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Constant Directional Characteristics from a Line Source Array*

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A constant-length line-source loudspeaker system will have directional characteristics that vary with frequency. This paper discusses the use of acoustical loading to effectively decrease the length of the line-source with increasing frequency, maintaining nearly constant directional characteristics.

LINE-SOURCE loudspeaker arrays, often called "column" loudspeakers, have recently become of great interest to sound-system contractors and equipment manufacturers in this country. These loudspeaker systems have been very popular in Europe because they could be easily assembled of relatively low-priced, cone-type loudspeakers to achieve considerable directivity in one plane. When used to replace conventional, single, cone-type loudspeakers in reverberant spaces (and properly aimed), they often have achieved dramatic improvements in speech intelligibility by apparently "cutting through" the room reverberation. Their greater directivity also gives the appearance of vastly greater efficiency when the listener is on or near on-axis.

Most of the recent commercial American line-source loudspeaker systems have been simple, straight-line arrays of identical type cone loudspeakers connected in some simple series-parallel arrangement. The following difficulties have been noted with nearly all such simple line sources, often reducing the quality of speech reinforcement systems:

1. Great roughness in response and lack of controlled directional characteristics at high frequencies, due to phase differences between individual loudspeakers, in turn caused by cone breakup and often emphasized by the series connections frequently used.
2. Narrowing of the major (on-axis) lobe at higher frequencies and broadening of the coverage at lower frequencies. Olson gives equations[1] for both continuous line sources and a series of point sources that demonstrate why any given line-source loudspeaker system, with all loudspeakers phased together, will have a major-lobe coverage angle that decreases with increasing frequency.
3. Strong minor off-axis lobes or side lobes at high frequencies; again Olson's equations indicate the inevitability of these side lobes, especially for a line actually made up of separated points.
4. Peaky and falling high-frequency response off-axis, even with uniform loudspeakers operating in phase. This is a natural corollary of factors 2 and 3.

Although these defects of most column loudspeakers have not prevented their application to many sound-system problems, the careful sound-system engineer may often desire the better results possible by overcoming these defects. We expect the practical results of such an improvement in line-source array design to include increased feedback rejection with properly placed microphone; more uniform coverage of the desired area; greater reduction of the energy in the reverberant field; and smoother frequency response in the area covered.

The problems caused by random differences in the phase response of the loudspeakers making up the line-source sys-

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[1] Harry F. Olson, *Acoustical Engineering*, (D. Van Nostrand Co., New York, 1957), pp. 35-36.

tem can, of course, be reduced by employing loudspeakers of known high quality and uniformity. We have designed a number of custom line-source loudspeaker systems over the past ten years and have generally been pleased with the uniformity of a number of commercially available speakers. We have also usually recommended simple parallel connections of loudspeakers with step-down transformers as required, and attempted to reduce side lobes and broadening main-lobe coverage at high frequencies by the use of padding in the lines feeding the loudspeakers at the outer edges. The improvement has been small, and predictable from Olson's equations for tapered line sources.[2] Curved-line sources have also been constructed and measured, and found to have generally rougher off-axis response at high frequencies.[3]

The only real solution to the problems inherent in a line source is the use of a line source of variable length, namely one that decreases in length with increasing frequency. From theory we know that a uniform line having a length equal to a constant times the wave length should have constant directional characteristics. Three previous attempts to approximate such a variable-length line source in practical loudspeaker systems were:

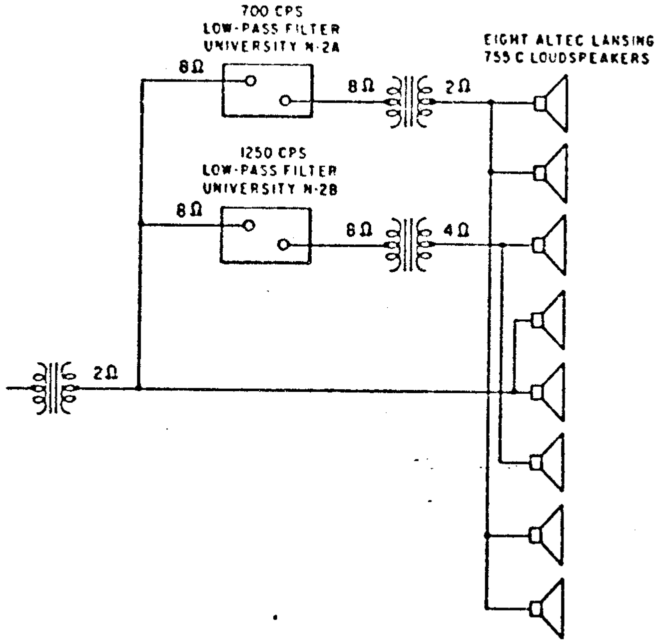

FIG. 1. Line-source loudspeaker with electrical filtering at Franklin Hall, Franklin Institute, Philadelphia, Pa.

1. The Electro-Voice LR-4S system, and similar custom-designed earlier systems employing filter networks to attenuate high-frequency signals at the outer loudspeakers. (For example, the system shown in Fig. 1.)

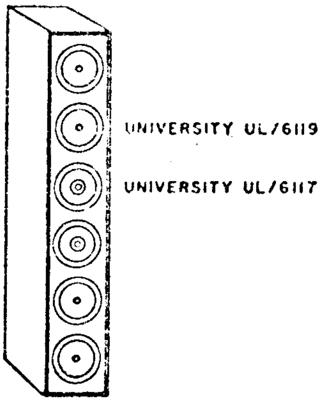

FIG. 2. Line-source loudspeaker with omission of high frequency "whizzer" in outer loudspeakers: University loudspeaker UCS-6.

2. A column using full-range loudspeakers only in the center, with outer loudspeakers that do not reproduce high frequencies. In one commercial example the cone-type of loudspeaker is employed throughout: each outer loudspeaker has its high frequency "whizzer" removed. (See Fig. 2.)

3. The "skewed" column or "barber pole" loudspeaker system, where the increasing directivity of the individual loudspeakers at higher frequencies is employed to reduce the line length.[4] (See Fig. 3.)

The remainder of this paper describes a fourth approach which effects a more precise reduction in the length of the line with increasing frequency. This approach uses acoustic loading in front of the line-source loudspeaker system.

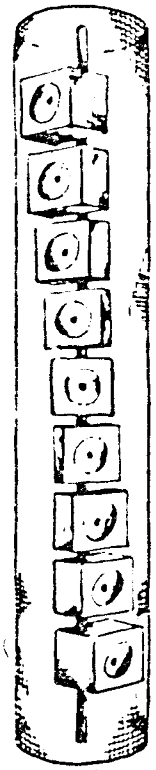

FIG. 3. "Barber pole" line source: Palais Chailot, Philips system.

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[2] *Ibid.*, pp 37-39.

[3] M. F. Gardiner and D. L. Klepper, "Recent Studies of Line-Source Loudspeakers." Oral paper presented at the Spring 1960 Meeting of the Acoustical Society of America.

[4] D. Kleis, "Modern Acoustical Engineering," *Philips Technical Review*, 20, 320 (1958-59).

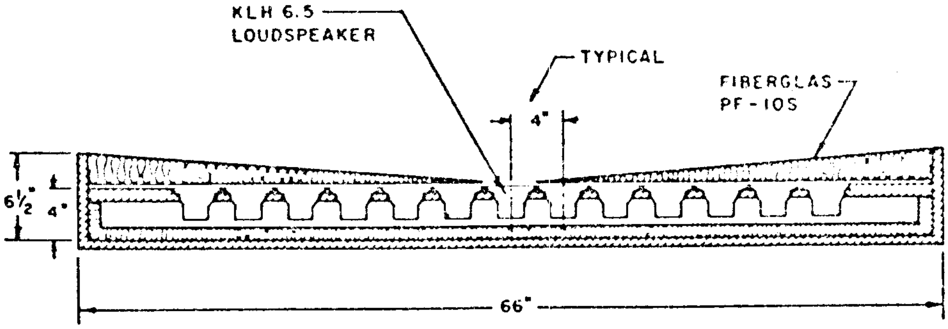

FIG. 4. Section through line-source loudspeaker (enclosure is made of ¾ in plywood).

Figure 4 shows the design of the line source used for the tests. It consists of 13 KLH Model 6.5 loudspeakers connected as parallel groups of three speakers each. The basic theory of operation is that at high frequencies the outer loudspeakers are attenuated so that they contribute essentially no sound energy. In this way the effective length of the line is reduced as frequency increases.

The glass fiber chosen for the wedges which are placed in front of the loudspeakers was O.C.F. PF-105. This particular type was picked because of its large attenuation, light weight, and rapid change of attenuation with frequency.[5] The shape of the wedge was calculated by making the attenuation due to the glass fiber equal to 3 db at the point where the length of the line is 1.75 wavelengths. This was chosen to make the beam width about 30°. Calculations showed that the phase shift due to the glass fiber is very small and would have its main effect in widening the beam (something that is desirable at high frequencies).

The KLH Model 6.5 loudspeaker was chosen for its extremely smooth frequency response and wide dispersion characteristics even at high frequencies. (See Fig. 5.) The wide dispersion is necessary if the line source is to have uniform *horizontal* coverage.

Measurements. Measurements were made with the following pieces of equipment: a Western Electric 640AA condenser microphone; an Altec M-11 microphone preamplifier; a McIntosh 50-w power amplifier; a custom-built polar plotter which automatically plots the polar response in db *vs* angle; a General Radio automatic level recorder; and a General Radio beat frequency oscillator.

The measurements of the line source were made in the M.I.T. anechoic chamber and were of two types. The first was the measurement of polar response at selected frequencies (400, 850, 1700, 2400, 3400, 4800, 6800 cps). The

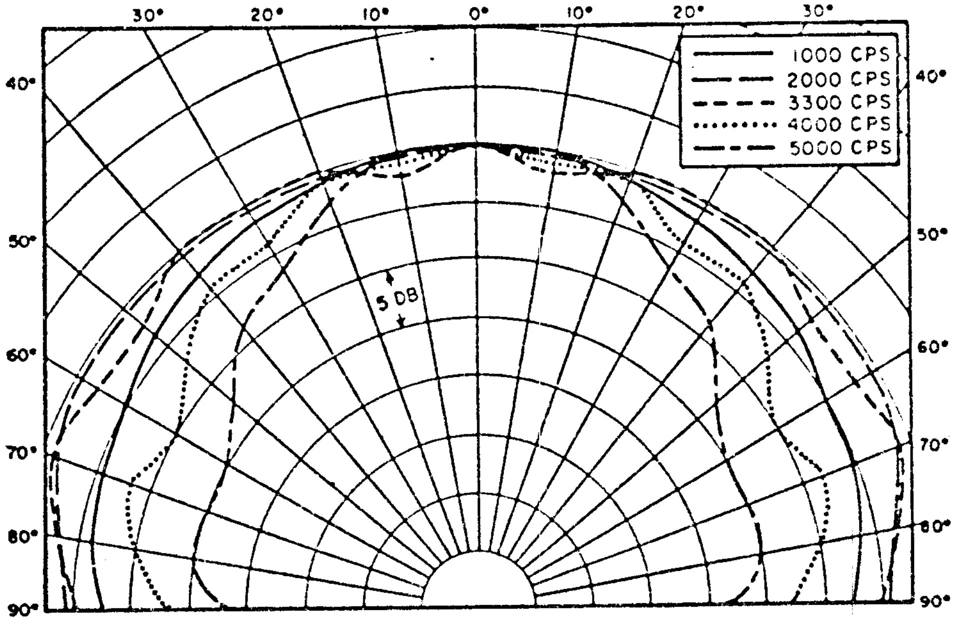

FIG. 5. Polar pattern: KLH 6.5 loudspeaker alone.

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[5] The attenuation characteristics of PF-105 and other typical common porous materials are illustrated in: Leo L. Beranek, *Noise Reduction* (McGraw-Hill Book Co., New York, 1960), pp. 270-271, Fig. 12.22.

second was a measurement of frequency response for selected angles (every 10° from −90° to +90°). In these tests the microphone was 17 ft from the center of the line source.

Figure 6 shows polar responses of the line source with no glass fiber wedge. As predicted, the beam width drops off with increasing frequency, and side lobes are very large. At 90° and 3400 cps the side lobe would be aimed directly toward the microphone in a typical reinforcement system.

Glass Fiber Loading. The enclosure for the line source was designed so that the glass fiber completely seals the air space in front of the covered speakers. This was done to take advantage of duct attenuation and thus reduce the side lobe at 90° and 3400 cps. Figure 7 shows the polar responses with the two glass fiber wedges in place. The beam widths are much more constant and the polar responses are reasonably smooth. The zero-degree frequency response curve made without the glass fiber wedge shows that between 1 and 3 kc the response of the line dropped about 15 db. (See Fig. 8.) The KLH Model 6.5 loudspeakers used in the lines have a frequency response which is down only 5 db at 19 kc. The reasons for the additional drop in the line source are the absorption of high-frequency energy from the outer loudspeakers and also cone-breakup, causing differences in the phase characteristics of the loudspeakers at high frequencies. Thus, the response is due to the addition of sound power rather than the addition of sound pressure as would be the case of the speakers all remained in phase.

To equalize the on-axis response of the line source, a network was designed to have a rising response above 2 kc to counteract the drop-off due to phase breakup. The response of the network and the resulting on-axis response of the line source are shown in Figs. 9 and 10.

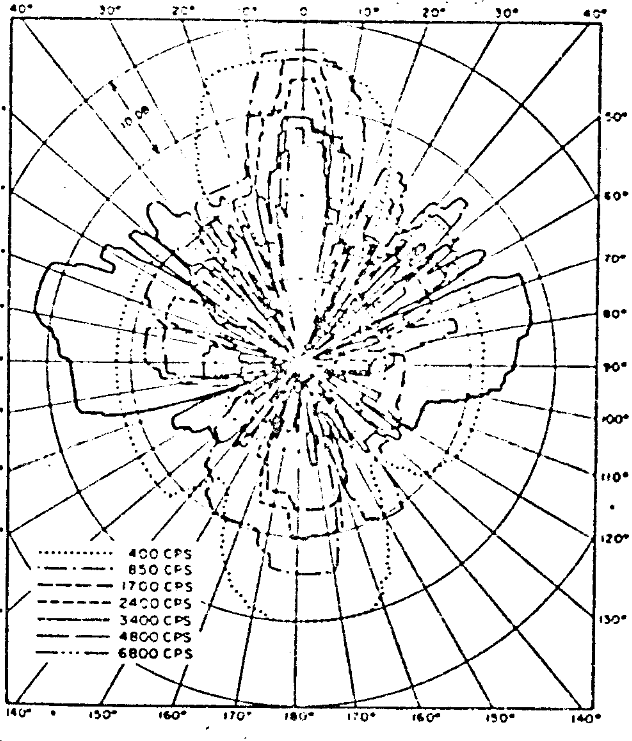

FIG. 6. Polar plot line source containing 13 4-in loudspeakers, no glass fiber.

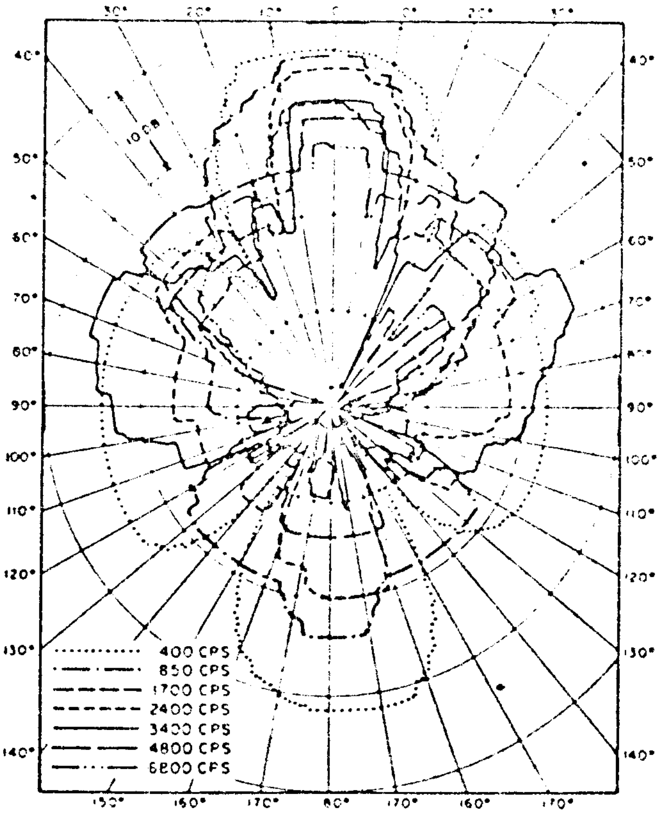

FIG. 7. Polar plot line source containing 13 4-in. loudspeakers with glass fiber wedges.

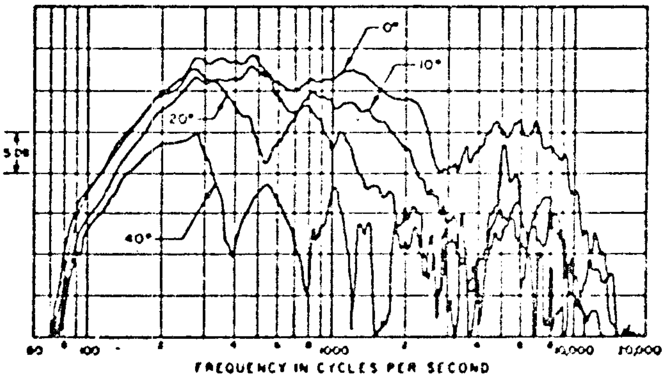

FIG. 8. Unequallized frequency response: line source of 13 4-in. loudspeakers without glass fiber wedges.

Use of the System. The system has been tested as part of a speech reinforcement system for the Tremont Temple Baptist Church in downtown Boston. In this application we assumed a vertical coverage angle of 25° and a horizontal coverage angle of 120°. The performing of the system was judged highly satisfactory with regard to providing coverage in the assigned area.

Further Improvements. In the line source, the spacing

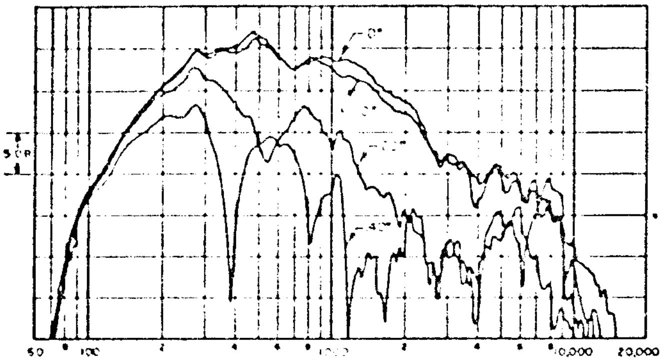

FIG. 9. Unequallized frequency response: line source of 13 4-in. loudspeakers with glass fiber wedges.

between all the speakers is 4 in. To reduce the size of the lobes at 3400 cps, it is recommended that the spacing between the speakers be made unequal to spread the energy of the side lobes over a wider frequency region. This will be tried in the near future.

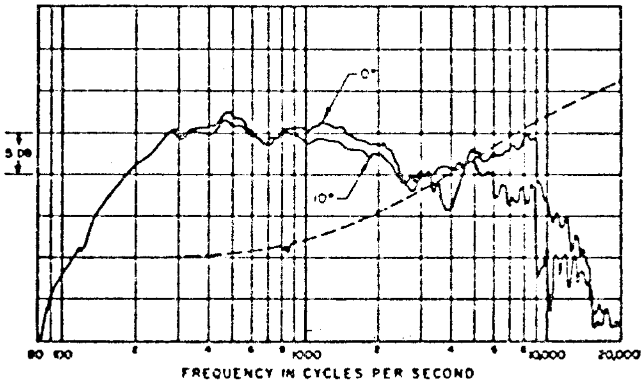

FIG. 10. *Equalized* frequency response: line source of 13 4-in. loudspeakers with glass fiber wedges.

Commercial Applications. This project was conceived as a study project, and we have no intention of marketing the loudspeaker system discussed. The features would appear to be applicable to numerous existing commercial line-source loudspeakers. A patent application is pending.

THE AUTHORS

David L. Klepper received the M.S. degree from the Massachusetts Institute of Technology in 1957; his B.S. degree was earned at the same school. While there, he designed a binaural microphone system that is now widely used for measurements in concert hall acoustics research. His experience also includes work with the U. S. Army Audio/Radio Section of the Psychological Warfare Board, 1955-1956, and with the Mystic Transformer Co., 1953-1954. In 1957 Mr. Klepper joined Bolt Beranek and Newman, Inc., where he currently supervises the integration of sound amplification system design with room acoustic design. His assignments in general architectural acoustics have included the design of numerous concert halls, auditoria, churches and exhibition halls.

Mr. Klepper has published several papers in his field. He is a member of Eta Kappa Nu, the Acoustical Society of America, the Audio Engineering Society, the Institute of Electrical and Electronic Engineers, and the Armed Forces Communications Electronics Association.

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Douglas Steele was born in Boston, Mass., in 1940. He received the B.S. (1962) and M.S. (1963) degrees from the Massachusetts Institute of Technology, and is currently studying there towards a doctorate. He has worked with Mr. Klepper on line-source loudspeakers as a special course project in 1962, and has prepared a Master's Thesis on the effect of the normal modes of a room on sound reproduction.