PROCEEDINGS

of the

RADIO CLUB OF AMERICA

Volume 3, No. 7 July, 1926

SPECIAL NOTICES

The Club Banquet

Nearly 150 enthusiastic members of the Club were present at the banquet held May 13, 1926, at the Hotel McAlpin. It was a real "old timers" gathering if ever there was one. One of the outstanding features was the presence of many leaders in the industry representing probably all important companies in the field today. It is significant that the amateur spirit never dies within the ranks of the Radio Club of America.

The speaker of the evening was Professor M. I. Pupin of Columbia University who delivered a timely address on the freedom of radio from the standpoint of too much regulation.

Major Edwin H. Armstrong, David Sarnoff, John V. L. Hogan, and Gano Dunn also spoke.

A feature of the program was the presentation of honorary memberships to professor Pupin and Mr. Sarnoff.

The Radio Franks entertained.

Proposing New Members

Are you acquainted with 'right smart' young men who should become members of the Radio Club of America? Remember, the Club is composed of up-and-coming fellows who are all banded together for one purpose—the exchange of views and information on one of the most interesting and fascinating subjects of modern times—radio.

The President of the Club will very much appreciate your sending in one or more names among your radio aquaintance whom you believe to be eligible for the grade of Member or Fellow.

L. C. Pacent
Chairman Committee on Papers
91 Seventh Ave., N. Y. C.

Pierre Boucheron
Chairman Committee on Publications
Room 2040, 233 Broadway, N. Y. C.

Tendencies in Modern Receiver Design

A Paper Delivered Before the Radio Club of America in Which Interesting Data Relative to R. F. Amplification, Audio Amplification, Etc., Are Given—Power From the Electric Light Lines

(Reprinted from "Radio Broadcast," July, 1926)

By JULIUS G. ACEVES

Research Assistant to Prof. M. I. Pupin

If WE look back into the history of radio sets, we will remember that it was not very long ago when the only available matter to be received was radio telegraphy, or "code," which came to us as a rule in the form of short and long musical tones usually of a pitch close to high "C", or about 1000 cycles frequency. To be sure, there were some sixty-cycle operated spark transmitters emitting lower tones, but their harmonics were the sounds that were usually heard in the telephones.

In order to accomplish the reception of "code," a rather simple hook-up was used, but when vacuum tubes came into use, and the regenerative detector became more or less understood, the number of controls increased to such a point that playing on the Wanamaker five-manual organ with its two hundred and twenty-five stops, became easy in comparison with the manipulation of some of the old-time sets for DX work.

With the radiophone started the tremendous development in radio with which we are dealing. The same instruments formerly used for telegraphy were now employed for listening to speech and music, with the same audio-frequency transformers that passed only about two octaves in the scale; yet many radio fans thought that the quality was quite close to the original.

It is our present purpose to review briefly how matters have changed since those days, and what we may expect in the future.

In order to do this in a systematic order, let us follow the developments from various standpoints, namely: technical, acoustical, and operative. Let us study: (a) the radio-frequency amplifier; (b) the detector; (c) the audio-frequency amplifier; (d) the translating device, or loud speaker; and (e) the source of power.

From a technical point of view, after the vacuum tube appeared, the discovery of regeneration by Armstrong was the first landmark in the history of modern radio. As we are supposed to be well acquainted with the mathematics and physics of this phenomenon, we will only touch on the subject lightly here insofar as the quality of reproduction may be affected by regeneration when we deal with this phase of reception. Many investigators found regeneration very readily in radio-frequency amplifiers, but nobody was able to eliminate it from them without also eliminating the amplification, and the next step of importance was the discovery of a means of neutralizing or balancing, the omnipresent regeneration wherever tubes were used, and particularly at high frequencies. Dr. L. A. Hazeltine developed the Neutrodyne, a receiver which has become very popular during the last two or three years on account of its non-radiating properties, and because it is easily tuned.

From these two forms of radio-frequency amplification the regenerative and neutralized forms, numerous combinations soon appeared, the most popular and simple being the Roberts, Browning-Drake, and other similar circuits.

During the War, a great step was taken to do away with the difficulties presented by regeneration in high-frequency amplifiers. As is well known, the cause of regeneration and oscillations in a high-frequency amplifier is the internal coupling in the tubes themselves, even if all the external sources of back coupling are eliminated. This is principally due to the capacity between the grid and the plate, which tends to introduce an effective resistance and an effective reactance in the grid circuit, depending upon the nature of the plate impedance. As a rule, the resistance is negative and therefore if it overcomes the positive effective resistance of the grid circuit, oscillations will immediately be set up. Inasmuch as capacitive couplings are more effective as the frequency becomes higher, it was very difficult to construct amplifiers for frequencies much higher than a few hundred kilocycles. Here we find a very good way of crossing the bridge—by jumping across. If we can't use high-frequency amplifiers, let us not use high-frequencies; rather, let us convert those high frequencies into lower ones that we can handle. The invention of the super-heterodyne by Armstrong was the result.

There are three classes to which most radio sets may belong: (1) The regenerative detector; (2) The neutralized radio-frequency amplifier with or without regeneration; and (3) The double detection or super-heterodyne types, which we shall take up each in its turn.

RADIO-FREQUENCY AMPLIFICATION

IN ORDER to avoid distortion before the detector, it is necessary that the radio-frequency amplification should be equal for all the frequencies within the transmitted band. This band is usually ten kilocycles wide for good articulation and for the highest notes in music, not including their overtones. These latter are, as a matter of fact, inaudible to many people when they exceed five kilocycles, and are rather unimportant for people who can hear them since frequencies above five kilocycles are overtones to high pitches. In many organs, the reed stops, such as the trumpets and oboes, extend to about one octave below the top note, and the last octave is made of flue pipes that have very much weaker overtones than reeds. If, however, the frequency band is reduced to much less than five kilocycles on either side of the carrier, the articulation becomes defective and the voice sounds nasal and the music, dull and drummy. This is precisely what happens when regeneration is pushed beyond a certain limit in order either to reach greater distance or to increase the selectivity. Here the multi-stage tuned amplifier comes in for additional selectivity without sacrificing unduly the side bands. It has been shown that a number of tuned stages in concatenation approach the effect of a band filter which would pass with practically the same amplitude, all the components of the band. The filter which would represent a multi-stage amplifier is represented in Fig. 1. The ideal band filter should not contain resistance elements in any part of the circuit if it must show the characteristics of the filter shown in Fig. 2, namely, a square top; but if the sharpness is not carried too far, a good practical compromise may be reached, and characteristics such as shown in Fig. 3 may be obtained. When regeneration is introduced in an amplifier of this sort, it is possible to vary the shape of the characteristics from curve A, Fig. 3, to curve E, according to the amount of feed-back, so that for distant stations the selectivity and sensitivity may be increased although the reproduction may be somewhat impaired. In multi-stage neutralized amplifiers, the sharpness of the tuning increases with the number of stages up to three or four· beyond this number the selectivity does not increase at the same rate. The filter shown in Fig. 1 exhibits the same characteristics.

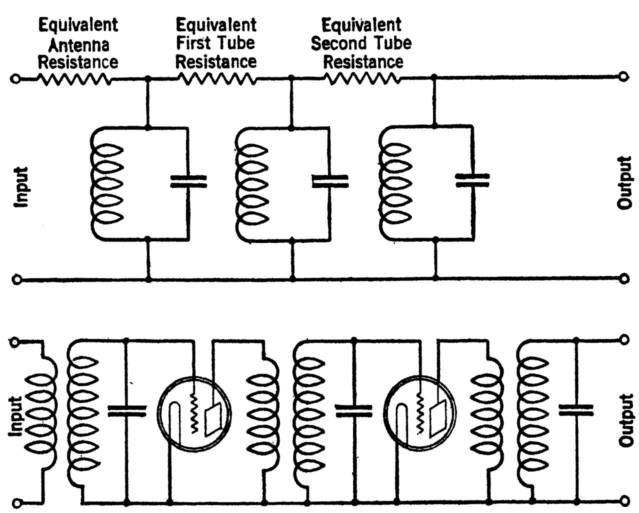

FIG. 1

SUPER-HETERODYNE RECEIVERS

NOW we come to the double detection or super-heterodyne receiver. It has been shown, both mathematically and experimentally, that as a result of the action of the local frequency with the incoming signal wave, the resultant lower frequency wave keeps exactly the same modulating envelope that the original carrier contained, and this is the same as stating that the first detection does not follow the square law, but a linear detection is obtained. Consequently, if the intermediate-frequency amplifier does not discriminate against frequency, the detector would receive a carrier modulated exactly the same as the original but of a lower frequency, and there would have been no inherent distortion introduced by the double detection or frequency conversion system. This holds, of

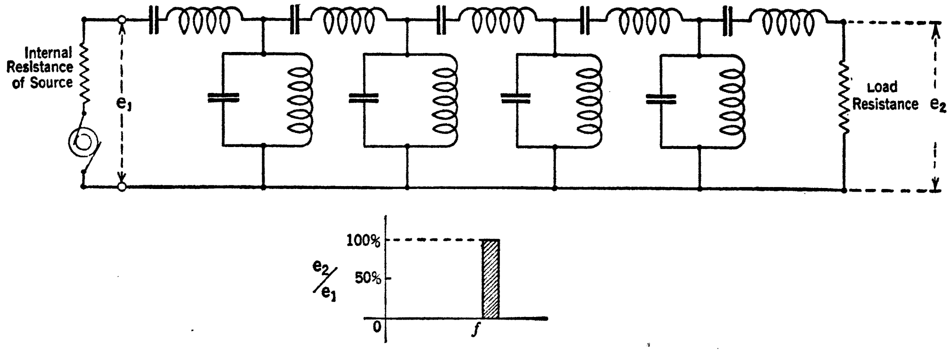

FIG. 2

course, within certain limits of intensity of signal, and local source. It follows that if there is any distortion in a super-heterodyne, it comes from the properties of the intermediate-frequency amplifier and the filters attached to it.

If a band filter, of the type shown in Fig. 2, is introduced between the first detector and the intermediate-frequency amplifier, and the frequency of the local source is so adjusted that the resultant beat frequency band comes exactly over the shaded area, the reproduction would be as good as if no filter were inserted, but the selectivity would be very

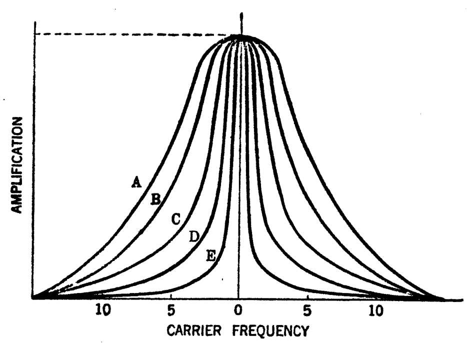

FIG. 3

great, in fact as great as it may be desired by properly constructing the filter. With this system there would be only one other band of frequencies that would pass through, and that is the corresponding band to a station having a frequency greater or less than that to which the receiver is adjusted by double the amount of the intermediate frequency. For that reason, all super-heterodynes have two points in the second dial for every station. As a rule, the undesired band is eliminated by tuning the loop, or input circuit, but this is not anywhere near as effective as the elimination due to the band filter, and for that reason I have suggested the use of a rejector in the input circuit that would short-circuit almost completely the undesired band. This contraption may be in the form of a series coil and condenser

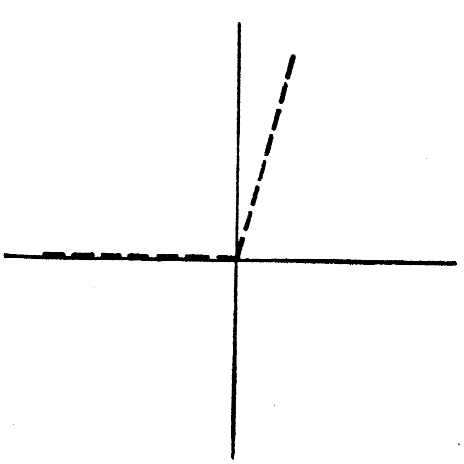
FIG 7

from the grid to the filament of the first detector or inductively coupled to the loop, as shown in Figs. 4 and 5. The same dial that controls the tuning of the loop may be made to control the variable condenser of the rejector, and thereby simplify the operation of the set. It must be borne in mind that the local oscillator should give a pure sine wave. Otherwise some of its harmonics may heterodyne with some other station whose frequency may give beats of the frequency of the band filter, and therefore will not be excluded as they should be.

Having examined the three principal types of radio-frequency amplifiers from a standpoint of good reproduction, let us see how they stand for simplicity of operation.

Unquestionably, the regenerative detector is the simplest receiver to tune if it is properly constructed, and providing a sufficiently long antenna is used so that the coupling between it and the tuned grid circuit may be made as weak as

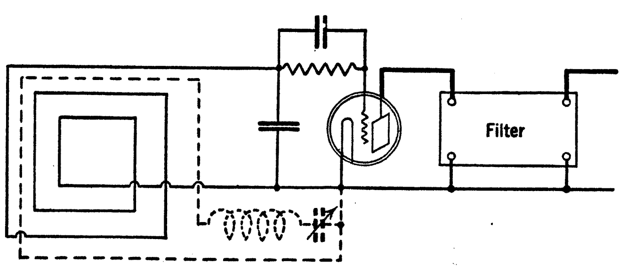

FIG. 5

possible to obtain a fair degree of selectivity with a single tuned circuit.

For local stations only, a very simple set may be made in accordance with Fig. 6, which will have the minimum of control dials, namely, one for selecting the station and another for volume control. If the circuit is in the hands of an intelligent operator, it will never "squeal."

Then comes the type of tuned multi-stage amplifiers in which no attempt is made to neutralize automatically the inherent regeneration. Here we may have a very great amount of distortion if the set is not properly tuned, and also if the regeneration is pushed to the limit. In the hands of inexperienced people, the tuning of several dials, and the control of the so-called "stabilizer", may produce very poor results. To obviate the difficulty, some sets have the "stabilizer" permanently adjusted, and the tuning operations become as simple as when handling a neutrodyne. However, the higher frequencies will be amplified more than the lower ones because the capacitive regeneration of the tubes increases with the frequency.

In order to simplify the tuning, both neutrodynes and tuned radio frequency sets are now being made so that the various tuning condensers may be operated by means of a single dial. If the various parts are made mechanically perfect within a reasonable cost of manufacture, there should be no need of auxiliary dials to correct the deviations, except in the antenna circuit where the reaction of the antenna on the first tuned circuit may be quite appreciable if the optimum coupling is used. A compromise may be reached by slightly sacrificing the sensitivity by reducing the coupling of the antenna to a point where the reaction is hardly appreciable. Also, the condenser that tunes

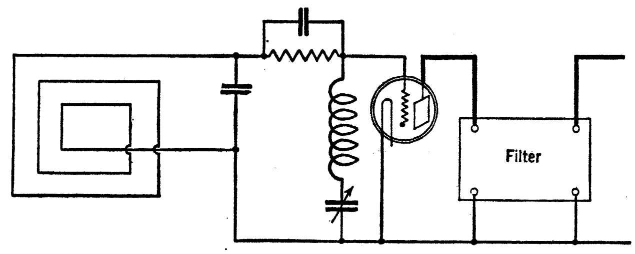

FIG. 4

the first tube and the antenna may be controlled by a separate dial, and the rest of them by a single dial. In order to control the amplification without resorting to dimming of the filaments, a variable inductive coupling from the antenna to the first input tuned circuit may be used, as in Fig. 6, where two coils at right angles are mounted on the shaft of the volume control dial or knob; one of these is connected to the antenna and the other one to a condenser having a capacity equivalent to that of the antenna. In this manner, the reaction of the antenna on the tuned circuit remains almost independent of the position of the volume control knob. The other tuned circuits of the multi-stage amplifier may be provided with coils similar to the first one, with condensers across them, so that an equivalent reaction may be introduced in the other tuned circuits, and all of them controlled from a single dial.

The super-heterodyne type of receiver comes next to the regenerative detector in simplicity of operation. There are only two dials to adjust, and then, if the parts are mechanically accurate and straight line frequency condensers are used, it is possible to control the tuning of

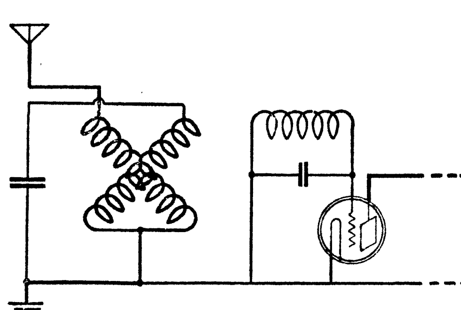
FIG. 6

the loop, or input coil, and the local oscillator by means of a single dial. As we said before, a rejector circuit may also be tuned by the same dial to eliminate the second frequency band, and this would bring us to the ideal receiver from a point of view of simplicity of manipulation and of the greatest distance range and highest degree of selectivity. With a band

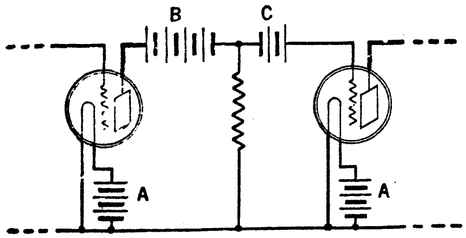

FIG. 8

filter of the type shown in Fig. 2, we would get a modulated carrier wave at the grid of the second detector as near as possible to the original.

DETECTORS

ONE of the elements that is quite often overlooked in a radio receiver is the detector. As a vacuum tube has a non-linear characteristic, it follows that every tube detects to some extent; even the audio-frequency tubes detect to a very small degree. In order, therefore, to make a tube detect, it is necessary to obtain a non-linear relation between the input voltage and the plate current either directly or indirectly. It is done directly when a very strong negative bias is applied to the grid so that the grid-voltage-plate-current characteristic at that point will bend considerably toward the voltage axis. The indirect method consists in utilizing the grid-voltage-grid-current curve which is considerably sharper than the former characteristic. To this end, a small condenser, with a high resistance leak in shunt with it, is interposed in the grid circuit so that when the grid takes current there will be a potential difference across the condenser, and this voltage will act upon the plate current following the grid-voltage-plate-current curve.

This latter method is used to a very much greater extent in radio receivers than the former, and it will not be entirely out of place to say something concerning the values of the bias voltage condenser and leak to be used.

The positive bias makes very little difference as a rule in the efficiency of the detector when strong signals are received, but for very faint

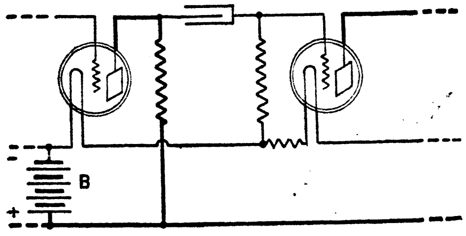

FIG. 9

ones it is best at a value close to the voltage of the A battery. In a recent paper before the I. R. E., a very good discussion on this subject was completely presented, and curves for various types of tubes were shown. Apparently the WD-12 is the most efficient detector with a grid bias of one volt.

The size of the condenser is fixed by the highest audio frequency to be detected, and by the value of the leak. The product RC gives the time constant of discharge of the condenser and leak, and should be smaller than the duration of a cycle for the highest audio frequency. On the other hand, the condenser should be larger than the grid to filament capacity of the tube so that the available signal voltage may not be reduced by the drop across the condenser.

The leak should have as high resistance as possible compatible with the condition above named about the product RC. This holds on the assumption that the tube has no internal leakage, that is, no gas. For strong signals, it may be better to use a lower resistance leak to avoid "blocking," and to flatten somewhat the detecting characteristic so that detected signals may not suffer distortion. An ideal detector should have a curve approaching the line of Fig. 7 so that there may be perfect rectification and linear detection. As much as the detection characteristic will approach this ideal, there will be more efficient detection and less distortion that is, the audio-frequency current will resemble the envelope of the carrier more closely. Crystal detectors are noted for their non-distorting properties, but unfortunately the great majority of them are not uniform and do not stay constant.

Now that we have glanced over the various

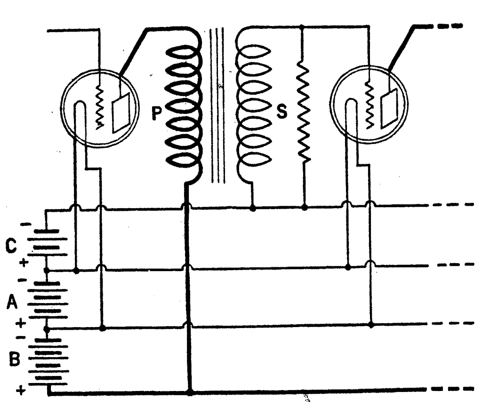

FIG. 10

types of radio-frequency amplifiers, let us examine the audio-frequency circuits.

AUDIO-FREQUENCY AMPLIFIERS

THE ideal audio-frequency amplifier would be made by using a resistance in the plate circuit of each tube and transferring the voltage variations directly to the grid of the following tube, the potential of the grid with respect to the filament being brought to a suitable value by means of a C battery, Fig. 8. This scheme is not practical, and in order to obtain the same results there are two general methods which theoretically should give exactly the same results as the directly coupled resistance amplifier, namely, by means of resistances and condensers, and by transformers.

It is obvious that in the case of resistance and condenser coupling, Fig. 9, if the reactance of the condenser for the lowest frequency is somewhat greater than the resistance of the leak, there would be a constant amplification at all frequencies, and therefore we would have ideal conditions. In the second method, if we had ideal transformers, that is, transformers in which the open cir-

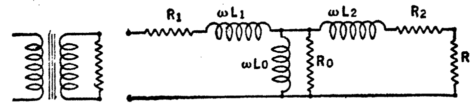

FIG. 11

cuit primary reactance is infinite, the leakage field between primary and secondary zero and the resistance of the windings also zero, and we connect a resistance across the secondary, as in Fig. 10, we would also have equal amplification of all frequencies, just as in the direct coupled resistance circuit of Fig. 8. In practice, the limitations are due to the magnitude of the primary reactance of the transformer, the leakage factor, and the distributed capacity of the windings. The eddy current losses in the iron may be represented by a shunt resistance across either winding, and, for that reason, in many cases it is not necessary to connect a high resistance across the secondary to get the effect of an equivalent resistance only across the primary. There are many excellent transformers on the market that have made their appearance within the last year or so that approach very closely the ideal conditions. They have a primary reactance of over 30,000 ohms at 50 cycles, which is about the lowest frequency transmitted by some of the very best stations, and the internal capacity so low that the upper frequency limit is beyond four kilocycles, which is the highest fundamental tone of the piano scale.

In order to illustrate, or rather to prove, that an ideal transformer used for coupling two tubes is equivalent to a resistance-coupling within a certain predetermined band of frequencies, let us assume that the transformer is of one-to-one ratio; for other ratios, it is only necessary to multiply the constants of the secondary by the square of the ratio of turns. A transformer is equivalent to a network as represented in Fig. 11 where R_1 and ωL_1 represent the copper resistance and the leakage reactance of the primary, R_2 and ωL_2 those of the secondary, R_0 the iron losses, and ωL_0 the open circuit primary reactance. R is the load. If the transformer approaches the ideal, R_1 and R_2 will vanish in comparison with R and also ωL_1 and ωL_2; that is to say there will be no leakage field, ωL_0 being very large in comparison with both R_0 and R in multiple, it may be taken off, and then the circuit will be reduced to a simple resistance.

Comparing the condenser-resistance and the transformer couplings, it will be noted that if the transformers approach the ideal, we may obtain a higher degree of amplification at all frequencies, since the ratio of turns may be made about three to one in practice without departing very much from perfect conditions. It will also be noted that when resistance-condenser coupling is used, a much higher plate battery voltage has to be used in order to bring the plate at rated potential. This has led to the so-called impedance coupling. Impedance coupling is identical with resistance-condenser coupling except for the substitution of the plate resistance by a very high reactance which has relatively low copper resistance, so as to get the full battery voltage

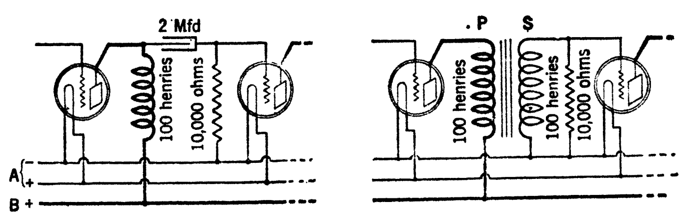

FIG. 12

on the plate. This system has just the same limitations as transformer coupling, and is theoretically equivalent to a one-to-one transformer, as shown in Fig. 12.

The faithfulness of reproduction of the demodulated wave at the detector grid, through the audio-frequency amplifier to the terminals of the loud speaker, may be preserved intact if the following conditions are fulfilled:

1. The amplifier must pass all the frequencies under consideration with an equal degree of amplification.
2. The plate impedances must contain no reactive component.
3. The tubes must be worked within the straight portion of their characteristics even for the loudest signal.
4. The grids must take a very small current if any; so small that the effective conductance at the peak values of that current may be negligible in comparison with the conductance of the plate circuit of the previous tube.

We have examined the requirements to fulfill (1).

It is quite essential to have plate impedances as nearly void of reactance as possible (2) because the dynamic characteristic of a tube with a reactance in the plate is not straight, but has the shape of a hystereis loop, and therefore the plate current variations are not proportional to the grid voltage changes.

Tubes are worked beyond the straight portions of their characteristics in many radio sets in order to obtain sufficient volume, and this is particularly true of the last tube, when insufficient plate voltages are used, and also when tubes of low power output are used in the last stage. For a moderate amount of volume, tubes such as the UX-171 with some 180 volts, should be selected, and for a volume approaching the original in the broadcasting room, a tube of five or more watts should be used with over 300 volts on the plate. In case a plate voltage sufficiently high is not available, for instance, when a set is operated from the 110 volt d. c. lines, an increase in volume may be obtained by the use of an extra tube and working the last stage in the positive part of the characteristic, provided that condition (4) may be fulfilled. The extra tube is not meant for additional voltage amplification, but simply to supply sufficient power to the grid of the last tube so that the grid may take an appreciable current, yet without lowering the voltage impressed upon it. Fig. 12 shows how this may be accomplished with impedance-capacity coupling, and with transformer and resistance coupling.

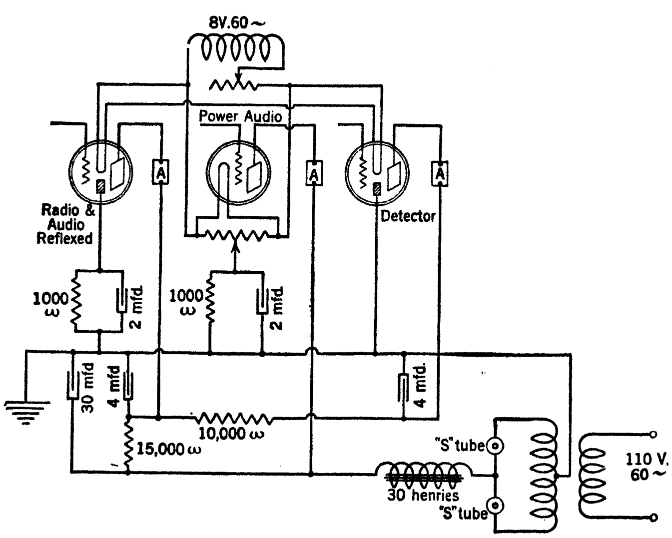

FIG. 13

Having preserved the wave shape of the modulated carrier from the broadcasting station and then detected and faithfully amplified to the terminals of the loud speaker, it is only necessary to avail ourselves of the best instrument on the market in order to complete the last link in the chain. As a number of very good papers on loud speakers have been read in the recent past, I shall not attempt to repeat their contents, and I will only make a few remarks on my personal experience with various types of speakers.

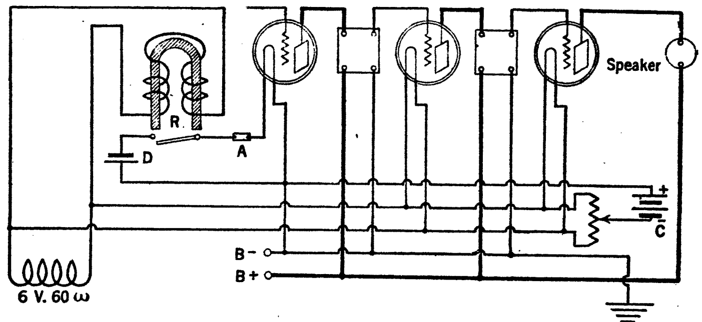

FIG. 14

TRANSLATING DEVICE OR LOUD SPEAKER

APPARENTLY there is no speaker on the market which can reproduce equally well all frequencies from 25 to 8000 cycles. Some very good types approach a linear and horizontal curve from 150 to 3000 cycles and can deliver a tremendous amount of tone, as, for example, the Hewlett and the Rice-Kellogg types. With large cones, very much lower frequencies may be reached. In 1923, I used a very large horn with an exponential curvature of expansion, approximately 19 inches in diameter at the opening and 71 inches long, with a very large diaphragm unit at the base. It has been working ever since quite well at the end of a three-stage resistance-condenser amplifier, with Western Electric high-mu tubes and a five-watt tube in the last stage (besides the last tube), using 400 volts B battery voltage, the latter being obtained from the 60-cycle 110-volt line, by means of S tubes. This horn gives a fairly uniform frequency reproduction from 120 cycles to about 1200 cycles, and then becomes weak very gradually, and for this reason I supplemented the deficiency by a short horn, with a condenser in series so that it would not rob the large horn of the lower tones. In order to obtain tones lower than 125 cycles, a cone was added, and the three of them together give a quality of reproduction that has received very favorable comments from all those who have heard them. The Western Electric cone seems to be at the present time the best all around reproducer of moderate price, and with a well made audio-frequency amplifier, all the harshness and rattle that it usually gives with carelessly designed sets disappears, and considerable volume almost approaching that of the Rice-Kellogg speaker may be obtained. This cone covers very well the two extremes of the musical scale for the average listener.

SOURCE OF POWER

NOW we come to another department of the radio receiver that has received considerable attention during the last few years, and that is the utilization of power from the electric light lines.

Power is delivered to consumers at a potential of 110-125 volts direct current, or 60 cycle alternating current. In some isolated cases 220 volts are furnished for lighting purposes, and also some lower or higher frequencies are found occasionally. On farms, a 32-volt equipment is often found. As the most common form of energy supply is the alternating current 60-cycle 110-volt lines, we will confine our discussion to this condition.

The first use of power for the operation of radio sets was to charge a storage battery by means of vibrating or tube rectifiers, there being no method of charging the B and C batteries. Later we find storage B batteries charged by means of tube rectifiers. Although the electrolitic rectifier was discovered by Doctor Pupin in 1895, it was not until recent years that it has been used for the purpose of charging radio batteries. Very good examples of chemical rectifiers are found in the market, and some of them are associated with storage cells of low capacity which they charge at a very low rate for considerable periods of time, or continuously. Alternating current has been used to energize the filament of transmitting tubes even in the days of radio telegraphy, but few have used it for radio telephone reception with any degree of success. As early as 1921, the author made a complete super-heterodyne receiver with all the tubes lighted by alternating current, and B and C potentials were derived also from the rectified current by the use of S tubes. To be sure, that particular receiver was not intended to cover thousands of miles, but on all local and moderate distance work it accomplished its purpose without objectionable hum. It must be said that the transformers used were of such type as would hardly pass frequencies below 200. Alternating current may be used to light the two last tubes of a receiver without an audible hum one or two feet away from a cone speaker provided that the following conditions are fulfilled: (1) The C voltage must be such that the grids never become positive with respect to any point in the filament unless the conductance of the circuit attached to the grid is large and takes a current many times greater than that which the grid may take at the peak values; (2) The middle point of the filaments must be at ground a. c. potential at all times; (3) The construction of the tube, with respect to the plate must be symmetrical with regard to the two ends of the filament; this is fairly well fulfilled in most of our commercial tubes; (4) The plate impedance must be non-reactive and large as compared with the internal plate resistance of the tube; in other words, the dynamic plate-current-grid-voltage characteristic must be straight within the portion used; (5) There shall be no inductive effects between the filament leads and the grids of the detector and audio-frequency amplifiers. From the first condition it follows that the detector cannot be lighted by alternating current except when moderately strong signals are available, and when the detection is accomplished by the curvature of the plate current characteristic at the negative end, and no condenser and leak device is attached to the grid.

ALTERNATING CURRENT TUBES

IN ORDER to solve the difficulty, and at the same time obtain a tube with very high amplification properties, Doctor Hull, of Schenectady, discovered a uni-potential cathode keno-pliotron which contains a separate heating element lighted by any current you please, and the cathode is at the same potential all over its surface. The McCullough tubes are built on this principle, and I had exceptionally good results with a pair of such tubes in a three-tube Roberts reflex set operated from a 60-cycle supply, using a power tube for the last audio stage with high plate voltage, as shown in Fig. 13. Unfortunately those tubes are not made with any degree of uniformity, and although their life should be theoretically much longer than thoriated tubes, it may be only one month, after which the emission has been reduced to a useless value, or the heater may burn out in a few weeks. If the McCullough tubes were properly made, they would unquestionably be the tubes of the future, and radio sets would be designed for them on account not only of the complete elimination of the A battery, but for their inherent high amplification with low plate resistance properties.

Another solution to the A battery elimination problem consists in using the same source of rectified current that furnishes the plate potential for the purpose of lighting the filaments. At present, with the 60-milliampere tubes connected in series, the problem is considerably simplified, since the size of filtering inductances may be materially reduced. Care must be taken to shunt every filament, or possibly every pair of tubes, with a certain resistance so proportioned that the plate currents from the following tubes that have to find their way through the series filaments will not increase the filament current of the tubes nearer to the negative pole of the d. c. source. Sets using $\frac{1}{4}$-ampere filament current, and operated by rectified a. c., are in existence. I constructed one that is still in operation at a club house after three years of continuous use. This receiver is a neutrodyne with 201-A tubes in series and a rectifier and filter unit containing S tubes and electrolytic condensers.

There are also hybrid sets in which a single dry cell is retained to energize the filament of the detector tube and the two audio-frequency tubes lighted by 60-cycle a. c. A relay, R, operated from either the B voltage supply, or from a. c., closes the circuit of the dry cell, D, through an "Amperite" A, and the filament of a WD-12 detector tube, Fig. 14.

The solution of the B voltage problem is very well known in principle, and the accompanying filters have been described in many publications. It should be emphasized that a B battery source costs a little more when made to supply over 300 volts than for less than 100 volts, and the resultant advantages of the high plate voltage in the last tube have been pointed out before in our discussion of faithfulness of reproduction. The resistances required to lower the plate voltage for

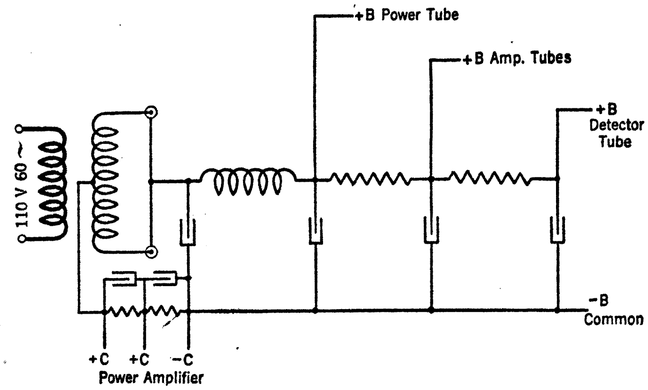

FIG. 15

the other tubes besides the last, and for the detector, fulfill a double rôle, that of voltage reducers and also filter impedances, as shown in Fig. 15. C battery voltage may be obtained from the same equipment as indicated.

[*Editor's Note:* With the new RCA UX-171 output tube, considerable undistorted power, without the use of high voltages, may be delivered to the loud speaker.]

In connection with some of these sources of rectified a. c., both for plate and for plate and filament power supply, an interesting phenomenon was observed during the early experiments that I conducted along these lines. A neutrodyne with tubes connected in series was supplied from a power unit similar to the one depicted in Fig. 15, using S tubes, two Mershon condensers, and a 25-henry RCA filter coil. By connecting a pair of head telephones with a condenser in series across the d. c. end, there was no sound to be heard, as was expected. Then the unit was made to supply the set, and a loud speaker attached to it, and still no sound or hum came forth from it; but as soon as the three dials of the neutrodyne were tuned to any particular frequency (the same for the three of them), a tremendous roar came from the speaker. This roar was aggravated if the carrier wave happened to be there and the set tuned to it. No amount of filtering would mitigate the racket and, if a separate ground was used for the set and the negative terminal of the power unit, the noise was somewhat diminished. Then, an apparently foolish thing was done; a tuned circuit, consisting of a coil and a condenser in series with it, were inserted in the ground lead that connected the neutrodyne to the radiator and when this contraption was tuned to the same wavelength as the neutrodyne, the roar disappeared just as if the power had been shut off. The case was undoubtedly one of shock excitation, and was proven to be such by operating the set from batteries and then running the power unit without any connection to the set. There was a faint sound like a saw mill the moment the a. c. switch was turned on, but the minute that any lead, even the negative terminal of the power unit, was touched to the negative terminal of the filament battery, the roar started almost as viciously as when the neutrodyne was operated by the power unit.

The rectifying tubes, when they allow the current to start with a rush, as in the case of the S tubes that I had, are equivalent to a rotating spark gap, or to a vibrating contact interrupter, in their production of severe interference with a radio set.

Another source of power for the operation of the filaments and plate current which has been used very little in receiving sets, yet is commonplace in transmitters, is the motor generator.

MOTOR GENERATORS FOR OPERATING RECEIVERS

AS EARLY as 1917 I successfully operated multitube sets by means of motor generators using various types of filters, and with the filaments in series, mainly with the idea of securing an absolute constancy of voltage and current, such as given by a synchronous motor generator set. Here we have many interesting effects produced by grounding or not grounding certain leads, even with perfect filtration of the commutator ripple and with a generator without visible sparking, but it would be rather long and involved to delve into this matter here.

Just let it be said that a well insulated d. c generator of a very small capacity, with field coils wound in series and with a large condenser across the brushes and another one across the output lead, as shown in Fig. 16, can operate very successfully a Freed-Eisemann receiver without noticeable noise.

When it is desired to energize a set that contains a semi-power tube from a source of direct current, it is not necessary to filter the current that lights the last tube, and a corresponding saving in the size of filter inductances may be effected by letting through them only the filament current of the other tubes connected in series. As a rule, one inductance of more than one henry is enough to filter out the commutation from an average radio set, except where motors with unbalanced armatures happen to be running in the vicinity of the set, which introduce tones of very low frequencies hard to eliminate with a single choke. The resistances that reduce the voltage for the operation of other tubes than the last, when large storage condensers are used, are sufficient to filter the B voltage supply.

A very useful device has appeared lately for the purpose of preventing the B voltage from rising to a dangerous value should any of the tubes go out. It consists of a tube of gaseous content that glows at about 90 volts, and which has the property of maintaining a constant current from a supply unit irrespective of the number of tubes or of the amount of emission in them. It is used in some power units made by the Radio Corporation of America.

As a result of our investigations we find that there is a very strong tendency toward the attainment of a reproduction as faithful as possible to the original, both in quality and volume. Then there is the tendency to simplify the tuning operations compatible with the required degree of selectivity, especially in the congested areas. And, thirdly, the elimination of adjustments and care and attention to the sources of energy to operate the set, using the available forms of power as supplied by the utility companies has received considerable attention. There is also a tendency to dispense with outdoor antennas in congested sections.