# What Makes a Good Loudspeaker?

## How faithfulness in reproduction is achieved in the design and manufacture of new loudspeakers

*By R. S. Lanier*

WHAT IS high quality in a loudspeaker? As an electro-acoustic transducer, a loudspeaker radiates an acoustic wave form equivalent to the electrical wave form reaching it from the other components of the system. As the final element in a system for entertaining or informing a listener, a fine loudspeaker, given faithful reproduction and transmission in the preceding components of the system, projects music and speech which are faithful reproductions and therefore satisfying to the listener.

A poor loudspeaker will destroy the quality of the finest system, although a fine speaker cannot project sound of higher quality than that of the electrical signal reaching it. A fine loudspeaker is thus an essential link in the chain of high quality reproduction.

These are simple statements of loudspeaker performance, but the achievement of such performance is a complex problem. An examination of the design objectives which guided the development of the new Western Electric loudspeakers, and the methods used to incorporate them in the speakers, will serve to illustrate the general principles of loudspeaker design, and will give a clearer understanding of the advanced reproduction qualities of these new speakers. The most commonly accepted criteria for high quality loudspeaker development can be grouped under the following general headings:

1. A wide frequency range must be reproduced;
2. Uniformity of response over the range reproduced is extremely desirable;
3. All forms of distortion must be reduced to very low levels;
4. A high degree of damping is desirable for faithful reproduction of transients and to improve the linearity of the system;
5. Uniform distribution of energy over an appropriate angle is required;
6. The power capacity must be adequate to cover the peak powers expected.

### Satisfying the Ear

The qualities listed above are all necessary for fine loudspeaker performance. Their application in a loudspeaker design is a difficult problem, because the human ear is a most particular and sensitive instrument, giving importance to many effects the engineer might overlook and often finds difficult to measure. Thus the designer of a fine loudspeaker must have full command of the electro-mechanical engineering art, and in addition, he needs a wide background of listening experience in order to interpret the actual subjective effect of various characteristics on the listener. The pioneering history of Bell Telephone Laboratories in electro-acoustics and its pre-eminent position as a development agency in this field have built up the kind of experience that is essential in this very difficult art.

Consider first the question of frequency response, undoubtedly the most discussed characteristic of loudspeaker design. No subject has been more beclouded and misunderstood than the relative merits of various loudspeakers as expressed by frequency response curves. Although a number of methods of measuring the frequency response of a loudspeaker are well understood in the industry, different methods are used by different manufacturers. In addition, it requires long experience to correlate curves taken under laboratory conditions with the subjective effect of the loudspeaker in a normal listening application. Thus the sound technician—and even more the layman—should not attempt to interpret the performance of a loudspeaker solely from curves published to show its frequency response. Even when published with the best of intentions, such curves are likely to be misleading as to what the ear is actually going to hear when the loudspeaker is installed in a living room or other enclosed space. But, though frequency response curves do not tell a simple story considered alone, they are extremely valuable as aids to the experienced designer.

### Response Curves as Design Tools

In the design of the new Western Electric speakers, many carefully derived frequency response curves have been used as engineering tools to guide the development engineer, and typical of such curves are those shown in Figures 1, 2 and 3 on pages 34 and 35. In Figure 1, the response of the 728B is shown under "dead room" conditions, at a point on the axis and at two points 15 degrees and 30 degrees off the axis.

Figure 2 shows the response of the 728B in a "listening room". This is a carpeted room simulating the characteristics of a living room. The measurement was made at a point on the speaker axis. Reflection effects due to the surfaces of the room are clearly seen. The "averaging" of the energy is demonstrated by the downward trend of this curve as compared to the upward trend of the "dead" room curve.

The "raggedness" of the listening room response, due to room reflections, obviously exists at a particular point in space for steady-state conditions (a continuing tone). Speech and music, however, are composed chiefly of transient impulses, and many of the standing waves do not have time to occur. Furthermore a listener, because of his binaural hearing, tends to average the pressure existing at two points, thus further minimizing the effect of reflections. It is interesting to note, in this connection, that from 80 to 95% of the sound heard under average listening conditions is reflected sound, even if the listener is sitting near the axis of the loudspeaker—indicating the vital importance of the room characteristics in determining the "sound" of a loudspeaker.

Figure 3 is the "dead room" response of the 755A speaker, at a point on the axis.

The over-all frequency response of the new Western Electric speakers has been designed, with the actual effect on the ear as the final criterion, to combine all such factors into a smooth, wide range response that would produce complete clarity and realism. The success of the design has had in some cases a curious effect. Some listeners, used to the overbright, rather "harsh" quality of loudspeaker systems with a "peaky" high frequency characteristic, and to the rather high noise level common in such systems, feel on first hearing them that the new speakers are lacking in high frequency response. But they soon discover, with further listening, that the new speakers actually have a wider, smoother high frequency range, that produces high clarity and definition without the harshness of the "peaky" speaker; and that the reduction in extraneous noise—such as surface noise—is a real gain, not achieved at the expense of high frequency response.

The same use of careful measurement together with reports from many experienced observers as to the subjective effects, was used to guide the engineer in producing a design with a very low level of all forms of distortion. The reduction of distortion to negligible levels in a direct radiator speaker is difficult, but it is important if the sound produced by the speaker is to give pleasure to the listener. The listener "acceptance" of the new speakers, the fact that the listener feels pleasantly relaxed when listening to them, is to a great extent a measure of the extremely low distortion level achieved in the design.

### Factors in Low Distortion

Many factors contribute to this low distortion level. Some of the principal ones are:

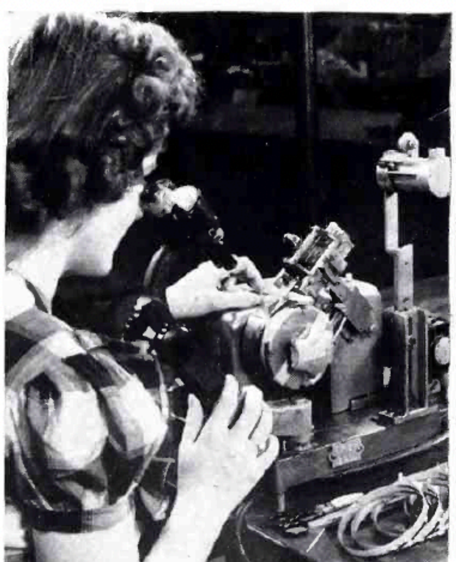
1. The voice coil has been made large for excitation of the whole cone in a uniform manner;

2. The special "shallow cone" design minimizes the interference effects which normally occur at high frequencies in cones of steep section;

3. Edge damping, a feature of the new designs, reduces distortion caused by cone breakup by attenuating reflections from the edge. It improves the linearity of the mechanical system in general by providing damping in the bass where the air loading is low, reducing the bass resonance and producing a smoother response;

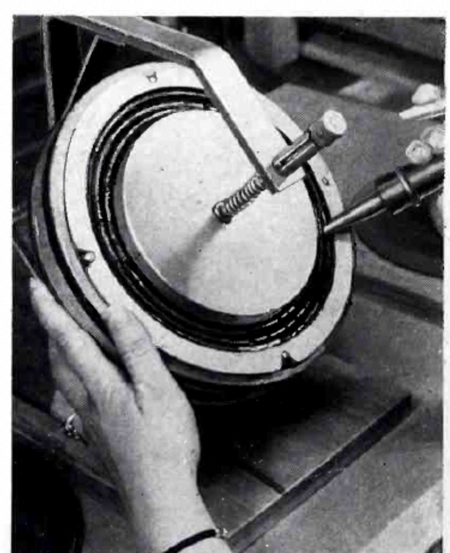
4. The shape and construction of the cone have been carefully selected for most desirable vibrational characteristics.

The mechanical characteristics of the new direct radiator speakers were considered with the same care as the electrical, in order to be sure that the speakers would be fully applicable to use in all forms of sound reproduction systems. Thus the new "flat" cone design was attractive not only for its acoustic superiorities, but because it could be combined with a new magnet configuration to produce the unusually small front-to-back dimension of the new speakers. The magnetic gap has been made somewhat wider than earlier standard practice would dictate, for increased stability and uniformity of characteristics over long



Winding machine produces voice coils of uniformity with each turn anchored permanently in position.

Unusually large magnet of Alnico is used in new 728B speakers to assure efficiency and quality.



Revolving fixture and special application device are used in applying cement to edge suspension.

periods of time under the most severe conditions of use. For improved efficiency a very large magnet of Alnico—weighing ten pounds in the 728B—has been incorporated in the new speakers.

### Dual Systems

The same general considerations with respect to frequency response, distortion, etc., guided the design of the new Western Electric high frequency receivers and horns, and of the dual systems in which they play a part. The new high frequency receivers, the 713B, with a phenolic diaphragm, and the 713C, using an aluminum diaphragm, are driven by an edge-wound voice coil, which maintains efficiency in the high frequency spectrum covered by these receivers. The new sectoral exponential horns, the KS-12024, KS-12025, and KS-12027 used with the high frequency receivers, are of cast aluminum. These horns have constants so chosen that a smooth frequency response is maintained over the whole range covered by the high frequency units.

In the design of the dual channel systems, special attention has been given to the choice of cross-over frequency, to the balancing of energy in the two channels, and to the relative positions, in the vertical and horizontal planes, of the low and high frequency speakers. A cross-over point of 800 to 1000 cycles has been chosen as indicated by careful listening tests as to the most effective design.

In the high-level systems, exponential horns for both low and high frequency projection, together with driving units of special high efficiency design, provide the increased efficiency which is economical in reproducing systems operating at high power levels. The low frequency drivers, the 12-inch 754A and 754B, have voice coils of edge-wound copper tape, and special magnet materials to furnish increased efficiency. The 754B has a phenolic dia-

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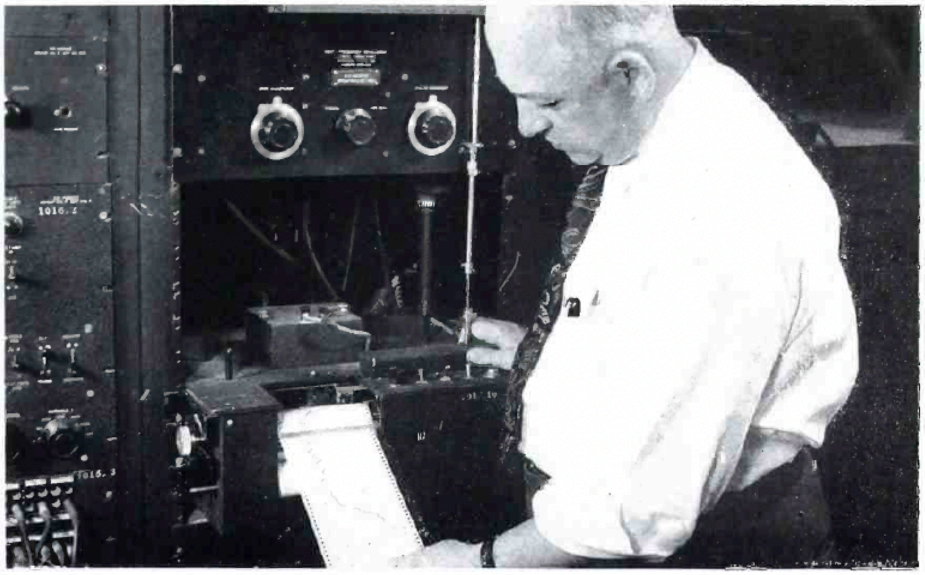
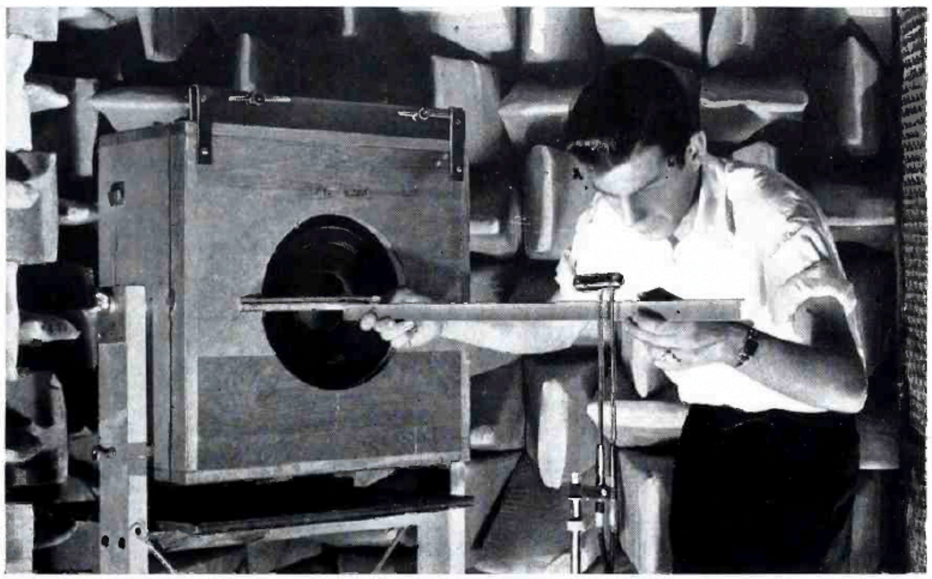
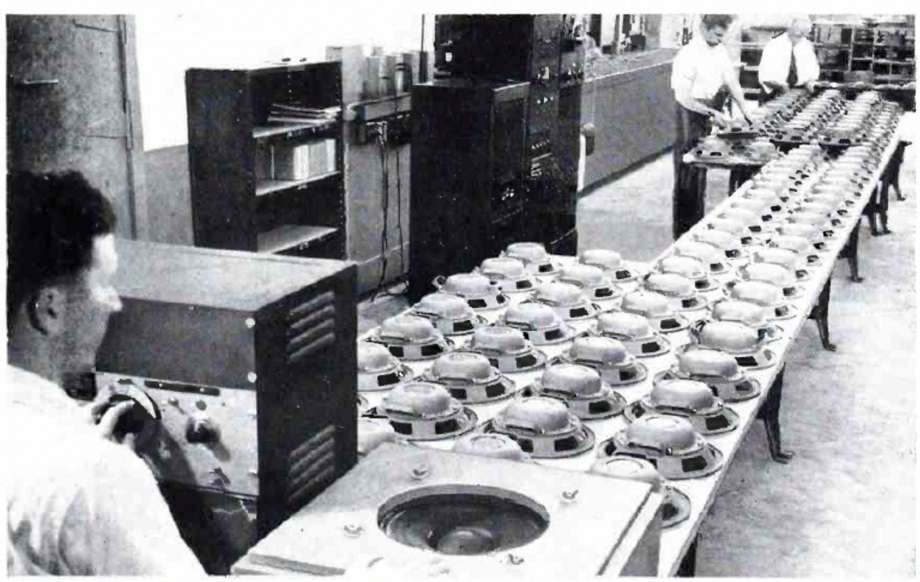


Automatically recorded graph showing frequency response of a completed loudspeaker comes off the machine specially designed by Western Electric to make this final quality test of the manufacturing process.



Setting up a 728B speaker in the dead room for the frequency response test includes accurate placement of the 640AA Microphone, which picks up the energy for measurement by the automatic recording device.

Magnetizing the speakers with a controlled pulse of energy produced in condenser discharge device.



Loudspeakers lined up for the sweep-frequency noise and rattle test, carried out by the operator in left foreground. The automatic recorder for the final frequency response test is in the middle background.

## New Line of Amplifiers

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reduction in rated power output or increase in harmonics.

As previously stated, this equipment is intended primarily for wire program service; hence it is designed to operate directly from telephone lines and meets all the requirements imposed by the telephone companies on equipment so operated. Thus, wherever local telephone company practices permit, this unit may be directly connected to the telephone line and requires no separate isolating coil. In addition, this amplifier complies with all the protective requirements of the Underwriters Laboratories and bears their stamp of approval. Its use on the subscriber's premises in no way jeopardizes the subscriber's fire insurance protection.

The 140A Amplifier is designed for either relay rack or cabinet mounting. This amplifier, mounted in its cabinet, is coded the 1140A Amplifier. Its use in this form is recommended for the usual subscriber's installation as no additional mounting facilities are required. When so mounted, it is light in weight and can be used as either fixed or portable equipment.

Detailed specification sheets on these new amplifiers are now available from the Graybar Electric Company. They deserve the careful attention of customers intending to install new sound distribution systems or provide wire program service to new subscribers.

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phragm adapted to use in outdoor installations.

Two exponential low frequency horns have been designed for these systems, one to accommodate a single 12-inch driver, and one for two 12-inch drivers working side by side. Response down to 40 cycles allows reproduction of the lowest frequencies required in high quality, high level sound systems. The mouths of the low frequency horns are designed for proper distribution of energy of the whole range of frequencies covered by the horns.

The air chamber in back of the low frequency drivers is completely enclosed and provides proper acoustic loading for the low frequency response described. This closed arrangement avoids the raggedness in the low frequency characteristic which often results from using a portion of the back radiation to reinforce the bass response.

The complete systems are furnished in various combinations of the low frequency horns and drivers with the KS-12024 and KS-12025 horns and 713B high frequency receiver, to form loudspeaker systems covering every requirement for high level, wide range reproduction.

The mechanical characteristics of the new high-level systems have been carefully considered to reduce to a minimum the size, weight, and space requirements of each system. As a result, each one of the new models offers a saving in weight and size over speakers of comparable power capacity formerly available.

Finally, in both the direct radiator speakers and the dual unit systems, every single feature of the design has been chosen for the maximum ease of manufacture consistent with the over-all objectives of the design. This means that the speakers will not cost more than their qualities demand. They have been designed, not only for superior reproduction and mechanical convenience, but also for full value to the user.

### Manufacturing Processes

In the new Radio Shops at Burlington, North Carolina, Western Electric's new loudspeakers are moving down the assembly line in a production process set up with every safeguard of inspection and quality control to insure that each speaker embodies to the full the high qualities of Bell Telephone Laboratories' design.

The vital dimensional accuracy of the air gap and voice coil parts is assured by maintaining close tolerances of these parts. Permanent rigidity and high mechanical strength result from actually welding the magnetic parts together, avoiding any form of soldering of the magnetic gap structure to the frame.

A specially designed machine has been developed to wind voice coils which have permanent uniformity of dimensions, with every turn of the coil anchored in place for good.

Another machine of Western Electric design is used for automatic production of the edge wound voice coils which are used in the 754A and 754B speakers and in the high frequency receivers. The use of flat tape to provide increased gap utilization, in special high efficiency voice coils, was developed by Bell Laboratories and the processes for manufacture of such coils have been pioneered by the Western Electric Company.

Magnetizing of the Alnico permanent magnets is accomplished in another special machine developed by Western Electric. The twelve-inch 728B speakers have a field coil permanently built in for original magnetizing of the permanent magnet; the 755A is fitted into a magnetizing coil built into the machine. In either case, the magnetizing coil is given its pulse of current from a condenser-discharge device, which assures use of the amount of energy required for complete magnetization.

Testing of the speakers as they move down the production line, and after completion of assembly, is careful and exhaustive. Quality control is rigidly maintained by complete testing of a very large sample of production—with the larger speakers, every unit is given the complete testing procedure.

The most important inspection and testing procedures are the following:

*Diaphragm Inspection:* When the diaphragm, voice coil and magnetic gap are assembled, the diaphragm is inspected for holes or other imperfections, and for the proper application of the edge damping material. The centering of the voice coil in the gap, and the proper relative position of the coil turns with respect to the gap, are carefully measured.

*Voice Coil Test:* The voice coil is tested for continuity and shorted turns.

*Mechanical Inspection of Parts:* Careful measurement of parts assures proper fitting on assembly.

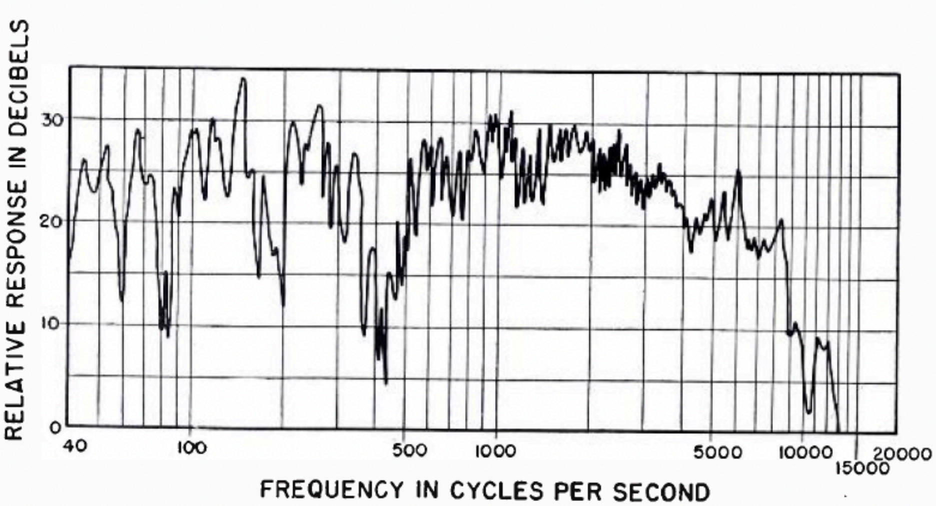


Figure 2 — Response curve of 728B speaker taken in a laboratory "live room" shows effect of reflecting surfaces on characteristic of speaker when sound is a "continuing tone", not like speech or music.

*Visual Inspection:* With the entire assembly bolted together, it is inspected for finish, mechanical imperfections, bends in the frame, loose terminals, etc.

*Noise and Rattle Test:* Every completed speaker is given this test, consisting of application of a sweep frequency from an oscillator to determine that the speaker operates properly, that the voice coil moves freely in the center of the gap, and has no obstructions or particles to impede it or loose parts that would cause noise or rattles.

*Magnet Flux Test:* The proper efficiency of the speakers is assured by a flux test on the permanent magnets, after they have been magnetized. Typical values maintained are the following.

755A—45,000 Maxwells Minimum
728B—90,000 Maxwells Minimum

*Response Test:* The testing of the completed speaker for frequency response is a most important part of quality control. Comparison of the frequency response of a production model with a previously determined normal curve very quickly shows up any change in manufacturing technique or in the quality or accuracy of any component of the speaker. In Western Electric's Burlington plant, two completely equipped dead rooms have been constructed to carry out the frequency response test. One of them is of conventional construction, lined with flat sound absorbing material about two feet thick. The other room, shown in the photograph on page 13, is a "little brother" of the remarkable new dead room at the Murray Hill Bell Telephone Laboratory, shown on the cover of this issue and described on page 39. It is lined with the wedge-shaped projections of sound absorbing material which provide the necessary coefficient of sound absorption.

The test is made with each speaker mounted in the baffle as shown, and the energy is picked up for measurement by Western Electric's new 640AA Condenser Microphone, which has won widespread acceptance for laboratory and production testing of acoustic devices. The energy applied to the speaker is automatically swept over the spectrum from 20 to 12,000 cycles for the 728B, for instance, and from 28 to 18,000 cycles for the 755A. The response of the speaker is automatically recorded in the form of the usual graph on semi-log paper. The photograph on page 13 shows a typical response curve being removed from the machine after a test. The response-test system was built by Western Electric especially for this purpose.

Thus Western Electric produces a whole line of high quality loudspeakers, each one manufactured and tested with the precision, ingenuity and care that are due a really fine acoustic instrument.

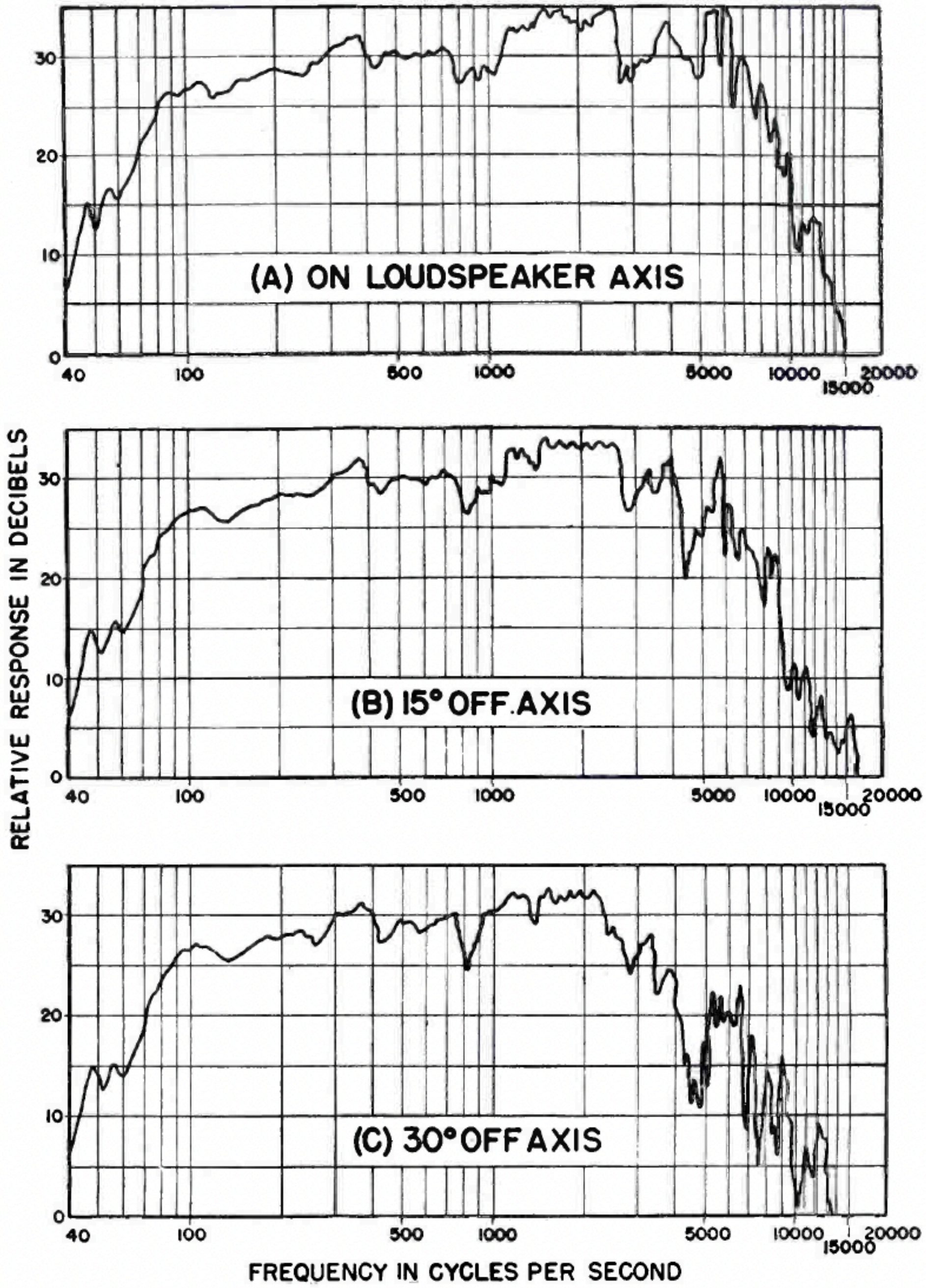


Figure 1 — Typical laboratory response curves used in design of 728B Loudspeaker are the above, which show the frequency characteristic in a "dead room", with microphone at three different positions for pickup.

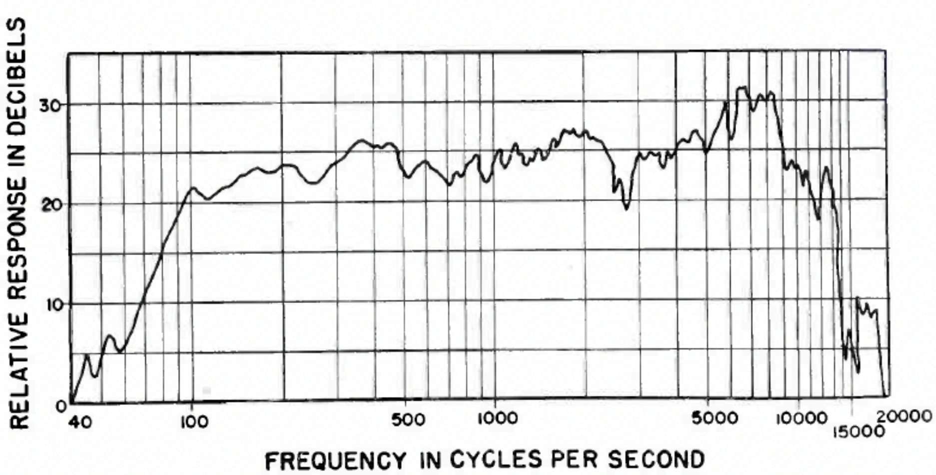


Figure 3 — "Dead room" response of 755A Loudspeaker, measured at a point on the axis of speaker, used to aid the designers in producing the wide angle, wide range response of this eight-inch direct radiator.