Nov. 26, 1935. H. A. WHEELER 2,022,067

FEED BACK CIRCUITS

Filed May 28, 1931

Fig. 1,

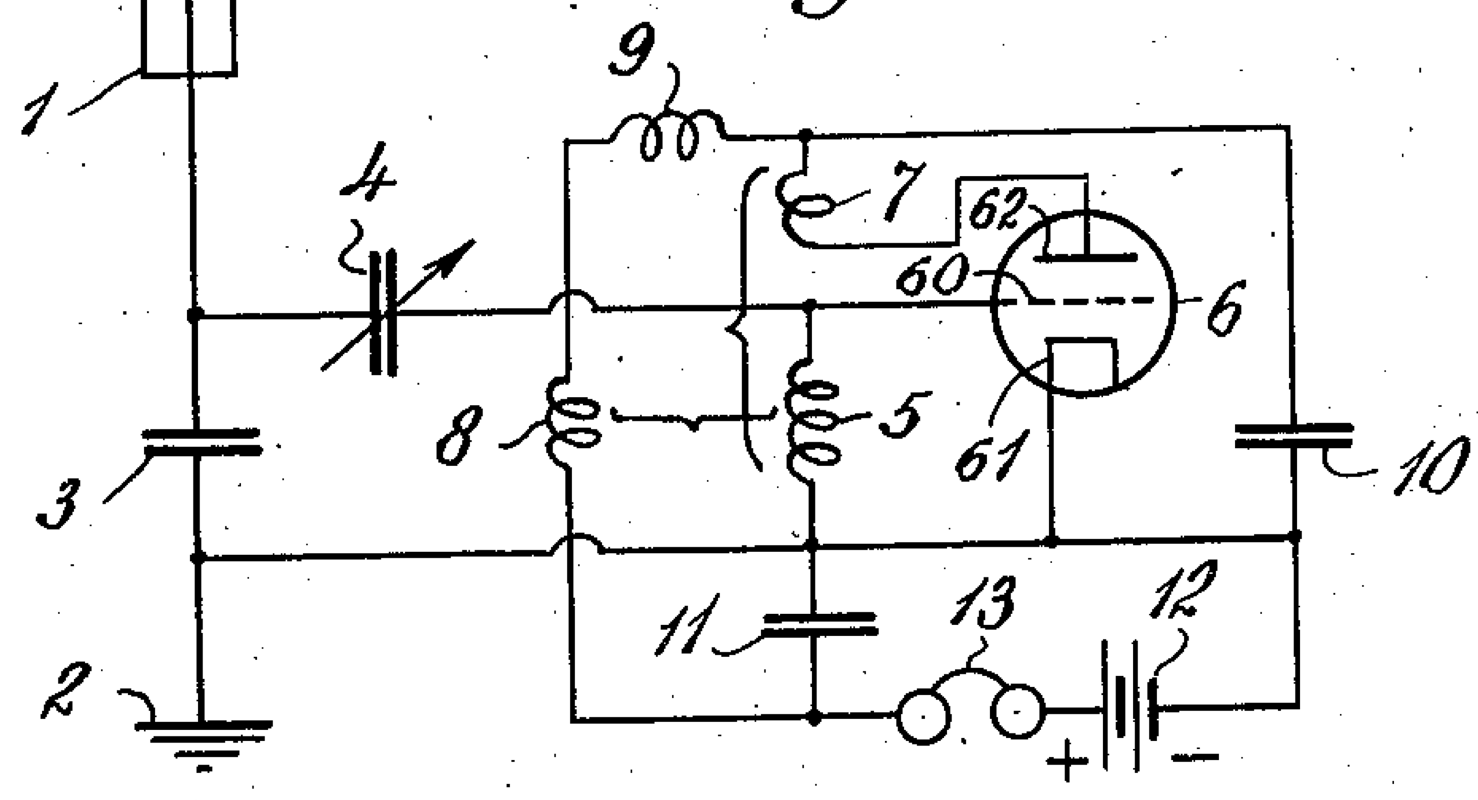


Fig. 2,

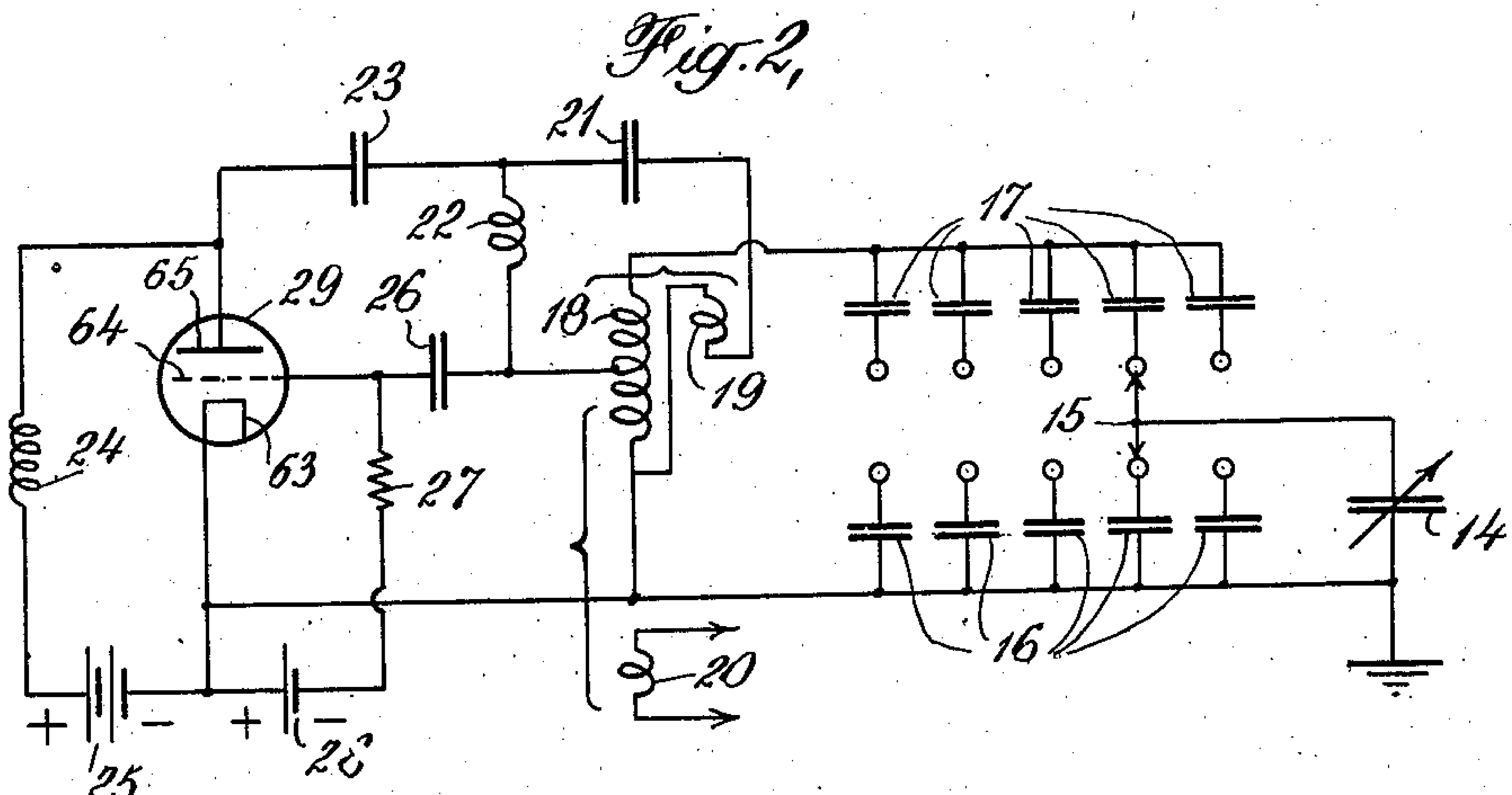


Fig. 3,

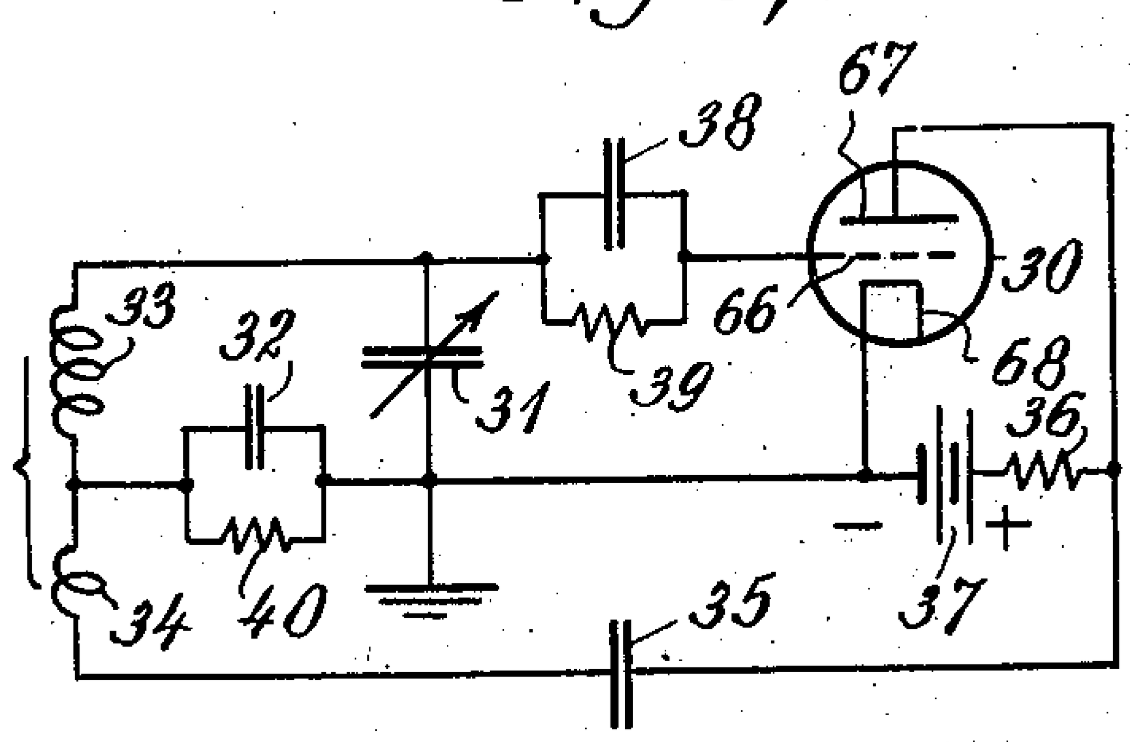
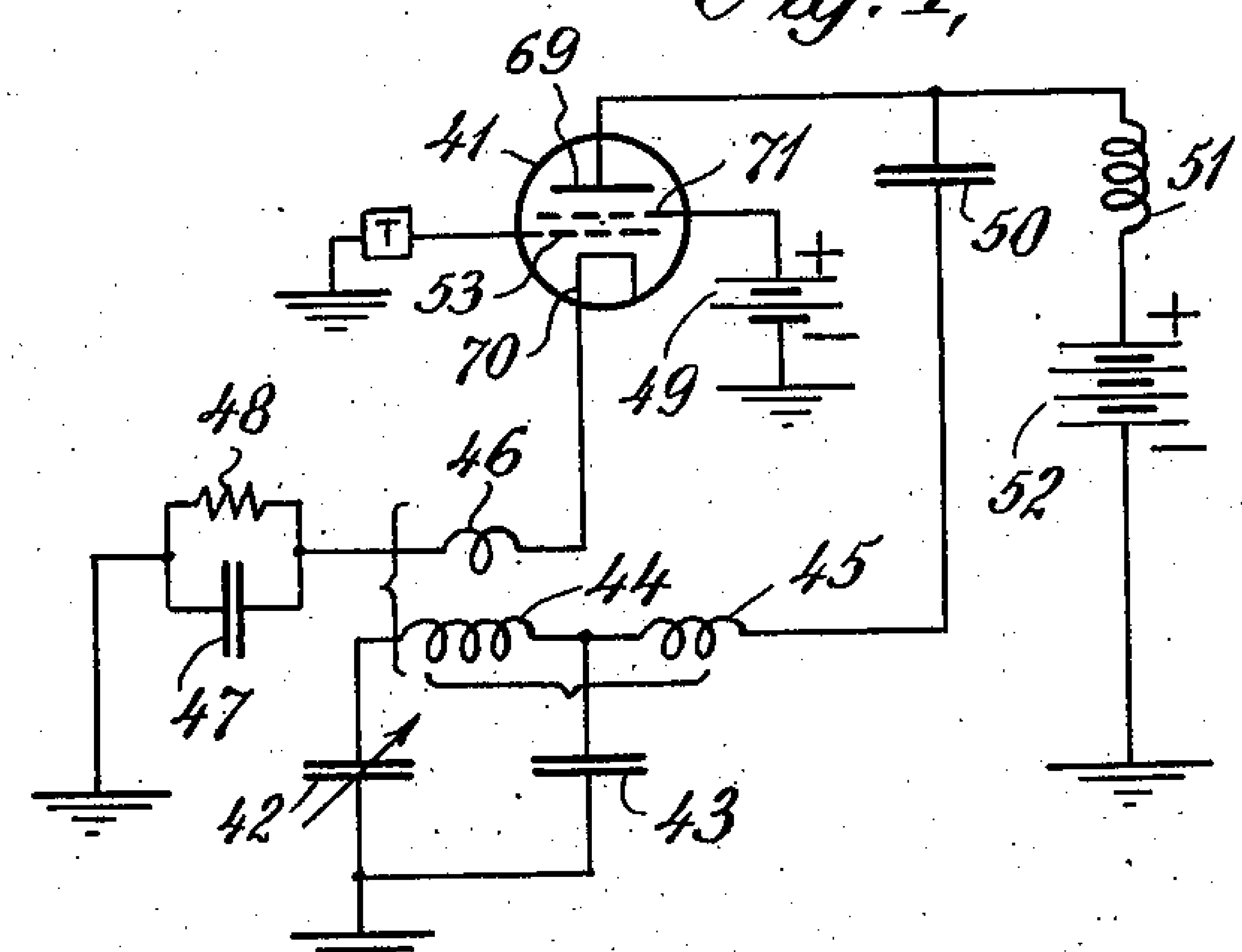


Fig. 4,



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FEED-BACK CIRCUITS

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6 Claims. (Cl. 250—20)

This invention relates to wave regeneration, and has for its principal object the provision of a feed-back, or oscillator, circuit utilizing a vacuum tube or other space discharge device coupled with a resonant circuit which is tunable over a frequency range.

The invention is equally applicable to the utilization of such systems both as regenerative amplifiers and as oscillation generators. In either case, the feed-back coupling or the coupling between the tuned circuit and the space discharge device is made automatically dependent on the frequency of tuning, by the use of coupling elements which remain physically fixed during tuning and which preferably do not rely on resistance for the performance of their functions.

A particularly useful application of the invention is found in an oscillating or regenerative circuit which is tuned by a variable condenser in parallel with a fixed inductance. Two or more reactance elements may be used in the well-known feed-back coupling circuit which is familiar in connection with the common triode vacuum tubes; and these elements may be chosen so that their individual contributions to the total feed-back coupling vary in different manners over the frequency range of tuning. The several kinds of couplings can then be proportioned so that the total coupling is caused to vary in any predetermined manner with the frequency of tuning.

Another very useful application of the invention employs in the feed-back coupling system one inductance whose resonant frequency in the circuits is substantially above the tuning range and another inductance which is resonant slightly below the tuning range. Each inductance contributes a greater degree of coupling at frequencies near its resonant frequency than at frequencies more remote from resonance. The total amount of coupling can therefore be given any predetermined variation by properly proportioning the individual coupling components.

Another method of practicing the invention lies in utilizing combined capacitive and inductive couplings in the feed-back circuit.

Improvements which are realized in the present invention are the following:

In accordance with the present invention, the amplitude of oscillation of a space discharge oscillator can be maintained substantially uniform while the oscillator is tuned over a wide frequency range, or on the other hand, can be made to vary with tuning in any predetermined manner. The desired amplitude vs. frequency relation is obtained by proportioning the different types of coupling to provide the necessary resultant coupling variation.

It is possible to construct an oscillator system in which the feed-back is so chosen that the amplitude of oscillation is uniformly low over the entire tuning frequency range, as compared with the maximum output which can be obtained from the particular oscillator device employed. This effect is obtained without adding resistance or damping effects in any appreciable amount to the tuned circuit of the oscillator system. Both the low amplitude of oscillation and the retained high selectivity of the tuned circuit contribute to the result that the output of the oscillator contains an extremely small percentage of harmonics or of distortion of the sine wave form. This result cannot be easily obtained by either of these features alone.

In the same manner it is possible to proportion the feed-back so that it is held just below the point of oscillation over the entire tuning range. This is a condition favorable to regenerative amplification, and has the advantages that the regenerative feed-back does not have to be continually adjusted during tuning and that squeals and whistles are not heard during the tuning process.

The features of small harmonic distortion and of small amplitude of oscillation are especially advantageous in the beat oscillator of a heterodyne receiver, particularly in the familiar superheterodyne receiver. The feature of small harmonic distortion contributes to the prevention of audio beat notes between harmonics of the oscillator and undesired signals, thus greatly improving the selectivity and the freedom from disturbances. The feature of low and uniform amplitude enables the functions of beat oscillator and modulator beat detector to be combined in a single tube of a heterodyne or a superheterodyne receiver without sacrificing performance in any way.

An oscillator with uniform output has advantages which are apparent if used in testing equipment where it is desired to avoid any unnecessary manipulation of the apparatus and, at the same time, to maintain a uniform output level. The fact that resistance effects are not relied upon in the circuits of the present invention makes the frequency of the oscillator much more stable than it would be if resistance effects were utilized. This result is also realized when the invention is utilized in heterodyne receivers.

The application of this invention to regenerative amplification, described above, is quite similar to its application in an oscillating detector used for self-heterodyne reception. It is well known that this last function requires a low amplitude of oscillation; and the maintenance of a low amplitude without the use of auxiliary controls is a great advantage.

Of the drawing:

Fig. 1 is a circuit diagram of a radio receiver employing a vacuum tube detector-amplifier provided with feed-back circuits for regeneration or heterodyne reception in accordance with the present invention;

Fig. 2 is a circuit diagram of a vacuum tube oscillator system which is particularly applicable to radio testing equipment;

Fig. 3 is a circuit diagram of a vacuum tube oscillator system which can easily be designed to provide a uniform output or an output which varies in any desired manner; and

Fig. 4 is a circuit diagram of an oscillator system utilizing a tetrode, or a so-called screen-grid vacuum tube, in addition to the features of this invention.

The use of the word "vacuum-tube" in this specification is not intended as a restriction of the invention to the ordinary high vacuum tubes. The invention is equally applicable to many other types of oscillating circuits. Particular reference is made to other types of oscillator devices employing a low pressure gaseous discharge, an electric arc discharge, or a secondary emission discharge such as the so-called "dynatron" effect. The present invention will be described as applied to the triode vacuum tube but is equally applicable to the other types of oscillating circuits.

The specific circuits described herein are intended to be tunable over the broadcast range of 550 to 1500 kilocycles per second or over the slightly different frequency range required in the oscillator of a superheterodyne receiver (for example 725 to 1675 kilocycles per second). The invention is equally applicable to other frequency ranges utilized in so-called long wave receivers or short wave receivers.

Fig. 1 illustrates a single tube radio receiver comprising an antenna 1 and a ground 2 coupled to a regenerative detector-amplifier tube 6 of the three-electrode type. The antenna 1 is coupled to the grid 60 of tube 6 through a variable condenser 4, and the cathode 61 of the tube is connected directly to ground. The system includes a resonant tuning circuit comprising the variable condenser 4, an inductance 5 connected directly between the grid and cathode of the tube and a fixed condenser 3 connected between the antenna and ground. The condenser 3 may be omitted if the antenna has sufficiently large capacity to ground.

The anode circuit of the tube 6 includes in series between the anode 62 and the cathode, in the order named, inductances 7, 9 and 8, headphones 13, and an anode battery 12. A fixed condenser 11 of relatively low reactance to radio-frequency currents is connected between the low potential end of inductance 8 and the cathode for the purpose of by-passing these radio-frequency currents past the battery 12 and headphones 13. A condenser 10 is connected between the cathode and the point between inductances 7 and 9.

The inductances 7 and 8 are each inductively coupled to inductance 5, as indicated by the brackets, and hence act as feed-back coils for producing regeneration from the anode circuit to the grid circuit.

While a battery is indicated as the source of anode potential in Fig. 1, and in the other figures of the drawing, it should be understood that the battery may be replaced by any equivalent such as an alternating current supply equipped with rectifiers and filters.

Considering for the moment the regenerative system, this comprises the two feed-back coils 7 and 8, each coupled to the inductance 5. Coil 7 has a relatively low inductance and is resonant together with inherent capacities at a frequency substantially higher than the tuning range of variable condenser 4. On the other hand, coil 8 may have somewhat higher inductance and is included in series with the fixed inductance 9 and condensers 10 and 11. This series circuit is resonant at a frequency slightly below the tuning range. This is accomplished either by making the total inductance of coils 8 and 9 large, or the capacities of condenser 10 and 11 large, or both.

In obtaining the advantages of the present invention from the circuit of Fig. 1, the following method of operation is employed: the feed-back coil 7, it is noted, has a relatively large feed-back effect at the higher frequencies. This is the recognized behavior of the well known "tickler coil." On the other hand, feed-back coil 8 with its associated inductance and capacity has a relatively larger feed-back effect on lower frequencies approaching its own resonant frequency. As a result, the amount of mutual inductance between coils 5 and 7 can be adjusted to secure the desired amount of feed-back coupling at the higher frequencies. Then the mutual inductance between coils 5 and 8 can be adjusted to secure the desired amount of feed-back coupling at the lower frequencies. Since each of these two adjustments is relatively independent of the other, the result will be that the total feed-back coupling will vary gradually over the frequency range at the rate determined by these two adjustments. If desired, the low frequency adjustment can be made by varying the capacity of condenser 10, instead of by varying the mutual inductance of coils 5 and 8.

It is usually desired, in the system of Fig. 1, that the two feed-back coupling components be combined in the proper polarities to aid each other. Because of the coil 8 being included in the circuit having a natural frequency below the tuning range, the radio-frequency current through coil 8 is opposite in polarity to the anode current through coil 7. Therefore, coils 7 and 8 must be coupled to coil 5 in opposite directions.

The above method of adjustment of the two feed-back coupling components is equally applicable whether it is desired that the circuit give regenerative amplification just below the point of oscillation, or oscillate at a uniformly low amplitude for heterodyne reception.

Fig. 2 shows an oscillator system which embodies the present invention in order to obtain a uniform voltage output when tuned over a large range of frequency. To enable the invention to be readily practiced, there are given numerical values for the elements, which have been found satisfactory. These values are not intended to constitute limitations upon the invention.

The system comprises a three-electrode oscillator tube 29 which may be of the 171—A type, and a resonant frequency-determining circuit including a fixed inductance coil 18, a variable tuning condenser 14 and a number of fixed condensers 16 and 17. The condensers 16 are adapted to be connected in parallel with condenser 14 and the condensers 17 in series with condenser 14 by switch 15, as required. One end of coil 18 is connected to the cathode 63 of tube 29, and an intermediate point of the coil is coupled to the grid 64 of the tube through a fixed grid condenser 26 (250 $\mu\mu$f.). The series combination of condenser 14 and one of condensers 17 (one of condensers 16 being in parallel with condenser 14), is connected across the entire inductance 18.

There is provided a feed-back arrangement which includes in a series circuit from the anode to the cathode of the oscillator tube, the following elements in the order named: fixed condensers 23 (0.1μf.) and 21 (250 $\mu\mu$f.), and an inductance 19 which is inductively coupled to coil 18, as indicated by the brackets. An inductance 22 is connected between the intermediate point of coil 18 and the point between condensers 21 and 23. The anode potential is furnished by a battery 25 (90 volts) connected between the cathode and the anode through a choke coil 24, (7 millihenries). The grid of the tube is negatively biased by a biasing battery 28 (about 20 volts) which is connected between the cathode and the grid of the tube through a high grid-leak resistance 27, (0.25 megohm).

The output of the oscillator is taken from across an output coil 20 which is coupled to inductance 18.

The switch 15 operates to connect condensers 16 and 17 in circuit, in pairs. Each pair of series and parallel condensers enables the same tuning condenser 14 to cover a different frequency range. The variable condenser preferably has a capacity range of 42 to 900 $\mu\mu$f. The following table gives the combinations of series and parallel condensers required to cover the given frequency ranges:

Frequency range (kc.)	Parallel condenser ($\mu\mu$f.)	Series condenser ($\mu\mu$f.)
500-700	586	----------
700-900	430	1,599
900-1100	330	646
1100-1300	214	355
1300-1600	108	215

In order to secure a practically linear frequency calibration for the scale of condenser 14 over these various ranges in frequency, the condenser plates are made semi-circular but the axis of rotation is located eccentrically so that the radius of the entering edge of the rotor plates is one-half the radius of the trailing edge. This shape gives very nearly linear calibration over the intermediate frequency range (900 to 1100 kc.) and only slight curvature in the frequency calibration of the other ranges. This combination of capacities has the advantage that a single half turn of the tuning condenser covers a frequency range of only one-fifth the broadcast range and therefore the scale divisions are relatively large and easy to read accurately. Each of the five frequency ranges has an individually engraved scale on the condenser dial. The dissipation in the condensers and switching system is negligible, and the feed-back is not varied when switching condensers, so that the output suffers no abrupt change with frequency at the boundaries between adjacent frequency ranges.

The feed-back coil 19 has a relatively low inductance and with incidental capacities has a resonant frequency which is substantially higher than the tuning range. The inductance coil 22, on the other hand, has a relatively high inductance (.4 millihenry) and is resonant with condenser 21 (250 $\mu\mu$f.) at a frequency slightly below the tuning range. Coil 19 and the lower half of coil 18 are effectively included in this low frequency resonant circuit but do not appreciably affect the resonant frequency because their combined inductance is much smaller than that of coil 22. At high frequencies the reactance of coil 22 is so large that almost the entire radio frequency plate current flows through condenser 21 and coil 19.

By connecting the feed-back circuits so that coil 19 is coupled to coil 18 in a reverse direction, while coil 22 is connected to a tap on coil 18, the feed-back current through condenser 21 and coil 19 has an effect which is augmented by the feed-back current through coil 22 and the lower half of coil 18, the latter making a substantial contribution only at the lower frequencies. It is well known that an oscillator tuned by a variable condenser requires a greater amount of feed-back at the lower frequencies than at the higher frequencies if the output is to be maintained at a uniform level over a frequency range. This result is accomplished with the circuit arrangement of Fig. 2 as described.

This circuit is utilized with excellent results as one element of a standard signal generator for testing radio receivers. The special tuning arrangement contributes greatly to the ease of operation of this equipment.

The coil structure of Fig. 2 is preferably constructed as follows and located in a cylindrical copper can, 3.25'' in diameter x 4.3'' in length:

The coil 18 comprises 63 turns of No. 22 B & S gauge wire spaced 22 turns per inch on a cylindrical form 2'' in diameter. The tap off is approximately at the center. Feed-back coil 19 comprises 12 turns of No. 30 B & S gauge wire spaced 16 turns per inch on a cylindrical form 2½'' in diameter. Output coil 20 comprises 50 turns of wire on a cylindrical form 1½'' in diameter. Coil 19 is wound over the upper half of coil 18 as indicated in the diagram, in order to prevent so-called "parasitic oscillations" which otherwise occur at frequencies much higher than the resonant frequency of the oscillator system.

Fig. 3 illustrates another type of oscillator circuit embodying the present invention. For reasons that will be mentioned below, it is especially adapted to the requirements of a beat oscillator in a superheterodyne receiver although it is also suitable for the other purposes mentioned herein. The system comprises a three-electrode oscillator tube 30, which may be of the 227 type, and the associated frequency-determining and feed-back circuits, as in the case of the oscillator of Fig. 2. The anode circuit comprises the series connection from the anode 67 to the cathode 68, of a fixed condenser 35, (.001 μf.) an inductance 34 and the parallel combination of a condenser 32 and resistance 40, (10,000 ohms). The tunable circuit comprises an inductance 33, a variable condenser 31 and the fixed condenser 32, which is preferably, but not necessarily, larger than the maximum capacity of tuning condenser 31. For example, the tuning condenser may have a maximum capacity of 350 $\mu\mu$f. and the condenser 32 may be of 700 $\mu\mu$f. Inductance 33 is connected at one end to the junction point of inductance 34 and condenser 32, and at the other end to the grid 66 of the oscillator through a condenser and grid-leak arrangement comprising condenser 38 (30 $\mu\mu$f.) and high resistance 39 (1 megohm). The variable condenser 31 is connected between the grid end of inductance 33 and the cathode, which is grounded.

The rectified current in the grid circuit of the tube is carried by the resistances 39 and 40; in this manner, a grid bias voltage is established, which automatically assumes the correct value during operation.

The anode current is supplied from a battery 37 (180 volts) through a resistance 36 (20,000 ohms) which, at the same time, serves the purpose of a radio-frequency choke.

The feed-back circuit comprises the condenser 35, the coil 34 coupled to coil 33, and the condenser 32. The function of condenser 35 is to separate the direct and radio-frequency components of the anode current. The coil 34 provides a feed-back coupling whose effect is relatively greater at the higher frequencies of the tuning range than at the lower frequencies. Condenser 32 provides an aiding feed-back coupling whose effect is greater at the lower than at the higher frequencies of the tuning range because of its greater reactance at the lower frequencies. The two feed-back couplings of coil 34 and condenser 32 are so proportioned that the total feed-back coupling has the correct value over the entire frequency range to maintain the grid voltage of the oscillator constant. It is equally possible to proportion these couplings in a different manner and thereby secure any desired variation of the oscillating grid voltage over the tuning range.

The system of Fig. 3 is one of the simplest possible arrangements of the present invention. When used in a superheterodyne radio receiver as a beat oscillator, the condenser 32 can be made to serve two functions at the same time. The feed-back function has already been described. The other function is the varying of the calibration curve of oscillating frequency against the setting of condenser 31. A radio receiver of the superheterodyne type generally employs several tuning condensers coupled together by a unicontrol device. All except one of these condensers are generally used to tune resonant circuits to the frequency of the incoming signal. The remaining condenser is required to tune the beat oscillator, whose frequency calibration must be different by the amount of the desired beat frequency. The difference in calibration is accomplished in some cases by the use of a condenser in the position of condenser 32. In accordance with the present invention, this condenser may be used for both this purpose and for the purpose of maintaining the oscillator voltage at a uniform level.

The oscillator system illustrated in Fig. 4 has some points in common with that of Fig. 3, and also has certain distinguishing features. It has the same advantages as that of Fig. 3 in regard to its use with superheterodyne receivers and has additional advantages which will presently be pointed out. The circuit arrangement includes a vacuum tube 41 of the tetrode, or screen-grid type, which may be of type 224, and a resonant frequency determining circuit, or oscillation circuit, including an inductance 44, a fixed condenser 43, (700 $\mu\mu$f.) and a variable condenser 42, (maximum 350 $\mu\mu$f.), in series with each other. The junction between the condensers 42 and 43 is grounded and the junction point between condenser 43 and inductance 44 is connected to the anode, or plate, 69 of the tube through an inductance 45 in series with a fixed condenser 50, (about 200 $\mu\mu$f.). The cathode 70 of the tube is connected to ground through an inductance 46 in series with the parallel combination of a radio-frequency by-pass condenser 47, (about 500 $\mu\mu$f.), and a resistance 48, which serves the purpose of furnishing a bias voltage between the grid 53 and the cathode. The inductances 44 and 45, together, are termed the main coil, and the inductance 46 an auxiliary coil. The screen grid 71 is grounded through a battery 49. Inductances 45 and 46 are each magnetically coupled to inductance 44, as indicated by the brackets.

The anode potential for the tube is supplied by a battery 52 in series with a choke coil 51, (about 5 millihenries). The radio-frequency component of the anode current is conducted through the feed-back path including condenser 50, coil 45, coupled to coil 44, and condenser 43.

The operation of the circuit is as follows: Coil 45 has a mutual inductance with coil 44 which is about half the self-inductance of coil 44. At high frequencies, this inductive coupling is the main feed-back from the plate circuit into the tuned circuit. At low frequencies, the reactance of condenser 43 has a value as high as one-third the reactance of coil 44. Therefore, the total mutual reactance between the plate circuit and the tuned circuit varies between the limits of 50% and 83% of the reactance of coil 44. The mutual inductance between coils 44 and 45 is of such polarity that this coupling aids the coupling of condenser 43. The mutual inductance between coils 46 and 44 is about one-fourth the self-inductance of coil 44. This ratio does not vary with frequency because only one kind of coupling namely, inductive, is used in the cathode lead. The polarity of coil 46 is such that the alternating potential of the cathode is intermediate between that of the grid (zero) and that of the plate.

The coupling values of coils 45 and 46 and condenser 43, as illustrated in the above example, are proportioned so that the feed-back effect varies over the tuning range in the same manner as the dissipation in the tuned circuit, namely; increasing at lower frequencies so that the oscillating current increases at lower frequencies more rapidly than the resistance decreases.

The cooperation of the two kinds of feed-back yields a uniform oscillating voltage across coil 44 and also across coil 46.

It is possible to utilize the circuit of Fig. 4 in a superheterodyne receiver, and to combine in it the functions of beat oscillator and modulator. A signal frequency tuned circuit, designated T, can be inserted if desired in the grid lead of grid 53 without materially affecting the oscillations.

Condenser 50 (about 200 micromicrofarads) and coil 51 (about 5 millihenries) can likewise be resonated at the super-audible beat frequency without affecting the frequency of the oscillator. The beat frequency amplifier of the superheterodyne can then be coupled to coil 51. The remainder of the superheterodyne receiver assumes any well-known arrangement.

In the circuit of Fig. 4, it is found that the oscillator voltage is greatly reduced if the oscillator is tuned to an even multiple of the natural frequency of coil 51. This is the result of resonant circulating currents in the coil which occur by virtue of its inductance and inherent capacity. Therefore the natural frequeny of coil 51 should be greater than half the highest frequency in the oscillator tuning range. This relation is not precise, but is very useful as a guiding rule.

While the invention has been described with particular reference to a number of specific arrangements, these are intended merely to illustrate the essential features and the wide field of usefulness of the invention. The circuits described and the circuit constants mentioned are not intended to indicate any restriction of the scope of the invention.

What is claimed is:

1. A vacuum tube feed-back arrangement comprising in combination a vacuum tube having an input electrode and an output electrode, a resonant circuit tunable over a frequency range and coupled to one of said electrodes, and a feed-back circuit comprising two parallel paths coupled in aiding phase between the other of said electrodes and to said tunable circuit, said parallel paths being resonant at fixed frequencies respectively above and below said range.

2. A vacuum tube feed-back arrangement comprising in combination a vacuum tube having an input electrode and an output electrode, a resonant circuit tunable over a frequency range and coupled to one of said electrodes, and a feed-back circuit coupled to the other of said electrodes and to said tunable circuit, said feed-back circuit having two parallel paths external to said tube and connected in aiding phase, one of said paths being resonant above and the other being resonant below said frequency range.

3. The method of operating an oscillator system tunable over a frequency range, which comprises inductively feeding back in the same phase energy from the output to the input of the system by two parallel paths and causing the energy fed back through one of said paths to increase and the energy fed back through the other of said paths to decrease while the tuning frequency is increased.

4. The method of maintaining a uniformly high degree of regeneration in an amplifier provided with input and output circuits and tunable over a frequency range, which comprises inductively feeding back in the same phase energy from the output to the input circuit by at least two parallel paths and causing the energy fed back through one of said paths to increase and the energy fed back through the other path to decrease while said amplifier is being tuned, whereby the overall feed-back energy may be maintained substantially uniform over said range.

5. An oscillator system tunable over a frequency range, comprising a vacuum tube having a cathode, grid, and plate, a connection between said grid and ground, a main coil having one end coupled to said plate, a variable tuning condenser connected between ground and the other end of said main coil, a fixed coupling condenser connected between ground and an intermediate point on said coil, and an auxiliary coil coupled to said main coil and connected between ground and said cathode, said coupling condenser having a value somewhat greater than the maximum value of said tuning condenser.

6. An oscillator system tunable over a frequency range, comprising a vacuum tube having a cathode, grid and plate, a connection between said grid and ground, a main coil having one end coupled to said plate, a variable tuning condenser connected between ground and the other end of said main coil, a fixed coupling condenser connected between ground and an intermediate point on said coil, and an auxiliary coil coupled to said main coil and connected between ground and said cathode, said coupling condenser having a value somewhat greater than the mean value of said tuning condenser.

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