Radio Frequency Amplifiers

And How to Make Them

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Radio Frequency Amplifiers and How to Make Them

CHAPTER I

TO the average radio experimenter the term "amplifier" means two or more vacuum tubes in cascade after the detector. With this detector arrangement the incoming signals of radio frequency are detected (or rectified) to make the signals audible in a telephone receiver, amplifier, or other audio frequency device. (By the term audio frequency we mean frequencies that are within range of the human ear.) The purpose of the audio frequency amplifier is to amplify the unidirectional impulses obtained from the detector. See Fig. 1.

The disadvantages of audio frequency amplification, however, are pronounced. If the amplifier is correctly designed and operated with the best low frequency transformers available, and the tubes are used in the most efficient circuits, more than two stages of amplification are undesirable, because an efficient amplifier of this type will make readable only signals which the most sensitive detector will rectify. Signals which are so feeble that they will not operate the detector can not be amplified by low frequency amplification, regardless of the number of tubes used. Another great disadvantage of low frequency amplification is that noises from mechanical and electrical sources are greatly amplified in the telephones, due to the audible period of the circuits, thereby giving much interference with otherwise readable signals. The more common sources of noise due to mechanical causes are mechanical vibration of the tube elements caused by vibration of the table, noises about the operating room, etc. This may be shown by gently tapping the first tube of an amplifier with the finger. Electrical noises are the most numerous and include eratic electron emission from the filament, due to unhomogeneity of the filament, filament and plate battery noises, poor grid leaks, etc. Low frequency regenerative action producing what is commonly known as "howling" or "singing", is one of the greatest drawbacks to low frequency amplification of two or more stages.

Having briefly outlined the limitations of low frequency amplification, we are now able to appreciate the effectiveness of radio or high frequency amplification. As we are mainly interested in bringing in distant signals of low power, and making them readable, and as the low frequency amplifier is useful only in that it makes weak rectified impulses readable, the obvious thing to do is to apply the incoming signals to an amplifier **before** detecting them, in order that extremely weak currents may be strengthened sufficiently to operate the detector. In other words, we are amplifying incoming or **radio frequencies.**

Advantages of High Frequency Amplification

The effectiveness of high frequency amplification is made further apparent when vacuum tube detectors are used, as the sensitiveness of these devices is proportional to the square of the voltage applied to them. In other words, if the incoming signal is amplified to double its normal voltage, the strength of signal in the plate circuit of the detector tube will be four times as great as before.

Another advantage of high frequency amplification is that "howling" is less troublesome. As has been shown, howling in a low frequency amplifier is due to regenerative or feed-back action of the audible frequency circuits. As the circuits of high frequency amplifiers are not of an audible period, it is easily seen that while regenerative action is possible, and in fact occurs quite frequently, it usually does so at frequencies above audibility and hence is not apparent. Due also to the fact that the circuits are tuned to an inaudible period, ordinary mechanical and electrical noises while present are not amplified. The elimination of audio frequency howling and of tube noises is of the greatest importance as it makes

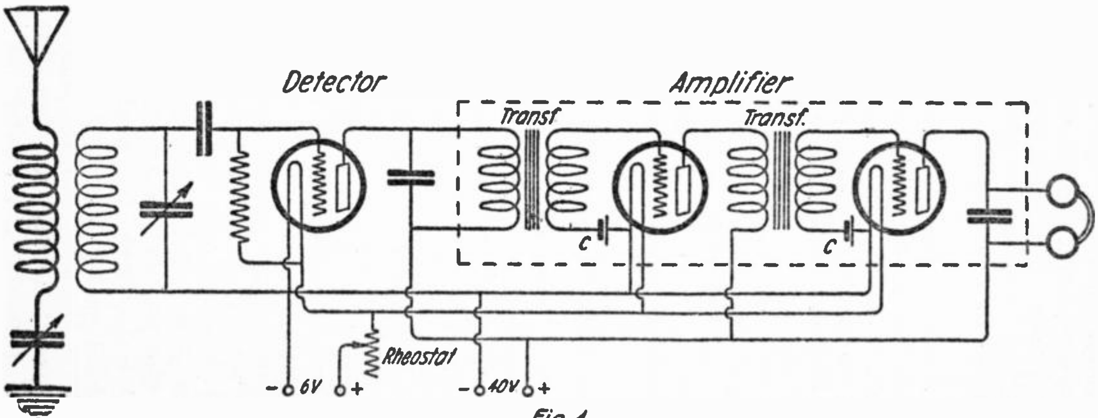

Fig. 1

Conventional Type of Two-Stage Audio Frequency Amplifier, amplifying the signal after it has been rectified in the detector valve.

possible the employment of more stages of amplification than would be possible otherwise. Moreover after we have used as many steps of high frequency amplification as can be advantageously employed it is always possible to connect an audio frequency amplifier after the detector thereby obtaining the advantage of low frequency amplification without detrimental results. Regenerative action between the low frequency and the high frequency amplifier circuits is impossible, due to the great differences of frequency. Other advantages of radio frequency amplification are selectivity, and reduction of the static signal ratio.

CHAPTER II

THE most commonly used radio frequency transformer at the present date is of the aperiodic type, one at least capable of efficient operation over a band of wave lengths. Since the construction of such a transformer is not at all difficult, the following design data is offered for those who would rather make their own.

Referring to Fig. 2, five discs are turned out of fibre or bakelite, two ⅞″ diameter by 3/16″ thick, and three 1⅛″ diameter by ⅛″ thick. By means of four brass machine screws 1″ long these are bolted together as shown.

The windings consist of No. 38 enamelled copper wire and are wound as follows: Starting with machine screw marked "1" solder one end of the fine wire and wind 123 turns in slot "A" in a clockwise manner, fastening the remaining end to screw "2". Then 195 turns are wound in slot "B" in the same clockwise manner, starting with screw "3" and finishing with screw "4". All four wire ends should be neatly soldered to the screw heads, using a non-corrosive flux or Solderall. In the winding, care should be taken that the enamel is not accidently scraped from the fine wire at any point, causing a shorted turn and probable impaired efficiency.

The finished transformer will have an efficient wave length range of from 160 to 450 meters and may be used with almost any amplifying tube on the market.

Since best results are obtained with untuned intervalve

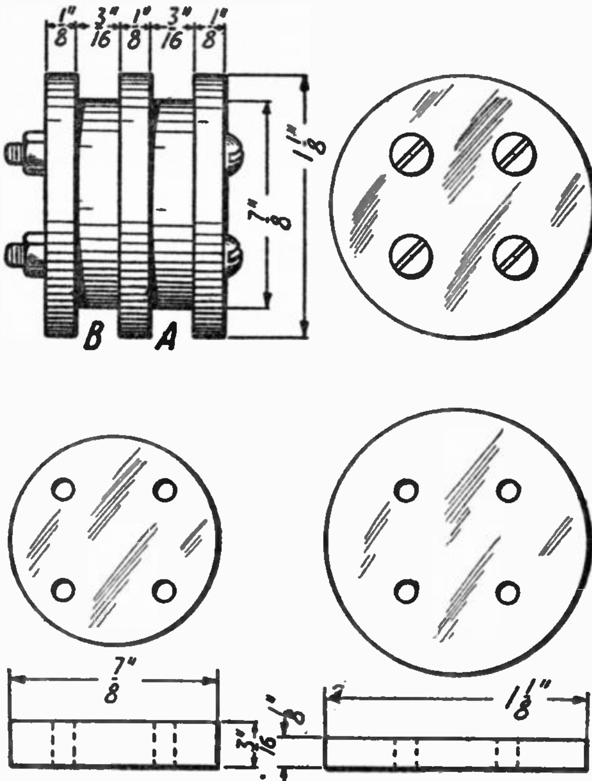

Fig. 2

radio frequency transformers over certain wave-length bands, the following are suggested for other wave-length ranges. Use same size core as per Fig. 2.

Wave-length	No. of Turns 1 to 2	3 to 4
145 to 375 meters......	108	145
350 to 750 meters......	135	240

Some Notes on the Use of the Transformer

The diagram in Fig. 3 shows the simplest manner of connecting an aperiodic transformer of the type under discussion for one step of radio frequency amplification.

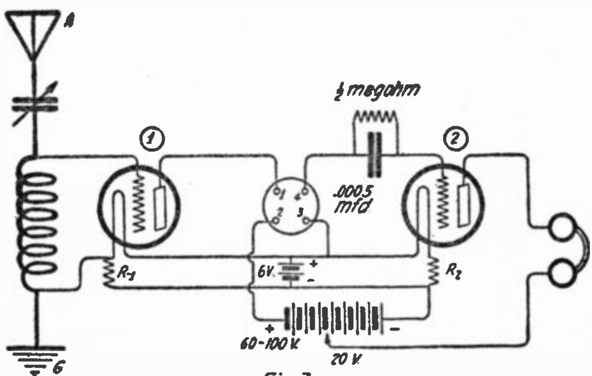

Fig 3

Tube 1 is any hard or amplifying vacuum tube, while tube 2 is preferably a soft or gas content tube. It will be noted that the lower end of the tuning inductance connects to the filament circuit of tube 1 at the negative end of the filament. When so connected it is possible to secure good amplification without the expense of a potentiometer, although the connections for this instrument are shown in Fig. 4.

Referring to Fig. 3, the condenser in the grid circuit of the detector tube is represented as being of .0005 mfd., but for the uninitiated it may be of interest to know that this may vary through wide limits, usually anywhere from .0001 to .0007 mfd., with very little variation in signal strength.

Filament rheostate R-1 may be adjusable in fine steps, but with the average tubes procurable today for detection purposes it is advisable that R-2 have a vernier adjustment capable of varying the filament current by milliamperes.

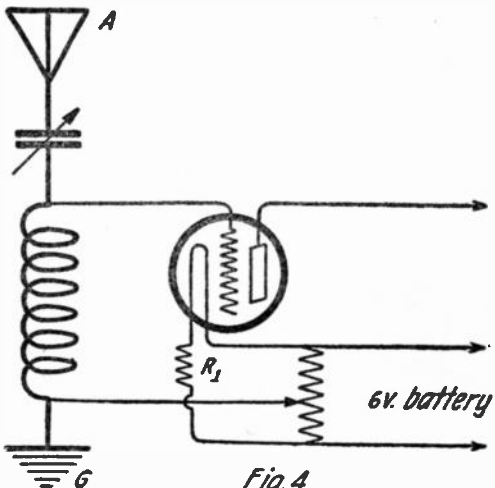

Fig. 4

CHAPTER III

Radio Frequency Amplification Through Tuned Stages

An ultra-selective method of radio reception with radio frequency amplification lies in the use of tuned stages. For such purposes as reception at pre-determined wavelengths, as in radiophone concert reception, working telegraph schedule between stations, etc., it is to be recommended and preferred.

The circuit, Fig. 5, is nearly self-explanatory. V is an inductance, such as a honey-comb coil shunted by a condenser, capable of being tuned to resonance with the wave-length it is desired to receive. The tube 1 is an amplifying tube and tube 2 is a "soft" or detector tube. AKLG is the input circuit, which may be an ordinary "single-circuit" or loose-coupled tuner. C-1, the grid condenser of the detecting tube, is not shunted directly by the grid leak, as in most ordinary circuits, but the grid leak is connected to the positive filament terminal, as at X. Were it to have been directly shunted across C-1 the high voltage battery would put a high positive potential on the detector grid, stopping detection.

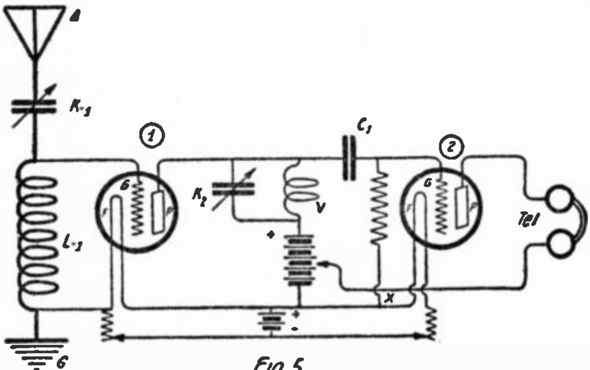

Fig. 5.

In operation V must be tuned to resonance with the antenna circuit, and it may be found that the tuning operation will be simplified if AKLG is considered a primary circuit and V a secondary circuit, although tuning qualities are many times sharper than a mere "coupled" circuit.

More than two such tuned impedance coupled stages are not usually practical, due to extreme sharpness and consequent difficulty of tuning. There is also a tendency for inter-tube reaction and regeneration, although this last item can usually be overcome by a potentiometer in the grid circuits and proper filament voltage regulation.

For waves between 180 and 350 meters it is recommended that a honeycomb DL 50 be used at V, and a DL

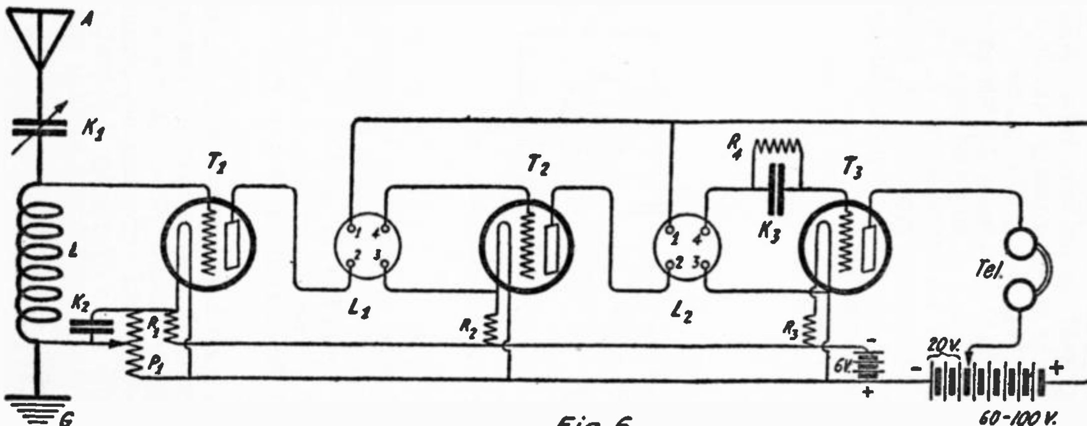

Fig. 6

Two-Stage Radio Frequency Amplifier using the Transformers described in Chapter II.

75 for waves from 300 to 800 meters. The coil used for antenna tuning will vary with the size of the antenna in use, but will probably be of the same size as V.

Two-Stage Radio Frequency Amplifier, Using Transformers Described in Chapter II

A —Antenna.
G —Ground.
K-1 —Antenna Tuning Condenser.
L —Tuning Inductance—may be a honeycomb coil.
P-1 —Potentiometer.
K-2 —½ mfd. Condenser, fixed.
R-1, R-2 —Filament Rheostat, adjustment in fine steps.
R-3 —Filament Rheostat, vernier adjustment.
T-1, T-2 —"Hard" or amplifying type tubes.
T-3 —"Soft" or detecting tubes.
K-3 —Grid condenser, .0001 to .0007 mfd.
R-4 —Grid leak resistance, ½ to 2 megohms.
L-1, L-2 —Amplifying transformers as described in Chapter II.
TEL—Head telephones.

Radio Frequency Amplification for Use of Loop Aerial

It is inadvisable, except over the shortest distances, to attempt to operate a radio receiver at short wave-lengths on a loop antenna, unless at least two or three stages of radio frequency amplification are included before the detector.

A circuit of this type is shown in Fig. 6. Tubes A, B, and C are of the "hard" or amplifying variety, the UV-201 of the Radio Corporation, the VT-1 or AP tubes being very well adapted for this service. It has formerly been supposed that radio frequency amplification at high frequencies (short wave-lengths) would be impossible unless the tubes were especially constructed to have extremely low capacitance internally, but practical experience has shown that with the type of transformer with

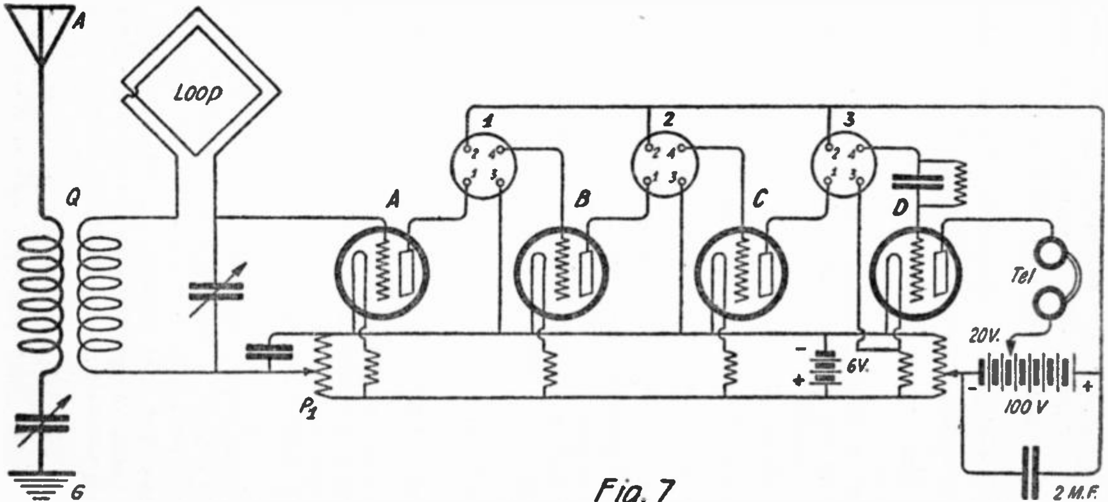

Fig. 7

An "Interference Balance". The desired signal is tuned in on the loop aerial. Any undesired signal which the loop may pick up is balanced out by tuning the regular aerial to resonance with it and proper coupling variation at Q.

which we are now concerned almost any amplifying tube can be used. The writer has used five-watt transmitting tubes for the purpose with good results.

When more than two stages of radio frequency amplification are used with tubes having a high amplification constant, trouble is sometimes experienced with regenerative effects, as has been mentioned before. Although inaudible in themselves, these effects may distort speech or spark telegraph transmissions. This condition can usually be remedied by proper adjustment of a potentiometer P-1, connected as shown. This is an ordinary wire-wound instrument of from 200 to 500 ohms and is shunted by a condenser of one-half microfarad as a radio frequency bypass in order that the potentiometer will not have a damping effect on the circuit.

For the inexperienced a few suggestions as to operation of the loop antenna may not be amiss. The coupling between inductances L and L-1 should be capable of a zero coupling adjustment and the loop capable of being swung through a 180 degree angle. Signals should be first picked up using the regular antenna and a moderate degree of coupling at Q, gradually decreasing the coupling at Q and swinging the loop for maximum signal strength. As a final adjustment the antenna circuit may be tuned to resonance with any interfering signal and by means of the coupling variation at Q the disturbing signal balanced out.

Radio and Audio Frequency Amplifier

This amplifier circuit is extremely sensitive, and especially adapted for long distance reception with an outdoor aerial, or for use with an indoor loop. By applying a high plate voltage on the audio frequency amplifier tubes a loud talker may be operated with success.

Jacks cannot be used in the various stages of a radio frequency amplifier. The tubes and transformers amplify

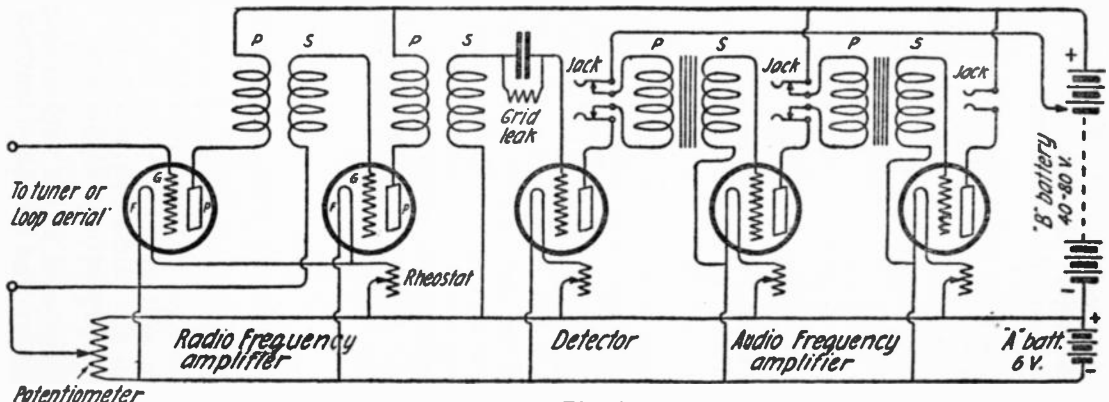

Fig. 8

Combined Radio and Audio Frequency Amplifier.

at radio frequency and rectification does not take place until these high frequency oscillations are impressed upon the detector tube. Since no rectification takes place before the detector tube, the telephones cannot be plugged in before the detector.

One Stage Radio Frequency Amplifier of Exceptional Tuning Qualities (Fig. 9)

L-1, L-2 —Coupled tuning inductances, such as an ordinary loose-coupler or honeycomb coil set, winding L-1 being connected to antenna and ground or other energy-collecting device.

L-3, L-4, L-5 -Inter-tube coupling and tuning inductances, the most convenient form of which is a three-coil honeycomb mounting.

Inductances L-3 and L-4 serve to couple the two stages as well as tune the detector tube to the incoming signal.

L-5 is a tickler coil, enabling ultra-amplification in the detector tube, as well as autodyne action for CW reception.

K-1 —Fixed condenser of .5 to 2 mfd. as a radio frequency by-pass around potentiometer P-1.

K-2, K-3, K-6 —Variable tuning condensers, capacitance .001 mfd.

K-5 —Fixed condenser, .001 mfd.

K-4 —Grid condenser and grid leak.

T-1 —Amplifying tube, preferably a "hard" tube.

T-2 —Detecting tube, may be a soft tube.

R-1, R-2 —Potentiometers of 200-500 ohms. R-1 controls amplifier grid potential. R-2 controls detector plate potential.

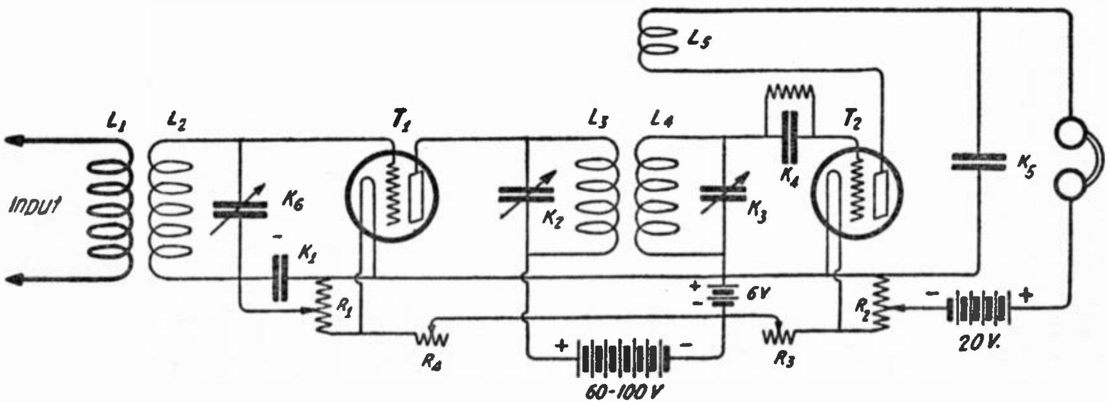

Fig. 9

A Circuit of exceptional tuning qualities for CW reception.

Honeycomb Coil Values for Tuned Stage Radio Frequency Amplifier (Fig. 9)

Wave-Length	L-1	L-2, L-3, L-4	L-5
150-350	DL-50	DL-25	DL-35
300-700	DL-100	DL-50 or 75	DL-50
450-1000	DL-150	DL-100	DL-75
800-2000	DL-250	DL-150	DL-100
1750-4000	DL-500	DL-250	DL-150
4000-8500	DL-1000	DL-500	DL-250
6000-12500	DL-1500	DL-1000	DL-500
12000-20000	DL-1500	DL-1500	DL-750
16000-25000	DL-1500	DL-1500	DL-1000

Two-Stage Radio Frequency Amplifier, Using Variometers as Tuned Impedances

A —Aerial.
G —Ground or counterpoise.
K-1 —Variable condenser, .001 mfd.
K-2 —Fixed condensed, .002 to .0005 mfd.
K-3 —Fixed condenser, .0001 to .00025 mfd.
R-1 —Resistance, ¼ to ½ megohms, fixed.
R-2 —Resistance, ½ to 2 megohms, fixed or variable.
R-4, R-5 —Filament rheostats, small steps.
R-6 —Filament rheostat, vernier adjustment.
V-1, V-2, V-3 —Variometers.
T-1, T-2 —Amplifying tubes.
T-3 —Detecting tube.

Variometers V-1, V-2 and V-3 should be equal in size, electrically. They are used for inter-valve coupling and when so used great selectivity is to be had, tuning being several hundred times sharper than an ordinary coupled circuit.

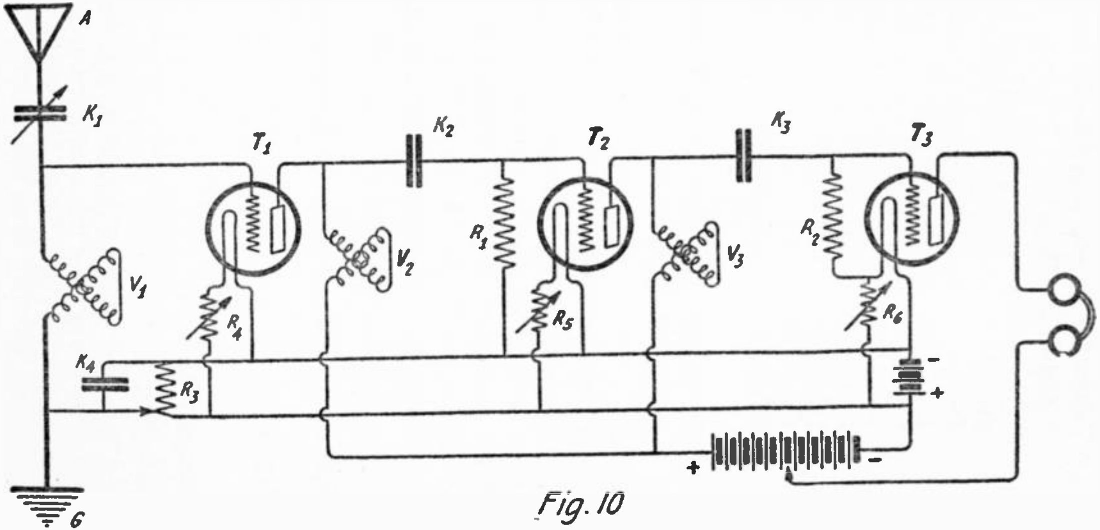

Fig. 10

Two-Stage Radio Frequency Amplifier, using variometers as tuned impedances

Loop Aerial Receiver

Excellent results may be obtained with a loop or coil aerial when used with this two-tube circuit. The first tube acts as an amplifier, boosting the very weak current received in the loop so as to operate the second tube, which is the detector, at maximum efficiency. For the reception of short wave lengths the loop, which is a wooden frame 4½ feet square, should be wound with four turns of No. 29 insulated wire with the turns spaced one-half an inch apart. The regenerative coupler consists of two coils, L and L-1, the latter turning inside of the former. Coil L consists of about 14 turns of No. 16 insulated wire, wound on a cardboard tube three inches in diameter. Coil L-1, which can rotate half a turn, is wound with 60 turns of No. 26 single cotton covered wire.

Standard Short Wave Regenerative Receiver Connected as a Short Wave Radio Frequency Amplifier

By the slight change in connections shown and the addition of one extra tube and a rheostat, a standard short wave receiver of the "two variometer and a vario-coupler" type can be converted into a tuned radio frequency amplifier.

It will be noted that most of the variable elements of the short wave set have retained their original circuit connections, but that no grid condenser is used in the first tube circuit. T-1 is any hard amplifying tube, and T-2 is a detector tube. Variometer L-4 formerly used to secure regeneration is now used as a tuned impedance coupling as elsewhere described. Note the 20-volt tap-off for the detector tube plate voltage.

Combined Radio and Audio Frequency Amplifiers

Figure 13 shows the hookup for a regenerative receiving set using two stages of radio frequency amplification, two stages of audio frequency and detector, all stages to use the same storage battery and plate battery. The diagram is divided into three sections to indicate the three divi-

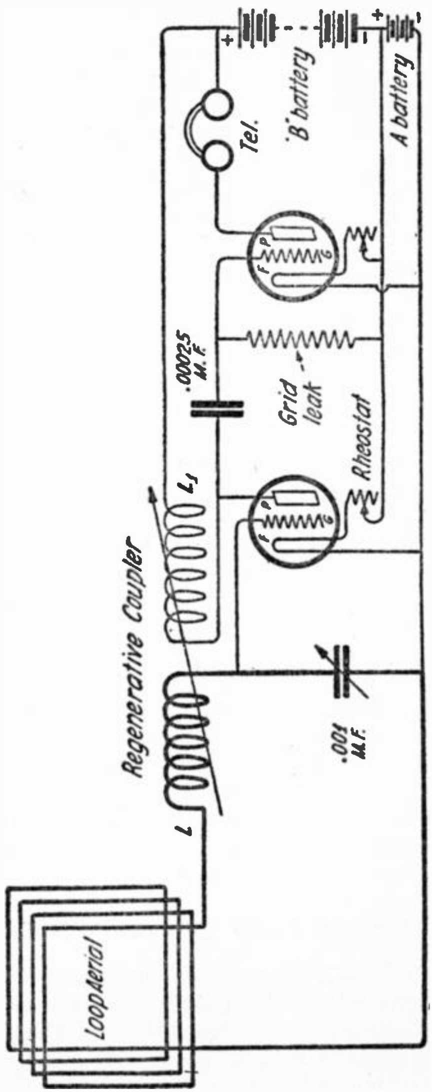

Fig. 11

Loop Aerial Receiver.

sions of the circuit. The tuner consists of the necessary inductances and condensers for tuning to the wave-length which it is desired to receive. The inductances may be in any suitable form—either a loose coupler with condensers or a variocoupler with variometers. Honeycomb coils may be used if desired. The condenser in series with the ground lead may be omitted and tuning accomplished by varying the inductance with taps alone. The aerial, ground and tuner may be substituted by a loop aerial shunted by a variable condenser, connected directly to the radio-frequency amplifier.

In the two-stage radio frequency amplifier, the transformers described in Chapter II or iron-core transformers may be used. This latter type of transformer is now on the market. Each transformer covers a limited band of wave-lengths, and amplification can only be obtained on wave-lengths within this range. If it is desired to receive and amplify on wave-lengths outside this range, different transformers must be used. Some types have convenient arrangements for plugging in other transformers. Another type short-circuits a portion of the turns to receive on lower wave-lengths. The potentiometer across the filament battery should be about 200 to 400 ohms resistance and is used to vary the potential on the grids of the two tubes in order that best advantage may be taken of the amplifying portion of the characteristic curve of these tubes. One rheostat is indicated to control the filament current of these two tubes. This is sufficient but two may be used if desired. The tubes used in the radio frequency amplifier should preferably be tubes with small internal capacitance such as the A. P. or the RAC-3 Audion.

The detector and two-stage amplifier is fairly familiar to most amateurs. The transformers are designed for amplification at audio frequency. The detector may be any type of soft detector tube which is not too critical; the amplifying tubes are of any make. The grid condenser and grid leak are variable according to the type

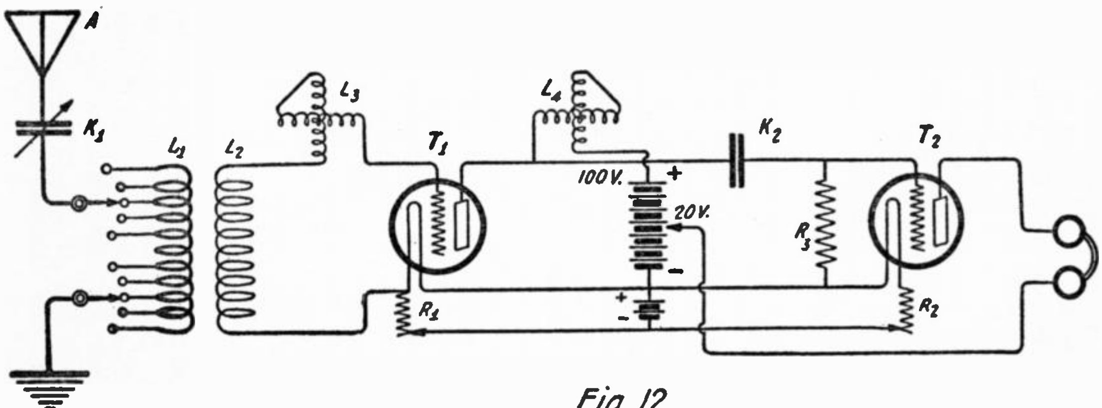

Fig. 12

Standard Short-Wave Regenerative Receiver Connected as a Short-Wave Radio Frequency Amplifier.

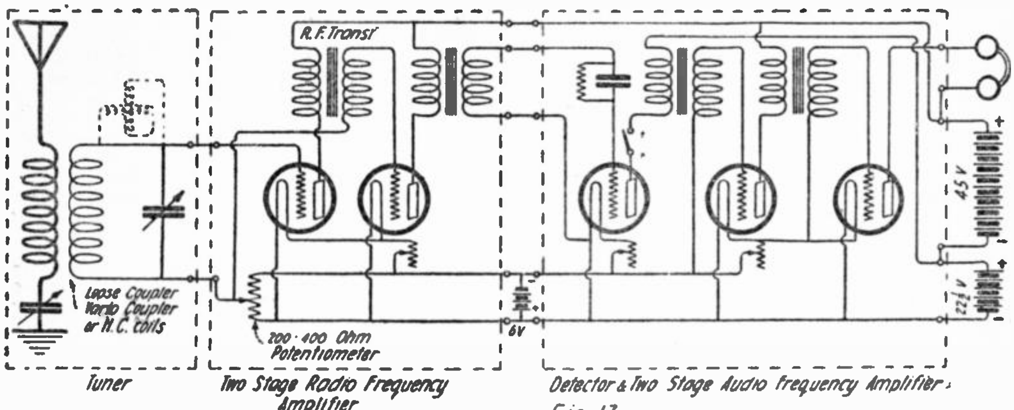

Fig 13

Two-Stage Radio Frequency Amplifier Detector and Two-Stage Audio-Frequency Amplifier using only one set of "A" and one set of "B" batteries.

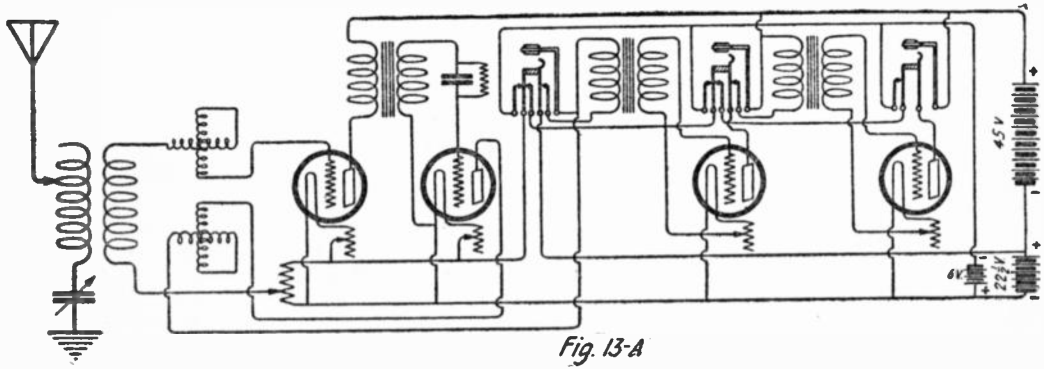

Fig. 13-A

One-Stage Radio-Frequency Amplifier, Detector, and Two-Stage Audio-Frequency Amplifier. The detector plate circuit is tunable by means of a variometer for self-hetrodyne and C. W. reception.

of tube used. The two terminals in series with the plate circuit of the detector tube may be connected to a variometer or tickler coil for additional amplification by regeneration or these terminals may be short circuited.

Another type of circuit employing two stages of radio frequency amplification in connection with a short-wave regenerative receiver is indicated in diagram, Fig. 13A. Only one iron-core radio frequency transformer is used. The output of the second tube is coupled to the detector tube by means of a condenser, and a variometer is used to tune the plate circuit of the second tube.

Adapting Receiver for Radio Frequency Amplification

A Grebe, or other type of short-wave regenerative receiver in which the detector tube is included in the same cabinet with the tuner, may be adapted for use with radio frequency transformers. This can be done by making the tube socket in the receiver contain the first amplifying tube. The grid condenser must be short circuited or removed from the circuit and connection taken directly from the antenna condenser to the grid. The wire which connects the center of the inductance switch to the filament terminal on the tube socket should be disconnected and brought out to the center of a potentiometer as shown in the diagram. The output of the first amplifying tube (in the cabinet) is applied through a radio frequency transformer to the input of a second tube outside the tuner; the output of this tube is applied through another transformer to the input of the detector tube.

In the case of the radio frequency transformers in which an iron core is used, it should not be necessary to shield them. If an air-core radio frequency transformer is used, the various stages must either be very widely spaced or some shielding arrangement made. The shield, however, must be perfect, or it will possess undesirable capacity effect.

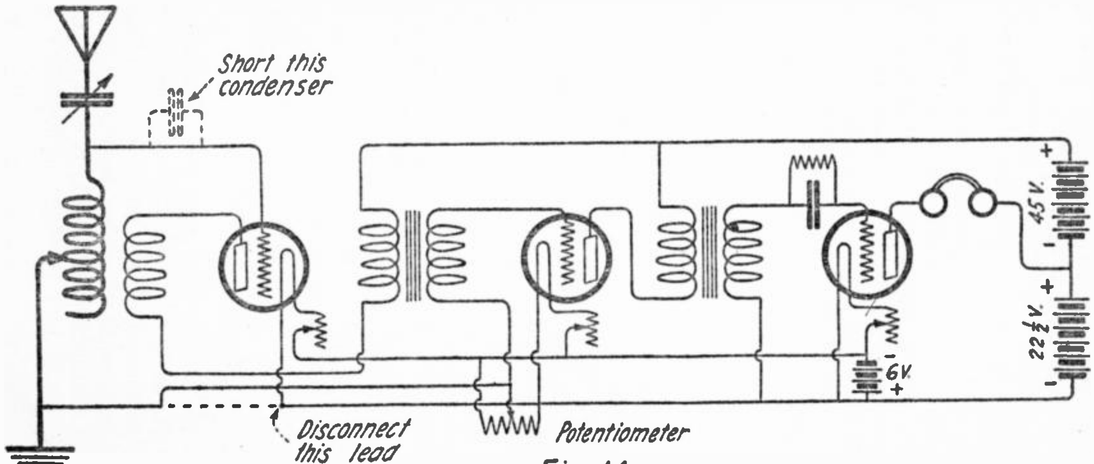

Fig. 14

Method of Converting a "Grebe" or Other Single-Circuit Receiver for Use with Amplifying Transformers.

Continuous Wave Receiver of the Retroaction and Self-Hetrodyne Type.

Retroactive amplification is of especial value in the case of C. W. reception. The problem here no longer involves the lessening of the decrement of the incoming wave-groups, as in the case of spark signals, but involves lessening the effective resistance of the antenna circuits. In other words, the positive resistance of the aerial circuit is almost completely neutralized by what is equivalent to putting a negative resistance in series with it. Referring to Figure 15, the aerial circuit L-1, K-1 is tuned exactly to the incoming continuous waves, the value of K-1 being kept at a minimum. In the plate circuit of the first tube is a tickler coil L-2, whose coupling with respect to L-1 may be varied. The magnified potentials in the plate circuit of the first tube L-2, L-3, are coupled magnetically to circuit L-4, K-2 and impressed upon the grid of the second valve.

In its plate circuit is inductance L-5 which magnetically couples the magnified oscillations to L-6. Inductance L-6 in combination with K-3 and L-7 are tuned slightly to one side of the incoming frequency, hetrodyning it, and the magnified oscillations in its plate circuit L-7, L-8 are magnetically impressed on tuned circuit L-9, K-4 located in the grid circuit of the last tube, which functions as the detector. The plate circuit of this last valve contains the headphones TEL shunted by a bypass condenser K-6. The circuit is so arranged that the first valve acts as a retroaction amplifier, or in other words, a means of introducing negative resistance into the aerial circuit. The coupling between L-1 and L-2 is adjusted to the point just preceding self-oscillation, in which condition the first tube lessens the resistance of the aerial circuit and reinforces the incoming waves which are amplified by the first and second valves, hetrodyned by the third and rectified by the fourth. An interesting feature of this arrangement is that it acts as a limiter. The third valve produces oscillations of fixed amplitude, so that incoming signals which are of greater amplitude (when they reach the third valve) than the oscillations

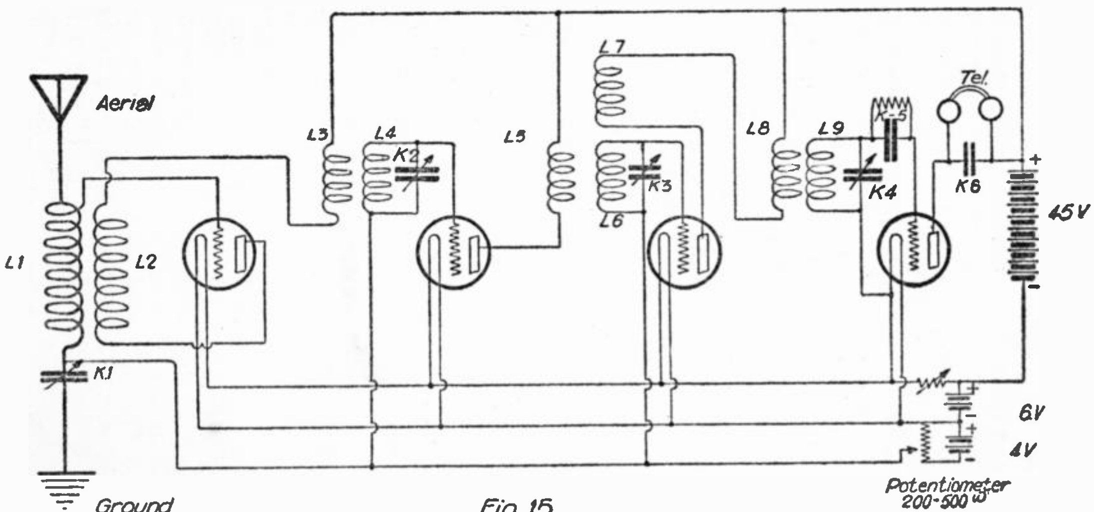

Fig. 15

Continuous Wave Receiver of the Retroaction and Self-Hetrodyne Type.

taking place there will not produce signals in proportion to their amplitude. When the amplitude of the local oscillations is greater than the amplitude of the incoming oscillations, the signal strength is dependent on the strength of the incoming oscillations. When, however, the local oscillations are the weaker, the signal strength is independent of the amplitude of the incoming oscillations. By taking advantage of this fact we can use the third valve as a limiting device to prevent very strong signals from interfering with weaker ones.

Nine radio-frequency inductances are used in the present form of this type of radio-frequency amplifier, and since the honeycomb coil type of inductance is most adaptable the following values are offered for wavelengths between six thousand and twenty thousand meters:

Table of Honeycomb Coils for Retroaction-Self-Hetrodyne Receiver.

	6,000 to 12,000 meters	12,000 to 20,000 meters
L-1	DL-1500	DL-1500
L-2	DL-750	DL-1250
L-3	DL-250	DL-400
L-4	DL-1000	DL-1500
L-5	DL-1250	DL-1500
L-6	DL-1000	DL-1500
L-7	DL-750	DL-1250
L-8	DL-250	DL-400
L-9	DL-1000	DL-1500

Condensers K-1, K-2, K-3, and K-4 are variable air condensers of about .001 mfd. each, K-5 a grid condenser with leak of from .0001 to .0006 mfd., and K-6 a fixed condenser of .005 mfd.

On small antenna such as the average experimenter probably will use it may be found necessary to shunt the antenna condenser K-1 around inductance L-1 rather than in series as it is here represented as being connected, due to the extremly low capacity of the average small antenna.

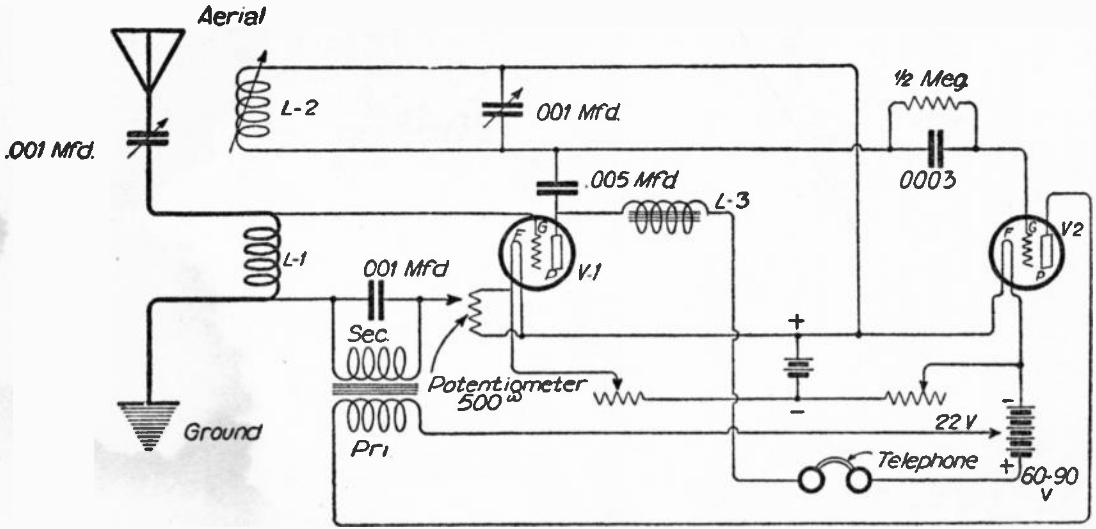

Fig 16

One-Step Radio Detector and One-Step Audio Frequency Amplifier, using only two tubes.

Radio and Audio Frequency Amplification in the Same Vacuum Tube.

A very interesting circuit, especially to the experimenter with a limited number of tubes at his command is that shown in Figure 16. Here only two valves are used for the purpose of radio-frequency amplification, detection and audio-frequency amplification, the amplifying tube being used twice. L-1, L-2 may be an ordinary vario-coupler of the rotating ball type, and should be capable of being rotated through a full 180 degrees.

Inductance L-3 may be any high-frequency choke coil of not too high resistance and serves to pass the audio-frequency current to the head receivers and at the same time shunt the radio-frequency energy to the tuned coupling impedance L-2. The operation of the circuit is as follows: The antenna circuit consisting of inductance L-1 and the condenser of .001 mfd. capacity is tuned to the incoming wave, impressing the energy on the grid of tube V-1. This tube has a battery of from 60 to 90 volts connected in its plate circuit, the direct current flowing through the headphones and inductance L-3. This D. C. flowing through tube V-1 is controlled in accordance with the variations at radio-frequency impresed on its grid, setting up corresponding radio-frequency currents through the .005 mfd. condenser and the tuned impedance circuit, finally being impressed on the grid of tube V-2. This tube should be one of good detecting quality, and may or may not have a grid condenser in its grid circuit, depending on the type of valve used. This valve through its detecting action causes variations in its plate current corresponding to the audio-frequency variation of the incoming wave. These current variations passing through the amplifying transformer primary induce currents in the secondary which are again impressed on the first tube grid, this time as audio-frequency currents, reamplified (at audio-frequency), and heard in the head phones. It will be seen, then, that the first tube does double duty, amplifying first at radio and then at audio frequency. This, however, will be found to introduce no undesirable effects, with the advantage of tube economy.