PREPRINT NO 1586 (C7)

AUTOMATED LOUD SPEAKER POLAR RESPONSE MEASUREMENTS UNDER MICROCOMPUTER CONTROL

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**Presented at
the 65th Convention
1980 February 25 through 28
London**

AES

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AN AUDIO ENGINEERING SOCIETY PREPRINT

AUTOMATED LOUDSPEAKER POLAR RESPONSE MEASUREMENTS UNDER MICROCOMPUTER CONTROL

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ABSTRACT

An automatic polar response measurement and analysis system controlled by an industrial/small-business grade microcomputer is described. A Z80 microprocessor based S100-buss computer (a Cromemco System 3) interfaced with a one-third-octave realtime analyzer and remote controlled turntable is used to gather response spectra at different angles. The disk stored spectral data is subsequently analyzed to generate polar/frequency response curves and beamwidth/directivity data. This paper emphasizes the practical aspects and problems encountered in development of the system's hardware and software.

INTRODUCTION: Present day loudspeaker horn design often entails specifications of the desired angular beamwidth and directivity of the horn as a function of frequency [1], [2]. In order to assess these characteristics of the horn, a detailed set of horizontal and vertical directional polar measurements must be taken at a number of different frequencies and then analyzed. If the measurement and analysis is done manually using traditional methods [3], the time consumed can often run into days for just one set of complete one-third-octave bandwidth vertical and horizontal polar curves.

Due to the mostly experimental nature of horn development, the design cycle often consists of a large number of "cut and try" steps with a measurement of the desired parameters after each step. Using manual methods of measurement and analysis, the time and labor envolved for even a few cycles is less than pleasant to think about.

This paper describes an automatic polar test setup run by a "high-end" microcomputer that considerably compresses the data taking and analysis cycle.

THE SYSTEM

The polar response measurement system block diagram is shown in Fig. 1. In addition to the microcomputer and its associated peripherals, the system includes: a remote controlled turntable, one-third-octave real time spectrum analyzer, pink-noise generator, bandpass filter, equalizer and power amplifier. The loudspeaker under test is energized with band-limited pink noise and then rotated by the turntable. The real-time analyzer with its measurement microphone gathers frequency response spectra while the loudspeaker rotates. The microcomputer is used to orchestrate the system and stores the measured spectra in a floppy disk file.

The disk stored spectral data is subsequently analyzed off-line to generate a number of very useful tables and curves including: normalized and un-normalized off-axis frequency response, normalized and un-normalized directional polar response at each frequency, 6-db-down beamwidth versus frequency, and directivity versus frequency.

HARDWARE

The system hardware was mostly assembled from pieces of existing test equipment. The one major exception was the turntable which was custom made to our specifications. The microcomputer and its associated peripherals were originally purchased as a general purpose computing device for use in the lab.

Turntable

The turntable has the capability of variable speed and bidirectional operation. Currently the computer can only start and stop the turntable and change its direction. The table's speed must be set manually depending on the weight and size of the object being rotated.

The turntable was built using a large 300 mm (12 inch) diameter spur gear with 192 teeth as the rotating base plate. A Bodine [4] fractional (1/50th) horsepower D.C. motor with reduction gear box was used to drive the spur gear. A Minarik [5] speed control box modified by the addition of relays for start-stop and reverse was used to control the motor.

Originally an optical shaft position encoder was planned so that the computer could sense the position of the turntable. In practice, the temporary use of a tooth counting microswitch to the system works so well that the encoder was not needed. The computer simply senses the operations of the microswitch and keeps track of the current position of the table by a simple software routine. The positioning resolution provided by this system is about plus or minus 0.5 degree when counting the tooth peaks and valleys on the 192 tooth spur gear (approximately 360 degs/(2 X 192)/2 = 0.47 deg).

Noise Generator

A pseudo-random noise generator [6] with variable clock speed (a Wavetek model 132 VCG-Noise Generator [7]) is used as the noise source to provide a broad band test signal. The repititiveness of the pseudo-random noise decreases the random variations in the levels of each of the one-third-octave bands of the real time analyzer. In practice, the generator's clock is set to the highest speed that provides a relatively flat low-frequency spectrum as viewed on the real-time analyzer. At this clock setting, the analyzer can be set to rather short averaging times to facilitate rapid spectral updates.

Band-pass Filter

A band-pass filter is included in the system to concentrate the broad-band random noise test signal in the desired pass band of the transducer being tested. This maximizes the signal-to-noise ratio of the system while minimizing heating of the device being tested. Two Krohn-Hite model 3200 high or low-pass filters in cascade are used to form a bandpass filter with 36 dB/octave filter skirts [8].

Equalizer

A one-third-octave bandwidth boost-cut equalizer is used in the signal chain to maximise the signal-to-noise ratio in each of the one-third-octave measurement bands. The equalizer is normally set to approximately flatten the on-axis frequency response of the device being tested. A signal-to-noise ratio of at least 30 dB in each spectral band for the on-axis signal is aimed for.

Real-Time Analyzer

A one-third-octave bandwidth real-time spectrum analyzer with measurement microphone is used to measure the spectral content of the radiated sound. The original analyzer used was the older Bruel & Kjaer model 3347. This analyzer was interfaced to the computer through two 8 bit parallel I/O ports. Currently we are using the more recent B & K model 2131 Digital Frequency Analyzer interfaced through the IEEE 488 (IEC 625-1) standard digital interface buss.

Computer and Peripherals

The microcomputer used in the polar measurement setup is a Cromemco [9] model Z-2D with 64K Bytes of main memory. This microcomputer is a heavy duty unit intended for industrial and small-business users. The computer uses an Intel Z80 microprocessor running at 4mHz clock speed and is based on the S100 buss. The following list represents the current state of the microcomputer and its peripherals:

Quantity	Model	Description	Manufacturer
1	ZPU	Z80 4mHz CPU card	Cromemco
1	4FDC	Disk Controller Card	"
4	16KZ	16K Ram Memory Card	"
3	TRT	TU-ART digital interface card with 2 Parallel & 2 Serial Ports	"
1	4PIO	4 Port I/O Isolated Parallel Interface	"
1	PRI	Printer Interface Card	"
1	D+7AI/O	Multi-Channel A/D & D/A Analog Interface Card	"
1	APU	High-Speed Arithmetic Processing Unit Card (uses AMD AM9511 chip)	MemTech [10]
1	CT100	Digital Clock Card	Compu/Time [11]

2	82	Minifloppy Disk Drive	Wangco
1	277	Dual 8" Floppy Disk Drive	PerSci
1	IP-125	Impact Printer	Integral Data Systems
1	IQ 120	Video Terminal	SOROC Technology, Inc.
1	4662	Digital Plotter	Tektronix, Inc.
1	1350A	Graphics Translator	Hewlett Packard
1	1311A	Large Screen Graphics Display	"

TEST SITE

Large test devices, which require at least a 3 meter measurement distance, are measured outside on a large ground-plane concrete test pad. In every case, the device under test is rotated so that the plane of rotation is co-planar (parallel) with the flat surface. Measurements have been taken both with the test device and measurement microphone elevated 3 to 4 meters above the plane and with the device very close to the ground plane (in this latter situation the microphone is actually laying on the concrete). Both measurment methods yield polar curves which agree quite well with corresponding measurements made in a large anechoic chamber. The latter test method is quite well suited to measurements on very large devices such as large low-frequency loudspeaker systems.

Smaller devices which can be measured at 1 meter or less are measured in our small 250 Hz anechoic chamber.

SOFTWARE

As in all automatic test equipment systems, the software and programming became the most time consuming and labor intensive part of the system (particulary graphics software). Several months of part-time programming were spent in the initial software developement of the data gathering and analysis portions of the program (and this included only the tabular output version of the program with no graphics!).

All initial programming was done using Cromemco's 16K BASIC language. Current programming, which is heavy with graphics, is being done using Cromemco's FORTRAN and RATFOR languages (RATFOR stands for "Rational FORTRAN", a FORTRAN preprocessor that allows purely structured code using IF-THEN-ELSE, WHILE, and REPEAT logic structures, etc., see [12]). For graphics programming, a commercial FORTRAN software package is being used (the Tektronix PLOT 10 Terminal Control System).

All software developement is being done right on the microcomputer itself (including the writing of this paper using Cromemco's word processing software). Heavy use of "top down structured" programming techniques is being used in all programming effort to clarify program design and expidite the program-debug-modify cycle.

Data Gathering Program

The data gathering program was written in 16K BASIC with the program listing extending over ten 8.5"X11" pages (about 18K characters of source code with remark statements).

The program starts by interactively requesting descriptive and command information from the operator. The polar spectral data is gathered at the equal angular increments selected by the operator. The frequency bandwith can be chosen anywhere in the range of the real-time analyzer.

A typical step in the data gathering operation consists of: positioning the turntable to the required angle, turning on the test signal, requesting one spectrum from the analyzer, turning off the test signal, requesting another spectrum, computing the signal-to-noise ratio in each one-third-octave band, and storing the spectrum if the s/n ratio is sufficient. If the s/n ratio is inadequate, the system will retry two times and then alert the operator for continued instructions. All data on disk is stored in non-binary character (ASCII) format to allow operator review of disk data without aid of a special program.

Data Analysis Program

The data Analysis program for tabular output (no graphics) was also written in BASIC and the listing exceeds 15 pages with about 30K characters of source code including remark statements.

The top module of the program allows 5 tasks to be selected:

1. List descriptive information,
2. Generate frequency response data,
3. Generate polar response data,
4. Generate angular beamwidth data, and
5. Generate directivity data.

The frequency response and polar response data generation modules allow the options of listing the data with-or-without right-left polar averaging and normalization of all data to the on-axis levels. Normalization of the data to the on-axis levels is very useful in emphasizing the directional characteristics of the device being tested with the usual non-flat on-axis frequency response effects being cancelled out. Additional options allow interactive listing of the frequency response at a specific angle and/or the polar response at a particular frequency. Of course, the complete analyzed data can be printed out at any time. The beamwidth and directivity modules generate a data table with the data listed as a function of frequency.

The graphics portion of the analysis program, which will generate data curves on the digital plotter and graphics display, is not complete at this time and is in the development stage.

TEST RESULTS

Typical test results of the measurement system will be illustrated by measurements taken on a large high-frequency radial horn and compression driver: the JBL model 2350 90 deg X 40 deg horn and 2440 driver. The format of the data stored in the disk file is shown in Fig. 2. Figs. 3 to 5 show some of the tabular results of the analysis program.

Setup and Measurement Time

As with all complex measurement setups, it often takes more

more time to set the system setup than to make the actual measurements. The polar measurement system once set up can take a set of polar measurements and analyze the results in a time span of about 30 minutes (one axis only with a 5 degree angular increment). The data gathering capabilities are such that a several speaker systems (about 5 to 15) can be measured in a single day long work session. The biggest problem in the setup often times ends up being mechanical difficulties in trying to mount the test device to the turntable (especially large horns).

SUMMARY

An automatic microcomputer operated system for taking loudspeaker polar response data was described. The system has turned out to be a time saver for measurements associated with the developement of high frequency horns. The system software design and developement however turned out to be a major time consuming task.

ACKNOWLEDGMENT

The author would like to thank the Cromemco Z2D microcomputer and Cromemco's Word Processing System software for the rapid creation and typing of this paper (who needs humans any way!).

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[6] D. B. Keele, Jr., "The Design and Use of a Simple Pseudo Random Pink Noise Generator," J. Audio Eng. Soc., vol. 21, pp. 33-41 (Jan./Feb. 1973).

[7] Wavetek, 9045G Balboa Ave., San Diego, Ca 92123 U. S. A.

[8] Krohn-Hite Corp., Avon Industrial Park, Avon, MA 02322 U. S. A.

[9] Cromemco Inc., 280 Bernardo Ave., Mountain View, CA 94040 U. S. A.

[10] MemTech Co., 4891 Clairemont Mesa Blvd., San Diego, CA 92117 U. S. A.

[11] Compu/Time, 8532 Hamilton Ave., Huntington Beach, CA 92646 U. S. A.

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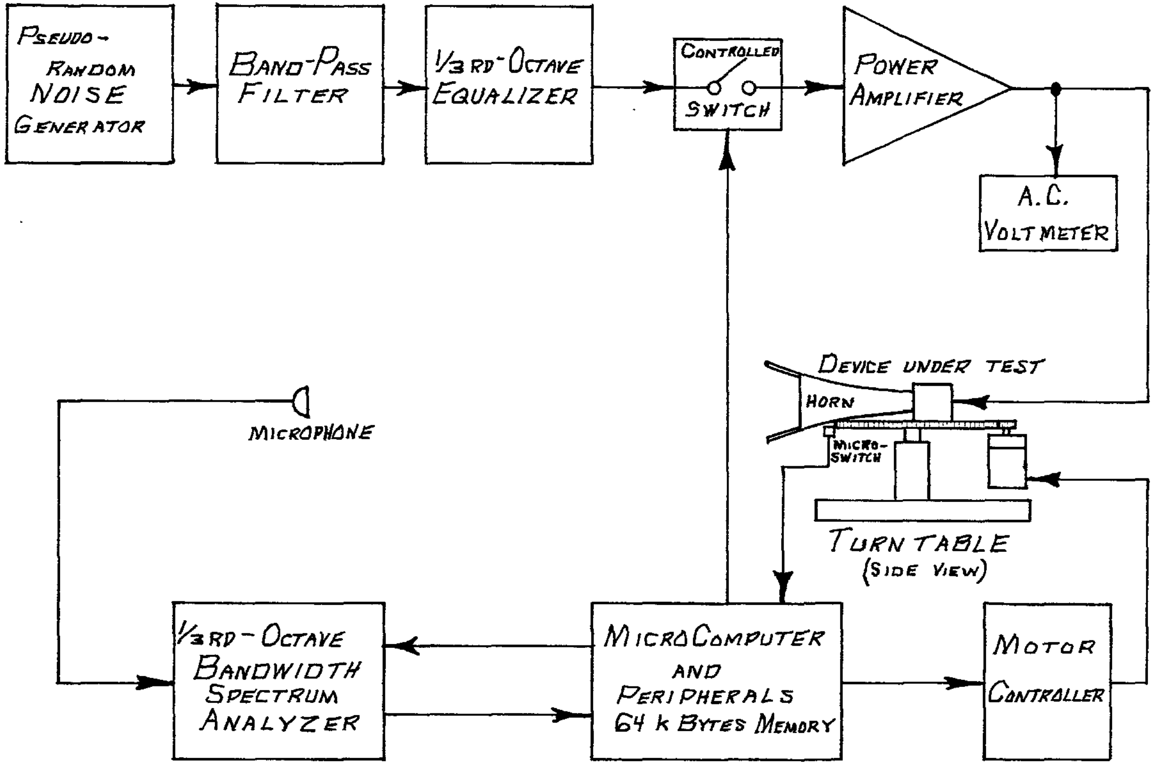

Fig. 1. Block diagram of automatic polar measurement response system. PLease refer to body of text for more information on each individual block.

```
**************** DATA FILE JBL2350H.PRN *******************
       **** POLAR FREQUENCY RESPONSE DATA *****

NAME/DESCRIPTION OF DEVICE TESTED:
JBL 2350 HORN, 2328 ADAPTER, 2441 DRIVER

DATE:
NOV. 20,78

NAME OF PERSON (S) DOING TESTING:
DON KEELE, WALT DICK, DREW DANIELS

NAME/DESCRIPTION OF TEST SITE:
OUTSIDE GROUND PLATFORM FROM B&K 1

MIC TO SPEAKER DISTANCE AND REFERENCE POINTS:
3 METERS FROM HORN MOUTH

MICROPHONE HEIGHT:
4 METERS

TEST DEVICE HEIGHT:
4 METERS

TYPE OF TEST ETC.:
HORIZONTAL POLARS

GENERAL COMMENTS:
USING 1/2" B&K 90 DEG MIC, PSEUDO RANDOM NOISE

START, STOP FREQUENCIES IN HZ.:
   250,   20000

START, STOP, INCREMENT ANGLES IN DEGREES:
     .00000,  360.00000,    5.00000

THE FOLLOWING TABULATION AT EACH ANGLE LISTS THE LEVEL IN
DB SPL AT EACH 1/3RD OCTAVE CENTER FREQUENCY STARTING
AT 250 HZ AND ENDING AT 20000 HZ.


ANGLE= 0 DEGS.
 79.2, 82.8, 82.0, 84.0, 87.2, 86.6, 85.8, 84.4, 82.6, 85.2
 85.0, 84.8, 85.6, 87.0, 86.4, 88.2, 89.0, 90.0, 88.2, 81.6

ANGLE= 5 DEGS.
 79.4, 83.0, 82.2, 84.2, 87.4, 86.4, 85.8, 84.4, 83.0, 85.6
 84.6, 85.0, 85.2, 87.0, 86.6, 88.8, 89.8, 90.4, 88.8, 82.8

ANGLE= 180 DEGS.
 80.8, 78.2, 79.8, 77.4, 73.0, 73.6, 72.2, 66.0, 64.4, 67.0
 65.0, 57.4, 58.0, 55.6, 54.4, 50.4, 50.0, 50.6, 50.0, 50.0

ANGLE= 360 DEGS.
 79.6, 82.8, 82.4, 84.4, 87.4, 86.6, 86.0, 84.6, 82.8, 85.4
 85.0, 84.8, 85.4, 87.0, 86.4, 88.4, 89.4, 90.4, 88.6, 82.[illegible]
```

Fig. 2. Format of stored data file that is created by the measurement system's data gathering program. The listing is an actual printout of the data file for the horizontal polar measurements taken on a large JBL radial horn and driver (model 2350 horn and 2440 driver). File is stored in a non-binary ASCII text format to facilitate operator review of file contents without special utility programs.

```
********************* POLAR RESPONSE DATA *********************
RESPONSE DATA FROM BOTH SIDES HAVE BEEN AVERAGED.
POLAR RESPONSES HAVE BEEN NORMALIZED TO ON AXIS VALUES.

FREQUENCY=  251 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,    .0,    .0,   -.2,   -.4,  -1.0,   1.3,  -1.6,   2.4,  -2.9
  -3.3,  -3.8,  -4.6,  -5.0,  -5.9,  -6.6,   7.5,  -8.1,  -8.8,  -9.0
  -8.4,   7.6,  -6.6,  -5.3,  -4.9,  -3.6,   2.5,   1.8,   1.0,   -.4
    .0,    .4,    .7,   1.0,   1.2,   1.3,   1.4

FREQUENCY=  316 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,    .1,   -.2,    .7,  -1.2,  -2.0,  -2.9,  -3.7,   5.0,  -6.3
  -7.4,  -8.9, -10.3, -11.5, -12.9, -13.9, -14.7, -16.1, -16.9, -16.8
 -17.4, -16.8, -15.5, -14.2, -12.5, -11.5, -10.2,   9.5,  -8.6,   7.7
  -6.9,  -6.2,  -5.6,  -5.2,  -4.9,  -4.7,  -4.6

FREQUENCY=  398 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,   -.2,   -.6,  -1.1,  -1.7,  -2.8,  -4.0,   4.7,  -6.3,  -7.7
  -8.6, -10.3,  11.1, -12.1, -13.0, -13.9,  14.5,  15.5, -16.3, -16.9
 -18.1, -18.7, -19.6, -19.3, -18.1, -16.5, -13.9, -11.8, -10.1,   8.0
  -6.6,  -5.4,  -4.2,   3.5,  -2.9,  -2.6,  -2.4

FREQUENCY=  794 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,   -.3,  -1.1,  -2.0,  -2.8,  -3.3,  -3.9,  -4.5,   5.4,   6.5
  -8.0, -10.0, -11.5, -12.9, -13.7, -14.7, -14.9, -15.4, -16.0, -16.6
 -18.3, -19.4,  19.9,  18.5, -17.2, -16.3, -16.6, -17.4, -19.0,  19.6
 -20.1, -20.4, -19.0, -17.0, -14.9, -13.5, -13.0

FREQUENCY= 3981 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,   -.5,    .0,   -.5,  -1.0,    .3,    .4,  -1.3,  -3.5,  -6.3
  -9.4, -12.5, -14.6, -16.4, -17.6, -18.4, -19.3, -19.9,  21.1, -21.7
 -21.6, -21.7, -22.9, -22.5, -23.6,  23.8, -24.5, -26.3, -25.5, -26.4
 -26.4, -27.6, -27.6, -25.4, -27.5, -28.0, -27.5

FREQUENCY= 7943 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,    .3,    .7,  -1.3,  -2.7,  -5.1,  -6.4,   7.2, -10.0, -13.9
 -17.7, -21.8,  23.8, -25.2, -27.9, -27.1, -26.6, -28.2, -28.3, -29.0
 -29.9, -31.2, -32.5,  31.8, -32.7, -33.6, -34.0, -33.6,  34.8, -35.6
 -36.3, -37.0, -36.6, -37.5, -37.3, -37.0, -37.9

FREQUENCY=15849 HZ
LEVEL IN DB. START AT 0 DEGS. END AT 180 DEGS. INCREMENT= 5 DEGS.
    .0,   -.2,  -2.6,  -5.1,  -7.7, -12.2, -14.9, -13.,   14.5, -18.8
 -24.3, -29.4, -32.6, -33.2, -34.9, -35.3, -34.9, -36.6,  37.3, -38.2
 -38.4, -38.4, -38.4, -38.4, -38.4,  38.4, -38.4, -38.4, -38.4,  38.4
 -38.4, -38.4, -38.4, -38.4, -38.4, -38.4, -38.4
```

Fig. 3. Example of the tabular output of the data analysis program for the polar response of the horn and driver (JBL model 2350 & 2440) whose measurement data is shown in Fig. 2.

```
*************** FREQUENCY RESPONSE DATA LISTING ***************
RESPONSE DATA FROM BOTH SIDES HAVE BEEN AVERAGED.
ALL RESPONSES ARE NORMALIZED TO THE AVERAGE ON-AXIS RESPONSE.

ANGLE=  0.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0
    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0,    .0

ANGLE=  5.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
    .0,    .1,   -.2,   -.2,   -.1,   -.3,    .2,    .1,   1.0,    .0
  -1.1,    .7,   -.5,    .0,    .1,    .3,    .2,   -.1,   -.2,   -.5

ANGLE= 10.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
    .0,   -.2,   -.6,    .8,   1.0,  -1.1,   -.8,    .9,   2.9,    .0
  -1.8,    .3,    .0,   -.2,   -.2,   -.7,  -1.1,  -2.6,   2.6,  -3.5

ANGLE= 15.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
   -.2,   -.7,  -1.1,  -1.5,  -2.2,  -2.0,   -.9,   1.6,   3.5,    .7
   -.7,   -.3,   -.5,    .1,   -.1,  -1.3,   2.1,  -4.8,  -5.1,  -6.2

ANGLE= 45.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
  -2.9,  -6.3,  -7.7, -10.0,  -8.9,  -6.5,  -7.6,  -6.0,  -5.2,  -6.7
  -7.0,  -5.7,  -6.3,  -7.3,  -8.2,  13.9, -15.7, -15.0, -18.8, -17.1

ANGLE= 50.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
  -3.3,  -7.4,  -8.6, -10.8,  -9.4,  -8.0,  -9.2,  -7.2,  -7.2,  -8.7
  -9.0,  -7.9,  -9.4, -10.4, -11.7, -17.7, -19.6, -19.8, -24.3, -23.5

ANGLE=175.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
   1.3,  -4.7,  -2.6,  -6.8, -14.9, -13.5, -14.1, -18.8, -18.8, -19.6
 -21.8, -26.1, -28.0, -30.5, -31.9, -37.0, -38.5, -40.2, -38.4, -31.8

ANGLE=180.0 DEGS
LEVEL IN DB AT EACH 3RD OCTAVE. START AT   251 HZ. END AT 20000 HZ
   1.4,  -4.6,  -2.4,  -6.8, -14.3, -13.0, -13.7, -18.5, -18.3, -18.3
 -20.0, -27.4, -27.5, -31.4, -32.0,  37.9, -39.2, -39.6, -38.4, -31.8
```

Fig. 4. The data analysis program's tabular output for normalized on-off axis frequency response for the horn and driver (JBL model 2350 & 2440) whose measurement data is shown in Fig. 2.

******* BEAMWIDTH VERSUS FREQUENCY *******
TABULAR FORMAT

FREQUENCY HZ	BEAMWIDTH DEGS
*********	*********
251	143.3
316	88.1
398	80.6
501	63.1
631	56.7
794	85.7
1000	81.7
1259	91.3
1585	94.0
1995	87.5
2512	84.6
3162	92.1
3981	89.5
5012	87.3
6310	83.8
7943	53.5
10000	48.9
12589	34.7
15849	33.9
19953	27.7

*********** DIRECTIVITY VERSUS FREQUENCY **********
TABULAR FORMAT

FREQUENCY HZ	DIRECTIVITY FACTOR Q	DIRECTIVITY INDEX DI (dB)
*********	***********	***********
251	1.82	2.6
316	3.93	5.9
398	3.40	5.3
501	4.23	6.3
631	4.91	6.9
794	4.43	6.5
1000	5.22	7.2
1259	4.26	6.3
1585	5.60	7.5
1995	10.05	10.0
2512	10.95	10.4
3162	10.62	10.3
3981	12.06	10.8
5012	13.75	11.4
6310	15.87	12.0
7943	30.21	14.8
10000	36.54	15.6
12589	49.32	16.9
15849	60.03	17.8
19953	58.40	17.7

Fig. 5. The data analysis program's tabular output for a. beamwidth (-6 dB) and b. directivity, for the horn and driver (JBL 2350 & 2440) whose measurement data is shown in Fig. 2.