One Kilowatt Cylindrical Wavefront Loudspeaker with Folded, Modular Horn for New York World's Fair*

JOHN E. VOLKMANN

RCA Laboratories, Princeton, New Jersey

The requirements and folded modular design are given for the huge one-kilowatt cylindrical-wavefront loudspeaker system used in the Fountain of the Planets spectacle at the 1964-65 New York World's Fair.

INTRODUCTION Work on the cylindrical wavefront loudspeaker with folded modular horn began at a brief exploratory meeting with Dr. Harry F. Olson of RCA Laboratories and with A. W. Schneider of Commercial Radio-Sound Corporation, who described the basic requirements for covering the 600 ft diameter fountain and lighting display— then called the Pool of Industry—for the 1964-65 New York World's Fair. The feasibility of a loudspeaker system centrally located in the fountain *vs* a distributed loudspeaker system located at the periphery of the "pool" was discussed. After much discussion and consideration of the various problems, such as hydraulic and pneumatic turbulence of the medium, directional illusion and concealment of the sound source, echo and other items, the central location for the loudspeaker was chosen, mainly for the following reasons:

1. A body of successful experience was available from the central loudspeaker system used under the Perisphere at the 1939 New York Fair.
2. There would be an obvious advantage in terms of spatial illusion by having the sound source concealed in and emanating from the fountain itself. (For clear projection of sound lines above the immediate environs, a hydraulic lift for elevating the loudspeaker system was specified.)
3. By locating the loudspeaker near the center of the pool the ratio of music signal to fountain noise would remain approximately constant with distance of projection.
4. Based on experiences with sound and picture in drive-in theaters, adequate synchronization between sound and fountain display could be expected for the 300 ft projection distance.
5. It was felt that the water vapor and high humidity of the air medium and the spacing between water streams and droplets (like perforated sound screens for movies) would not seriously attenuate sound transmission except possibly in case of high winds. Likewise, modulation of the projected sound due to the changing pattern and motion of the water curtain would be minor, and merely add to the illusion of the sound emanating from the fountain display itself.
6. The possibility of a high degree of uniformity in coverage and in frequency response from a cylindrical horn array would further lessen the risks of any variances due to turbulence. (Sufficient space would be available for a height up to 10 ft and a diameter up to 16 ft if needed for vertical directivity and power capacity).

PERFORMANCE REQUIREMENTS AND AUDIO POWER CALCULATIONS

At the meeting it was stipulated that the "fountain loudspeaker" be capable of covering the peripheral area of the 600 ft pool with a minimum sound level of 100 dB peaks on music. Using the sensitivity of the RCA 3 in. theater-type driver unit as a basis for calculation, this meant that for a projection distance of 300 ft and coverage area of one tenth to one quarter million square feet,

* Presented October 16, 1964 at the Annual Fall Convention of the Audio Engineering Society, New York.

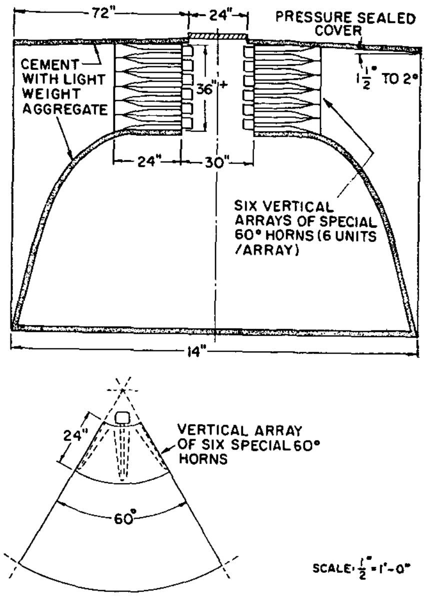

Fig. 1. Preliminary outline of the loudspeaker for the "Pool of Industry," New York World's Fair. **a.** Radial section. **b.** Plan of the 60° array.

approximately 400 to 1000 audio watts would be required. Full-spectrum driver mechanisms were chosen since slow taper horns appeared feasible from the space requirement standpoint, and since it was desired to avoid crossover frequency problems. A low-frequency cutoff, not to exceed 80 Hz, was specified. Preliminary calculations and design information on available horn driver mechanisms (RCA MI 9584B) indicated that a minimum of 36 to 48 driver mechanisms would be required; with full horn loading the units would pass frequencies down to cutoff. Later calculations on diaphragm excursion limits indicated that the audio power input to a single unit should be limited to 2 W at 65 Hz. A rough sketch to check the feasibility of design is shown in Fig. 1. Figure 2 is a plan view of the fountain pool showing the central location of the loudspeaker and the area to be covered.

The great advantage of a cylindrically stacked array of radial horns, that is, of a 360° cylindrical wavefront horn with infinite length, is that the fall-off in sound energy is inversely proportional to the linear distance, rather than to the square of the distance as in the case of a spherical wave progression. For a cylindrical array of finite length it can be shown by Huygens' principle that the fall-off in energy with distance is somewhere between the linear and spherical conditions, depending on the wavelength of the energy radiated (linear for high frequencies and spherical for low frequencies).

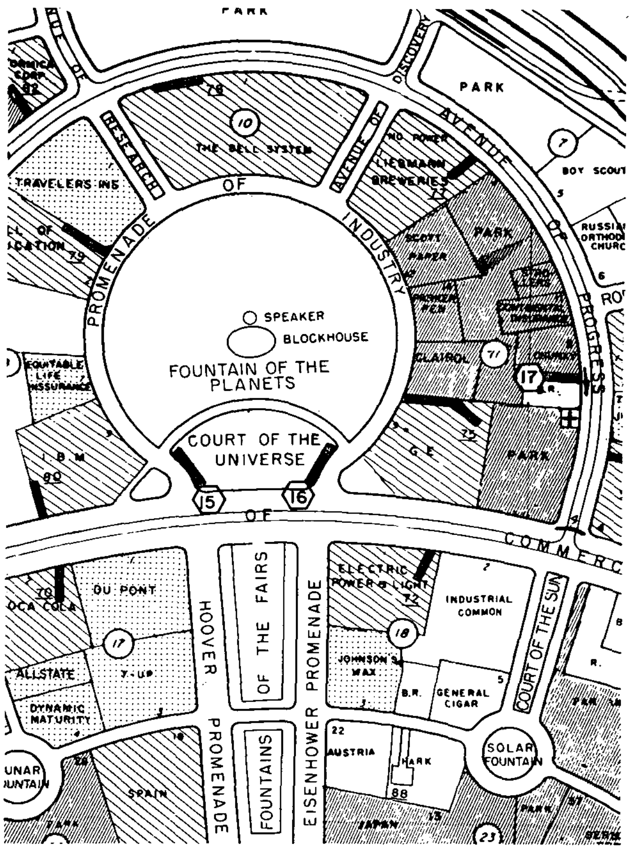

Fig. 2. Location of the 1964-65 New York World's Fair loudspeaker in the 600 ft diameter Fountain of the Planets pool.

RATE OF FLAIR AND DESIGN OF "CYLINDRICAL WAVE" HORN MODULE

The 360° full-spectrum loudspeaker shown in Fig. 1 proposed 36 sixty-degree modular, folded, radial horns stacked in six vertical arrays of six each, coupled to a common radial horn extension. In the final design, a 360° cylindrical array employing forty-eight 22½° modular horns, stacked in three layers of 16 each and coupled to a common radial horn extension of 16 ft diameter and 5 ft height was chosen. Figure 3 shows the general outline, radial disposition, flare, etc. of the final modular horn and extension horn design. The 22½° modular horns were designed for a 65 Hz rate of flare, while the 360° horn extension was designed for 40 Hz. To permit easy vertical and peripheral stacking of the complete assembly, the height of the modular horn units was kept constant from front to back. To meet the basic requirements of a low rate of flare, matched phasing

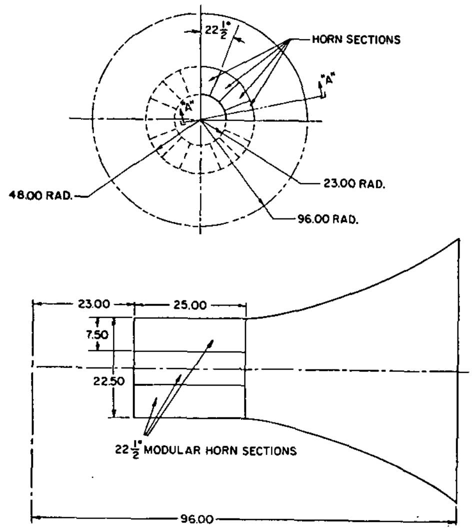

Fig. 3. **a.** Outline of the 360° assembly of forty-eight 22½° modular horn sections. **b.** Outline of a horn extension along the centerline "A"-"A".

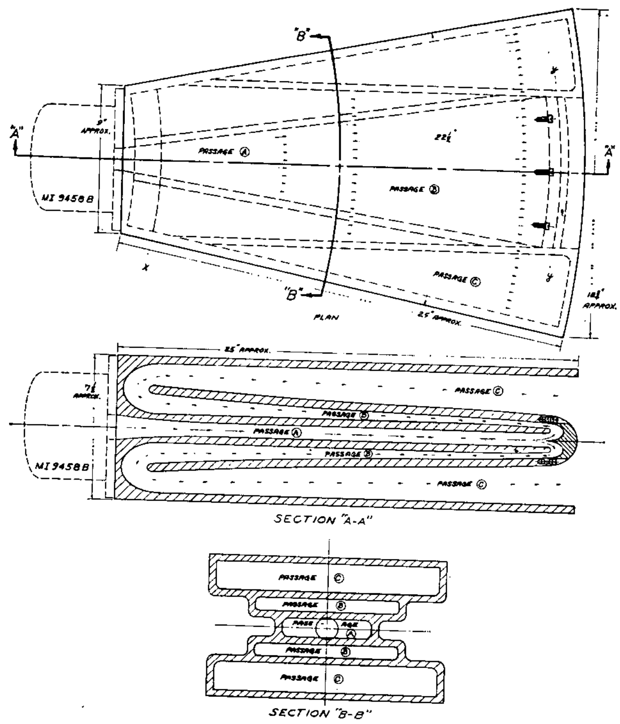

Fig. 4. Diagram depicting folded construction and passage of wavefront through a 22½° modular section of the cylindrical wavefront horn.

between adjacent horns, adequate physical clearance between driver units, and modular construction in a cylindrical array of radial horns, it was necessary to design the folded horn in such a way that it would maintain uniform phase across its wavefront, i.e., maintain a uniform path length for all radial paths in the progress of the wavefront through the horn. This was achieved by folding the passageways from the throat to mouth opening along the curved lines *x* and *y* shown in Fig. 4. This sketch was used in the preliminary discussions with the patternmaker. The small arrows show the progression of the wavefront from horn throat to horn mouth through the folded passageways *A, B* and *C*. The tips of the arrowheads in the plan view depict the points in the wavefront which are of the same phase. In the plan view it will be noted too that the wavefront in passage *A* and *C* expands circumferentially, while in the intermediate passage *B* the wavefront width remains constant. The flare in all three passages is basically exponential.

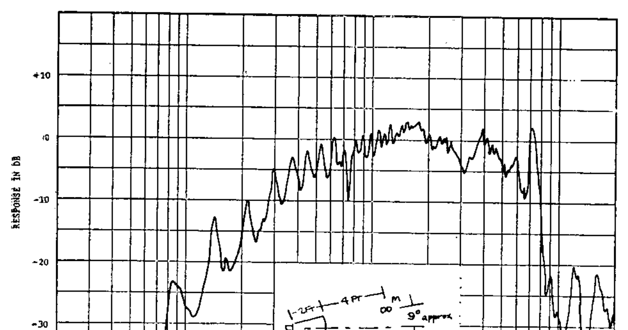

Fig. 5. Response-frequency characteristic of the first aluminum casting of a 22½° horn module.

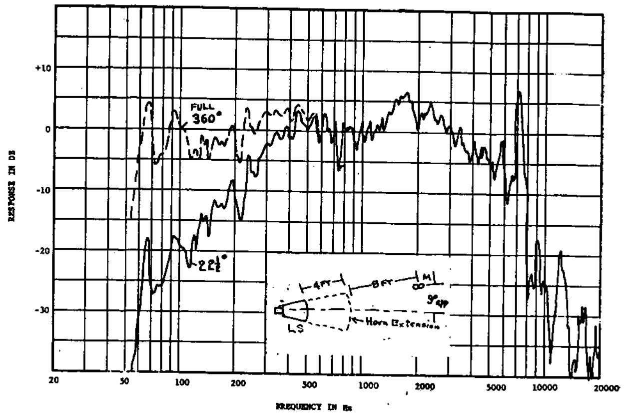

Fig. 6. Response-frequency characteristic of a single 22½° horn module extended 4 ft to simulate the radial length of the overall 360° assembly.

PERFORMANCE DATA

Figure 5 shows the response-frequency characteristic at 4 ft at an angle of 9° from the centerline of a single 22½° horn module made from the first aluminum casting submitted by Commercial Radio-Sound Corporation.

Figure 6 shows the response-frequency characteristic of the single 22½° horn module extended 4 ft to simulate the radial length of the overall 360° assembly. As expected, the additional horn loading increases the low-frequency response and smooths out the "reflection" peaks and dips.

For relatively close-up measurements on the centerline of the 22½° horn module, the response-frequency characteristic showed an interference dip in the region above 5000 Hz due to reflection from the horn sidewalls. This reflection effect is shown in Figs. 7 and 8 for 4 ft and

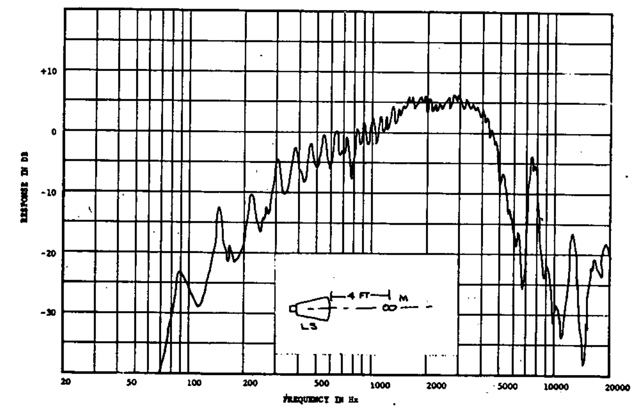

Fig. 7. Response-frequency characteristic of a 22½° horn module measured at 4 ft on the centerline.

8 ft, respectively. It was eliminated by padding the flat sidewall of the horn with a sound-absorbent lining, as shown in Fig. 9. At a radial distance of 300 ft the interference would be shifted to a much higher frequency and effectively out of the working spectrum. In the final assembly the horn modules were staggered, i.e., the middle layer of modules were rotated 11¼° relative to the top and bottom layers so as to avoid or minimize this reflection effect.

Several meetings were required with the patternmaker and foundry personnel to make sure that construction

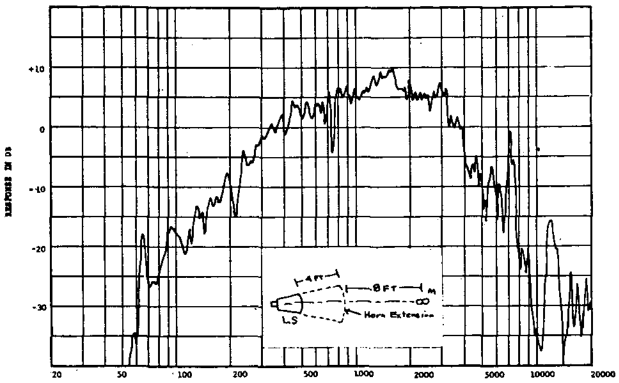

Fig. 8. Response-frequency characteristic of a 22½° horn module with 4 ft extension measured at 8 ft on the centerline.

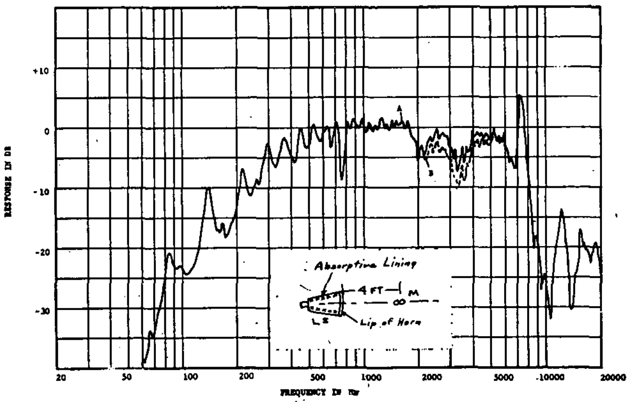

Fig. 9. Response-frequency characteristic of a 22⅓° horn module with a sound absorbent pad, measured at 4 ft on the centerline. **a.** With horn tip attached. **b.** With horn tip removed.

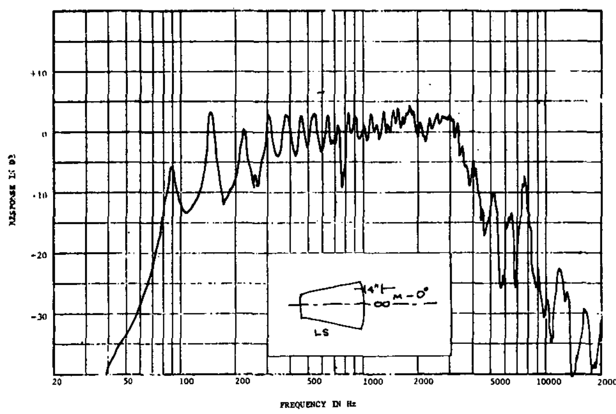

Fig. 10. Response-frequency characteristic measured close to the mouth of the horn at an angular position of 0°.

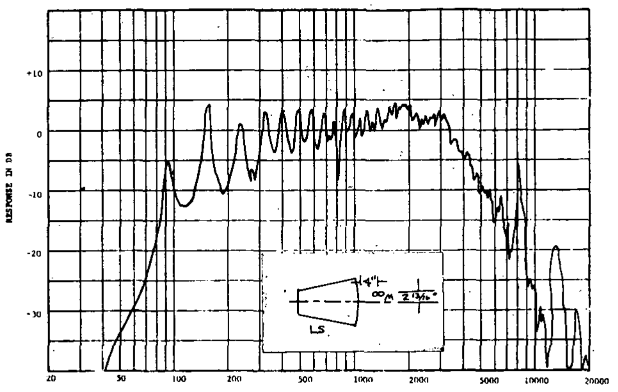

Fig. 11. Response-frequency characteristic measured close to the mouth of the horn at an angular position of 2¹³⁄₁₆°.

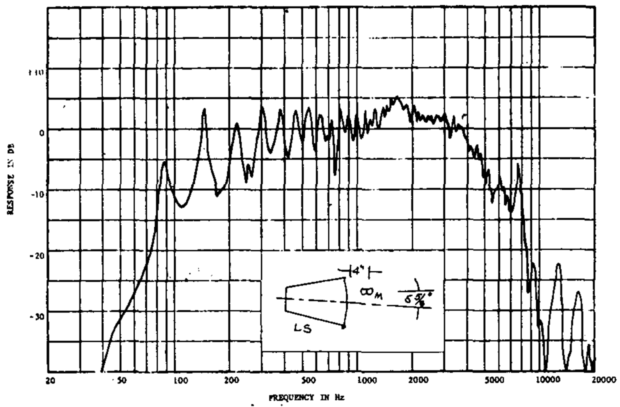

Fig. 12. Response-frequency characteristic measured close to the mouth of the horn at an angular position of 5⅝°.

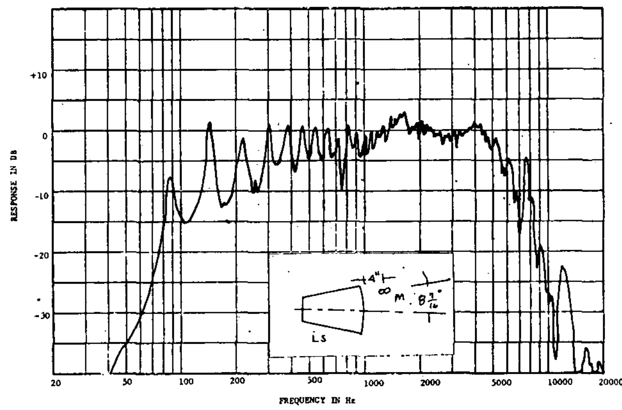

Fig. 13. Response-frequency characteristic measured close to the mouth of the horn at an angular position of 7⁹⁄₁₆°

and dimensions conformed to the basic rate of flare. For example, one question asked was: Could the small "lip" extension from the center of the horn mouth be removed? Figure 9 shows the change in response which would have occurred if the lip had been eliminated.

The concept of folding a radial horn on a segment of a circular line, rather than on a straight line, made it possible to maintain a constant length for all radial paths and hence constant phase for all points in the progressing cylindrical wavefront. The degree of uniformity of response for different angular positions close to the mouth of the horn is shown in Figs. 10 through 14.

Listening tests on the single horn module with and without extension horn sounded clear, clean and smooth. In order to simulate the full bass response of the final 360° assembly, low-frequency equalization which made the response essentially flat was also tried. The response-frequency characteristic of the 360° assembly thus simulated is shown by the dotted line in Fig. 6. For maximum power levels, under conditions of full horn loading, it was recommended that the diaphragm excursion of the driver units be attenuated 8 dB at 65 Hz with an electrical filter having a cutoff slope of 3 to 6 dB/octave. In addition, it was recommended that overload limiters

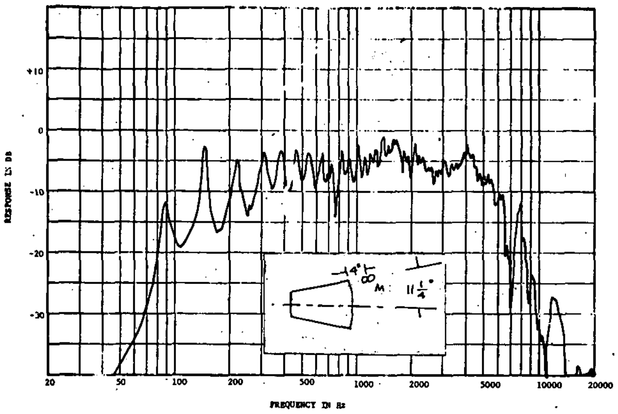

Fig. 14. Response-frequency characteristic measured close to the mouth of the horn at an angular position of 11¼°

be used in the loudspeaker circuits. Compensators for adjusting the overall system response and subjective frequency balance during final installation was likewise recommended.

Figure 15 is a photograph of a single 22½° aluminum horn module, while Fig. 16 shows the complete assembly.

CONCLUSION

This paper has covered the salient features and performance of the 22½° modular folded radial horn, 48 of which were used in the completed 360° "cylindrical wavefront" loudspeaker array designed by the author for Commercial Radio-Sound Corporation for the Fountain of the Planets spectacle at the 1964-65 New York World's Fair. The complete loudspeaker system, with 4 ft radial horn extension, was built by Commercial Radio-Sound and had a diameter of 16 ft, a mouth height of approximately 5 ft and a weight of 7000 lb. It handled an audio input of over 1 kW and delivered a maximum sound power output of over 250 W, or a peak sound-pressure-level of over 100 dB at 300 ft. We believe this to be not only the largest loudspeaker used at the New York World's Fair but the most powerful ever built for the reproduction of music and speech. It was equivalent in acoustic output to 1000 home phonographs.

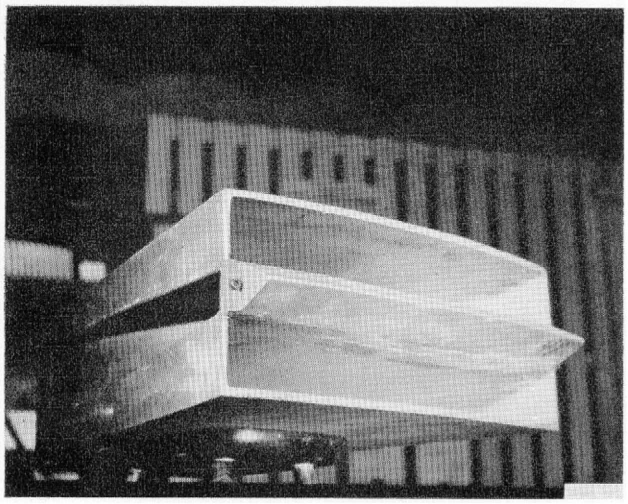

Fig. 15. A single 22½° aluminum radial horn module.

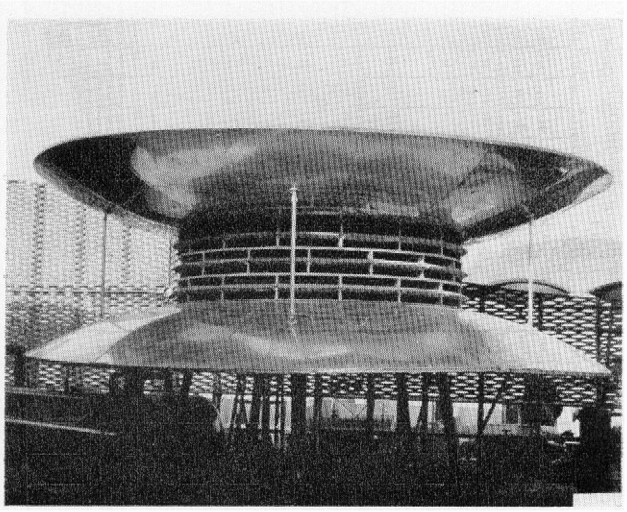

Fig. 16. Complete 360° cylindrical-wavefront speaker.

THE AUTHOR

John E. Volkmann received his BS (1927), MS (1928) and his Professional Degree (1940) in Engineering Physics from the University of Illinois. Since then he has worked continuously with RCA in the field of acoustics, specializing in the development and application of large-scale auditorium loudspeakers and stereophonic sound systems, as well as consultant on architectural, electronic and acoustic problems. He has contributed to the solution of innumerable projects including: stereo sound systems for the Radio City Music Hall, the Hollywood Bowl, the recording acoustics for Walt Disney's Fantasia; custom loudspeakers for New York World's Fairs of 1939 and 1964-65, and the Jones Beach Marine Stadium and most recently, he has been responsible for the acoustic design of RCA Italiana's 364,000 cu ft Studio A—regarded as the largest and first ever built specifically for the recording of full-scale Operas and large Symphonic Orchestras.

Mr. Volkmann has been responsible for much of the advanced acoustic development and theatre equipment engineering activities at RCA in Camden, N. J., and is a member now of the Technical Staff at the RCA Laboratories in Princeton, N. J.

In 1962 he received the RCA Achievement Award for "Advances in the Development of Architectural Acoustics" and, in 1967, the John H. Potts Memorial Award from the Audio Engineering Society for "elegant application of acoustic principles in the development of large-scale loudspeakers and sound systems." Mr. Volkmann is a member of several honorary scientific fraternities and is a fellow member of the Society of Motion Picture and Television Engineers, the Audio Engineering Society, and is a fellow member of the Acoustical Society of America.