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RADIOTRONICS

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Seasons Greetings

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RADIOTRONICS

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By the way —

Supplies of the 4th edition of the Radiotron Designers' Handbook are being received slowly but steadily from the bookbinder. Distribution is proceeding as rapidly as stocks permit in strict rotation to all who have lodged pre-publication orders.

We would ask all concerned to bear with us and refrain from inquiring about their books in the interim as all orders will be filled in due course. All packages are registered and there will be little chance for any copies to go astray.

We would remind our readers that subscriptions for 1953 are now due and these should be forwarded immediately to avoid any break in the sequence of copies received.

The May, June and July, 1952, issues are no longer available.

Mr. Snyder, author of "Toward a More Realistic Audio", which appears in this issue, is an Audio Consultant with Consumers' Research Inc., Washington, N.J., U.S.A. Consumers' Research is a non-profit organisation which examines a large variety of consumer goods and makes reports evaluating them in a published bulletin.

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Power and Voltage Amplifiers

W. R. Ayres,
RCA Victor Division.

Through the use of well-known circuit techniques, one can obtain enormous amplification over the entire audio frequency band, and in general the linearity of a vacuum tube amplifier can be made better than any preassigned degree. Really basic physical limitations are rarely reached before mechanical or economic considerations rule; often further improvement is incommensurate with the additional effort involved. Thus a vital part of good engineering judgment is recognition of diminishing returns.

Table 1—Frequency Range for Various Services.

Use of Equipment.	Low	High	Approx. Mean
High intelligibility speech	300	6,000	1,340
Narrow ban speech	400	3,000	1,100
Public address	100	6,500	800
Phonograph records	50	10,000	710
Broadcast studio	30	15,000	670
Proposed audibility limits	20	20,000	630

None of these bands impose any burden upon the vacuum tubes themselves. The principal difficulties arise with related components, coupling devices such as transformers being the chief offenders. In general, the lower the frequencies to be amplified, and particularly the lower the frequency at which full power output at low distortion is required, the heavier and more costly the amplifier will be. Design inconveniences are likewise increased if both very high and very low frequencies must be handled simultaneously, since success at one end of the band requires methods which are detrimental to the other.

Voltage amplifiers

Amplification from input to power amplifier grid is customarily obtained with resistance-capacitance coupling, for which one may be guided by data published in tube handbooks. These charts present values of cathode and screen resistance for use with various values of plate voltage, plate load-resistance and resistance in the grid circuit of the following stage. Values of cathode and screen resistance are based upon maximum useful output voltage. The data includes this output voltage, and the amplification under the stated conditions.

With triodes, the cathode bias resistance is chosen so that the stage will accommodate the largest output signal for 5% harmonic distortion and no more than 0.1 microampere grid current. Cathode bypass and coupling capacitances listed in the data each cause 10% lower amplification at 100 cps than at mid-frequencies. Thus, the relative gain at 100 cps will be down approximately 2 db. per stage. Suggested capacitances, of course, may be modified in proportion to the ratio of 100 cps to some other frequency at which this attenuation is permissible.

With pentodes, the cathode bias and screen dropping resistances are chosen so that the stage will accommodate the largest output signal for 0.1 microampere grid current and balanced overdrive into grid-current and cut-off regions. Cathode bypass, screen bypass and coupling capacitances individually cause 10% lower stage amplification at 100 cps than at mid-frequencies. Thus, the relative gain at 100 cps will be down approximately 3 db. per stage.

A special case of vacuum tube "amplifier" is the cathode follower, in which the entire plate load impedance is placed in the cathode circuit. The input signal must be equal to the sum of the output voltage and the grid-cathode voltage required to produce that output. Thus, in the true cathode follower, the output is always somewhat less than the input voltage. However, this is permissible if other features are of sufficient value.

The cathode follower is not basically different in either performance or capability than other feedback amplifiers having the same effective gain reduction; the cathode follower is just the simplest of such amplifiers. Optimum load conditions are no different than with plate loading, and the same general rules apply regarding selection of operating point, etc. Similarly, the available output voltage at the point of flat-top is no greater than with the same load and bias resistances in the corresponding plate-load circuit. Thus, even though a cathode-follower output impedance of 500 ohms is easily obtained, only a very small output voltage at low distortion can be produced across the load impedance if it has the same value. With high a-c load impedance, however, the distortion contributed by a cathode follower is usually negligibly small.

One of the most useful phase inverter arrangements is the split-anode-cathode circuit. Here the tube load is equally divided between the plate and cathode circuits. In practice, there are additional capacity loads due to input capacity of the following tubes, wiring capacity to ground, etc. If the complex plate and cathode loads are exactly equal, then since they are in series and carry the same current, the voltages across them are exactly equal and in phase (proceeding from ground to B+). Or, relative to ground, the a-c plate and cathode voltages are equal in magnitude and opposite in phase to the same degree of exactness that the complex plate and

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cathode load impedances are alike. It is usually easier to maintain good high-frequency balance with this type phase inverter than with other types in common use. Due to negative feedback in the cathode circuit, the output impedance at the cathode may be considerably lower than the plate. Thus, the amplification of the stage is less affected by changed cathode loading than changed plate loading. Nevertheless, the two output voltages still *differ* only to the extent that the cathode and plate load impedances differ, since they are series elements carrying the same alternating current.

Power amplifiers

Class A is seldom used in push-pull power amplifiers, as any preassigned performance characteristic can usually be met more economically with the more efficient classes of operation. Class A_1 is perhaps the most popular type operation in single-ended power amplifiers, and AB_1 for push-pull output stages. AB_2 is only rarely employed in low-distortion amplifiers; it is generally more economical from the standpoint of the finished design to use additional or larger tubes in Class AB_1.

The maximum power output under various classes of operation is limited by maximum allowable electrode voltages, and permissible power dissipations within the tube. Operation of tubes outside the limits set by the tube manufacturer is usually rather poor practice, and seldom economical in the long run. If either low values of distortion are involved, or if high accuracy is required, distortion prediction by graphical methods is usually impractical. One reason is that the accuracy with which published curves are drawn, and the closeness to which they can be read, is necessarily limited. Another important reason is that simply executed graphical solutions assume resistive loads and perfect power-supply regulation. A third difficulty is that preparation of the curve family describing distortion vs. power output for various load impedances, is a laborious process by graphical means. The experimental determination of proper loading is undoubtedly the best, it solves the problem and checks the result at the same time. Distortion vs. output curves for a power amplifier stage should preferably be run at a mid-frequency, and at the lowest and highest frequencies at which rated output is to be obtained. The reason for this formality is that optimum loading is a compromise giving proper weight to tube overload and output transformer limitations. One might argue, of course, that if leakage inductance, iron distortion and reactive loading are severe enough to influence optimum loading, then the output transformer should be of better quality. On the other hand, if the measured distortion at rated power output is no greater at the lowest and highest frequencies than it is at 1,000 cps, the transformer is probably better than is warranted by the power output capability of that particular tube.

Power sensitivities of various tube types

A comparative basis for power sensitivity is the ratio of the power output in milliwatts to the square of the peak grid signal required to produce that power output. In Table II, tube types are listed in the order of their power sensitivities when operated single-ended output stages with conventional electrode voltages. Pentode and beam-power operating conditions do not include those in which different d-c plate and screen voltages must be provided.

Table 2.

Tube	Operation	Milliwatts Output	Eg Peak Approx.	Power Sensitivity	D-C Power Rqd.	Per Cent. Eff.
45	Triode	2000	56	0.64	11.9	16.8
50	Triode	4600	84	0.65	29.3	15.7
2A3	Triode	3500	45	1.7	17.7	19.8
6F6	Triode-connected	800	20	2.0	8.4	9.5
6L6	Triode-connected	1300	20	3.2	10.8	12.0
6N6-G	Direct-coupled	4000	21	9.1	15.3	26.2
6F6	Pentode	4500	20	11.3	13.7	32.8
6K6-GT	Pentode	3200	16.5	11.7	9.7	33.0
6V6-GT	Beam Power	4500	12.5	28.8	13.0	34.6
6L6	Beam Power	6500	14	33.1	21.2	30.6
25L6-GT	Beam Power	2200	7.5	39.2	6.2	35.5

Push-pull amplifiers

For even low-distortion amplifiers of up to a watt or so, a single-ended output stage will usually suffice. For larger power output it is usually less costly to use a push-pull amplifier, which connection reduces the d-c magnetizing component in the transformer core. Thus, the low frequency distortion contributed by the output transformer is less with push-pull than with a single-ended output stage; or for preassigned performance characteristics, a smaller transformer will suffice. More plate-supply ripple voltage is allowable for a given amplifier hum output. A third and very important feature is the cancellation of even-harmonic components of distortion; thus, one can build practical amplifiers with Class AB_1 tube operation.

Negative feedback

The original amplification A_v is usually a complex quantity; i.e., there is phase shift as well as frequency distortion. However, if β is real only, the A_v is also real to the extent that $\beta A_v \gg 1$. Both phase shift and variation in amplification may be reduced by factors comparable to the gain reduction. With certain assumptions, harmonic and intermodulation distortion are reduced by that same factor. In addition, the output impedance may be controlled over wide limits. With voltage feedback, the new value is:

$$R^1_p = \frac{R_p}{1-\mu A_1 \beta}$$

where R_p = plate resistance of the output tube
μ = amplification factor of the output tube
A_1 = amplification without feedback between the grid of the output tube
β = portion of output voltage feedback to input.

Through the proper use of negative feedback, an amplifier can be operated with much improved characteristics; or to meet previously assigned performance specifications, a more economical amplifier can be built. Whether the feed-back voltage should be derived from the primary, the secondary, or a tertiary winding (included for feedback only) depends upon exactly what characteristics the amplifier is supposed to have. A point in favour of secondary or tertiary feedback in low cost systems is that much less plate-supply filtering is required for a given hum output than with primary feedback giving the same output impedance. For general usage, primary feedback is the most easily applied, can be applied in greater quantity, is more readily adaptable to simple circuits, and is more stable with generalized load conditions that either secondary or tertiary feedback.

Output transformer requirements

The basic purposes of the output transformer are efficiently coupling the output stage to the load with d-c isolation, and transforming the load impedance to a value suitable for loading the tubes. To avoid adversely affecting amplifier operation, the transformer should not only be efficient from a power standpoint, but should have large winding inductance and low leakage inductance, and should not contribute objectionable distortion at low frequencies.

It is interesting to note the effects of source and load impedance upon output transformer performance, neglecting capacities, and with all quantities referred to the primary side, let:

L_{oc} = shunt inductance with secondary open circuited,
L_{sc} = total (series) leakage inductance,
R_{par} = source and load impedances in parallel,
R_{ser} = series total of source and load impedances,
ω_h = $2\pi f_h$, the higher frequency at which the response is down 3 db. and
ω_l = $2\pi f_l$, the lower frequency at which the response is down 3 db.

Then at these 3 db. down points,

$$\omega_h L_{sc} = R_{ser}, \text{ and } \omega_l L_{oc} = R_{par}$$

Dividing,

$$\frac{\omega_h}{\omega_l} = \frac{R_{ser}}{R_{par}} \times \frac{L_{oc}}{L_{sc}}$$

The ratio L_{oc}/L_{sc} is a function of transformer size, core material and winding configuration. Representative values in output transformers are less than 200 for ordinary radio receivers, 1000 for motion picture and monitor use, and 10,000 or more in costly idealizations.

Increase of the ratio R_{ser}/R_{par} is effective in increasing the frequency range which can be covered with an output transformer of given cost. Neglecting winding resistances, let g = the ratio of source impedance R_s to load impedance R_L.

$$\frac{R_{ser}}{R_{par}} = \frac{R_s + R_L}{\dfrac{R_s R_L}{R_s+R_L}} = \frac{(R_s+R_L)^2}{R_s \quad R_L} = \frac{\left(\dfrac{R_s}{R_L}+1\right)^2}{\dfrac{R_s}{R_L}}$$

$$= \frac{(g+1)^2}{g}$$

which has a value of 4 for g = 1 and is a minimum for this ratio. Thus, having the source and load impedances equal is the worst possible combination if wide range frequency response is a principal object. For all other values of g, R_{ser}/R_{par} has a larger value.

The question of whether to make g high or low is answered by low frequency transformer distortion considerations, for which a low source impedance is desirable. Hence the amplifier designer should choose the alternative of making $g \ll 1$, that is, make the source impedance very low as compared with the load impedance. Without negative feedback, this can be done only at severe expense of power output capability.

The general subject of transformer distortion has received little quantitative attention in popularly published literature. Also, there is considerable variation among core materials of otherwise similar character. The general trend of the data has been analysed, however, and is reviewed briefly here.

Let X/R = the ratio of the open-circuit reactance of the transformer primary to the total resistance in the driving circuit. R is the effective parallel circuit resistance, including the secondary load, with all quantities referred to the primary side. The quantity X may vary over wide limits with frequency, flux density and changes in d-c magnetization.

With X/R as the independent variable.

a. The distortion at a given flux density varies roughly inversely with X/R for values of this ratio greater than about unity.

b. The variation of distortion with flux density for constant X/R is of the general form $y = a+bx^n$ (i.e., a straight line on log-log paper) in the flux density ranges of approximately 200 to 8,000 gausses for silicon steel and 300 — 4,000 gausses for common nickel alloys.

c. The distortion falls only very slowly as the flux density is reduced below about 200 gausses; in some cases the distortion is only halved for a 10 to 1 reduction of flux density. In other cases, the distortion may actually rise at lower flux densities before finally approaching zero.

d. With d-c magnetization, the distortion may be materially greater than without d-c, and will consist of even as well as odd harmonics. As the air gap is varied, lowest distortion and highest inductance occur simultaneously.

Thus to obtain lowest distortion due to the nonlinearity of the transformer inductance, the d-c should be minimized and the ratio X/R made as large as practicably possible. Balancing the d-c plate currents of a push-pull output stage permits the use of a much less expensive transformer. Low cost single-ended output transformers are limited to those of small power capacity.

General evaluation considerations

Showing that one design is better than another requires more than a simple agreement about which features to compare. It requires numerical statement of all pertinent facts. Unless numerical values can be and have been assigned to all important quantities, and measured figures compared therewith, one can hardly claim that his conclusions were drawn scientifically. Or, as Lord Kelvin once noted:

"I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be."

If one design principle does not yield more favourable numbers than another, then it is no better, regardless of the particular method employed to obtain those numbers. Hence the importance of determining and specifying just what are the minimum performance requirements of the apparatus. Then if several possible designs are being considered, all having numerically adequate electrical and mechanical capabilities, one makes his final choice on some simple basis such as size, weight or cost.

New RCA Releases

6199 MULTIPLIER PHOTOTUBE

Radiotron-6199 is a small, head-on type of high vacuum multiplier phototube intended for use in scintillation counters to detect and measure nuclear particle radiation, and in other applications involving low-level, large-area light sources. Because of its small size, the 6199 is especially suitable for use in portable equipment.

The spectral response of the 6199 covers the range from about 3000 to 6200 angstroms. Maximum response occurs at approximately 4000 angstroms. The 6199, therefore, has high sensitivity to blue-rich light and negligible sensitivity to red radiation. Because of its spectral response, the 6199 is well suited for use with organic phosphors such as anthracene, as well as with inorganic materials such as thallium - activated sodium iodide.

Design features of the 6199 include a semi-transparent cathode having a diameter of $1\frac{1}{4}$ inches on the inner glass surface of the face end of the bulb; a face with a flat surface having a diameter of 1 inch to facilitate the mounting of flat phosphor crystals in direct contact with the surface; and ten electrostatically focused multiplying stages. The relatively large cathode area permits very efficient collection of light from excited phosphor crystals, such as are employed in scintillation counters.

The 6199 is capable of multiplying feeble photoelectric current produced at the cathode by an average value of 600,000 times when operated with a supply voltage of 1000 volts. The output current of the 6199 is a linear function of the exciting illumination under normal operating conditions.

The frequency response of the 6199 is flat up to a frequency of about 50 megacycles per second, above which the variation in electron transit time becomes the limiting factor.

In the scintillation type of nuclear radiation detector, the 6199 is particularly useful because of its relatively large, flat-cathode area which permits excellent optical coupling between the phosphor and the cathode. As a result, the scintillation pulses are larger in amplitude than the majority of dark-current pulses, and thus discrimination against the dark-current pulses is facilitated. The 6199 permits the design of a scintillation counter with high efficiency and a resolving time of only a small fraction of a microsecond.

7VP1 OSCILLOGRAPH TUBE

Radiotron-7VP1 is a 7-inch cathode-ray tube of the electrostatic focus and deflection type designed to give sharp focus and to provide high brightness of the trace. Intended for general oscillographic applications, the 7VP1 has a small, brilliant, focused spot and high deflection sensitivity for its relatively short length. The screen is of the medium-persistence, green-fluorescence type and provides high contrast.

Superior in performance capability to the older type 7JP1 which it supersedes, the 7VP1 utilizes an electron gun designed to give high resolution of the line trace as distinguished from the gun used in the 7J-types to provide maximum brightness in a television raster. The gun in the 7VP1 has a grid No. 2 which is operated at grid-No. 4 potential so that beam current and grid-No. 1 cutoff voltage will not be affected by focusing adjustment. Focusing is obtained by adjusting the voltage applied to grid No. 3. As a result of these and other features incorporated in the gun design, the spot can be sharply focused on the screen, and remains sharp when beam current is varied over a wide range. The very small grid-No. 3 current permits the use of a low-current voltage-divider system.

Other features of the 7VP1 include a bulb face with minimum curvature consistent with bulb-strength requirements; separate base-pin connections for each of the four deflecting electrodes; well-balanced deflecting-electrode input capacitances; and a large-diameter neck with medium-shell diheptal base which not only provides the required insulation so that the high-voltage electrodes can have base-pin terminals but also permits reduction and better balancing of capacitances.

The 7VP1 is especially suitable for use in balanced electrostatic-deflection circuits and gives best definition when so used. However, the 7VP1 may be used with unbalanced deflection because of design features which minimize the spot and pattern distortion usually characteristic of unbalanced operation.

The 7VP1 can be used as a direct replacement for the 7JP1 in all equipment where the high-voltage supply does not provide more than 4000 volts.

CRYSTAL TRIODES

By E. G. James, Ph.D., and G. M. Wells, B.A.

Research Laboratories of The General Electric Company Limited, England.

1. Introduction.

The crystal diode, or cat's whisker, as it was then called, was very extensively used as a detector in the earliest days of radio, but with the advent of the thermionic valve it disappeared almost completely.

However, during the early years of the last war it was resurrected for use as a mixer in high frequency radar equipment. The first radar equipments operated at 200 Mc/s, where normal thermionic valves operated reasonably satisfactorily. To obtain better resolution, the frequency was raised to 600 Mc/s (50 cm), and this introduced many difficult valve problems. At this frequency, mixing or frequency changing with multi-electrode valves was almost impossible, and a special small-clearance diode was designed for the purpose, and this operated reasonably satisfactorily.

The next frequency jump was to 3000 Mc/s (10 cm), when the cavity magnetron was developed, and now the performance of the special diode was poor, partly due to lead length, partly to capacitance and partly to electron transit time. It was at this stage that the crystal and cat's whisker came into the picture.

Remembering the early cat's whisker, it appeared possible to make a unit whose dimensions were a small fraction of a wave-length and whose capacitance was low.

A very crude arrangement was first tried and it gave a superior performance to the diode as a 10-cm mixer. Many semi-conducting materials were investigated at that time; these included galena, carborundum, copper pyrites, silicon and germanium. The early measurements indicated that galena and silicon were outstanding, but that galena required a very light contact pressure which made stabilization difficult. Silicon with a tungsten whisker gave about the same sensitivity with a rather higher pressure.

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2. The silicon rectifier.

In view of this result, all the available effort was concentrated on silicon, and to this day, the silicon tungsten combination gives the best operation as a high frequency mixer. It is interesting to note that silicon crystals are now being manufactured for operation at 40,000 Mc/s and higher.

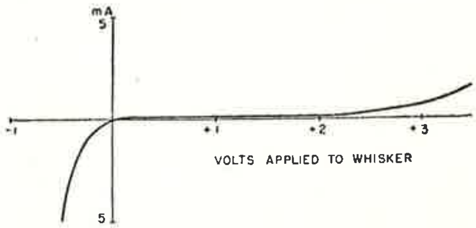


Fig. 1. Current-voltage characteristic of a silicon rectifier.

The current-voltage characteristic of a silicon-tungsten combination is shown in Fig. 1. The current increases very rapidly when the silicon is made positive with respect to the tungsten, but in the reverse direction the current is small up to about 3 V and then increases rapidly. When used as a mixer, the local oscillator is arranged to apply a voltage swing of about half to 1 V peak about the origin.

3. The germanium rectifier.

After the war when it became possible to go back to re-examine some of the other sime-conductors, it was found that germanium exhibited some very interesting properties which had been missed in the early days. The most important of these was the very high voltage which it could withstand in the reverse direction.

A typical current-voltage characteristic of a germanium crystal with a tungsten whisker is shown in Fig. 2. The direction of easy flow is opposite to that of silicon, and the voltage in the reverse direction can be increased to about 150 V or more before breakdown occurs. This is about 50 times that obtained with silicon.

This high voltage phenomenon with germanium was missed in the early experiments because the germanium available was not very pure. In fact, it is only possible to obtain a high reverse voltage with very pure germanium.

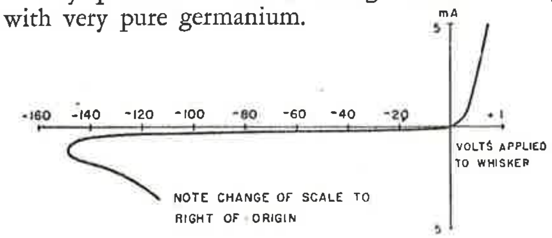


Fig. 2. Current-voltage characteristic of a germanium rectifier.

4. Conduction in silicon and germanium.

The reason for the reversed polarity is to be found in the structure of the crystal lattice of the elements.

The atoms of both silicon and germanium have four electrons in their outer ring and their crystal structure is identical with that of diamond.

A crystal of pure silicon or germanium has very low electrical conductivity. This is because all the outermost electrons of the individual atoms are occupied in forming bonds to neighbouring atoms, and they become very tightly bound. However, if a small number of atoms having either three or five outer electrons are introduced into the crystal lattice, then the electron behaviour is entirely changed.

For example, if in a germanium crystal lattice one of the germanium atoms is replaced by an atom of antimony which has five outer electrons, four of these electrons will form bonds with four adjacent germanium atoms, while the fifth will tend to orbit about the antimony atom. It will, however, be loosely bound and will easily move under the influence of an electric field. This type of semi-conductor in which the current is carried by electrons is known as an *n* type semi-conductor — the *"n"* standing for negative electrons.

On the other hand, if an impurity atom such as boron, which has three outer electrons, is substituted for a germanium atom, there will be an electron missing from the lattice. Conduction will now take place because electrons tend to jump into the vacant position, or hole, leaving another hole to be filled, and so on. This type of semi-conductor is known as a *p* type semi-conductor, because the vacant positions or holes behave as positive charges, and are called positive holes.

Silicon is usually a *p* type semi-conductor, whereas germanium is usually *n* type.

When a metal is brought into contact with a semi-conductor, a potential barrier is set up, the direction of which depends on the relative energies of the electrons in the metal and semi-conductor. With *n* type germanium and a tungsten whisker, the energy of the electrons in the germanium is higher than that in the tungsten, and some will spill over into the metal, leaving behind them impurity centres which have a net positive charge. A field is thus set up which will grow until equilibrium is reached.

If an external potential is now applied, the field or potential step at the barrier will act as a valve which allows current to flow very much more easily in one direction than the other.

The peak reverse or turnover voltage of a germanium rectifier appears to be related to the width of the potential barrier, and this, in turn, is dependent on the amount of impurity in the germanium. The lower the impurity content the higher the turnover voltage, and this is borne out by the following table which shows the dependence of turnover voltage upon arsenic content.

Arsenic Content parts per million	Turnover Voltage
5	24
4	26
3	28
2	33
1	48
0.5	69
0.2	90

It is seen that the arsenic content must be less than two parts in 10^7 if we are to obtain a turnover voltage of 100 V. (It is interesting to note that food is considered safe for human consumption if the arsenic content is less than five parts per million.)

5. Germanium triode design.

In 1948, Bardeen and Brattain, of the Bell Telephone Laboratories, announced their discovery that if two metal points are placed in close proximity — about 0.005 in. apart — on the surface of a germanium wafer and d.c. potentials are applied to both, then there is a mutual interaction between them which makes it possible to amplify d.c. voltages.[1]

Each electrode operated independently has a current voltage characteristic identical with that of the high back voltage rectifier. If, however, a negative voltage is applied to one of the electrodes, usually called the "collector", then the current to it can be varied by varying the positive voltage on the other, called the emitter. This property gives the device the ability to act as a triode valve.

Figure 3 shows a family of collector voltage-collector current characteristics of a typical triode for various emitter voltages.

The explanation of the operation of the triode is still the object of much argument, but it appears that both electrons and holes play a part in the operation. The theory generally accepted is that when the emitter electrode is made positive, electrons flow from the germanium to it, and, simultaneously, positive holes flow from the emitter to the germanium. The collector being negatively biased, attracts these positive holes, and so the collector current increases.

Now, in many triodes, the increase of collector current is greater than the increase of emitter current, i.e., there is a current gain. This is thought to be due to the fact that the potential barrier at the collector electrode is reduced by the concentration of positive holes in its immediate vicinity, thereby causing an increase of reverse current.

The one experimental fact that all are agreed on, is that it is necessary to have very pure germanium, i.e., germanium capable of making very high back voltage rectifiers to make triodes which have reasonable control action.

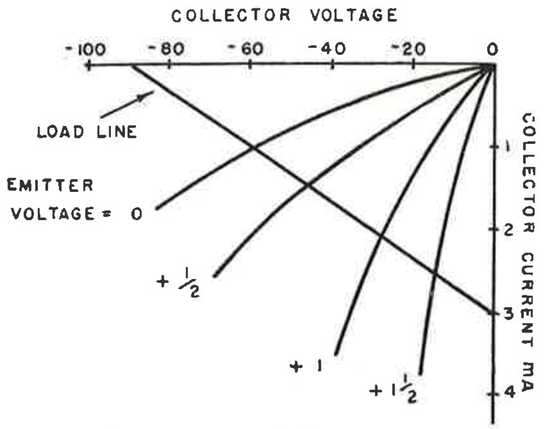


Fig. 3. Collector current/collector voltage characteristics of a germanium triode for various emitter voltages.

Two forms of triode assembly have been described by the Bell Telephone Laboratories. In the first (Fig. 4) a small block of germanium is soldered to a metal disc which is supported and makes good electrical contact with a metal cylinder. The two whiskers are formed from thin tungsten or phosphor-bronze wires, about 0.003 in. in diameter. These are supported by two rods which also act as lead wires. The whiskers make contact with the upper face of the germanium about 0.002 in. to 0.003 in. apart.

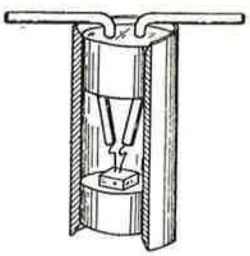


Fig. 4. B.T.L. transistor type A.

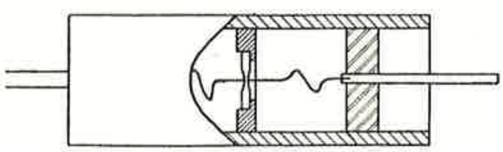


Fig. 5. B.T.L. transistor type B.

In the second Bell Telephone Laboratories design (Fig. 5), a small disc of germanium, about $\frac{1}{8}$ in. diameter, is cut from a slab of germanium and dish-shaped depressions are ground and lapped into the two faces. The disc is then supported centrally in a metal tube and two whiskers are arranged to make contact onto the germanium in the two depressions.

Whichever of these designs is used, the most critical and delicate operation during manufacture is the adjustment of the two whiskers to their optimum position relative to one another. An attempt has, therefore, been made to evolve a design which would need less skill during assembly. One such design is shown in Fig. 6.

The whiskers in this case consist of two phosphor-bronze blades, 0.003 in. thick and 0.04 in. wide which are supported in a moulded insulator. In order to attain a controlled gap between the blades, one method of manufacture which has been used successfully is to mount a single strip across the channel in the moulding and subsequently shear a gap 0.003 in. wide with a specially designed cutter. Another method is to make two separate blades and adjust them to the correct spacing with the aid of an optical viewer. Both methods give an extremely close control of the whisker spacing.

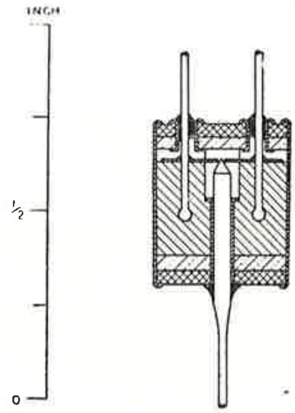
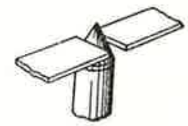


Fig. 6. G.E.C. germanium triode.

Fig. 7. Whisker details of G.E.C. triode.



The germanium is soldered onto the end of a metal stub, and is ground to a cone. By inserting the apex of the cone into the gap between the metal blades (Fig. 7), two-point contact onto germanium is obtained, with an accurately controlled spacing. Two flexible wires form the external connections to the emitter and collector, and another wire, soldered to the stub supporting the germanium, forms the connection to the base. The unit can therefore be soldered directly in the circuit without the use of a socket.

6. Crystal triode applications.

One way to use the germanium triode as an amplifier is to earth the base electrode, apply the input signal to the emitter and take the output from the collector as shown in Fig. 8.

The large signal performance of this circuit can be predicted from a set of static characteristics such as that shown in Fig. 3. As with a normal triode, the voltage gain and power output can be obtained if a load line corresponding to a resistor R is superimposed on the characteristics. In order to obtain the input resistance and the driving power, we must also, of course, have a similar set of emitter current-emitter voltage characteristics, just as we would with a normal triode which was being driven into grid current. It is interesting to note here that when the emitter is made more positive, the collector voltage becomes less negative, i.e., more positive. That is, there is no phase change as with a normal thermionic triode.

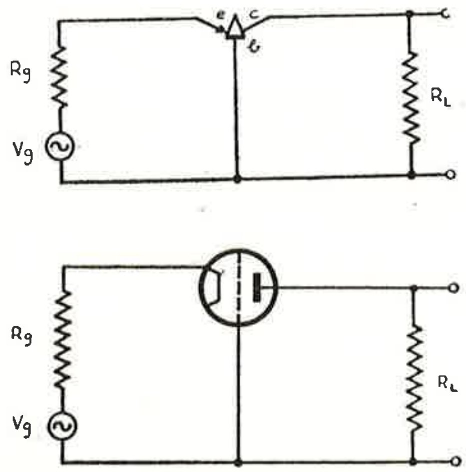


Fig. 8. Grounded base amplifier.

When dealing with small signals, it is useful and instructive to be able to deal with the triode in terms of some equivalent circuit.

If we treat the triode as a box with two input and two output terminals, there are a number of possible equivalent circuits which we can put in the box.

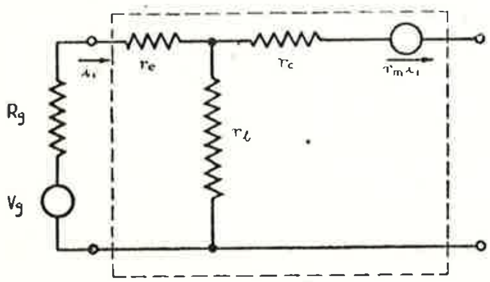


Fig. 9. Equivalent circuit of germanium triode.

One of the most useful equivalent circuits is that shown in Fig 9[2]. There are three resistances; r_e associated with the emitter contact, r_c with the collector contact and r_b with the base contact. The active property of the triode is described by the inclusion of a voltage generator $r_m\ i_1$, where i_1 is the a.c. component of the input current. The external bias voltages and currents are not shown. Typical values in ohms are:—
$r_e = 250$, $r_c = 20{,}000$, $r_b = 300$, $r_m = 35{,}000$.
The input impedance, output impedance and gain can be calculated from this circuit in the usual manner. If one carries out the analysis, one finds that the input impedance is of the form

$$R_1 = r_e + r_b - \frac{r_b\ (r_b + r_m)}{R_L + r_c + r_b}$$

Now if an external resistance is connected in series with the base electrode, r_b is increased and it is possible to make the negative term greater than the positive term. When this occurs the circuit becomes unstable.

Another way to look at this phenomenon is to examine the currents in the two meshes of the network.

The net current through r_b is $i_b = i_2 - i_1$.

If $i_2 = \alpha\ i_2$

Then $i_b = i_1\ (\alpha - 1)$ and the voltage drop across r_b is $= r_b i_1\ (\alpha - 1)$.

If α is greater than 1, then it is possible to make this voltage equal to V_g. That is, the current is self maintained.

If therefore a tuned circuit of a sufficiently high dynamic resistance is inserted in series with the base, the triode will oscillate at approximately the resonant frequency of the tuned circuit.

The earthed base circuit is similar in many respects to the earthed or grounded grid thermionic triode circuit. For example, both have low input impedance, high output impedance and no phase change between input and output. The big difference between them is the current gain which one can get with the

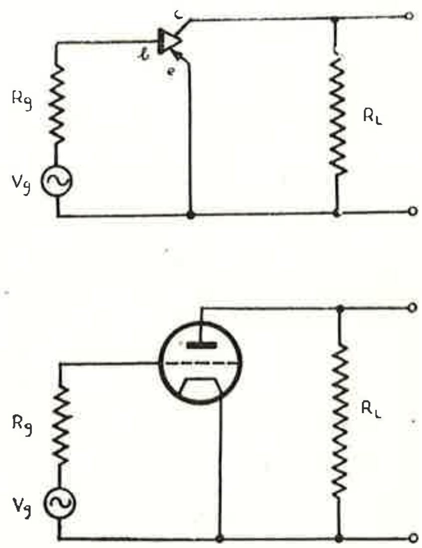


Fig. 10. Grounded collector amplifier.

crystal triode, whereas there is no current gain in the case of the grounded grid thermionic triode.

Since, in the above example the emitter was found to be analogous to the cathode, the base to the grid, and the collector to the anode of a normal triode, it is reasonable to assume that an earthed emitter circuit (Fig. 10) behaves similarly to the earthed cathode triode circuit. The behaviour is very similar when α is slightly less than unity, in that the input and output impedances are fairly high. But when α is greater than 1, then the circuit is difficult to handle owing to the fact that we now have an appreciable resistance in the base lead which tends to make the circuit unstable. However, one can cure this by adding resistance in the collector circuit so as to make the effective value of α less than unity.

The power gain of this circuit is usually greater than that of the emitter input circuit. A typical value is 25 db, but higher values can be obtained. The power output is very similar to the first circuit.

The third way to use a triode valve is as a cathode follower. In the germanium triode analogue, the collector is earthed and the output is taken from the emitter (Fig. 11).

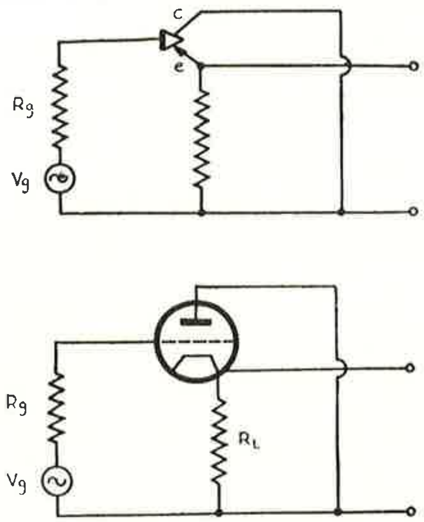


Fig. 11. Grounded emitter amplifier.

Again when $\alpha = 1$, this circuit behaves very much like the usual cathode follower circuit, in that the input impedance is fairly high and the output impedance low.

However, when α is greater than unity, the circuit loses its resemblance to the cathode follower and begins to transmit in both directions; that is, it has gain in both directions.

When $\alpha = 2$, the gain in both directions is the same, and for α greater than 2, the backward gain becomes greater than the forward gain. A curious feature of this circuit is that the forward transmission has no phase change, whereas the reverse transmission has a phase change of 180 deg.

This type of amplifier opens up some interesting possibilities in the field of line communications, in that it is possible to carry a two-way communication with only two wires instead of three as at present.

Amplifiers can, of course, be cascaded to obtain greater overall gain. The emitter input amplifier will, however, need interstage transformer coupling in order to match the high impedance to the low input impedance.

It is easier to design a multi-stage amplifier using the base input circuit, since in this case no matching transformers are necessary. The thing to be careful about is that when α is greater than 1, oscillation may occur if the resistance in the collector circuit is not high enough.

We have made a three-stage amplifier of this form which was stable, and in which the overall gain was 66 db.

Since the characteristics of the triode have curved portions, it is possible to use the triode as an anode (or collector) bend detector. Fig. 12 is the circuit diagram of a complete radio receiver which has operated satisfactorily. It incorporates four emitter input R.F. stages, and an "anode bend" detector driving a push-pull output stage, giving about 50 mW output.

One type of oscillator circuit which can be used with the germanium triode has already been mentioned. Another obvious oscillator circuit is that in which the tuned circuit is in the collector circuit and a feed-back coil is connected in the emitter circuit.

A field where the crystal triode is likely to prove very useful is the computor filed where counting is usually performed with pairs of triodes operating in an Eccles-Jordan or a "flip-flop" circuit. This arrangement has two stable states and a pulse is arranged to trip the pair from one stable state to the other.[3]

It is possible to arrange two crystal triodes in a similar "flip-flop" circuit, and reap the very large saving in heater current. The cathode heating of the valves in a modern electrical computor is very embarrassing as not only does the equipment get hot, but so does the room itself, and cooling becomes a major difficulty. The transistor should go a long way to solving this difficulty.

The unstable feature associated with a crystal triode having a resistance in the base lead makes it possible to design one triode circuit with two stable states, so that with this arrangement the number of counting valves is halved. For these reasons, computing is likely to be one of the first fields to adopt crystal triodes in preference to thermionic triodes.

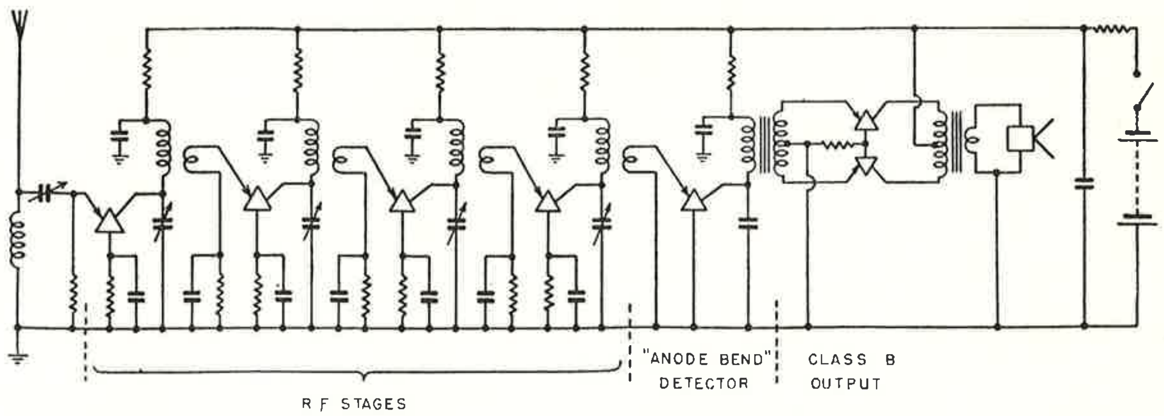


Fig. 12. Germanium triode radio receiver.

7. Peculiarities of crystal triode circuits.

The above examples give an idea of the possible applications of the crystal triode in terms of analogies with the thermionic triode. It will have been noticed that the analogies are by no means complete. This is hardly surprising since the control actions in the two types of valve are radically different. In one case collector current is controlled by emitter current, in the other case anode current is controlled by grid voltage.

It has recently been pointed out by Wallace and Raisbeck[4], of the Bell Telephone Laboratories, that the crystal triode is analogous to the vacuum triode if every voltage applied to the vacuum tube is compared with the corresponding current drawn by the crystal triode and vice-versa. That is, the crystal triode may be regarded as the "dual network" of the thermionic triode. This conception provides a most useful approach to circuit design. We will give two specific examples to illustrate the need to devise special circuits for crystal triodes.

The low input impedance of the grounded base amplifier has been mentioned. For an ideal crystal triode this would be zero ($r_e = r_b = 0$), making the input power zero and the power gain infinity. A practical consequence is that it is often better to connect the emitter circuit of the triode in series with a tuned circuit rather than in parallel with it.

The instability of the grounded emitter amplifier when α is greater than 1 may be expressed in terms of negative values of input and output resistance. As the threshold of instability is passed due to an increase of α, the output resistance drops to zero and then assumes larger and larger negative values, whereas the input resistance rises to infinity and then falls from very high to low negative values. This implies that a suitable series-tuned circuit connected to the output will oscillate at its resonant frequency, while a parallel tuned circuit will oscillate on the input side.[5] Coupling filters for a cascade of such amplifiers should be designed so that outside the pass band they present high impedance to the output circuit and low impedance to the input circuit. If this is not done, oscillation at some frequency outside the pass band will probably occur.[6]

8. Limitations and scope of crystal triodes.

A semi-conductor, such as germanium, allows current to flow at normal temperatures because electrons become detached from some of the impurity atoms in the lattice and jump to neighbouring impurity atoms which have lost an electron. Since this movement of electrons takes appreciable time, the change in the collector current resulting from a change of emitter current only occurs after a finite time delay. This means that the collector current lags behind the emitter current. This effect limits the maximum frequency of operation of existing triodes to about 10 Mc/s.

As one would expect, the maximum frequency is dependent on the spacing between the whiskers, but there are also other factors which have not yet been sorted out.

As is well known, the Shott noise generated in a thermionic valve is constant at frequencies above a few kilocycles, but below this frequency the noise increases. This low frequency noise is known as flicker effect and is inversely proportional to frequency.

The same sort of thing happens with crystal triodes, but with the difference that the low frequency noise extends to a much higher frequency — of the order of a few megacycles — and is greater in magnitude than that of thermionic valves. The exact mechanism of the noise generation is not at all clear at the moment, but is probably connected with the migration of ions over the contact between the metal and the crystal.

If we express the noise as an equivalent voltage at the input of the triode — assuming an emitter input circuit — and taking a bandwidth of 4 kc/s, then this equivalent voltage is about 5 μV at 1 Mc/s, 25 μV at 100 kc/s, and 70 μV at 10 kc/s. This means that one cannot use a crystal triode as the first stage of a high gain audio amplifier.

However, at the order of 1 Mcs the magnitude of the noise is reasonable, and is not noticeable in a receiver designed to amplify a signal of the order of 1 mV. This is typical of a local station receiver.

It is inevitable that there should be much speculation as to how far the crystal triode will replace thermionic valves. There is no doubt that the crystal triode has a number of advantages over the thermionic triode, but it also has a number of disadvantages.

Among the advantages are: the absence of a heater simplifies many circuits, and, since no "warming-up" time is required, the equipment would operate instantaneously; the life should be very long since it has no sensitive cathode: while the triode can be made very rugged, so that microphony is not likely to be troublesome.

The disadvantages at present are: the power output is limited; the maximum frequency of operation is limited to about 5 to 10 Mc/s, and the device is inherently more noisy than a thermionic valve.

One can fairly safely predict, therefore, that the crystal triode, when it has been further developed, will find many applications where it will perform better than the thermionic triode, but there are others where it is never likely to compete. One will find, therefore, that one is likely to be complementary to the other.

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TOWARD A MORE REALISTIC AUDIO

Ross H. Snyder.

This is, first, a report on the attitudes Consumers' Research has found commonest among those interested in high-fidelity in the home. CR receives more inquiries on this subject than on any other except automobiles, so we believe we are dealing by no means with an insignificant minority. Common factors in these inquiries have importance to those in the profession.

Assemblies of high-fidelity components have been well received by consumers. We are much impressed with the willingness they show to make substantial investment in their equipment. It is surprising that so many are asking, not for the "best low-cost equipment," but for the "best available". Encouraging as this may be, there are widespread danger signals of consequence to everyone in audio.

The amount of misinformation reflected in our inquiries is appalling. Some of what passes for quantitative data in advertising is, we believe, downright misleading. Some of it may be written by people who are, themselves, misled, but much of it appears to be deliberately misinforming, composed with full understanding that however ambiguous the impressive figures may be, even professionals are enormously influenced by graphs and charts that appear to be derived from measurements on equipment too complex and expensive to be familiar.

Aside from the advertisements, the dealer himself too often sponsors confusion in the buyer. There seems to be two common types: the one who first feels out the customers' prejudices, and then feeds on them; and the type which assumes an Olympian attitude toward *all* mere customers—an attitude whose loftiness is the best measure of its ignorance. There are, of course, the honored few who offer respect and seek to inform: we owe them a profound debt of gratitude.

Nature of unfilled demand for audio systems

Non-professional high-fidelity enthusiasts, we find, are more interested in good record-playing equipment than in anything else. Radio is most often regarded as an accessory, to be used for incidental listening, but not as a primary source of serious musical entertainment.

There is an important minority of non-technician consumers which is interested in home recording. These are almost exclusively concerned to-day with magnetic apparatus, with tape commanding most inquiries.

Another matter of wide concern is the consumers' inability to hear and see the equipment before purchase. Many still are unaware that well-equipped sound salons are maintained by dealers in the larger metropolitan areas.

Many purchasers of assemblies inform us that they experience difficulty in making the necessary interconnections in their assemblies. Much hum, and most reports of unreliable performance are traceable to this difficulty. Often when the supplier has not volunteered full information on the necessary wiring, the non-technician is at a complete loss.

A fourth too-common complaint is made over the difficulty of laying out as assembly so that the controls come out symmetrically and at one central point, so that duplication among them is avoided, and so that convenience of operation is optimum. The physical configuration of the equipment is blamed.

Related to this objection is the series of inquiries on how to arrange the equipment in either built-in or cabinet set-up so that the final assembly looks neat and professional. It is said that expensive arrays of fine equipment should look well enough to justify their cost. Nobody, it is suggested, short of a combination architect and electronic engineer could assemble, re-arrange, and alter some of the components on the market, so as to avoid ugly cabinet proportions, eccentric lumpy shapes, and trailing wires.

To most of us here the most important objection raised by non-technical people is this: many expensive assemblies *don't sound good enough.* The specific complaints most often received are with respect to *noise, shrillness,* and *weak or dirty bass response.* This is not with reference to users of faulty equipment, either.

Now, presumably, the reason we make measurements in designing and building equipment is in order to *predict,* in the scientific sense, the *end result* to be obtained, namely listener satisfaction. If we refuse to recognize a listener's objections on the ground that *he* is incompetent, we are ignoring a serious discrepancy in the accuracy of our predictions. A refusal to admit that the experimental results disagree with the predictions is an inexcusable violation of scientific method, and can't be tolerated. Before we conclude that the listeners are mainly tin-ears, and retire to the laboratories to please no one but ourselves, we had better re-examine our measuring methods and their interpretations. It is suggested that the trouble lies with simple and attractive, but unrealistic, interpretations of our evidence. We're not relating the physics *and* the psychology of the problems before us in an adequate way. Our engineering, it is suspected, is

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excellent, but our psychology needs an overhaul. We are preoccupied with the glamorous means we are using to the point that we're forgetting the ends towards which we should be working.

Listener preference

Our findings indicate that listener satisfaction increases with increasing frequency-range *only* when *noise, distortion,* and *raggedness of frequency response* are *all* greatly reduced simultaneously. To be sure, there is nothing new about such a theory. Many investigators feel these are the culprits in the public's notorious distaste for wide-range systems. Yet, many of us continue to display attitudes — *and equipment* — which over-emphasize wide range to such a degree that, *by comparison,* noise, distortion, and raggedness are ignored. Equipment is commonly designed to pass 30 to 15,000, or even 20 to 20,000 cps — the very limits of human hearing — yet how miserably short are we still of getting *noise* down to the threshold of hearing, of reducing distortion to the point where it's undetectable, or of producing *acoustic* output that is free of dips and peaks. Extending *range* is easy, and therefore tempting. But extending range without correspondingly improving noise, distortion, and smoothness characteristics, is costing us listeners. We think it cannot be overemphasized that in a system of *any* range — wide or narrow — noise, distortion, and raggedness are *not* sufficiently reduced if the listeners don't like the sound. Sometimes a *reduction* of frequency-range will improve the listeners' reactions. Still better listener-reaction is observed if, instead, further reductions are made in noise, distortion, and raggedness. We think that in *this* direction, laboratory predictions and listener reactions may be brought to coincide.

Suggestions for improvements of acoustic quality

These, then, are our impressions of the most significant needs of the home user, and a theory from which we think better satisfaction of those needs can grow. On the basis of these needs we suggest expanded criteria for judging components and assemblies, to include not only (1) highest possible acoustic quality, defined in terms of listener satisfaction, but also (2) convenience of installation, maintenance and operation, (3) appearance matching or excelling that of comparable-cost production consoles, and (4) reliability and safety above any reproach.

Noise level limits

To evaluate audio quality realistically by means of physical measurements, we have to *integrate* them together at every point. Quantitative standards are necessarily arbitrary, so it is best to make them marginally more exacting than the majority of cases requires. To illustrate how much electrical noise is tolerable, we find that listeners are displeased if such noise, in the absence of signal, is audible a few feet from the speaker. In our tests the electrical output, in tube-noise and hum, that was just audible varied between 0.1 and 5.0 microwatts, depending upon the level and character of ambient noise and upon the efficiency of the speaker system. This amounts to between –23 and –40 dbm, representing performance which, with a nominal 10-watt amplifier, would be described as "Noise 63 to 80 db below full output." The first figure is not hard to attain, but the latter, when high-gain magnetic pickup preamps are in the circuit, is rarely achieved, representing noise corresponding to a noise-input level of –118 dbm. The listener who wants quietness enough to pay two or three hundred dollars for his amplifier expects to have this demand *met.* Lower-cost installations will, presumably, involve speakers of lower efficiency, especially at the hum frequencies, and will meet the requirement with the higher noise figure.

Record scratch limits

Take another example: how much record-scratch is tolerable? When we integrate *several* factors together at once, we find that the *character* of the scratch is at least as important as its relative level. If the sound-pressure response of a *whole system* is full of dips and peaks, scratch causes objections out of all proportion to its level. But if the system is *smooth* throughout its range, and that range does not include much more than the cleanly-recorded frequencies, the silky character of the hiss is tolerable when its measured level is as little as 25 db below peak recorded signal; with modern recording means it can be reduced much more than this — and it should be.

The pickup cartridge

A common source of gross distortion and intolerable raggedness is the alignment of the cartridge relative to the record, especially in changers as they are installed by dealers, some of whom seem to have the impression that the cartridge is properly installed if its stylus manages to contact the record surface once each revolution. If gross disorders of this kind are relieved, the loudspeaker becomes the limiting factor. As response-smoothness improves, the upper tolerable range, we find, can be extended.

Distortion limits

When we consider *distortion* limits we have to integrate them *power* requirements. At the risk of extended argument, we report that oscilloscopic observations at the final grids of a number of amplifiers in actual home service, using musical transmissions with low-deficiency speakers, showed *no* peaks driving the amplifiers beyond 5 watts, even when uncomfortably high sound levels were developed. With high-efficiency speakers the signals were considerably lower. Furthermore, when peaks of this power, transient or otherwise, drive virtually all our tested speakers into violent distortion, we feel that a 10-watt amplifier which is uncritical of its load at any usable frequency, is generous, and that expense incurred for greater power is extravagance. We find that such an amplifier contributes no audible unpleasantness if the following conditions are met: distortion must decline with power, and at the 10-watt level must not exceed 2 per cent. r.m.s. at any frequency from 40 to 7000 cps. IM distortion of 8 per cent. is alternately acceptable if the frequencies are 40 and 7000 cps separated by 12 db.[1] Pre-amplifier and tone-control stages must be included, and must not, except in treble-boost or bass-cut positions, increase these figures.

Distortion in AM receivers is, we think, inadequately measured at the low percentage-modulation used in standard test procedures. With the high modulations routinely maintained nowadays, there is need for drastic improvement in detectors. FM distortion may be expected to be below 1 per cent. with ±75 kc swing and 50-microvolt signal, at which 40 db of quieting should be observed. Such a standard is attainable and is, we find, required in many locations to satisfy critical listeners.

We come last to the question of frequency-range because we are so firmly convinced that this is the *last* place where improvement should be sought. It will appear sheer heresy to speak of a high-fidelity system whose range is good only from perhaps 70 to 6000, or 60 to 8000 cps. *But if we measure in terms of acoustic output, according to the same standards we apply to filters and other electrical elements, the loudspeaker imposes such limitations.* That this is due to no form of carelessness or lack of research by loudspeaker makers does not obviate the necessity that we recognize the problem is enormously complex and difficult. *For this reason* we feel required to consider the limitations of *the best speaker which the economics of any given installation will permit* when we select every other component. We believe the profession owes the speaker-makers the compliment of recognizing the magnitude of their problem, and that we ought to discredit the misconception that such a range as 30 to 15,000 or 20 to 20,000 cps is now expectable with *anything resembling* the smoothness and low distortion we realize routinely from the electrical components. We can find *no* evidence that *any* speaker or system accomplishes such a standard. See *Fig.* 1. Only the costliest systems we have examined produce a *recognizable* 40– or 50– cps tone, much less one of low distortion. The hash which most speakers make of the range above 4000 or 5000 cps may best be judged by the jaggedness of their response-curves in that region. Even the vital mid-range is full of points of violent disturbance. Where frequency-response range is concerned, no engineer would rate the "upper cutoff" of a filter or an amplifier at the point where response is just measurable, on the tail-end of an 18-db-per-octave declination, but the practice is apparently common in rating loudspeakers. We think the industry is sufficiently grown-up to-day that it can afford to apply the same rigorous standards to speakers that it does to other components.

[1] **It has been shown elsewhere, by C. J. LeBel and others, that the relation between total r.m.s. and IM distortion is by no means a simple or a constant proportion. To the conditions defined here needs to be added only the condition that distortion-content shall decline regularly with its harmonic number in order to make the meaning of the 2 per cent. r.m.s. figure coincide with that of the 8 per cent. IM distortion figure.**

If the speakers merely cut off the top and bottom, it wouldn't be so bad. But the distortion that results in the middle-range when a cone is driven out of the linear portion of its magnetic gap by boosted 40-cps fundamentals makes a strong argument for electrically restricting the bass range. The same holds for the top, when the ragged residue of response goes to work on the harmonic structure. Horns help a great deal in the top range, of course, but if they are to begin handling power at 800 or 1200 cps their diaphragm-mass forces a fast roll-off from 6000 to 7000 cps. The value of adding a miniature third unit for the extreme top is questionable, since in our experience its function is largely to make a fine display of the hash to be found there from *almost* all programme sources. *Provision* for cutting off the top electrically should be provided in every quality installation. If our listeners set the cutoff lower than we do, we might inquire what distortion products and jagged responses up there drove them away. Control of the high frequencies presents more complexities than the usual controls allow for. If horn speakers, or others of good distribution and smoothness, are used, sharp cutoff points are needed to minimize programme-source irritations. If ragged speakers are dictated by economics, gentle roll-off of the whole upper range is demanded, we find, by listeners. Very sharp cutoffs, or, worse, peaks followed by sharp declination, produce the same sort of listener-irritation as does excessive raggedness.

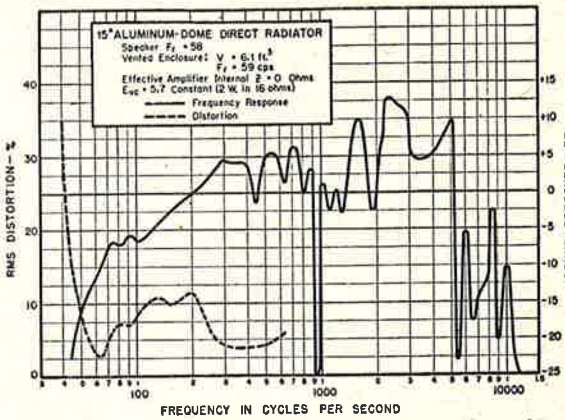

Fig. 1. By no means a "horrible example", this is one of the most highly-regarded of contemporary loudspeaker systems. The measurement was made outdoors from the top of a high building in a silent location. It should be noted that the amplifier source impedance was artificially reduced to absolute zero (constant-voltage) conditions. The bass characteristic assumes somewhat more normal proportions when the source has some, if little, effective internal impedance. The 1000-cps dip may be due to rim resonance or to a cancellation arising out of cabinet conditions.

Where bass response is concerned, we find once more a widespread engineering reluctance to take the listener seriously. If he prefers a loud one-note-thump to electrically-measured flatness, there is entirely too much tendency to charge off the trouble to the listener's tin ear. Reconsideration indicates that many electrically flat systems are acoustically decidedly weak at the bass end. We customarily drive speakers from extremely low source-impedance amplifiers, so that the power expressed into the speakers at their high-impedance bass frequencies, is low. Furthermore, loudspeakers work into living-rooms whose dimensions do not encourage excitation at long wavelengths. Because higher source impedances involve us in serious damping problems, some provision is needed to lift the voltage output approximately with speaker impedance. Further boosting will be needed to overcome the living-room's unfriendliness to low frequencies. The boost should not be extended too far down, of course, or the amplitudes involved will drive the voice-coils out of their magnetic gaps, with attendant uproar.

We're getting better speakers all the time, but until the problem is much better solved we'll make more friends by allowing realistically for necessary speaker shortcomings. Our present speaker systems, if kept within their power and frequency capabilities, and properly baffled, will produce great satisfaction — even though it's within a range of 60 to 8000 cps.

Suggestions for improvements in system design

So much for the audible characteristics of systems. The weight and spatial requirements of some of the best quality components impose difficulties. The problem of interconnections among components is vexing, and indicates that it is surely time for an industry conference on standard plugs, at least for inputs and outputs. Fortunately many audio houses are willing to make up the necessary intercables, and to code them clearly. That doesn't help much when the healthy curiosity of the owner leads to his changing amplifiers or tuners or what not.

The difficulty of arranging controls into a compact and attractive centre are formidable. Consumers want the knobs to come out symmetrically, with none duplicated or useless. It seems to them a reasonable request. This may involve alterations in wiring and chassis arrangement which non-technicians cannot be expected to make. Some of the best amplifiers cannot, for this reason, be used attractively. Long steps in the direction of solving this problem are being made in the various remote-control amplifiers. Such a technique as the use of removable lock-in shafts could be applied both to tuners and to amplifiers, so that duplicate controls could simply be pre-set, and removed when their function can be served by an adjacent knob on another chassis. Some tuners are so designed that removal of one, two, or more shafts, whose function may be duplicated at the amplifier, leaves a symmetrical panel. This is admirable, and could and should be adopted with amplifier-control panels. Most of these will be mounted in cabinets, and that fact should be considered in their design. Great flexibility in provisions for the connection of antennas to tuners can and should be provided. Tuners which are designed to serve also as control-centres need flexible arrangements for the connection of external inputs, like tape-recorders and TV sound. These are only *some* of the means available to meet listeners' needs. The important thing is that these needs *exist*, and for the sake of survival of the profession deserve attention.

It seems to us that some of the problems of high-fidelity are in an admirable state of solution, and that time can be spared from them to pursue the acoustical rodents that still plague us. Among the best-solved problems in all electronics is that of the amplifier output stage. What we emphatically do *not* need is more good engineering talent devoted to yet another variation of the push-pull feedback power amplifier. At their best, tape and disc recording means have reached a degree of excellence that far outstrips our ability to display it acoustically. The finest of existing pick-up cartridges, arms, and turntables leave little to be desired except cost-reduction. May we not hope for concentration, then, on those elements that are still giving trouble? The biggest problem, of course, is the loudspeaker system. But there are others: record-changers, for all the low esteem in which they are held by the professional, are seriously wanted by most consumers, and their wishes deserve more than our disapproval. The techniques that have made separate turntable-and-arm combinations so satisfactory, are applicable to changers. Tone-control systems designed to meet real needs, instead of to fill graph-paper prettily, are not beyond reach, technically or economically. AM radio receivers are not hopeless: we have recently seen demonstrated an AM detector circuit whose distortion did not exceed $\frac{3}{4}$ of 1 per cent. at 99 per cent. modulation. A tuner with performance approaching this should be made available. ※

Realism toward high-fidelity in the home requires our taking the non-professional listener seriously. It may be that he cannot *define* exactly what he wants, in our terms, but his approval ultimately determines the success of our efforts. We hold that it is the audio professionals' deepest responsibility, not only to understand and to meet, but *to anticipate* the needs of those whose interest lies in the *programme*, not in the equipment. More realistic and respectful attitudes toward the *listener*, we are sure, will result, in the end, in more realistic sound reproduction.

※ See June '53 issue, P.79 for this circuit.