The Neutrodyne Receiver

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Reprinted from
STEVENS INDICATOR
July 15, 1923

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IT is the purpose of this article to describe in an elementary way, not merely the neutrodyne principle, but rather the complete radio receiver in which this principle has found its most useful application. We will therefore first briefly review the different processes which are combined in a radio receiver and which are essential to proper reception of radio broadcasting.

To start with, we must consider the character of the electric power which is put into the transmitting antenna, is thence radiated into space, and is in part picked up by the receiving antennas. At the transmitting station there is an electric oscillator which consists of vacuum tubes and associated circuits and which serves to convert direct-current power into alternating-current power having a frequency of the order of one million cycles per second. When the oscillator is connected to the antenna but music or speech is not being transmitted, the current supplied to the antenna is perfectly steady and regular, just like the alternating current which is used to light an incandescent lamp or to run a motor, except for its much higher frequency. When transmission begins, however, this alternating current is *modulated*, which means that its magnitude is varied in accordance with the wave form of the music or voice. Such a modulated alternating current is represented in the lower curve of Fig. 1, which includes for comparison the modulated direct current existing in the ordinary telephone transmitter and the pure voice current existing in a long

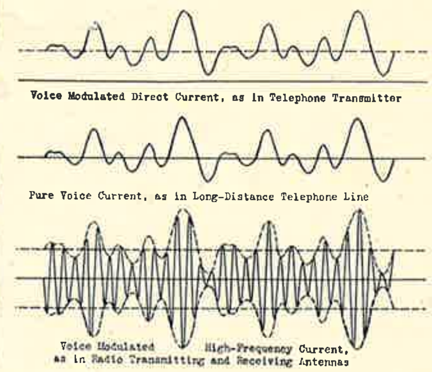

Fig. 1

distance telephone line. It will be seen that the envelope of the high-frequency current curve has the form of the actual current curves above; and it is this envelope which follows the variations of air pressure impressed on the telephone transmitter, say by the voice. (It is not possible to show the respective frequencies to scale; there are actually hundreds of cycles of the high-frequency current in the lobe of the envelope.)

The use of a high-frequency alternating current for radio transmission (instead of the direct current ordinarily used for wire telephony and telegraphy) is not only necessary for efficient radiation but has the added advantage of permitting selection at the receiver. Wire communication provides separate circuits for each conversation, but all radio transmission is through the same space, except in so far as a radiated wave becomes too weak to affect a receiver at a great distance from the source. The only generally available means for selecting the radio wave of a desired station from the waves of the many other stations that may be simultaneously transmitting is by arranging for all stations that might interfere to operate with different frequencies. The receivers are then designed to be selective with respect to frequency. Such selectivity is accomplished by the employment of capacities and self-inductances which are so adjusted that the negative capacity reactance and the positive inductive reactance of a circuit cancel one another out at the frequency of the desired signal, but not at other frequencies; this process is called *tuning*. Selectivity may be increased, or the tuning made "sharper," in two ways: (1) by making the resistances of the coils and condensers low relative to their individual reactances; and (2) by employing several successive tuned circuits. The former method is particularly efficacious in selecting between frequencies very close together, but if carried too far results in distortion, as will be described when regeneration is taken up below. The use of many successive tuned circuits is limited only by the complication and the inconvenience of adjustment; two tuned circuits are very common and may be arranged as in Fig. 2, where the antenna circuit and the secondary circuit are each tuned by a variable condenser and are coupled by the mutual inductance between the coils.

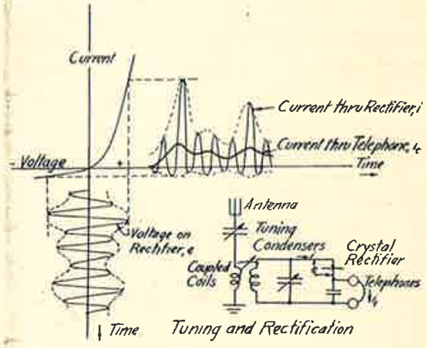

Fig. 2

The currents and voltages produced in a receiving circuit are of the same form as the current in the transmitting antenna and are not suited to actuate the ordinary telephone receiver, which requires a current of the form of either the upper or middle curve of Fig. 1. The process by which a modulated high-frequency current or voltage is converted into modulated direct current is called *rectification* and is illustrated in Fig. 2. Here the modulated high-frequency voltage e delivered from the tuning apparatus is impressed on a "crystal rectifier" which has the property of permitting current (or changes in current) to flow more readily in one direction than in the other, as represented by the characteristic curve at the upper left of the figure. This modulated voltage is plotted along a vertical time axis below the characteristic curve, and the resulting current, as determined from the characteristic curve, is plotted at the right. The successive cycles of this current curve have a mean height which varies similarly to the envelope of the voltage curve and therefore to the voice modulation at the transmitter; this means height curve represents the current which flows through the telephone receiver, which therefore reproduces the voice.

In addition to the process of tuning and rectification, a third process, *amplification*, is necessary except when the transmitting station is very powerful or very near-by. Amplification consists in using the incoming power to control a local source (ordinarily a battery) so that this gives out power which is much greater in magnitude but of the same character as that received. This control is accomplished by the three-electrode vacuum tube, which is now-a-days so familiar. The step of amplification may be applied prior to rectification, in which case it is "radio-frequency amplification," Fig. 3, or it may be applied subsequent to rectification in which case it is "audio-frequency amplification," Fig. 4. In both cases the power to be amplified is supplied to the grid-filament circuit and causes a variation in the voltage e_g between the grid and the filament, as represented by the lower curve. This variation in grid voltage, or "potential" causes a corresponding variation in the current i_p of the plate-filament circuit, in accordance with the characteristic curve, and as represented by the current-time curve at the right. The variation in plate current in flowing through the resistance of its path is accompanied by a voltage variation of the same form, so that the power produced is of the same character as that received in the grid circuit, but of much greater magnitude, its source being wholly the battery in the plate circuit. The action is essentially that of a relay, the grid being the control element. Almost any degree of amplification may be attained by the use of successive stages.

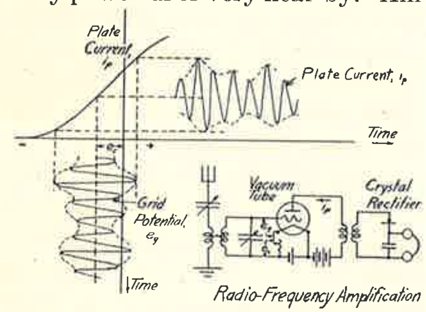

Fig. 3

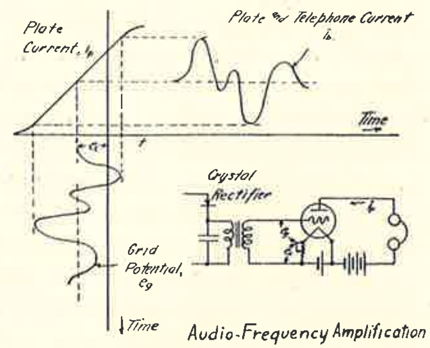

Fig. 4

A three-electrode vacuum tube is commonly employed, instead of a crystal, as a rectifier (or "detector"), in which case it combines the functions of amplification and rectification.

Another process which is sometimes employed in radio telephone reception is *regeneration*, which consists in employing a portion of the radio-frequency power in the output (plate) circuit of a vacuum tube to assist the current in the input (grid) circuit, and which is accomplished by coupling these two circuits in a suitable manner and under appropriate circuit · conditions. Sometimes the grid and plate circuits are inductively coupled by the use of a "tickler" coil in the plate circuit, but frequently the inherent capacity between the grid and the plate of the tube is relied on. In the latter case it is necessary that the plate circuit act like a high inductance, and this is accomplished by "plate-circuit tuning", which consists in bringing the plate circuit almost into resonance by adjusting either its self inductance ("variometer method") or a capacity in parallel with a fixed self-inductance. If regeneration is carried beyond a certain point, the vacuum tube will ocillate of its own accord, at the frequency for which it is tuned. If a signal (that is music or the voice) is being received, the local oscillation will interfere with the signal oscillation to produce beats having a frequency which is equal to the difference between the frequencies of hte two oscillations; if this beat frequency is within the audible range, the result will be a whistling note in the telephone receiver, whose pitch varies with any change in adjustment. This not only destroys the music or voice to be received, but it also causes the receiver to act as a transmitter—relatively weak it is true, but strong enough to cause serious interference to other listeners in the neighborhood. With very careful tuning, the local oscillation may be adjusted to exactly the same frequency as the signal oscillation. The music or speech will then be received clearly and relatively loud, as the presence of the local oscillation improves the rectifying property of the detector; this is the "synchronous heterodyne" or "zero-beat" method of reception.

While regeneration may bring in louder signals, all forms which have so far been made public are accompanied by serious disadvantages in radio telephone reception. It results in "beat notes" and "squeals" when out of adjustment, which are re-radiated and (except in the regenerative neutrodyne) cause interference to others as well as to the operator. It causes distortion when adjusted for the loudest signals, for the reason that it acts to introduce negative resistance and makes the circuit so highly selective as to discriminate against components of the received wave which are due to high-pitch components of the music or voice. It causes the various adjustments of the receiver to be interdependent; for if the filament current or plate voltage is changed, the regeneration control must be readjusted and this in turn changes the tuning adjustment. Further, the adjustments are very critical, especially for zero-beat operation which gives the loudest signal. These disadvantages seem to the writer to be so great as to make regeneration generally undesirable in radio broadcast reception.

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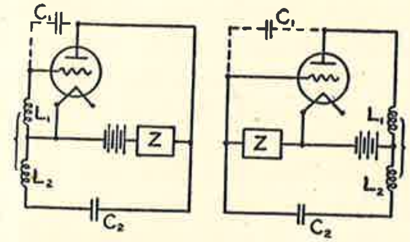
Now with the elementary processes of radio telephone reception in mind, let us consider how they can best be combined, say to operate a loud speaker for radio broadcast reception under moderately severe conditions as to strength of signal and presence of interference. These conditions all require the use of vacuum tubes for amplification and it will therefore be convenient also to use a vacuum tube for rectification. A vacuum tube when rectifying is not operating under the best advantage with respect to its audio-frequency output, and one stage of audio-frequency amplification is therefore necessary to supply sufficient power to a loud speaker. On account of the fact that with weak signals the output audio-frequency current of a rectifier varies as the square of the input radio-frequency voltage, radio-frequency amplification for weak signals is far more effective than audio-frequency amplification, provided that the radio-frequency amplifier has a suitable output circuit. This proviso requires that the radio-frequency amplifier be *tuned*, for an untuned radio-frequency amplifier cannot be designed to give high amplification over the broadcast range of frequencies, 550 000 cycles per sec. (545 meters) to 1 350 000 cycles per sec. (222 meters). As the input circuit will also be tuned, there will be at least two tuned circuits, which is sufficient for selectivity. Thus the ideal receiver has one or more stages of tuned radio-frequency amplification, a rectifier, and one stage of audio-frequency amplification.

Now a tuned radio-frequency amplifier is naturally regenerative since it has tuned grid and plate circuits and inherent capacity between the grid and the plate. In fact, if efficiently designed, it will be so regenerative as to persistently oscillate. Thus without means to eliminate this difficulty, we would be unable to employ what otherwise



Neutralization of Capacity Coupling in Triode Vacuum Tubes

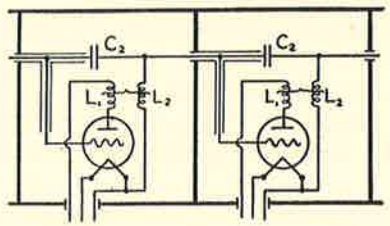
(a) *Fig. 5* (b)

would be the most attractive circuit. *It is the primary function of the writer's neutrodyne system, as applied to radio receivers, to neutralize the capacity coupling between the grid and the plate circuits so as to make tuned radio-frequency amplification feasible and fully effective.*

Two ways of employing the neutrodyne principle* are illustrated in Fig. 5. In each circuit C_1 represents the inherent coupling capacity between the grid and the plate, C_2 the neutralizing capacity, L_1 and L_2 two coupled coils, and Z any impedance, as one coil of a transformer. In Fig. 5a suppose the potential of the plate to be varying; then a current will flow through C_1 and L_1

*A quantitative discussion of the neutrodyne principle, together with other applications was given in a paper recently presented by the writer before the Radio Club of America and published in "Q S T" for April, 1923.

to the filament, and a second current will flow through C_2 and L_2; with proper adjustments the self-inductive effect of the first current in L_1 will be neutralized by the mutually inductive effect of the second current acting from L_2 to L_1, so that no voltage will exist across L_1—that is, a variation in the potential of the plate does not cause a variation in the potential of the grid. Again, in Fig. 5b, suppose the potential of the plate to vary, then a current will flow through C_1 and L_1, and a second current will thereby be induced in L_2 and will flow through C_2; with proper adjustments these currents will be equal and in such relative directions that no current will flow through Z, so that no voltage will be built up in Z—that is, as before, a variation in the potential of the plate does not cause a variation in the potention of the grid. In both cases then, there

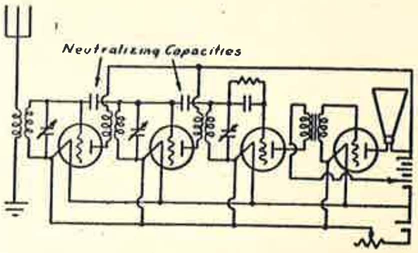


Multistage Amplifier with Capacity Coupling Neutralization

Fig. 6

is no regeneration and the grid and plate circuits behave as if they were not coupled, except by the mutually conductive coupling of the vacuum tube which gives the amplification.

The coils L_1 and L_2 of Fig. 5 may be coils already present for other purposes, as indicated in Fig. 6, which shows the arrangement of Fig. 5b applied to a multistage amplifier. In this figure the various stages are isolated as far as possible by enclosing them in separate metal compartments, even going so far as enclosing some of the leads in metal



Non-Regenerative Neutrodyne Receiver with One Stage Audio-Frequency Amplifier

Fig. 7

tubes. This shields the stages from one another completely except for the capacity between the grid and the plate proper of each vacuum tube which capacity is all that remains to be neutralized by the adjustable capacity C_2. Such shielding is not needed for one or two stages of radio-frequency amplification, but is essential when three or more stages are to be employed.

Fig. 7 shows connections for two stages of radio-frequency amplification, a rectifier, and one stage of audio-frequency amplification. This circuit with 16-turn primary coils on 2.75 inch tubes, 65-turn secondary coils on 3-inch tubes, and 0.0003-microfarad variable condensers is suitable for vacuum tubes similar in characteristics to the old UV-201 and 200, such as the WD-11 and 12 and the UV-199. The coils are wound in the same direction with the polarities indicated; No. 24 double-cotton-covered wire is suitable and should be closely wound, the primary coil being near the filament

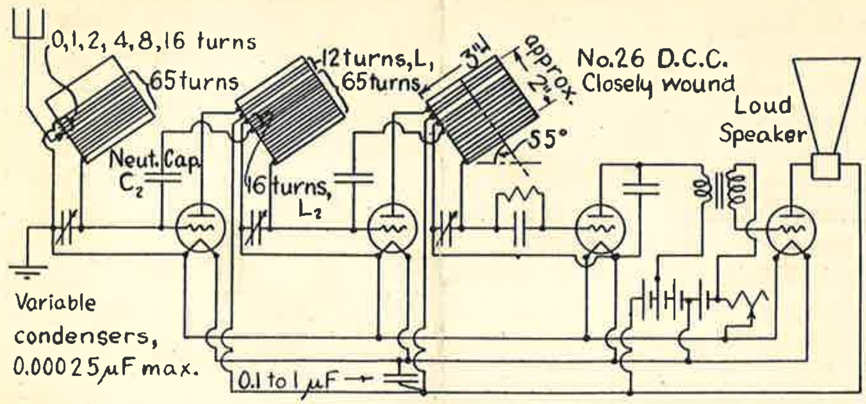


Fig. 8

end of the secondary. The transformers must be so mounted as to avoid magnetic coupling.

Fig. 8 is a modification of Fig. 7, with certain refinements and with values suited to UV-201-A or Western Electric 216-A vacuum tubes. The taps on the antenna coil are for the purpose of controlling the intensity of the signal. The radio-frequency transformers are represented as mounted with parallel axes at such an angle as to have zero magnetic couplings. Both coils of each interstage transformer are wound in the same direction on the same insulating tube, and must be connected as indicated. In arranging the set liberal spacing is desirable and all accidental coupling between stages must be carefully avoided; for example, the antenna lead-in must be kept away from the last stage. The large capacity at the bottom acts to short circuit the reactance of the leads to the plate battery, which would otherwise couple the stages.

The neutralizing capacities for either Fig. 7 or 8 are commonly made of a stiff wire and metal tube, separated by a spaghetti insulating sleeve. The overlap is adjusted by trial and may be about ¼ inch. To make the adjustment the filament is left cold in one of the amplifier tubes (by putting a piece of paper under one of the prongs) and a strong signal is tuned in; the neutralizing capacity connected around that tube is then adjusted until the signal disappears. The process is then repeated for the other tube. With proper adjustments no sign of regeneration should be evident at any frequenty setting.

The writer wishes to acknowledge his indebtedness to Mr. W. H. Taylor, Jr., (Stevens '16) for coining the word *neutrodyne* (signifying the neutralizing of a force, regeneration), and to Mr. Harold A. Wheeler for the method of adjustment of the neutralizing capacities and for other development work.

[The Stevens Indicator wishes to express its appreciation to Mr. K. B. Warner of the Radio Relay League of America and of "Q.S.T." and also to Mr. W .S. Lemmon of the Radio Club of America for the use of the diagrams known as Figures 5, 6 and 7 in Professor Hazeltine's article.—Ed.]