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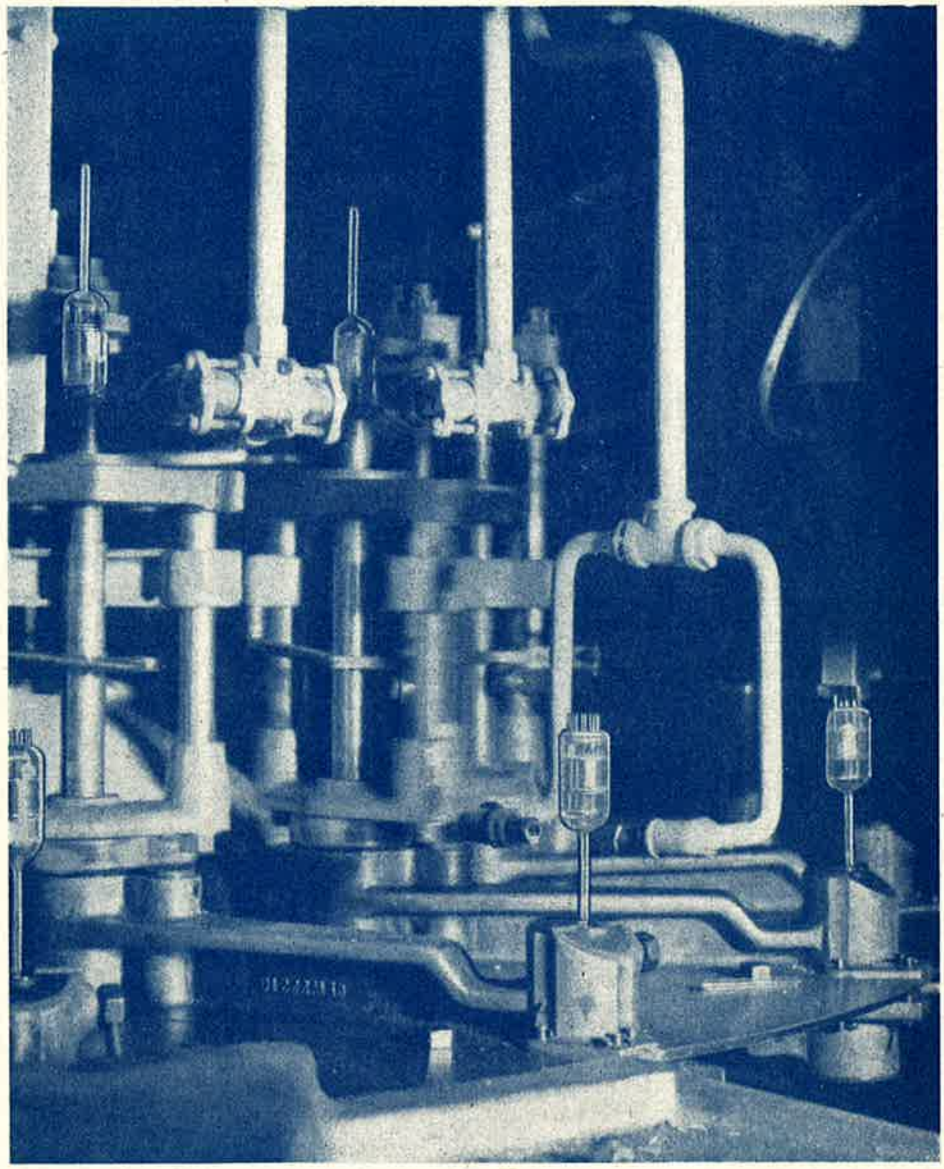
RADIOTRONICS

Volume 17 June 1952 No. 6



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RADIOTRONICS

Volume 17 **June 1952** **Number 6**

By the way—

Our front cover this month shows an AWV noval miniature sealex machine in operation, exhausting and sealing the new triode-hexode converter, 6AE8.

Concerning the 4th edition of the Radiotron Designer's Handbook, less than two months have elapsed since the initial publicity for this world-renowned book commenced. In that short time nearly half the first printing has had to be set aside for orders received from Radiotronics subscribers and others. A check of our records indicates that quite a number of our regular readers have put off returning their order forms. To them we would say that the present indication is that the first printing will be sold out before publication date. They are therefore strongly advised to forward their orders immediately, as orders received too late may have to wait an indefinite time for a second printing.

Owing to circumstances beyond our control, the publication of the May issue was delayed some two weeks. To save double handling it was therefore decided to mail both May and June issues together, by arranging for earlier release of the June number.

We have, in recent months, by courtesy of the Institute of Radio Engineers, U.S.A., reprinted articles of interest to our readers from the "Transactions of the I.R.E. Professional Group on Audio."

This original material, for the most part, will be available only to those who are members of this I.R.E. Group. We are sure our subscribers will appreciate the wealth of information in these very readable articles.

Should there be sufficient interest in the construction of the horn featured in this issue, we will make available a reprint with working drawings to a larger scale.

Back issues of Radiotronics prior to 1952 are no longer available.

Information published in Radiotronics concerning new RCA releases is intended for information only, and present or future availability is not implied.

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CONTENTS

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A HIGH-QUALITY SOUND SYSTEM FOR THE HOME

By H. F. Olson & A. R. Morgan, RCA Laboratories

The main objective of this article is a rationalization of the problems confronting the enthusiast for good sound reproduction.

The statement, "high quality sound reproduction," implies a desire for realism or naturalness in the reproduced sound. The ideal in sound reproduction would result from subjecting each of the listener's ears to the exact sound that would be received by attending the original source. To achieve this ideal, resort must be made to such complications as Binaural[1] or Auditory Perspective[2,3,4] Reproduction Systems. These systems are not within the province of practicality and need be discussed no further.

Practical considerations dictate the use of monaural or single channel reproducing systems. The ideal of this system would be an exact reproduction, from the loudspeaker, of the sound impressed on the microphone of the system. To the enthusiast, then, the basic problem involves the cost of a satisfactory approach to this ideal. He finds that he must weigh such factors as response, distortion, and power output against cost.

A reasonable solution for the problem will result from limiting the demands on the system to those which are truly needed for satisfactory high-quality sound reproduction in the home. If this approach is used, it is possible to develop a wide range, low distortion sound reproducing system in which the cost is comparable to the cost of mass produced systems.

It is a further objective of this article to describe in detail the elements and performance characteristics of a practical high-quality sound reproducing system consisting of a record player, amplifier, loudspeaker unit, and cabinet. This description will enable the enthusiast to assemble a high-quality sound reproducing system at a moderate cost.

Frequency response.

To determine the frequency response needed for an ideal sound reproducing system, it is necessary to consider, in combination, the response of the human ear and the frequency ranges encountered in speech and music. The frequency range of the average normal ear[5] is from 20 to 20,000 cycles. It is likely that frequencies higher and lower than the limits of the ear will, at times be encountered in music or in certain noises. It has been shown[6,7] however, that the frequency range required for no appreciable loss in quality of reproduction is from 40 to 15,000 cycles. This range, therefore, might well be treated as an ideal.

Any attempt to evaluate the effect of restricting the frequency range of reproduction involves a personal judgment of quality and for all but minor range restrictions can be very confusing. Since the purpose of this discussion is to establish a criterion for high-quality reproduction, the drastic frequency range restrictions are, fortunately, not important. If terms such as: "Almost as satisfactory," or "Slight effect upon tone quality," be taken as a criterion, it can be shown[6] that a frequency range from 60 to 10,000 cycles would be indicated.

The choice between ideal and restricted frequency ranges reduces to a balance between cost and performance. It appears, therefore, that the enthusiast must make his own decision as to the desirability of using less than ideal response.

Distortion.

The allowable amount of distortion in a high-quality sound system is rather difficult to specify. The difficulty lies in the lack of any but general correlation between subjective and objective tests on distortions in sound reproducing systems.

Some idea of the subjective effects of distortion can be obtained from a study of the masking curves of the human ear. It will be seen, for instance: that the higher order harmonics are more easily discerned than the lower order harmonics; that the masking of harmonics increases as the signal level increases; that difference tones may be of more importance than the harmonics. With the complex waves of speech and music it becomes more difficult to speak, even in generalities. The amount of masking depends on the spectral distribution of the sound. A general idea can be obtained from a consideration of the masking effects of wide-band thermal noise. It is seen that at higher levels it becomes increasingly difficult to detect harmonics. The authors and their associates have reached a similar conclusion regarding the masking of distortion by higher level speech and music. Furthermore, it has been observed that the sensitivity of the ear to distortion in music appears to be a maximum for sound levels in the vicinity of 70 to 80 db.

If an attempt is made to evaluate the subjective effects of distortion, it immediately becomes evident that a continuous scale of values is impossible.

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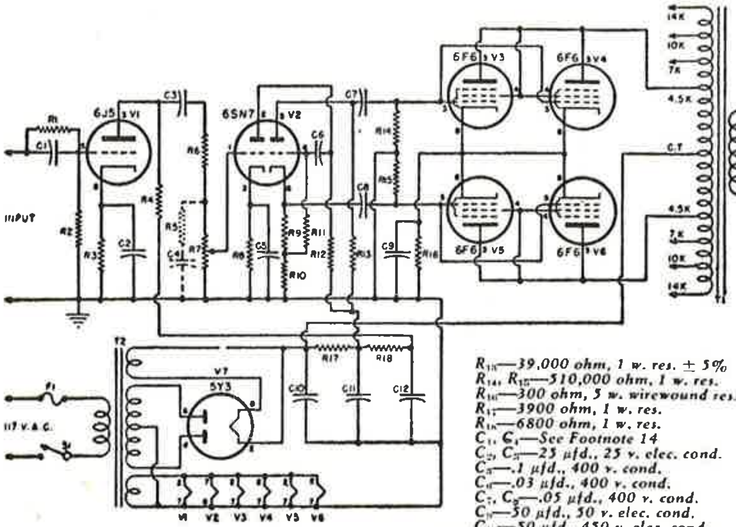


R_1, R_2—See text
R_3—1800 ohm, 1 w. res.
R_4, R_{12}—22,000 ohm, 1 w. res.
R_5—100,000 ohm pot. (See Footnote 14)
R_6—47,000 ohm, ½ w. res.
R_7—50,000 ohm pot.
R_8—390 ohm, 1 w. res.
R_9—5600 ohm, 1 w. res. ± 5%
R_{10}—33,000 ohm, 1 w. res. ± 5%
R_{11}—510,000 ohm, ½ w. res.
R_{13}—39,000 ohm, 1 w. res. ± 5%
R_{14}, R_{15}—510,000 ohm, 1 w. res.
R_{16}—300 ohm, 5 w. wirewound res.
R_{17}—3900 ohm, 1 w. res.
R_{18}—6800 ohm, 1 w. res.
C_1, C_4—See Footnote 14
C_2, C_3—25 μfd., 25 v. elec. cond.
C_5—.1 μfd., 400 v. cond.
C_6—.03 μfd., 400 v. cond.
C_7, C_8—.05 μfd., 400 v. cond.
C_9—50 μfd., 50 v. elec. cond.
C_{10}—50 μfd., 450 v. elec. cond.
C_{11}—40 μfd., 450 v. elec. cond.
C_{12}—20 μfd., 450 v. elec. cond.
T_1—Universal output trans., 4500 ohm plate-to-plate, to v.c., 25 watt (RCA 214T1)
T_2—Power trans., 390-0-390 v. @ 140 ma., 6.3 v. @ 4 amp., 5 v. @ 2 amp (RCA Stock No. 37048)
V_1—6J5 tube
V_2—6SN7 tube
V_3, V_4, V_5, V_6—6F6 tube
V_7—5Y3 tube

Fig. 1. Diagram of triode amplifier. It is straightforward and easy to duplicate.

Resort must be made to grouped gradations, such as; perceptible, tolerable, or objectionable. A perceptible level of distortion is dependent on experience and is, therefore, a fairly definite quantity. Tolerable and objectionable levels of distortion are dependent on personal opinion and are, therefore, very indefinite.

Obviously, the perceptible level of distortion can be used as an ideal — one can hardly ask for more than being unable to hear the distortion. For the type of distortion contemplated, for the frequency response contemplated, and for a sound level of 75 db, it has been shown[7] that a total r.m.s. distortion of approximately 0.75% is perceptible to critical listeners. This figure, therefore, is selected as the ideal for distortion performance. As pointed out before, the ear is not as critical at higher sound levels. It is probable, therefore, that this ideal figure can be relaxed for higher sound levels.

Any compromise with the ideal of distortion performance becomes so involved, with the items mentioned previously, that a single answer as to what constitutes tolerable distortion is unavailable. Distortions greater than ideal are most likely to occur at the higher power or sound levels. If it is assumed, for the moment, that ideal distortion performance can be achieved at intermediate (and lower) levels, then the concern is reduced to consideration of tolerable distortion at higher levels. It is the opinion of the authors that, for the type of reproduction contemplated in this article and for sound levels of 90 db, total r.m.s. distortions of 2 to 3% are tolerable.

Power output.

The electrical power input and sound power output of a loudspeaker are related by the efficiency of the loudspeaker. The electrical power requirements are, therefore, directly dependent on the sound level requirements.

Sound level requirements will vary, depending on individual tastes. It appears that, in the home, a habit pattern has developed from radio listening. It would seem that the radio volume control is adjusted so that speech is reproduced at ordinary conversational level and then no change is made as the programme changes to music or whatever. Ordinary conversation has an average sound level of approximately 70 db. Opinion and scattered tests of sound levels found in home reproduction offer a figure ranging from 65 to 75 db.

Numerous demonstrations of high fidelity sound reproduction have been made to visitors to the RCA Laboratories. The demonstrations were made in the Living Room Laboratory which is representative[8] of a typical living room in a house or apartment. The average power input to the loudspeaker for these demonstrations was approximately 0.050 watt and resulted in an average sound level of approximately 80 db. This sound level has been objected to by some as being too loud, but never as being too low.

From the above, it would seem that an average sound level of approximately 75 db would be adequate for most home reproduction. The power corresponding to this sound level would be approximately 0.016 watt.

For satisfactory performance, a sound reproducing system must be able to handle the power peaks encountered in speech and music. It has been established,[9,10] that the ratio between r.m.s. peak power and r.m.s. average power in speech and music is approximately 10 db. For an average power level of 0.016 watt the peak power would, therefore, be approximately 0.160 watt. **Using round numbers and a moderate safety factor we have the surprising result that a ¼ to ½ watt amplifier would give satisfactory performance in many home installations.**

There are, of course, many persons who desire the illusion of placing a large orchestra in their living rooms. Let us assume that the sound levels experienced in a concert hall for "full orchestra" from a large symphony orchestra will be adequate. It can be shown[11] that the peak sound level at a desirable seat in such a concert hall is not likely to exceed a value of 100 db. Extrapolating from the above figure of 0.050 watt corresponding to a sound level of 80 db in an average living room, we reduce that peak sound levels of 100 db would correspond to peak powers of 5.0 watts. It appears, therefore, that we are justified in limiting the power requirements of the amplifier and loudspeaker to approximately 5.0 watts.

Amplifier.

The choice of an amplifier for a high fidelity sound reproducing system has become one of the most discussed problems in the audio field. A discussion of the problem immediately becomes involved with arguments, pro and con, concerning triodes, pentodes, feedback, power output, distortions, etc. To the innocent bystander, the consensus of these discussions, is an amplifier having the more power the better, the lowest possible distortion at maximum power and, as a result, a disappointingly high cost.

The price of an amplifier depends on the performance required from the amplifier. Again, it seems proper, therefore, to insist only on that performance which is truly necessary. The necessary requirements for the amplifier are essentially the same as the system requirements set down before. It is very important to consider the distortion generated by the amplifier for the power level at which it will be most used. That power level would probably be of the order of ¼ watt and the distortion would be all the more important because of the increased acuity of the ear at the corresponding loudness level.

The selection of the amplifier configuration to meet the desired performance brings up the argument concerning triodes, pentodes, feedback, etc. It is generally conceded that the triode is superior to the pentode on a distortion basis. Consequently, the choice lies between the triode and the pentode with feedback. Triode amplifiers have been in commercial use for many years and, it would appear, have almost become a standard for comparison. It is claimed by many that pentode amplifiers with feedback can be made as good as or better than triode amplifiers. There is no reason to doubt this claim; however, it should be pointed out[12] that the price for the improvement to be obtained by feedback is the necessity of design control over a considerable frequency range below and above the useful frequency range of the amplifier. It is tacitly assumed here that the benefits of feedback will be required over the whole of the useful frequency range. The particular reasons for wanting to use a pentode derive from the improved power sensitivity and plate efficiency of such tubes. In an over-all sense these advantages are reduced, when feedback is applied. Negative feedback always reduces the over-all gain of the amplifier, and hence the advantage of power sensitivity of the pentode is reduced. The saving in power supply cost, in a pentode-feedback amplifier would be practically used up in supplying the necessary quality of components to allow the desired amount of feedback.

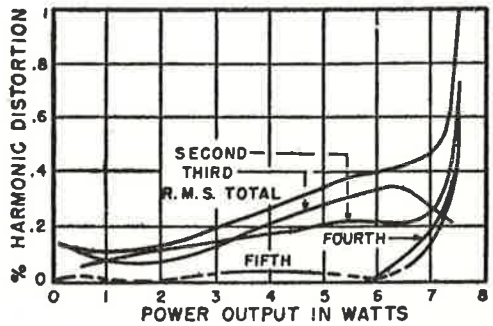


Fig. 2. The 2nd, 3rd, 4th, and 5th harmonic distortion components and total r.m.s. harmonic distortion as a function of power output measured at 400 cycles.

Summing up, it appears that from a performance standpoint there is probably little difference between a triode amplifier and a *properly designed* pentode-feedback amplifier. From a custom design and construction stand-point the inherent simplicity of the triode amplifier is certainly to be preferred over the inherent complicacy of the pentode-feedback

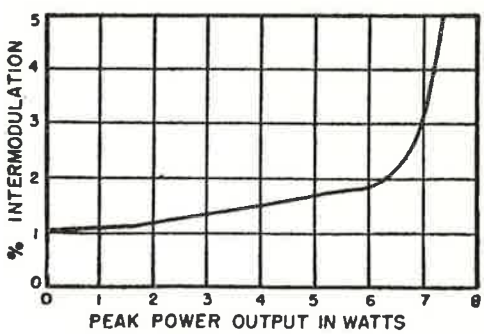


Fig. 3. Intermodulation distortion produced by combined inputs of 100 cycles and 2,000 cycles. The amplitude of the higher frequency is one-fourth of the lower frequency. The curve shows total distortion, that is, the results have not been divided by 4.

amplifier. There can hardly be any other conclusion than to recommend a triode amplifier for a custom type system, provided the desired performance is obtainable with the relatively few output triodes available.

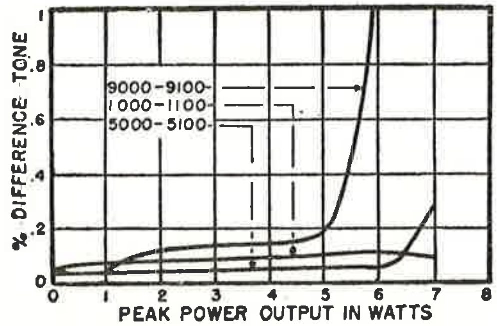


Fig. 4. Difference tone generation produced by an input of two h.f. components.

A triode amplifier using readily available tubes and as simple a construction as possible has been developed. The circuit diagram is shown in Fig. 1. The component specifications are given in the parts list.* The simplicity of the amplifier is obvious and also leaves little to be desired.

As can be seen in the following exposition of data, the amplifier performance is well within the specifications developed above. Fig. 2 shows the harmonic distortion of the amplifier for resistive loading for 400 cycle input. The distortion is shown on an individual harmonic and on a r.m.s. total basis. To be noted is the lack of higher order harmonics. For those who may be interested in the intermodulation distortion of the amplifier the results are shown in Fig. 3. The results of difference tone generation tests on the amplifier are shown in Fig. 4. The test consisted of introducing, to the amplifier, two equal primary voltages having a small difference in frequency. Then, the relative amplitudes of corresponding primary output voltages and the difference tone generated were determined by means of a wave analyzer. The result has been expressed as the ratio of the amplitudes of difference tone to either output voltage, in per-cent. The tests were conducted for primary voltage frequencies in the vicinity of 1,000, 5,000, and 10,000 cycles, and for difference frequencies ranging from 50 to 500 cycles. The power levels at which the tests were made are on the basis of the peak power obtained with the two primary voltages acting simultaneously. From a consideration of Figs. 2, 3, and 4, it is readily seen that the amplifier leaves little to be desired for output powers up to 5 watts. The frequency response of the amplifier is shown in Fig. 5.

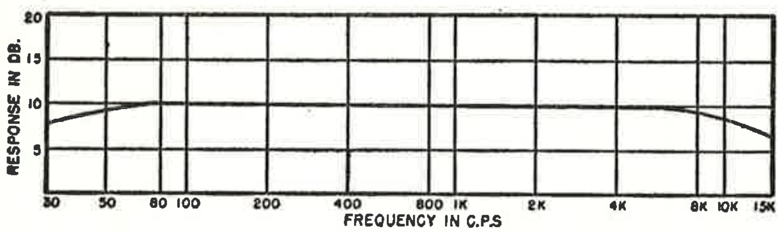


Fig. 5. Output response of amplifier for constant voltage at grid of the input tube.

FOOTNOTES.

[1]Olson and Massa: "J. Soc. Mot. Pic. Eng.," Vol. 23, No. 2, p. 63, 1934.

[2]Fletcher, H.; "J. Soc. Mot. Pic. Eng.," Vol. 22, No. 5, p. 314, 1934.

[3]Maxfield, Colledge, Friebus; "J. Mot. Pic. Eng.," Vol. 30, No. 6, p. 666, 1938.

[4]Fletcher, H.; "J. Acous. Soc. Amer.," Vol. 13, No. 2, p. 89, 1941.

[5]"Bell Laboratories Record," Vol. 12, No. 10, p. 314, 1934.

[6]Snow, W. B.; "J. Acous. Soc. Amer.," Vol. 3, No. 1, Part 1, p. 155, 1931.

[7]Olson, H. F.; "Elements of Acoustical Engineering," 2nd Edition, pages 488-491.

[8]H. F. Olson; "J. Acous. Soc. Amer.," Vol. 15, No. 2, 96-102, Oct. 1943.

[9]Wolf, S. K. and Sette, W. J., "J. Acous. Soc. Amer.," Vol. 2, No. 3, p. 384, 1931.

[10]Sivian, Dunn and White: "J. Acous. Soc. Amer.," Vol. 2, No. 3, p. 330, 1931.

[11]"Bell Laboratories Record," Vol. 12, No. 10, p. 314, 1934.

[12]Bode, H. W.; "B.S.T.J.," Vol. 19, No. 3, p. 421, July 1940.

[13]Resistors R_1 and R_2 and C_1 are included for pickup frequency compensation purposes. Values recommended by the pickup manufacturer should be used.

[14]If a high frequency tone control is desired, the dotted components may be added in shunt with the volume control.

* A triode-connected 6J7-G is suggested in place of the 6J5.

New RCA Releases

NEW PROJECTION KINESCOPE FOR THEATRE TELEVISION

Radiotron-7WP4 is a new projection kinescope for use in theatre-television equipment. It is capable of providing a clear, bright picture 20 feet by 15 feet when used with a suitable reflective optical system. Contributing to the brightness of the theatre-size picture is a high-efficiency, metal-backed, white fluorescent screen developed especially for theatre-projection service.

In general design and appearance, the 7WP4 is similar to the 7NP4. However, the 7WP4 is designed with a faceplate curvature intended for use in an optical system having an 80-foot throw whereas the 7NP4 has a faceplate curvature intended for a system having a 60-foot throw.

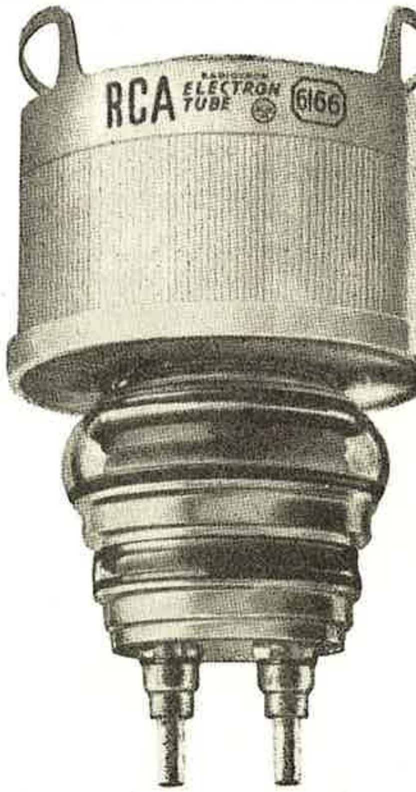
The 7WP4 employs electrostatic focus and magnetic deflection. Electrostatic focus facilitates use of the tube with a reflective optical system and permits maintaining focus simply and automatically by means of an associated voltage-control circuit in combination with a voltage-regulated d.c. power supply. Magnetic deflection provides essentially uniform focus over the entire picture area.

Operating with a maximum ultor voltage of 80,000 volts and a maximum focusing-electrode voltage of 20,000 volts, the 7WP4 incorporates high-voltage design features including (1) a bulb having corrugated side walls with insulating coating to provide a long leakage path over its external surface, (2) an inner cone-neck section to provide adequate vacuum insulation between internal ultor coating and outer neck section, and (3) only one high-voltage envelope connection — all other connections are made through a plastic-filled diheptal 14-pin base.

NEW VHF POWER TETRODE WITH 10-KW PLATE DISSIPATION

The new **Radiotron-6166** is a forced-air-cooled power tetrode designed for vhf service in television and c-w applications. It has a maximum plate dissipation of 10 kilowatts, is rated for operation up to 220 Mc/s, and utilizes an economical thoriated-tungsten filament.

The coaxial electrode structure of the 6166 is designed especially for use with high-power circuits of the coaxial-cylinder type. The design provides low-inductance, large-area, r-f electrode terminals for insertion into the cylinders, and facilitates the multiple use of the 6166 in cavity circuits. An efficient external radiator provides for cooling by forced air. The conical support for grid No. 1 and grid No. 2 is structurally strong, serves to cool these grids, and effectively reduces their inductance. These various features all contribute to the excellent performance of the 6166 in vhf applications.



The 6166 can deliver a synchronizing-level power output of 12 kilowatts in broad-band television service at 216 Mc/s; and a power output of 9 kilowatts in class C telegraphy service in circuits operating at 216 Mc.

"PREMIUM" MINIATURE VOLTAGE REGULATORS

Radiotron types 6073 and 6074 are cold-cathode, glow-discharge tubes of the 7-pin miniature type intended for voltage-regulator service critical as to excessive shock and vibration.

These new types are "premium" versions of the OA2 and OB2, and are constructed and processed to meet military requirements. They can withstand an instantaneous impact acceleration of 900 g, and a vibrational acceleration for extended periods of 2.5 g. Furthermore, these new types are processed to have very stable characteristics.

The 6073 and 6074 have an operating-current range from 5 to 30 milliamperes. The 6073 regulates at an average value of 108 volts, whereas the 6074 regulates at an average value of 151 volts.

Coupling the Speaker to the Output Stage

By Vincent Salmon, **Stanford Research Institute, Stanford, California.**

The loudspeaker is the weakest link in a sound reproduction system because no other component is required to transform energy from one form to the other with all of the following characteristics: (1) the transformation should be accomplished with a smooth response over a maximum range of about ten octaves; (2) this should be done with high efficiency; (3) directional effects should be controlled; and (4) the speaker should be able to handle the output stage power with a minimum of non-linear and transient distortion. According to these criteria, the speaker is the worst element; others might follow the order; microphone, phono-disk cutter, pickup, phono-tape recorder, and amplifier. Here we shall be concerned with the factors entering into the proper coupling of the strongest and weakest links, the amplifier and speaker.

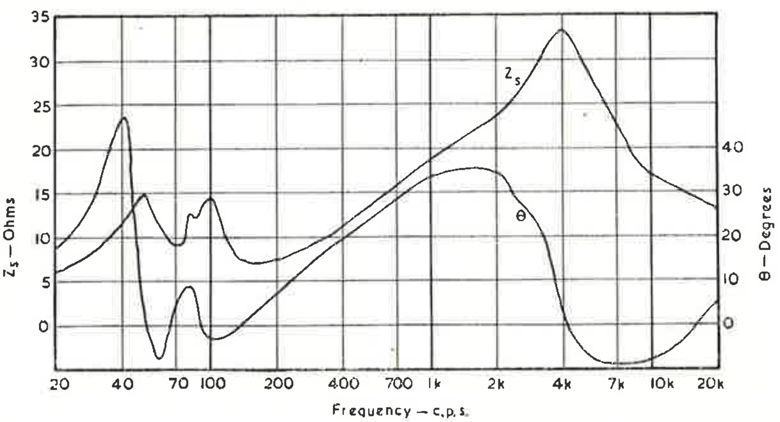


Fig. 1. Impedance Z_s and phase angle θ of 12″ coaxial speaker in a bass cabinet.

We first consider the situation from the point of view of the amplifier: how well does the speaker serve as load for the linear absorption of the power available from the amplifier? In general this is answered by stating the speaker impedance as a function of frequency (and possibly level). (We confine ourselves to moving coil speakers in a baffle or cabinet.) Now, amplifiers are designed, tested, and rated with a constant resistive load. For comparison, Figure 1 shows the impedance Z_s of a medium-efficiency 12-inch coaxial speaker in a conventional bass-reflex cabinet. The tweeter has been bridged across the woofer by a capacitor, which accounts for the anti-resonance at 4 Kc/s. The small peak at 80 c/s can be removed by bracing the cabinet, especially that portion between the speaker and port. From the curves, it is seen that the amplifier is certainly not being loaded by a constant resistance.

This, then, is an indication of the load presented to the output stage. What we need is a single figure for the impedance which permits attaining, with this load, the maximum acoustic power consistent with prescribed distortion limitations. This impedance, defined as the speaker rating impedance R_{sr} by the RTMA, is generally selected by the manufacturer. The value is determined by a variety of considerations, but the basic one is that for most orchestral and voice programme material the most probable peak power spectrum maximizes between 300 and 400 c/s, so the rating impedance should be a value in this range. Against this is the fact that output stage distortion increases more rapidly for decreasing than for increasing load resistance. Thus the value selected must not be too far above the minimum in Z_s, if the minimum occurs within an octave of 300 cps. The manufacturer's rating impedance for the speaker of Figure 1 is eight ohms; it is seen that a slightly higher value might be used.

Another factor entering into the selection of rating impedance is the character of the programme spectrum. In organ music, for example, the design centre frequency is reduced to below 100 c/s. This has led to an RTMA suggestion that transformers used in organ reproduction be derated to about one-fourth the normal power handling capacity,

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indicating the extreme conditions of operation. On the other hand, military announce systems are commonly rated at 1,000 c/s or higher. However, for ordinary broadcast or home use, the design centre should be in the 300-400 c/s region.

A factor commonly neglected in the choice of the rating impedance is the effect of a reactive load on the path of the operating point of the output tubes. For a resistive load the path is almost a straight line in the family of effective plate current-plate voltage curves. Under truly linear conditions, the path for a reactive load would be an ellipse. This path greatly increases the possibility of non-linear effects, since it is displaced to positions on the tube characteristics that are highly curved. It would be most instructive to construct the equivalent circuit for a speaker (say in an infinite baffle for simplicity), and then obtain with this load the amplifier output at 2 per cent. harmonic distortion, as a function of frequency. It is likely that the results at low frequencies would be not too meaningful, since the low-frequency distortion from any commercial loudspeaker will be vastly greater than that for a corresponding amplifier.

Another factor affecting output distortion is the reflection of magnetic and mechanical non-linearities back into the electrical impedance. However, owing to the inefficiency of most speakers and the over-riding effect of distortion on the mechanical side, this effect will be small.

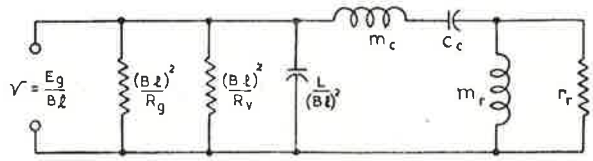


Fig. 2. Equivalent mechanical circuit of direct-radiator speaker in a Rayleigh (infinite plane) baffle.

We now turn from the effects of the speaker considered as a load, to the effects of the output stage considered as a generator feeding the speaker. For this it is illuminating to use the lumped mechanical circuit of a direct-radiator speaker in a Rayleigh baffle, as shown in Figure 2. The subscripts *v* denote voice coil, *g* generator, *c* cone and motor, and *r* radiation. The principal low-frequency consideration is that for transient excitation at the input, the force across r_r should be damped to the degree determined as optimum by the ear. There is some vague and rather ill-formed evidence that the ear prefers a slightly underdamped condition, but this writer knows of no well-planned experimental attack on the problem. Of course, at the frequencies where this is of importance, the discreteness and relatively wide spacing of room modes make it necessary to consider the problem as a whole, rather than merely the speaker portion.

Under ordinary conditions, the circuit of Figure 2 reduces to a series combination of m_r, m_c, c_c and $(B1)^2/(R_g + R_v)$. Now assume a source impedance much less than R_v. Then the condition for critical damping is $[(B1)^2/R_v] / \omega_0 (m_c + m_r) = 2$, where ω_0 is the resonant angular frequency of the baffled speaker. Now it can be shown that the bracketed numerator is equal to $8\pi\sigma\alpha E$, where σ is the conductivity of the voice coil, and αE is the magnetic energy in the volume occupied by the conductor. Although αE will thus depend on the conductor mass, this is usually less than 40 per cent. of the total mass. Thus the damping is fixed primarily by the amount of magnetic energy and hence primarily by the size of the magnet.

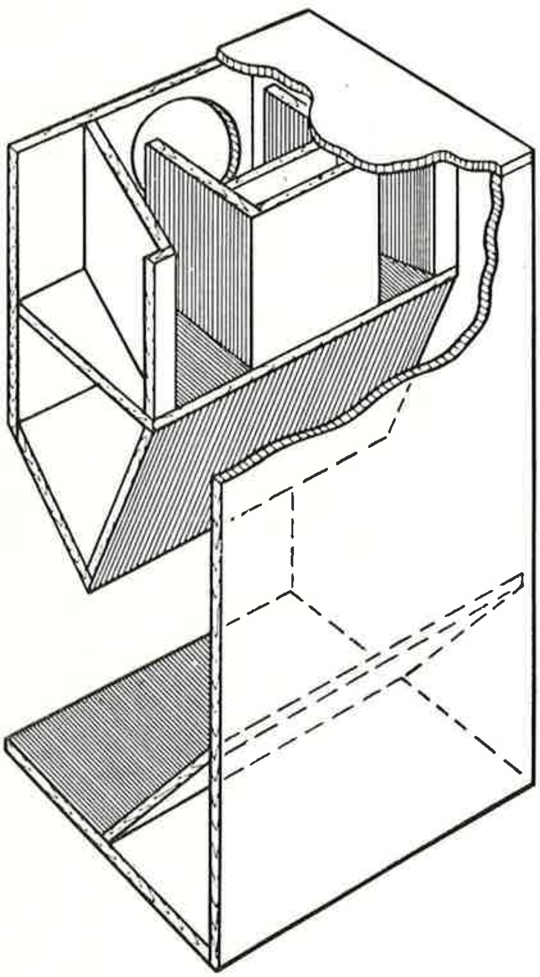
Since the voice coil resistance R_v is always in the circuit, reduction of the generator resistance R_g much below R_v is hardly worthwhile from the point of view of increased damping. This means that the output regulation need be no better than 6 db if damping is the only factor (As defined by the RTMA, the regulation is the terminal voltage rise, measured in db, from rated load to open circuit conditions). However, there are at least two reasons why a smaller regulation may be desirable. First, it is usually obtained by increased feedback, which represents lowered distortion in the operating range. Secondly, the lowered distortion is accompanied by an increasing insensitivity to variations in load impedance, permitting use of the so-called constant-voltage system.

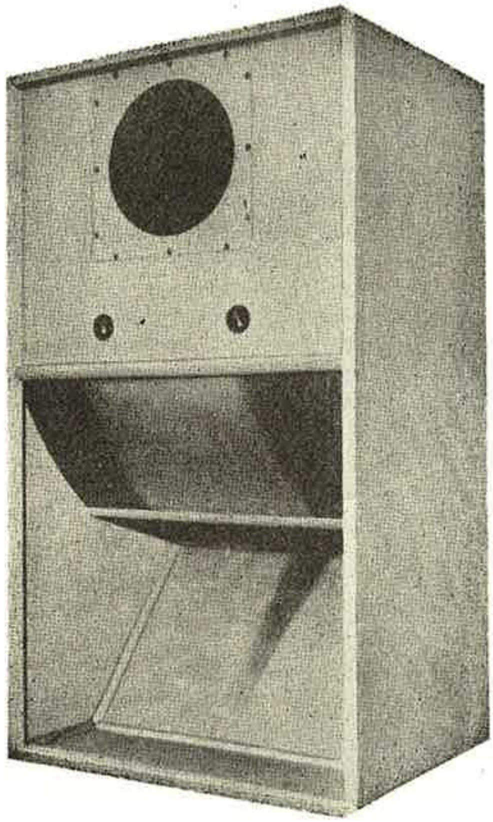
We now discuss this third and final aspect of the coupling problem. In the constant-voltage system, enough feedback has been added so that if the load resistance is increased from the rated value (maximum power for given distortion), and the drive is maintained constant, the distortion never increases beyond that at the rated load. For beam power stages, this condition is normally attained when there is sufficient feedback to achieve a regulation of less than about 3 db. These coupling conditions permit speakers to be added across the line without regard for impedance, until the load equals the rated value. Thus for a standard line voltage, speakers and transformers may be rated in terms of wattage, just like lamps, motors, etc. For the purpose of avoiding special problems due to extreme voltage rise, the RTMA has recommended a primary standard line voltage of $\sqrt{5,000}$ volts, with secondary ones obtained by multiplication by $2^{\pm n/2}$, where *n* is an integer. The freedom from impedance problems should recommend this type of output coupling to all users of public address equipment, wired music systems, or the like.

HORN-LOADED LOUDSPEAKERS

By Daniel J. Plach & Philip B. Williams,

Jensen Manufacturing Company.





FEATURES.

Optimum mouth size and path length for effective loading to 30 cycles.

Folded horn path permits compactness and minimum size for given mouth size and path length.

Back-loading design permits use of unitary multiple channel loudspeaker arrays.

Hypex* formula maintains effective loading to lowest frequency. Efficiency increase of 4 to 6 db over best conventional enclosure in l-f region

Low diaphragm excursion minimizes non-linear distortion.

Sound chamber design gives acoustic crossover of 300 cycles preventing interference between mouth and direct diaphragm (front-side) radiation.

Permits use of higher frequencies for electrical crossover without loss in m-f region.

Does not require corner position.

Space available for amplifier, crossover and/or control networks.

Can be "built-in" or used as separate self sufficient unit.

Cuts economically from standard 4′ × 8′ plywood panels.

* U.S. Patent No. 2,338,262.

There are two kinds of radiation means used to produce sound from a speaker. One is to couple the moving system to the air by the transformer-like action of a loading horn. The more common method is to couple the cone directly to the air, in the so-called direct radiator, or cone type unit. Most speakers used to-day are of the relatively low-cost cone type. Efficiency of the direct radiator is poor, being 2 to 3 per cent. for smaller magnet sizes. Use of extremely large magnets can boost efficiency to about 10%, but at a disproportionately high cost. It is cheaper to increase the electrical watts output of an amplifier source than to increase the speaker efficiency beyond a point, where decibels must be balanced against cost. However, there are other considerations in favour of the higher efficiency units. Heavier magnetic structures can furnish improved damping and transient response. Examination of the early "dynamic" speakers shows little fundamental difference in their basic construction from the cone speaker of to-day. Magnetic materials and circuits are considerably improved, yielding much greater efficiency and response smoothness in to-day's product. Cone and spider materials are better, and with the materials available the moving systems have run the gamut of variation based upon weight and contour. But this type speaker looks very much like the first "dynamic" speakers, with similar response balance and fundamental resonance.

It should not be inferred from this that the design or operation of a moving system is simple.

The operation can be predicted quite well over a relatively narrow band called the piston range, in which the cone moves as one piece. Design equations necessarily refer to operation in this range. The piston range of practically all speakers covers 4 to $4\frac{1}{2}$ octaves. Below resonance, response falls off rapidly, and above the piston range the cone no longer moves as a unit. As the frequency is increased beyond the top limit of the piston range, the cone goes into a variety of radial and circumferential modes of vibration which make scientific prediction and analysis very difficult. Here, speaker design becomes an art, based to a great degree upon empirical work.

Figure 1 shows the equivalent circuit of a direct radiator in an infinite baffle. Radiation resistance at low frequency for a typical 15″ high efficiency speaker is measured in hundreds of ohms, while the mechanical resistance losses in the same speaker are measured in thousands of ohms. So regardless of the amount of magnet used, theoretical efficiency at resonance is limited. However, the higher the product of flux density and voice coil wire length, the more favorable the ratio between reflected radiation resistance and voice coil resistance.

A practical result of the change of cone operation to various modes is to allow considerable extension of the response. Current practice in advertising in the industry is to claim for single motor speakers another 3 to 4 octaves response beyond the 4 to $4\frac{1}{2}$ in the piston range. Much of this response extension, especially where elements such as double cones or aluminium domes are used, is accompanied by a choppy sound pressure on the speaker axis, and the presence of strong sound pressure lobes at various angles from the axis. Regardless of the method used for extension beyond the piston range, the total radiation output begins dropping at a point far below the high frequency cutoff of the speaker. In the case of 10″ and 12″ sizes, this point usually occurs at 5,000 to 6,000 cycles.

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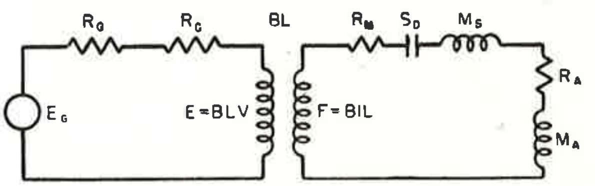
Changeover from piston to modal operation at the higher frequencies is accompanied usually by effects which tend to reduce the value of range extension. The resulting generation of spurious sounds called breakups or birdies in sine wave operation gets the most attention, as this phenomenon is easily noticed and measured. Actually these sounds rarely are troublesome in actual operation of the speaker, and are noticeable only upon sustained application of a single note at the particular frequencies of occurrence. More serious for the most critical applications are the response roughness, transient, harmonic and intermodulation distortion resulting. An analysis of existing commercial designs indicates that at the present stage of the art, the best compromise between extreme top frequency limit and other important factors is to design around conventional domes, cones and suspensions. Multi-channel systems, of course, are widely used to hold the operating range of speakers more nearly within the piston range octaves.



DIRECT RADIATOR EQUIVALENT CIRCUIT IN INFINITE BAFFLE

R_g = SOURCE IMPEDANCE
R_c = VOICE COIL RESISTANCE
BL = FORCE FACTOR
R_M = MECHANICAL RESISTANCE
S_D = SUSPENSION STIFFNESS
M_S = DYNAMIC MASS OF SPEAKER
R_A = RADIATION RESISTANCE
M_A = RADIATION MASS

Fig. 1.

Driving amplifier damping.

Beside these considerations, quality of a speaker depends upon size and upon magnetic energy available. The larger the cone with respect to frequency, assuming it is still operating in the piston range, the less excursion is necessary for a given amount of output, therefore the less the distortion arising from non-linearities in the moving system. Greater magnetic energy makes greater damping possible. Damping also depends upon the internal impedance of the driving amplifier. The current trend in amplifiers is to aim at internal impedance which is a fraction of the rated output impedance of the amplifier.

For instance, in some of the more expensive amplifiers intended to drive 16 ohm speakers, rated internal impedance is a small fraction of an ohm. This excellent regulation is better than required for critical damping of high quality speakers. The d.c. resistance of a 16 ohm speaker voice coil is about 8 to 12 ohms. The point of diminishing returns from the standpoint of damping would seem to be reached when the amplifier internal impedance is brought down to as low as $\frac{1}{3}$ to $\frac{1}{5}$ that of the voice coil resistance. In the case of the 16 ohm system, that would be 2 to 4 ohms, roughly 1 to 2 db regulation. For a balance in damping qualities as well as response, the present state of the art dictates that you must spend considerably more money for the speaker than for the amplifier, if the quality of all the elements of the listening system is to be in line.

In one respect, an amplifier of extremely good regulation punishes the speaker performance. A highly efficient speaker, that is, with high magnetic energy, has an impedance rise in the region of fundamental resonance which can be as high as 10 to 15 times the rated speaker impedance. This condition reduces the amount of power that can be drawn from the amplifier at resonance, especially where the amplifier approaches the constant voltage or perfect regulation condition. The effect may be that of less bass response than if an amplifier of poor regulation is used. As damping is highly desirable from the standpoint of transient performance, response smoothness and efficiency, what can be done to achieve a boost in low frequency output of a good speaker on a good amplifier?

Bass output increase.

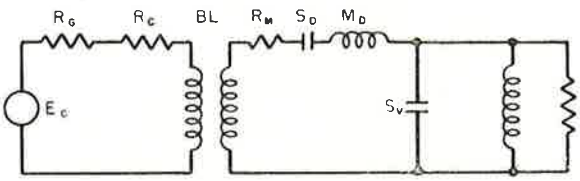
Adjustable bass boost in the amplifier is always desirable, to compensate for listening levels lower than the original, and for bass deficiency in some programme material. There are ways to increase the speaker efficiency too.

At low frequencies the speaker is no better than the enclosure used with it. A properly tuned bass reflex enclosure delivers more low frequency output at lower distortion than can be obtained from open-backed or closed box type cabinets. Over about one octave, movement of the cone is less, while the port radiates most of the power. The reduced cone movement lowers distortion generated by nonlinearities in the moving system and magnetic field. Increasing the enclosure size beyond a point gains little in practical performance. In the case of a 15″ speaker, this point is 8 to 9 cubic feet.

A tuned pipe, or column, enclosure can add large thumps at resonant frequencies of multiples of one quarter wave. The problem with this type enclosure is loss of level where the enclosure is not resonant. Absorption damping is required to reduce roughening effects of resonances of higher order than the fundamental.

A good method is to mount a number of speakers in a large enclosure. This does not mean that two speakers of cone area equal to one larger speaker cone will be superior to the larger one, however. Area is what counts. Resonance of the speakers must be low enough for the intended purpose, as operation will not be improved below their resonant frequency. The size of the enclosure should be greater than that used for a single speaker.

The most effective way to boost output at the speaker is to load the cone with a horn. The horn acts like a transformer to give the speaker a higher radiation resistance load. Figure 2 shows the equivalent circuit of a horn loaded speaker. Here, the ratio of radiation resistance to mechanical losses can be more favorable than in the case of a direct radiator. At low frequency, the loading on a 15″ speaker cone can be measured in tens of thousands of ohms, instead of hundreds of ohms when an infinite baffle is used. Resulting advantages of high efficiency, low distortion and high power handling capacity come from the decreased cone movement.



EQUIVALENT CIRCUIT
HORN LOADED LOUDSPEAKER

R_G = SOURCE IMPEDANCE
R_C = VOICE COIL RESISTANCE
BL = FORCE FACTOR
R_M = MECHANICAL RESISTANCE
S_D = SUSPENSION STIFFNESS
M_D = DYNAMIC MASS OF SPEAKER
S_V = SOUND CHAMBER STIFFNESS

Fig. 2.

Horn type units of medium frequency type long have been used commercially for public address work, both with straight and folded horns. More recently middle and high frequency horns have given a boost to the high fidelity audio industry. These units radiate into what is essentially free space, and in this case a minimum mouth size is required to prevent reflections which roughen response, and to attain necessary output. Radiating members in horn driver units usually are called diaphragms instead of cones; these are mostly of phenolic composition, with natural or synthetic cloth base. This type diaphragm is more rugged than metal, and has a greater resistance to emission of spurious sounds during operation.

The fundamental parameters of a horn are the throat size, mouth size, flare and cutoff frequency. Cutoff frequency and mouth size are determined by the lowest frequency to be passed, and cutoff frequency is fixed by flare of the horn. The flare determines the diaphragm load resistance at the throat near cutoff frequency. While the exponential flare is widely used, an advantage in operation near cutoff can be obtained with hyperbolic flares shaped from a formula trade-marked Hypex. Figure 3 shows the shapes of various Hypex flares possible. The parameter T determines the flare shape.

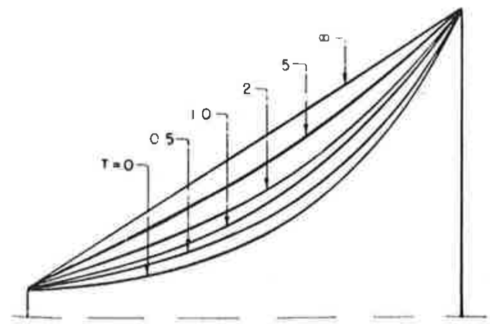


Fig. 3. Hypex horn flares.

For some time, horn loading has been used in conjunction with conventional direct radiator speakers as drivers for theatre and outdoor use, for low frequency reproduction. The same design elements apply to horns for low frequencies, except that two factors are smaller problems in actual performance. Spatial distribution is no longer a problem at low frequencies, and configuration of the mouth and the flare are of less consequence. Mouth size compared to wavelength of the sound can be less than in higher frequency units radiating into space. The reason is that floor, walls, and other larger surfaces close to the mouth effectively act to create mirror images of the radiating surface, thus raising the radiation resistance and increasing efficiency. For free space radiation a satisfactory rough figure of mouth diameter in inches for circular horns is the quantity 4,000 divided by the lowest frequency to be reproduced. Placement of a horn close to another surface which acts as an additional baffling surface can reduce the mouth area requirement to approximately one-half.

Recently there has been interest in adapting horn loading for use in the home, where space usually is at a premium. Space can be saved by use of a corner of a room as one section of a folded horn. The other section or sections are then built into an enclosure for the speaker. Currently there are three main types of corner horns.

The pyramid type has symmetrical radiation areas from the enclosure leading on to the floor and each wall of the corner. The assymetrical type has symmetrical radiation areas from the enclosure on to the walls only. Another type of corner horn is something like a bass reflex enclosure with the ports horn loaded to some extent by the corner. There

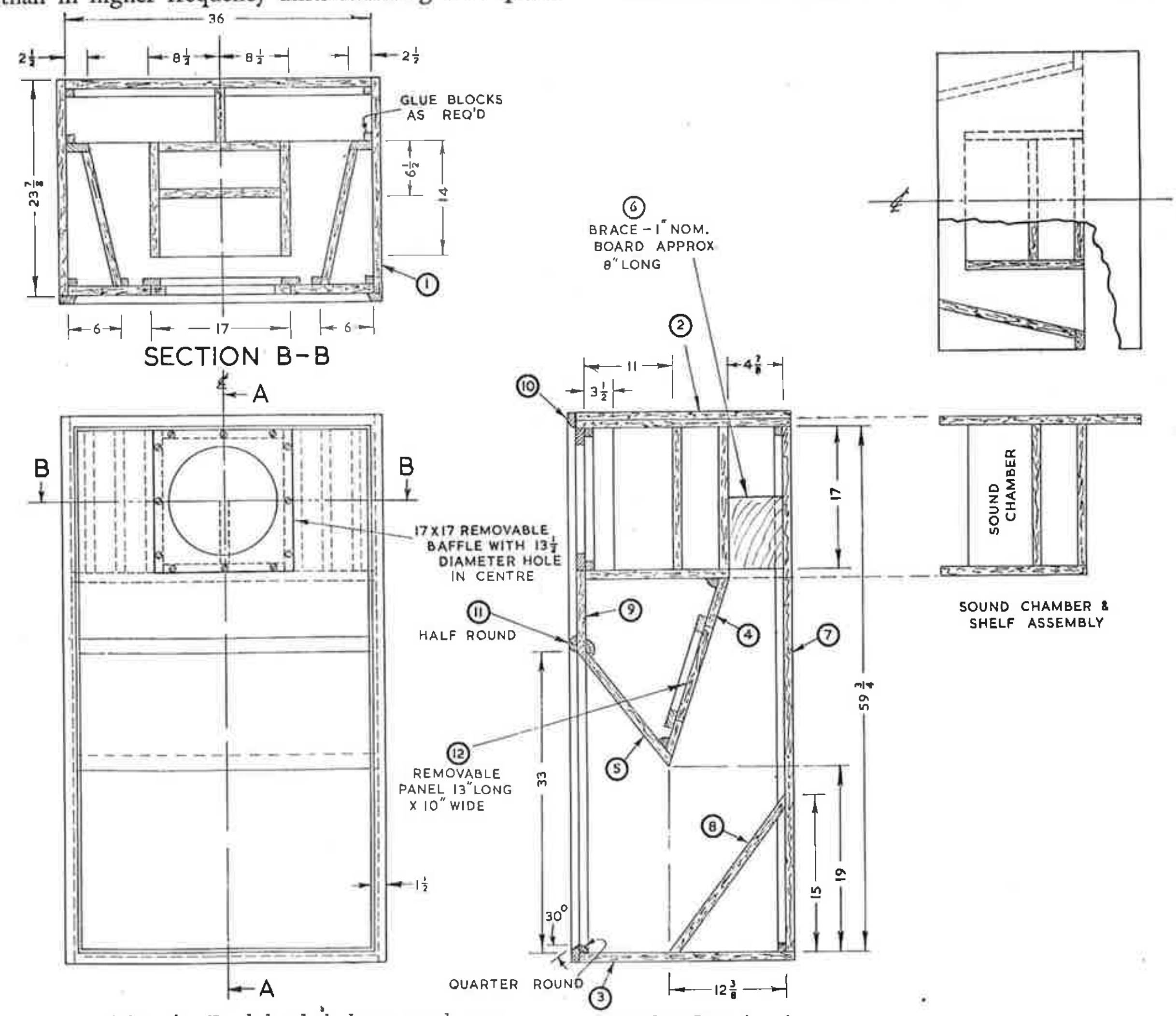


Fig. 4. Back-loaded horn enclosure.

are various versions of these as to size, and there is considerable difference in operation between large and small size corner horns. The large horns have more output and smoother response.

In the types of corner horns available on the market commercially, to our knowledge, there are none of optimum size which will allow for the front radiation required for the higher frequencies by a unitary coaxial or triaxial speaker. Additional to this, it seems that most people just do not have a corner available for installation of a corner horn. Of a local group of high fidelity enthusiasts numbering about thirty, we are told that only one of the group has a corner in which to place a corner horn. For these reasons, it was decided at Jensen to develop a non-commercial back-loading enclosure in which the front of the speaker could radiate in normal fashion. The main criterion was to be performance, although size admittedly is important.

Back-loaded horn enclosure.

After investigation and construction of a number of types of back loading enclosures, it was found that the one of Figure 4 gave the performance wanted. It consists of a Hypex horn of T equal to 0.7, mouth area of 1,260 square inches and a sound path length of 62 inches. Theoretical cutoff is 40 cycles, with good contribution at 30 cycles. The heavy air mass loading of the high efficiency 15″ direct radiator used with it reduces the resonant frequency of the speaker to 25 cycles. In infinite baffle, the same speaker has a resonance of 45 cycles. This direct radiator driver has an infinite baffle efficiency of about 10%, so the 4 to 6 db gain shown in Figure 5 indicates that with this enclosure, efficiency of 30% to 50% is attained.

The enclosure has a sound chamber such as is used in higher frequency horns. This serves the purpose of shunting out radiation from the rear of the cone above about 300 cycles, where cone front radiation takes over. Total volume is about 27 cubic feet, with outside measurements of 63″ height, $24\frac{3}{4}$″ depth and $37\frac{1}{2}$″ width. The sides, top and bottom can be cut from standard 4′ x 8′ sheets without wastage. Three-quarters inch wood is found to be sufficiently heavy to prevent excessive vibration of the sections. Beside the interbracing effect of joining the various sections of the enclosure, one brace is used between the sound chamber shelf and the back. Construction is not too difficult for the home woodshop worker, but must be carefully done so that air leaks are avoided. High sound pressures are developed, so all cracks should be tightly sealed to confine air movement to the proper path. Joints should be well made, so that the interbracing effect of joining the sections can be obtained. Assembly is most easily done in a sequence of operations. It would be difficult to build the shell and then install the sound chamber, separators and baffles. The best way to make the structure is to construct the sound chamber-shelf assembly, and then add the sides (1), top (2), bottom (3), cavity back (4), cavity baffle (5), brace (6), back (7), bottom baffle (8), front panel (9), and then the trim (10 and 11), in that order.

Variations of this design can be used if the air path dimensions are not changed much, and if the structure is not weakened by thinning down the wood or reducing the bracing. Vibration of a panel section of the enclosure is a sign of power being lost, and can be detected by touching the section during high level operation from programme material source. There is space available in the centre of the enclosure to mount networks, amplifiers and other apparatus. Speaker controls can be mounted in the front panel.

Placement is not critical. Operation is slightly better in an upright position than when placed on a side, but either mounting method is satisfactory. Corner operation is satisfactory, but not necessary.

Summary.

Direct radiation from a loudspeaker moving system is comparatively economical, but places a limit upon reproduction in the piston (low-frequency) range. Components of a reproducing system should balance in quality for most effective results per dollar. Low end (bass) performance depends to a great degree upon the enclosure, but is not improved markedly by increasing the enclosure size beyond a point. The transformer action of a horn achieves greater loading, high efficiency, lowered distortion and smoother response. Useful boost of low end output can be attained by proper horn loading design, but space requirements have limited the application. A new back loading horn enclosure of moderate size does not require a corner for efficient operation. Output is substantial at 30 cycles, and efficiency is 4 to 6 db above that of a conventional enclosure.

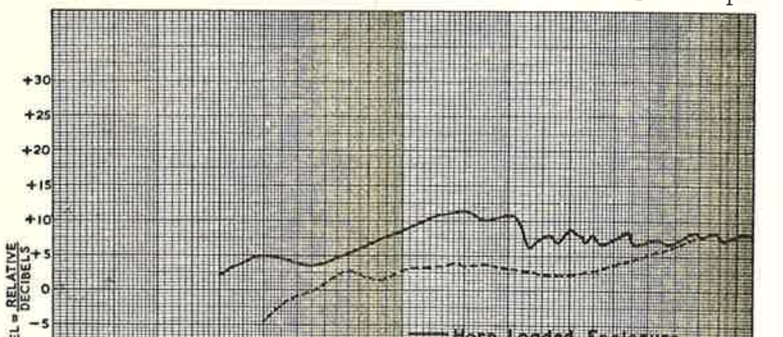


Fig. 5. Total radiation from bass-reflex and back-loaded horn enclosures.

First data printed on P. 48.

RADIOTRON 6AE8

9-PIN MINIATURE TRIODE HEXODE

-●-

APPLICATION.

The Radiotron type 6AE8 is a nine-pin miniature converter with a conversion conductance, under recommended operating conditions, of 750 micromhos, a hexode plate resistance of 1.5 megohm and an oscillator transconductance of 2,800 micromhos. The signal grid has a remote cut-off characteristic, and a signal-grid bias of −25 volts reduces the conversion transconductance to 10 micromhos.

Recommended operating conditions.

Signal-grid bias. The recommended signal-grid bias is −2 volts and is the minimum bias at which the 6AE8 should be operated. The comparatively low cut-off bias voltage of −25 volts is useful in avoiding overloading of a following i-f amplifier when a common a.v.c. voltage is applied to the two valves. It also assists in reducing playthrough in reflex receivers by restricting the i-f signal applied to the grid of the reflexed amplifier on strong stations.

Screen voltage. Although a screen voltage of 85 is recommended for the 6AE8, this figure is not critical provided that the screen dissipation is not exceeded.

The screens of the converter and i-f amplifier in a typical receiver are usually operated from a common source, and when a.v.c. voltage is applied to the two grids the screen voltage will rise. This may decrease the plate resistance of the converter and thus alter the coupling, and reduce the selectivity, of the converter plate circuit i-f transformer. This effect occurs only on stations of sufficient strength to operate the a.v.c. system; where it is undesirable it can be eliminated by stabilising the screen voltage by the use of a suitable voltage divider. In the case of the 6AE8, provided that the screen voltage does not rise above 140 volts due to normal a.v.c. action, the plate resistance of the valve should not fall below 1 megohm, for plate voltages between 180 and 250 volts.

Oscillator grid resistor. The comparatively low value of oscillator grid resistor, 30,000 ohms, specified for the 6AE8 greatly reduces the possibility of squegging occurring at the high-frequency end of the 6-18 Mc/s short-wave band, so that a grid stopper is not normally required.

Oscillator grid current. Under typical conditions of operation, optimum performance will be obtained with an oscillator grid current of 300 μA in the 30,000 ohm grid resistor. If the grid current is allowed to fall appreciably below this figure loss of conversion gain will result. The range between 300 and 400 μA will provide the best compromise of sensitivity, noise and spurious responses in most cases, although somewhat higher figures can be used.

Oscillator-signal-grid coupling. On the short-wave band the oscillator should be operated on the high-frequency side of the signal and, particularly when a low value of signal-grid bias is used, care should be taken to see that coupling between signal-grid and oscillator-grid circuits is not great enough to cause signal-grid current to flow at the high-frequency end of the band, due to the presence of oscillator voltage on the signal grid. If, with a particular layout, the oscillator voltage cannot be reduced to a sufficiently low value, then neutralising may be required, though this is not normally the case.

It should be noted that it is not necessary to reduce the oscillator voltage on the control grid to zero because a small amount of correctly-phased oscillator voltage will increase the conversion transconductance of the valve.

Grid versus plate tuning. Plate tuning of the oscillator gives better frequency stability on the short-wave band than grid-circuit tuning, but due to the greater amplitude of oscillator voltage developed in the oscillator plate circuit, it may make unnecessarily difficult the reduction of oscillator voltage in the signal circuit to a satisfactory level, even on the broadcast band. Accordingly, grid-circuit tuning of the oscillator is recommended unless an unusual degree of oscillator-frequency stability is required. With either plate or grid-circuit tuning of the oscillator, better frequency stability is obtained with high values of oscillator grid current.

RADIOTRON 6AE8 TENTATIVE DATA.

Electrical:

Heater, for Unipotential Cathode:

Voltage	6.3	a.c. or d.c. volts
Current	0.3	amp.

Direct Interelectrode Capacitances:°

Hexode grid No. 1 to all other electrodes (RF Input)	4.5	$\mu\mu$F
Hexode plate to all other electrodes (Mixer Output)	6.2	$\mu\mu$F
Triode grid and hexode grid No. 3 to all other electrodes (Osc. Input)	5.3	$\mu\mu$F
Hexode grid No. 1 to hexode plate	0.05 max.	$\mu\mu$F
Hexode grid No. 1 to triode grid and hexode grid No. 3	0.25 max.	$\mu\mu$F
Triode plate to all other electrodes (triode grid earthed)	1.7	$\mu\mu$F
Hexode grid No. 1 to triode plate	0.07	$\mu\mu$F
Triode grid and hexode grid No. 3 to triode plate	1.8	$\mu\mu$F

° With no external shield.

Mechanical:

Mounting position	Any
Maximum overall length	$2\frac{3}{16}''$
Maximum seated height	$1\frac{15}{16}''$
Maximum diameter	$\frac{7}{8}''$
Bulb	T-6-$\frac{1}{2}$
Base	Small Button Noval 9-pin

Base Connections:

Pin 1 — Grid Nos. 2 & 4
Pin 2 — Grid No. 1
Pin 3 — Cathode
Pin 4 — Heater
Pin 5 — Heater
Pin 6 — Plate
Pin 7 — Grid No. 3 & Triode Grid
Pin 8 — Triode Plate
Pin 9 — Internal Connection.

CONVERTER SERVICE.

Maximum Ratings:—Design-Centre Values.

Hexode	Plate voltage	300 max. volts
	Plate dissipation	1.5 max. watt
	Screen (grids 2 & 4) supply voltage	300 max. volts
	Screen (grids 2 & 4) voltage	125 max. volts
	Screen (grids 2 & 4) dissipation	0.4 max. watt
	Control grid (grid 1) positive voltage	0 max. volts
	Cathode current	10 max. mA
	Peak heater-cathode voltage	±90 max. volts
Triode	Plate voltage	175 max. volts
	Plate dissipation	1 max. watt
	Cathode current	6 max. mA

Triode Characteristics.

Plate voltage	100 volts
Grid voltage	0 volts
Amplification factor	22
Plate resistance	7,800 ohms
Transconductance	2,800 μmhos
Plate current	10 mA

Typical Operation.

Hexode plate voltage	250 volts
Hexode screen (grids 2 and 4) voltage	85 volts
Hexode control grid (grid 1) voltage	−2 volts
Triode plate supply voltage	250 volts
Triode plate voltage	115 volts
Triode plate dropping resistor	30 kilohms
Triode grid resistor	30 kilohms
Hexode plate resistance	1.5 megohms
Conversion transconductance	750 μmhos
Hexode control-grid bias for S_c = 10 μmhos	−25 volts
Hexode plate current	3.5 mA
Hexode screen current	3.2 mA
Triode plate current	4.5 mA
Triode grid and hexode (grid 3) current	300 μA