J. Kelly Johnson

PROCEEDINGS

of the

RADIO CLUB OF AMERICA

A. C. as a Filament Supply Source

A Paper Delivered Before the Radio Club of America on September 15, 1926

PART TWO

By B. F. Miessner

Chief Engineer, Garod Corporation

Transformer-Coupled Audio Amplifiers

A Discussion of a Paper Presented Before the Radio Club of America, April 15, 1926, by A. W. Saunders

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The Radio Club of America

Bryant Park Building, Room 819

55 West 42nd Street, New York, N. Y.

Telephone—Longacre 8579

Organized in 1909 by pioneer amateur radio experimenters of America for the purpose of exchanging views and scientific data on the most fascinating subject of modern times—radio telegraphy and telephony.

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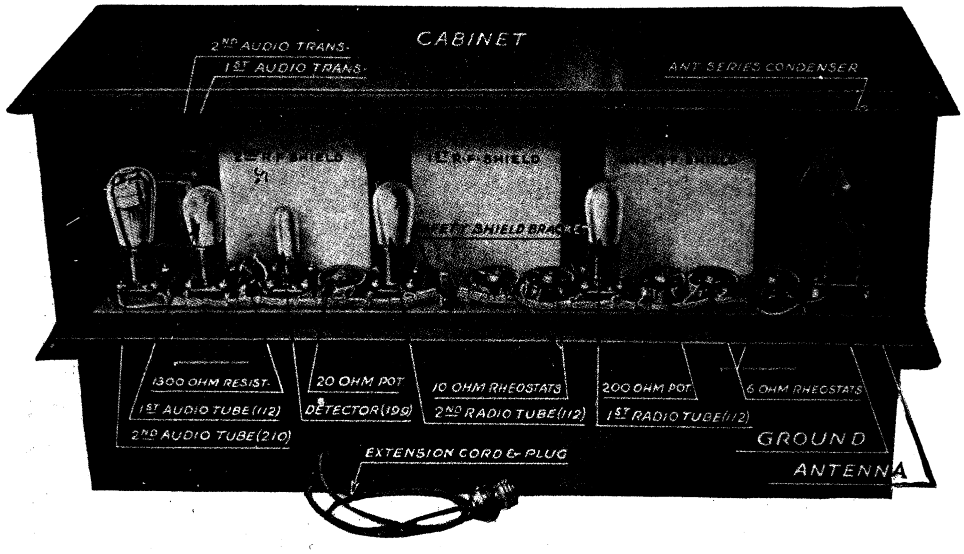
It is hoped that many others of the "old timers"—and the later ones, too—who have the interests and welfare of The Radio Club of America at heart, will follow suit.



AN INTERIOR VIEW OF THE GAROD EA RECEIVER
Note the neat cabled wiring at the rear of the sub-panel

A. C. as a Filament-Supply Source

A Description of a Popular Commercial Receiver—the Garod Model EA—Which Is Operated Entirely from the A. C. Mains

By B. F. MIESSNER

Chief Engineer Garod Corporation

THE operation of radio receivers directly from the a. c. house mains has always been a problem which has greatly interested radio engineers. After extensive research, and the accumulation of a great amount of data, the problem of design has been solved in a few instances. Whether a. c. operation will entirely supplant other means of powering the receiver is a question which will have to be left for the future.

Of the tubes in commercial use, the 112 type has been found to lend itself most readily to a. c. operation. This is due, in the most part, to the heavy oxide coated filament which does not fluctuate so much in temperature with the alternations of the current. By using the correct grid, plate and filament voltages as previously shown, the operation of such tubes is entirely satisfactory. As yet, no completely satisfactory means have been devised to use a detector supplied directly by a. c. To take care of this, it is customary that one of the 199 type tubes be used, its filament being energized by the total plate current of the other tubes in the receiver.

In the December issue of the PROCEEDINGS was discussed, with the help of curves, the different types of tubes and their characteristics under actual a. c. operation. The preceding article also dealt thoroughly with the different causes of hum and the methods of eliminating it. The present article will take up the practicable application of a. c. operation to a commercial receiver.

The Model EA Garod receiver has been designed and produced to meet a growing need for a receiver in which all batteries are eliminated, and with a much finer and fuller tone quality than has hitherto been available. The receiver is of the neutrodyne type, employing five tubes in the receiver and one rectifying tube in the a. c. power supply unit. It is made under licenses from Hazeltine and from the writer.

The power conversion system does two things; first, it develops an alternating current suitable for excitation of the filaments of the amplifier tubes, and second, it develops a direct current for supplying the plate current of all the tubes and the filament current of the detector tube.

The power-supply unit is mounted in the table portion of the receiver, and is entirely enclosed in an enameled sheet-iron box. The top and sides are removable as a whole without disturbing the enclosed apparatus which is mounted on the base-board. The opening or lifting of the lid opens an automatic safety switch which cuts the line circuit so that the user can not make accidental contact with high voltage terminals. The unit is designed to operate on a. c. lines of 60 cycles, 110 to 125 volts. It will not operate on 25 or 40 cycles, or on direct current, but seems to operate satisfactorily on a 50-cycle line.

To provide for voltages which differ slightly from the usual 110-volt standard, the transformer primary is tapped at different points which are designed to take care of any voltage variation in the mains and still provide the same value of voltage for the vacuum tubes.

There are three secondary windings on the power transformer, one of 7.5 volts and 3 amperes for exciting the filaments of the amplifier tubes in the receiver; another of 7.5 volts and 1.5 amperes for exciting the rectifier tube filament; and a third of 525 volts and 60 milliamperes for providing the a. c. for rectification of the B supply power.

To prevent the passage of electrostatic disturbances from the lighting circuit to the receiver circuits, a shield winding is provided, consisting of a layer of wire insulated from, and between, the primary and secondary windings of the transformer. One end of this winding is connected to the transformer clamping frame and grounded through the power box and receiving set ground.

The line current from the house lighting socket enters the power box through the attachment cord provided, one wire of which has connected in it the operating switch mounted on the front of the table. This side of the line is connected through one of the fuses on the output terminal board to one side of the transformer primary. The other side of the line enters the power box and connects directly to the other fuse, and from this through the automatic switch, to the other side of the transformer primary. These fuses are provided to protect the power converting equipment from overloading, which might result from excessively high line voltage, or from connection to direct-current or 25-cycle lines, which would produce excessive current in the transformer, and which might burn it out.

House lighting fuses ordinarily are of 15-ampere capacity, and would provide no protection whatsoever for the power equipment. The power consumed by this receiver is approximately 100 watts, the primary current being about $\frac{8}{10}$ of an ampere at 110 volts. The fuses are rated at one ampere and will open the circuit should the primary current of the transformer exceed one ampere. No apparatus other than the A winding on the transformer is necessary for providing the filament current. The system, therefore, is exceptionally simple in this regard, as no conversion system from alternating current to direct current, such as is used in most power driven receivers, is necessary. The power equipment provided is used chiefly for B power of high voltage and high current capacity, which is so desirable in providing distortionless reproduction at the required volume.

The B supply portion of the power equipment consists of the rectifier tube, the high-voltage secondary winding of the transformer, the choke coil, several condensers, and resistors.

The rectifier tube and transformer winding together provide a half-wave rectifier for the a. c. supply, and the filter system converts this rectified a. c. into practically pure direct current. Directly across the rectifier output is a 4-mfd. condenser which is flash tested at 3000 volts before assembly at the factory. Its purpose is to provide a reservoir for d. c. energy and a bypass for a. c. energy.

In series with the positive side of the filter line is the choke coil marked A in the accompanying diagram. It is a 50-henry choke having two air gaps of 0.01 inches formed by ten-mil paper between the laminations forming the two halves of the choke coil's magnetic circuit. This choke coil has a resistance of approximately 600 ohms and consists of about 7000 turns of copper wire.

Across the filter line, on the output side of the choke, is another 4-mfd. filter condenser which functions as a d. c. reservoir and as an a. c. bypass to further smooth out the ripple of the rectified current The voltage across the first 4-mfd. condenser should measure approximately 400 volts (r. m. s.). The actual peak value of the voltage across this condenser is approximately 525 volts. The second 4-mfd. condenser has approximately 364 volts (r. m. s.) across it, and its rated operating voltage is 600 (the same as the first one).

The plate supply of the second audio or power tube is taken from the filter output on the output side of this filter choke coil. A reduced B voltage is obtained for the radio- and first audio-amplifier tubes of the receiver by connecting in series with their plate supply a 5000-ohm resistor. This resistor is at the front of the power box at the right-hand side. To ventilate it properly, holes have been provided beneath it and above it in the power box lid so that air may circulate and prevent overheating. These same holes also provide for ventilation of the rectifier tube.

Directly across the filter line, between the B and the output side of the 5000-ohm resistor, is a 100,000-ohm fixed resistor which is located in the rear right-hand corner of the output terminal board. It is soldered in the connecting clip provided for it. This resistor prevents excessive voltages in the filter circuit when the set load is taken off by the removal of all the tubes.

To the left of the 100,000-ohm resistor is a 500,000-ohm one of similar type mounted in the same manner, which provides a plate current of reduced voltage for the detector tube. The voltage of the input side of the 500,000-ohm resistor, or directly across the 100,000-ohm resistor, is the voltage which feeds the two radio- and the first audio-amplifier tube plate circuits. It should measure about 150 to 175 volts, depending upon the adjustment of grid voltage for these tubes, as will be explained later.

Across the output side of the 500,000-ohm resistor supplying the detector plate circuit is a 1-mfd. condenser whose function it is to still further eliminate the slight alternating current ripple superimposed upon the direct current output of the filter system. Inasmuch as the audio frequencies of the plate circuit of the detector tube are twice amplified, that is, by the first and second audio tubes, the plate circuit supply for the detector tube must be perfectly smooth and without any variation.

THE OUTPUT DEVICE

INCLUDED in the power box assembly, besides the power conversion equipment proper, is the output choke (B in the accompanying diagram) together with a 1-mfd. condenser, the two combining to form an efficient output device for the protection of the loud speaker and to better quality. The plate circuit of the second audio tube is fed from a point on the output side of the filter choke, A, through the output choke B. This latter choke is, of course, connected in series with the lead to the plate circuit of the second audio tube.

The output choke for the loud speaker coupling is mounted on the rear side of the transformer. Air gaps in the two choke coils are provided for the purpose of giving maximum inductance to the chokes at the particular value of direct current flowing through the coils. If the air gaps provided by the paper spacers were omitted entirely, magnetic saturation of the iron core would result, and this would produce a considerably lower inductance in the coil than if saturation did not occur. It has been found that, for a given amount of direct current in the coil, a definite size of air gap will provide the maximum amount of inductance. Choke A, which must carry about 60 milliamperes of direct current, requires a considerably larger air gap than the choke B, which carries only the plate current of the second audio tube (approximately 25 milliamperes).

The two 4-mfd. filter condensers, the detector bypass condenser, and the 1-mfd. loud speaker output condenser are all mounted in a condenser unit installed beneath the output terminal board.

The terminals on the power box are arranged for connection to the cable leads coming downward from the receiver.

The pilot light receives its illumination from the rectifier tube and thus an extra lamp for this duty is dispensed with. The rectifier tube socket is mounted in such a position that the majority of rectifier tubes fit in it with the long axis of the elliptical plate in a vertical position, so that no danger of a sagging filament touching the plate will be encountered.

A COMMERCIAL A.C. OPERATED RECEIVER
It is the Garod EA receiver, the circuit diagram of which is shown on the following page

USING A LOOP

THE radio circuit of the EA receiver, as has been stated is of the neutralized tuned radio-frequency type, consisting of two such stages, a detector, and two stages of transformer-coupled audio-frequency amplification. The receiver is designed for use with antenna and ground, and these, in as good a form as possible, should always be used. In locations, however, where it is impossible to put up an outdoor antenna, an indoor antenna or a portable loop may be used. A loop may be connected directly across the antenna and ground binding posts and should be tuned by means of the radio-frequency volume-control knob (left-hand small knob) which operates a series tuning condenser.

In some localities, where many powerful broadcasting stations are located and interference is troublesome, a loop may be preferable to an outside antenna. By tuning the loop, and by virtue of the directional effects obtained by turning the loop, selectivity of a considerably higher order is obtained over that of an outside antenna. The range, however, is reduced.

When an antenna is used, the series antenna condenser is of great service in controlling the radio-frequency input to the receiver. It is also possible, by means of this condenser, to change the electrical length of the antenna within wide limits so as to change the overall selectivity of the receiver. When the condenser is all in, it is short-circuited so that the full antenna pick-up is available. As its capacity is decreased, the energy transfer is decreased, and the selectivity of the receiver is increased, in the same manner as if the actual physical length of the antenna itself were reduced.

Coupled to the antenna through the first radio-frequency transformer primary is the tuned input, or grid circuit, to the first radio-frequency tube. A bypass condenser of 0.006 mfd. is connected between the low-potential side of this grid circuit and the filament for the purpose of bypassing radio-frequency currents which otherwise would be compelled to flow through various portions of the receiver, including particularly the grid biasing resistance common to the plate circuits of the receiver.

The plate circuit of the two radio-frequency tubes is bypassed by a 0.01-mfd. condenser to the filament circuit for the same purpose as the grid bypassing condenser. The radio-frequency transformers consist of low loss bakelite tubes upon which are wound the primary and secondary coils of the transformer.

In the operation of the vacuum-tube filaments on a. c., it is necessary to use negative biasing on the grids to eliminate a certain type of disturbing hum which would otherwise be produced. The biasing necessary for this purpose, and for the normal biasing required for the audio tubes to prevent distortion, is obtained from the voltage drop across the resistors in the negative leg of the B supply to the filament circuit. The normal biasing voltage for the first and second radio stages and first audio stage is obtained from the voltage drop across the 200-ohm variable resistor in the receiving set on the right-hand side of the first radio tube socket.

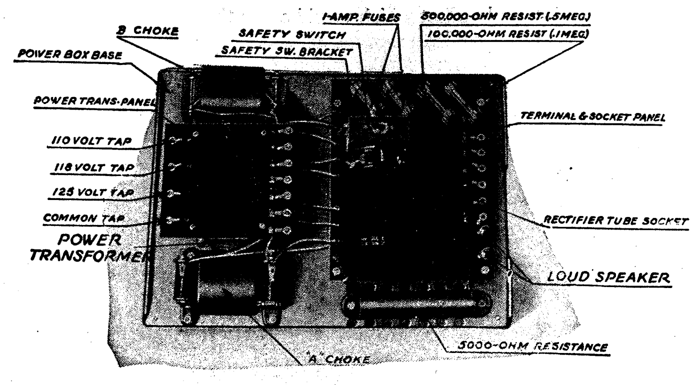
Since the total plate current of all the tubes of the receiver passes through this resistance, and since this resistance is variable, the biasing on these tubes may be controlled by a variation of this resistance. Its chief value is in the control over the total plate current which energizes the detector filament and which control makes it possible to change the natural vibration period of the detector filament. It is found that a small percentage of the 199 detector tubes, even with the use of the best obtainable cushion sockets, will pick up energy from the loud speaker and develop an audio frequency or acoustic howl between the detector and loud speaker. If the loud speaker is resting in its normal position on the top of the receiver cabinet it is possible to eliminate this howl by a small change in the 200-ohm biasing resistance. This will change the filament current in the detector tube, and so alter its natural vibration period that the sound energy fed back will be out of phase with the vibration in it, and thus stop the howl. The detector filament, as before explained, is inserted in the negative B lead and is energized by the total plate current (approximately 60 milliamperes), of all the amplifier tubes in the receiver. Across this detector tube filament is connected a fixed resistor of 1000 ohms which will maintain the B circuit should the detector tube be pulled out while the set is in operation. A sudden interruption of the circuit by the removal of the detector tube will produce a high inductive voltage across the choke coil which would be impressed upon the filter condensers, and might possibly cause their breakdown were the resistance not to be included.

The first and second radio-frequency tube filaments are connected in parallel and have resistances connected in them. The first audio tube also has, in each leg of its filament supply, a variable resistor. These resistors are provided for the purpose of regulating the voltage of the tubes at the desired value below the 7½ volts supplied by the A winding of the transformer for use directly upon the filament of the 210 power tube.

A one-half megohm potentiometer regulates the signal voltage to the first audio tube for volume control, and a one-quarter megohm fixed resistor across the second audio grid circuit adds a slight load, which improves quality.

SELECTIVITY AND DISTORTION

TESTS have proved that there is a definite point in selectivity in the radio-frequency circuit of a receiver beyond which a designer cannot go without materially increasing the distortion introduced. If the selectivity is too high, the side bands which carry the higher audio frequencies of the broadcast signals will be cut down materially, and the reproduction will suffer because of this. The EA receiver has been designed to provide as satisfactory a degree of selectivity as is possible without materially, or seriously, cutting off the higher frequencies by side-band elimination. You will find receivers which are more selective than the EA receiver, but a careful examination of reproduction quality will show that side bands are probably being cut by the more selective receiver, and that the reproduced quality is sacrificed because of it.



THE POWER CONVERSION UNIT

Overall resonance curves for the whole receiver show a band width at one-half the resonant response of about 7 kilocycles at 500 meters and 15 kilocycles at 300 meters.

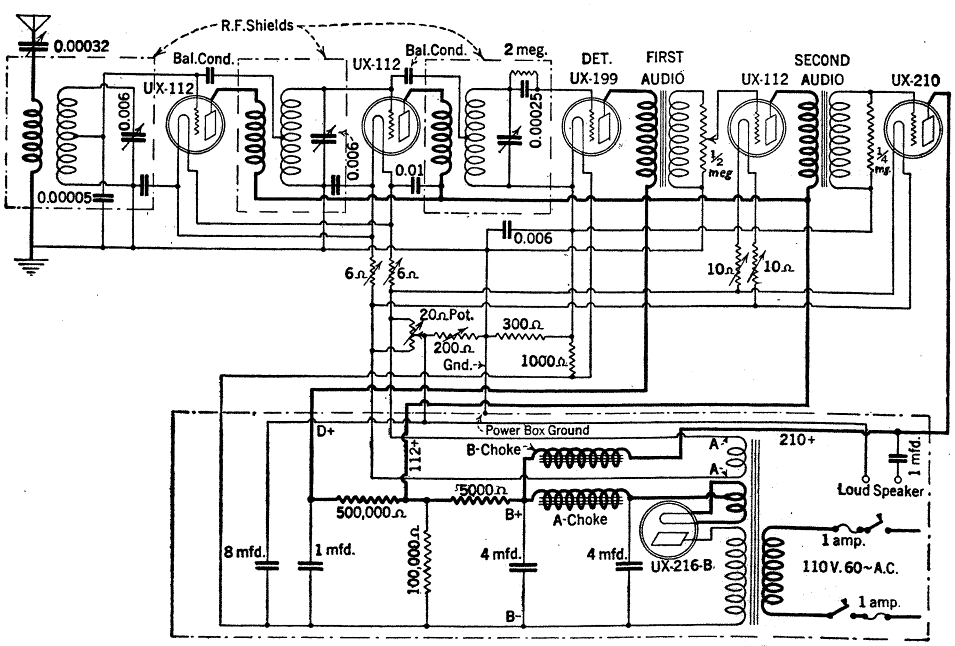
In addition to the inherent design of the radio-frequency circuits which reduces side-band cutting in this receiver, there is provided an audio-frequency amplifying and reproducing system which has been designed with utmost care for the preservation of all the frequencies present in the broadcast music. The transformers are of special construction, with a large amount of iron to prevent saturation, and coils of large dimensions to prevent the loss of high frequencies by capacitive bypass, and with windings of extremely high inductance for the preservation of extremely low tones, which form the foundation of the musical structure.

In addition to these high-quality transformers, another extremely important feature is the use of power tubes for the prevention of overloading and the reproduction of low tones at high volumes.

Even with the best of transformers it is not possible to reproduce the whole audio spectrum as transmitted by our better broadcasting stations with tubes of ordinary size and operating at ordinary plate voltages. The 210 power tube provides an undistorted output energy of approximately 100 times that obtainable with the 201-A tube and for this reason provides an amplifier of correspondingly lower distortion.

The 201-A tube will not reproduce the lower tones, necessary for satisfactory musical reproduction, at the volume levels ordinarily used in the home. A 210 tube will accomplish this result very easily and will, in addition, extend the volume many times without distortion so that practically full tone reproduction is available without distortion.

Another factor of importance in connection with the high tone quality in this receiver is the use of an output coupling device for the loud speaker. The use of a large size choke coil and a condenser as an output coupling is the simplest and best way to eliminate distortion resulting from high plate current in the loud speaker windings. In addition, the use of this coupling removes the high B voltage of the power-tube plate circuit from the loud speaker terminals and entirely prevents any danger of accidental shock from such a cause.



THE CIRCUIT DIAGRAM OF THE RECEIVER DESCRIBED
Adequate protection of the power unit from the mains is provided by the fuses

Transformer-Coupled Audio Amplifiers

A Discussion of a Paper Presented Before the Radio Club of America, April 15, 1926, by A. W. Saunders

D. F. Whiting: I trust that it is not too late for me to offer at this time my discussion of a portion of a paper which was presented before the Radio Club of America at a meeting which I was unable to attend. I refer to the paper entitled "Transformer Coupled Audio Amplifiers" which was presented by Mr. A. W. Saunders last April but which came into my possession only recently with the September issue of the "Proceedings."

So many bugbears to good radio reception have been found to have been caused by improperly designed audio-frequency amplifiers that it is with a feeling such as that which inspired Mr. Samson, which prompts me to oppose criticism of this much abused instrument. While there are many portions of Mr. Saunders' paper with which I do not fully concur, yet I will limit my comments to the latter part of the paper which has to do with resistance-coupled audio-frequency amplifiers.

Let me make it clear that I have no predilection for the indiscriminate use of resistance coupling for all apparatus; neither do I hold any brief for those companies who advertise resistance coupling by illogical reasoning, and other unsavory methods, because they do not manufacture good audio-frequency transformers, but who do have resistances to sell. My interest in this discussion is to the end of scientific truth and engineering fairness, and it may serve to forestall both amateurs and broadcast listeners from modifying their resistance-coupled amplifiers in the hope of improving conditions existing at high frequencies.

Briefly stated, the effects, as described in this section of Mr. Saunders' paper, do not exist in audio-frequency amplifiers when they are used as such. On the contrary, it is essential for the proper functioning of a resistance-coupled amplifier that the time constant of the coupling condenser and grid leak combination be high for all the frequencies intended to be amplified.

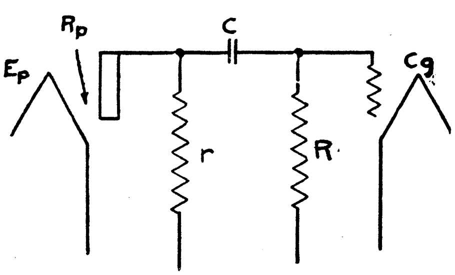


FIG. 1

The effect described in the paper does occur if the apparatus is used as a detector, and it will function if the tubes are overloaded, or if too little negative grid potential is supplied. In these cases, the remedy, obviously, is to apply the proper grid bias and stop overloading the tubes.

When properly designed and operated, an audio frequency amplifier draws no grid current, and a flow of grid current is necessary to produce the effects described in the paper. Since no grid current flows when amplification is taking place, the effect described can not occur.

The only effect which would cause the amplification of the high frequencies to be reduced below the normal amplification in a resistance-coupled amplifier, is the same effect that occurs to a considerably more marked extent in trans-

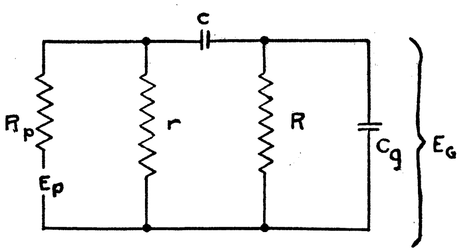


FIG. 2

former-coupled amplifiers. I shall illustrate this effect, just to point out its relatively small magnitude, although the effect is entirely unrelated to the mythical phenomenon described in the paper. Fig. 1 shows the circuit under discussion and Fig. 2 is its electrical equivalent. Let us assume the very worst case, applying to audio-frequency amplifiers of this type, namely successive stages of an amplifier using high mu tubes having an output impedance of 80,000 ohms and having an effective input capacity of about 200 mmfd. Let us assume a circuit of infinite time constant that is R and C both equal to infinity and let r also be infinity to make the conditions the worst possible. The circuit then reduces to that of Fig. 3. Assuming the frequency of 6000 cycles as the maximum useful audio frequency, we have—

$$X_c = \frac{10^{12}}{2\pi \times 6000 \times 200} = 132{,}800 \text{ ohms}$$

Total impedance Z to Ep-

$$Z = \sqrt{R_P^2 + X_2} = \sqrt{80{,}000^2 + 132{,}800^2} = 155{,}000 \text{ ohms}$$

$$\text{and } \frac{E_g}{E_p} = \frac{X_c I}{Z I} = \frac{X_c}{Z} = \frac{132{,}800}{155{,}000} = 0.856$$

which corresponds to 1.3 TU loss.

For two stages this would be 2.6 TU loss, which compares favorably with the curve of Fig. 12 of the paper under discussion, which shows the characteristic of the two-stage transformer-coupled amplifier used in Fada receiving sets, in which the loss at this frequency appears to be 7 TU. For the purpose of showing the maximum possible effect, I have chosen extreme conditions in the above discussion. In the more usual practical cases the effects are of considerably smaller magnitude.

I note that although many curves are shown in the paper to illustrate the effects caused by the use of transformers, similar data which might serve to illustrate the effects described with respect to resistance-coupled amplifiers is prominent owing to its absence. The presumption appears to be that no tests were made to verify the theory as presented.

A. W. Saunders (In answer to Mr. Whiting): I have read with great interest Mr. Whiting's discussion on resistance-coupled audio amplifiers. It has held particular interest for me since I know of no abler eponent of audio amplifier operation than he. Being a practical minded man, laboring without inspiration, and devoid of any ambition to emulate the role of an intellectual giant, I must admit that I should hesitate to disagree on fundamentals with a scientific man of Mr. Whiting's undoubted ability. Happily Mr. Whiting does not disagree with my interpretation of fundamental facts. He has, as a matter of fact, elaborated on a detail of the paper, which I had considered of minor importance, and which, I fear, I failed to explain fully.

This was a fortunate oversight however in that it called forth a discussion which I feel is a valuable addition to the subject.

I fully concur with all of Mr. Whiting's discussion except his original premise. It is true that the paper fails to specifically mention grid current. It does, however, imply that grid current is drawn by the amplifier tube on the high amplitude peaks, which is always the case in practice.

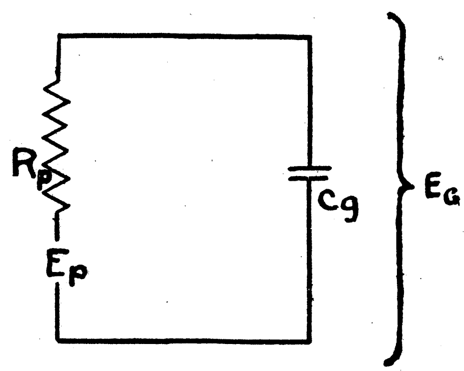


FIG. 3

It is, I believe, common practice (even in the Bell System) to consider an amplifier overload serious only when the change in plate current exceeds ten per cent. of its steady state value. At any rate, this amount of overload in transformer-coupled amplifiers does produce negligible distortion. The same, obviously cannot be said of resistance-coupled amplifiers, since any rectification will cause the action described in the paper.

I must apologize for showing only those curves pertaining to transformer coupling. I trust, however, that this indiscretion is excusable since the subject of the paper was "Transformer-Coupled Audio Amplifiers."

L. G. Pacent

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