velocities. IP2 sets of horizontal and vertical patterns will be computed for each frequency. Only one velocity distribution will be computed for each frequency. IP8 = 1 is used to generate two-dimensional beam patterns, printed out by S1478 (restricted to 43 azimuth angles), or nearfield vertical slices (for more than one azimuth) plotted (IGS) by S1475.
	IP9	0	Not used.
		1	Read in decimal ratio of phases to be used to ideal plane phases from Card No. 8c. There will be IP2 numbers on Card No. 8c.

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
7 (Cont'd)	IP10	1	Only a horizontal pattern will be computed (θ fixed at θ_{steer}, ϕ varying).
		2	Horizontal and vertical patterns will be computed (θ fixed at θ_{steer}, ϕ varying, ϕ fixed at ϕ_{steer}, θ varying).
	IP11	Usually 0 or 3	Beamwidths will be computed between the X dB down points, where X = IP11 + 3.
	IP12	0	Not used.
		1	Phase to a cylindrical surface of radius (inches) = CCRAD, read in from Card No. 11.
	IP13	0	Not used.
		1	For arrays on spheres there is no azimuthal phase dependence, but there still is vertical phasing to a cone.
	IP14		Number of nearfield ranges used.
	IP15		Number of polar beam patterns to be plotted by S1111. If S1475 or S1478 is used and S1111 not used, set IP15 = 1.
	IP16		Number of two-dimensional vertical slice nearfield pressure plots produced by S1475.
	IP17		Number of two-dimensional fixed range patterns printed by S1478.
	IP18	0	S1478 not used.
		1	Patterns printed by S1478 normalized to zero dB for the maximum response.
		2	Patterns printed by S1478 are actual responses minus 100 dB.
8			If time delay is used, zero may be read in for frequency of compensation. θ steering angle is overridden by Card No. 3 of S0577B if IP1 = 4.

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
9	IA1	0 1	Generate array coordinates. Read in array coordinates.
	IA2	1 2 3	Planar array. Cylindrical array. Spherical array.
	IA3		Number of separate arrays superimposed, or number of different types of transducers.
	IA4	1 2 3 4	No symmetry used. Left-right symmetry. Up-down symmetry. Four-fold symmetry.
	IA5	0 1	Planar array. Cylindrical or spherical array.
	IA6 and IA7		The size of the mutual impedance matrix to be inverted will be N by N where N = 100 x IA6 + IA7. The array contains N elements if no symmetry is used, 2N elements if two-fold symmetry is used, and 4N elements if four-fold symmetry is used. N $\leq$ 200 if S1480 is used, and N $\leq$ 90 if S1468 is used.
	IA8	0 1	Print out dimensioned coordinates at the end of the program. Print out dimensioned coordinates at the beginning and end of the program.
	IA9	0 1 2 3	Unshaded array. Generate shading coefficients by horizontal and vertical shading coefficients (Card Nos. 22 and 23). Read in one shading coefficient for each separate superimposed array (Card No. 24). Read in the shading coefficients for all transducers (Card No. 25a).

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
9 (Cont'd)	IA9 (Cont'd)	4	Read in "1." for unused transducers (Card No. 25b.) This option is useful for generating an odd-shaped array from a rectangular array, avoiding the tedious process of coding the individual transducer coordinates via Card Nos. 19, 20, or 21.
	IA10		Applies only if IA9=1.
		0	Shading coefficient is the product of the appropriate horizontal and vertical shading coefficients.
		1	Shading coefficient is the average of the appropriate horizontal and vertical shading coefficients.
10			Card No. 10 requires up to 9 data cards, depending on the value of IA3 (Table 3, Card No. 9). For planar arrays, the starting X and Y coordinates are in inches. For cylindrical arrays, the starting X coordinate is the ϕ coordinate of the first element in degrees, and the starting Y coordinate is the Z coordinate of the first element in inches. For spherical arrays, the starting X and Y coordinates are the ϕ and θ of the first element in degrees.
12a			There are IA3 piston radii on Card No. 12a.
13a	IT1	=1	Electric field transducers.
	IT2	=1 =2	Series tuning. Parallel tuning.
	IT3		Number of transducer data pieces in Card No. 14a or 14b; IT = 6 if IT9 = 0 and IT6 = 0; IT3 = 10 if IT9 = 0 and IT6 = 1; IT3 = 0 if IT9 = 1 or 2.
	IT4	=1	For flat pistons; for circular flexural disks IT4 = the number of terms N in the velocity expansion summation $V(r) = V(0) \sum_{n=1}^{3} \alpha_{2n-2} (r/a)^{2n-2}$. IT4 is less than or equals 3.
	IT5	0 1 3 5	Flat pistons. Circular flexural disks. Flexing bar heads — see Appendix B. Mobility matrix input for flexing head — see Appendix C.

Table 3 (Cont'd)

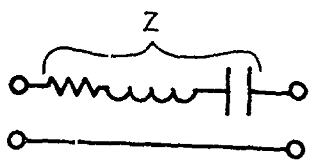
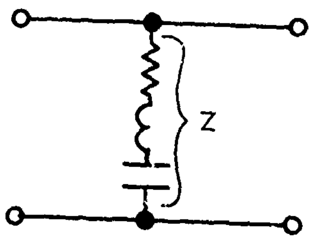
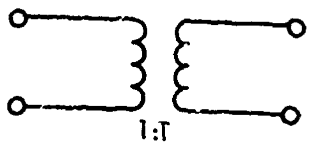
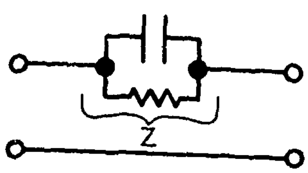
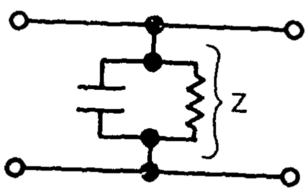
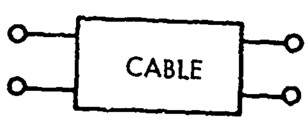
INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
13a (Cont'd)	IT6	0 1	Do not use EJPABC for transducer model. Do use EJPABC.
	IT7		Number of passive electrical sections before the transducer $(1 \leq IT7 \leq 10)$.
	IT8	=1 or 2	Number of data pieces read in on housing data card.
	IT9	0 1 2	Generate transducer ABCD matrix by subroutines XDRABC or EJPABC for lumped-element equivalent circuits. Read in ABCD matrix for transducer without housing, by Card No. 14c. ABCD matrices generated by S1173.
	IT10		Electrical section in front of which measurement data are desired.
	IT11		Electrical section in front of which the amplifier output terminals are located. If the amplifier has no passive sections associated with it, then IT11 = 1.
13b	The passive sections are numbered starting with the first section after the electrical source. The section types are (see Fig. 4): 1 R-L 2 C-G 3 R-L-C 4 Cable 5 Transformer The series/parallel tag is 1 for a series section, 2 for a parallel section, and 0 for a cable or transformer. Only the values of resistance, inductance, capacitance, etc. that apply to a particular section need be specified; the others may be zero or blanks. Both R-L and R-L-C sections were included to avoid having an infinite capacity in an R-L-C circuit that had no C.		

Table 3 (Cont'd)

INPUT DATA NOTES FOR PROGRAM S0577A

Card No.	Data	Value	Significance
13b (Cont'd)	If the section is a cable, then the resistance, etc. is given on a per-foot basis. The inductance and capacitance per foot must not be given as zero. The cards in 13b are grouped by subarray, not section number.		
16	IS1	1	Voltage source with series source resistance or sections of passive elements.
		2	Current source with no source resistance, or else sections of passive elements.
		3	Constant power source with series source resistance or sections of passive elements.
		4	Constant volt-ampere source with series source resistance or sections of passive elements.
		5	Black-box voltage source with sections of passive elements.
		6	Black-box current source with sections of passive elements.
	Note: See Fig. 5 for diagrams of the above six amplifiers.		
	IS2	IA7	Number of amplifiers = 100*IS9+IS2.
	IS3	1	Number of transducers per amplifier
	IS4	0	Modular drive (IS3=1).
	IS5		Maximum number of iterations permitted in the iterative processes of the constant power drive, constant volt-ampere drive, or black-box amplifier problem.
	IS6	0	
	IS7	0	
	IS8	0	
	IS9	IA6	
17a			The data in Card No. 17a that are not applicable may be read in as zeros. In the constant power (or volt-amperes) case, the convergence test is on the electrical power or volt-amperes: $\left\|1 - \frac{\text{computed power (or volt-amperes)}}{\text{desired power (or volt-amperes)}}\right\| = \text{tolerance}$ A tolerance of 0.01 (1 percent) is suggested for the above test.

PASSIVE SECTION	TYPE	ABCD MATRIX
	SERIES R-L-C	$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$
	PARALLEL R-L-C	$\begin{bmatrix} 1 & 0 \\ 1/Z & 1 \end{bmatrix}$
	TRANSFORMER	$\begin{bmatrix} 1/T & C \\ 0 & T \end{bmatrix}$
	SERIES CAPACITANCE-CONDUCTANCE	$\begin{bmatrix} 1 & Z \\ 0 & 1 \end{bmatrix}$
	PARALLEL CAPACITANCE-CONDUCTANCE	$\begin{bmatrix} 1 & 0 \\ 1/Z & 1 \end{bmatrix}$
		$\left[\begin{array}{c:c} \cosh\left(L\sqrt{ZY}\right) & Z_o \sinh\left(L\sqrt{ZY}\right) \\ \hdashline \dfrac{\sinh\left(L\sqrt{ZY}\right)}{Z_o} & \cosh\left(L\sqrt{ZY}\right) \end{array}\right]$

Z = IMPEDANCE/UNIT LENGTH
Y = ADMITTANCE/UNIT LENGTH
L = LENGTH
$Z_o = \sqrt{Z/Y}$

Fig. 4. Allowed Types of Passive Electrical Elements Between Amplifier and Transducer

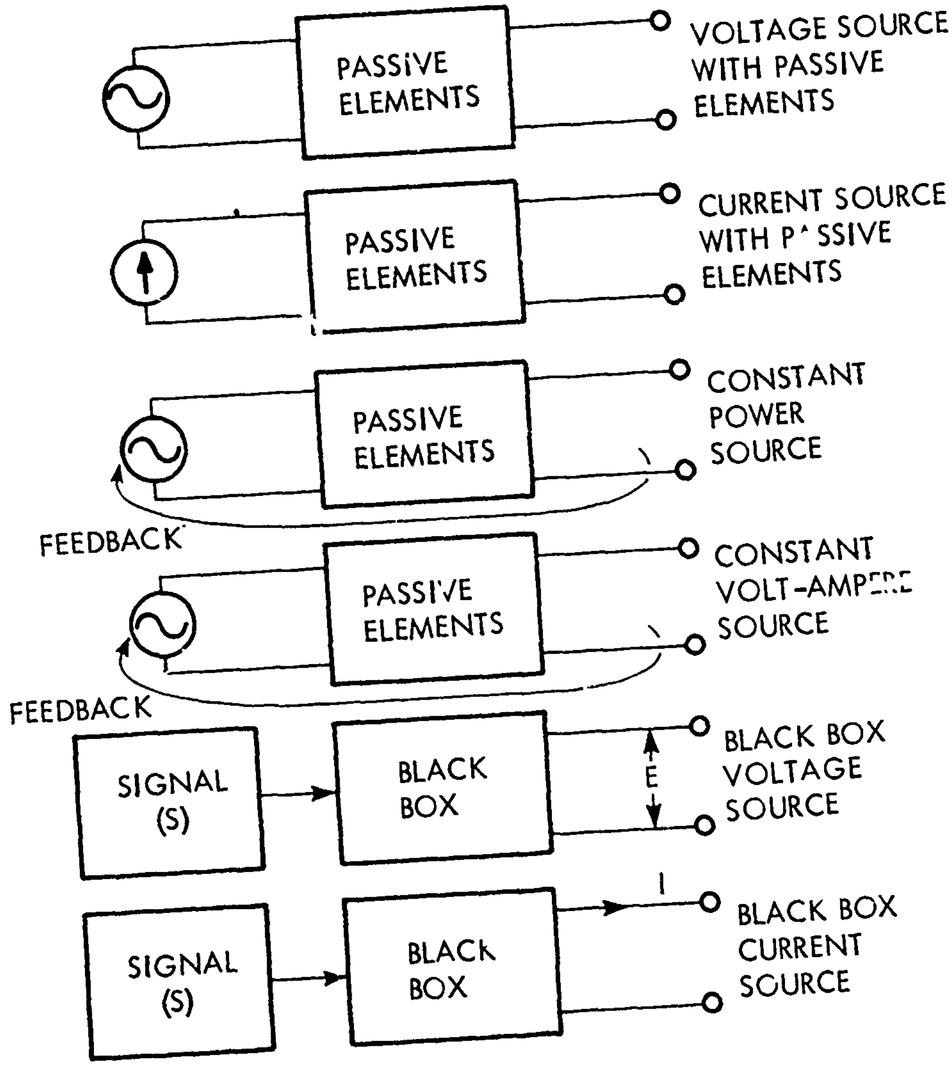


Fig. 5. Amplifier Models

If the array has square or rectangular piston faces, the computation of the mutual impedance (Z_{ij}) matrix for a large array can be extremely time consuming. To save computer time, it is possible to compute the Z_{ij} matrix by the rectangular subroutine if the separation distance is less than a given "DMIN" (Card No. 12c) and by the much faster circular subroutine if the separation distance exceeds "DMIN".

The equations used for the directivity functions of individual transducers are given in reference 1, pages 6 and 7.

Provisions now exist in S0577A for the analysis of flexing head transducers whose heads vibrate along one dimension only, in the manner of a flexing beam or bar. (The flexing beam model is discussed in Appendix B.) No plotting is done in Program S0577A.

PROGRAM S1468

This program inverts the array's complex mutual impedance Z matrix,

$$[Z]^{-1} = [R + iX]^{-1} = [C] - i[E] \quad , \tag{1}$$

where

$$[C] = [R + XR^{-1}X]^{-1} \tag{2}$$

and

$$[E] = [CXR^{-1}] \quad . \tag{3}$$

The C and E matrices are written onto the scratch drum area for later use by Program S0577B. The inversion is done entirely in core and can presently be accomplished in S1468 for Z matrices as large as 90 by 90. No card input is needed by S1468, and no plotting is done by this program.

PROGRAM S1480

As does S1468, this program inverts the array's complex Z matrix. It is presently dimensioned for a Z matrix as large as 200 by 200. Program S1480 uses scratch drum area for the inversion. It requires the storage in core of only one real matrix at a time. Because of the extra drum operations, S1480 is slower than S1468 for the same matrix. S1480 has successfully inverted a 192-by-192 complex Z matrix in 4 minutes on the NUSC UNIVAC 1108. No plotting is done in this program.

PROGRAM S0577B

This program is essentially the second half of Program S0577 located on the first file of NUSC Cur Tape U230.[2] S0577B generates a driving force vector, based on the given data for the amplifiers and beamformers. The transducer head velocities (V) are related to the complex mutual impedance matrix (Z), and the driving force vector (F) by the matrix equation

$$[F]_{nx1} = [Z]_{nxn} \cdot [V]_{nx1} \,, \tag{4}$$

where n is the number of transducers in the array divided by the number of folds of symmetry use (one, two or four). IA7 (Card No. 9 of S0577A) is n. S0577B obtains the head velocities by multiplying both sides of Eq. (4) by the inverse of Z, leaving

$$[V]_{nx1} = [Z]^{-1}_{nxn} [F]_{nx1} \,. \tag{5}$$

S0577B then uses the head velocities to obtain radiation impedances, electrical input impedances, currents, powers, voltages, etc., as well as nearfield and farfield pressure patterns. The source level is taken to be the maximum computed value of farfield pressure (dB//1 dyne/cm^2 at 1 yard). Directivity index (N_{DI}) is found from the source level equation:

$$L_s = N71.6 + N_{DI} + 10 \log \text{(total acoustic power)} \,, \tag{6}$$

where N71.6, which is usually close to 71.6, depends on the density and sound velocity of the water and is computed in the program.

The program now allows for the CALCOMP plotting of several different transducer variables, such as shading coefficients and electric power, as a function of array location, as shown in Fig. 6. This option is useful for rapid observation of trends in the array and for checking that the transducer array coordinates which were generated are indeed those that were intended. The transducer variable to be plotted is determined by the value of IM16 on Card No. 4 of S0577.

A second type of plot now available from S0577B is a frequency plot of source level, maximum-to-minimum velocity ratio, maximum-to-minimum electrical input impedance ratio, or nearfield-to-farfield source level correction factor as shown in Fig. 7. (See Appendix D for a discussion of this correction factor.) The variable to be plotted is determined by the value of IM17 on Card No. 4 of S0577A. A third type of CALCOMP plot available from S0577B is an impedance or admittance plot for element number 1 in the array. The plot to be made is determined by the value of IM17 on Card No. 4 of S0577A.

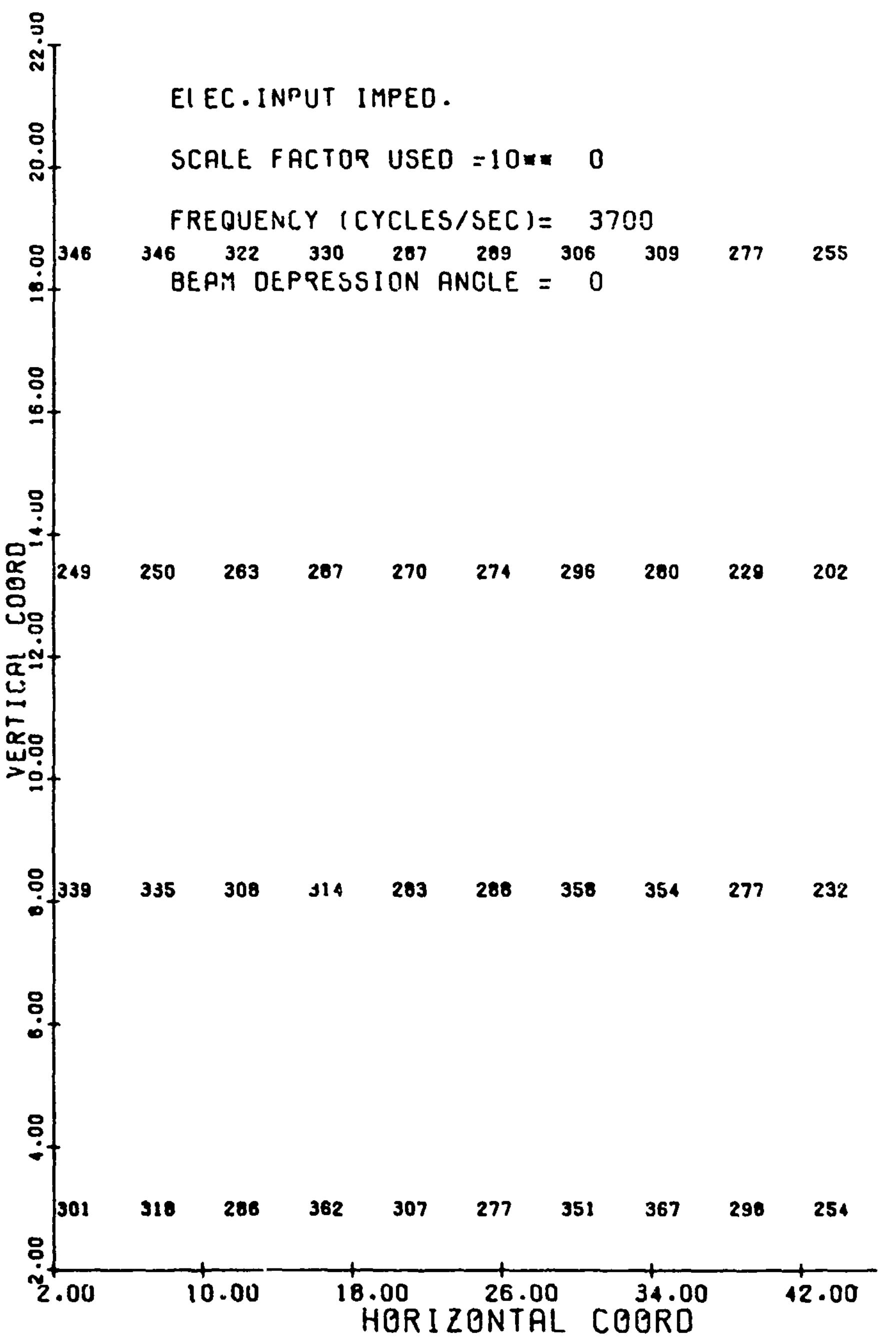


Fig. 6. Array Location Plot from Program S0577B

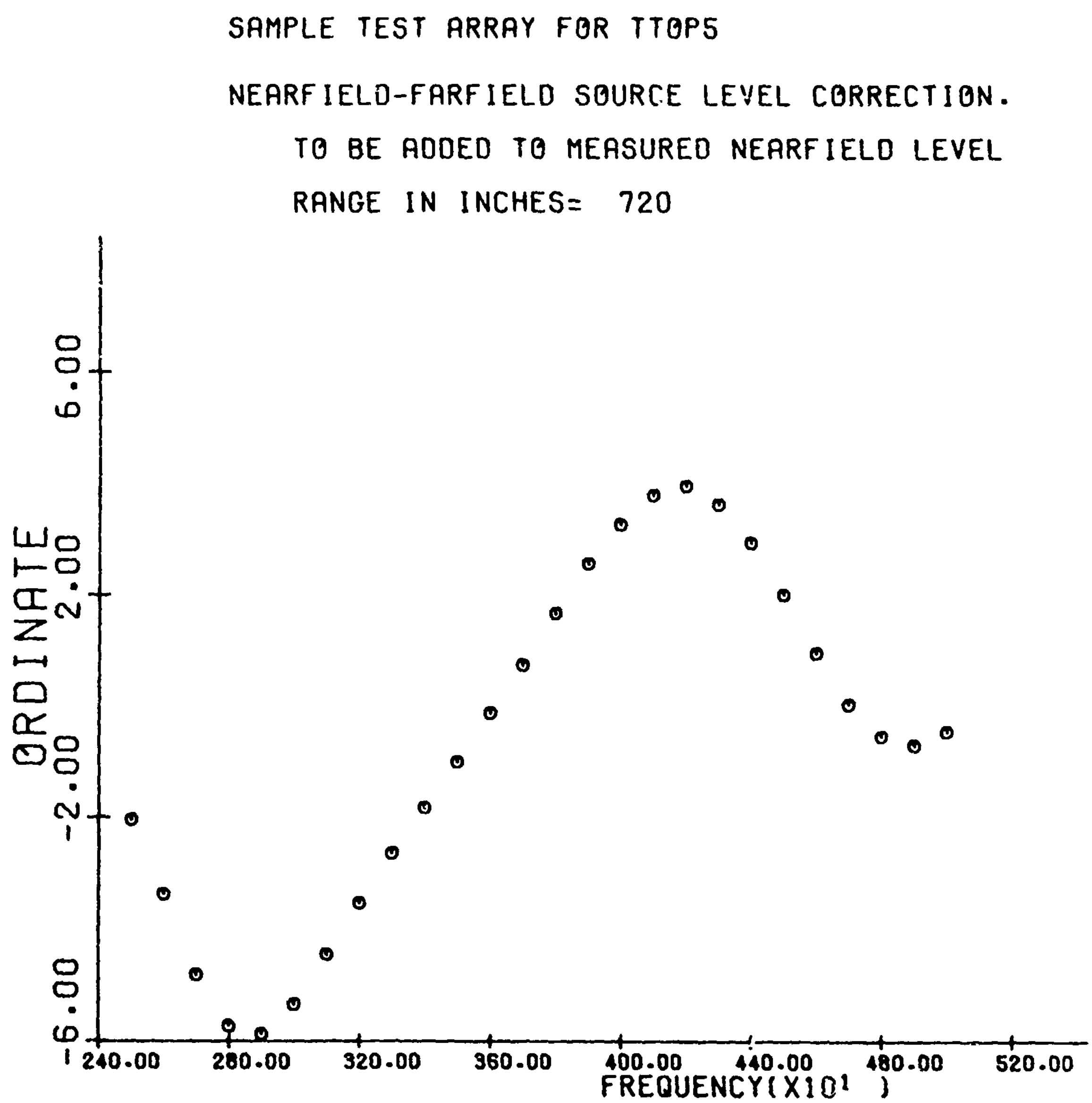


Fig. 7. Nearfield-Farfield Correction vs Frequency
Plot from Program S0577B

These three types of CALCOMP plots can not yet be plotted on the Stromberg-Carlson 4060 IGS cathode ray tube plotter because of the large storage required by both S0577B and the "CALIGS" (CALCOMP-to-IGS) conversion package. The card input data required by Program S0577B is given in Table 4.

PROGRAM S1111

This program receives nearfield and farfield pattern information via tape from S0577B and produces polar plot information for the Stromberg-Carlson 4060 plotter. The total number of graphs produced will be IP15 (Card No. 7 of S0577A). No card input data are read in by S1111.

PROGRAM S1475

This program receives nearfield pattern information via tape from S0577B and computes nearfield pressures in psi (peak rather than rms). The pressures at each field point are computed by adding up the contributions from each individual transducer, assuming that the nearfield point is in the farfield of the individual transducer. Therefore, pressures computed close to the array surface (i.e., less than two piston face diameters away) will be inaccurate.

IGS plotter information is produced; the plots are for a vertical slice (fixed azimuth angle). At each point where the peak acoustic pressure exceeds the static pressure, an X is plotted indicating the predicted areas of cavitation. A sample plot is shown in Fig. 8. No card input data are required for this program.

PROGRAM S1478

This program receives nearfield and farfield pattern information via tape from program S0577B. Printed (UNIVAC 1108) two-dimensional patterns and plotted (IGS) three-dimensional patterns are produced — each for a fixed range from the origin of the coordinates. The printed two-dimensional patterns are limited to 60 ϕ (azimuth) angles and 91 θ (elevation) angles. The three-dimensional plots are limited to 40 azimuth angles and 60 elevation angles. Program S1478 pieces together vertical pattern slices where the slices are made at different azimuth angles.

To use Program S1478, some of the steering and pattern data take on meanings different from the usual. In Card No. 7 (S0577A), IP2 is the number of azimuth angles desired. IP3 is 0, IP4 is 1, IP5 is 0, IP6 is the number of elevation angles desired, IP8 is 1, IP10 is 2, IP15 is 1, IP16 is 0, and IP17 is the number of two-dimensional pictures desired. If no three-dimensional plots are desired, IP18 is 0;

Table 4

INPUT DATA FOR PROGRAM S0577B

Card No.	Data	Format	Condition	Note
1	Frequency Subscript	I4		"1" for first, "2" for second, etc.
2	Electrical Driving Phases (degrees) for IA7 transducers	1X6F10.2	IP1 = 3	See Card Nos. 7 and 9 of S0577A
3	θ_{steer}, Constant, Electrical Driving Phases for 1 row (or 1/2 row) of a Cylindrical Array	F5.0, F5.3, 12F5.0/14F5.0	IP1 = 4	See *para. 3, p. 10 of reference 2*
4	Transducer Failure Data	80I1	IM12 = 1	IP2 failure cases will be done. The first case will be for no failures. In subsequent cases, a "1" in the jth column will result in the jth transducer having a zero driving voltage. For the last failure case the card or cards should be blank. If IA7 is less than 81, there will be 1 card per failure case. For IA7 between 81 and 160, there will be 2 cards per case. For IA7 between 161 and 200, there will be three cards per case. (See also Note 30, p. 28 of reference 2.)

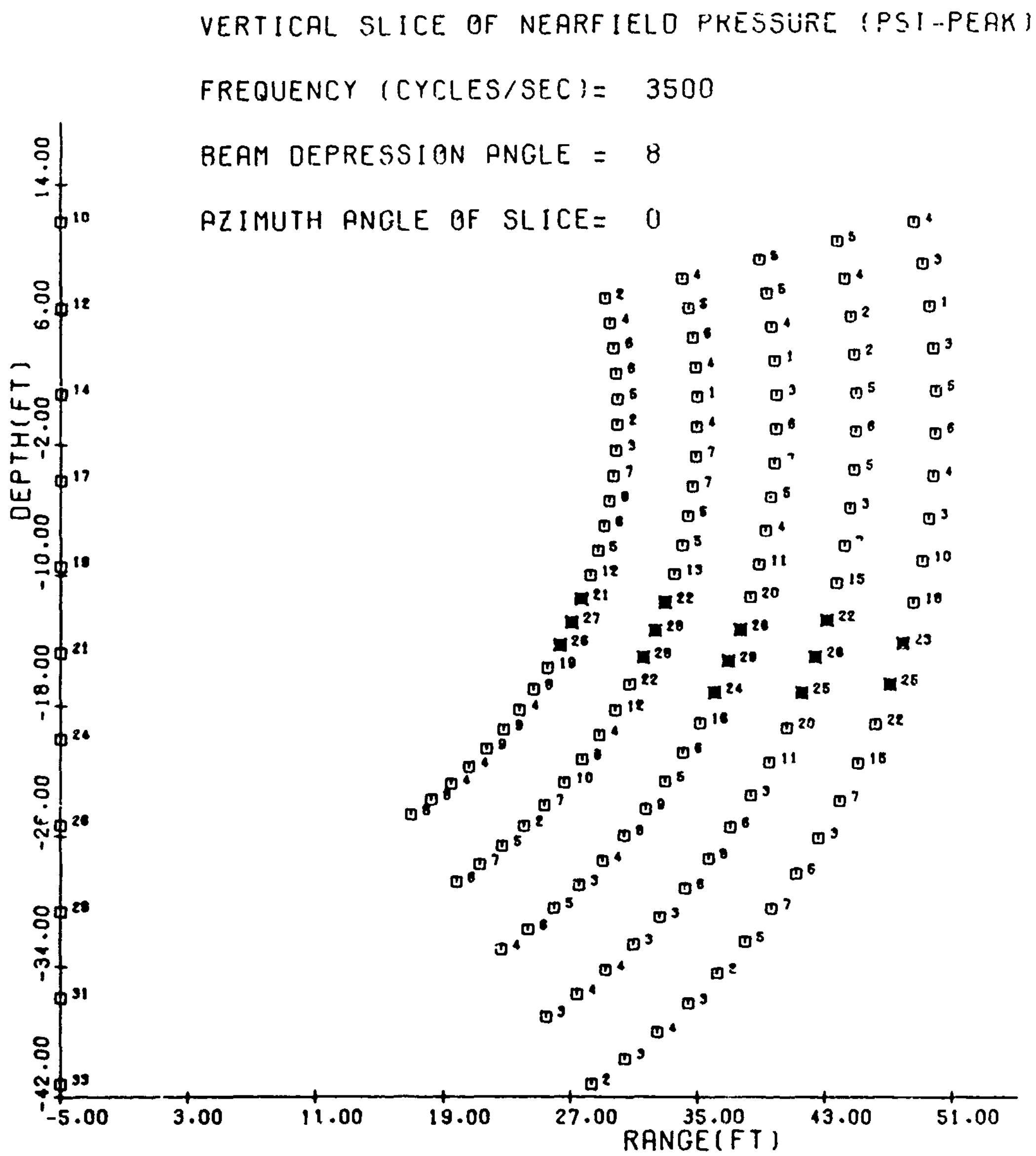


Fig. 8. Nearfield Pressure Plot from Program S1475

if three-dimensional plots are desired, IP18 is 1. The increment in azimuth pattern angle is taken to be the value read in (Card No. 8a) for the increment in azimuth steering angle. Sample two- and three-dimensional plots are shown in Figs. 9 and 10.

PROGRAM S1625

This program computes the internal stresses, strains, voltages, currents, etc., of each transducer in the array for each frequency considered. It was originally written[6] by the HMES Division of General Electric Co., Syracuse, N. Y., and is proprietary to General Electric Co.

Program S1625 receives distributed element information concerning the transducers ceramic and nonceramic pieces from Program S1173; the velocities, radiation forces, and mechanical resistance losses associated with each transducer head are obtained from S0577B. S1625 computes Stromberg-Carlson 4060 histogram plots for each frequency for as many of the following transducer variables as desired:

1. Magnitude of impedance at ceramic terminals (ohms)
2. (Do not use)
3. (Do not use)
4. Magnitude of voltage at ceramic terminals (volts)
5. (Do not use)
6. Ceramic field (volts/mil)
7. Maximum stress occurring within the ceramic stack (psi)
8. Power lost within the ceramic stack (watts)
9. Electric power into ceramic stack (watts)
10. Volt-amperes into ceramic stack
11. Phase of impedance at ceramic terminals (degrees)
12. Magnitude of total current into ceramic stack (amperes)
13. Stress rod stress (psi)
14. Acoustic power out (watts)
15. Head displacement (inches)
16. Ceramic strain (dimensionless)

BOX 15//D PORTER//TRANSMIT

2 - DIMENSIONAL PATTERN IN dB NORMALIZED TO MAXIMUM RESPONSE FOUND

FREQUENCY = DEPRESSION ANGLE = 20.0 AZIMUTH STEERING ANGLE = 0.0

Elev.°\Az.°	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
0	15	15	15	15	14	13	13	13	14	15	15	16	18	20	19	20	24	25	23	23	25	25	25	25	25
-2	16	16	16	16	16	15	14	14	15	16	16	17	20	22	21	21	25	25	24	25	25	25	25	25	25
-4	21	21	20	20	20	20	19	18	20	21	21	22	24	25	25	25	25	25	25	25	25	25	25	25	25
-6	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
-8	18	18	18	18	17	16	16	16	17	18	18	19	22	22	22	24	25	25	25	25	25	25	25	25	25
-10	12	12	11	11	11	10	9	10	11	12	12	13	15	17	16	17	20	23	20	20	24	25	24	22	23
-12	8	8	8	7	7	6	6	6	7	8	8	9	11	13	13	13	16	19	18	17	19	25	22	19	19
-14	6	6	5	4	4	4	3	3	4	6	6	7	9	11	11	11	13	17	16	14	16	21	21	17	16
-16	4	4	3	2	2	2	2	2	2	4	5	5	7	9	10	9	11	15	15	13	14	18	21	16	15
-18	3	3	2	1	1	1	1	0	1	3	4	4	6	8	9	9	10	13	15	13	13	16	20	17	14
-20	3	2	1	0	0	0	0	0	1	2	4	4	5	7	9	9	9	12	15	13	12	14	19	18	14
-22	3	2	1	0	0	0	0	0	1	2	4	4	5	7	9	9	9	11	15	14	13	14	17	19	16
-24	3	2	1	0	0	0	0	0	1	2	4	5	6	7	9	10	10	11	15	15	14	14	16	19	17
-26	4	3	1	0	0	1	1	1	2	3	5	6	7	8	10	11	11	12	14	17	15	15	16	19	19
-28	5	4	2	1	1	1	2	3	3	4	6	8	8	9	11	13	13	13	15	18	17	16	17	19	21
-30	6	5	4	2	2	3	4	5	5	6	8	10	10	11	12	14	15	15	16	19	20	19	18	20	21
-32	7	7	6	5	4	5	6	7	7	8	10	12	13	13	14	16	18	18	19	20	22	22	21	21	23
-34	10	10	9	8	7	8	9	10	11	11	13	15	17	17	18	19	21	22	22	23	25	25	24	25	25
-36	13	13	13	12	11	12	13	15	16	16	17	19	21	22	23	24	25	25	25	25	25	25	25	25	25
-38	21	21	20	20	19	19	21	23	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
-40	24	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
-42	15	16	17	18	18	18	19	22	24	24	23	25	25	25	25	25	25	25	25	25	25	25	25	25	25
-44	11	11	13	14	15	15	16	18	20	21	21	21	24	25	25	25	25	25	25	25	25	25	25	25	25
-46	9	9	11	12	14	14	14	16	18	21	21	20	22	25	25	25	25	25	25	25	25	25	25	25	25
-48	8	8	10	12	13	14	14	15	18	21	22	21	21	23	25	25	25	25	25	25	25	25	25	25	25
-50	7	8	9	11	14	15	15	16	18	21	24	23	22	23	25	25	25	25	25	25	25	25	25	25	25

Fig. 9. Two-Dimensional Plot from Program S1478

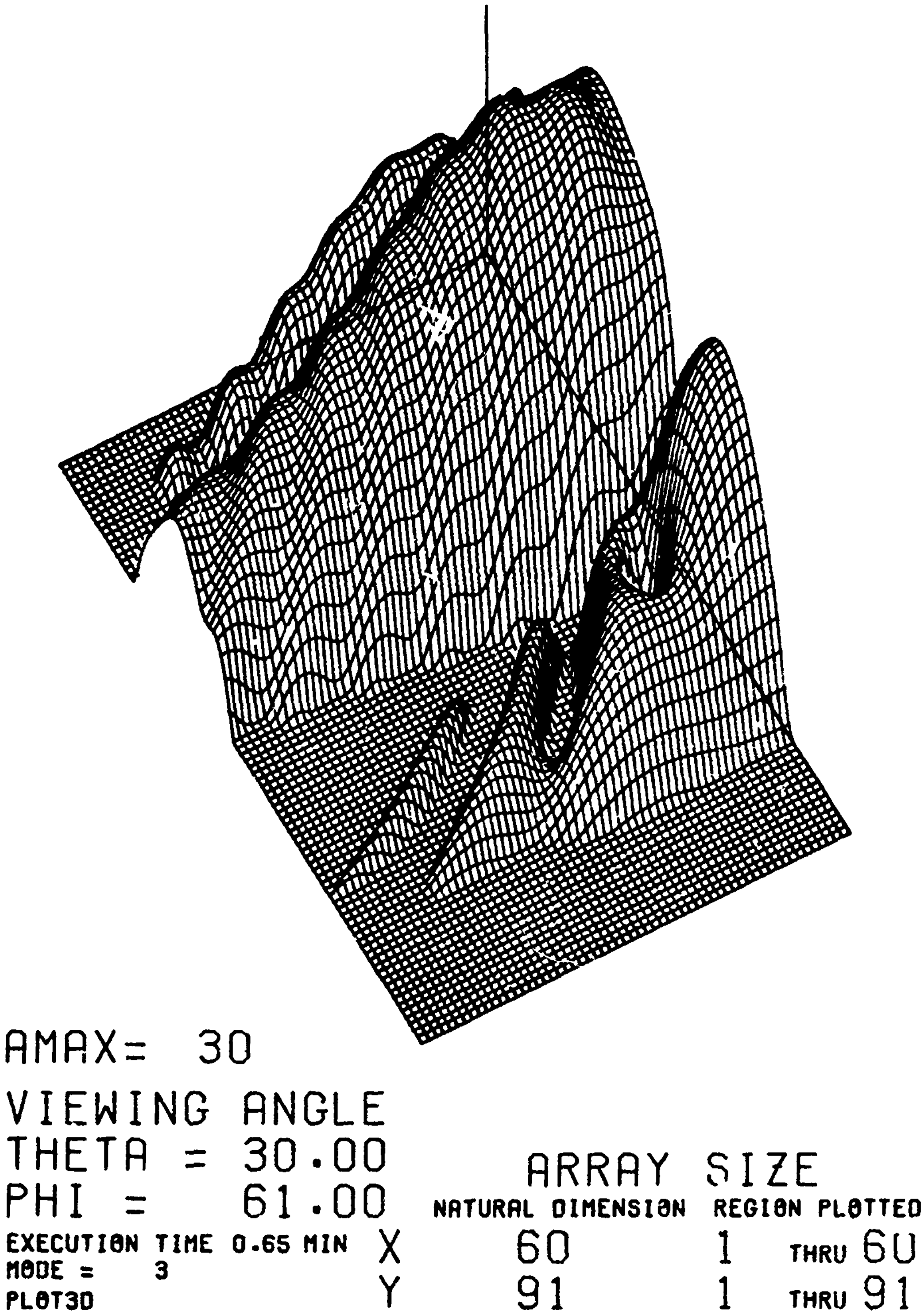


Fig. 10. Three-Dimensional Pattern Plot from Program S1478

Program S1625 does not require any information concerning the amplifier model or the passive electrical sections (cables, transformers, tuning devices, etc.) between the amplifier and transducer.

When S1625 is used, the distributed-element transducer description given to S1173 must have at least one piece in the head and tail sections. If the actual transducer model has no real piece in the head (or tail) section, then the program can be fooled by inserting a very thin piece of steel into the empty head (or tail) section. For a transducer operating at 4.0 kHz, a length of 10^{-4} meters and a cross-sectional area of 0.007 square meter worked well for a dummy head piece. If the dummy piece is too short, mathematical inaccuracies due to roundoff may occur; if the dummy piece is too long, the mathematics will be accurate, but the piece will begin to affect the transducer's behavior.

S1625 requires one data card, reading 16 integers by a 16I1 format. The integers will be zero (blank) or one. The columns containing "1" determine which of the 16 transducer varaibles in the preceding list will be displayed in histograms. For example, if only columns 10 and 16 contain a "1," then only histograms of ceramic volt-amperes and ceramic strain will be plotted. If all 16 columns are blank, no histograms will be plotted. However, maximum, minimum, and averages of the 16 transducer variables will still be calculated and listed by the UNIVAC 1108.

The calculations done by S1625 assume that the array is composed of identically manufactured transducers. If more than one type of transducer (more than one subarray) is inputted to S1173, then the first transducer model given to S1173 will be used by S1625 for all the transducers in the array.

In addition to the histograms, S1625 plots (Stromberg-Carlson 4060) a scattergram for the desired transducer variable, showing the relative distributions of the variable for all frequencies in one plot. A sample histogram and scattergram are shown in Figs. 11 and 12, respectively.

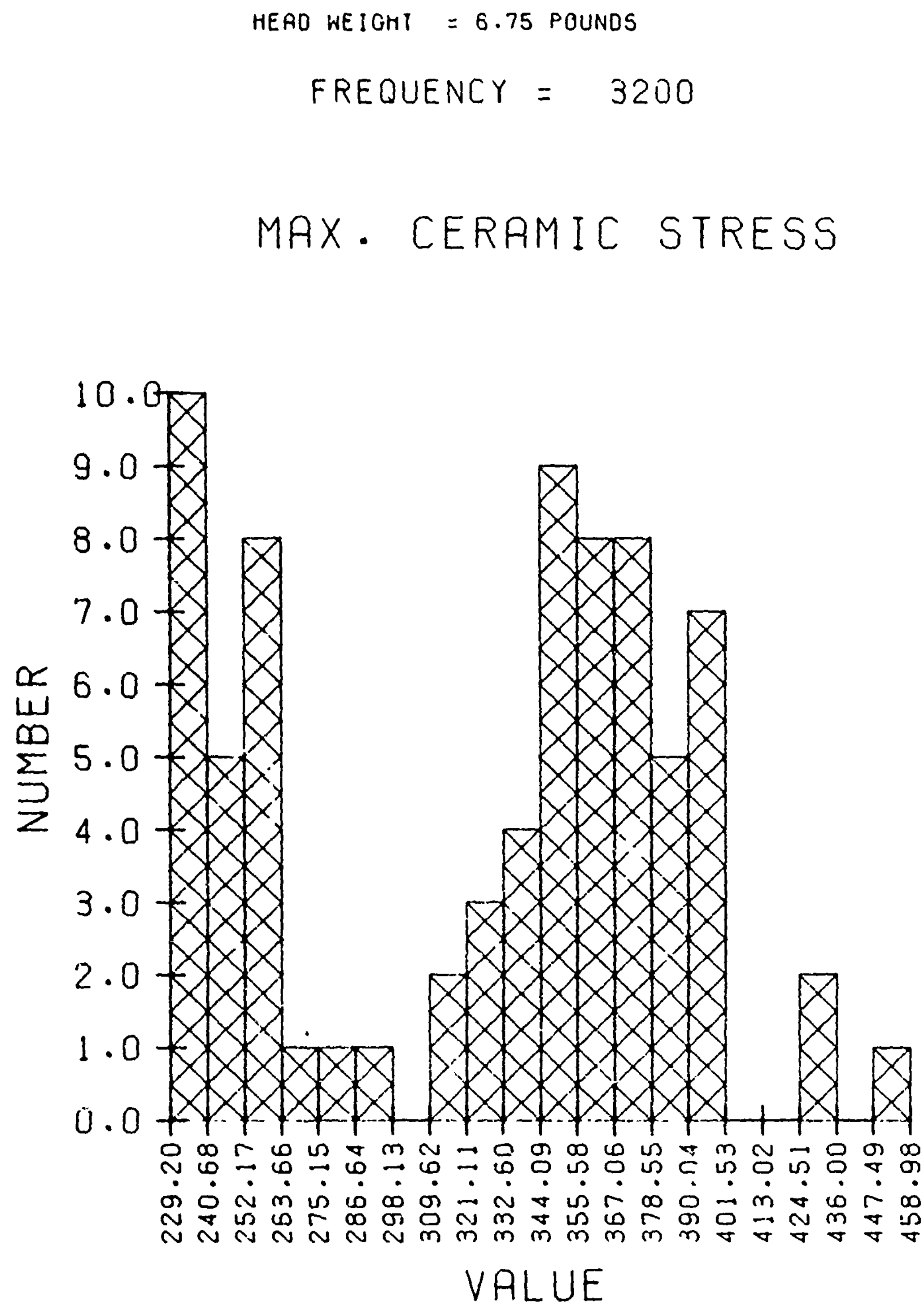


Fig. 11. Histogram Plot of Ceramic Stress from Program S1625

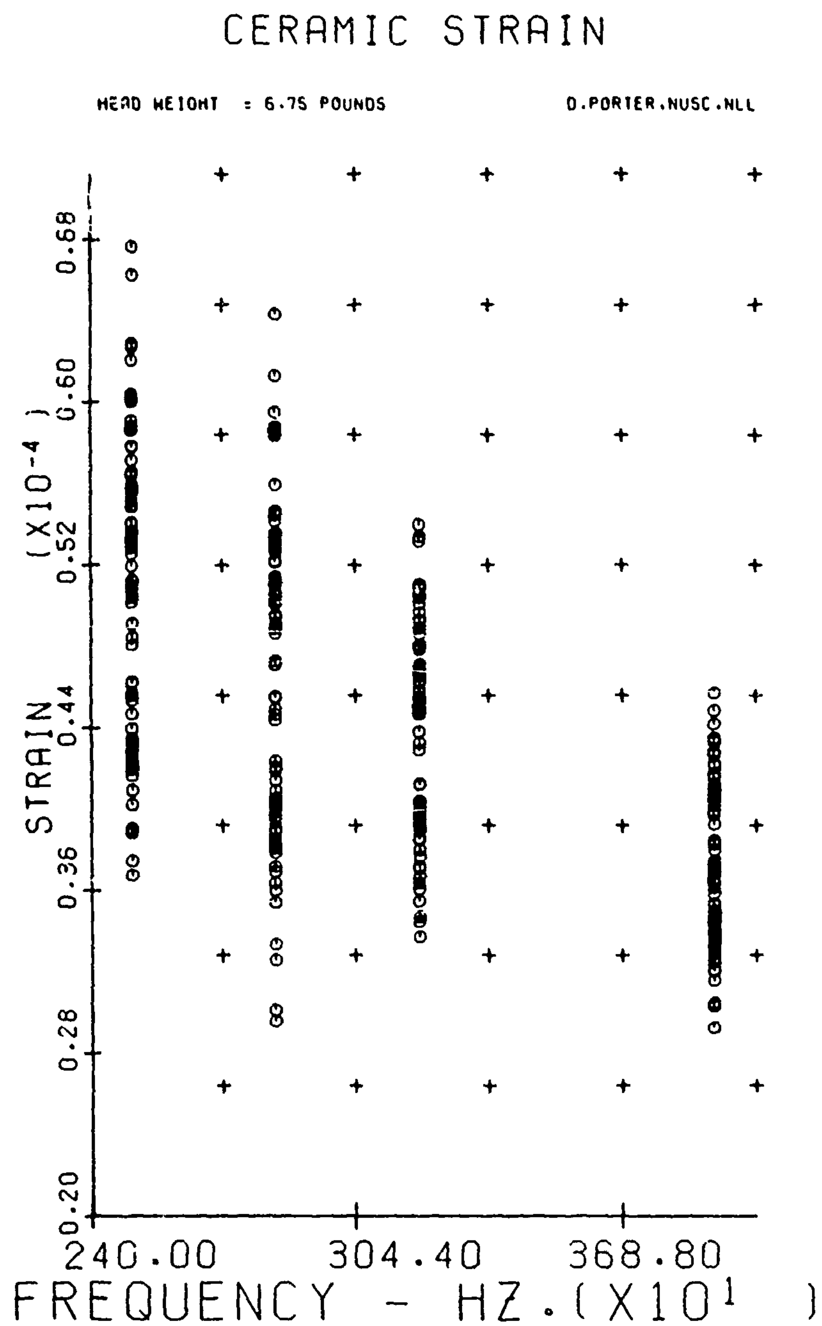


Fig. 12. Scattergram Plot of Ceramic Strain from Program S1625

Appendix A

COMPARISON OF TTOP5 WITH OLDER VERSIONS OF THE NUSC TRANSMITTING TRAIN OF PROGRAMS

Table A-1 compares the five versions of the Transmitting Train of Pr grams. As would be expected, Table A-1 shows that Version 5 (TTOP5) has the most versatility. Under certain conditions, the four older versions may also be useful.

Version 1 offers the capability of having each amplifier drive more than one transducer (the multielement drive or "stave" problem). An approximation to this problem is given in Appendix F.

Version 2 is faster than Version 4 or Version 5, as it requires neither tape/drum data storage nor multiple program executions. Therefore, Version 2 is useful for small arrays for which lumped-element transducer circuits are sufficient and for which automatic plotting is not required.

Version 3 is similar to Version 2; it solves the simultaneous array equations by iteration, using tape storage, and can handle up to 350 simultaneous equations.

Version 4 has most of the capability of Version 5 but requires only a small amount of drum storage, which can easily be converted to tape storage.

Table A-1

SUMMARY OF DIFFERENCES FOR THE FIVE VERSIONS

Version	1	2	3	4	5
Title	S0577-original	S0577-improved	S1090	TTOP4 (tape)	TTOP5
Cur Tape File	U360 1	U230 1	U360 3	U359 1	U358 1,2
Maximum number of equations	65	65	350	200	200
Maximum number of subarrays	1	3	1	9	9
Method of solution of equations	Matrix Inversion	Matrix Inversion	Iteration	Matrix Inversion	Matrix Inversion
Multi-element amplifier capability	Yes	No	No	No	No
Polar beam patterns plotted	No	No	Yes	Yes	Yes
Nearfield pressure plots (psi)	No	No	No	Yes	Yes
Two- or three-dimensional beam patterns plotted	No	No	No	Yes	Yes
Transducer model, lumped (L) or distributed (D)	L	L	L	L,D	L,D
Transducer stress, strain calculations and plots	No	No	No	No	Yes
Passive electrical sections	Few	Many	Many	Many	Many
Stromberg-Carlson 4060 plots (cathode ray tube)	No	No	No	No	Yes
Drum storage required	None	None	None	470* words	987,136 words

*Can be eliminated

Appendix B

FLEXING BAR MODEL OF A RECTANGULAR FLEXING TRANSDUCER HEAD USING MODAL ANALYSIS

A general transmitting array analysis, including provisions for a radiating head that is not required to be rigid, but can vibrate in any given number of modes, has been described by Sherman.[7] If an array has N transducers, each having M modes of vibration, then N x M equations can be written, in the general form

$$F_{mj} = \sum_{n}^{M} \cdot \sum_{i}^{N} Z_{mnij} V_{ni} \, . \qquad \text{(B-1)}$$

F_{mj} is the effective driving force on the mth mode from within the jth transducer. Z_{mnij} is the mutual acoustic coupling coefficient between the mth mode of the ith transducer and the nth mode of the jth transducer. V_{ni} is the velocity of the nth mode of the ith transducer. These N x M equations can be solved for the N x M transducer modal velocities in the same manner as is described in this report under Program S0577B for arrays of piston transducers. Knowing all the velocities of all transducer modes, deflection profiles of each transducer can be calculated. An average velocity over the interface of the head and ceramic stack can then be computed, and the transducer analysis can proceed as usual. In like manner, nearfield and farfield pressures can be calculated by totaling the contributions of all modes of all the transducers.

If a rectangular head is treated as a flexing bar or beam, flexing along its longer dimension only, then the mode shapes for the head can readily be derived and the process of the preceding paragraph can be carried out. This has been done and the pertinent equations have been included in TTOP5.

The computed results for this flexing head model are strongly dependent on the assumptions made about the force distribution of the transducer structure onto the head. The model used in TTOP5 assumed that the force onto the head was concentrated at two points (A and B in Fig. B-1). These two points are the intersection of the axis of the longer side of the plate with the projection of the outer edge of the ceramic stack onto the plate.

Thus far, only symmetric bending modes are included in the computer model. Antisymmetric modes could only be excited through mutual coupling. The computation of the mechanical impedance that the transducer structure offers against anti-

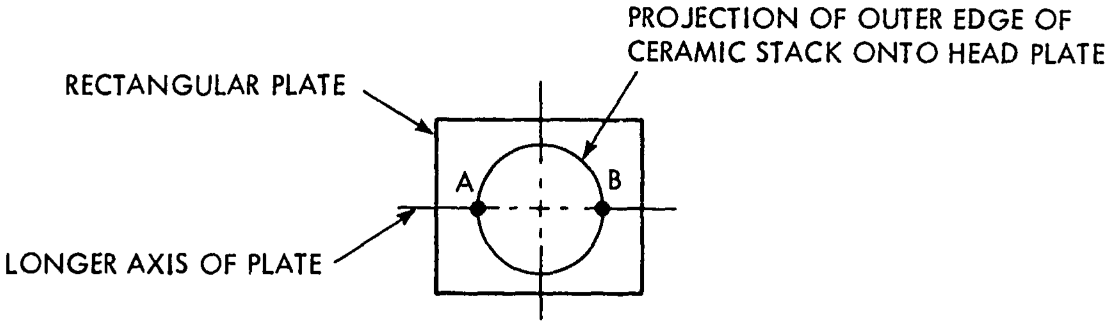


Fig. B-1. Effective Driving Points at Head-Stack Interface

symmetric (rocking) modes is beyond the present scope of the transducer models in TTOP5. The effects of the non-piston bending modes upon radiated patterns have not been included in TTOP5.

Sherman has shown that the bar modes are othogonal.[7] A consequence of this is that only the first (piston) mode has a non-zero volume velocity. Therefore, the radiated pressure pattern of any higher bar mode (symmetric or antisymmetric) will have a null at the normal to the plate. Unless the flexing is severe, the effects on the main beam of the radiated pattern by the non-piston bending modes will be unimportant.

To use this flexing bar model, the following special restrictions are imposed onto the input data:

1. If distributed-element analysis is used, do not include the head plate in the S1173 data.

2. If lumped-element analysis is used, remove the head plate from the model (Card No. 14b of S0577A), and adjust the effective head mass and air resonant frequency accordingly.

3. In Card No. 13a of S0577A, set IT5 = 3, and IT4 equal to the number of modes considered (usually two).

4. Read in the plate data from Card No. 15b of S0577A. The height and width of the plate are read in on Card No. 12b.

5. The total number of simultaneous equations to be solved will be (IA7) x (IT4). If this number is greater than 90, S1480 must be used for the matrix inversion.

6. The programs assume that for a given transducer face there is flexing only along lines of constant X (planar coordinates) or constant ϕ (cylindrical or spherical coordinates).

Appendix C

TWO-BY-TWO MOBILITY MATRIX REPRESENTATION OF A FLEXING HEAD

A process for representing a flexing head by a 2 x 2 complex mechanical mobility matrix has been described by Sefcik.[8] Shown in Fig. C-1 is a flexing transducer head mounted in a baffle with forces acting on it from both the water and the interior of the transducer.

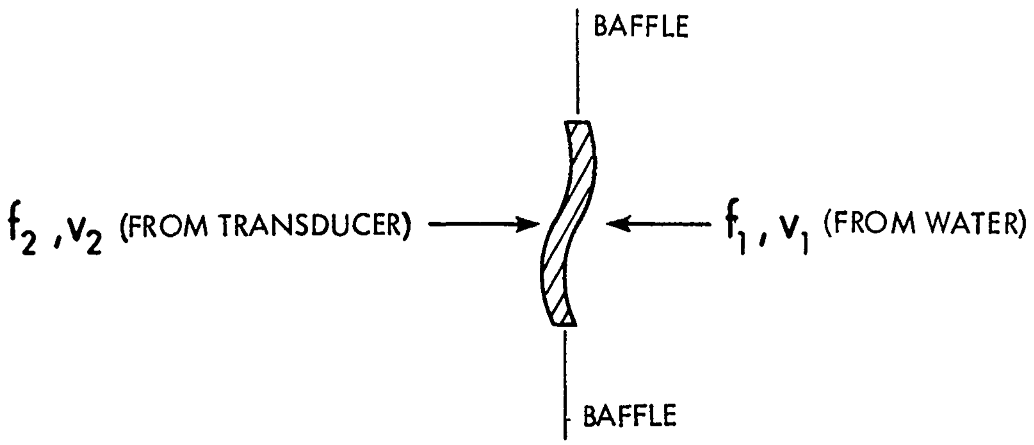


Fig. C-1. Flexing Head with Forces Exerted by Transducer and Water

The relationship between f_1, v_1, f_2, and v_2 and the complex mobility matrix, q_{ij}, is described by Sefcik[8] as follows:

"The 2 x 2 takes on the following form

$$\begin{bmatrix} q_{11} & q_{12} \\ q_{21} & q_{22} \end{bmatrix} \begin{bmatrix} f \\ f_2 \end{bmatrix} = \begin{bmatrix} v_2 \\ v_2 \end{bmatrix}$$

where

f_1 = total force on head-water interface;

f_2 = force on head-stack interface;

v_1 = average velocity on head-water interface

v_2 = velocity of head-stack interface."

S0577A reads in the q_{ij} matrix from cards, and converts the diagram of Fig. C-1 to a mechanical ABCD transfer matrix (see Fig. 2 of this report), by the following equations:

$$ABCD(1,1) = q_{11}/q_{12} \tag{C-2}$$

$$ABCD(1,2) = 1/q_{12} \tag{C-3}$$

$$ABCD(2,1) = -q_{21} + \frac{q_{11}\,q_{22}}{q_{12}} \tag{C-4}$$

$$ABCD(2,2) = q_{22}/q_{12} \tag{C-5}$$

This ABCD matrix for the head is then cascaded onto the ABCD matrix previously generated by S0577A for the rest of the transducer and the electrical elements connected to it.

The principal advantage of this mobility matrix head representation is that if the user has access to a suitable finite element structures program, appropriately interfaced to other programs needed to obtain the 2 x 2 q_{ij} matrix, then a flexing head of arbitrary size and shape can be analyzed. An alternate method for analyzing flexing heads is modal analysis, such as was used for the flexing bar model described in Appendix B. Unfortunately, modal analysis can be carried out for only a few highly idealized classes of heads.

A second advantage of the 2 x 2 mobility matrix method is that the head has only one radiating port. In the modal analysis method, each of th transducers has as many ports as the number of modes considered; the number of simultaneous array equations to be solved is proportional to the product of the number of transducers in the array and the number of head ports. Because of the limited core storage available, the use of modal analysis can greatly restrict the size of the array that can be analyzed. For the 2 x 2 mobility matrix method to be valid, the transducer heads can not be wildly flexing.[8] Also, the head flexure profile must be nearly invariant over the array for a given frequency. The 2 x 2 mobility matrix method also requires that for radiation purposes the radiation port act like a piston with velocity v_1, which is its volume velocity divided by its face area. For the radiation impedance of a non-piston radiator (referred to its volume velocity), the radiator's flexure affects the radiation reactance much more than the radiation resistance.[9]

Sefcik has also combined multiport head analysis with the finite element analysis. This improvement yields more accuracy, but is also more complex. It has not been incorporated into TTOP5.

To use the 2 x 2 mobility matrix method with TTOP5, the following restrictions are imposed:

1. If distributed-element analysis is used, do not include the head plate in the S1173 data.

2. If lumped-element analysis is used, remove the head plate from the model (Card No. 14b of S0577A), and adjust the effective head mass and air resonant frequency accordingly.

3. In S0577A, set IT4 = 1 and IT5 = 5 (Card No. 13a).

4. For each frequency read in two cards, according to the format !X4E13.6, containing the following eight quantities:

Card No. 28.7a: Real parts of q_{11}, q_{12}, q_{21}, q_{22}.

Card No. 28.7b: Imaginary parts of q_{11}, q_{12}, q_{21}, q_{22}.

The q_{ij} all have dimensions of seconds/kilogram.

Appendix D

NEARFIELD-TO-FARFIELD SOURCE LEVEL CORRECTION FACTORS

Because of the limited sizes of test tanks and other calibration facilities, source level measurements with a single hydrophone are often made on arrays in their nearfields, and a correction must be made to the measured source level to account for the fact that the measurement was not in the farfield. By using the appropriate options in the TTOP5, a correction can be computed. This correction factor will be referred to as the NFFFSLC. The computation process for the NFFFSLC, and relevant input data directions are given in the following paragraphs.

Nearfield pressures off the array are first calculated by TTOP5, in dynes/cm^2; they are then converted to an equivalent level relative to 1 microbar at 1 yard, by multiplying by the ratio of the measuring distance to 1 yard. The measuring distance is taken as the distance of the measuring hydrophone to the origin of the coordinate system used. A level in decibels is then obtained by taking 20 $\log_{10}$ of the above result. As TTOP5 also obtains a farfield level for azimuth and elevation for which a nearfield level is obtained, then for any azimuth and elevation combination a correction can be found:

$$\text{Correction} = \text{Farfield Level} - \text{Nearfield Level} \qquad \text{(D-1)}$$

Therefore the NFFFSLC given by TTOP5 should be algebraically added to the measured nearfield source level.

If the reference range used by the measurement facility to obtain nearfield source level was not the distance from the hydrophone to the center of the mathematical model's coordinate system but was some other distance, such as from the face of the array to the hydrophone, then a further hand correction must be made to the computer calculated NFFFSLC. This hand correction is $20 \log_{10} (D_{mf}/D_{calc})$, which must be added to the computed NFFFSLC, where D_{mf} is the measurement facility's reference range, and D_{calc} is the computer's distance from the hydrophone to the origin of the coordinates.

Therefore, it is not important what the measurement facility used for a reference range as long as the array-hydrophone geometry is the same for the measurements and calculations and as long as the $20 \log_{10} (D_{mf}/D_{calc})$ adjustment is made by hand to the printed NFFFSLC.

If the NFFFSLC is desired as a function of range, then the initial range from the origin of the coordinates and the incremental range (both in inches) are thus chosen (Card No. 8b, S0577A). For a cylindrical array it is usually convenient that the 0-value of the vertical (Z) coordinate be halfway up the array, as the 0-value establishes the origin of the coordinates.

Only a horizontal pattern is needed (IP10 = 1, Card No. 7, S0577A) and only one point need be computed for each range having azimuth and elevation angles corresponding to the ray from the coordinates' origin on which the measurements are to be made.

If the NFFFSLC is desired as a function of frequency, then one nearfield range and one set of azimuth and elevation pattern angle should be chosen. If IM17 = 4 (Card No. 4, S0577A), then a plot of NFFFSLC vs frequency will be made, as shown in Fig. 6.

Appendix E

USE OF TTOP5 FOR ANALYSIS OF RECEIVING ARRAYS

NUSC Computer Program S1000[10] predicts the electroacoustical behavior of receiving arrays. The arrays are restricted to longitudinal vibrator transducers, mounted on planar, cylindrical, or spherical rigid baffles. Mutual acoustic interactions are accounted for. The program is limited to a simplified lumped-element equivalent circuit and tuning apparatus.[1] S1000 does not produce a directivity index. It is interfaced to S1070, which given CALCOMP plots of polar beam patterns. The program assumes that the target remains fixed at an assigned bearing and depression, and that the array is electrically steered to form a pattern.

Unfortunately, no further work has been done on S1000 so that the program has not received the many improvements that the transmitting versions have. In particular, TTOP5 can handle much larger arrays, produce directivity indices, accommodate distributed-element transducer models, and give two- and three-dimensional pattern plots.

Receiving patterns for most of the present U. S. Navy arrays are only very slightly affected by mutual coupling in the array.[11] Three notable exceptions are: planar arrays steered near endfire, arrays whose interelement spacing is less than 1/4 wavelength, and small apertures where the nonused elements can make a substantial contribution to the acoustic loading of the used elements.

The transmitting programs naturally handle the acoustic mutual coupling differentially from S1000. There are differences in the equations determining transmitting and receiving patterns.[10] In particular, in a transmitting array the beamforming and shading are done first, followed by acoustic mutual coupling, and finally the formation of a beam pattern by the addition of the pressure contributions from the transducers. In a receiving array the order is reversed; the incoming pressure wave is felt first, followed by the acoustic interactions, followed by the beamforming and shading, and finally the addition of the electrical signals to form a pattern. Therefore, in a receiving array, the driving forces on the transducer are the incoming pressure forces, and the beamforming and shading are completely decoupled from the acoustic interaction.

For receiving arrays in which mutual acoustic coupling does not have a large effect on the patterns, TTOP5 will give beam patterns that are as accurate as those produced by S1000 and will also produce directivity indices.

When using TTOP5 for receiving arrays, it is best that the effects of mutual coupling be removed from the calculation. This is done by specifying for the transducer housing loss (Card No. 14d, S0577A) a large dummy resistance, such as 10 ρcA (A = piston face area) or greater. The transducers can be voltage- or current-driven; the beamforming and shading used for the receiving array will be used in the beamforming and shading data for TTOP5. The resulting electroacoustical transducer results will be meaningless of course, and should be disregarded. If it is desired to obtain a difference pattern while using TTOP5 as a receiving program, this can readily be done by adding 180° to the "driving signals" of half the array.

If the user is in doubt as to whether or not mutual coupling is important to a given receiving array, the array, or a portion of it, can first be tested with Program S1000. Although S1000 is restricted to a lumped-circuit description, it handles the mutual coupling in a legitimate manner.

If the user feels that mutual coupling is not important to the receiving array and does not require a directivity index but only beam patterns, then other "geometric" programs should be referred to.[12] These other programs do not account for the transducer circuit or mutual coupling; but, as they omit analysis of transducer circuits and mutual coupling, they can analyze a receiving array in much less computer time than either S1000 or TTOP5.

Program S1000, TTOP5, and the other programs referred to, all analyze arrays one frequency at a time; none of these programs produces a broadband pattern. If broadband capability is essential to a given problem, programs offering this capability are available.[13,14]

Appendix F

AN APPROXIMATION OF THE MULTIELEMENT DRIVE PROBLEM

The problem of analyzing a transmitting array in which each amplifier drives more than one transducer was programmed into the original version of S0577.[1] The current version (TTOP5) was programmed for each amplifier to drive only one transducer. As TTOP5 has so much more versatility than Version 1 and can handle much larger arrays, some approximation for using TTOP5 for multielement drive problems is desirable. Provided that the array does not have poor velocity control, such an approximation can be made.

One amplifier driving N transducers is shown in Fig. F-1. The amplifier open-circuit voltage is E, the amplifier source impedance is Z_s, and the transducer electrical input impedances are Z_1, Z_2, ..., and Z_N.

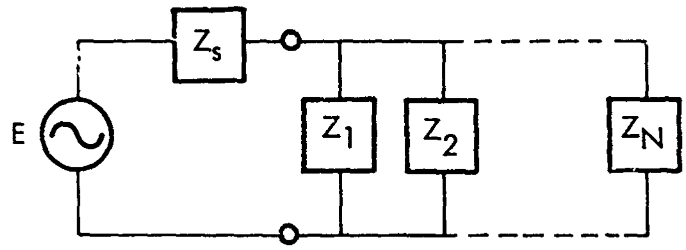


Fig. F-1. One Amplifier Driving N Transducers

Now, let us remove the source impedance (Z_s) and place an impedance (NZ_s) in each of the N parallel legs. The resulting circuit is shown in Fig. F-2. If we were to connect the points M_1, M_2, ..., M_N by short circuits, the circuit of Fig. F-2 would reduce to the circuit of Fig. F-1. However, making these connections would disturb the transducer voltages and currents in Fig. F-2, unless the N Z's were all equal, or unless Z_s were zero.

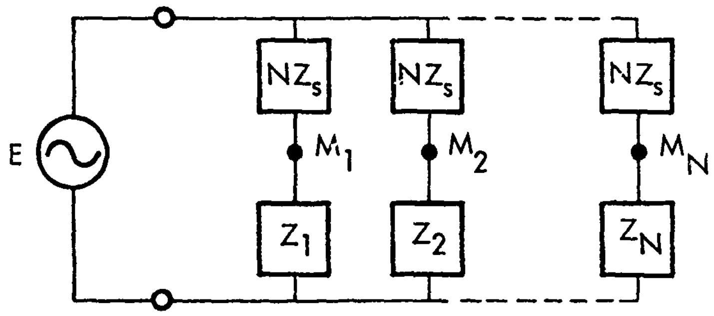


Fig. F-2. An Approximation to the Circuit of Fig. F-1

The advantage of the circuit of Fig. F-2 is that the N transducers can now be separated and each can be considered to be driven by its own separate amplifier, as shown in Fig. F-3. The N circuits of Fig. F-3 are in a form suitable to be handled by TTOP5.

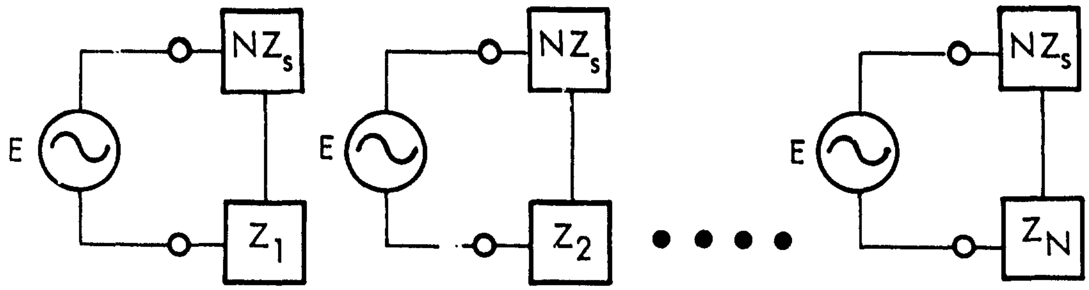


Fig. F-3. N Circuits Equivalent to the Circuit of Fig. F-2

The following procedure is suggested for using TTOP5 with an array whose amplifiers drive more than one transducer:

Step 1: Construct on paper the circuits corresponding to Figs. F-1 and F-3.

Step 2: Run TTOP5 for the circuits corresponding to Fig. F-3. Input shading coefficients for each transducer, even if these shading coefficients are all unity.

Step 3: Hand-calculate a mean transducer voltage for each group of N transducers.

Step 4: Raise or lower each amplifier voltage (E) to make the transducer voltages approach the mean voltage of their groups, as calculated in Step 3. Changing the amplifier voltages is accomplished by changing the amplifier shading coefficients.

Step 5: Rerun TTOP5 with the adjusted shading coefficients.

Step 6: Repeat steps 3 and 4 until a desired degree of convergence is achieved.

Step 7: The acoustic and transducer results have now been computed. The calculated Z's (or corresponding admittances) are inserted into Fig. F-1. By the hand calculation, the final amplifier results can be obtained.

This method is not restricted to arrays in which each amplifier drives exactly N transducers. For example, an array in which some of the amplifiers each drive four transducers and the other amplifiers each drive five transducers could still be analyzed by this suggested approximation and by using TTOP5.

An exact method for solving the multielement drive problem has been derived by Martin,[15] but this method has not yet been incorporated into TTOP5.

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13. ABSTRACT

The fifth version of the NUSC Transmitting Train of Programs comprises nine computer programs that predict the electrical, mechanical, and acoustical behavior of sonar arrays. Several improvements and necessary changes have been made to the older version of the train of programs resulting in a new version with greater versatility. The nine programs, which have been completely interfaced by tape and drum connections, can now be run together in one computer run. A description of the updated programs is provided and the currently required input data and control cards are given together with samples of the plotted output.

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TTOP5						
Prediction of Behavior of Sonar Arrays						

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