

ELECTROSTATIC LOUD SPEAKERS

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THE PURPOSE of this article is to describe some interesting features in connection with a recent type of electrostatic loud speaker and to discuss its electrical and acoustical characteristics as determined by engineering tests.

At the present time, as is generally conceded, the electrodynamic loud speaker, which makes use of a moving coil in a strong magnetic field, is the most powerful and efficient sound reproducer that engineering science has developed. It is not only a satisfactory loud speaker from the engineering standpoint, but its even response, good tone quality, and ability to transform comparatively large audio-frequency currents into sound, have made it exceedingly popular with the radio public.

Despite this tendency toward loud speakers of the electrodynamic type, interest has lately been aroused in certain electrostatic loud speakers now in the course of development, which, because of their simplicity, may be manufactured at a comparatively low cost.

Engineers in general are, for good reasons, inclined to look with disfavor upon any device which transforms electrical energy into mechanical through the medium of electrostatic attraction and repulsion alone. Everyone knows that the sources of power loss in such devices are many, that electric charges are prone to leak off before they can be put to use, and that even where the best dielectrics and best design are used, the loss of energy due to dielectric hysteresis and corona effects is liable to be considerable. If high voltages are used, these losses are greatly magnified, though they are also present when comparatively low voltages are employed.

While many claims are being made in favor of electrostatic loud speakers, at the present time there is little engineering data available as to their characteristics, and it was for this reason, coupled with the widespread interest in such devices, that the tests described in this article were undertaken.

Mechanical Construction

The mechanical construction of the loud speaker tested is as follows: The back plate (see Fig. 1A) is a disc of 24 gauge sheet-iron thirty inches in diameter,

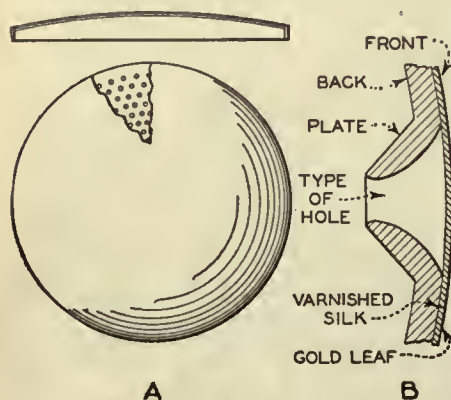


Fig. 1

whose periphery is bent up to form a flange half an inch wide. In this back plate are punched some 2000 quarter-inch holes, the holes being punched so that there is a sharp bur at the back of the plate, but none in front. In addition to this, the back of the plate is "dished-in" half an inch, as shown in the figure. Over this back plate is stretched a membrane of varnished silk two-thousandths of an inch thick, and a layer of imitation gold foil is applied to the outer surface of the membrane. An enlarged cross-section of the loud speaker is shown in Fig. 1B, which shows the type of hole punched in the back plate, as well as the relation of the varnished silk and the gold foil with respect to the back plate.

In using this loud speaker, it may be

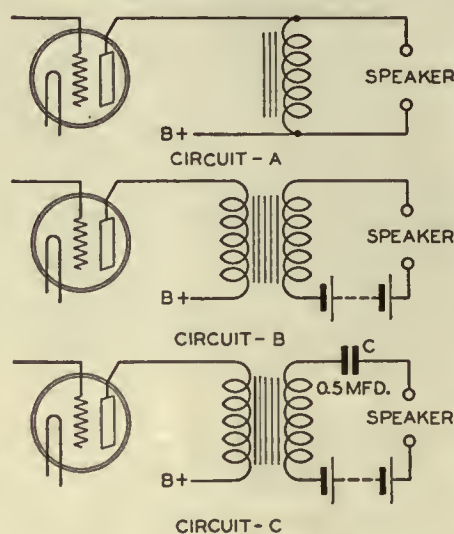


Fig. 2

connected to the amplifier in a number of ways—three of which are shown in Fig. 2. Referring to Fig. 2, circuit A is one in which no external source of bias voltage is used. In circuit B, bias potential is supplied by means of a battery. Circuit C is the same as circuit B, except that the resonant frequency of the loud speaker and effective inductive reactance of the output transformer have been altered by placing a condenser in series with the loud speaker. These circuits were chosen for tests because the results obtained could be analyzed more easily with respect to the effect of the resonant frequencies of the loud speaker circuit and the effect of various bias voltages.

For the sake of clarity in explaining its characteristics, the theory of the loud speaker in question will first be outlined. It can be seen that the electrostatic loud speaker is nothing more than an electrostatic condenser, one of whose plates is fixed, and the other is free to vibrate. When the condenser charges, there is an attractive force which pulls the diaphragm more closely to the back plate. When it is discharged, there is a certain restoring force supplied by the elasticity of the diaphragm which pulls it back to its initial position. It can be seen, therefore, that the dia-

phragm will vibrate in accordance with voltages across the loud speaker.

Source of Sound

It might be thought that the foregoing was the entire theory of the loud speaker, and that the holes in the back plate were merely for the purpose of allowing air to escape. On the contrary, we have found that very little of the sound comes from vibration of the diaphragm as a whole, but that most of it comes from a more intense vibration taking place in the parts of the diaphragm immediately over the holes. It is proposed by the authors that this increased vibration is partly due to distortion of the electrostatic field about the holes, in such a way that there exists a large difference of potential between the sharp burred edges of the holes, and the parts of the diaphragm over the holes. The electrostatic field about the holes is by no means uniform, and changing the shape of the holes may greatly alter the distribution of electrostatic flux lines between the membrane and the back plate. This increased vibration is also partly due to the curvature of the holes from the front inward. As shown in Fig. 4, the vibration of the membrane may be thought of as a progressive process. As the diaphragm rolls inward over the hole in Fig. 4, it can be seen that there is always a comparatively large force on such parts as at A for position 1 and B for position 2.

In addition to this, the authors have found that when large holes are used, the loud speaker responds more easily to the lower frequencies, while if smaller holes are used, it responds better to the higher frequencies.

From theoretical considerations, the response of the loud speaker with change of frequency may be said to depend mainly upon the following factors: mechanical resonance points in the back plate caused by the particular construction used; the size of hole used; the shape of hole used; the electrical resonance effects due to the circuit used in connecting the loud speaker to the amplifier; and the magnitude of the bias potential applied to the loud speaker plates.

It can be proven both mathematically and by experiment that harmonic dis-

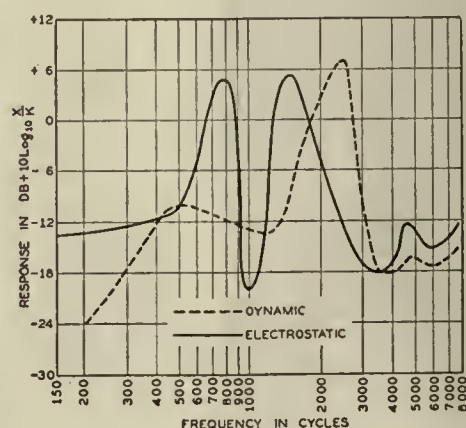


Fig. 3

tortion in the loud speaker can be reduced greatly by application of bias voltages which are large in comparison with the varying audio-frequency voltages supplied by the amplifier.

Electrical Efficiency

The method of test and the results obtained will now be discussed.

For the particular case of a loud speaker, efficiency, as it is generally defined, is not of the greatest interest. Since it is the duty of a loud speaker to utilize all the available power that can be supplied to it by the input circuit, a ratio of output watts to watts input cannot adequately describe its worth. Therefore, in testing loud speakers, efficiency is defined as the ratio of the sound output in watts to the maximum power in watts the supply circuit is capable of delivering under the conditions of optimum impedance. This efficiency ratio in turn is usually expressed in Decibels, or ten times the logarithm to the base ten of the ratio of the output watts to the total available input watts.

In order to test the efficiency of the loud speaker, the authors devised the circuit shown in Fig. 6. The procedure in making measurements was as follows:

The oscillator was first set at a given frequency, as for example, 500 cycles. Switch A was thrown to position (1) and Switch B also to position (1). The alternating component of the voltage drop E_1 across the non-inductive resistor was read with the vacuum-tube voltmeter. The total power available from the amplifier was then expressed by the equation,

$$P_1 = E_1^2 \times K$$

where K is a constant. Switches A and B were then thrown to position (2) and the sound-power output of the loud speaker was then expressed as:

$$P_2 = E_2^2 \times X$$

where X is a variable function, depending upon the frequency only if the volume of the sound issuing from the loud speaker is kept fairly constant by using larger or smaller inputs. The response of the loud speaker in dB was then expressed by the equation:

$$R = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{E_2^2}{E_1^2} \times \frac{X}{K} = 20 \log_{10} \frac{E_2}{E_1} + 10 \log_{10} \frac{X}{K}$$

Since the value of the term $10 \log_{10} X/K$ depends upon the frequency only (assuming a reasonably constant sound output), it will be seen that the response curve of the loud speaker will be raised or lowered at any ordinate by the value of $10 \log_{10} X/K$. Readings were thus taken over the frequency range of from 200 to 6000 cycles, and a curve of response versus frequency as abscissas was plotted.

Response Characteristics

Since the actual power represented by the sound coming from the loud speaker is only a few microwatts, it is exceedingly difficult to calibrate the apparatus so that absolute values can be obtained. In order, therefore, to get the response of the electrostatic loud speaker without actually calibrating the apparatus,

a high-quality modern electrodynamic loud speaker was placed in the same position as the electrostatic and the readings repeated over the frequency range of 200 to 6000 cycles—enough readings being taken to make an accurate curve. By plotting the

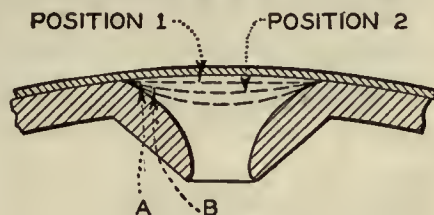


Fig. 4

curves of both electrodynamic and the electrostatic loud speakers on the same sheet, the difference in their responses in dB at any ordinate may be read off the curve, since both curves are raised or lowered at any ordinate by the same amount, namely $10 \log_{10} X/K$. Difficulties will be encountered, however, if attempts are made to find the difference in response

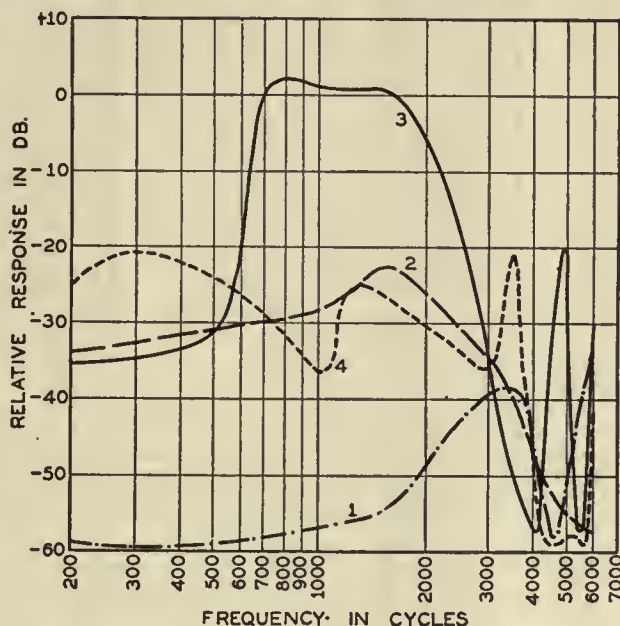


Fig. 5

at ordinates where the responses are of different sign. Fig. 3 shows two such curves plotted on the same sheet. It can be seen that the response of the electrostatic loud speaker is better than that of the electrodynamic by -10 db. at 200 cycles. At 420 cycles they are equal. At 500 cycles they are again equal. At 1000 cycles the electrostatic response is less than the electrodynamic by -6 db. at 1800 cycles and 3500 cycles the responses are equal, and so on. This set of curves indicates that the response of the electrostatic speaker was uneven as compared to that of the moving-coil type.

In Fig 5 we have a set of curves of the response of the electrostatic loud speaker

plotted upon the assumption that the curve of the electrodynamic is a straight line. Curve 1 is for the loud speaker using circuit B (Fig. 2) and a bias potential of 25 volts. Curve 2 is for circuit B and a bias potential of 100 volts, and curve 3 is for the same circuit with a bias of 250 volts. Curve 4 shows the relative response of the electrostatic loud speaker when a 250-volt-bias and circuit C are used.

Without going into a detailed discussion of these curves, it can be seen that, in general, the larger the bias potential used, the greater will be the response of the electrostatic loud speaker. It is also seen from curve 4 that changing the resonant frequency of the loud speaker circuit by inserting different values of capacity (0.5 mfd in this case) in series with the loud speaker, changes the shape of the response curve.

In general, it is desirable to have the main resonant frequency of the loud speaker circuit considerably above the highest frequency at which it will be used.

Volume vs. Bias

While a bias voltage of 500 to 600 volts or more is desirable for good results, fair reproduction is obtained with this loud speaker when only 200 or 300 volts is used as a bias.

As shown in Fig. 5, the volume of sound delivered by the loud speaker for a given input voltage increases as the bias voltage is increased. It is also true that harmonic distortion decreases as the ratio between the bias voltage and the amplifier voltages applied is increased. Although in a.c. machinery, only odd harmonics occur, in the case of the electrostatic loud speaker both odd and even harmonics may be present. In other words, if an initial frequency of 500 cycles is applied to the loud speaker, we may have 1000 cycles, 1500 cycles, or any other frequency or combination of frequencies which are integral multiples of 500 cycles. This combination of the original frequency with its harmonics, gives rise to a sound wave which is distorted with respect to the original frequency, and the effect is called harmonic distortion.

When attempts are made to reproduce music by means of a loud speaker in which harmonic distortion is present, the quality is poor. This is the case when the electrostatic loud speaker is operated at low bias potentials. If, however, the bias is increased, this distortion will be reduced. Let the bias potential across the loud speaker be denoted as E and the varying voltage supplied by the amplifier expressed as $e \cos \omega t$, then the force upon the diaphragm tending to make it vibrate may be expressed approximately by the equation.

$$F = 2KEe \cos \omega t + \frac{1}{2} Ke^2 + \frac{1}{2} Ke^2 \cos 2\omega t$$

It can be seen from this equation, that by increasing E, the harmonic term $\frac{1}{2} Ke^2 \cos 2\omega t$ becomes less important, and if the bias potential is increased to a high enough value, it will be negligible.

The humps in the curves in Fig. 3 are not entirely dependent upon the electrical characteristics of the loud speaker circuit, but can be seen to depend also upon the various mechanical resonances which may be present in the back plate and the diaphragm of

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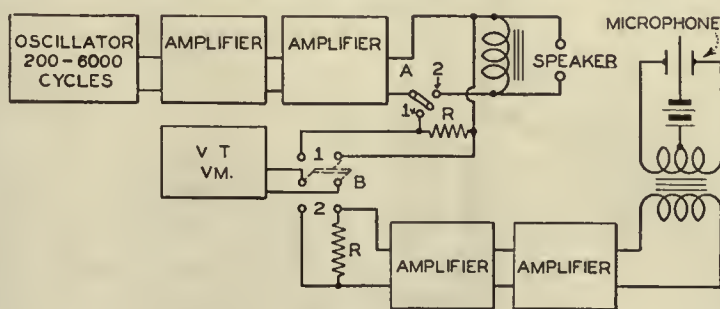


Fig. 6

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the loud speaker. The size of the holes in the back plate may also affect the shape of these curves. Such mechanical resonances are very important in the design of electrodynamic and magnetic loud speakers, as well as in the design of electrostatic loud speakers. It is only by proportion of the mechanical and electrical resonances that even response can be obtained.

In drawing conclusions from the tests just described, it must be borne in mind that they apply to a particular type of electrostatic loud speaker tested under particular conditions. Although some of the results apply to all types of electrostatic loud speakers, the authors prefer to limit their conclusions to the particular type in hand.

The results of the investigation so far may be summed up as follows:

1. That the greater part of the sound comes from vibration of the diaphragm over the holes, and that this vibration may be increased or decreased by changing the shape of the holes.

2. That harmonic distortion may be reduced by the use of high bias potentials;

3. That the response of this loud speaker is very uneven as compared to a well-designed standard electrodynamic loud speaker.

4. That it would seem that by proper combination of size of holes, size of back plate, and correct design of input circuit, an electrostatic loud speaker of this type can be designed which will give very even response.

5. That this loud speaker in its present stage of development is inferior to the electrodynamic type in evenness of response, general efficiency, and convenience of operation.

6. That while the results obtained in testing this particular loud speaker show that it is inferior to the electrodynamic type, it should not be thought that it is impractical or that it cannot be designed so as to give good reproduction. As a matter of fact, this particular loud speaker performs much better, and gives much more natural reproduction, than the magnetic loud speakers of only one or two years ago, and in addition it has the advantage of distributing its sound much more evenly than many loud speakers now in use.

GENERAL MOTORS—AND RADIO

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It is pointed out that RCA in absorbing Victor, continued the merchandising policies and avenues of distribution of the old company, while maintaining the separate product and merchandising avenues of the Radiola line. Thus far, this policy has apparently not interfered with either complete line.

Charles F. Lawson, president of Day-Fan, the organization absorbed into General Motors Radio Corporation, has announced to his dealers and distributors: "The enormous advantages which General Motors' backing gives to us—manufacturer, distributor, dealer—are obvious. At once, there is the authority of a great name in engineering, research, and manufacturing behind the claim of excellence in our product. There is the distinct advantage of the General Motors Acceptance Corporation plan of financing deferred payments. Looking to the future, the implications of General Motors' entry in the radio field, with its great resources, are tremendous.

"The Day-Fan dealer franchise is a most valuable one to-day. It is potentially the most important franchise in radio."

Those in the industry who have given serious thought to the implications of the General Motors Radio Corporation's entry into the field, feel that it means first, the coming into radio of a new manufacturing company with ample financing and an important history of experience in mass production, secondly, the entry of skilled merchandising experience suggesting many possible innovations, thirdly, the further extension of radio deferred payment sales through the large resources of General Motors Acceptance Corporation, and fourthly, the probable building up of a new distributing group. Radio is already linked closely to sales outlets for refrigerators, automobiles, and automobile accessories, and it is expected that this new company would not confine its dealer outlets exclusively to those now handling Frigidaire on the one hand or automobiles on the other. It is more likely that the distributing set-up will include outlets from each of these major groups and build up a primary set of radio outlets rather than select one complete ready-made dealer group.

HOUSE-TO-HOUSE SELLING IS NOT A SIDELINE

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That's the outstanding reason why there has been so much unfavorable reaction of late against the method on the part of home owners. It is just as important that the man who represents your store on the outside be as courteous, honest, and fair as those behind the counter."

No matter how many door-to-door men he may employ, however, Mr. Green is firm in his opinion that the store should be the dealer's first consideration. Regardless of the future of the outdoor salesman, the store is practically certain to continue as the backbone of the merchandising structure. Then too, the more attractive and better known the store, the more weight that is added to a salesman's visit to a home.

The better the store the better the chances for success in house-to-house selling—and the better the chance to keep abreast of the merchandising trends of the future.

HOW ABOUT TIME PAYMENTS?

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per cent. of their volume, 38 per cent. report cash sales between 5 and 10 per cent. of volume, 16 per cent. have from 10 to 20 per cent. cash sales, only 8.5 per cent. report 20 to 30 per cent. cash sales, 11 per cent. get from 30 to 50 per cent. cash sales, and 4 per cent. of the dealers reporting have as high as 80 per cent. cash sales.

Seriously, I ask, for the good of the business and of those in it, shouldn't those cash sale figures be going up and up? But, I am sorry to say it looks as though they were not, for in answering the next question—"Are cash sales larger than last year?"—30 per cent. of the dealers say "Yes" and 70 per cent. say "No."

I fancy I can see a bright light in the answers to the last question—"What proportion of your sales do you write off as bad debts?" More than one quarter of the dealers—29 per cent.—say "None" and 38 per cent. say 1 per cent. or less. Glory be! Two thirds of the dealers who report say 1 per cent. or less of bad debts. Looks like a fairly good customer-credit situation.

Straws which indicate which way the breeze blows—that's what these reports mean. Something to think about. Suggestions for a change in practice if it is needed. We cannot take these figures as the last word of authority on common practice. Five hundred dealers were questioned, a lot of dealers to be sure, but a

small proportion of the whole. Not all of them answered, of course.

Accuracy of percentage is not the criterion of this questionnaire. More replies might change these percentages, but I'm sure they wouldn't change the broad high lights of the picture, in which I fancy I see these facts.

(a) It is possible and wise to finance installment sales without loss, and even at a profit for financing as well as for selling.

(b) Customers can and should be made to pay a reasonable price for the very great accommodation of time payments.

(c) Down payments may easily be as high as 25 per cent. or even higher.

(d) The cash sales in the industry are too low in proportion to time sales, particularly till the percentage of cash down on time-payment sales is increased.

(e) The showing in bad debts is one of great credit to the industry.

THE JOBBER'S NEW PLACE

(Continued from page 79)

located in non-competitive neighborhoods.

The unsound and uneconomical elements of long terms and credit losses will be practically nil. Equally out of date will be the practice of having eleven jobbers' salesmen all undertaking to sell a quarter of a case of a standard brand of soap or milk to a retailer whose credit is Z-blank.

The independent retailer will have changed his mind about not letting his jobber tell him what to buy and what to sell. He will no longer take the position that he is an independent business man who can go broke any time he wants to and nobody can stop him. Such an individual will have a hard time finding a jobber who will work with him.

In brief, the jobber of 1935 will have practically as close supervision over his retailers as the chain-store management has over its units. The outstanding difference will be that when the contract which the retailer has signed expires, he will be free to sign up with another jobber.

The great difference between the individual retailer of 1935 and the individual retailer of to-day will be that the 1935 model will be in position to merchandise right along with anybody else in his neighborhood.

All in all, it is safe to say that the lot of the individual retailer in 1935 is going to be much happier and more profitable than it is now. The manufacturer of drug sundries, dry-goods products—he'll have a new worry. These combinations of wholesalers and their groups of retailers, buying, selling, merchandising, and advertising as large groups will do some interesting things in the way of pushing private brands.

They'll go just as far in this direction as proves profitable. They will attack in the weakest spots. They will take hold of a kind of product which is not dominated by one or more well-advertised brands which have the popular demand and put back of such items a much more intelligent sales effort than they have thus far been able to provide.

The turmoil and tumult of 1920 to 1930 will have quite definitely subsided by 1935. The spread between the actual cost of the product on the manufacturer's floor and the price paid for it by the ultimate consumer will have shrunk materially.

There will be little difference, so far as the consuming public is concerned, between the individually owned stores and the units belonging to chains, except that the individually owned stores will be in position to exert more latitude, more individualism, be more in tune with their immediate neighborhood than the chain-store unit.