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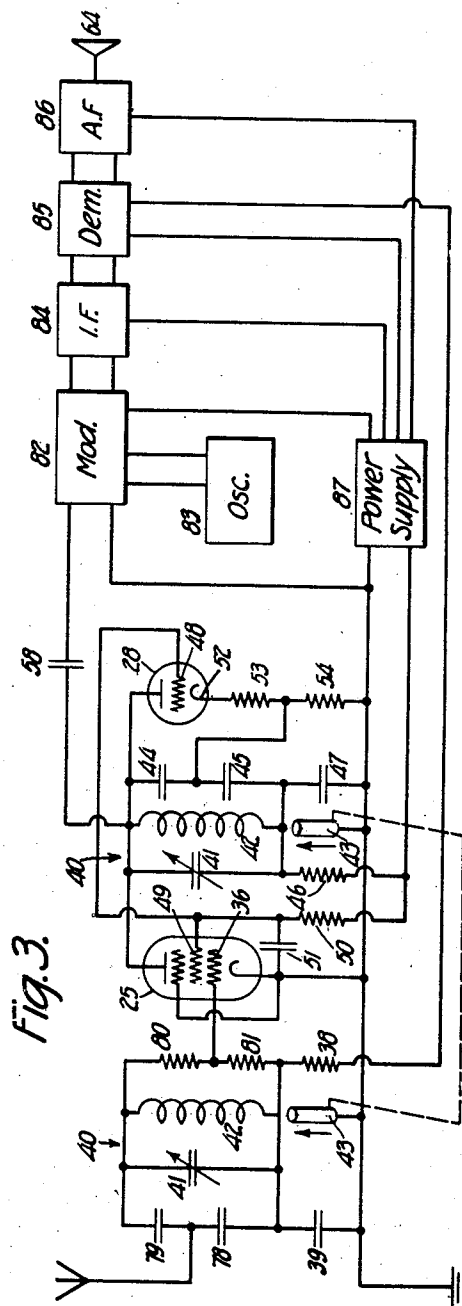
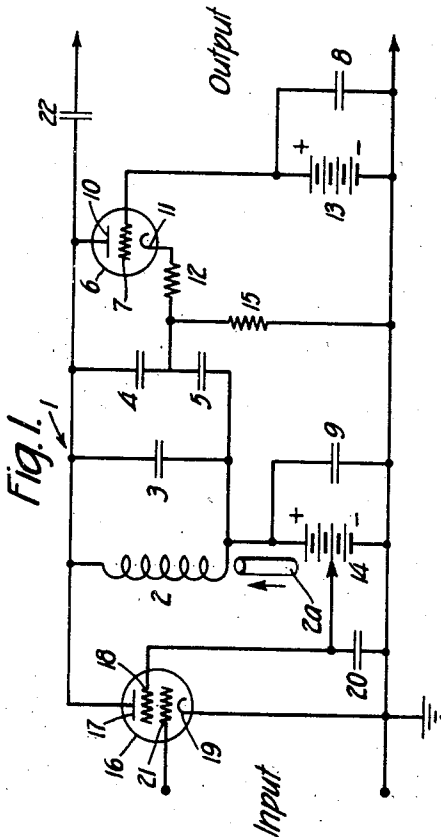
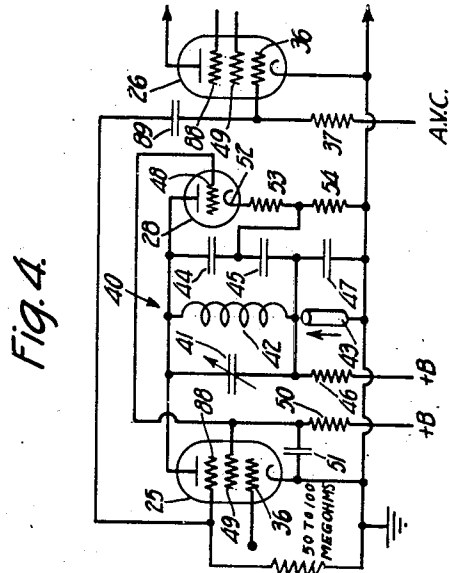
W. A. SCHAPER

2,298,629

RADIO RECEIVING SYSTEM

Filed June 10, 1940

3 Sheets-Sheet 1



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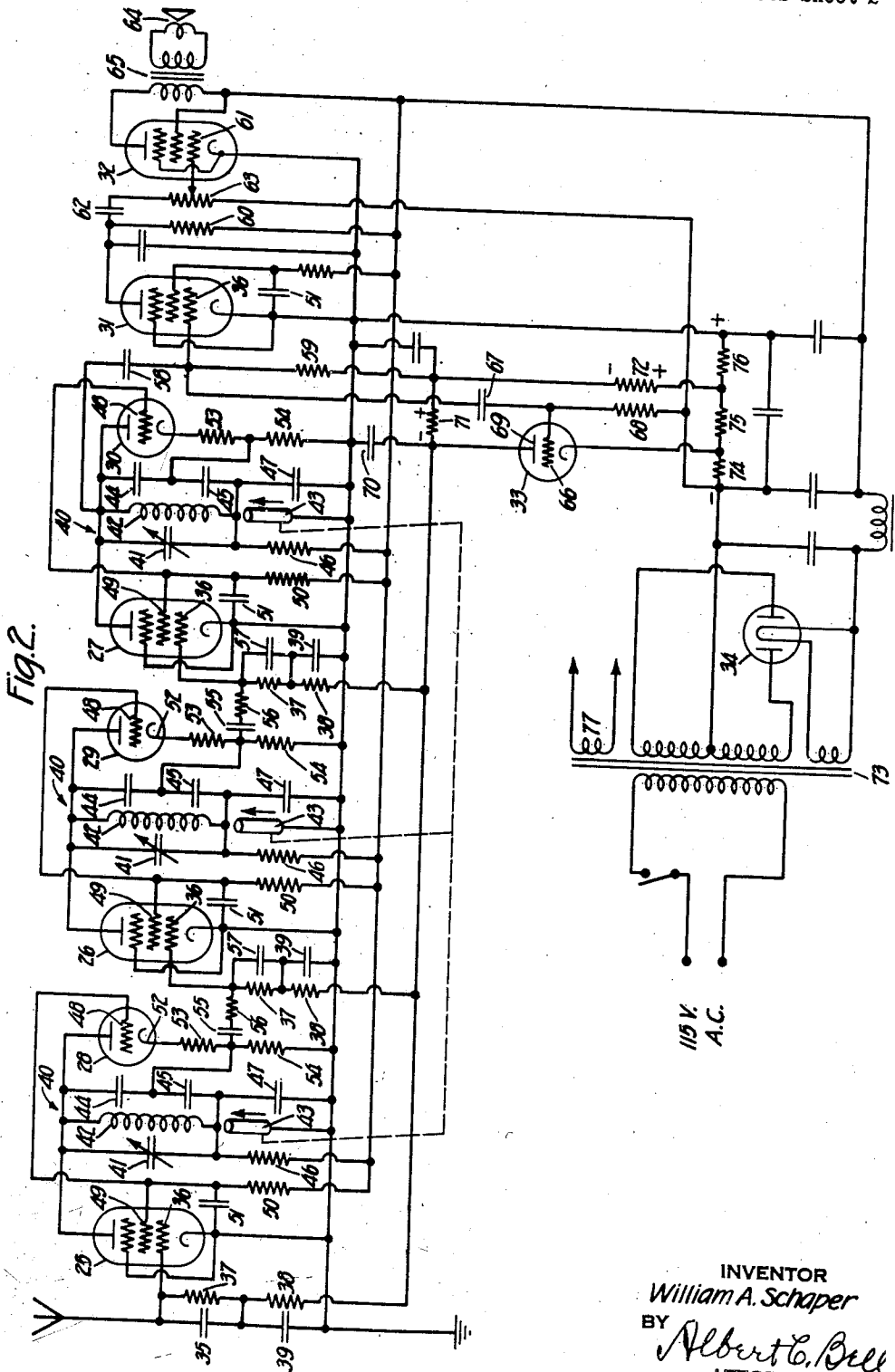
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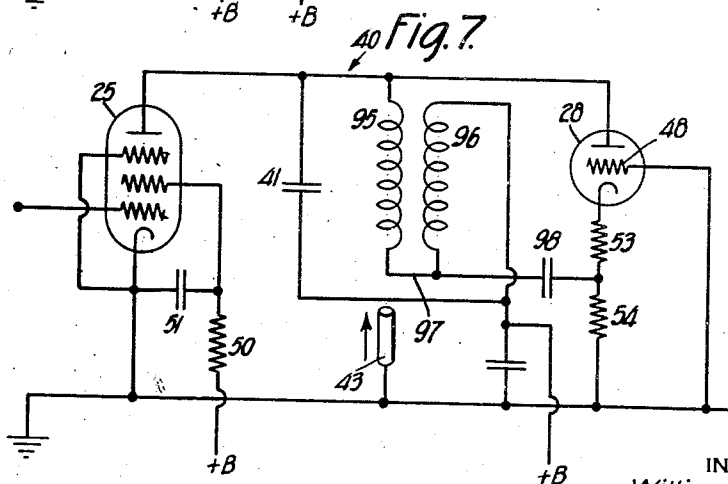
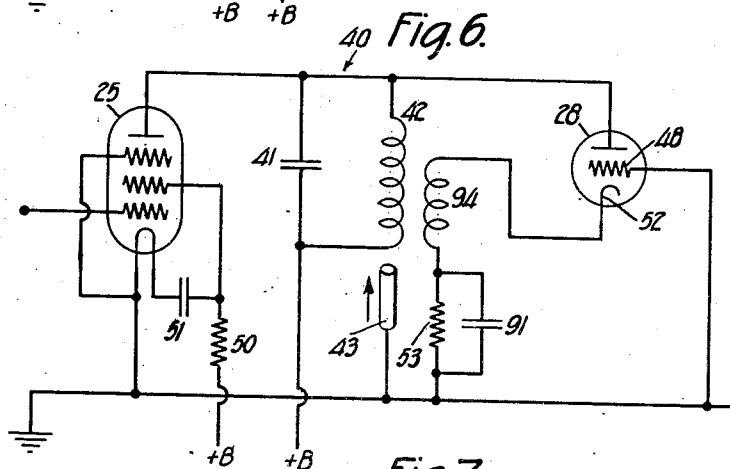
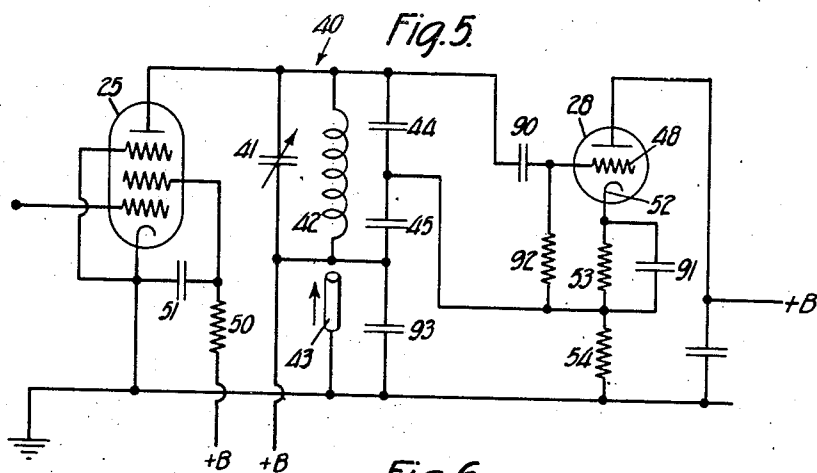
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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,298,629

RADIO RECEIVING SYSTEM

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Application June 10, 1940, Serial No. 339,697

18 Claims. (Cl. 179—171)

This invention relates to selective resonant high frequency amplifying systems employing vacuum tubes, such as are commonly employed in radio receiving apparatus. More particularly the invention relates to systems in which the vacuum tubes are employed, not only to selectively amplify a desired high frequency signal, but simultaneously to improve the performance of the resonant circuits associated with the vacuum tubes. Systems of this class have been known for over twenty years, and have been commonly described as regenerative systems.

In prior regenerative systems, as is well known, numerous inherent difficulties have resulted in undesirable performance characteristics including (1) the necessity for critical adjustment of the controls, (2) serious detuning of the system with increase of regenerative effect, (3) wide variation of the amplification and the selectivity over the frequency range covered by the receiver, (4) serious distortion of the voice or music transmitted, (5) self-oscillation of the receiver circuits with resulting cessation of reception of the desired signal, (6) the production of highly unpleasant noises from the loud speaker, and (7) radiation from the receiver which interfered with the performance of other neighboring receivers.

It is a principal object of the present invention to provide a regenerative system in which all of the above-enumerated difficulties are completely overcome. Other objects and advantages of the system in accordance with the invention will be apparent from what is to follow.

In previously known regenerative systems, high orders of amplification and great selectivity were obtainable by critical adjustment, the apparatus itself being relatively simple, the manipulation, however, being extremely difficult. The system in accordance with the invention provides amplification and selectivity at least as high if not higher than was possible with previous systems, without, however, the disadvantages inherent in the prior systems, and with no necessity for manual control of either the amplification or the selectivity.

In accordance with the present invention, arrangements are employed which eliminate the underlying causes of the performance difficulties of prior systems. An adequate understanding of the present invention will be assisted by a brief

review of these underlying causes of improper performance in prior systems, together with a short statement as to how, in accordance with the present invention, they are avoided or overcome.

A chief cause of prior difficulties has been the non-uniform performance of the selective resonant circuits employed, both as to resonant gain and as to selectivity, as the system was tuned over the frequency range. While this non-uniformity was highly disadvantageous in non-regenerative receiving systems (such for example as the widely used Neutrodyne system) it was very much more troublesome in regenerative systems, since, broadly speaking, its effect was greatly multiplied.

In accordance with the present invention, I employ selective resonant circuits whose performance as to both resonant gain and selectivity is substantially uniform over the frequency range. It is only recently that such circuits in commercially feasible form have become available. Additionally, I employ circuits which are, in general, of considerably lower inherent resonant gain and selectivity than prior used non-uniform circuits, but this deficiency is more than compensated by their uniformity and by the method employed to greatly increase their effective resonant gain and selectivity, as will be clear from what is to follow.

By using circuits having low inherent resonant gain, it is possible to use inexpensive coils in which the ratio of L/R is of a relatively low order, the use of coils wound with special very low resistance windings not being required in order to secure an adequate amount of gain. The use of such low Q coils for the resonant circuits naturally results in a decrease in cost of the receiver.

By employing regeneration, however, the selectivity and gain per resonant circuit are very substantially increased so that it is possible to secure a degree of gain and selectivity with a single resonant circuit comparable to that which might be obtained by the use of three or four Polydorff circuits of the kind below described in a cascade radio frequency amplifier. The number of resonant circuits required to secure the desired gain and selectivity is thus reduced, resulting in a further decrease in the cost of construction of the receiver.

As is stated by Polydorff in United States Pat-

ent No. 1,940,228, a resonant circuit having constant gain and constant selectivity over the frequency range through which it is tunable, is a circuit having a constant ratio of inductance to resistance (L/R) and a constant dynamic resistance (L/RC), and reference to either of these relations adequately describes such a circuit. In the patent just referred to, Polydoroff describes an arrangement of this type in which a resonant circuit having an inductance coil and a capacitor is adjusted over a range of frequencies by movement of a compressed comminuted ferromagnetic core relative to the inductance coil. This method of tuning is commonly called permeability tuning. An improved form of such a system is described in my United States Patent No. 2,051,012. Both Polydoroff's original system and my improved system readily cover an adequate range of frequencies and may easily be ganged to provide multiple-unit systems.

In introducing regeneration into a system having one or more of such permeability tuned circuits, it was found that with known regenerative arrangements, the regenerative effect itself varies materially with the frequency so that the selectivity of the circuit is no longer uniform and there is also a tendency for the system at certain adjustments of the tuning control to go into oscillation. My present invention provides an arrangement whereby these disadvantages are overcome and according to which it is possible to realize substantially uniform over-all performance in a regenerative system.

A second underlying cause of prior difficulties in regenerative systems was the use of a single vacuum tube or electron relay to achieve both amplification and regeneration, since these two functions are basically different in mechanism. Thus any attempt to improve the performance of one function was at the expense of inferior performance of the other function, particularly with regard to uniformity of action over the frequency range.

In accordance with the invention, I avoid the difficulties inherent in the use of a single vacuum tube for both amplification and regeneration by employing separate vacuum tubes for these functions, and by so arranging my system that one function is incapable of disadvantageously influencing the other function. I am thus able to greatly improve the resonant performance of the resonant circuits of my system without decrease, and in fact with noticeable increase, in the non-regenerative amplification provided by the amplifying vacuum tubes.

A third underlying cause of prior difficulties in regenerative systems was the employment of coupling means for securing the regenerative effect which was (1) inherently incapable of uniformity of action over the frequency range, and (2) inherently capable of producing self-oscillation of the receiving system. I am aware that many attempts were made to obviate this cause of improper performance, and that some degree of success was attained in this direction, but in the prior art so long as a single vacuum tube was used for both amplification and regeneration, the difficulties could not be completely overcome, even with critical manual control of the regenerative feature.

In accordance with the invention, I provide coupling means to produce the regenerative effect which is inherently adapted to secure uniformity of action over the tuning range, and I so arrange this coupling means that no self-

oscillation will be produced. The coupling means which I employ is somewhat similar to arrangements which have been employed, not to avoid oscillations, but to deliberately produce them, as, for example, in oscillator and transmitter circuits, where the self-oscillating condition is the only desired condition. As a principal feature of my invention, however, I rearrange a coupling system of this type in such a way that, while the regenerative effect is secured in ample degree and with substantial uniformity over the frequency range, the system is inherently incapable of producing self-oscillation. I secure this adequate and complete control of the regenerative effect by the expedient, among other things, of employing separate vacuum tubes for the regenerative and amplifying functions, as above pointed out. A second and equally distinguishing expedient of my system in this regard is that I invert the vacuum tube employed for the regenerative function, connecting it to the resonant circuit and to the sources of its operating potentials in such a way that its control grid remains substantially at ground potential for high frequency currents. This assists materially in rendering the tube incapable of producing self-oscillations without in any degree detracting from its regenerative effect or its inherent uniformity of performance over the frequency range.

In an inductance-tuned circuit having constant dynamic resistance, L/RC , the inductance is inversely proportional to the square of the frequency, and the total effective resistance must, therefore, also be inversely proportional to the square of the frequency. If a negative resistance device is now added to the circuit, the effective resistance of the circuit becomes $R-R'$ where R is the loss resistance of the circuit and R' is the negative resistance, and it is this total resistance which must now be maintained inversely proportional to the square of the frequency. If a resonant circuit is used whose inherent resistance is inversely proportional to the square of the frequency, then the subtracted or negative resistance should also be inversely proportional to the square of the frequency in order to secure constant selectivity.

In practicing my invention, a negative resistance which is substantially inversely proportional to the square of the frequency may be produced by employing two capacitive couplings in cascade between the plate and grid circuits of a vacuum tube. Since the mutual reactance due to each of these couplings is inversely proportional to the first power of the frequency, the total effective mutual reactance between the plate and the grid circuits due to these two couplings is inversely proportional to the square of the frequency. Neglecting the relatively minor effects of other couplings which may be presented, therefore, this arrangement provides a regenerative effect which varies appropriately with frequency to produce the desired value of negative resistance.

I have found that certain factors have such an appreciable effect upon the uniformity of performance of the simple system just described that they are preferably taken into account in the design of a practical receiver. For example, it is common practice to control the high frequency amplification of the signal voltage in a radio receiver by varying the voltage applied to the control grids of one or more of the high frequency amplifying vacuum tubes. Since these

tubes operate in close cooperation with the resonant circuits of the receiver, the changes in their characteristics with changes in control grid voltage have an important effect upon the performance of the resonant circuits of the receiver and hence upon the uniformity of its performance. In accordance with one form of the invention, therefore, I overcome this difficulty, where it arises, by providing means for automatically regulating the degree of regeneration in accordance with the control grid bias voltages which are applied to the high frequency amplifying vacuum tubes.

It is an object of the invention, therefore, to provide a high frequency amplifying system having a high degree of gain and selectivity which is maintained substantially uniform over a wide range of frequencies.

A further object of the invention is to provide simple and inexpensive means for improving the selectivity and gain of a high frequency amplifying system and at the same time maintain its performance substantially uniform over a wide range of frequencies.

Another object of the invention is to improve the resonant gain and selectivity of an inductively tuned resonant circuit by a substantially uniform degree throughout a wide range of frequencies.

Still another object of the invention is to produce a substantial increase in the effective dynamic resistance of a tunable resonant circuit possessing relatively low but substantially constant inherent dynamic resistance.

It is also an object of the invention to effect any one or more of its desirable results, in conjunction with permeability tuning of the selective resonant circuit or circuits of the system.

The attainment of these and other highly desirable objects is accomplished in accordance with the invention in a manner brought out more fully in the specification which follows.

The invention comprehends the use of a regenerating vacuum tube to improve the performance of an arrangement including an amplifying vacuum tube and a resonant circuit. The regenerating vacuum tube, in accordance with the invention, is arranged to counteract the effective resistance of the resonant circuit, thus increasing its resonant gain and improving its selective properties. In a preferred arrangement, in accordance with the invention, in which the resonant circuit forms the plate load of the amplifying vacuum tube, there is provided an additional and worthwhile increase in the useful amplification obtainable due to the increased load impedance in the plate circuit of the tube. It will be understood, however, that the invention is equally applicable to arrangements in which the resonant circuit is not employed as the plate load of an amplifying vacuum tube.

Furthermore, the disclosure includes means for maintaining, in amplifiers which are tunable over a range of frequencies, a desired freedom from oscillation without sacrifice of the advantages above outlined which are derived from regeneration. In each instance, the degree of regeneration is regulated automatically without requiring any manual adjustment by the user of the amplifier.

The amplifier of the invention is especially well adapted for use in radio receivers of the tuned radio frequency type, in which all of the high frequency amplification of the signal is accomplished with no change in its carrier frequency,

but amplifiers of the type herein disclosed may equally well be employed in the preselector portions of radio receivers of the superheterodyne type. These and other uses of the invention, both at standard broadcast and at higher frequencies, will readily occur to those skilled in the art, and such uses will be understood to be within the scope of the invention.

As is well known, regenerative systems in general tend to build up the resonant response to any signal, regardless of its original strength, to an extent which is substantially the same for all signals. In this respect, the operation of the regenerative system is analogous to that of the well known automatic amplification control arrangements commonly employed, in which the gain of the amplifier tubes is automatically regulated in approximate inverse proportion to the strength of the impressed signal. In arrangements according to my invention, however, the regenerative element is not applied directly to the amplifier tubes, and has only an indirect effect upon their amplification, as will be described later. I, therefore, find it advantageous to employ an automatic amplification control arrangement in association with the amplifier tubes, and also in some cases to employ a portion of the control voltages thus secured to regulate the regenerative element as to its contribution to the total gain and selectivity of the receiver.

For a better understanding of the invention reference is made to the accompanying drawings in which:

Fig. 1 is a circuit diagram of a single-stage amplifier embodying the invention;

Fig. 2 is a circuit diagram of a tuned radio receiver employing amplifiers embodying the invention;

Fig. 3 is a schematic circuit diagram, partly in block form, of a superheterodyne radio receiver incorporating the arrangements of my invention;

Fig. 4 is a circuit diagram of a modified form of the coupling arrangement of Fig. 2; and

Figs. 5, 6 and 7 are circuit diagrams showing other modified forms of the coupling arrangement shown in Fig. 2.

Referring to Fig. 1 of the drawings, the basic arrangement according to the invention, in the illustrative example here shown, comprises a resonant circuit 1, tunable over a range of frequencies, for example the broadcast range, by a ferromagnetic core 2a movable relatively to the inductive branch of the circuit, namely, the inductor 2. The circuit has two capacitive branches 3 and 4-5, one of which comprises two capacitors, 4 and 5, connected in series. As a means for producing a substantially unvarying increase in the dynamic resistance of the circuit 1, there is provided a vacuum tube 6 having its control electrode 7 connected through a path of negligible high frequency impedance through capacitors 8 and 9 to the low potential terminal of resonant circuit 1. Vacuum tube 6 has its anode or plate 10 connected directly to the high potential terminal of circuit 1, and has its cathode 11 connected through a resistor 12 to the junction of capacitors 4 and 5. A source of positive potential 13 is shown connected between control grid 7 and ground and preferably maintains grid 7 at a positive potential relative to the cathode 11, the resistors 12 and 15 being preferably of such values, and the plate and grid voltages being so chosen, as to effect this result. A second source of positive potential 14 is provided for anode or

plate 10 of vacuum tube 6. By-pass capacitors 9 and 8 across sources 14 and 13, respectively, provide a path of negligible high frequency impedance between control electrode 7 of vacuum tube 6 and the low potential terminal of resonant circuit 1. Cathode 11 of vacuum tube 6 is connected through resistor 12 previously mentioned and resistor 15 to the common negative terminal of sources 13 and 14, which is preferably grounded.

Still referring to Fig. 1 of the drawings, the plate circuit of amplifying vacuum tube 16 includes plate 17, variable inductor 2, and voltage source 14. The screen grid 18 of vacuum tube 16 is connected to a tap on source 14 and is by-passed to cathode 19 of vacuum tube 16 by capacitor 20. The input signal is applied to control grid 21 of vacuum tube 16, and the output is taken off through capacitor 22.

In operation, vacuum tube 16 functions as a high frequency amplifier. Its plate load comprises resonant circuit 1, which may be tuned to a desired frequency by adjusting variable inductor 2 by means of the core 2a. The path for high frequency currents in the grid circuit of vacuum tube 6 may be traced from grid 7 through by-pass capacitors 8 and 9, and through capacitor 5 and resistor 12 to the cathode 11. Thus capacitor 5 is common to the grid circuit and to resonant circuit 1. High frequency currents in the plate circuit of vacuum tube 6 follow a path which includes capacitor 4 and resistor 12. Thus capacitor 4 is common to the plate circuit and to resonant circuit 1. The grid and plate circuits are, therefore, each capacitively coupled to resonant circuit 1, and it is these two cascaded couplings which cause vacuum tube 6 to regenerate, the feedback automatically varying with frequency in the desired manner. Resistor 12 functions to improve the stability of vacuum tube 6, and resistor 15 provides a direct current path for the cathode current of vacuum tube 6 to follow. Due to the effect of regeneration in vacuum tube 6, the effective resistance of resonant circuit 1 is greatly reduced, with the result that this circuit has much higher resonant gain and provides much better selectivity than would otherwise be realized from it. Furthermore, the resonant impedance of circuit 1 is substantially increased due to the effect of vacuum tube 6, thus somewhat increasing the effective amplification of vacuum tube 16 because of the improved relation between the plate resistance of the tube and the impedance of its plate load.

The degree of regeneration at any given frequency depends upon the adjustment of vacuum tube 6 and the amount of coupling between the plate and grid circuits of the tube. The regeneration provided by vacuum tube 6 may be varied by adjusting the value of resistors 12 and 15 in series, the degree of regeneration increasing as this resistance value is decreased. The amount of coupling depends upon the relative values of capacitors 3, 4 and 5, the coupling increasing as capacitors 4 and 5 in series are made larger in comparison with capacitor 3.

The variation of the gain and selectivity of the amplifying stage as resonant circuit 1 is tuned over a range of frequencies depends partly upon the characteristics of variable inductor 2, that is, the relation of its inductance to its high frequency resistance over the frequency range. The device is preferably such that the ratio of the inductance to the effective resistance of the resonant circuit remains substantially constant

over the frequency range. The desired relation is conveniently achieved in a preferred arrangement by employing a variable inductor of the type which uses a ferromagnetic core movable relatively to a suitable inductance coil. By proper design of the core with respect to the coil, as described in the patent to Polydoroff above referred to, a desired relation between inductance and resistance variations may readily be obtained.

Although a tetrode and a triode are shown in the circuit shown, it will be understood that they were chosen for purposes of illustrative example only, and that other types of vacuum tubes may equally well be employed. For instance, the amplifying vacuum tube may be a pentode having a suppressor grid in addition to the electrodes shown. Furthermore, it is within the scope of the invention to include the elements of vacuum tubes 6 and 16 within a single envelope and mounted upon a single base. Such a combination tube may employ a single heater to heat the cathodes 11 and 19, or separate heaters connected in series or parallel may be employed.

When in the claims, therefore, I describe my novel structure as including first and second vacuum tubes, it will be understood that the essential elements of these vacuum tubes may be incorporated in a single evacuated envelope with the possible elimination of some of the elements which would be required in the case of plural evacuated envelopes. For example, if the several elements were arranged in a single evacuated envelope, only one element to heat the plural cathodes might be necessary.

Fig. 2 is a schematic diagram of a tuned radio frequency radio receiver incorporating the arrangement of Fig. 1, but it will be understood that other modifications to be later described may equally well be employed in a receiver such as that of Fig. 2. This receiver employs ten vacuum tubes arranged as follows: three radio frequency amplifying vacuum tubes 25, 26 and 27, arranged in cascade; three auxiliary vacuum tubes 28, 29 and 30, cooperating respectively with resonant circuits 40; a vacuum tube detector or demodulator 31; an audio frequency amplifying and power output vacuum tube 32; an automatic amplification control vacuum tube 33; and a rectifier vacuum tube 34. With the exception of the novel arrangements now to be described, the receiver is of conventional design and operates in the usual manner.

The signal voltage developed across capacitor 35 in the antenna circuit is applied to control grid 36 of vacuum tube 25. A direct current biasing potential is applied to control grid 36 by means of resistor 37. Resistor 38 and capacitor 39 filter the bias voltage. The plate circuit of vacuum tube 25 includes resonant circuit 40, comprising adjustable capacitor 41, inductance coil 42, movable ferromagnetic core 43 and capacitors 44 and 45, capacitor 44 being also included in the plate circuit of vacuum tube 28. Plate voltage for vacuum tubes 25 and 28 is supplied through resistor 46, which is by-passed to ground by capacitor 47. Grid 48 of vacuum tube 28 may be connected to screen grid 49 of vacuum tube 25, which is supplied with a positive potential through resistor 50 and by-passed to ground by capacitor 51, or to any other suitable source of positive potential. Cathode 52 of vacuum tube 28 is grounded through resistors 53 and 54 in series, and the junction of resistors 53 and 54

is connected to the junction of capacitors 44 and 45.

That portion of the resonant signal voltage developed across resonant circuit 40 which appears across capacitor 45 is applied to control grid 36 of vacuum tube 26 through capacitor 55 and resistor 56 in series. Direct current bias voltage is applied to control grid 36 by means of resistor 37 shunted by capacitor 57, the bias voltage being filtered by resistor 38 and capacitor 39. Vacuum tubes 26 and 29 are arranged in a manner similar to vacuum tubes 25 and 28, respectively, like circuit components being designated by like reference characters. Vacuum tubes 27 and 30 also are arranged in a similar manner, except that the total signal voltage developed in the output circuit of vacuum tube 27 is supplied to control grid 36 of vacuum tube 31 by means of capacitor 58. A suitable direct current biasing potential is applied to control grid 36 of vacuum tube 31 by means of resistor 59.

The audio frequency voltage developed across load resistor 60 in the plate circuit of vacuum tube 31 is applied to the control grid 61 of vacuum tube 32 by means of capacitor 62 and volume control potentiometer 63. The plate circuit of vacuum tube 32 is coupled to loud speaker 64 by means of transformer 65.

A portion of the signal voltage at control grid 36 of vacuum tube 31 is applied to grid 66 of vacuum tube 33 through capacitor 67, direct current bias voltage being supplied to grid 66 by means of resistor 68. Plate 69 of vacuum tube 33 is by-passed to ground by capacitor 70, and the plate circuit includes resistors 71 and 72 in series.

The power supply for the receiver includes rectifier vacuum tube 34, multiple-winding transformer 73, and a voltage divider comprising resistors 74, 75 and 76 in series. It will be understood that the heaters of vacuum tubes 25-33 inclusive are energized by winding 77 of transformer 73, the heaters and the associated connections having been omitted from the circuit diagram to avoid unnecessary complication. One side of the heaters is preferably grounded.

In operation, a modulated high frequency signal impressed on the antenna is amplified successively by vacuum tubes 25, 26 and 27 operating in conjunction with resonant circuits 40, which are each tuned to resonance with the signal, and whose dynamic resistance is increased by auxiliary vacuum tubes 28, 29, and 30. This tuning is preferably accomplished by moving cores 43 simultaneously with respect to inductance coils 42, but it is within the scope of the invention to provide separate actuating means for one or more of the cores 43. The amplified high frequency signal is demodulated by vacuum tube 31, which is arranged to operate as a plate circuit detector, and the resulting audio frequency signal is amplified by vacuum tube 32 and supplied to loud speaker 64. The plate current of vacuum tube 33 depends upon the amplitude of the amplified signal at the input to the detector, and this current produces a voltage drop in resistors 71 and 72 in series. The total voltage developed across resistors 71 and 72 is applied to control grids 36 of vacuum tubes 25, 26 and 27, to provide automatic high frequency amplification control. The voltage drop across resistor 72 is also applied to control grid 36 of vacuum tube 31, in order to provide an additional degree of automatic amplification control. The volume level at the loud speaker is regulated by adjustment of potentiometer 63.

The circuit constants are so chosen that a suitable value of initial bias voltage for vacuum tubes 25, 26, 27 and 31 is provided by the potential drop across resistor 76, since the plate current of vacuum tube 33, and therefore the potential drop across resistors 71 and 72 in series, is substantially zero when no signal is impressed upon the antenna.

The values of resistors 53 and 54 are such that vacuum tubes 28, 29 and 30 regenerate but do not oscillate. The degree of regeneration is varied automatically in accordance with the signal strength by virtue of the connections between the grids 48 of vacuum tubes 28, 29 and 30 and the screen grids 49 of vacuum tubes 25, 26 and 27, respectively. When the control grid bias voltage is increased on the latter vacuum tubes by the automatic amplification control means, the screen grid currents decrease and the plate resistances of the tubes increase. The increase in the plate resistance of each of the amplifying vacuum tubes tends to increase the degree of regeneration as well as improve the selective properties of each of the resonant circuits 40. This tendency is overcome, however, in the following manner. Since the screen grid currents simultaneously decrease, the potential drops across resistors 50 decrease, and the effective voltage applied to grids 48 of vacuum tubes 28, 29 and 30 increases. This in turn increases the triode plate currents and hence decreases their plate resistances, which tends to compensate for the increase in the plate resistance of vacuum tubes 25, 26 and 27. So effective is this means of compensation that not only may the variation of the regeneration be maintained in proper relation to the frequency of the signal, but also, if desired, the regeneration may be made to decrease as the control grid bias on vacuum tubes 25, 26 and 27 is increased. In this manner, the band width of the receiver may be made to increase in the presence of a strong signal, thus improving the fidelity on signals otherwise capable of providing satisfactory reception, and the gain due to regeneration is decreased, thus supplementing the automatic amplification control system.

The paralleled resistor 37 and capacitor 35 in the input circuit of vacuum tube 25 and the paralleled resistors 37 and capacitors 57 in the input circuits of vacuum tubes 26 and 27 provide an impedance which increases as the frequency decreases, so that the signal voltage which is applied to control grids 36 of vacuum tubes 25, 26 and 27 increases toward the low frequency end of the frequency range over which the receiver is tunable. This effectually compensates for the increase of amplification with frequency due to the regenerative tendency of vacuum tubes 25, 26 and 27. Additionally, paralleled resistors 37 and capacitors 57, by changing the phase of the signal voltage applied to the succeeding stage, make the amplifier stages slightly degenerative with respect to each other. The function of resistors 56 is to minimize the effect of changes in impedance with frequency of coupling capacitors 55. Each of the resistors 56 also serves as an isolating resistance between stages, and tends to aid in adjusting the phase of the voltage transferred from one stage to the succeeding one.

Ferromagnetic cores 43 are preferably grounded and arranged to enter the low potential ends of inductance coils 42. However, the cores may be insulated from ground and may be arranged to enter the high potential ends of inductance coils 42 if desired.

In the embodiment shown in Fig. 2, the following components or values of constants may be successfully employed, but it will be understood that this is not to be taken as in any way limiting my invention, since other types and values of components may be employed, even in a circuit arrangement identical with that shown in Fig. 2.

Reference numeral	Type or value
Vacuum tubes 25, 26, 27 and 31	6K7G
Vacuum tubes 28, 29, 30 and 33	6C5G
Vacuum tube 32	6F6G
Vacuum tube 34	5Z4
Capacitor 35	500 micromicrofarads
Capacitors 39	0.05 microfarad
Capacitors 41	2-15 micromicrofarads
Capacitors 44 and 45	50 micromicrofarads
Capacitors 47, 51 and 70	0.1 microfarad
Capacitors 55 and 58	10 micromicrofarads
Capacitors 57	250 micromicrofarads
Capacitor 62	1,000 micromicrofarads
Capacitor 67	200 micromicrofarads
Inductance coils 42	133.5 microhenries
Resistors 37, 38 and 50	0.1 megohm
Resistors 46	5,000 ohms
Resistors 53	8,100 ohms
Resistors 54	20,000 ohms
Resistors 56	3,500 ohms
Resistor 59	1.0 megohm
Resistors 60, 71 and 72	0.5 megohm
Potentiometer 63	1.0 megohm
Resistor 68	2.0 megohm
Resistor 74	50 ohms
Resistor 75	200 ohms
Resistor 76	30 ohms

Fig. 3 shows the application of the invention to a superheterodyne radio receiver. In this particular embodiment, the invention is employed in the preselector portion of the superheterodyne. The preselector is tuned to the frequency of the desired signal, so that its operation is similar to that of the high frequency amplifying portion of the receiver of Fig. 2. Like circuit components are designated by like reference numerals.

The signal voltage developed across capacitor 78 in the antenna circuit is applied to resonant circuit 40 by means of capacitor 79. A voltage divider comprising resistors 80 and 81 in series is shunted across resonant circuit 40, the junction of resistors 80 and 81 being connected to control grid 36 of vacuum tube 25. A direct current bias voltage is applied to control grid 36 through resistor 38, the voltage being filtered by means of capacitor 39.

The plate circuit of vacuum tube 25 includes a second resonant circuit 40, associated with which is vacuum tube 28. Vacuum tube 25 functions as a radio frequency amplifier and vacuum tube 28 regenerates to improve the performance of resonant circuit 40. Input and output resonant circuits 40 are tuned to the frequency of the desired signal by means of movable ferromagnetic cores 43, which may be arranged to be actuated simultaneously with a single control.

The signal voltage developed in the output circuit of vacuum tube 25 is applied by capacitor 58 to the modulator, represented by block 82, associated with which is local oscillator 83. The output of the modulator 82 supplies the intermediate frequency amplifier 84, the demodulator 85, the audio frequency amplifier 86, and the loud speaker 64, respectively. Power supply 87 furnishes the other units of the receiver with suitable operating potentials.

In operation, the oscillator 83 is tuned in such a manner that its frequency differs from the frequency of the desired signal by the intermediate frequency. The oscillator tuning may be varied simultaneously with the tuning of the two resonant circuits 40, so that the receiver may be

tuned over a range of frequencies by the manipulation of a single control.

Fig. 4 of the drawings is similar in most respects to portions of Figs. 2 and 3, and like reference numerals are used to designate like circuit components throughout these three figures. In Fig. 4, however, the output signal from vacuum tube 25 is applied to the control grid 36 of the succeeding vacuum tube 26, not from the junction of cathode resistors 53 and 54 of vacuum tube 25, but from the suppressor grid 88 of vacuum tube 25 by means of coupling capacitor 89. This modified interstage coupling arrangement depends upon electron coupling within the vacuum tube 25. Thus the reaction upon the first stage which the second amplifying vacuum tube 26 would normally have is substantially eliminated, and additionally the performance of vacuum tube 26 is improved because of the relatively low grid circuit resistance which is made possible by this arrangement. The modified arrangement of Fig. 4 has been found especially advantageous at the higher radio frequencies, some of which may be covered by the tuning range of a radio receiver employing my system. It will be understood, however, that this modification does not affect the basic operation of my novel arrangements, and that it may be employed with equally good results between stages other than the first and second, which are shown by me in Fig. 4 merely by way of illustrative example.

In the modification of the invention shown in Fig. 5, the grid 48 of the regenerative tube 28 is connected to the high potential terminal of resonant circuit 40 through a coupling capacitor 90. Cathode resistor 53 is shunted by a capacitor 91 and a grid leak resistor 92 is shown connected between grid 48 and the lower end of resistor 53. Also the low potential terminal of circuit 40 is grounded through a condenser 93 of relatively large capacity. In this form of the invention the amplified voltage of tube 25 is applied across the grid 48 and cathode 52 of the regenerative tube 28. This voltage causes a corresponding change in the plate current of tube 28 which flows through condenser 45 of the resonant circuit and develops a voltage across this condenser. This voltage causes a corresponding voltage to be developed across condenser 44 which reinforces the grid voltage and causes a still further change in the plate current of the tube in the same direction. This process is repeated until the full regenerative effect of tube 28 is developed. Since the condensers 44 and 45 are in series in the permeability tuned circuit, the negative resistance developed will vary inversely as the square of the resonant frequency of the circuit 40 as controlled by the adjustment of the ferromagnetic core 43. It is to be noted that in this modification one of the series connected condensers, namely 44, is connected in the grid circuit of the regenerative tube and the other, 45, is connected in its plate circuit.

In the embodiment of the invention shown in Fig. 6, the series connected condensers of the resonant circuit 40 are omitted and condenser 41 may have a fixed value. As in the case of Fig. 1, the plate of the regenerative tube 28 is directly connected to the high potential terminal of the resonant circuit and the grid 48 of the regenerative tube is maintained at ground potential for radio frequencies. The grid circuit of tube 28 comprises a coil 94 which is connected in series with the bias resistor 53, the latter being shunted by a condenser 91, as in the circuit of

Fig. 5. With resistor 53 having a value of about 250 ohms, a suitable bias voltage is developed for the grid 48 and a value of 0.1 microfarad is suitable for the condenser 91. Slight changes in the value of resistor 53 will have but little effect on the bias voltage and a comparatively negligible effect on the regeneration. Since the reactance of condenser 91 at the signal frequencies only amounts to a few ohms, a substantial change, for example 50%, in the size of this condenser will not materially affect the degree of regeneration.

The regeneration is due to the coupling between the plate coil 42 and cathode coil 94, which in one embodiment of the invention are mounted coaxially with their opposite ends in the same planes and with coil 94 surrounding the coil 42. The core 43 preferably enters the low potential ends of the coils, as shown, and produces an increase in their mutual inductance which is proportional to the extent of adjustment of the core. At the same time an increase in the inductance of the tank coil 42 is produced which is proportional to the extent of adjustment of the core. The feedback, a function of the mutual inductance, varies as the inductance of the tank coil and the negative resistance developed by the regenerative tube 28 is substantially proportional to the inductance of the tank circuit 40. The cathode coil 94 is preferably wound with a variable pitch, the turns at the high frequency end which the core 43 first enters being wound closely together while the turns at the opposite end are spaced apart by an appreciable distance. With the coil construction described, the construction of the core 43 is preferably such as to provide higher losses toward its rear end than at its front end which first enters the coil 42. For the end first entering the coil, a very high grade of iron is used, such as hydrogen iron which passes through a 400 mesh screen. The central portion of the core is composed of a mixture of this high grade, finely powdered iron and a coarser grade of iron of larger particle size and the rear end is composed of iron particles which pass through a 50 mesh screen. Instead of using a core of variable composition, it is also possible to provide a negative resistance which is substantially proportional to the inductance of the resonant circuit by using a core of uniform composition and a coil 94 of suitable diameter and having a variably pitched winding, and properly spacing said coil with reference to the tank coil 42. By means of the coil and core arrangements described, the selectivity and gain of the resonant circuit 40 may be maintained substantially constant throughout the range of tuning from 600 kc. to 1500 kc.

The coupling arrangement between the amplifier and regenerative tubes 25 and 28 shown in Fig. 7 is generally similar to that shown in Fig. 2, but instead of the tap point being provided in the capacitive branch of the resonant circuit 40, it is provided in the inductive branch, the condensers 44 and 45 of Fig. 8 being omitted. In this case the permeability tuned coil comprises two coil sections 95 and 96 which are wound directly over each other but in opposite directions, so that their mutual inductances are additive. As shown, the upper ends of sections 96 and 95 are connected to the source of plate supply voltage and the plates of the tubes respectively. The tap point 97 is connected to the junction of the resistors 53, 54 by means of a blocking condenser 98 which serves to prevent the positive voltage applied to the coil sections from entering the cathode circuit of the regenerative tube 28.

Since the direct plate current of tube 28 passes through the resistors 53, 54, these resistors provide the desired bias voltage for the grid 48 of the regenerative tube.

It will be understood that certain types of coils are above described to illustrate the operation of the invention, and that any other types of coils may be used respectively therein, that are susceptible of effecting substantially the operations described.

While I have shown my invention in the particular embodiments above described, I do not limit myself thereto as I may employ equivalents thereof without departing from the scope of the appended claims.

Having thus described my invention, what I claim is:

1. In combination, a resonant circuit comprising a coil having resistance, means for changing the inductance of said coil to tune said circuit over a range of frequencies, a regenerative vacuum tube including anode, cathode and control elements for supplying energy to said circuit substantially in phase with the current therein, said control element being effectively grounded for radio frequency current flow, and means for automatically varying the coupling between said energy supplying means and said resonant circuit in such manner as to maintain the ratio between the inductance and effective resistance of said circuit substantially constant as the circuit is tuned through the frequency range.

2. In combination, a resonant circuit having resistance and comprising a coil and capacitor, means for varying the inductance of said coil to tune said circuit over a range of frequencies, an electron discharge device having coupled grid and plate circuits and a control grid effectively grounded for radio frequency current flow, and means for coupling one of said circuits to said resonant circuit in such manner that the degree of coupling therebetween is automatically varied to maintain the ratio between the inductance and resistance of said resonant circuit substantially constant as said resonant circuit is tuned through the frequency range.

3. A selective high frequency resonant system comprising, in combination, a resonant circuit comprising an inductance and having a relatively low dynamic resistance, permeability-changing means for varying the inductance to tune said circuit over a range of frequencies, an electron discharge tube having its plate connected to the high potential terminal of said resonant circuit and having a control grid effectively connected for radio frequency current flow to the ground potential terminal of said resonant circuit.

4. A selective high frequency resonant system comprising, in combination, a resonant circuit comprising an inductance and having a relatively low dynamic resistance, permeability-changing means for varying the inductance to tune said circuit over a range of frequencies, an electron discharge tube having its plate connected to the high potential terminal of said resonant circuit and having a control grid connected to the ground potential terminal of said resonant circuit, said connection of said control grid having a negligible impedance at the frequencies within the tuning range of said resonant circuit.

5. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said cir-

cuit having parallel inductive and capacitive branches, and one of said branches being provided with an intermediate tap, and means for producing a substantial increase in said dynamic resistance including a vacuum tube having a control grid connected to the ground potential terminal of said circuit, an anode connected directly to the high potential terminal of said circuit, and a cathode connected through an impedance to said intermediate tap, the resulting dynamic resistance being substantially constant for different tuned frequencies of said resonant circuit.

6. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit having parallel inductive and capacitive branches, and one of said branches being provided with an intermediate tap, and means for producing a substantial increase in said dynamic resistance including a vacuum tube having a control grid connected to the ground potential terminal of said circuit, an anode connected directly to the high potential terminal of said circuit, and a cathode connected through an impedance to said intermediate tap, said intermediate tap being in the capacitive branch of the resonant circuit.

7. In a system for selectively amplifying a high frequency signal including first and second vacuum tubes each having a plate and a control grid, and a resonant circuit connected to the plate of said first tube, the method of improving the amplification and selectivity of said system which comprises the steps of tuning said resonant circuit to the signal by varying the inductance thereof by permeability changes, amplifying the signal by the first vacuum tube, connecting the plates of said vacuum tubes together, supplying to the resonant circuit from the second vacuum tube an amount of energy which is sufficient to only partly overcome the dissipative losses of the resonant circuit at the frequency of the signal, maintaining said control grid at substantially the potential of the low potential terminal of the resonant circuit.

8. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit comprising a coil, a regenerative vacuum tube having a cathode circuit comprising a second coil coupled to said first coil and a plate connected to the high potential terminal of the resonant circuit, and a single adjustable means arranged to simultaneously tune said circuit over a range of frequencies and to vary the mutual inductance between said coils, said tube having a control grid effectively grounded for radio frequency current flow.

9. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit comprising a coil, a regenerative vacuum tube having a cathode circuit comprising a second coil coupled to said first coil and a plate connected to the high potential terminal of the resonant circuit, and a single adjustable means arranged to simultaneously tune said circuit over a range of frequencies and to vary the mutual inductance between said coils, said tube having a control grid effectively grounded for radio frequency current flow, said second coil including a

winding having varied pitch producing by said adjustable means approximately an inverse proportionality between said mutual inductance and the square of the tuned frequency over the tuning range.

10. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit comprising a coil, a regenerative vacuum tube having a cathode circuit comprising a second coil coupled to said first coil and a plate connected to the high potential terminal of the resonant circuit, and a single adjustable means arranged to simultaneously tune said circuit over a range of frequencies and to vary the mutual inductance between said coils, said tube having a control grid effectively grounded for radio frequency current flow, said adjustable means including a core formed of powdered ferromagnetic material.

11. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit comprising a coil, a regenerative vacuum tube having a cathode circuit comprising a second coil coupled to said first coil and a plate connected to the high potential terminal of the resonant circuit, and a single adjustable means arranged to simultaneously tune said circuit over a range of frequencies and to vary the mutual inductance between said coils, said tube having a control grid effectively grounded for radio frequency current flow, said adjustable means including a core formed of powdered ferro-magnetic material so arranged as to provide a greater core resistance at the low frequency end of the tuning range than at the high frequency end thereof.

12. A selective high frequency resonant system comprising, in combination, a permeability-tuned resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit comprising a coil, a regenerative vacuum tube having a cathode circuit comprising a second coil coupled to said first coil and a plate connected to the high potential terminal of the resonant circuit, and a single adjustable means arranged to simultaneously tune said circuit over a range of frequencies and to vary the mutual inductance between said coils, said tube having a control grid effectively grounded for radio frequency current flow, said adjustable means including a core formed of powdered ferromagnetic material particles, the size of the particles at one end of the core being substantially larger than those at the other end thereof.

13. A selective high frequency resonant system comprising, in combination, a tunable resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit having parallel inductive and capacitive branches and the inductive branch being provided with an intermediate tap, and means for producing a substantial increase in said dynamic resistance including a vacuum tube having a plate connected to the high potential terminal of said resonant circuit, said tube also having cathode and grid electrodes, a circuit connecting said cathode to said intermediate tap, and a circuit connecting said grid to the ground potential terminal of the resonant circuit, the resulting dynamic resistance being substantially constant for different tuned frequencies of the resonant circuit.

14. A selective high frequency resonant system comprising, in combination, a tunable resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit having parallel inductive and capacitive branches and the inductive branch being provided with an intermediate tap, and means for producing a substantial increase in said dynamic resistance including a vacuum tube having a plate connected to the high potential terminal of said resonant circuit, said tube also having a cathode and grid electrodes, a circuit connecting said cathode to said intermediate tap, and a circuit connecting said grid to the ground potential terminal of the resonant circuit, the circuit connecting said cathode to the intermediate tap including a blocking condenser.

15. A selective high frequency resonant system comprising, in combination, a tunable resonant circuit having a relatively low but substantially constant dynamic resistance, said circuit having parallel inductive and capacitive branches and the inductive branch being provided with an intermediate tap, and means for producing a substantial increase in said dynamic resistance including a vacuum tube having a plate connected to the high potential terminal of said resonant circuit, said tube also having cathode and grid electrodes, a circuit connecting one of said tube electrodes to said intermediate tap, and a circuit connecting the other tube electrode to the low potential terminal of the resonant circuit, the resulting dynamic resistance being substantially constant for different tuned frequencies of the resonant circuit, said inductive branch including two coil sections connected in series, the winding of one coil section being wound in an opposite

direction to the winding of the other coil section.

16. In combination, a circuit tunable throughout a band of radio frequencies, a vacuum tube for supplying regenerative energy to said circuit, said tube having plate and cathode electrodes coupled with said circuit and having a control grid which is effectively grounded for radio frequency current flow, and devices for varying the coupling between said resonant circuit and said tube circuits including a coil having a varied winding pitch and a ferromagnetic core associated with and movable relatively to said coil.

17. In combination, a resonant circuit comprising capacitive and inductive branches, means for tuning said circuit over a range of frequencies, an electron discharge device having grid and plate circuits coupled with said resonant circuit and having a cathode, and a degenerative impedance connected between said cathode and ground, said impedance including a resistance external to said resonant circuit and including a resistance and reactor constituting a part of said resonant circuit.

18. In combination, a resonant circuit comprising capacitive and inductive branches, means for tuning said circuit over a range of frequencies, an electron discharge device having grid and ground, said impedance including a resistance circuit and having a cathode, and a degenerative impedance connected between said cathode and ground, said impedance including a resistance external to said resonant circuit and including a resistance and reactor constituting a part of said resonant circuit, said grid being effectively grounded for radio frequency current flow.

WILLIAM A. SCHAPER.

CERTIFICATE OF CORRECTION.

Patent No. 2,298,629.

October 13, 1942.

WILLIAM A. SCHAPER.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 44, for "kind" read --kinds--; page 5, second column, line 23, for the word "wall" read --well--; page 7, first column, line 63, for "Fig. 8" read --Fig. 2--; page 8, first column, line 45, claim 7, before "maintaining" insert --and--; page 9, first column, line 11, claim 14, for "having a cathode" read --having cathode--; and second column, line 28, claim 18, for "nd ground, said impedance including a resistance" read --and plate circuits coupled with said resonant--; line 31, same claim, for "including" read --including--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 1st day of December, A. D. 1942.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.

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