Sept. 3, 1935. E. A. BEANE ET AL 2,013,430

HIGH FREQUENCY AMPLIFIER

Filed June 17, 1924 3 Sheets-Sheet 1

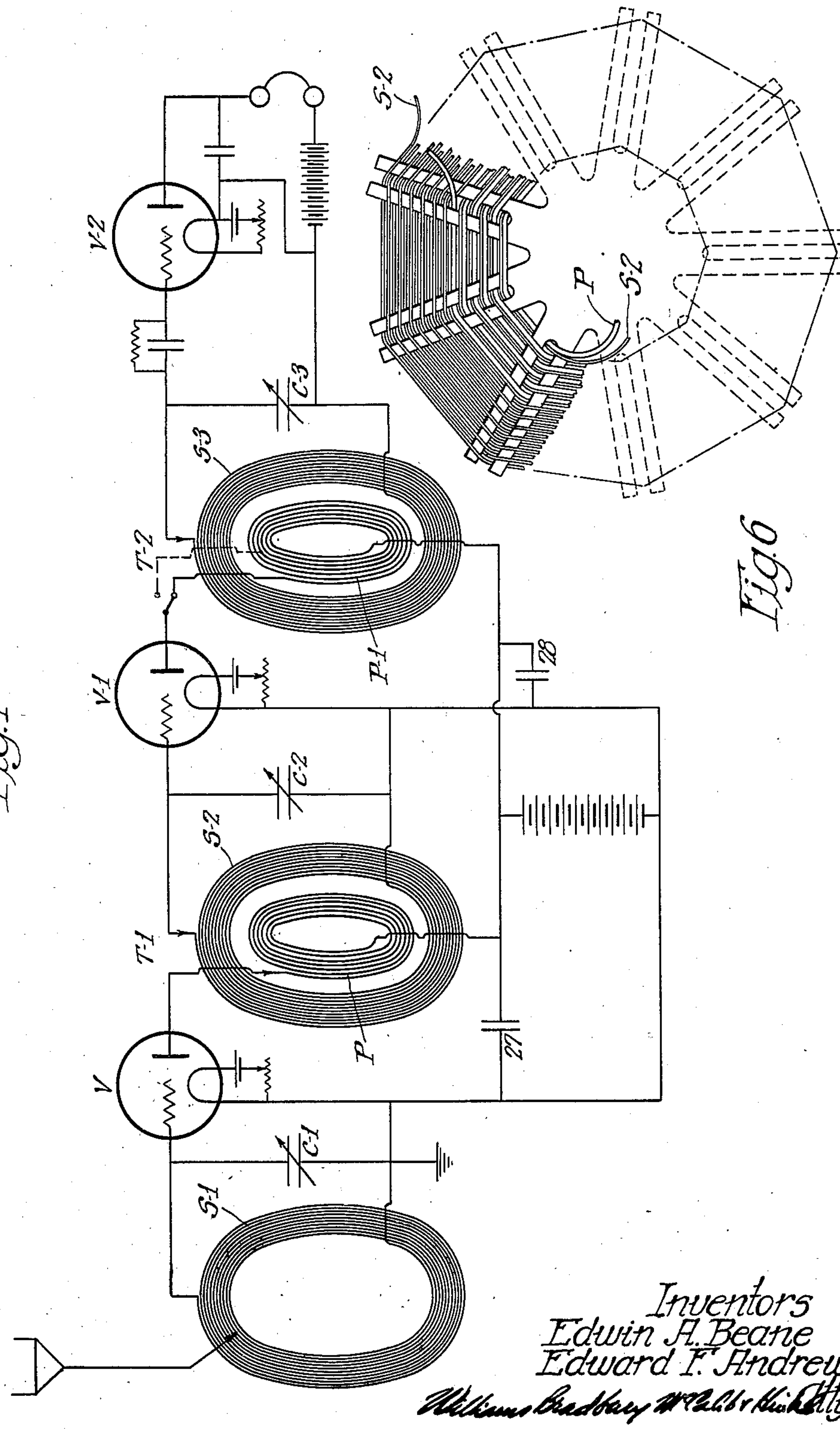

Fig. 6

Fig. 1

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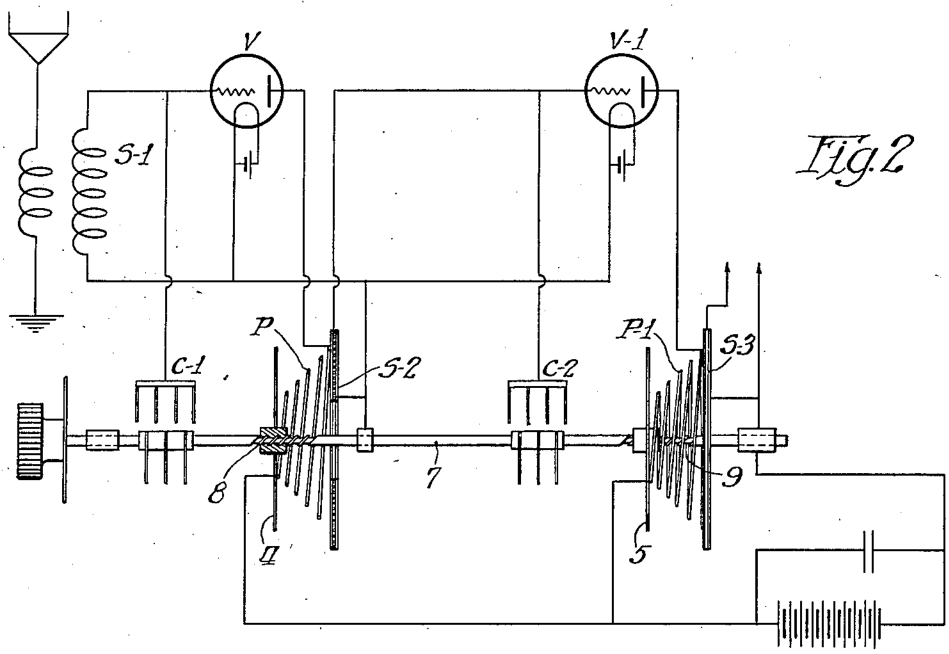

Fig. 2

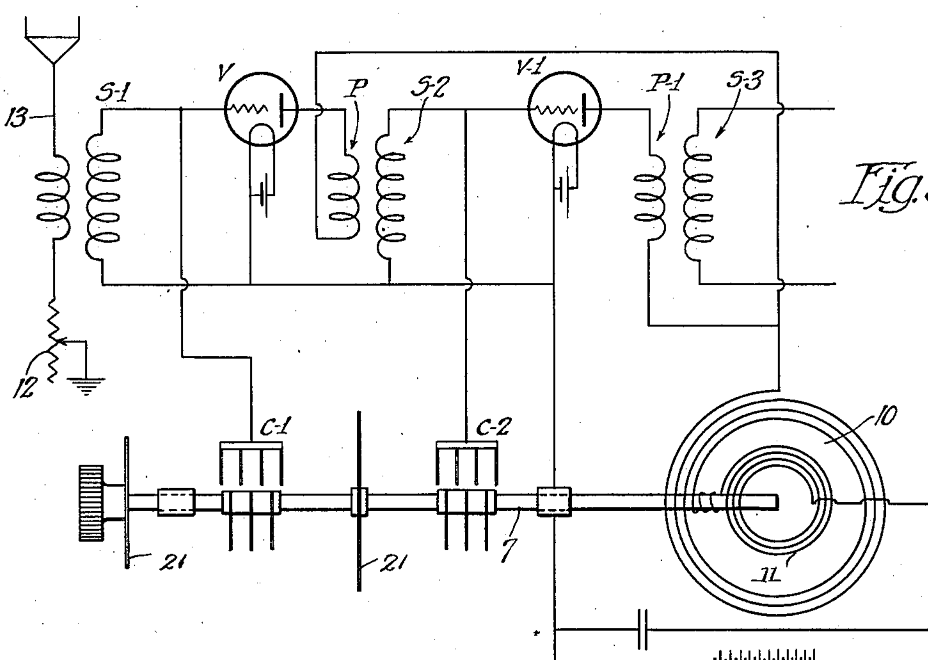

Fig. 3

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Filed June 17, 1924 3 Sheets-Sheet 3

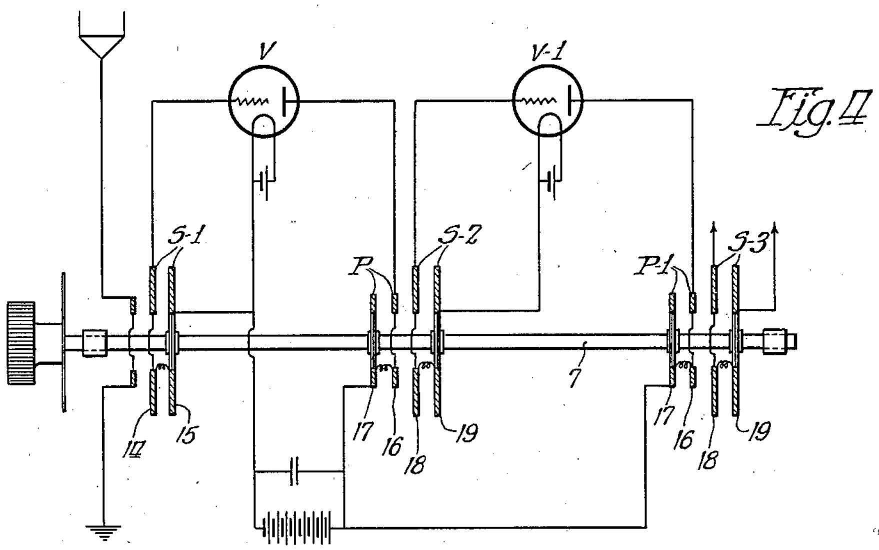

Fig. 4

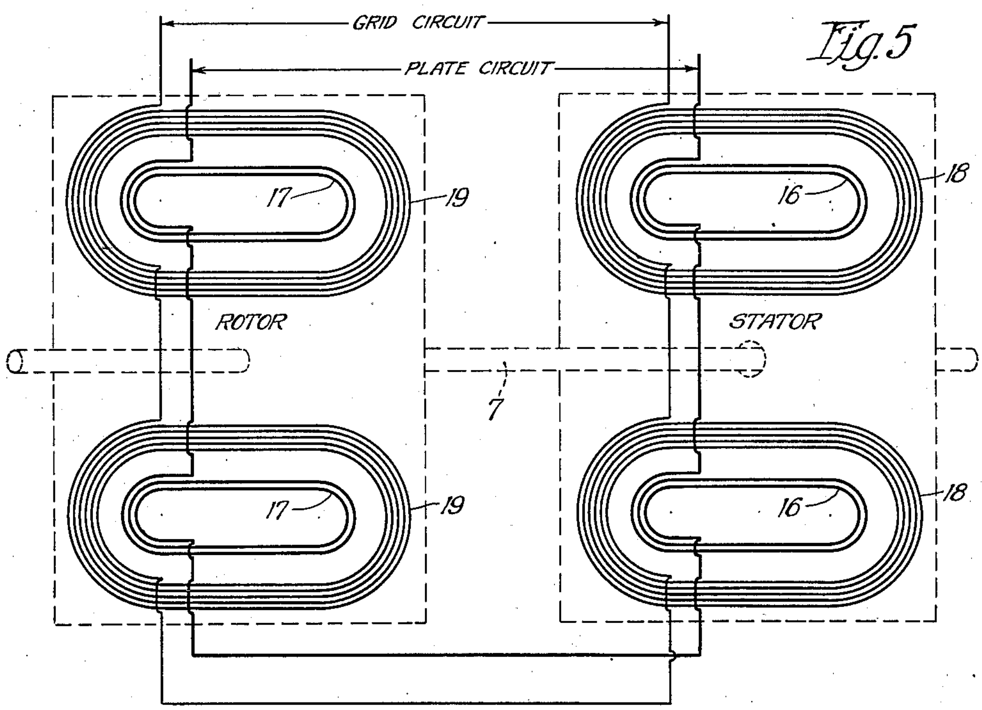

Fig. 5

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UNITED STATES PATENT OFFICE

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HIGH FREQUENCY AMPLIFIER

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Application June 17, 1924, Serial No. 720,549

5 Claims. (Cl. 179—171)

Our invention relates to circuits and apparatus for use with thermionic tubes and to the proportioning of the elements of said circuits and apparatus for securing efficiency in the amplification of high frequency electric currents, such, for example, as are encountered in radio reception. The object of our invention is to prevent sustained or otherwise objectionable oscillation, to secure stability in radio frequency amplifiers throughout a broad band or range of carrier frequencies and, at the same time, to secure efficient selective amplification without distortion and to accomplish these objects in a simple and effective manner.

Sustained oscillation is due to a transfer of energy from the output to the input circuits of thermionic tubes. This transfer of energy takes place in part through the capacitative coupling between the grid and plate element within the tube, and in part through the electro-static and electro-magnetic coupling between the transformer windings, wires, and other apparatus included in the input and output circuits of the tubes. The tendency of a three element thermionic tube to become a self excited oscillator is a fundamental characteristic of this device, when used in a radio frequency amplifier in which a plurality of tubes are coupled together by means of transformers. This is especially true when the thermionic tube in question is being used for the reception of signals at relatively high frequencies such, for example, as are used at the present time for broadcasting news and entertainment.

Sustained oscillation and instability occur when the amount of energy fed to the input circuit from the output circuit is such that the total amount of energy reaching the input circuit is equal to or greater than the total energy losses in the input circuit from all sources. At lower frequencies below 150 kilocycles the natural tendency of an efficiently designed, transformer coupled, radio frequency amplifier to sustained oscillation is not so great as at frequencies of 550 kilocycles or above such as used at present for broadcasting news and entertainment, the tendency to oscillate increasing as the receiver is tuned or designed to receive higher frequencies.

In a three element thermionic tube used as an amplifier, the grid circuit must control the plate circuit. The coupling existing between the plate circuit and the grid circuit limits the potential which can be built up across the plate circuit without so great a transfer of energy back to the grid circuit that the plate circuit will exercise a detrimental control over the grid circuit, thereby producing distortion and instability. This limit is somewhat lower for weak signals than for strong ones.

Even a transformer coupled, radio frequency amplifier, such as herein described, the plate circuit impedance of which is so designed as to avoid oscillation at a given frequency, will oscillate when the grid circuits of the amplifier are tuned to receive a signal at a certain sufficiently higher frequency, unless the inductance of the plate circuit be lowered or some equivalent effect secured as the frequency to be amplified is increased.

Our invention recognizes the inherent tendency toward sustained oscillation in transformer coupled radio frequency amplifiers, especially at relatively high frequencies and contemplates limiting this inherent tendency so as not only to prevent sustained oscillation at all times but also to secure stability over a relatively broad band of frequencies at which signals are received and to which the grid circuit is tuned.

With the foregoing object in view, our invention consists in proportioning the inductance in the plate, or output circuit, of thermionic tubes, used in radio frequency amplifiers of one or more stages, with respect to the frequency to be received and the various losses of the associated circuits, so that the frequency to which the plate or output circuit is resonant shall be at all times sufficiently different from the frequency of the carrier wave being received, and to which the grid circuit of one or more tubes are tuned, that resonance in the plate circuit never occurs or is never too closely approached at frequencies intended to be received on the grid circuit. Our invention also consists in preventing the transfer of electro-magnetic energy between the coils in the input and output circuits of the amplifier tubes and, at the same time, securing the maximum sensitiveness and amplification in the amplifier, consistent with stable operation over a broad band of wave lengths.

One simple embodiment by which our invention can be practiced consists in providing the primaries of radio frequency transformers, which primaries are connected in the plate circuits of radio frequency amplifying tubes, with such widely spaced turns and so few of them that the impedance across the plate circuit will be relatively low at the highest frequencies to be impressed upon the grid circuit of the amplifier tube, so intimately coupling this primary winding with the secondary winding of the transformer that the tuning of the circuit including the secondary winding will exercise a very great influence upon the actual impedance of this primary circuit, and at the same time mounting the transformers in non-axial positions in substantially parallel planes with their turns all running in the same direction but with the plate of the first tube connected to the outer end of the primary winding and the grid of the succeeding tube connected to the outer end of the secondary winding of the same transformer, all of the radio frequency transformers being connected in the same way, so that their fields oppose the transfer of electromagnetic energy from one to the other.

Several embodiments of our invention are illustrated in the accompanying drawings, in which

Figure 1 represents diagrammatically the circuits for two stages of radio frequency amplification, where the frequency to which the plate circuits are resonant is changed only automatically through the adjustment of the next succeeding grid circuit;

Figure 2 represents diagrammatically two stages of radio frequency amplification, where the frequency to which the plate circuits are resonant is changed by a manual adjustment of the inductances through a change in the mutual inductance between primary turns brought about by changes in the spacing of the primary turns on the radio frequency transformers, which change in spacing is brought about mechanically responsive to tuning one or more grid circuits;

Figure 3 represents diagrammatically a circuit arrangement similar to Figure 1, in which the inductances of one or more plate circuits are changed through the operation of a variometer mechanically connected to move with one or more of the tuning devices for the grid circuits;

Figure 4 represents diagrammatically a circuit similar to that of Figure 1, but in which vario-transformers are used for adjusting the impedance of the plate circuits responsive to changes in adjustment of the impedance of the grid circuits; and

Figure 5 represents a preferred form of vario-transformer.

Figure 6 represents a form of inductance found to be suitable for use in the system shown in Figure 1.

Referring specifically to Figure 1, the thermionic tubes V, V1 and V2 are the amplifiers and detector in a two stage radio frequency amplifying circuit in which S1, S2 and S3 are the secondaries and C1, C2 and C3, the variable condensers in the grid circuits of said amplifiers. P and P1 are the primaries located in the plate circuits of V and V1 respectively, the proper connection and winding of the transformers being indicated.

In Figure 2, the same circuit arrangement is shown as in Figure 1, and the same numbers designate similar parts. The primaries P and P1 are constructed so that their inductance can be varied as the capacity of condensers C1 and C2 are varied. When the shaft 7 is rotated, this is accomplished by the discs 4 and 5 moving toward the secondaries S2 and S3, by means of the threads 8 and 9 or other suitable mechanism. As the discs 4 and 5 approach the secondaries S2 and S3, the turns in the primaries P and P1 come closer together, thus increasing their mutual inductance. It will be seen that the primaries P and P1 are wound in the form of volute springs. The condenser C1 and the disc 4 can be separated from the condenser C2 and the disc 5 and operated by separate controls, if desired. When the connections to the transformers are made as shown in Figure 2, it is desirable that the primary and secondary turns run in the same direction. This causes the magnetic field around S1 to oppose the transfer of electro-magnetic energy to it from P and S2 to oppose a similar transfer from P1.

Figure 3 is similar to Figure 2, except that a variometer 10 varies the inductance of both primaries P and P1. This variometer has a relatively small inductance and a relatively small inductance change; its rotor 11 may be mounted on the shaft 7 which may be common to condensers C1 and C2. A metallic shield 21 carried upon the shaft 7 prevents coupling between the condensers C1 and C2. When the capacity is minimum in condensers C1 and C2, the inductance of the variometer 10 is also at its minimum. When the inductance in the primary must be kept very low, this arrangement is not as suitable as that shown in Figure 2 as it is desirable to keep all of the inductance in the primaries where it will be effective in securing the proper coupling to the secondaries. A variable resistance 12 may be included in the antenna circuit 13, which is used only when antennas of very low resistance are employed and when the frequency being received is very high. This resistance is only varied when the antenna is changed or when it is desired to receive very high frequencies. With the ordinary antenna, it is not required except at extremely high frequencies and it is not necessary even with a loop antenna of very low resistance at frequencies not higher than 1350 kilocycles.

Figure 4 represents a similar circuit to Figures 2 and 3, except that disc type variometers are used for tuning the secondaries S1 and S2 and the primaries P and P1. In this case as in those shown in the other figures, the direction of the primaries and secondaries relative to the connection of their various ends should be made so that their magnetic fields will oppose any energy transferred from P1 to S2, or P to S1. The element 14 of S1 is stationary while 15 rotates; the element 16 of P is stationary while 17 rotates. The element 18 of S2 is stationary while 19 rotates, etc. These coils of wire may be wound upon spider web forms; one coil above and one coil below the center as shown in Figure 5. It will also be seen that the coils 16 and 18 may be wound on the same form and likewise 17 and 19 as shown in Figure 5. This forms a flat or pancake type of variable transformer with a primary consisting of a very small number of turns, half on the rotor element, and half on the stator element, and a secondary consisting of a relatively large number of turns, half on the rotor and half on the stator. Varying the position of the stator relative to the rotor changes the inductance in the primary and secondary simultaneously. By varying the number of primary turns relative to the number of secondary turns any desired variation of inductance in the primary relative to the variation of inductance in the secondary may be had. Although only two stages of amplification have been shown, it will be understood that more stages may be added if desired, or that only one stage may be used.

If desired, the manual means for varying the plate circuit inductance with changes of frequency to be amplified, may be applied to only one of the plate circuits, and may be carried out in one or more large steps as shown in dotted lines in Fig. 1, instead of gradually as in Figs. 2, 3, and 4.

The operation of all of the foregoing embodiments of our invention and other embodiments coming within the scope thereof may be explained by the following theoretive consideration, which is here included because of the absence in published form of any concise statement of these theories, the understanding of which is important to a thorough understanding of our invention.

The sensitiveness and efficiency of a radio frequency amplifier depends, among other things, upon the impedance of the plate, or output circuit of the thermionic tubes, to the frequency of the current being received upon the input circuits of the tubes. If the output circuit is tuned to resonance at the frequency of current in the input circuit, the impedance across the output circuit increases at that frequency and the current in the primary of the transformer also increases. As the impedance of the output circuit increases, the voltage across that circuit increases, and the energy which is transferred into the input circuit of the same tube is also increased. When the impedance across the output circuit reaches a value sufficiently great, that the energy transferred from the output circuit to the input circuit, is equal to or greater than all losses in the input circuit, sustained oscillations and instability occur. Inasmuch as the transfer of energy from the output circuit to the input circuit increases as the impedance across the output circuit to the frequency of the carrier wave being received increases, it is apparent that by reducing the inductance in the output circuit, this circuit can be brought sufficiently out of resonance to the frequency of the current in the input circuit so that the voltage across the plate circuit, and therefore the energy transferred from the plate circuit to the grid circuit, will be limited, at least to such an extent that substantially less energy will be transferred to the grid circuit from the plate circuit than is dissipated in the grid circuit. The plate circuit must be kept sufficiently away from resonance so that it is removed by a substantial distance from this critical condition if stability in the circuit and freedom from distortion and noises due to more or less sustained oscillation is to be secured. It is, of course, desirable to maintain the current in the transformer primary in the plate circuit as high as possible consistent with the elimination of undesired oscillation so as to transfer the maximum energy to the secondary in the grid circuit of the succeeding tube. It is therefore desirable to operate the plate circuit as close to resonance as possible consistent with stability over the band of frequencies to be received, in order to secure the maximum radio frequency relay amplification.

It will be seen that the fundamental tendency of radio frequency amplifiers to oscillate, particularly at high frequencies, presents itself as the factor limiting radio frequency relay amplification at these frequencies. In order to prevent this oscillation, losses must be voluntarily imposed in some manner upon some one or more of the associated circuits so as to prevent the tubes from becoming self excited oscillators. It is believed that the reason for the greater efficiency of radio frequency amplification at the lower frequencies is that it is possible to operate a low frequency amplifier with its output circuits much closer to resonance without producing undesired oscillations than it is with similar amplifiers when the frequencies are higher. It is one of the outstanding advantages of this invention to impose these losses which are necessary to prevent oscillation in the form of reactance in the plate circuit at which point and in which form the losses appear to be least objectionable.

Heretofore, so far as we are aware sustained oscillation has always been prevented and stability secured in tuned transformer coupled radio frequency amplifiers by imposing artificial losses, or some equivalent effect upon the grid circuit. This has been done in some cases by means of a variable resistance in the grid circuit and by varying the grid bias. Another general method which is susceptible to a number of variations is to transfer energy to the grid circuit of such phase as to oppose the normal energy in the grid circuit. This has an effect which is similar to the method previously described inasmuch as it reduces the effective energy in the grid circuit thereby reducing the energy in the plate circuit. Our invention differs from all previously employed methods for preventing sustained oscillation and securing stability in that it prevents the transfer of energy through the grid plate capacity solely by maintaining the impedance across the plate circuit sufficiently low so that the voltage built up across this circuit is not great enough to cause sustained oscillation or instability even though the losses in the grid circuit are so low that the tube would immediately become a self excited oscillator if resonance, which is coincident with maximum impedance across the plate circuit was anywhere nearly approached. The output circuit of previous radio frequency amplifiers have been constructed with inductances so high relative to the frequency of the signals which they were designed to receive and with so much electro-magnetic coupling to the input circuit that they would normally oscillate violently unless prevented from doing so by the introduction of some device for producing losses or an equivalent effect in the grid circuit. In our invention the inductance in the plate circuit is not only reduced to the critical point at which oscillation is just prevented without the introduction of artificial losses in the grid circuit and in which condition a disturbance will throw the circuit into more or less sustained oscillation but the inductance of the plate circuit is reduced sufficiently to bring the amplifier substantially past this critical point so that stable operation is secured over a relatively wide band of wave lengths without the use of a separately operated control for maintaining this condition. The reduction of plate circuit inductance which we employ to prevent maximum impedance across the plate circuit, also reduces the magnetic field around the primary of the transformer in the plate circuit thereby reducing the tendency for electro-magnetic energy to be transferred to the secondary of the preceding transformer in the grid circuit of the same tube. The transfer of electro-magnetic energy from the plate circuit to the grid circuit is further prevented by the arrangement of these circuits so that their respective magnetic fields oppose the transfer of energy from one to the other.

We believe our method for accomplishing the above object to be superior to that in which energy of reverse phase is transferred to the grid circuit as proposed by Hartley in Patent No. 1,183,875, Rice in Patent No. 1,334,118, or Hazeltine in Patents No. 1,450,080 and No. 1,489,228 in that it is more simple, more direct, easier to construct and control and also for other reasons among which is that by our method the original transfer of energy is prevented instead of a transfer occurring and being afterwards neutralized by a more or less equal and opposite E. M. F. Our method is also superior to the grid resistance or grid biasing method above referred to for the following reasons:

If losses introduced to prevent sustained oscillation take the form of resistance, they necessarily increase the damping of the circuits, broadening their tuning and making it difficult to separate signals of slightly different frequencies. For this, and also for other reasons, it is far less objectionable to introduce any losses necessary to prevent sustained oscillation by varying the reactance rather than by increasing resistance. We have also found that it is preferable to introduce these reactance losses in the plate circuit. There is a larger amount of energy in the plate circuit which permits of the use of larger values for its control. Therefore, the balancing of values for accomplishing the desired result without the introduction of excessive losses is far less critical.

Although it is desirable to reduce the resistance of all circuits, employed in the amplifiers herein described, a certain amount of resistance is nevertheless unavoidable. This is not altogether objectionable as it would be very difficult, if not impossible, to secure stable operation in such an amplifier were it not for the presence of some appreciable resistance. The lower the resistance becomes, particularly of the grid circuit, the greater the variation of the plate circuit reactance required to secure stability. Also the higher the frequency of signal being received, the greater the energy transfer from the plate circuit to the grid circuit through a given coupling. It is conceivable that at very high frequencies and with all resistance losses reduced to a very low point, a condition might be arrived at under which the above described method would not be adequate for securing stability. Should such a condition be encountered, we have shown means by which it can be overcome by placing a variable resistance in the antenna circuit. It must be borne in mind, however, that this expedient should only be adopted after the method herein described for preventing oscillation has been applied as far as possible, so as to make necessary the introduction of only the smallest possible amount of resistance to secure the desired degree of stability.

We have found experimentally, however, that at frequencies of from 1350 to 550 kilocycles, it is possible and desirable to reduce all losses, except plate circuit reactance losses, to the lowest practicable values, and still prevent undesired oscillation by the method of reducing plate circuit inductance as herein described, even when loop antennas of very low resistance are employed as collectors.

A further feature of this invention is the maintenance of radio frequency amplifier herein dealt with in its most sensitive condition consistent with stable operation while it is tuned to receive signals of different frequencies covering a relatively wide band such as the various frequencies now being used for broadcasting news and entertainment. It is a well known fact that previous radio frequency amplifiers of this type tend to oscillate more and require the introduction of greater losses to prevent this oscillation when they are tuned to receive signals at higher frequencies than when they are tuned to lower frequencies. It has been supposed that this was due to a more advantageous inductance capacity ratio at these frequencies in the grid circuit resulting in a higher potential across the grid circuit. We have discovered, however, that the greater tendency to oscillate at the higher frequencies is not due in any large measure to the above mentioned cause but principally to the fact that, the transfer of energy from the plate circuit to the grid circuit increases as the frequency increases. There are two reasons for this; first, a greater amount of energy can be transferred through a given coupling, other conditions remaining the same, at a higher frequency than at a lower frequency, and second, when the plate circuit is slightly above resonance at a lower frequency, and the grid circuit is then tuned to receive a signal at a higher frequency without any change of the values connected in the plate circuit, the plate circuit will be closer to resonance at this higher frequency which will result in a higher voltage across it and a greater transfer of energy to the grid circuit. If a radio frequency amplifier of the type described is to be maintained in the desired state of maximum sensitivity and responsiveness to weak incoming signals (consistent with stable operation over a relatively broad band of frequencies, the impedance of the plate circuit to the higher frequencies should be reduced as the grid circuit is tuned to receive higher frequencies thus preventing an increase in the transfer of energy from the plate circuit to the grid circuit at the higher frequency. This can be done in two ways; first, by reducing the physical inductance in the plate circuit as the frequency of the signal being received increases, and second, by coupling the plate circuit of one tube to the grid circuit of the succeeding tube as closely as possible, so that when the grid circuit of the succeeding tube is tuned to a higher frequency, this effect will be imposed in the greatest possible measure upon the plate circuit of the preceding tube. This latter method, while very useful, does not with the degree of coupling so far obtained prevent the tendency toward oscillation increasing slightly as the frequency increases. However, as long as the antenna resistance is fairly high, very satisfactory results can be obtained by this method. We have also found another effect which can also be made to act against the greater tendency toward oscillation with increases in frequency. This can be accomplished by arranging the connections and turns in the coils contained in the output and input circuit of an amplifier tube in such a way that a very small amount of energy is transferred electromagnetically from the output circuit to the input circuit of such phase as to oppose the current in the input circuit. Now, as the energy transfer through a given coupling increases with the frequency, whatever transfer of negative energy occurs from the plate coil to the grid coil under the above mentioned conditions will oppose the increase in the tendency toward oscillation as the frequency increases. It must be understood that the particular effect above described is not essential to a satisfactory operation of this invention, but constitutes a means of opposing the increase in the tendency toward oscillation at higher frequencies which may be useful under certain special conditions.

There is still another method by which the increase in the tendency to sustained oscillation and instability as the frequency increases can be minimized or eliminated. This consists of placing a greater amount of inductance or capacity in the plate circuit than the amount required to produce resonance at the frequency being received. A point at which the plate circuit is not resonant to the frequency being received on the grid circuit can be thus reached by adding to the inductance in the plate circuit as well as subtracting from it. If this inductance is increased sufficiently above resonance so that oscillation is prevented at the lowest frequency to be received, tuning the grid circuit to and receiving a signal of higher frequency will now bring the plate circuit still further away from resonance than before thereby decreasing the potential across the plate circuit and tending to decrease the transfer of energy to the grid circuit. This effect would then work against the greater transfer of energy through a given coupling at higher frequencies. In this way the two effects may be made to more or less balance one another thereby minimizing or eliminating the increase in the tendency toward oscillation as the frequency increases. There are, however, two objections to this method, first, the increase in the inductance across this circuit and it is conceivable with a large coil that an appreciable voltage might be built up across the plate circuit due to the impedance of the inductance coil. This could be minimized by using as small a coil as practicable with a large condenser across it. Second, this method necessitates having a large inductance in the plate circuit, as large or larger than in the grid circuit of the suceeding tube. Unless the inductance in the plate circuit was separated into two inductances, only one of which was used for the transformer primary a step down transformer would result instead of a step up transformer with more secondary turns than primary turns. A step up transformer is furnished naturally by the type of transformer in which the inductance of the plate circuit is reduced by reducing the primary turns. This step up transfomer effect is highly desirable as it considerably increases the voltage amplification over lower ratio step up transformers or other coupling means which do not provide in themselves a high voltage amplification, it also secures a high degree of selectivity.

It is an essential feature of this invention to reduce the coupling between the plate circuit and the grid circuit of the amplifier tubes which tends to produce undesired oscillation, either by the method herein described or by the reduction of the physical coupling of these circuits through the tubes transformers and associated circuits to the lowest point possible. The more completely this coupling is reduced, the less reduction will be necessary in the inductance of the plate circuits to prevent undesired oscillation, and inasmuch as the reduction of plate circuit inductance also increases the plate circuit reactance losses at the frequency being received and to which the grid circuit is tuned, and as it is desirable to maintain these losses as low as possible consistent with stable operation, it will be seen that great care should be taken to avoid the reduction of plate circuit inductance beyond the amount necessary to secure stability. It is also desirable to avoid the unnecessary reduction of plate circuit inductance for the reason that it reduces the electromagnetic coupling between the plate circuit of one tube and the grid circuit of the succeeding tube. It is desirable to maintain this coupling quite close, at least in the form of this invention where the physical inductance in the plate circuit is not varied.

By connecting the proper end of the primary coil in the plate circuit of a tube in an amplifier of the type described, to the plate, with relation to the end of the secondary coil in the grid circuit of the same tube which is connected to the grid and by maintaining this proper connection in all the coils and by fixing the coils in the proper position, a condition can be secured by which the field of any transformer, or variotransformer used in the amplifier can be made to oppose the field of the transformer on either side of it to just the proper degree so that the fields of these transformers will not interlink and there will be no transfer of electromagnetic energy from the plate circuit to the grid circuit of the amplifier tubes. This condition of zero magnetic coupling is the desired condition and when this is attained it is only necessary to compensate for electrostatic coupling between the plate and grid circuit by reducing plate circuit impedance. We have found with flat spider web transformers four inches in diameter with sixty three turns in the secondary and six to eight turns in the primary, that good results are obtained when the transformers are placed parallel to one another on a common axis with a separation of approximately six and one quarter inches. When all the turns on all the transformers run in the same direction, all the grids should be connected to the outside of the secondary winding and all the plates to the outside of the primary windings. If the coils are put at right angles to one another or if one of them is turned through 180 degrees without at the same time turning the other two, sustained oscillation will immediately result and can only be checked by a very great reduction in the number of primary turns. It is possible to also place these coils in non-axial positions in parallel planes and still maintain the desired condition, but if the coils are placed end to end in the same plane, even with a considerable spacing, oscillation will commence. The primary turns may be wound if desired, in the opposite direction from the secondary turns. Under these circumstances the inner end of the primary windings should be connected to the plate, all other conditions remaining the same. By placing the transformers at the proper distance, one from the other and rotating them simultaneously to more or less axial positions, the desired condition of maximum stability can be obtained. This can likewise be accomplished when the coils occupy axial positions by varying the distance between them.

Relative to the embodiment of this invention in which the physical inductance of the plate circuit is not changed with the frequency, it is important that the inductance of the output circuit be made such as to avoid objectionable oscillation at the highest frequency to be received. It is also desirable to impose the least possible reactance losses in the plate circuit at the frequency of the signals being received consistent with stability. As the grid circuit is tuned to receive signals of lower frequency, the action of the succeeding grid circuit upon the plate circuit to which it is coupled will be such as to prevent in a measure the increase of the reactance losses of the plate circuit at the lower frequencies being received. This effect will be greater the closer the coupling between the primary and secondary of the transformers employed.

It is therefore desirable to produce a transformer which shall have the closest possible coupling between the primary and secondary and at the same time maintain a low primary inductance. We secure these characteristics by constructing our air core transformers with a small number of primary turns which are separate one from another preferably by being interwoven with the secondary turns, so as to space the primary turns and thereby reduce their mutual inductance and distributed capacity. Any number of secondary turns desired may be wound between one primary turn and the next. This arrangement secures a very intimate relation of the primary to the secondary turns and makes it possible to secure a greater length of primary turns in direct contact with the secondary turns, at the same time maintaining the minimum primary inductance consistent therewith.

To take full advantage of our invention all electrical losses except plate circuit losses purposely imposed should be reduced as far as possible. We therefore prefer the spider web type of coil for transformers with a minimum of dielectric material necessary to support the wire. We have devised a form of spider with a greatly reduced amount of dielectric material and also an easy way of winding these transformers consisting of winding the primary and secondary turns together as if they were one wire, then cutting off the primary at the desired point and continuing the secondary to the outside of the spider.

We have found that with the form of this invention in which the physical inductance in the plate circuit is not changed, that when the transformers are so constructed that the reactance losses of the plate circuit containing the primary of the transformer is as low as possible at the lowest frequency to be received, consistent with stable operation that when the amplifier is tuned to a higher frequency (a change for example of from 550 to 1350 kilocycles), the tendency to oscillate is greater at the higher frequencies despite the action of the secondary circuit upon the primary circuit.

Our invention, therefore, contemplates where desired means for varying the physical inductance in the plate circuit so that it becomes progressively lower as the amplifier is tuned to receive higher frequencies. By a slight variation of the very small inductance in the plate circuit as the grid circuit control is adjusted, the amplifier may be maintained in that desirable state just sufficiently below the critical condition in the plate circuit previously referred to while the grid circuit tuning is changed over a relatively broad band of frequencies such, for example, as are now in use for broadcasting music and entertainment.

This changing of the frequency to which the plate circuit is resonant by changing the physical values connected into the plate circuit can be accomplished either by a variable condenser or by a variable inductance either of which can be operated by a separate control or by being connected to the controls used for tuning any or all of the grid circuits. Where this form of the invention is employed, we prefer to use a variable inductance which constitutes the primary of an air core transformer and this inductance is varied in the desired manner by connecting it either directly or through a proportioning mechanism to the control which operates one or more tuning devices used for tuning one or more of the grid circuits of the amplifier tubes.

We claim:

1. In a radio receiver provided with at least two cascaded electron discharge tubes, a source of signal energy coupled to the input circuit of the first of said tubes, a variable condenser in the input circuit comprising stator and rotor plates, a transformer coupling the output electrodes of the first tube to the input electrodes of the second tube, the transformer comprising an immobile secondary coil and an adjustable primary coil wound in substantially spiral manner, a variable condenser connected across the secondary coil and comprising stator and rotor plates, a shaft supporting the rotor plates of both condensers whereby adjustment of the shaft changes the tuning of the receiver, and means, actuated upon adjustment of the shaft, for varying the spacing between the turns of the primary coil thereby varying the inductance of the primary coil with tuning changes.

2. In a receiver as defined in claim 1, said primary and secondary coils being arranged coaxially of said shaft, and the last means comprising a reciprocatory member.

3. In a receiver as defined in claim 1, said secondary coil being disc-shaped, said primary coil being arranged co-axially of the secondary coil, and the said last means comprising a plate in threaded relation with said shaft.

4. In a radio receiver provided with at least two cascaded electron discharge tubes, a source of signal energy coupled to the input circuit of the first of said tubes, a variable condenser in the input circuit comprising stator and rotor plates, a transformer coupling the output electrodes of the first tube to the input electrodes of the second tube, the transformer comprising an immobile secondary coil and an adjustable primary coil wound in the form of a volute spring, a variable condenser connected across the secondary coil and comprising stator and rotor plates, a shaft supporting the rotor plates of both condensers whereby adjustment of the shaft changes the tuning of the receiver, and means, actuated upon adjustment of the shaft, for varying the spacing between the turns of the primary coil thereby varying the inductance of the primary coil with tuning changes.

5. In a receiver as defined in claim 4, said varying means comprising a disc arranged in operative association with said shaft in such a manner that the said spring is compressed between the disc and said secondary coil upon adjustment of the shaft in a given direction.

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