July 3, 1934. C. L. HOPKINS 1,964,990

RADIO FREQUENCY RECEIVING SYSTEM

Original Filed March 26, 1928 2 Sheets-Sheet 1

Fig. 1.

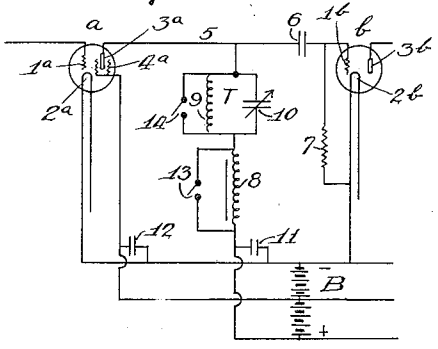


Fig. 3.

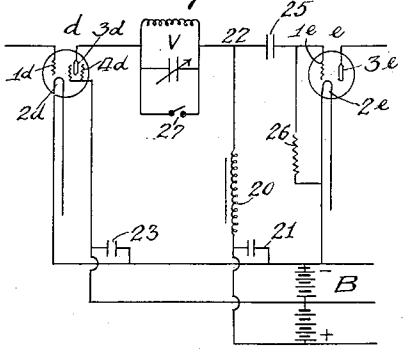


Fig. 2.

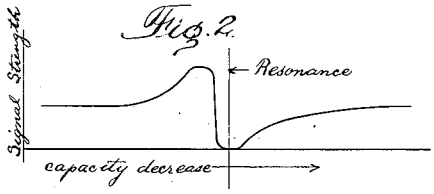


Fig. 4.

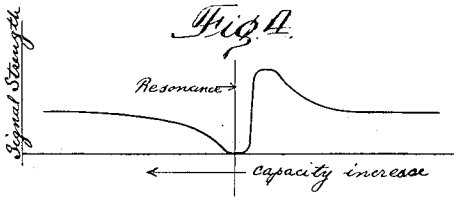


Fig. 6.

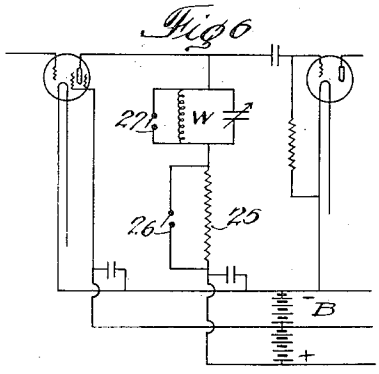


Fig. 8.

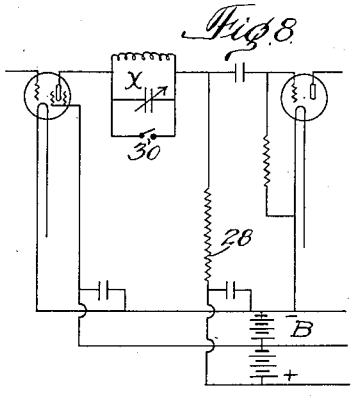


Fig. 7.

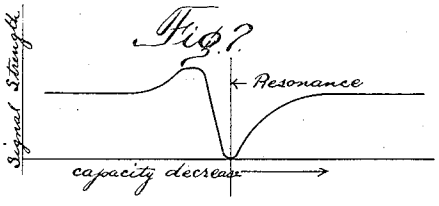


Fig. 9.

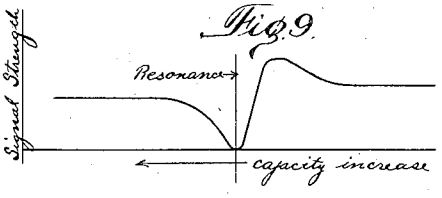
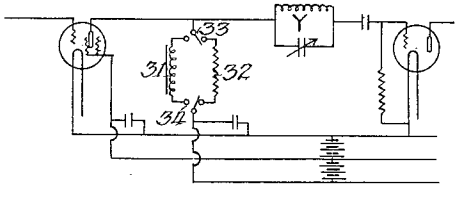


Fig. 5.



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Fig. 10

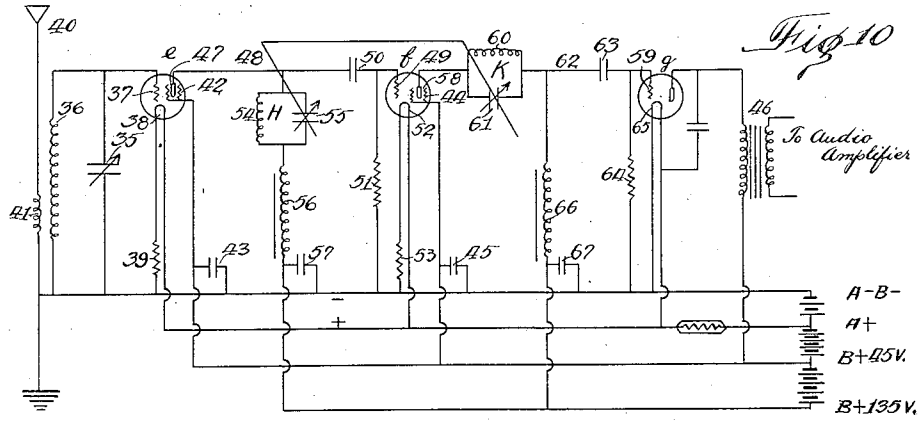


Fig. 11

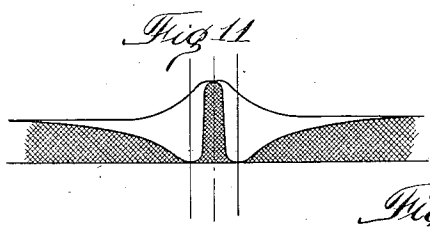


Fig. 13

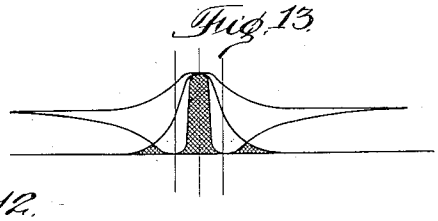


Fig. 12.

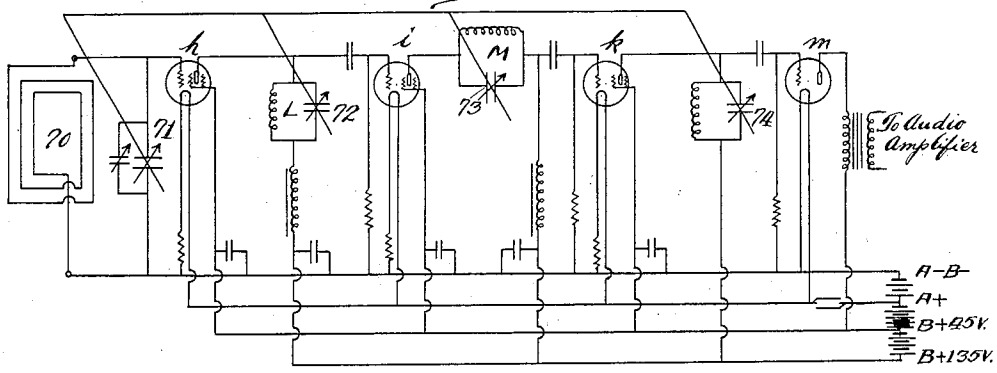
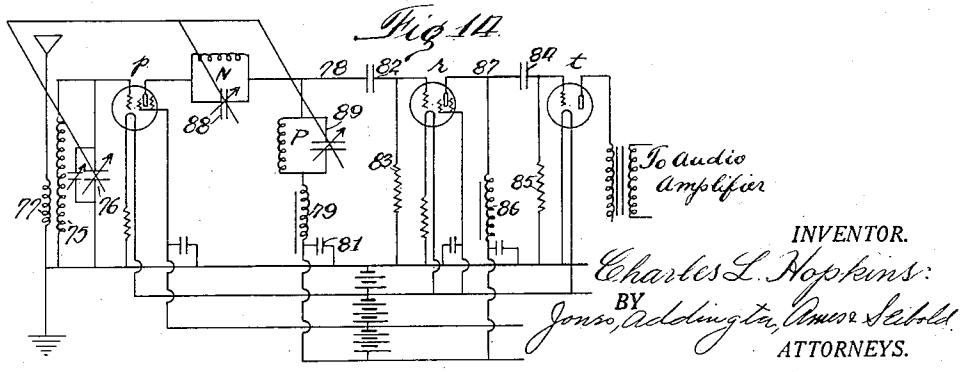


Fig. 14



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UNITED STATES PATENT OFFICE

1,964,990

RADIO FREQUENCY RECEIVING SYSTEM

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Application March 26, 1928, Serial No. 264,821
Renewed June 19, 1933

11 Claims. (Cl. 179—171)

This invention relates to means for securing selectivity in radio frequency receiving systems in which a series of thermionic valves or tubes are employed in conjunction with tunable circuits, and the object of the invention is to provide a system in which certain objections common to the systems in general use are overcome.

The system which is most commonly used at the present time, sometimes called the "tuned radio frequency" system, includes a series of amplifying tubes or "valves" coupled together by means of circuit arrangements including tunable circuits so related that when the set is used the whole series of tunable circuits are tuned to the same frequency, that is, to the frequency of the signal which is to be received. In some cases one or more of the coupling devices between adjacent valves in a receiver of this type will be of the so-called "untuned" type, that is, no variable capacity or inductance element is included, and the device is supposed to pass all frequencies within the band which the receiver is designed to cover, about equally well. When such untuned coupling means are employed the selectivity attained is due to the presence in the receiver of a certain number of tunable circuits which are all tuned to the same frequency.

In the usual so-called "tuned radio frequency" system, the addition of another stage including a circuit tuned to the frequency which is to be received always results in increasing the selectivity, because the so-called "amplification peak" becomes sharper and sharper as the signal passes through the succession of filters.

While it is desirable in a broadcast receiver that the instrument be capable of separating stations operating on frequencies but slightly separated, experience has shown that a receiving set which is sufficiently selective to eliminate a powerful nearby station and permit the reception of distant stations only slightly separated in frequency from the local station, will have the undesirable characteristic of cutting off the side bands of the modulated carrier wave emitted from a station and thus spoiling the tone quality of music received. It is generally accepted that if selectivity is required in a broadcast receiver, it can only be had at the expense of tone quality.

In receivers of the type referred to above, when the variable elements of the tunable circuits are mechanically interconnected so that they may be moved simultaneously by one manual operation, great exactness in the manufacture of the coils and condensers employed in the tunable circuits is necessary, as otherwise the matching of the various stages with each other could not be accomplished at all points over the band of frequencies on which the receiver is designed to operate. The amplification curve representing the signal strength in a radio frequency stage always takes the form of a slope gradually increasing in steepness as the frequency approaches that to which the circuit is tuned, and in the case of the last tuned circuit in a selective receiver having several stages, the two sides of the so-called "peak" meet at a point, showing high amplification on the peak, and slope gradually away on each side of the high point. An ideal form for this curve would be one in which there was no sharp peak but a flat top with a very steep descent on each side, running clear down to the base line representing no signal.

In this specification and the accompanying drawings I have shown an arrangement of thermionic valves and tunable circuits which, when properly constructed and adjusted, gives great amplification over a band of substantial width, but affords a sharp cut-off on each side of this band. This is accomplished by employing two trap circuits, each of which is capable of blocking, absorbing, or otherwise preventing the passage through the receiver from valve to valve of signals of the frequency to which the trap is adjusted. Preferably, one of the traps will be included in the means employed for coupling the output of one valve to the input of the next, while the other trap will be included in the coupling means employed between another pair of valves. When receiving a station, one of these traps will be tuned so as to suppress signals on wave lengths slightly below that of the station, while the other trap will be tuned to suppress signals on wave lengths slightly above that of the station. Such a trap can be so designed and combined with other elements that it will show a very decided depression in the curve representing the strength of signal which will be permitted to pass through the receiver. It is not necessary, however, that this depression or valley be steep on both of its sides, but it is desirable that one of the traps give a curve with a steep side above what might be called its dead point, and that the other trap have a curve with the steep side below its dead point. The reason for this will appear in the more detailed explanation in connection with the description of the drawings. In addition to the two trap circuits whose function is to eliminate stations just above and just below the desired station, the system may include another tunable circuit which is

to be brought into resonance with the carrier wave of the station. This tunable circuit may be placed in the input circuit of the first valve, or may form the coupling means between two valves, as for instance, following the last radio-frequency valve, in which case it would be the input circuit for the detector tube. The preferred arrangement is one in which the following sequence is employed: First, a circuit which is to be tuned to the desired station, this tunable circuit forming the coupler between the antenna and the grid of the first valve; second, a coupling means between the first and second valves including a trap circuit tuned to afford resonance at a frequency slightly above or slightly below the frequency of the station; third, a coupling means between the second and third valves including a trap tuned to afford resonance at a frequency slightly separated from that of the station and on the opposite side of the station from the frequency to which the first coupling means is tuned. The third valve may be the detector tube, or there may be one or more additional valves in the series, the last one of which would be the detector tube. These additional valves may be coupled together by tuned or untuned transformers, or by resistance coupling devices, or choke coils or other impedance devices. In the embodiment of my invention now to be described one stage is tuned in series resonance to a wave length on one side of the station, while the other stage is tuned in parallel resonance to a wave length on the other side of the station. Undesired stations differing only slightly in wave length from the desired one are tuned out, while the desired one is tuned in. In a system of this kind a definite width is established for the admission band, because the frequencies corresponding to the low or no-signal bends in the response curve are established by the constants of the circuits, and no amount of signal strength can move these points away from each other.

In the drawings accompanying this specification,

Figure 1 shows two thermionic valves or vacuum tubes, the output of one being coupled to the input of the other by means of an untuned impedance device consisting of a choke coil. In addition to the choke coil (which serves the purpose of impressing the signal voltage on the second tube), the coupling means shown in this figure includes a tunable trap circuit so located as to block out, absorb or suppress certain frequencies.

Fig. 2 is an amplification curve representing somewhat roughly the signal strength at different settings of the variable condenser when using the circuit of Fig. 1.

Fig. 3 shows two tubes with the input of one tube coupled to the output of the other by means of a coupling device including a choke coil and also a tunable trap circuit which when used in the position shown, will block, absorb, or otherwise suppress any station to which it may be tuned.

Fig. 4 is an amplification curve corresponding to the curve of Fig. 2, representing the signal strength at different settings of the variable condenser when using the circuit of Fig. 3.

Fig. 5 shows an alternative arrangement of two vacuum tubes coupled together by means including a choke coil and a trap circuit having the same characteristics as that of Fig. 3.

Fig. 6 shows an arrangement similar to that of Fig. 1 but employing a resistance unit in place of the choke coil.

Fig. 7 is similar to Fig. 2 but shows the results obtained with resistance coupling as used in Fig. 6.

Fig. 8 is similar to Fig. 3, but in this case a resistance unit takes the place of the choke coil.

Fig. 9 is the curve for the circuit arrangement of Fig. 8.

Fig. 10 is the circuit diagram of a receiving set designed for broadcast reception and employing a type of vacuum tube which has recently appeared on the market and is particularly well adapted for use in connection with the improved means for obtaining selectivity forming the subject of this application for patent.

Fig. 11 is a combination of several curves, showing the amplification and selectivity obtained with the combination of stages used in the receiver shown in Fig. 10.

Fig. 12 is the circuit diagram of a receiver employing one more tube than in Fig. 10.

Fig. 13 is similar to Fig. 11, but relates to the receiver of Fig. 12; and

Fig. 14 is the circuit diagram for a receiver in which both traps are placed between the first and second tubes.

Referring to Fig. 1, which shows a laboratory hook-up adapted for studying the characteristics of a single stage, *a* and *b* are vacuum tubes, each having a control element or grid, 1*a* and 1*b* respectively. Each of these tubes has a filament, 2*a* and 2*b* respectively, and a plate, 3*a* and 3*b* respectively. Tube *a* as shown, is of the type in which a fourth element is provided, this element being a shield surrounding the plate and intended to be connected to the B battery so as to have a plus potential of about 45 volts with respect to the filament. This fourth element is designated 4*a*. The plate 3*a* of the first tube is connected to the grid 1*b* of the second tube by means of the conductor 5. A fixed condenser 6 having a capacity of .00015 microfarads is inserted in the conductor 5 in order that the plate voltage may be kept off the grid. The presence of the condenser 6 necessitates the provision of a grid leak 7. A choke coil 8 serves as a coupling impedance and has its lower end connected to the B battery B, and has its upper end connected to one end of a wave trap T. This wave trap includes an inductance coil 9 and variable condenser 10 by means of which the trap can be tuned over the entire band of wave lengths which the receiver is designed to cover. The upper end of this wave trap is connected to the line 5.

It will be seen that the alternating current plate circuit of tube *a* includes the trap circuit 9—10, the choke coil 8, the bypass condenser 11, the filament 2*a* and the stream of electrons passing from the filament to the plate. It will be seen also that the grid circuit of tube *b* includes the fixed condenser 6, the trap, the choke coil 8, the bypass condenser 11, and the filament 2*b*. Included in the direct current portion of the plate circuit is the B battery B. A bypass condenser 12 provides a path for any radio frequency current which may flow in the shield grid circuit of the first tube.

As is well known, the voltage changes impressed on the grid of the second tube are proportional to the product of the impedance common to the plate circuit of the first tube and the grid circuit of the second tube and the current flowing through this impedance. It is, therefore, essential, if high amplification is to be obtained, that

the impedance of the common path be made high so that the voltage drop across this path will be large. If, however, this impedance were made infinite there would be no current and the I R product would be zero. In the type of tube which is provided with a shield surrounding the plate the internal resistance from filament to plate is much higher than it is in other tubes suitable for use in radio frequency amplification, and the amplification factor is also much higher. The greatest voltage amplification obtainable with any tube is theoretically to be had when the external plate impedance is equal to or greater than the internal plate resistance of the tube.

In attempts to use these tubes with hookups designed to give great amplification, such as a circuit using tuned impedance coupling, it has been found that although surprising amplification can be had with comparatively few tubes, the problem of securing selectivity with stability is a serious one. If a sufficient number of stages of tuned radio frequency amplification are employed to give any degree of selectivity, then the difficulty arises that the receiver becomes tricky and cannot be prevented from oscillating violently. It therefore becomes desirable to find some means for gaining selectivity without using an excessive number of stages, and it is to be remembered also that the excessive amplification theoretically possible with this type of tube is not required, for which reason it is permissible to sacrifice some of the excessive sensitiveness in favor of stability and selectivity.

Referring again to Fig. 1, 13 is a switch which when closed short-circuits the choke coil 8. The hookup then becomes the familiar tuned impedance one and the greatest amplification would occur when the tunable trap circuit 9—10 was brought nearly into parallel resonance with the frequency of a signal which was impressed on the grid of tube *a*. If the condenser were provided with a dial or pointer this indicator would not stand at exactly the point which it would occupy were the trap circuit disconnected at both ends and tuned to resonance with a laboratory oscillator operating at the same frequency as the station. This is because of the fact that small capacities exist in the tubes *a* and *b* and these tube capacities are in shunt to the condenser 10 and, of course, add to the capacity of this condenser and make it necessary to turn the condenser out slightly. It is to be remembered also that with the trap circuit tuned to a wave length slightly shorter than that of the signal the reactance across the trap would be inductive and very high, which would cause regenerative feed back through the tube. The choke coil 8 is so wound as to have a large inductance (about 250 millihenries) and very little distributed capacity. Now, if the switch 13 be opened so that the current flows through the choke coil 8, it will be found that the signal is absorbed or blocked by the trap at practically the same setting of the condenser 10, and if the coil 9 be of good quality having low resistance and low distributed capacity, no signal will be heard so long as the condenser 10 is left at this setting. The explanation of the above is to be found in the fact that the choke coil 8 acts as a small condenser at all wave lengths shorter than the natural wave length of the choke coil. This coil has a small distributed capacity which, with the inductance of the coil, gives the latter a natural wave length greater than any which the set is designed to receive. Under this condition the choke will, of course, always give capacitive reactance. Now this capacitive reactance is in series with the reactance of the wave trap, and this reactance is either inductive or capacitive, depending on whether the wave trap is tuned to a wave length longer or shorter than the wave length of the signal. This will be explained more fully in the following paragraphs.

When an alternating voltage is impressed on a circuit containing an inductance and a capacity in parallel, and the circuit is brought into resonance at the frequency of the impressed voltage, the lagging current in the inductance and the leading current in the capacity oppose each other, the result, if the resistance of the circuit is low, being that the impedance of the trap becomes that of resistance only, and this resistance is very high. In the usual tuned impedance hookup this impedance and the current flowing through it furnish the I R drop for impressing the voltage changes on the grid of the succeeding tube.

An explanation sometimes given to account for the action of a wave trap is that a very large current flows in the resonant circuit, the energy being first stored in the coil and then in the condenser, and this oscillating current heats the coil. Energy is thus dissipated in the form of heat and only sufficient line current is permitted to pass through to make up for this loss. But if the trap is tuned to a wave length shorter than that of the signal the reactance across the trap is inductive, and is very high when the trap is tuned but slightly off resonance.

Returning to Fig. 1, and assuming, as before, that the condenser 10 of the trap circuit stands at the adjustment where the signal is loudest when the choke coil 8 is shunted out: as stated above, this is also the point of adjustment of the condenser where the signal is not heard when the switch 13 is open, and we will call this the "dead point." This is a point where the trap is tuned just "short" of the signal, that is, to a wave length very slightly shorter than that of the signal. We then have a very large inductance in series with a very small condenser (the choke coil) and so we have two high reactive impedances of opposite sign in series with each other. One reactance balances out the other and we have series resonance. The radio frequency current at the frequency or wave length of the signal meets with no opposition and consequently there is no voltage drop to be applied to the grid of the second tube. The signal is thus absorbed at this particular setting of the variable condenser. At the same time there is another frequency at which a signal would be impressed on the grid of the second tube, this being the frequency to which the trap is tuned in parallel resonance.

Now, if the condenser be turned so as to increase its capacity and raise the wave length of the trap, (going to the left in Fig. 2) the signal will be heard again, but with somewhat slightly less volume than when the trap was tuned to the signal with the switch 13 closed. If the condenser be turned still farther so as to further raise the wave length of the trap, the signal will fall somewhat in strength and will have the value which it would have with the trap shunted out by closing the switch 14, leaving the coil 8 to serve as the repeating impedance. If now the trap be again tuned to the dead point and then slowly turned out, the signal will gradually reappear and will finally remain substantially equal in strength until the condenser is turned completely out. The volume will be found to be substantially

the same with the condenser at either end of its adjustment. This is shown in Fig. 2, which is a curve showing signal strength plotted against condenser settings. No attempt has been made to make this curve represent accurately the values of signal strength obtained and it is to be noted that this curve represents only a small portion of the entire tuning range of the condenser.

It will be seen from the above that if the rotor of the condenser be slowly turned from its position of maximum capacity, (going to the right in Fig. 2) the signal strength will remain practically constant for a time, then will begin to rise and when at its highest will suddenly fall to practically zero, rising again to substantially its first value. With the trap circuit placed in the circuit in the position shown in Fig. 1, it is possible to get a sharp cut-off on one side of the signal. Another arrangement giving a sharp cut-off on the other side of the signal will now be described.

Referring to Fig. 3, *d* and *e* are two vacuum tubes, the output of one of which is coupled to the input of the other by means of an arrangement of parts and connections including a trap circuit V. Tube *d* is of the four-element type and has a grid 1*d*, filament 2*d*, plate 3*d*, and shield grid 4*d*. The tube *e* may be another tube of the same type or may be a detector tube of any suitable type. 1*e* is the grid of this tube, 2*e* is the filament, and 3*e* is the plate. 20 is a high impedance choke coil so wound as to have as little distributed capacity as possible. This choke coil is connected at one of its ends to the B battery B and bypassed to the negative filament line by the condenser 21. At its opposite end it is connected to the line 22 which extends from the plate of the first tube to the grid of the other tube. Shield grid 4*d* is connected to the B battery so as to have a plus potential of about 45 volts with respect to the filament of the tube, and is bypassed to the negative filament lead by the condenser 23.

Inserted in the line 22 is a blocking condenser 25 having a capacity of .00015 microfarads capacity, the object of which is to keep the plate voltage off the grid of the tube *e*. The presence of this condenser makes it necessary to provide a grid leak 26 which may have a resistance of two or three megohms. In the line 22 at a point between the plate of the first tube and the point where the choke coil 20 is connected into this line, is inserted the trap circuit V. This trap circuit is similar to the one in Fig. 1 and is shown as being provided with a switch 27 which may be closed to short-circuit the trap. It is to be understood, of course, that in receiving sets no switches such as shown here and in Fig. 1 are provided, as there is no occasion to short-circuit the traps.

Assuming that this wave trap V be disconnected at each end and tuned to the wave length of the signal coming from a broadcasting station or a modulated laboratory oscillator; then suppose the connections to be re-established so that the trap is connected into the plate circuit of the first tube as shown in the figure and the signal impressed on the grid of the first tube. It will now be found that the signal will not be heard so long as the tuning condenser of the trap circuit be left in this position. This is due to the fact that the signal is absorbed or blocked in the trap and therefore is not permitted to pass through the path which includes the choke coil 20, which is the repeating or coupling impedance of the system. Now, if the condenser be turned to tune the trap to a slightly shorter wave length (going to the right in Fig. 4) the signal will suddenly come up with good volume, and will probably fall somewhat as the condenser is moved to still further shorten the wave length. The reason for this will be explained in the next paragraph. If, on the other hand, the condenser is turned to tune the trap to a slightly longer wave length than that of the signal (going to the left in Fig. 4), the latter will appear but it will not rise so suddenly as before and will not rise to as high a value as when the trap was tuned slightly below the wave length of the station. At all points in the tuning range of the condenser which are not in the neighborhood of the resonant point, the signal strength is that which is due to the coupling afforded by the choke coil 20. This is shown in the curve of Fig. 4. By opening and closing the switch 27 with the tuning condenser in various positions, this peculiarity of the circuit may be easily studied.

The choke coil 20, like the choke coil 8 in Fig. 1, acts as a very small condenser to all frequencies or wave lengths which the set is designed to receive. It, therefore, offers at all times a high capacitive reactance. Now if the trap V is tuned to parallel resonance with the signal it will absorb or block the signal, as the impedance across it is neither inductive nor capacitive reactance, but resistance, and the drop across it is not impressed on the grid of the next tube as it is not in the grid circuit of this tube. If the condenser be turned out to tune the trap to a slightly lower wave length than the signal the impedance across the trap becomes inductive reactance, and this reactance is very high if the coil in the trap has a low resistance. Now this high inductive reactance is in series with a high capacity reactance (the reactance of the choke coil 20) and we have therefore a condition of series resonance in the plate circuit of the first tube of the pair, and the radio-frequency current is at a maximum. It is well known that in the case of series resonance there is no voltage drop across the inductance and capacity taken together, but there is a very large voltage drop across either the inductance or the capacity taken by itself. In this case we are taking the drop across the capacity reactance element (choke coil 20) and applying it to the grid of the following tube. This explains why the signal rises to its highest value when the condenser is turned out slightly from its position of least signal, which is the setting where the trap blocks the signal.

It will be apparent that for any setting of the condenser in Fig. 3 there will be one frequency at which the signal is blocked or absorbed by the trap, which will be tuned in parallel resonance for that frequency, and there will be another frequency at which the plate circuit of the first tube will be tuned in series resonance, this frequency being that at which a signal would be impressed on the grid of the next tube. Likewise, in the arrangement shown in Fig. 1, it is apparent that for any setting of the condenser 10 there will be one frequency at which the trap circuit will be tuned in parallel resonance and another at which the plate circuit of the tube will be tuned in series resonance. In this case, however, the signal which is absorbed is the one having the frequency corresponding to series resonance in the plate circuit, while the signal which is passed on to the next tube is the one having the frequency corresponding to parallel resonance in the trap.

By comparing Figs. 2 and 4 it will be seen that we have here two types of coupling means adapted

for use between adjacent tubes, in one of which the signal is suppressed when a tunable circuit is brought into series resonance with the signal and in the other the signal is suppressed when a tunable circuit is brought into parallel resonance. In one of these circuit arrangements it will be observed that the curve representing the strength of signal rises very rapidly from what might be called the dead point when the tuning of the trap is changed in one direction, and in the other circuit arrangement the curve representing the signal strength rises very rapidly from the dead point when the tuning of the trap is changed in the other direction. In the familiar tuned radio frequency system each stage tunes to a single frequency at a given setting of the condenser and all the circuits are brought into resonance with the signal which is to be received. In the present system, a circuit of either of the two types thus far described may be tuned to a signal in such a way that the signal is not heard. It will readily be seen that a receiving set can be constructed in which these two circuits are employed to give a sharp cut-off on each side of the signal. By combining, either in two separate stages or in one stage, circuit arrangements having the characteristics of the hookups described above, it is possible to provide a receiver in which there are two dead points, one on each side of the signal. It might be said that these dead points straddle the station which the instrument is adjusted to receive.

Circuit diagrams of such receivers are shown in Figs. 10, 12, and 14. Fig. 10 shows a receiving set having two stages of radio frequency amplification ahead of the detector and employing the circuit arrangement of Fig. 1 between the first and second tubes, and the arrangement of Fig. 3 between the second and third tubes. Fig. 14 shows a receiver in which the two trap circuits are placed between the first and second tubes. Before taking up in detail the hookups shown in these figures, an explanation will be given of the effect of substituting resistance units for the choke coils.

Referring to Figs. 6 and 8, it will be seen in comparison with Figs. 1 and 3 that the hookups are the same except that in place of choke coils, 8 in Fig. 1 and 20 in Fig. 3, high resistance units are used as the coupling or repeating impedances. In Fig. 6 the resistance unit 25 may be shunted out by means of the switch 26, and the trap W may be shunted out by the switch 27. When switch 26 is closed the receiver behaves like the familiar tuned impedance amplifier, as explained in connection with Fig. 1. When the switch 27 is closed, with switch 26 open, the receiver behaves like a resistance coupled amplifier. The signal strength is not quite so great as with choke coil coupling, due to the fact that the resistance unit offers impedance to the direct current of the B battery and thus lowers the voltage on the plate of the first tube. However, very good amplification may be had by raising the voltage of the B current supply somewhat above that usually recommended for this tube, and a receiver giving satisfactory performance can be constructed using resistances in place of choke coils. When both switches 26 and 27 are open and the resonant frequency of the trap circuit W is changed by manipulating the condenser, the signal disappears and reappears just as was explained in connection with Fig. 1. The explanation of this is to be found in the fact that neither side of the condenser of the trap is grounded, and, of course, any capacity across the resistance unit 25 will combine with the reactance across the trap to give the same effects as in the case of Fig. 1. There will always be some capacity between the wires leading to the resistance unit, and in most cases this will be sufficient to make the circuit behave as though the choke coil shown in Fig. 1 had been used.

The curve of Fig. 7 relates to the circuit shown in Fig. 6, and corresponds to the curve of Fig. 2, relating to the circuit of Fig. 1. It will be seen that curve 7 agrees rather closely with curve 2. The amount of resistance in the unit 25, the capacity across it, the voltage of the B supply, the resistance and capacity of the coil, etc., may to some extent alter the shape of this curve.

It will be seen that Fig. 8 is the same as Fig. 3 except that in Fig. 8 a resistance unit 28 has been substituted for the choke coil 20. A switch 30, when closed, shunts out the trap X. When this switch is closed this hookup behaves like an ordinary resistance coupled amplifier. With switch 30 open and the trap tuned to resonance with the signal, no signal is heard. When the trap is detuned the signal will pass through to the second tube and may be heard, as in the case of the hookup shown in Fig. 3.

A curve showing the performance of the circuit is given in Fig. 9, and it will be seen that this curve is quite similar to that of Fig. 4. None of these curves is supposed to be accurately drawn, and in any event their exact forms may depend somewhat on the constants of the apparatus used. The presence of the high point in the curve is due to the fact that capacity across the unit 28 causes the plate circuit to tune to series resonance, as in the case of Fig. 1.

In Figs. 3 and 8 the trap circuit is shown as being inserted between the plate of the first tube and the point where the impedance coupling unit is connected into the plate-to-grid line. This trap may, however, be moved over to the position shown in Fig. 5, that is, between the grid of the second tube and the point where the impedance coupling unit is connected to the plate-to-grid line. The effect is the same in either case, and when a choke coil is used as the coupling impedance the curve of Fig. 4 applies to either Fig. 3 or Fig. 5. When a resistance unit is used as the impedance coupling, the curve of Fig. 9 corresponds to either the hookup of Fig. 8 or that of Fig. 5. In Fig. 5 there is shown both a choke coil 31 and a resistance unit 32 with switches 33 and 34 which may be thrown so that either of these impedance devices may be inserted in the circuit With such an arrangement the performance of the amplifier may be studied under both conditions.

Referring now to Fig. 10, which is the circuit diagram of a receiver having two stages of radio frequency amplification ahead of the detector, *e* is the first tube and *f* the second. These tubes are of the four-element type. The detector tube *g* may be of any type desired which is suitable for use as a detector. No audioamplifier is shown, but in a manufactured set this would usually consist of two or three tubes with the proper audiofrequency transformers or other apparatus. The input circuit of tube *e* is tunable and includes a variable condenser 35 and a coil 36 connected to the gird 37 and filament 38 of the tube as usual. The grid return to the filament is through a resistance 39 of a few ohms in the A-lead to the filament to place a negative bias on the grid. The antenna 40 is connected to ground through a coil 41 which forms the primary winding of a coupler of which the coil 36 is the secondary. The shield

grid 42 of the first tube is connected to the B battery so as to have a positive potential of about 45 volts impressed on it, and is bypassed to the A-lead by the condenser 43. The second tube *f* is also of the four-element type and has its shield grid 44 similarly connected to the B battery and bypassed by the condenser 45. Tube *g* has its plate connected through the primary of the audio-transformer 46 to the B battery.

The plate 47 of the first tube is connected by means of conductor 48 with the grid 49 of the second tube, this conductor being broken by the grid condenser 50. A grid leak 51 is connected between the grid 49 and the minus side of the filament 52 of the second tube. A small fixed resistance 53 is inserted in the A-lead to the filament so that the grid return will be through this resistance and the latter will place a small negative bias on the grid.

A wave trap H consisting of a coil 54 and a variable condenser 55 has one of its ends connected to the conductor 48 and has its opposite end connected to one end of a choke coil 56. The other end of this choke coil is connected to the B battery so as to have a potential of about 135 volts placed on the plate 47. The lower end of the choke coil 56 is bypassed through condenser 57 to the A-line to afford a path for the radio frequency alternating current without passing through the B battery where it might cause troublesome coupling between circuits.

The plate 58 of the second tube is connected to the grid 59 of the detector tube *g* through a wave trap K comprising a coil 60 and a variable condenser 61. The line 62 from the trap to the grid is broken by the grid condenser 63, and a grid leak 64 is connected between the grid 59 and one end of the filament 65 of the detector tube. With some types of detector tubes this leak goes to the negative end and with others to the positive end of the filament. A choke coil 66 is connected at one end to conductor 62 at a point between the grid condenser 63 and the wave trap. The other end of the choke coil goes to the B battery and the bypass condenser 67 which is connected to the A-lead.

The movable elements of the variable condensers 55 and 61 are mechanically interconnected so as to be moved simultaneously by the same manual operation. When the trap circuit K is tuned in parallel resonance to the frequency on which a transmitting station is operating, no signal from that station will be heard, or at least the signal will be very faint. If trap circuit H is adjusted to give, in combination with the capacity reactance of choke 56, series resonance, the station will not be heard. Suppose now that the resonant circuit which includes the coil 36 and condenser 35 be tuned to the frequency on which the station is operating, by the manipulation of the condenser. Now, in order that the signal may pass through the receiver, it will be necessary to adjust both of the trap circuits H and K. Going back to the discussion of Figs. 1 and 3 and the curves shown in Figs. 2 and 4, it will be seen that in order to receive the signal with the greatest volume, condenser 55 should be adjusted to slightly decrease its capacity, (see curve of Fig. 2) and condenser 61 should be adjusted to slightly increase its capacity (see curve of Fig. 4). If now the movable members of these two condensers be locked together so that they will always move simultaneously and be kept in the same positions relative to each other, there will always be a dead point on each side of a station when the interconnected or teamed condensers are adjusted to the point where the station is heard with the greatest volume. If the curves given in Figs. 2 and 4 be superposed this will be made clear, and Fig. 11 shows the result. Now, if the curve representing the response of the tuned circuit which includes coil 36 and condenser 35 be laid over the curves in Fig. 11, the result will be something resembling Fig. 13. It will be seen that the first tunable circuit in this receiver, when tuned to a desired station, will eliminate or "tune out" other stations which are somewhat separated in frequency from that one, and that the two teamed trap circuits will eliminate stations close to the desired station on both sides. The cut-off on each side of the desired station is much sharper with the pair of traps than with the first circuit. When a series of circuits is used, each of which is tuned only to the frequency of the station, as is done in most broadcast receivers, the cut-off can be made sharp but there will be a sharp pointed peak, instead of a rounded or flat top, to the curve. The disadvantages of such a peak are well known, and have been discussed hereinabove. Moreover, the response curve will broaden out at the bottom, on a strong signal, which is not the case with a receiver such as described herein.

In a receiver manufactured for sale the first condenser would preferably be connected to the other two, so as to make the instrument a single control one, as is shown in Figs. 12 and 14. Suppose, however, a person were to manipulate the dials or knobs of a receiver arranged as shown in Fig. 10, that is, having one control for the first variable condenser and another for the two wave trap condensers. In this case the following would be observed after the first circuit had been tuned to a desired station:

As the second dial or knob was turned slowly from one end of the scale to the other it would be found that the amplification would be substantially equal at all points on the scale of the second control except in the neighborhood of that point on the scale corresponding to the wave length of the station. (See Fig. 11). As this point was approached from either direction the signal strength would suddenly begin to drop and would fall rather rapidly, then rise almost instantly to a value higher than at any other part of the scale. If the dial were moved still farther, the signal would remain at this strength for a point or two on the scale, then almost instantly drop again, then rise again to about its original value and continue at this value to the other end of the scale. However, it will be seen that there should be some means for tuning out the stations which lie on each side of the one which is to be received and which are far enough from this station to be unaffected by the trap circuits. This is the purpose of the one tuned circuit which is to be brought into resonance with the carrier wave from the station. When this stage is the first in the series its performance curve will have a broad and much rounded peak, but will eliminate the stations which are not close to the desired one. After passing through this stage the signal will have to pass through two others in which the band of frequencies which can pass through will be narrowed to possibly 15 or 20 kilocycles, or it can be made even less, if desired, by shifting the teamed condensers so that the dead points come closer together. This narrowing of the band is accom-

plished without creating a sharp peak in the curve.

When distant stations are received on a receiving set of this type, these stations do not drop out on a very slight movement of the dial, nor does music from these stations sound "drummy" and unnatural due to so-called "side band cutting."

In Fig. 12 is shown a receiver designed for use with a loop antenna. In this receiver an extra stage of radio frequency amplification has been provided, making three stages ahead of the detector. The coupling between the third radio frequency tube and the detector may be by means of an untuned or tuned transformer, a choke coil, a resistance unit, or a tuned impedance device as shown in the figure. In the diagram *h*, *i*, and *k* are the radio frequency amplifying tubes, of the four-element type, and *m* is the detector tube.

The loop antenna 70 is tuned to resonance with the signal by the variable condenser 71. The arrangement of Fig. 1 is used between tubes *h* and *i*. and the arrangement of Fig. 3 between tubes *i* and *k*. A tuned impedance coupling hook-up is used between tube *k* and the detector tube *m*. The variable condenser 71, which tunes the loop, and the variable condensers 72 and 73, which are included in the trap circuits, together with the variable condenser 74 which tunes the last circuit, are all mechanically interconnected so as to move together when the set is being adjusted to receive a station.

In the receiver shown in Fig. 12, before the variable condensers are permanently connected together for control as a unit, they are first aligned in such relation to each other that the first and last of the series (71 and 74) will always tune their circuits to the same wave length, while condensers 72 and 73 will always tune their circuits with a certain amount of separation, between the low points on their response curves, 72 slightly above and 73 slightly below the wave length to which the first and last are tuned.

In Fig. 14 there is shown a receiver in which the two trap circuits are placed between two adjacent tubes. In this figure *p* and *r* are radio frequency amplifying tubes of the 4-element type, and *t* is the detector tube. The input circuit of the first tube comprises a resonant circuit consisting of the coil 75 and condenser 76, the coil 75 being coupled to a coil 77 which is connected into the antenna circuit. A trap circuit N, similar to the trap circuit of Fig. 1, is inserted in the line 78 which connects the plate of tube *p* to the grid of tube *r*. The other trap circuit P is inserted between the plate-to-grid line 78 and the choke coil 79, as in Fig. 1. The lower end of the choke coil is connected to the B battery and is bypassed to the A-lead. A grid condenser 82 and grid leak 83 are provided for tube *r*. The tube *t* is the detector, of any suitable type, provided with grid condenser 84 and grid leak 85. The coupling between tube *r* and tube *t* may be accomplished in any of the familiar ways. As shown here, the coupling is secured by utilizing the I R or I Z drop through a choke coil 86 connected between the plate-to-grid line 87 and the A-line. This choke coil may be similar to the other choke coil 79.

In this receiver, when the condensers 88 and 89 are properly adjusted with respect to each other and to condenser 76, and with the latter tuned to a station, this station will come in with strong signals, while other stations, on frequencies at either side, will not be heard. Those which are close to the frequency of the desired station will have their signals absorbed or blocked by the functioning of the trap circuits. At the frequency of parallel resonance for trap N, signals will be suppressed as very little current at that frequency can flow in the plate circuit, and the voltage drop across this trap is not applied to the grid of the second tube. At the frequency of series resonance for the trap P and choke 79 taken together, there will be no voltage drop because the reactances balance out, therefore no voltage is applied to the grid of the second tube. At another frequency, between the other two, trap P will be in parallel resonance and will cause a large voltage drop to occur across itself and this drop is applied to the grid of the next tube. At this frequency, trap N will be out of resonance and will not materially affect the signal.

It is apparent that in a receiver such as shown in Fig. 12, there are two stages which tune, each of them, to two frequencies at the same time, for any setting of the gang condenser. One is a frequency at which there is a series resonant circuit in the stage, the other a frequency at which there is a parallel resonant circuit. In one stage parallel resonance causes the desired signal to be passed to the following tube, while series resonance prevents signals of another frequency from passing to this tube. In the other stage series resonance causes the signal to be passed to the following tube, while parallel resonance prevents signals of another frequency from passing to this tube. In a receiver such as shown in Fig. 14 one stage tunes to three frequencies at the same time, signals at one of these frequencies being passed to the following tube, while signals of the other frequencies are not permitted to pass to this tube. In both receivers wave traps, that is, circuits capable of being tuned to parallel resonance, are employed to prevent undesired signals from passing to a following tube and causing desired ones to pass. In some cases the traps are adjusted to give series resonance and thus absorb the signal. In other cases the traps are adjusted to give parallel resonance and thus absorb the signal.

I claim:

1. In a radio receiver, the combination with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is variable, said means tuning to the received frequency and at the same time to a rejected frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to the received frequency and at the same time to a rejected frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of one frequency are amplified and signals in the neighborhoods of two other frequencies, one on each side of the first-named frequency, are extinguished, and the spacing between the extinguished frequencies is made adjustable.

2. In a radio receiver, a series of vacuum tubes, inductive and capacitive reactance elements between adjacent tubes, at least one of which is variable, other inductive and capacitive reactance elements between other adjacent tubes, at least one of which is variable and arranged to be adjusted to different values simultaneously with

the adjustment of the first-named variable reactance element, the first-named reactance elements tuning to two separate frequencies at the same time and passing signals of one frequency from one tube to the other and suppressing signals of the other frequency, the second-named reactance elements tuning to said one frequency and passing signals of said one frequency to the next tube and tuning also to a third frequency and suppressing signals of said third frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of one frequency are amplified and signals in the neighborhoods of each of the other frequencies are extinguished, the two frequencies at which signals are extinguished lying on opposite sides of the amplified frequency and at substantial distances therefrom throughout the frequency range of the receiver, and adjustable toward and away from each other.

3. A radio receiver having a series of stages, inductive and capacitive reactances in one stage tuning to two frequencies at the same time and passing signals of one frequency to the next tube and suppressing signals of the other frequency, inductive and capacitive reactances in another stage tuning to two frequencies at the same time and passing signals of one frequency to the next tube and suppressing signals of the other frequency, the tuning in the stages being overlapped so that signals in the neighborhood of one frequency are amplified in both stages, signals in the neighborhood of another frequency are extinguished in one stage and signals in the neighborhood of yet another frequency are extinguished in the other stage, and means for adjusting the amount of overlap.

4. In a radio receiver, means for coupling the output of one vacuum tube to the input of another vacuum tube comprising a capacitive reactance device, a tunable trap, said reactance device and said trap being in series with each other and located in both the plate circuit of the first tube and the grid circuit of the second tube so that, at a certain setting of the variable element of the trap, the elements of said trap, in combination with the said reactance device, affords series resonance to a signal of a certain frequency and therefore by-passes the signal without permitting it to be impressed on the grid of the second tube, said trap at another frequency acting as a coupling impedance, the voltage across it at said other frequency being impressed on the grid of the second tube.

5. In a radio receiver, a vacuum tube, an impedance device in the plate circuit of said tube, a tunable impedance trap device also in said plate circuit and in series with said first-named impedance device, a second tube having its grid connected to said plate circuit, said elements being so related that at any setting of the tunable impedance trap device a non-reactive path for a signal of one frequency is afforded and the signal is bypassed substantially without affecting the grid of the second tube, and for another frequency the impedance of this path is at a maximum and the signal is impressed on the grid of the second tube.

6. In a radio receiver, a vacuum tube, an impedance device in the plate circuit of said tube, a trap circuit also in said plate circuit and in series with said impedance device, said trap circuit being tunable so that at a certain setting its reactance may be made to cancel out the reactance of said impedance device and cause a minimum voltage drop across itself and said impedance device, and at another setting of the tunable trap circuit the impedance across it will be at a maximum and consequently the voltage drop will also be at a maximum, and a second tube so connected to the plate circuit that the voltage drop in said plate circuit across the trap and impedance device will be impressed on the grid of said second tube.

7. In a radio receiver, the combination, with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is variable, said means tuning to and passing a desired frequency and at the same time tuning to and rejecting an undesired frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to and passing the desired frequency and at the same time tuning to and rejecting another undesired frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of the desired frequency are amplified and signals in the neighborhoods of two undesired frequencies, one on each side of said desired frequency, are substantially extinguished.

8. In a radio receiver, the combination, with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is variable, said means tuning to and passing a desired frequency and at the same time tuning to and rejecting an undesired frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to and passing the desired frequency and at the same time tuning to and rejecting another undesired frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of the desired frequency are amplified and signals in the neighborhoods of two undesired frequencies, one on each side of said desired frequency, are substantially extinguished and the spacing between such substantially extinguished frequencies may be adjusted.

9. In a radio receiver, the combination, with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is variable, said means tuning to and passing a desired frequency and at the same time tuning to and rejecting an undesired frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to and passing the desired frequency and at the same time tuning to and rejecting another undesired frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of the desired frequency are amplified and signals in the neighborhoods of two undesired frequencies, one on each side of said desired frequency, are substantially extinguished and the spacing between such substantially extinguished frequencies is maintained serviceably constant as the said variable elements are adjusted to tune from one desired frequency to another desired frequency.

10. In a radio receiver, the combination, with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is va-

riable, said means tuning to and passing a desired frequency and at the same time tuning to and rejecting an undesired frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to and passing the desired frequency and at the same time tuning to and rejecting another undesired frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of the desired frequency are amplified and signals in the neighborhoods of two undesired frequencies, one on each side of said desired frequency, are substantially extinguished and the spacing between such substantially extinguished frequencies and said desired frequency is substantially equal.

11. In a radio receiver, the combination, with a series of vacuum tubes, of means between adjacent tubes comprising inductive and capacitive reactance elements, at least one of which is variable, said means tuning to and passing a desired frequency and at the same time tuning to and rejecting an undesired frequency, other inductive and capacitive reactance elements, at least one of which is variable, between other adjacent tubes, also tuning to and passing the desired frequency and at the same time tuning to and rejecting another undesired frequency, whereby the overall amplification characteristics of the series of tubes and reactances are such that signals in the neighborhood of the desired frequency are amplified and signals in the neighborhoods of two undesired frequencies, one on each side of said desired frequency, are substantially extinguished, and the spacing between such substantially extinguished frequencies and said desired frequency is substantially equal and serviceably constant as the said variable elements are adjusted to tune from one desired frequency to another desired frequency.

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