July 5, 1938. M. G. CLAY 2,122,558

SHORT WAVE RADIO FREQUENCY AMPLIFIER SYSTEM

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Fig. 1

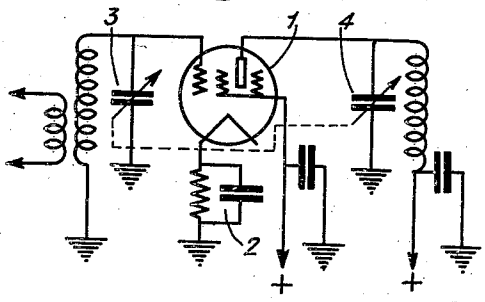


Fig. 3

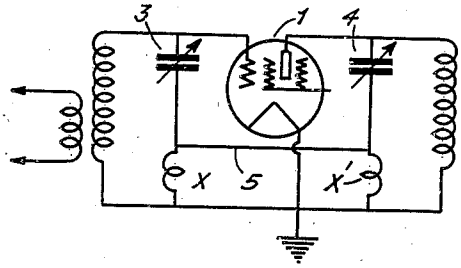


Fig. 2

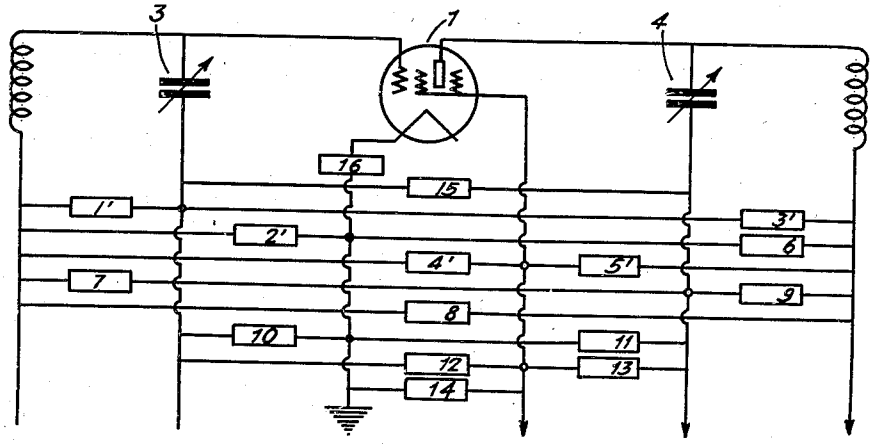


Fig. 4

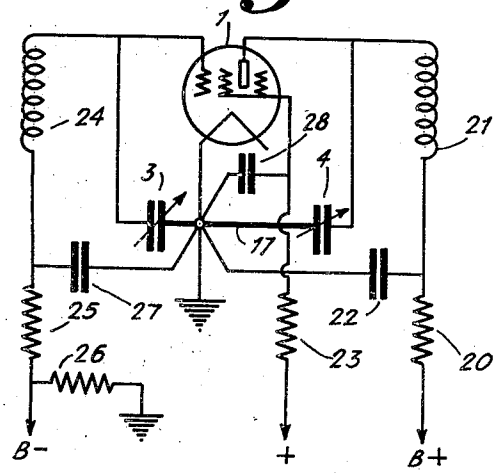
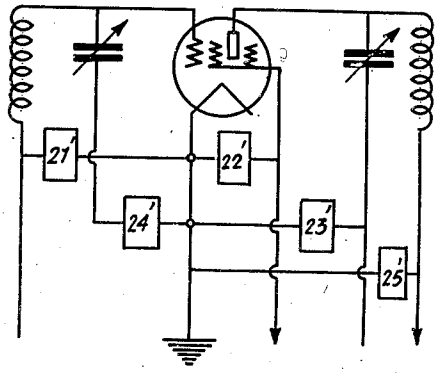


Fig. 5



INVENTOR
MURRAY G. CLAY
BY H. G. Grover
ATTORNEY

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Fig. 7

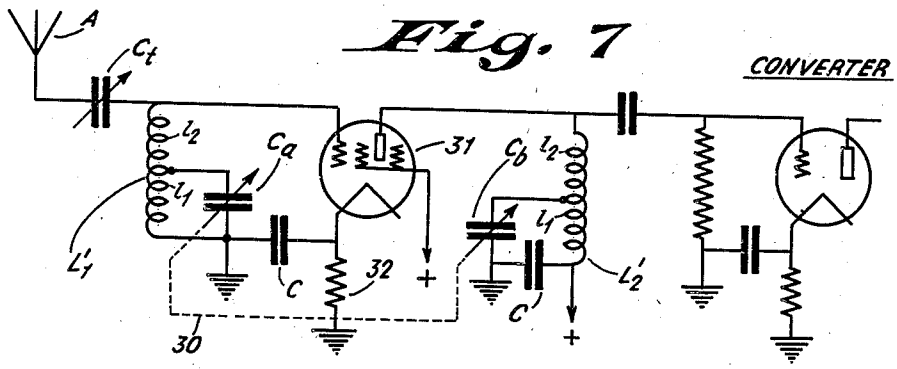


Fig. 8

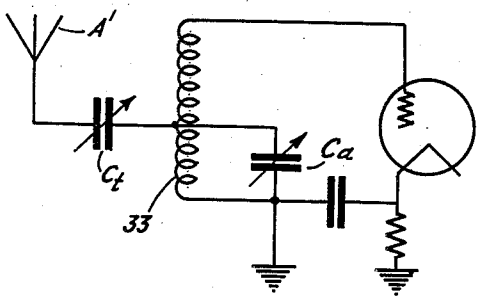


Fig. 6

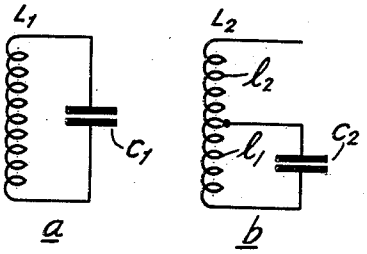
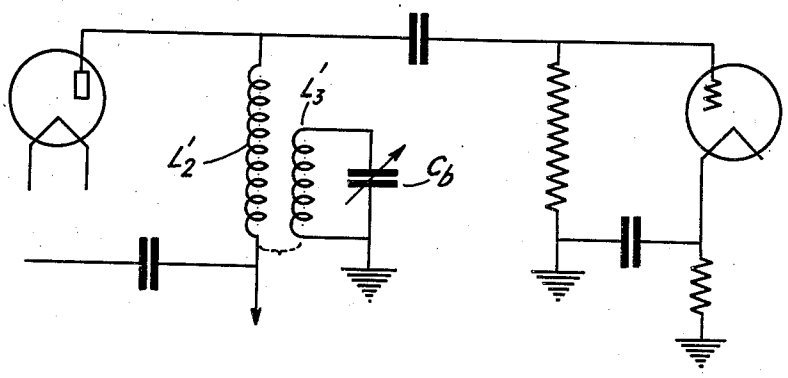


Fig. 9



INVENTOR
MURRAY G. CLAY
BY H. G. Grover
ATTORNEY

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Fig. 13

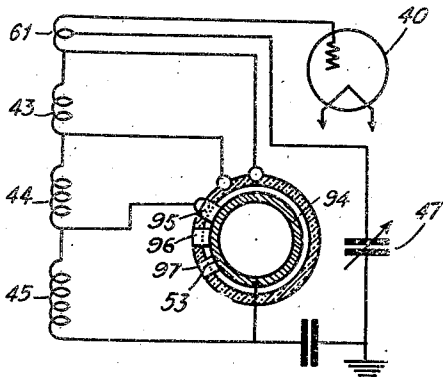


Fig. 9-A

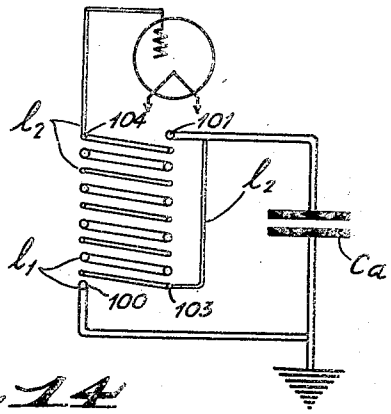
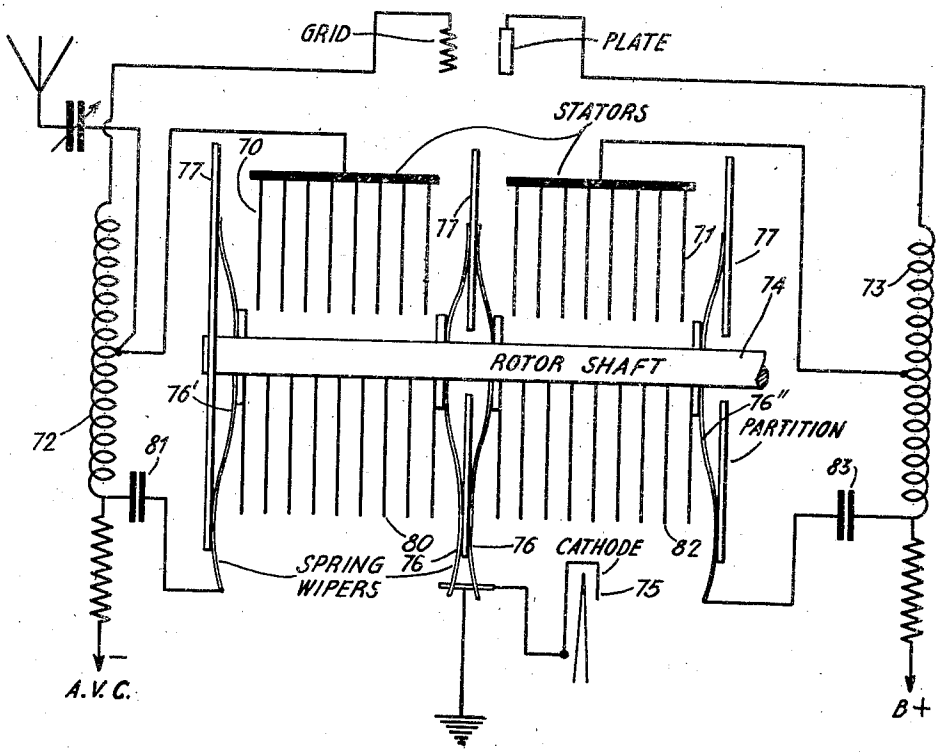


Fig. 14



INVENTOR
MURRAY G. CLAY

BY H. G. Grover

ATTORNEY

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Fig. 10

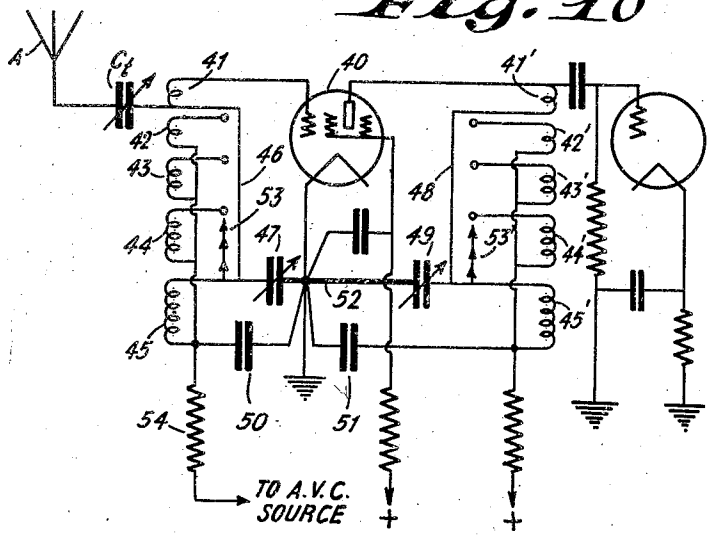


Fig. 11

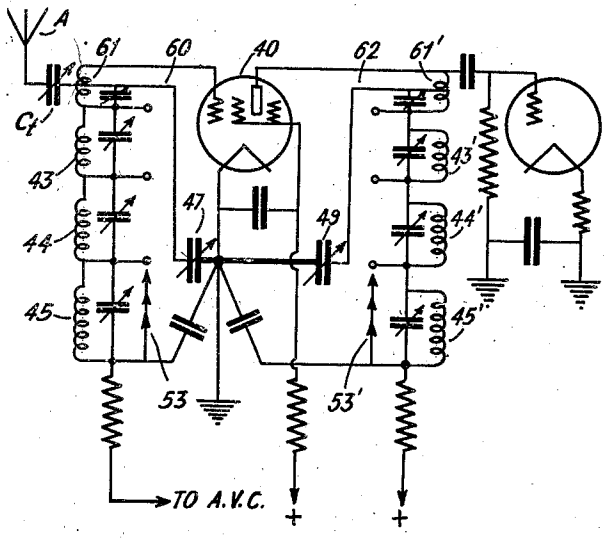
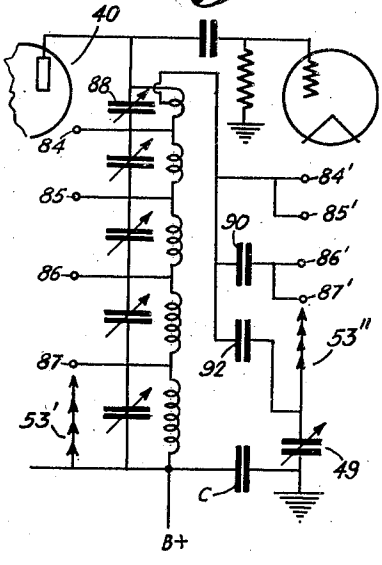


Fig. 12



INVENTOR
MURRAY G. CLAY
BY H. G. Grover
ATTORNEY

Patented July 5, 1938

2,122,558

UNITED STATES PATENT OFFICE

2,122,558

SHORT WAVE RADIO FREQUENCY AMPLIFIER SYSTEM

Murray G. Clay, Hasbrouck Heights, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application May 21, 1934, Serial No. 726,634

9 Claims. (Cl. 179—171)

My present invention relates to tuned radio frequency amplifier systems, and more particularly to such systems which are stable and of high gain when used for short wave reception.

Heretofore at the higher radio frequencies, particularly above 1½ megacycles, it has been difficult or, in the case where ganged condensers having a common, metallic, electrically conductive rotor are used, practically impossible to operate relatively high gain tuned circuits without objectionable instability, noisy regeneration or intolerable oscillation. A tuned radio frequency amplifier adapted to operate in a short wave range with a really high gain, such as an amplifier stage with "low loss", tuned grid and plate circuits, has been thought practically impossible to construct without encountering the aforementioned objections. When a radio frequency amplifier stage, operating in the short wave range, precedes a super-regenerative circuit, it is of paramount importance that coupling between the plate and grid circuits be practically eliminated because of the considerable signal voltage built up in the plate circuit of the radio frequency amplifier.

Accordingly, it may be stated that it is one of the principal objects of this invention to provide a short-wave, tuned radio frequency amplifier wherein impedances common to both the input and output circuits of the amplifier are eliminated, such impedances generally being responsible for both regeneration and degeneration and including such elements as the ganged condenser rotors, cathode bias resistors and the like; it being, additionally, stated that the invention also permits escape from random highly undesirable coupling between input and output circuits of amplifiers, or between components of one or more amplifiers, by completely eliminating the chassis currents at the frequency of the signal which is being amplified.

Another important object of the invention resides in the elimination of all feed back between component parts of a short-wave, radio frequency amplifying system, and wherein the feed back is substantially limited to that resulting from inter-electrode capacities and electronic coupling in the vacuum tubes themselves, the method of elimination essentially comprising connecting the return circuits of all circuit elements to the cathode circuit whereby no impedance of the system can be common to the grid and plate circuits.

The prior art further teaches that, in general, higher efficiencies are obtained using low loss components when a minimum capacity and a maximum inductance are used to attain tuning. However, practical obstacles have limited the attainment of the full benefits of this principle, especially for short wave work. Sets adapted to cover the broadcast band, as well as the short wave range, must have relatively high capacity condensers suitable for tuning over the broadcast range, but the use of these same condensers for short wave tuning results in low gain due to the resulting unfavorable inductance to capacity ratio, it being understood that when relatively large condensers are employed at short waves, the inductances must, with usual circuits, be small. From the standpoint of the cost of production, it is very desirable to use the same tuning condensers for all ranges of tuning of a set.

Hence, it may be stated that it is another important object of the present invention to provide a tuning system for operation on short waves, as for example in all-wave sets, the term "all-wave" being used to designate a set having a plurality of tuning ranges, the tuning system employing a much larger inductance than would normally be used with a practical tuning capacitance and utilizing the output or input, or both, from the total inductance, the capacitance being connected across only a portion of the inductance.

A low inductance to capacity ratio is particularly bad in an antenna circuit, because it reduces the antenna circuit gain, which ultimately limits the maximum useful sensitivity of any receiving system. Antenna circuits have previously been devised employing special low capacity condensers, instead of using the condensers of the broadcast range, but even such circuits have not possessed the advantages in performance obtainable by use of this invention. Separately tuned, high gain antenna systems have the disadvantage that, unless the user happens to tune the antenna circuit very closely to the frequency of the desired station and in close tuning alignment with other circuits, a desired station may be completely missed, unless the signal energy from it is strong and antenna circuits which afford high gain at short waves and which are adapted for accurate, uni-control tuning with other tuned circuits of a receiver have not heretofore been available.

Another object of the invention is to provide a high gain antenna circuit, which, using large ganged variable capacitors desirable for broadcast coverage, will track or very nearly track for customary systems now in use, so that stations will not be missed due to the antenna circuit

not being tuned exactly, this system being advantageous even in receivers which embody additional small variable capacitors in an attempt to maintain high inductance values for short wave reception, since under these conditions the present invention makes practical the use of even higher inductance values.

Still another object of the invention is to provide a tuning system for a short wave amplifier wherein there is permitted a closer approach to optimum matching of the plate circuit impedance with the internal plate resistance of modern high resistance tubes, this being an important advantage since with such tubes the gain or amplification is almost proportional to the magnitude of the impedances in their output circuits, the invention additionally affording a better matching of antenna circuit impedance to that of a tuned input circuit associated therewith and consequently a more efficient transfer of energy from an antenna having a high effective resistance, such as the usual antenna used for high frequency reception.

The novel features which I believe to be characteristic of my invention are set forth in particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, will best be understood by reference to the following description, taken in connection with the drawings, in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect. In the drawings:—

Fig. 1 shows a conventional, tuned radio frequency amplifier of the prior art for the purpose of analyzing the invention,

Fig. 2 is an analysis of the circuit shown in Fig. 1,

Fig. 3 is a further analysis of the prior art arrangement shown in Fig. 1,

Fig. 4 shows a circuit embodying the present invention in one of its aspects,

Fig. 5 is an analysis similar to Fig. 2 of the circuit of Fig. 4,

Fig. 6 is a graphic representation of another feature of the invention,

Fig. 7 shows a receiving system embodying the arrangement shown in Fig. 6,

Fig. 8 shows a modification of the arrangement shown in Fig. 7,

Fig. 9 shows still another modification of the arrangement shown in Fig. 7,

Fig. 9A shows a modfication of the circuit *b* in Fig. 6,

Fig. 10 shows an all-wave receiving system embodying the inventive features shown in Figs. 4 and 7, and other features of my invention.

Fig. 11 shows a modification of the arrangement shown in Fig. 10,

Fig. 12 shows still another modification of the arrangement shown in Fig. 10,

Fig. 13 shows a wave changing switch adapted for use in the systems of Figs. 10, 11 and 12, and

Fig. 14 shows another modification of the arrangement of Fig. 4 and also embodying the circuit of Fig. 8.

Referring now to the accompanying drawings, wherein similar circuit elements are denoted by corresponding reference numerals, it is first pointed out that the general purpose of the circuit arrangements to be hereinafter disclosed is to make it possible to increase the radio frequency gain in a tuned radio frequency amplifier adapted to operate over a short wave range without objectionable self-oscillation, noise production and other disadvantages which usually occur when an attempt is made to increase the gain in all-wave sets of the prior art. In order to clearly point out the features of the present invention which make for a stable radio frequency amplifier operating in a short wave range, there is shown in Fig. 1 a conventional tuned radio frequency amplifier of the prior art.

Fig. 1 shows a typical amplifier stage including a screen grid tube **1**, the tube having a tuned plate load which is used for high gain at the higher radio frequencies. The ground representations denote connections to the chassis of the receiver, and it will be observed that the usual grid bias network **2** is disposed in the ground lead of the cathode of the tube for providing the bias for the control grid of the tube. The rotors of the tuning condensers are usually mechanically coupled for uni-control, and the rotors are grounded as shown. A dotted line denotes the mechanical uni-control drive of the rotors of the tuning condensers **3** and **4**. It will be understood, of course, that the tuned input circuit of the tube **1** is coupled to a source of signal energy such as an antenna circuit, or the plate circuit of a preceding amplifier, and the plate circuit of the tube is, of course, coupled to any utilization circuit, such as a frequency changer, or additional amplifier stage. The screen and plate electrodes are shown arranged for connection to positive voltage sources of predetermined values.

In Fig. 3 there is shown a simplification of the circuit arrangement in Fig. 1, and the purpose of Fig. 3 is to demonstrate a source of serious feedback coupling between the plate and grid circuits of the tube **1**. The reference numeral **5** denotes the path due to the rotor shaft connecting the rotors of tuning condensers **3** and **4**, and the coils x and x' designate the effective inductances which are provided at the higher radio frequencies by the tuning condenser leads. From Fig. 3 it will be seen that the arrangement in Fig. 1 actually has its grid circuit coupled to the plate circuit through the rotor shaft of the tuning condensers due to the fact that at high frequencies encountered in short wave work the tuning condenser leads constitute a considerable part of the tuning inductance. However, the coupling path shown in Fig. 3 is not the only source of feedback in a circuit of the type shown in Fig. 1.

In Fig. 2 there is shown a graphical analysis of the various feedback paths or admittances existent at the higher radio frequencies encountered in short wave reception in a circuit of the type shown in Fig. 1. It will be understood that the circuit analyzed in Fig. 2 is that shown in Fig. 1, but the actual circuit elements which create the coupling paths have been replaced by numered blocks. Fig. 2 shows six leads or individual circuits associated with the vacuum tube **1**, four of these being the leads conductively connected to the respective tube electrodes and the other two being respectively the leads to condensers **3** and **4**.

Fig. 2 shows that each of such leads or circuit elements is coupled by an admittance to each of the other leads or elements. For example, the circuit to the grid of tube **1** is coupled to the other elements by admittances **1'**, **2'**, **4'**, **7** and **8** respectively, and the lead to the anode is coupled to the other leads or elements by admittances **3'**, **6**, **5'**, **9** and **8** respectively. From the above it will be clear from the drawings that admittances

10, 11, 12, 13 and 14 couple still other of the leads to each other. Even in the unusually favorable case where chassis ground returns are not so extensively used, impedance 16 in the cathode circuit (representing the cathode bias resistor and condenser 2 of Fig. 1) is common to every return circuit, thus resulting in instability especially at the higher frequencies, as for example above 5000 kilocycles.

It is to be particularly noted that in Fig. 2 the admittance 15, representing the common metallic rotor of two sections of the ganged tuning condensers 3 and 4 of Fig. 1, is of large value due to the large diameter and short length of the shaft, and it is also apparent from Fig. 2 that the rotor shaft provides an admittance between the input and output circuits. The other admittances shown in Fig. 2 (representing ordinary wiring leads and/or a section of the chassis) have values much smaller than that of the rotor shaft. From inspection of Fig. 2 it will be seen that the input circuit has not only admittance 15 between condensers 3 and 4 of the input and output circuits respectively, but admittance 3' between tuning condenser 3 and the anode circuit of the tube, 4' between the input circuit and the screen grid circuit, 7 between the input circuit and tuning condenser 4 in the output circuit, 8 between the input and output circuits, and 12 between condenser 3 and the screen grid circuit. These are undesirable admittances which permit an appreciable portion of the signal, or other energy, in the plate circuit to be coupled into the grid circuit, thereby limiting the stable gain attainable at these frequencies by producing, or approaching, oscillation. Fig. 2 also shows a number of other admittances which are necessary and which do not couple the input and output circuits, except as they are coupled thru the tube itself.

Certain of the numbered blocks, corresponding to admittances mentioned in the preceding paragraph, represent random coupling paths, existent in the chassis, which are generally present but may vary considerably in producing instability, depending on component part layout and wiring. These coupling paths may exist even tho they are not apparent from inspection of Fig. 1, because the grounds indicated in Fig. 1 may be read as connections to the chassis, and the chassis itself is, in operation at very high frequencies, by no means an absolute ground. In the construction and operation of all-wave receivers with one or more high frequency ranges the inductance present in the chassis has been found in cases, which are by no means extreme, to be of the order of 10% of the effective inductance of the tuning circuit at the highest frequencies of operation.

Fig. 4 shows the circuit of Fig. 1 modified to embody the present invention in several of its aspects. The circuit of Fig. 4 employs the screen grid tube 1 of Fig. 1 and the variable tuning condensers 3 and 4. The rotor shaft of the tuning condensers 3 and 4 is represented by a heavy line 17, and is connected to the grounded cathode lead of tube 1. A resistor 20 is connected in the plate circuit of tube 1 in series with the plate tuning inductance 21, the stator of tuning condenser 4 being connected to the plate side of tuning coil 21. A by-pass condenser 22 is connected between the coil side of resistor 20 and the grounded cathode lead of the tube. A resistor 23 is connected in the screen lead of the amplifier tube.

The control grid of the tube is connected to the —B terminal of the voltage supply source through a path including the grid circuit tuning coil 24 and the resistor 25, the other side of resistor 25 being connected to ground through a resistor 26. The grid side of resistor 25 is connected to the grounded cathode of tube 1 through a condenser 27. The resistor 26 supplies the bias to the grid of tube 1, and therefore it will be noted that the usual bias network 2, as shown in Fig. 1, is not disposed in the cathode lead in Fig. 4. A by-pass condenser 28 is connected between the grounded cathode lead and the screen grid circuit.

The values of the elements of Fig. 4 mentioned above are not critical and may vary throughout a wide range without departure from the principles of this invention. In an embodiment of the invention which operated very successfully, the elements had the values indicated below:—

Resistor 20	approximately 2500 ohms
Condenser 22	approximately .1 mfd.
Resistor 23	approximately 10,000 ohms
Resistor 25	approximately .5 megohms
Resistor 26	approximately 300 ohms
Condenser 27	approximately .1 mfd.
Condenser 28	approximately .1 mfd.

From an inspection of Fig. 5, which is an analysis of Fig. 4, similar to the analysis of Fig. 1, shown in Fig. 2, it will be observed that the serious faults shown to exist in the circuit of Fig. 1 do not exist in the circuit of Fig. 4. In other words, complete isolation, or mutual independence, of all the circuits of the high frequency amplifier stage has been attained in a very practical and simple manner. The exception exists in the case of the minimum required length of heavy cathode lead which can be made very short. In addition, it will be noted that the cathode is maintained in Fig. 4 at absolute ground potential thereby rendering all by-passing to it more effective, and thus minimizing over-all electrostatic coupling, radiation and interference pick up. What is of particular significance is the fact that the feedback path shown by Fig. 3 to exist in Fig. 1 is entirely absent from the circuit of Fig. 4.

The admittances 21' to 25' of Fig. 5 can be seen to be only those remaining paths necessary for operation of the present system shown in Fig. 4. In this connection it is to be particularly noted that no coupling path between the input and output circuits exists in the embodiment of Fig. 4, indicated in Fig. 5. This assures complete operational stability, and renders possible the use of low loss-high gain circuit components. It will be noted that the admittances 23' and 24' in Fig. 5 are, like admittance 15 of Fig. 2, provided by the metallic rotor shaft but, unlike admittance 15, do not provide an undesired energy path which would couple the input and output circuits to each other. Admittances 1', 2', 5', 6, 9, 10, 11, 13 and 14 of Fig. 2 are needed to complete necessary circuits and do not provide undesired coupling between the input and output circuits. These numbers are not repeated in Fig. 5, but it will readily be understood that the admittances which they represent are inherent in the arrangement of Figs. 4 and 5.

The amplifying arrangement shown in Fig. 4 is particularly well adapted for use in the short wave range because there has been provided means for preventing feedback between component parts of the circuit carrying high frequency energy. As a matter of fact, the feedback existent in the circuit of Fig. 4 is substantially limited to that resulting from inter-electrode capacities and electronic coupling in the vacuum tube itself. It is thus possible to use an amplifier

stage of the type shown in Fig. 4 ahead of a super-regenerator circuit where considerable voltages are built up in the grid circuit of the super-regenerator, and which voltages must not be fed back into the grid circuit of the preceding tuned radio frequency amplifier stage. This has all been accomplished by the comparatively simple method of having all circuit elements, other than the electrodes in the tube 1, terminate at a lead which is at cathode potential.

In Figs. 6 to 9 inclusive are shown arrangements for overcoming another difficulty encountered when operating a tuned radio frequency amplifier for short wave reception. As is well known, all-wave sets, for example those including the broadcast band, must have high capacity condensers suitable for tuning over the broadcast range. However, the use of these high capacity condensers for short wave tuning results in a low gain due to the resulting unfavorable inductance to capacity ratio. This is particularly bad in an antenna circuit, the gain of which ultimately limits the maximum useful sensitivity of any receiving system. High antenna circuit gain is a most important factor in any high sensitivity receiving system, especially for short waves.

The basic scientific principle utilized according to the present invention is that of employing a much larger inductance than would normally be used with a practical tuning capacitance, this practical capacitance being connected across only a portion of the inductance and the total inductance being utilized for output or input or both. A simple embodiment, as well as a graphic comparison with the prior art, is shown in Fig. 6. Considering the latter figure, under ideal conditions with L_1 equal to L_2, the capacity of condenser C_1 must be one quarter the magnitude of the capacity of condenser C_2 to tune to the same frequency in both circuits when the tap in circuit *b* is connected to the center of coil L_2. Conversely, where the capacities of condensers C_1 and C_2 are equal, the coil L_2 must have an inductance four times the inductance magnitude of coil L_1 for both circuits to tune to the same frequency.

Thus, in Fig. 7 the reference letters C_a and C_b represent sections of a standard broadcast type of ganged tuning condenser. The rotors of the condensers are shown arranged for mechanical unicontrol, the dotted lines **30** representing this uni-control arrangement. The tuning coils of the signal frequency amplifier tube **31** are represented by the reference letters L'_1 and L'_2, the former coil being a high inductance, low loss, antenna coil, and the latter coil being a high inductance, low loss, interstage coupling coil. The two coils have approximately twice the number of turns that could be used were the tuning condensers C_a and C_b connected across the total coil, thus providing much greater tuned impedance and voltage step up than is usually attained. The antenna A is coupled through a small capacity C_t to the grid side of coil L'_1. The condenser C_t is made variable and may be used for final trimming to compensate for antenna variations, or to simulate the circuit and tube capacity across coil L'_2, thus affording perfect tracking.

In the plate circuit of amplifier tube **31** the unusually high impedance tuned circuit affords a proportionately high gain, although still using broadcast range condensers. It will be noted that the rotors of the tuning condensers are grounded, while the stator of each tuning condenser is connected to an intermediate tap on the associated tuning coil. The cathode lead of tube **31** includes the usual biasing resistor **32**, and the cathode side of the resistor is connected to ground through a by-pass condenser C; the plate lead of the tube is also connected to ground through a similar by-pass condenser. Merely by way of illustration, and not by way of limitation, the output circuit of tube **31** is shown arranged for coupling to a converter, or mixer, stage. Since the feature of the invention involved in Fig. 7 is independent of the construction of the stage following tube **31**, a merely conventional representation of the following stage is believed sufficient. It is only necessary to point out that the tuning condensers employed usually in a converter stage may be uni-controlled with the uni-control means **30**.

In Fig. 8 there is shown a modification of the invention shown in Fig. 7, wherein a large high inductance antenna coil **33** may be used to provide excellent tracking with any usual system. Fig. 8 shows an antenna A' coupled through the condenser C_t to an intermediate tap on coil **33**. The arrangement shown in connection with Figs. 7 and 8 may, also be employed to advantage even in the extreme case where special low capacity short wave condensers are used instead of the larger broadcast range type. Actual tests have shown that the system in Fig. 7 affords two or three times the gain which has previously been obtained in both antenna and interstage circuits at frequencies between 5 and 20 megacycles. A practical system embodying the construction of Fig. 7 was nearly self-tracking so that no stations would be missed due to incorrect antenna adjustment. When the small capacity in the antenna circuit was adjusted, the antenna gain, and consequently the noise level, was much more favorable than attainable with systems known in the prior art.

In Fig. 9 there is shown still another modification of the arrangement shown in Fig. 7. This modification is shown applied only to the plate coil L'_2 although it may also be applied to the antenna circuit. The plate circuit tuning condenser C_b is shown connected across a coil L'_3, of a relatively smaller inductance value than that of coil L'_2. The coil L'_3 is magnetically coupled to coil L'_2. The operation of the modification shown in Fig. 9 is as follows: Assuming the ideal case of unity coupling (approximated by inter-wound turns) a "tuning autotransformer" results in which C_b had the effect of a tuning capacity of magnitude C_b multiplied by L'_3/L'_2 across L'_2. Thus, a variable capacitance of any magnitude at C_b may be made to simulate any suitable tuning capacity across L'_2 by using the correct inductance ratio L'_3/L'_2 with the sometimes practical advantage of avoiding electrical connection between C_b and L'_2. This keeps the direct current plate voltage off of C_b.

Since the efficacy of the systems in Fig. 6 to 9 depends on the degree of coupling attained between the two sections of the coil shown as L_2 in Fig. 6, various practical constructions may be utilized to maximize this coupling. These purely design considerations might include the use of a coil such as L_2 indicated in Fig. 6 (*b*) where l_1 and l_2 are sections of a continuous, uniform, low-loss inductive winding; or where l_1 is as above, but l_2 is wound with smaller wire close to, and connected to, the upper end of L_1; or, where l_1 is space wound with heavy wire and l_2 is wound

with finer wire between the turns of l_1 and connected in series aiding to l_1.

Maximum coupling may be obtained in other ways known to those skilled in the art, but since these are matter of engineering design, the scope of the present invention is not to be limited to only those embodiments shown. Fig. 9A indicates one method of inter-winding the two coil portions l_1 and l_2 of circuit *b* in Fig. 6 where l_1 is the heavy wire extending between terminals **100** and **101** and l_2 is finer wire connected between terminals **103** and **104** with the two coil portions connected in series aiding. The circuit is shown adapted for the grid circuit of Fig. 7 or 8.

All of the arrangements of Figs. 7, 8 and 9 are well adapted to use in receivers, previously mentioned herein as all-wave receivers, or for other radio apparatus which operates over a plurality of tuning ranges. Frequently in such apparatus one of such ranges is the broadcast range of 550 to 1500 k. c. In such receivers the circuits of Figs. 7, 8 and 9 will operate efficiently with usual receiving antenna, which may also serve for all of the other frequency ranges. It has been found, however, as between the circuits of Figs. 7 and 8, that a special short-wave antenna having an effective impedance of several thousand ohms operates very effectively with the circuit of Fig. 7 and that the arrangement of Fig. 8 is very well suited to larger antennae of the type more usually employed with broadcast receivers. Users of apparatus designated herein for convenience as the all-wave type, may, however, prefer to employ more than one antenna, for example, one antenna covering the relatively low frequency ranges such as the broadcast range and another antenna for use on the short wave band or bands. In such an installation the circuits of both Figs. 7 and 8 are entirely suitable for use with the short wave antenna.

The operation of the antenna coupling systems of Figs. 7 and 8 is as follows:—The resonance frequency of the combination of inductance L'_1 and capacitance C_a is normally tuned slightly higher than the frequency of the incoming signal when the interstage tuned circuit is tuned exactly to the signal. The addition of the small effective capacity due to the antenna and C_t in series causes the antenna coupling system to tune exactly to the incoming signal. Under these circumstances, the effective capacity of the antenna and C_t co-acts with the residual inductive reactance of the circuit L'_1 and C_a to give a resonant rise of signal voltage on the grid of tube **31**. The circuit of Fig. 8 further furnishes a voltage step up by auto-transformer action between the part of coil **33** across which condenser C_a is connected and the whole coil.

Referring to Fig. 7, the operation of the revised circuit in which the condenser C_b is tapped across, for example, one half of the coil L_2' is as follows:—

The plate load impedance of a vacuum tube is in series with the internal plate resistance of the tube which in the case of modern screen grid tubes is very high. Accordingly, in order to transmit voltage efficiently from such a tube, the plate load impedance must also be high. In Fig. 7 the plate load impedance is that of the tuned anode circuit L'_2, C, C_b in which C is so large that it functions merely as a blocking condenser for direct current. The present invention accomplishes a considerable increase in tuned plate load impedance, particularly at high frequencies where tuned impedances have been low, by connecting the tuning condenser across a portion only, for example, half of the coil L_2'. In such an arrangement, assuming the ideal case of unity coupling of each turn in the coil with every other turn in the coil, the tuning condenser has the effect of a condenser connected across the entire coil with a capacity equal to

$$C_b \times \frac{n^2}{N^2}$$

where n is the number of turns across which C_b is connected and N is the total number of turns in the coil. Due to the fact that the tuned impedance is proportional to

$$\frac{L}{RC}$$

it will be seen that with a given condenser capacity the tuned impedance may be increased, for example with the center tap connection, to approximately four times the value obtainable with condenser C_b connected across the whole coil L_2', it being understood that the self inductance of a coil varies in the ideal case as the square of the number of turns.

Although the invention of Figs. 6 to 8 has been described generally with reference to tapping the tuning condensers across one-half of the coils with which they are respectively associated, it will be understood that benefits of the invention may also be obtained by circuits in which the tuning condensers are tapped across a greater or less portion of the coils. However, as the tuning condensers are tapped across smaller and smaller portions of the coils, the tube and other capacities associated with the coils become more and more injuriously effective in limiting the higher frequencies which may be achieved in tuning and thereby limiting the tuning range which may be covered by adjustment of the tuning condenser.

It should be understood that the statements made in the preceding paragraph concerning the plate tuned impedance L'_2, C, C_b also apply to the tapped antenna circuits of Figs. 7 and 8.

It has been seen above that in the ideal case of unity coupling between turns in coils L'_1 or L'_2 of Fig. 7, the circuits there shown would afford four times the voltage gain that would be obtained with the tuning condenser connected across the whole coil. Unity coupling is not obtainable in commercial circuits. It can be shown mathematically that with the coupling of coil portion l_1 to itself taken as unity and with 40% coupling between coil portions l_1 and l_2, the voltage gain obtainable over a circuit having the condenser connected across the whole coil is substantially 1.4 squared or approximately 2; that obtainable with 50% coupling would be approximately the square of 1.5, etc. It is feasible by circuits such as are shown in Fig. 9A and other circuits to attain much higher degrees of coupling than these with corresponding increase in voltage gain.

In Fig. 10 there is shown a tunable radio frequency amplifier circuit similar to those shown in Figs. 4 and 7, but differing from the latter in that the inventive features of both these circuits are embodied in Fig. 10, and moreover the amplifier arrangement is shown arranged for operation in a multiplicity of ranges in accordance with still further features of my invention. In other words, let it be assumed that Fig. 10 shows the tunable radio frequency amplifier stage of an all-wave receiver adapted to operate not only in the broadcast range, but also in a plurality

of short wave ranges. The circuit comprises the antenna A, as well as the antenna trimmer condenser C_t. The screen grid tube **40** has its plate circuit coupled to the following stage which, for the purpose of the present description, may be assumed to be a frequency changer network.

Of course, and as stated heretofore, the following network may also comprise another radio frequency amplifier stage, a simple detector, a super-regenerator network or other apparatus. In any case, the tunable input circuit of tube **40** comprises coils **41** and **45** which are always in circuit and a plurality of coils **44**, **43**, and **42**, capable of being cumulatively connected in parallel across coil **45**, the high alternating voltage side of coil **41** being connected to the signal grid of tube **40**, and its other terminal being connected by a lead **46** to the stator of the variable tuning condenser **47**, the latter also being connected to the high alternating voltage side of coil **45**. The low alternating voltage terminals of coils **42**, **43**, **44** and **45** are connected together, and the low alternating voltage side of coil **45** is connected to the grounded cathode lead of tube **40** through a condenser **50**. The adjustable antenna trimmer condenser C_t is connected to the low alternating voltage side of coil **41**.

The plate circuit of tube **40** is constructed in a substantially similar manner. Coils **41'** and **45'** are always in circuit and coils **44'**, **43'**, and **42'** may be cumulatively connected in parallel with coil **45'**, the high alternating voltage side of coil **41'** being connected to the plate of tube **40**, while the low alternating voltage terminal of the coil is connected by lead **48** to the stator of the variable tuning condenser **49**, the stator of the latter condenser being connected to the high alternating voltage side of coil **45'**. The low alternating voltage terminals of coils **42'**, **43'**, **44'** and **45'** are connected together, and the low alternating voltage terminal of coil **45'** is connected to the grounded cathode lead of tube **40** through a condenser **51**. The heavy dark line connecting the rotors of tuning condensers **47** and **49** is designated by the numeral **52** and denotes the metallic rotor shaft which is connected to the grounded cathode lead of tube **40** in the manner explained in connection with Fig. 4 or in the manner shown in detail in connection with Fig. 14. The screen grid, control grid and plate electrodes are connected to suitable sources of potential through suitably chosen resistors including resistor **54** in the control grid circuit, and radio frequency energy is by-passed to ground from the low alternating voltage sides of the several circuits through the suitable by-pass condensers **50** and **51**.

The high alternating voltage terminals of coils **44**, **43** and **42** are each provided with a contact, and these contacts are arranged to be cumulatively engaged by an adjustable switch element **53**. The latter is represented in conventional manner as having one end thereof connected to the high alternating voltage side of coil **45**, while the three arrows thereon are to be understood as representing a type of switch which is adapted to be moved into contact with the contact members on coils **44**, **43** and **42** in succession. The lowest arrow may be taken to indicate a contact co-acting with coil **44**, the intermediate arrow a contact coacting with coil **43** and the upper arrow a contact co-acting with coil **42**. As the switch element **53** is moved toward closed position, contact is first made with the upper terminal of coil **44**, then with coil **43**, and lastly with coil **42**. This switch **53** is the range selector switch, and the numeral **53'** designates a similar switch arrangement in the plate circuit of tube **40**. The switches **53** and **53'** may in practice be of the fan type more fully illustrated in Fig. 13, and may be mechanically coupled so that the appropriate tuning coil combination may be chosen in each circuit simultaneously. If the network following tube **40** is another stage of tuned radio frequency amplification constructed in a manner similar to that shown in connection with tube **40**, then the range changing switches of that following stage would be uni-controlled with switches **53** and **53'**.

The numeral **54** denotes a resistor which may be disposed in an automatic volume control network, and to preserve simplicity of description it is noted in connection with Fig. 10 that the lead is to be connected to an A. V. C. source, those skilled in the art being well acquainted with the construction of such an arrangement. Any well known type of automatic volume control circuit can be used, that commonly employed being a signal rectifier developing, under control by the received signal energy, a direct current voltage across a resistor in the space current path of the rectifier, the negative side of the resistor in the space current path being connected to the A. V. C. lead. Fixed negative bias for the grid of tube **40** may be supplied from the A. V. C. network, or as in Fig. 4.

It will be observed that in Fig. 10 the novel constructional features of both Figs. 4 and 7 are embodied. That is to say, the amplifier circuit is substantially stable even at the higher gains, because there is no radio frequency feedback path between the plate and grid circuits outside the electrodes of tube **40**, and with respect to these electrodes the screen grid tube substantially limits such feedback to a minimum. Again, the tuning condensers **47** and **49** are, as pointed out in connection with Figs. 7 and 8, of standard broadcast ganged type. These condensers can be employed efficiently at the short wave range because of the construction explained in connection with Fig. 7.

This arrangement in Fig. 10 embodies the novel feature described in connection with Figs. 4, 5, 7 and 8 because rotor shaft and other forms of undesirable feedback have been eliminated (as set forth in Figs. 4 and 5) and the high gain signal frequency amplifier and antenna coupling principles have been incorporated (as set forth in connection with Figs. 7 and 8) for operation on the highest frequency band where it is needed most. When switches **53** and **53'** are fully closed to connect all of their respective coils **42**—**45** and **42'**—**45'** in shunt the major portions of the tank currents flow through **42** and **42'**, the inductance of coils **42**—**45** and **42'**—**45'** in parallel respectively being substantially that of the smallest coil **42** or **42'**. For the next lower frequency band the major portion of the tank currents flows through **43** and **43'** with the result that **41** and **41'** have relatively less boosting effect (due to lower relative turns ratio and greater physical separation). For the highest frequency band switch **53** connects coils **42** to **45** in parallel. Most of the current then flows through coil **42** (the higher inductances of the other coils make them act as chokes), flux through coil **41** producing an increased voltage on the grid of tube **40**. As the fan switch **53** is moved toward open position to switch into the longer waves, the high frequency

coils are progressively dropped from the shunt circuit until coil 41 has little effect.

In Fig. 10, assuming that the switches 53 and 53' are open so that only coils 45 and 41 and 45' and 41' are in circuit, the position is that for reception over the range of tuning of lowest frequency, which in an all-wave receiver as now usually constructed would be the broadcast range of 550 to 1500 k. c. In this position the inductance of coils 41 and 41' is so small relative to coils 45 and 45' respectively, that the tuning condensers 47 and 49 are, for practical purposes, connected across the entire coils. It will be noted, therefore, that the present invention, as embodied in Fig. 10, does not materially affect reception over the broadcast range. As switch 53 is moved toward closed position, it first connects in circuit coil 44, which is smaller than coil 45 and makes the total inductance of coils 44 and 45 in parallel close to the inductance of coil 44 alone. It will be noted that the effective inductance associated with coil 41 and across which tuning condenser 47 is connected is thereby decreased so that the inductance of coil 41 bears a larger ratio to the total inductance in circuit. It will further be understood that the position of the switch 53 which connects coil 44 in circuit provides a range of tuning which is next to the lowest frequency range. As the switch 53 is further moved toward closed position, it connects coils 43 and 42 successively in circuit across coils 44 and 45 and in that way successively decreases the effective inductance in the circuit, whereas the value of coil 41, of course, remains unchanged. It will be seen, therefore, that coil 41 has successively greater effect as switch 53 is adjusted to change from the lowest frequency range to the highest frequency range. In the highest frequency range the inductance of coil 41, as in Fig. 7, may be substantially equal to the effective inductance of the other coils connected in parallel. Another way of stating this is that in switching successively from lower to higher frequency tuning ranges the fraction of the inductance in each range which is shunted by the tuning condenser becomes less as the inductance itself is decreased in changing from lower to higher frequency ranges, whereby the effective

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is maintained higher for the small inductance; i. e., high frequency or short-wave ranges than it would be if the tuning condenser were shunted across the total inductance. Manifestly, the description given above of switch 53 and the coils controlled thereby applies equally well to switch 53' and the coils controlled by it, coils 44 and 44' being switched in or out together and the same being true of coils 43 and 43' and 42 and 42'.

Fig. 11 differs from Fig. 10 in that the tuning coils in the grid and plate circuits of tube 40 are arranged in series relation, instead of parallel relation as in Fig. 10. It will be noted that in this modification the stator of tuning condenser 47 is connected by lead 60 to an intermediate tap on the first coil 61, which corresponds in function to the coils 41 and 42 of Fig. 10. The stator of tuning condenser 49 is connected by lead 62 to an intermediate tap on the first coil 61' which corresponds to the coils 41' and 42' of Fig. 10. The range changing switches 53 and 53' are again used to successively connect the different range tuning coils into the amplifier system. Additionally, there are shown trimmer condensers connected across each of the coils in the grid and plate circuits, the trimmer condensers associated with coils 61 and 61' being connected only across the tapped portions of the coils in parallel with the respective tuning condensers. The trimmer condensers are used for tracking and adjusting each coil for each range. The condenser C_t is connected to the tap point on coil 61.

The operation of the modification shown in Fig. 11 is similar to that shown in Fig. 10. This arrangement embodies the principles of construction shown in Figs. 4 and 7 because on the highest frequency band, when switches 53 and 53' have shorted their respective lower frequency coils leaving only 61 and 61' operable, coils 61 and 61' function as set forth in Figs. 6, 7 and 8. For the next lower frequency band coils 61 and 43 are operated in series in the grid circuit with 44 and 45 shorted by switch 53, while in the plate circuit the corresponding coils and switch operate in the corresponding manner. On this band the turns of the coils 61 and 61' above the taps have less effect than in the highest frequency band. On the next to the lowest frequency band coils 61, 43 and 44 operate in series with only coil 45 shorted by switch 53 in the grid circuit, while the corresponding action takes place in the plate circuit. On this band the effect of the grid and plate turns of coils 61 and 61' above the taps becomes still less. On the lowest frequency band all coils in each circuit are operated in series with the extra grid and plate turns having small effect.

Fig. 12 shows a modification of the arrangement of Fig. 11, which has been found useful for tracking a signal frequency system with the oscillator where a long wave band is to be covered, or where a special type oscillator is to be used, (such as the ultra-audion). 53'' is another "fan" switch which moves with 53'. Trimmer condensers are used as shown.

It will be noted that in Fig. 12 an arrangement is shown for covering five tuning ranges, as against four in Figs. 10 and 11 respectively. It is evident, however, that the arrangements of Figs. 10 and 11 might cover five or some other desired number of tuning ranges. One manner in which Fig. 12 might be employed is with the lowest frequency range constituting an additional range of frequency below the broadcast range. It will be noted that switches 53' and 53'' in Fig. 12 are each represented by four arrows indicating individual switch blades, it also being noted that vertically above each of the elements 53' and 53'' on the drawing are four small circles 84, 85, 86, and 87 and 84', 85', 86' and 87' respectively indicating switch contacts. The lowest arrows may be taken to indicate switch elements co-acting with the contacts 87 and 87' respectively; the next lowest arrows to indicate switches co-acting with the contacts 86 and 87', etc. From the above it will be understood that when the switches 53' and 53'' are both fully closed the upper coil only is effective, and the apparatus is operable over the highest frequency or shortest wave tuning range. In this position the lower fraction of the upper coil is connected in series with the tuning condenser 49 and blocking condenser C. As shown the trimmer condenser 88 is connected across all of the upper coil, but it may be connected across only the lower portion of the coil as in Fig. 11. When the switches 53' and 53'' are moved away from contacts 84 and 84' respectively while retaining engagement with the other contacts 85 to 87 and 85' to 87', the next to the upper coil is

operatively connected in series with the upper coil for operation over the second highest frequency range. In both of the two highest frequency ranges no additional reactance is connected between the coils and tuning condenser 49. It will be seen, however, that as switch elements 53' and 53'' are moved away from contacts 85 and 85', padding condensers 90 and 92 in parallel with each other are connected in series with the tuning condenser 49 and the three upper coils which are then in circuit. It will also be seen that these padding condensers remain in circuit when the switches 53' and 53'' are opened by an additional stage in moving away from contacts 86 and 86' and that when switches 53' and 53'' are fully opened for tuning to the lowest frequency range by breaking contact at the points 87 and 87' the padding condenser 90 is removed from the circuit and only padding condenser 92 is connected in circuit in series with tuning condenser 49.

It will be understood that the relation of the switches 53 and 53' shown in Figs. 10 and 11, indicated by arrows, to the contacts indicated by small circles vertically above switches 53 and 53' is the same as between switches 53' and 53'' and contacts 84 to 87 and 84' to 87' in Fig. 12.

In each of the systems described in connection with Figs. 10, 11 and 12, the circuit stabilization means indicated in Figs. 4 and 5 have been incorporated as shown, and function with efficacy on every frequency band covered.

This invention may, of course, be used in tuned radio frequency receivers or, as indicated in Figs. 7 and 10 which show a converter, or frequency changer, may be employed in superheterodyne receivers. In the use of the multi-range or all-wave arrangement shown in Figs. 10, 11 and 12 in superheterodyne receivers, the local oscillator of the superheterodyne receiver (not shown) will be provided with tuned circuits and may have switching means similar to that shown in Figs. 10, 11 and 12 and uni-controlled with the switches 53' and/or 53''. Oscillator circuits provided with such switching means and suitable for use with the arrangements of Figs. 10, 11 and 12 are known.

Figs. 10, 11 and 12 are, of course, intended to show only a few of many practical embodiments of my invention, and it is not intended that my invention shall be limited thereto but only as required by the appended claims. Referring to Fig. 12, this figure should be understood as illustrative of only one arrangement for connecting padding condensers into the tuned circuits. The principle of using padding condensers in connection with the switching arragements shown in the various figures of the drawings may be embodied, without departing from the principles of the invention, in other combinations and arrangements, not shown, to obtain such padding effects as may be desired.

In the description of the switches 53, 53' and 53'' of Figs. 10, 11, and 12, mention has been made of shorter and longer switch arms or switch elements represented diagrammatically by shorter and longer arrows respectively. A type of switch which gives similar results, is more often used commercially, and is also suitable for use with this invention is shown in Fig. 13. This figure shows a switch of the "fan" type employing an inner metal ring 94 carrying metal blades 95, 96 and 97 so that when the switch is rotated clockwise, coils 45, 44 and 43 are cumulatively shorted and the coil 61 connected directly to R. F. ground for operation on the highest frequency band. In the position shown 45 is shorted, while 44, 43 and 61 are connected in series for operation in the next to the lowest frequency range.

In Fig. 14 is shown an improved embodiment of the circuit shown in Fig. 4. In this modification the antenna connection of Fig. 8 and the plate circuit connection of Fig. 7 are shown. The stators 70 and 71 of a conventional ganged condenser are connected to mid-points on coils 72 and 73 respectively. The rotor shaft 74 is connected to the grounded cathode 75 through wipers 76. The low alternating voltage side of coil 72 is connected to the rotors 80 through condenser 81, while rotors 82 are connected to the low alternating voltage side of coil 73 through condenser 83.

The shaft 74 is arranged to rotate in apertures provided in end and partition plates 77 of the condenser frame. The cathode 75, grid and plate are, of course, disposed in a single tube envelope. They are shown in the manner of Fig. 14 in order to illustrate the shortness of the lead between the cathode and the rotor shaft. It will be noted that, as shown in Fig. 14, the cathode 75 is connected to the rotor shaft 74 by wipers 76 at an intermediate point on the rotor shaft, whereas the input coil 72 is connected to the rotor shaft through condenser 81 and a wiper 76' at a point separated from said intermediate point by the condenser unit 70—80, and plate coil 73 is connected to the rotor shaft 74 through condenser 83 and wiper 76'' at a point separated from said intermediate point by the condenser unit 71—82. The connections through condensers 81 and 83 respectively to such points on the rotor shaft have been found to give improved stability over connections through condensers 81 and 83 to the middle wipers 76, because the connections shown avoid any coupling between input and output circuits which might otherwise result by reason of the impedance at high frequencies of the middle wipers 76.

While I have indicated and described several systems for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organizations shown and described, but that many modifications may be made without departing from the scope of my invention, as set forth in the appended claims.

What I claim is:

1. A radio frequency amplifier stage comprising an amplifier tube provided with at least cathode, grid and plate electrodes, an input inductance connected to the grid and an output inductance connected to the plate, a gang tuning condenser having one section in shunt to the grid inductance and another section in shunt to the plate inductance, said inductances and condenser sections constituting similarly tuned input and output circuits, the rotors of said condenser sections being mounted side by side on a common control shaft, a conductive connection from ground to the control shaft between adjacent ends of the rotor sections, a connection from cathode to said ground connection, and connections from the low potential ends of the grid and plate inductances to their respective rotor sections at the ends which are opposite to the adjacent ends to which the cathode and ground are connected.

2. A radio frequency amplifier stage comprising an amplifier tube provided with at least cath-

ode, grid and plate electrodes, an input inductance connected to the grid and an output inductance connected to the plate, a gang tuning condenser having one section in shunt to the grid inductance and another section in shunt to the plate inductance, said inductances and condenser sections constituting similarly tuned input and output circuits, the rotors of said condenser sections being mounted side by side on a common control shaft, and means for substantially eliminating external feed-back between said input and output circuits, comprising a conductive connection from ground to the control shaft between adjacent ends of the rotor sections, a connection from cathode to said ground connection, and connections from the low potential ends of the grid and plate inductances to their respective rotor sections at the ends which are opposite to the adjacent ends to which the cathode and ground are connected.

3. A radio frequency amplifier stage of the type including an amplifier tube and a tuning condenser in its grid circuit and a similar tuning condenser in its plate circuit, the cathode of the tube having a direct connection to ground, a conductive connection between the rotors of the tuning condensers, the conductive connection being connected to the grounded cathode of said tube, a tuning coil in each of the grid and plate circuits having its high potential end connected respectively to the grid and plate, the stator of each variable tuning condenser being permanently connected to an intermediate tap on its respective tuning coil.

4. In a tunable radio frequency amplifier adapted to operate over a plurality of signal frequency ranges, said amplifier including a tube provided with input and output circuits and a cathode directly connected to ground, each of the circuits including a plurality of coils corresponding to different signal ranges and a variable tuning condenser, the variable tuning condensers being of a high capacity adapted for operation in the broadcast band, a common metallic shaft connecting the rotors of the variable condensers, the shaft being connected to the grounded cathode of the tube, and means for permanently connecting the stator electrodes of each of the variable condensers to an intermediate point on at least one of the coils in each of the input and output circuits, the coils to which the variable condensers are connected having the high potential points connected to their respective input and output electrodes.

5. In a tunable radio frequency amplifier adapted to operate over a plurality of signal frequency ranges, said amplifier including a tube provided with input and output circuits and a cathode directly connected to ground, each of the circuits including a plurality of coils corresponding to different signal ranges and a variable tuning condenser, the variable tuning condensers being of a high capacity adapted for operation in the broadcast band, a common metallic shaft connecting the rotors of the variable condensers, the shaft being connected to the grounded cathode of the tube, and means for connecting the stator electrodes of each of the variable condensers to an intermediate point on at least one of the coils in each of the input and output circuits, certain of the coils in each of the input and output circuits having their low potential terminals connected together and to a source of steady potential, the opposite ends of said coils terminating in contacts, and a coil changing switch in each of the input and output circuits cooperatively disposed between the connected coil terminals and the coil contacts.

6. In a tunable radio frequency amplifier adapted to operate over a plurality of signal frequency ranges, said amplifier including a tube provided with input and output circuits and a cathode directly connected to ground, each of the circuits including a plurality of coils corresponding to different signal ranges and a variable tuning condenser, the variable tuning condensers being of a high capacity adapted for operation in the broadcast band, a common metallic shaft connecting the rotors of the variable condensers, the shaft being connected to the grounded cathode of the tube, and means for connecting the stator electrodes of each of the variable condensers to an intermediate point on at least one of the coils in each of the input and output circuits, the coils in each of the input and output circuits being connected in series relation between their respective input and output electrodes and a source of steady potential, a coil changing switch in each of the input and output circuits cooperatively disposed between the source of steady potential and the common terminals of said series connected coils.

7. In a multi-range tuner, means for cumulatively connecting in circuit variable amounts of inductance in changing from one tuning range to another, a variable tuning condenser for tuning the inductances over each of a plurality of ranges of tuning, and connections between the condenser and only part of the inductances such that the fraction of the operative inductance which is shunted by the condenser in changing from one tuning range to another becomes less as the inductance is made less in changing to higher frequency tuning ranges, whereby the effective

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ratio is maintained higher for small inductance ranges than it would be if the common tuning condenser were connected across the whole inductance.

8. In a multi-range tuner, a plurality of inductances of varying values for use in different tuning ranges, switching means controlling said inductances for cumulatively connecting in circuit variable amounts of inductance in changing from one tuning range to another, a variable tuning condenser for tuning all of the inductances over their respective ranges of tuning, and connections between the condenser and only part of the inductances such that the fraction of the inductance which is shunted by the condenser in changing from one range to another becomes less as the inductance is made less in changing to higher frequency tuning ranges, whereby the effective

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ratio is maintained higher for small inductance ranges than it would be if the common tuning condenser were connected across the whole inductance.

9. In a multi-range tuner, a plurality of inductances of varying values for use in different frequency ranges, a variable tuning condenser for tuning all of the inductances over their respective ranges of tuning, connections between the condenser and a portion of the smallest operative inductance such that in operation over

the highest frequency range the tuning condenser is connected across an inductance which is of the order of one-fourth of the operative inductance at that range, and means for cumulatively switching more or less inductance in circuit across the tuning condenser in changing to lower and higher frequency ranges respectively so that the fraction of the inductance which is shunted by the condenser in changing from one range to another becomes less as the inductance is made less in changing to higher frequency tuning ranges, whereby the effective

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ratio is maintained higher for the highest frequency ranges than it would be if the common tuning condenser were connected across the whole inductance.

MURRAY G. CLAY.