July 2, 1935. A. NYMAN 2,006,872

SERIES OSCILLATOR

Filed May 27, 1931 6 Sheets-Sheet 1

Fig. 1

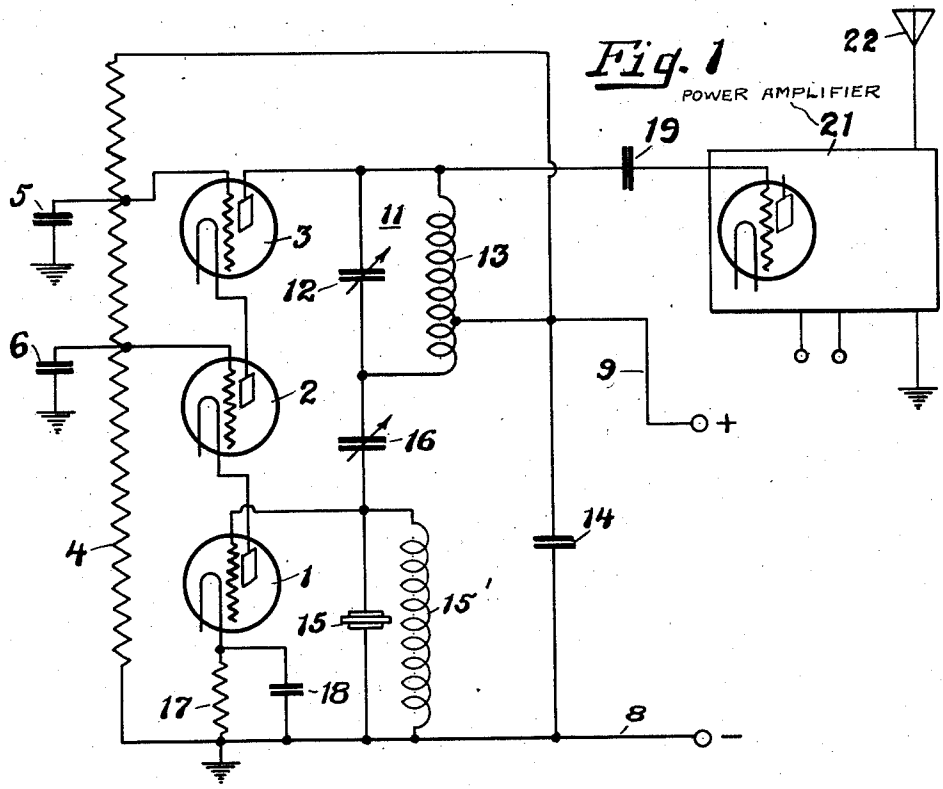


Fig. 2

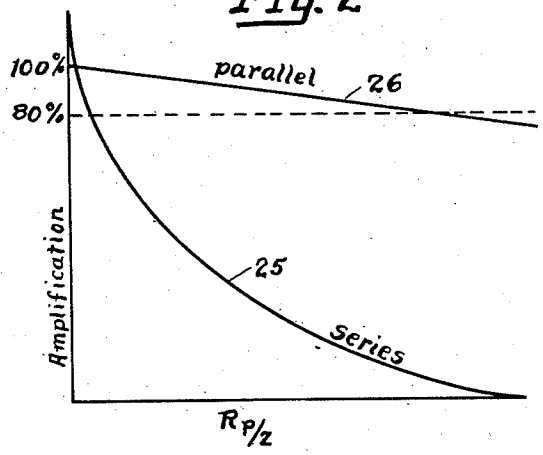
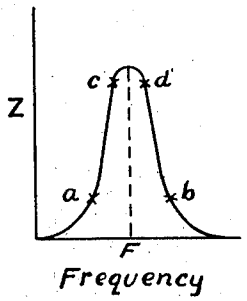


Fig. 2a



INVENTOR
Alexander Nyman

BY

ATTORNEY

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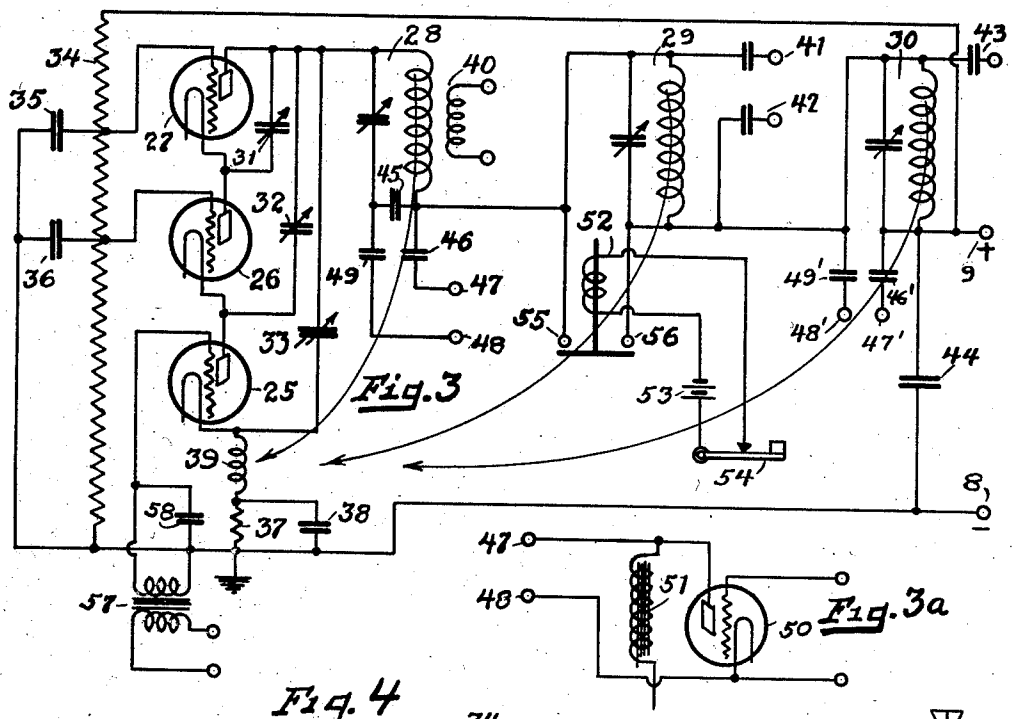
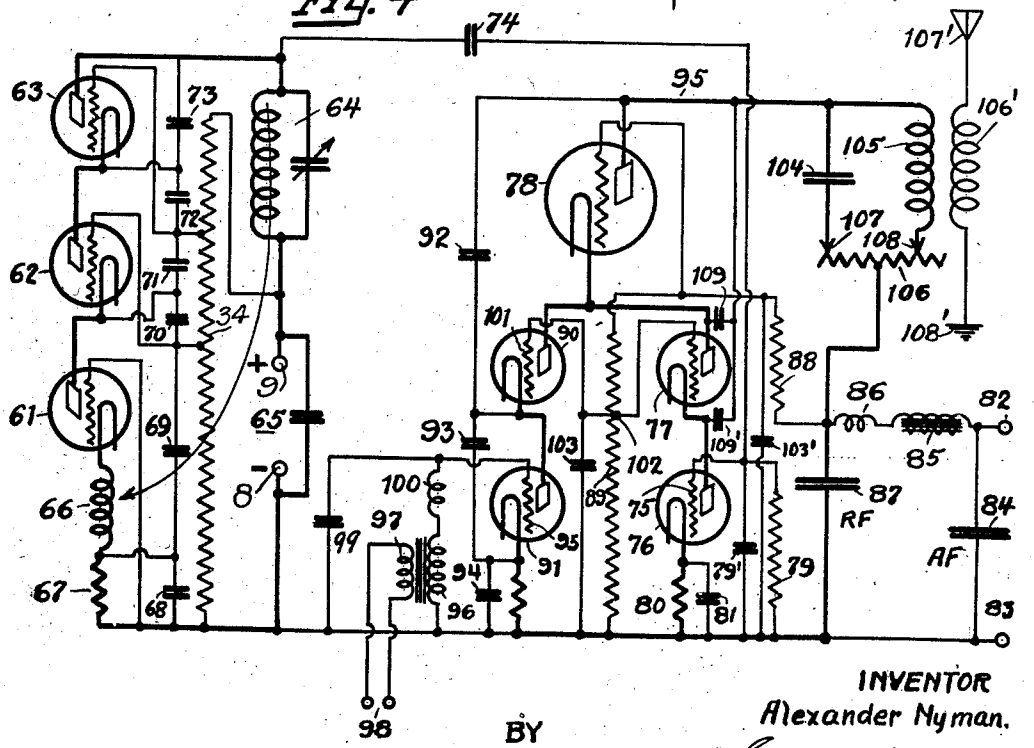


Fig. 3

Fig. 3a

Fig. 4



INVENTOR
Alexander Nyman.

BY

ATTORNEY

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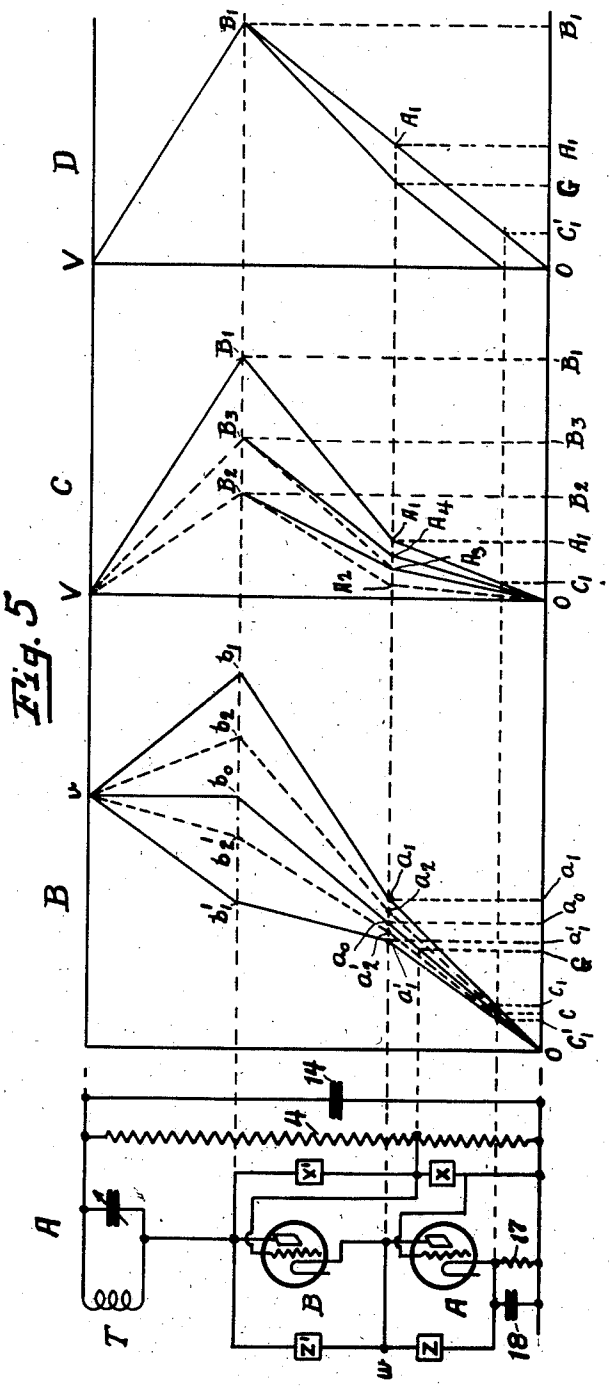


Fig. 5

O a_0 b_0 Steady condition.
O a_1 b_1 at low frequency for cathode at C_1.
O a_1' b_1' " " " " " C_1'.
O a_2 b_2 " high " " " C_1.
O a_2' b_2' " " " " " C_1'.

O A_2 B_2 Radio frequency voltages on tubes.
O A_3 B_2 " " on bridge.
O A_3 B_3 Resulting R.F on tubes.
O A_4 B_3 " " " " bridge.
O C_1 A_1B_1 Final R.F on tubes and bridge.
G Alternative grid of B by bridge X, X'
O C_1 $A_1'B_1'$ " R.F. on tubes and bridge.

INVENTOR
Alexander Nyman
BY
ATTORNEY

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SERIES OSCILLATOR

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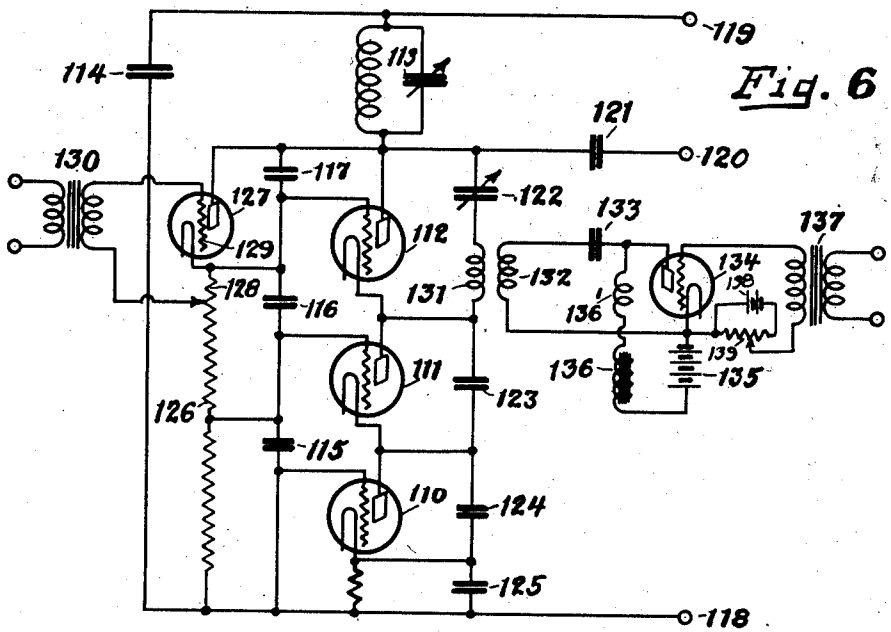


Fig. 6

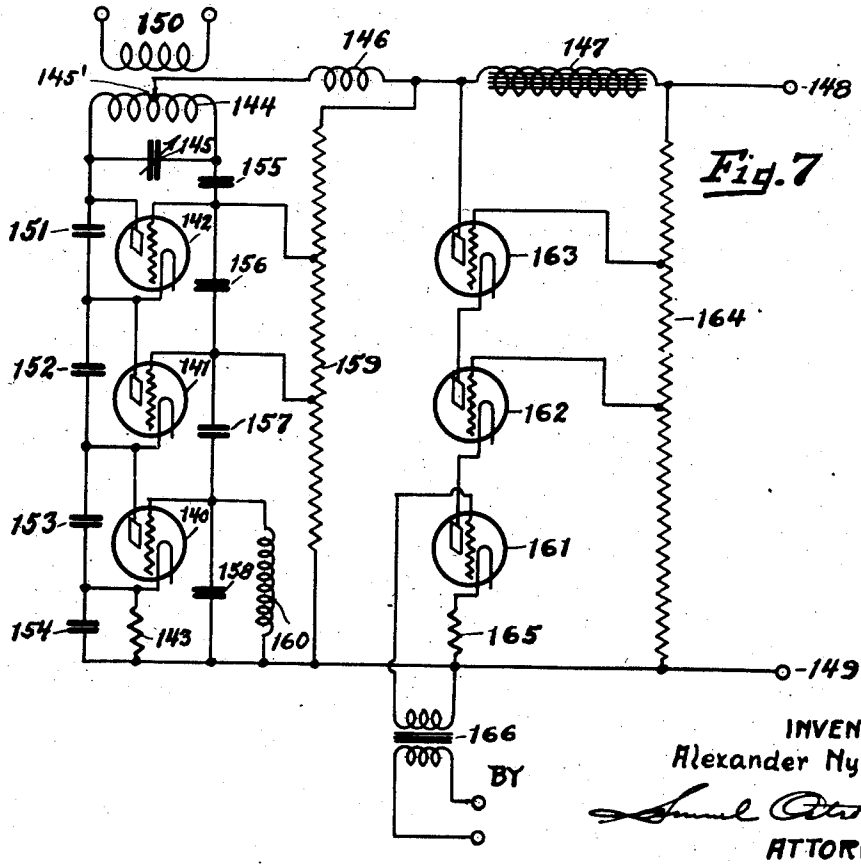


Fig. 7

INVENTOR
Alexander Nyman

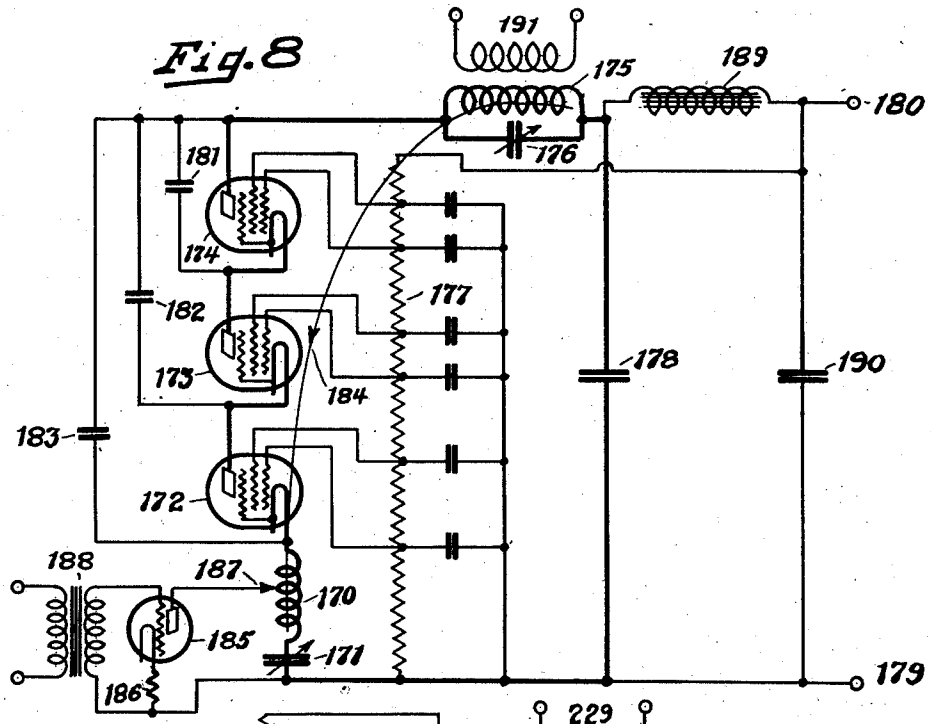
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Fig. 8



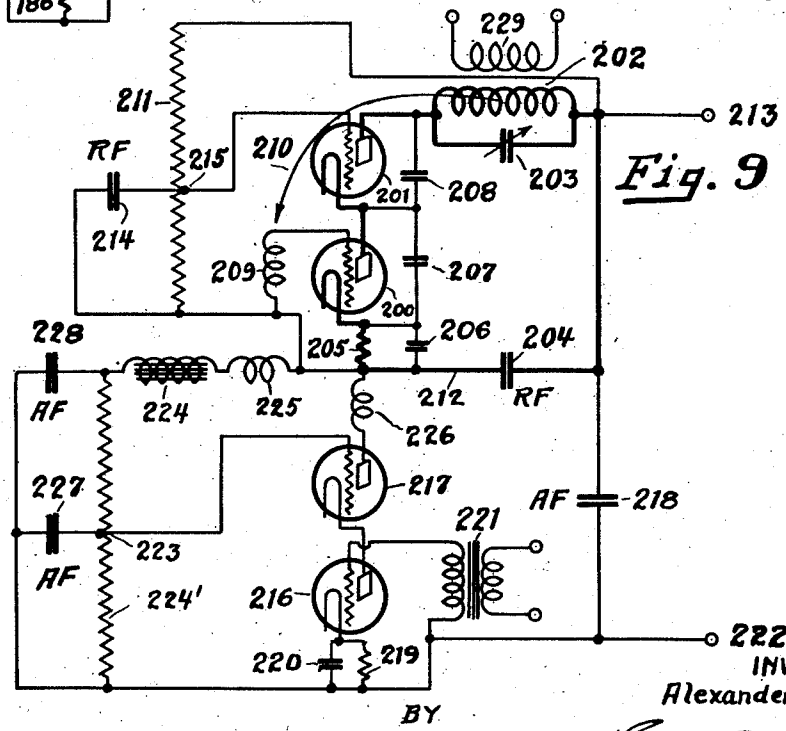


Fig. 9

INVENTOR
Alexander Nyman

BY

ATTORNEY

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Fig. 10

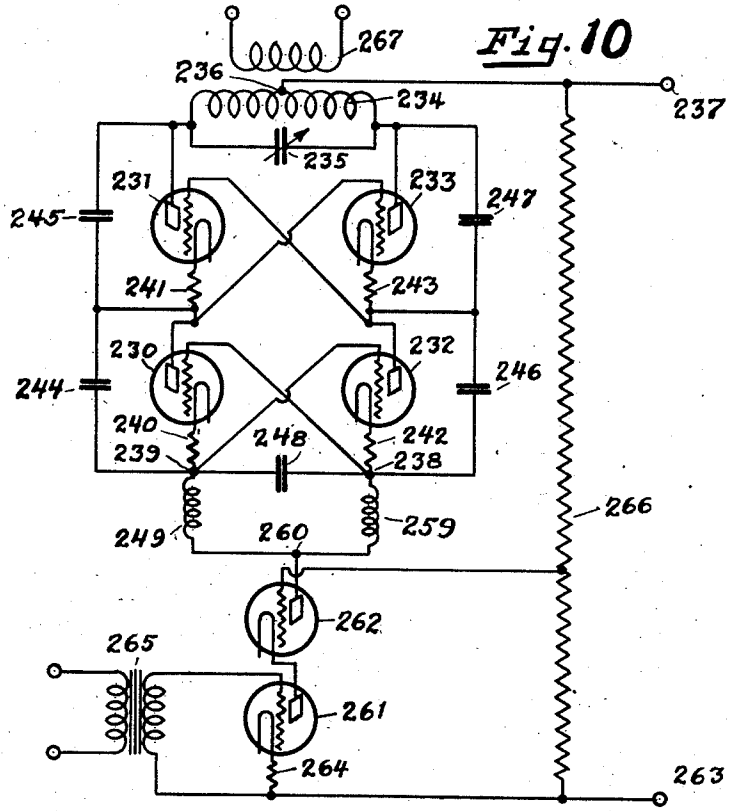
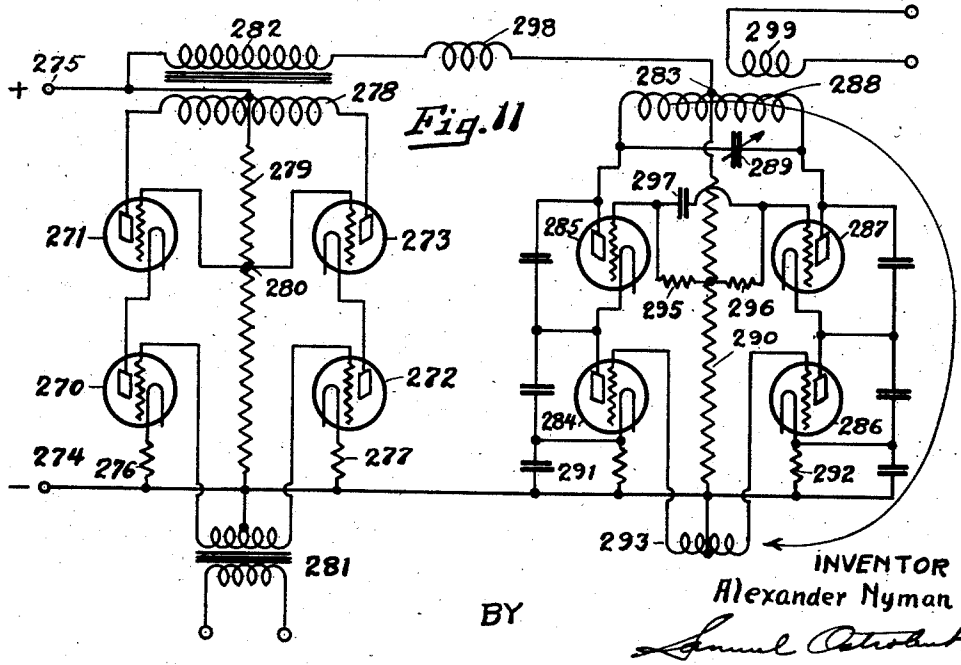


Fig. 11



INVENTOR
Alexander Nyman

BY

ATTORNEY

Patented July 2, 1935 2,006,872

UNITED STATES PATENT OFFICE

2,006,872

SERIES OSCILLATOR

Alexander Nyman, Dobbs Ferry, N. Y., assignor, by mesne assignments, to Radio Corporation of America, a corporation of Delaware

Application May 27, 1931, Serial No. 540,257

7 Claims. (Cl. 250—36)

My invention relates to novel apparatus for and methods of signalling systems and more particularly relates to a novel method of and apparatus for operating an electrical oscillator and amplifier.

Electrical oscillators heretofore used in transmitting stations have comprised either a single thermionic valve with an associated tuned circuit or a plurality of thermionic valves connected in parallel.

In either case, the electrical characteristics of the oscillator circuit are such that the frequencies fluctuate over a very wide range and this serious fluctuation of the frequencies is very undesirable as it tends to cause a transmitting station to radiate frequencies which varies from its own assigned frequency to frequency within the frequency range assigned to some other transmitting station, resulting in interference.

Because of this, strict regulations of the transmitting stations have been issued compelling stations to operate close to the assigned frequency.

Heretofore, the method of holding the oscillating frequency within the assigned frequency range has been by means of crystals, tuning forks, and other complicated apparatus which need careful attention to hold the frequencies over a smaller range of fluctuations and are expensive in construction and operation.

Accordingly, an object of my invention is to provide a novel method of operating an oscillator which will prevent frequency fluctuation.

Still a further object of my invention is to provide an oscillator which inherently oscillates only within a narrow frequency band.

Still a further object of my invention is to provide an oscillator comprising a plurality of thermionic valves connected in series.

In the present oscillators the arrangement is such that the oscillator is adapted to operate only one frequency range. It is often desirable, however, to utilize the same oscillator for a plurality of oscillating frequencies.

Accordingly, a further object of my invention is to provide an oscillating circuit which will simultaneously oscillate at a plurality of different frequency ranges.

Another object of my invention is to provide a series oscillator for generating a plurality of oscillating frequencies simultaneously.

In any oscillator the fundamental feature is the feed back arrangement whereby output energy is fed back into the input circuit to set up and maintain the oscillator in oscillation.

I have discovered a novel apparatus for and method of producing oscillations. One object of my invention, therefore, is to provide an oscillator in which feed back is obtained by applying a portion of the output electrical oscillating quantities to a portion of the series amplifier circuit.

A further object of my invention is to provide in a series oscillator means for feeding the output of the last series tube to the grid of the preceding series tube.

Still a further object of my invention is to provide means in a series oscillator for applying part of the output energy of the last tube of the series amplifier to the cathode of a preceding tube of the series amplifier.

Still a further object of my invention is to provide means in a series oscillator for feeding back part of the output energy of one of the series tubes of the oscillator simultaneously to the cathode and grid of a preceding tube.

A further object of my invention is to provide a push-pull series oscillator.

Still a further object of my invention is to provide an electro-magnetic feed back in a series oscillator.

Another object of my invention is to provide an electrostatic feed back in a series oscillator.

Another object of my invention is to provide a series oscillator in which a series tuned circuit is connected in series with a series amplifier.

In series oscillators, the problem of modulation is somewhat different than that present in the usual oscillator heretofore used.

Accordingly, an object of my invention is to provide novel apparatus for and methods of modulating oscillations in a series oscillator.

A further object of my invention is to modulate by changing the impedance of the tuned circuits in a series oscillator.

A further object of my invention is to provide frequency modulation in a series oscillator.

A further object of my invention is to modulate the output energy of a series oscillator by varying the impedance of one of the thermionic valves of said oscillator.

Still a further object of my invention is to provide modulation in a series oscillator by a capacity varying means.

A further object of my invention is to provide a novel method of modulation which comprises varying the capacity in the feed back circuit.

Another object of my invention is to provide a novel method of modulation which comprises the step of varying the impedance of a series tuned circuit connected in series with the oscillator.

Still another object of my invention is to provide

a variable voltage supply to a series oscillator in accordance with the desired modulations.

A further object of my invention is to provide a method of modulation of series oscillator by connecting it in series with a series amplifier to which modulating signals are conveyed.

Still a further object of my invention is to provide a novel power amplifier.

Another object of my invention is to provide a power amplifier in which tubes of different energy characteristics are used.

A further object of my invention is to provide a novel method of cutting off undesired frequencies in a modulated carrier frequency system.

Still a further object of my invention is to provide novel means, in a series oscillator circuit, for broadening the range of frequencies at which it is operated in accordance with requirements.

Figure 1 is an elementary diagram of a series oscillator.

Figure 2 consists of curves illustrating the amplification characteristic of a series amplifier compared to other amplifiers.

Figure 2*a* is a curve showing the variation and impedance of a tuned circuit with a frequency.

Figure 3 is a form of series oscillator adapted to operate simultaneously at a number of different frequencies.

Figure 3*a* illustrates the modulating means applicable to circuits of Figure 3.

Figure 4 is a complete diagram of a series oscillator in combination with a novel power amplifier and modulating means.

Figure 5 consists of diagrammatic charts illustrating the voltage relations in various parts of a series oscillator.

Figure 6 is a diagram of a series oscillator showing novel potential bridges and modulating means.

Figure 7 is an alternative form of series oscillator and modulating means therefor.

Figure 8 is a further alternative form of series oscillator showing a double function of modulation and oscillation.

Figure 9 shows an alternative form of oscillator with a series connected modulator.

Figure 10 shows a push-pull series oscillator with series modulating means.

Figure 11 shows an alternative form of push-pull series oscillator with push-pull modulating means.

Referring to Figure 1 which illustrates the simplest form of oscillator; this comprises broadly a plurality of thermionic valves **1**, **2**, and **3**, connected in series with each other in such a fashion that the anode of the first tube **1** is connected to the cathode of the valve **2** and the anode of thermionic valve **2** in turn is conductively and directly connected to the cathode of the valve **3**. The control electrode or grids of thermionic valves **1**, **2**, and **3** are maintained at predetermined fixed potentials by means of connections taken therefrom to the taps of a potentiometer **4**.

In order to insure that the control electrodes are maintained at the predetermined fixed potentials, the control electrodes are further grounded through condensers **5** and **6**. Energy for the oscillator tubes and the potentiometer **4** is supplied from the potential leads **8** and **9** connected to the opposite terminals of the potentiometer and through the tuned circuit **11** to tubes **3**, **2**, and **1**.

The oscillator circuit is completed from the output circuit of the tube **3** through the parallel tuned circuit **11** comprising a variable condenser **12** and inductance **13** through the condenser **14** to the input of the first tube **1**.

Such a circuit will operate as a series amplifier with regard to potentials applied to the grid of tube **1** of a frequency to which circuit **11** is tuned. In this circuit a condition of oscillation is established by feeding back a predetermined percentage of the output potential in the last stage **3** of the oscillator through the variable condenser **16** to the control electrode of the first thermionic valve **1**.

Inasmuch as the output potential of the thermionic valve **3** is in phase with the output potential from valve **1**, a phase reversal of the output potential which is to be fed back to the grid of tube **1** is necessary. This is accomplished by tapping the inductance **13** at some intermediate point thereof for the supply connection **9** so that the feed back potential applied to the control electrode of tube **1** is reversed in phase with respect to the output potential from tube **3**.

A biasing resistor **17** for the first tube **1** is bypassed by a condenser **18** for the high frequency currents. A frequency controlling crystal **15** cooperates with condenser **16** to give the correct feed back potential and helps to stabilize the frequency although, as explained below, such stabilization is in general not necessary as the circuit is inherently stable. A choke coil **15'** around the crystal admits the steady potential bias to the grid of tube **1**.

The oscillating energy from the series oscillator just described is applied through a condenser **19** to the input of a power amplifier **21** which is here diagrammatically illustrated as any well known form of amplifier and modulator may be used. The output energy of the oscillator is then radiated over the antenna **22** in any well known manner.

The advantages of this form of oscillator; namely, a series connected oscillator, can best be explained by reference to Figures 2 and 2*a*.

Figure 2 discloses the gain obtained in a series amplifier and explains the stability of such an amplifier with regard to frequencies when used as an oscillator. The curve shows the amplification as a function of the ratio of tube impedance R_p to the impedance of the tuned circuit Z.

The curves were obtained by mathematical calculations which show with the series amplifier the gain or amplification expressed as the ratio of output voltage to input voltage to be as follows:—

$$A_n=\frac{\mu(\mu+1)^{n-1}Z}{\sqrt{(K_nR_p+R_z)^2+X_z^2}}$$

in which μ is the amplification constant of each tube.

Z is the impedance of the tuned circuit at the operating frequency.

R_z is the energy component of Z at the operating frequency.

X_z is the reactive component of Z at the operating frequency.

R_p is the internal impedance of the tube at the operating frequency.

n is the number of stages of amplification, and

K_n is a constant different for each number of stages, and calculated to be for two stages $K_2=2+\mu$ and for three stages $K_3=3(1+\mu)+\mu^2$.

The amplification as calculated from these formulae is illustrated by the curve **25** which corresponds to a three stage amplifier and certain assumed values of the circuit constants. It can

be seen that the amplification falls off very rapidly with the increase of ratio:

$$\frac{R_p}{Z}$$

On the other hand, with a parallel amplifier of a number of stages with a corresponding number of tuned circuits, the amplification falls off relatively slowly, illustrated for three stages in the curve **26** and expressed by the formula:

$$A_n^1=\left[\frac{\mu Z}{\sqrt{(R_p+R_z)^2+X_t^2}}\right]_n$$

As shown in Figure 2*a*, the impedance of the tuned circuit will vary with frequency, giving a maximum at the resonant frequency F. If the input energy from a feed back or back coupling is such that a reduction of oscillations to, say, 80% of the amplification at the resonance point maintains a stable oscillating condition, then, as shown by the dotted line in Figure 2, the parallel amplifier would permit a very large variation of the above ratio corresponding, for instance, to the range of variation of Z from *a* to *b* of Figure 2*a*. While with a series amplifier the corresponding range of variation of ratio is much narrower, as indicated by points *c* and *d* of Figure 2*a*. This latter is due to the fact that a further reduction of the impedance of the tuned circuit reduces the amplification below the 80% which was assumed to be necessary for maintaining oscillations.

It is clear from Figure 2*a*, therefore, that the oscillations for a fixed condition of the tuned circuit must take place at a frequency within the range determined by the points *c* and *d* while with a parallel oscillator the corresponding range is much wider, as indicated by points *a* and *b*.

I have found from practice, that the series amplifier has extremely sharp tuning characteristics, in accordance with the above explanation, and also that if a feed back circuit is supplied, the oscillation will maintain its frequency at a very stable value while the oscillations cannot, at the same time, be easily suppressed or changed in frequency by changes in the various tube potentials. One theory for explaining this stability is as follows:

The changes of frequency that occur in an ordinary single tube oscillator or an oscillator comprising a number of tubes connected in parallel is caused to a large extent by variations of the tube impedance caused by such factors as variation in filament potential, in grid biasing potential, or in plate potentials at which the tube operates.

However, in a series amplifier, where a number of tubes are connected in series, I have found that if the electronic current on one of these tubes has changed, for instance, due to the change of filament emission, there is an immediate readjustment of the grid potentials as secured from a common potentiometer, and of the plate potentials as secured from a common source of plate current, by means of which the change in electronic emission caused by the change of filament potential is automatically compensated. For example, if the filament potential has dropped, with a consequent decrease of emission, the plate potential will increase until the system is stabilized and supplies this plate current, but at the value of tube impedance which is practically the same as the original tube impedance.

Thus, although the direct current resistance of the tube, as measured by the ratio of stable voltage to current on the particular tube, may have changed, the actual tube impedance which affects the oscillating characteristics and which is represented by the slope of voltage and current characteristic at the operating point, that is, the dynamic impedance of the tube may remain practically the same. Therefore, the operating frequency will also remain constant.

Figure 3 shows a modification in which several frequencies are generated simultaneously. Three electrode tubes **25**, **26**, and **27** are connected in series relation substantially in the manner as in Figure 1 so that the anode of tube **25** is connected to the cathode of the next succeeding tube **26**, and so on. The anode of tube **27** is connected in series with a plurality of tuned circuits **28**, **29**, and **30**, each of which comprise an inductance and variable capacity and is tuned to an individual frequency.

Three adjustable condensers **31**, **32**, and **33**, each adapted to compensate for the effect of the tube capacities of the thermionic valves **27**, **26**, and **25**, are connected from the plate circuit of tube **27** to the cathode lead of each of these respective tubes. Condensers **35** and **36** are connected respectively from the grids of tubes **27** and **26** to the negative lead **8**. The function of condensers **31**, **32**, **33**, **35**, and **36** is discussed in detail in reference to diagrammatic Figure 5 below.

The remaining connections for the oscillator itself are similar to those shown in Figure 1, including the potentiometer **34**, bias resistance **37**, and a bypass condenser **38**. Instead of a feed back condenser **16** as in Figure 1, an inductive feed back by means of a coil **39** coupled to the inductances of the tuned circuits **28**, **29**, and **30** is used in this circuit. In practice, however, I have found that it may be possible to omit the coil **39**, as the condensers **31**, **32**, **33**, **35**, and **36**, serving to supply the capacity current between the elements, can be so chosen as to supply an excess of current to the connections between the tubes, and thereby create oscillations in accordance to the resonant frequencies of the circuits **28**, **29**, and **30**.

In an ordinary type of oscillating circuit, it is conceivable that several oscillating systems are introduced and that oscillations would be created at several frequencies. However, in general, due to the ability of an ordinary oscillator to swing over a fairly large range of frequencies for the same tuned circuit, if several circuits are included in the tuning path, it is likely to oscillate at a frequency corresponding to the summation of all inductance and all capacity elements instead of at three definite frequencies. On the other hand, with a series amplifier as has been explained in connection with Figure 2, the circuit relations are such that the circuit oscillates at exactly the resonance frequency of the tuned circuit and the swinging of the frequency is prevented by the nature of the circuit connections.

It follows from this also, that the variation of impedance of the tube elements caused by oscillations of the frequency of, say circuit **28**, would not interfere or affect the effectiveness of circuit **29** in interposing a high impedance at its own resonant frequency and thus maintaining oscillations at its frequency. On the other hand, the circuit **29** considered at the frequency of circuit **28**, will be equivalent to a relatively large capacity or relatively small inductance in series with the tuned circuit **28**, and will in no way affect the operation of the system at the frequency of circuit **28**.

Similarly, circuit 30 will interpose a high impedance at its own resonance frequency and, provided suitable feed back means, will oscillate at that frequency, while at the frequency of circuits 28 and 29 it will merely interpose a low reactive or capacitative impedance.

The oscillating circuit for the three frequencies includes all of the three circuits, so that the same current flows therethrough. On the other hand, the voltages generated in the tube circuit is impressed respectively on circuit 28 at its frequency, on circuit 29 at its own frequency, and on circuit 30 at its own frequency.

This voltage, being the measure of the energy circulating in the corresponding tuned circuit, can be abstracted from this circuit by suitable coupling means, and I have shown three possible alternatives: The coil 40 coupled to coil 28, condensers 41 and 42 connected to the opposite ends of the circuit 29, and a condenser 43 connected to one end of the circuit 30 while the other end of the same circuit is grounded through the condenser 44 for the same purpose as the condenser 14 of Figure 1.

Different means for modulating each one of the three independent frequencies is shown. Thus, included in circuit 28 is a radio frequency bypass condenser 45 shunted by the equivalent of a series modulating resistor which will change the effective resonance impedance of circuit 28 and thereby the amplitude of the resulting modulations. The modulating resistor may comprise a microphone, but in the preferred form, coupling condensers 46 and 49 are used, the other side of which may be connected to the output circuit from an audio source such, for instance, as is illustrated in Figure 3*a* in which the terminals 47 and 48 correspond to the terminals 47 and 48 of Figure 3.

This circuit may consist of an amplifying tube 50, the grid of which is supplied with audio frequency source, while the plate circuit is connected to terminal 47. The plate power to the tube 49 is supplied through a choke coil 51. Accordingly, the modulating resistance includes, at radio frequency, condensers 46 and 49 and the resistance of tube 50. And since this resistance is modulated by the audio frequency applied to the grid of tube 50, a correspondingly varying resistance effect is introduced into the tuned circuit 28. In practice, such a connection may be used to introduce frequency modulation by proper choice of the values of various condenser elements.

Connected in circuit 30 are similar condensers 46' and 49' connected to terminals 47' and 48', which may be again supplied with the modulating resistor in accordance to Figure 3*a*. In this case this modulating resistor is in parallel with circuit 30 and must have, therefore, a relatively high impedance value approximating the tuned impedance value of circuit 30. The variation of this shunting modulating resistor will then modulate the oscillations at the frequency of circuit 30. This arrangement may again serve as a frequency modulating means.

Connected to circuit 29, there is a keying arrangement including a relay 52 operated from the battery 53 by means of key 54. In the normal non-operating position, the circuit of relay 52 is closed and the relay is thereby energized, short-circuiting the contacts 55 and 56, and thereby short-circuiting the circuit 29.

Thus, no oscillations of the frequency of the circuit 29 will be generated. However, when the key is depressed the relay 52 is deenergized, the short circuit across the contacts 55 and 56 is removed, and the impedance of circuit 29 is interposed in the series oscillator circuit, thereby generating oscillations of the frequency of circuit 29.

An alternative modulation scheme which will simultaneously modulate all of the three frequencies and which includes control elements of tube 25 and the secondary of an audio frequency transformer 57 bypassed by condenser 58, is also shown. This audio frequency transformer may be supplied from any suitable source of audio frequencies or other control currents, and will impress on the grid of tube 25 a voltage corresponding to the audio frequency oscillations. Thus, the impedance of tube 25 will be varied in accordance with this impressed voltage and thereby, as explained in connection with Figure 2, the oscillations at all of the frequencies will be varied. If the modulation of all of the circuits is not desired, the transformer 57 is merely omitted and the grid is connected directly to ground.

These methods of modulation possess certain limitations in so far as they control directly the ratio of tube impedance to the impedance of the tuned circuit and as the degree of amplification through the series circuit is dependent on this ratio, a change in the above ratio above a certain limit would entirely stop the oscillations.

I have, however, shown the alternative ways of modulation without these limitations and it will be understood that these alternative systems can be also applied to the circuits of Figure 1 and Figure 3.

In Figure 4 there is shown a further modification of series oscillator in a system more adaptable to power circuits where the energy to be transmitted will require large power tubes and relatively high voltages and currents. Under such condition, it is desirable to confine the generation of oscillations to a so-called "master" oscillator of relatively low energy and then amplify and modulate the oscillations generated as above in a power amplifier and modulator.

This system comprises a series oscillator similar to that of Figure 1 and consisting of three series tubes 61, 62, and 63 connected in series with a tuned circuit 64 and a bypass condenser 65 across the power input terminals 8 and 9. Connected to the cathode of tube 61 is an inductive element 66 and a biasing resistor 67 bypassed by condenser 68. The inductance 66 may serve in a manner similar to the inductance 39 of Figure 3 for supplying the feed back potential to the cathode of tube 61. The grid of this tube is held at the ground potential and therefore the creation of oscillations in the series amplifier will be in accordance with the general theory, as explained in connection with Figure 1.

Bypass condensers 69, 70, 71, 72, and 73 supply the necessary capacity currents to the tube elements, as discussed in detail in connection with Figure 5. These condensers forming a bridge circuit across the tuned circuit 64, may also be utilized for establishing oscillating conditions, as explained in connection with Figure 5 in which case the inductance 66 may be omitted. The potentiometer 34 serves the same purpose as in the previous diagrams. The master oscillator is, therefore, arranged to generate oscillations of a definite frequency and a constant amplitude.

The output of the series oscillator is conducted through a coupling condenser 74 to the grid 75

of the first tube 76 of a power amplifier. The tube 76 is shown to be connected in series with another tube 77 and the power tube 78, the latter being of the type suitable for large energy oscillations and having relatively high voltage and relatively high current carrying capacity. Of course, the tubes 76 and 77 may also have energy capacity in excess of the tubes 61, 62, and 63, as they form an intermediary step between the master oscillator and the final tube 78 of the power oscillator.

A resistor 79 is connected between the grid 75 and the ground connection which, in cooperation with bypass condenser 79', will in general be sufficient to supply the necessary grid bias to tube 76, but additional grid bias may be introduced by a cathode resistor 80 with a bypass high frequency condenser 81. The power supply for the series amplifier is obtained from terminals 82 and 83 which is in series with a filter arrangement comprising an audio frequency bypass condenser 84, an audio frequency choke coil 85, a radio frequency choke coil 86, and a radio frequency bypass condenser 87. The function of this filter will be described below. A potentiometer consisting, as shown, of two parts, 88 and 89, applies the proper bias potential to the grid of tube 78, and to the grid of tube 77, and serves also to supply the biasing potential to a tube 90 of the modulator and compensator circuit, to be described below.

Since the power tube 78 will in general carry a current in excess of the current which may flow through tubes 76 and 77, a compensator circuit is provided comprising tubes 90 and 91 connected in series, and a bridge arrangement consisting of condensers 92, 93, and 94 by means of which the cathodes of tubes 90 and 91 are supplied with a potential from the output lead 95 of tube 78 in phase with the currents flowing through the tubes 76 and 77.

Thus, the resistance of the tubes 90 and 91 is varied to have, at any instant, a constant proportion to the resistance of tubes 76 and 77, and insure a proportionate division of the current of tube 78 between the two circuits of the tubes 76 and 77 and of the tubes 90 and 91.

The circuit of tubes 90 and 91 may be utilized for modulation purposes in the following manner: Connected to the grid 95 of tube 91 is the secondary 96 of a modulation transformer, the primary 97 of which has terminals 98 to which audio frequency or any other control modulation may be applied. To separate the radio frequency from the transformer secondary 96 there is provided a bypass condenser 99, and in series with the secondary 96 there is connected a radio frequency choke coil 100. I have, furthermore, shown the connection of grid 101 of tube 90 to a tap 102 on the resistor 89, and through a grounding condenser 103, to negative lead 83.

In this way, audio frequency potentials are applied to grid 95 and amplified by tubes 90 and 91 in the usual series amplifier connection so that the impedance of tubes 90 and 91 is increased or reduced in proportion to audio frequency modulations taking larger or smaller proportion of the total current flowing through tube 78.

It is, of course, evident that the audio frequency modulations on tubes 90 and 91 are also impressed on the cathode of tube 78 and therefore the output of tube 78 is modulated in accordance with this impressed voltage.

The function of choke coil 85 will now become evident as a coupling inductance for the audio frequency changes in potential due to the series audio frequency amplifier consisting of tubes 91, 90, and 78. The radio frequency choke coil 86 blocks the passage of radio frequency currents to the input terminals 82 and 83 while the radio frequency bypass condenser 87 returns the radio frequency currents to the negative lead 83. An audio frequency bypass condenser 84 serves to return the audio frequency currents to the negative lead 83.

A condenser 109 may be provided to supply the capacitative current to the tube elements of tubes 77 and 90 while a condenser 109' will supply the capacitative current of the elements of tube 76. A condenser 103' may be also provided for grounding the grid of tube 78.

While the circuit described refers to the tubes 76, 77, and 78 as a series power amplifier in which the power tube 78 carries an excessive current which must be provided by the compensator consisting of tubes 90 and 91, it is evident that the same series of tubes, that is 76, 77, and 78, may be used directly as an oscillator. In that case, the feed back system, which will be described below in connection with Figure 5, may be provided by a suitable choice of condensers 109, 109', 103, 103' or some other alternative form of bridge, as discussed in connection with Figure 5. If the tube 78 under these circumstances is a tube carrying a current in excess of tubes 76 and 77, then a compensator consisting of tubes 90 and 91 may be also provided connected identically to this figure and this compensator may again be used as a modulator of the oscillations created in the oscillator 76, 77, and 78. Again, the bridge of the compensator consisting of condensers 92, 93, 94, 103, and 99 can be arranged for the proper feed back service so that the tubes of the compensator 90 and 91 will also create oscillations. The tubes 78, 90, and 91 will then be acting both as a modulator and as an oscillator.

The output circuit of tube 78 includes a tuned circuit comprising a condenser 104 and an inductance 105. The inductance 105 may be coupled to the antenna circuit, for instance, by means of a secondary coil 106' in series with an antenna 107' and a ground connection 108'.

The tuned circuit may include also an adjustable resistor 106 with suitable taps at 107 and 108. The object of the resistor 106 is to widen the responsive range of frequency of the tuned circuits 104 and 105 to include the full range of modulation of tube 78. This range would thus include the side bands caused by the modulation of the high frequency currents in this circuit. The resistance of circuit 106 as well as the tuning of the circuits 104 and 105 and 106 can be adjusted to include the carrier with all of the side bands or merely the carrier with the side bands on one side, or even to include merely the side bands on one side of the carrier. It is evident, of course, that the tuned circuits 104, 105, and 106 can also be modified to any other type of radio frequency filter which, in conjunction with the series amplifier consisting of tubes 76, 77, and 78, would more perfectly cut off any but the desired side band ranges.

The series amplifier at radio frequency including tubes 76, 77, and 78 cooperates with the tuned circuits 104, 105, and 106 in a manner similar to that explained in connection with Figures 2 and 2a. It is, therefore, evident that by introducing damping in this circuit by an increase of resistance 106, the top of the curve, *a, c, d, b,* in

Figure 2*a* is widened and the operation of this amplifier, which is ordinarily limited as explained in connection with that figure to the range between such points as *c* and *d*, will be extended over a wider frequency band.

In other words, the power amplifier can be made responsive to as wide a range of frequencies as is desired for the practical operation of the transmitting set. Thus, for instance, if the carrier wave and one range of side bands are to be suppressed and the remaining side bands to be transmitted, the circuit of **104**, **105**, and **106** is merely tuned to a frequency intermediate of the desired side bands and the flatness of the tuned circuit, as determined by resistor **106**, is arranged to have the points *c* and *d* cover the desired frequency band.

In Figure 5 a theoretical explanation is made of another system of feed back, applicable to series oscillators. In this diagram the abscissa represents the voltages on the different parts of the circuit and the ordinate represents the parts of the circuit, as illustrated on the left hand side of this figure, marked A, including the tubes A, B, and a tuned circuit T, in a series amplifier connection including a potentiometer **4** and a grid biasing resistor **17** connected to the cathode of tube A.

Referring to part B, Fig. 5, when a direct current is applied to this series amplifier, the voltage distribution will be in accordance with the curve Oa_0b_0v, the voltage drop being distributed over the resistor **17**, the tube A and the tube B, while no voltage drop occurs on the line *bv* across the tuned circuit T.

The cathode of tube A will be at the potential indicated as c_0 on the abscissa while the grid of this tube is as shown, connected to the ground potential O. Similarly, the grid of tube B is shown to be connected to a potential marked *g* on the abscissa. a_0 is the potential of the anode of the tube A and the cathode of tube B, while b_0 is the potential of the anode of tube B.

Assuming that a change is applied to the cathode of tube A. If this change is at a frequency to which the circuit T is tuned and between the limits c_1 and c_1' then the voltage on the system will vary from the curve oa_1b_1v to the curve $oa_1'b_1'v$. This can be explained as follows: As the potential of the cathode of tube A is changed from c_0 *to* c_1 the amplification of tube A will raise its anode potential from a_0 to a_1, increasing the difference of potential from grid to cathode of tube B from the value ga_0 to the value ga_1.

The tube B will then amplify this changed potential so that its anode potential will have changed from b_0 to b_1 and the difference between the original voltage relation and the present voltage relation expressed by the value b_0b_1 is impressed on the tuned circuit T. Similarly, when the cathode has changed from c_0 to c'_1, the cathode of tube B will change to a_1' and the anode of tube B to b_1'.

In practice, however, I have found that owing to the distributed capacity of the tube elements to each other and the tube elements to ground, the amplification does not entirely conform to this relation but is rather smaller, as indicated by dotted lines oab_2 and $oa_2'b_2'$. The circuit is inherently stable insofar as the tube amplification is reduced by the inherent capacity of the tube.

It is evident, however, that as the output of tube B is connected to a tuned circuit T, including an inductance, this inductance can be made to supply the capacity currents of tubes B and A, and I have secured this by connecting elements, such as Z and Z' which may be condensers or combination of condenser and resistors, which bypass the cathode to anode of each of the tubes A and B.

Assuming for simplicity that Z and Z' are condensers in series, then it will be seen that condensers Z and Z' and the bypass condenser **18** are in parallel with the tuning condenser of the circuit T since the supply leads of the circuit are bypassed by a large condenser **14**. The capacity current of these condensers is thus supplied by the inductance of the tuned circuit T when it is operating at the resonance frequency. For theoretical consideration, it may be assumed that the elements Z and Z' include also the distributed capacities of the tube elements and the tube elements to ground. There is shown, on the part marked C of Figure 5, separately the radio frequency potentials existing in the series oscillator. Thus, the curve OA_2B_2V corresponds to the voltage generated in accordance with the curves oa_2b_2v, and $oa_2'b_2'v$ according to part B of this diagram. Radio frequency potential VB_2 exists across the tuned circuit and is applied to the bridge circuit Z—Z'—**18** and by choosing the proper values for the bridge capacity or resistors, this voltage may be given a distribution corresponding to curve OA_3B_2.

Since the central point *w* of the bridge is connected between the tubes A and B, the potential OA_3 of this central portion is applied to the cathode of tube B, and thus the tube B can be made to amplify to a new potential B_3, giving a final voltage across the tuned circuit VB_3 and a distribution of the voltage across the condenser bridge as OA_4B_3. The potential at point *w* is therefore raised to OA_4, and further amplification will take place. At the same time, the potential of the cathode of tube A as determined by the drop through the condenser **18**, will be raised to a higher value so that the amplification of tube A is also raised. Such a capacity bridge will, therefore, cumulatively raise the amplification of the series system until a final value of radio frequency voltage is reached, such as $OC_1A_1B_1V$, shown at part B of Fig. 5 which represents its resulting output.

It is seen, from Figure 5C that the radio frequency potential across tube A is represented by a value C_1A_1 while the radio frequency potential on tube B is represented by the value A_1B_1. The diagrammatic derivation from the series amplifier connection shows these voltages to be unequal in value. This need not be so however, since the grid of tube B can be supplied by another bridge, such as is illustrated in part A of Fig. 5, by impedance elements X and X' with a potential which would give the amplification in tube B of the same magnitude as that in tube A. Thus, Figure 5D shows for two equal tubes, equal voltage increments $C_1'A_1'$ for tube A and $A_1'B_1'$ for tube B, which require equal grid potentials OC_1' and GA_1' on the two tubes.

It is quite evident that since the grid of tube A is grounded the impedances X and X' can be chosen to give the desired value G on the grid of tube B, while the impedance Z, Z' and **18** will give the potentials C_1' and A_1' on the cathodes of the respective tubes A and B. It is quite evident also that the particular combination of impedances such as X, X', Z, Z' need not be utilized, but alternative bridge constructions may be also supplied to secure the necessary potentials on the various elements.

I have illustrated already such alternative arrangements in Figure 3 as applied to a three stage oscillator and consisting of condensers 31, 32, and 33 for the cathode circuits. The bridge for each cathode is then completed through the distributed capacity of all of the cathode connections to the negative lead 8. I have also shown condensers 35 and 36 which form a bridge arrangement for the grids of tubes 27 and 26 respectively through the tube capacities of the respective grids to their respective cathode and anode elements.

I have also shown an alternative arrangement in Figure 4 where the condenser bridge 68, 69, 70, 71, 72, and 73 supplied by capacitative current from the tuning circuit 64 through the bypass condenser 65 forms a bridge on which any desired radio frequency potential can be secured and an arrangement of taps from the different points of this bridge to the various tube elements of the tubes 61, 62, 63 is also shown. Thus, an oscillating condition can be established either in Figure 3 or in Figure 4.

This oscillating condition will be practically independent of the frequency to which the tuning circuit, such as circuit 64 of Figure 4 or tuning circuits 28, 29, and 30 of Figure 3, are adjusted.

Figure 6 illustrates the application of this system of feed back to a practical oscillator including three tubes, 110, 111, 112, in series with the tuned circuit 113 with a return condenser 114. The direct current is applied to terminals 118 and 119, the terminal 119 being positive, and the output may be derived from the terminal 120 connected to the tuned circuit and to the anode of the tube 112 through condenser 121.

The feed back arrangement may include an adjustable condenser 122 forming a part of a condenser bridge including also condensers 123, 124, and 125. By means of this bridge the suitable potentials are applied to the cathodes of all of the tubes while a similar bridge comprising condensers 115, 116, and 117 applies the correct potentials to the respective grids. As shown, however, the grids may have a feed back in parallel with the condenser elements consisting of a potentiometer 126 in series with a tube 127 with taps from the cathode of tube 127 to grid of tube 112 and from an intermediate point on the potentiometer 126 to the grid of tube 111. Either the resistance element alone or the capacity elements alone may be used, or the combination of the two. The tube 127 may be replaced by a suitable resistor except when it performs a special function as follows:

The resistance bridge may be utilized as a part of a modulating system in which the grid 129 of tube 127 is supplied with modulating transformer 130. The return from the modulating transformer 130 is to a tap over a portion 128 of potentiometer 126 sufficient to give the correct grid bias to grid 129.

It is evident that if modulating potentials are applied to transformer 130, they are impressed on the grid of 127 and will change the impedance of this tube, thus varying the feed back potentials applied to the grids of tube 111 and 112.

As an alternative, the tube 127 may be connected below the potentiometer 126; that is, between the negative lead 118 and the grid of tube 111 which will also result in effective operation. With this type of connection, it is possible to omit the usual potentiometer, such as potentiometer 4 of Figure 1 as the steady potentials to the grids will be supplied from the feed back potentiometer 126 and the cooperating tube 127. Thus, the connection departs in this respect from the usual series amplifier circuit, but in general, unless this specific system of modulation is used, such a connection is not desirable as the oscillator is evidently bypassed by the resistor 126 and the tube 127, and, therefore, an extra load is imposed on it.

An alternative manner of modulation utilizing the capacity bridge consisting of condensers 122, 123, 124, and 125 is also shown. This can be accomplished by introducing the equivalent of a capacity element variable in accordance with modulation in series with condenser 122 and consisting of a primary 131 of a radio frequency transformer, the secondary 132 of which is connected via the condenser 133 to the anode and cathode of a tube 134. This tube has a suitable energy supply, such as a battery 135 and a choke coil 136, and a grid input consisting of the audio frequency transformer 137 the primary of which may be supplied with modulating currents while the secondary is connected to the grid of tube 134 and through a tap on the potentiometer 139 across a biasing battery 138 to the cathode of the same tube. The value of potentials of batteries 138 and 135 is chosen in such a way that the dynamic impedance of tube 134 to radio frequency will vary with the variations of the impressed modulation potentials from transformer 137. The effect of condenser 133 in series with impedance 134 will be to apply these modulations through the transformer 131 and 132 to the feed back circuit condenser 122. While batteries are shown at 135 and 138, any other suitable energy supply may be used instead.

It is also evident that the impedance characteristic of tube 127 should be arranged with the same object in view; that is, that its impedance will vary with the variation of the potential impressed by transformer 130. As the operating characteristics of tubes are well known, such a choice of a suitable tube and suitable potentials are quite easily accomplished. In this way, I have shown two alternative ways of modulating by inserting modulating means in the special feed back arrangement of a series oscillator.

As the effect of modulation of tube 134 on the feed back of condenser 122 is to change the capacity current flowing through this condenser 122, it will result in changing slightly the frequency of the operating system since the condenser 122 in series with the bridge 123, 124, 125 is supplied with capacity current from the tuned circuit 113. Thus, I have secured a frequency modulation system which can be arranged by a suitable choice of the condenser 133, the transformer 131 and 132 of the cooperating impedance of tube 134, relative to the other capacities in the tuned circuit, to secure any degree of modulation that may be desired.

Referring to Figure 7, another arrangement of series oscillator is shown in which the principle of capacity bridge feed back illustrated in Figure 6 and discussed in connection with Figure 5, is further extended to include feed back bridges of opposite phase applied to the grid and the plate circuits. Tubes 140, 141, and 142 are connected in series with grid biasing resistor 143 to a tuned circuit including an inductance 144 and the tuning condenser 145. The inductance 144 may be supplied by direct current via a tap 145' through a radio frequency coil 146 and an audio frequency coil 147 from the terminal 148, while the resistor 143 is connected to the negative terminal 149.

The coil 144 may be coupled to the output coil 150 or its output may be derived by any alternative means, such as illustrated in Figure 3.

The terminals of the tuned circuit 144—145 are connected to two capacity bridges. The capacity bridge including condensers 151, 152, 153, and 154 correspond to those illustrated in Figure 6 and explained in Figure 5, and includes means for applying suitable capacity currents and suitable potentials to the intertube connections and to the cathode of tube 140. The condensers 155, 156, 157, and 158 are shown connected to the opposite side of the tuned circuit 144—145 and will therefore apply potentials to the grids opposite in phase to the plate and cathode potentials, and thus increase their feed back effectiveness.

Since the condenser bridge connected to the grid circuit carries an opposite phase of radio frequently from the bridge connected to the cathode circuits, it is evident that the condition shown in Figure 5D cannot be met with regard to the potential of the grids of tubes 141 and 142. This connection will be more satisfactory if the tubes chosen for this circuit are graded with regard to their potentials so that the grid of each tube, although receiving a potential of a phase opposite to the cathode potential will bear the correct ratio to the corresponding plate potential.

In other words, if the tubes are graded with regard to potentials in accordance to their amplification, so that tube 140 will have a relatively low voltage, tube 141 a larger voltage, and tube 142 still a larger voltage, then it is evident that the potential between the grid of, say, tube 142 and its cathode, although almost double the potential of the cathode of tube 142 with regard to lead 149, may be just correct to give the oscillating condition within this tube.

This circuit in this way will be equivalent to a graded parallel power amplifier of oscillations in which the oscillations of small power are passed on to a larger tube which amplifies them further, and from that tube to a larger tube still, with the exception that oscillating conditions are provided for all of the tubes on the same oscillating circuit 144 and 145 and therefore that the frequencies in all of the oscillators are determined by the same tuned circuit. In other words, there is no interstage coupling and the current in all of the oscillators is substantially the same.

The grids of tubes 141 and 142 are further shown connected to the potentiometer 159 for securing the proper steady potential bias, the potentiometer 159 being supplied from the terminals 148 through the choke coil 147 and from the terminal 149. The grid of tube 140 may be supplied with a steady potential from the negative lead 149 via a radio frequency choke coil 160. I have thus established a double feed back on the series oscillator consisting of tubes 140, 141, 142, and I have found that by this means a very effective and powerful oscillation of definite frequency can be secured.

In order to modulate such an oscillation, I have shown a series amplifier consisting of tubes 161, 162, and 163 connected to the same power supply terminals 148 and 149 through the choke coil 147. The radio frequency currents are prevented from passing into this amplifier by the choke coil 146 and are confined to the oscillating system including inductance 144, condenser 145, and the two bridge systems. The grids of tubes 162 and 163 may be connected to a separate potentiometer 164 but could be also supplied from the potentiometer 159 if the latter were connected directly to terminal 148. In that case, choke coils and grounding condensers would be necessary in the leads from the grids of tubes 141 and 142.

The grid of tube 161 is connected to a modulating transformer 166, the primary of which may have any desired modulating currents applied to it. Bias resistor 165 insures the proper steady potential to the grid of tube 161. The effect of the modulating amplifier of tubes 161, 162, and 163 is to impress to the input tap 145 and potentiometer 159 of the series oscillator a varying potential depending on the modulating potential of transformer 166, and thus, vary the output of the series oscillator in accordance with this modulation. As the frequency of the oscillator is in this case defined by the oscillator circuit 144 and 145, and the plate and grid bridges, the impressed modulation will merely affect the amplitude of these oscillations.

Referring to Figure 8, I have shown another modification of series oscillator which utilizes an additional tuning circuit on the negative side of the series amplifier for the purpose of sharpening the definition of frequency as generated by the oscillator. As discussed in connection with Figure 2, the steadiness with which the frequency is held at a definite value is dependent on the ratio of tube impedance to the impedance of the tuned circuit. Thus, if in series with the tube impedance, another impedance is inserted and it has tuning characteristics such that its impedance is lowest at the tuning frequency and increases as the frequency deviates from this value, the above ratio becomes more dependent on frequency and therefore, the steadiness of the frequency is enhanced.

As shown in Figure 8, I utilize for this purpose a so-called series tuning device consisting of an inductance 170 in series with condenser 171 and connected to the negative side of a series oscillator comprising tubes 172, 173, and 174. The positive side of tube 174 is connected to a parallel tuning device including the inductance 175 and a tuning condenser 176. It is to be understood that the tuning circuit 175—176 may be adjusted to the same frequency as the tuning circuit 170 and 171. The other elements of the oscillator include the potentiometer 177 connected to the supply terminals 179 and 180 with taps to the various grid connections and a bypass condenser 178 to return the radio frequency currents from the tuned circuit 175 and 176 to the negative line 179. The positive line 180 supplies the tuned circuits 175, 176 and therethrough the series oscillator.

I have shown for tubes 172, 173, and 174 the so-called pentode tubes, the inherent characteristics of which is that of low impedance which makes them particularly suitable for series oscillator. The first and second grids of the pentode are shown connected to suitable points of the potentiometer 177, while the third grid is in the usual manner internally connected to the cathode of each tube. I have further shown bypass condensers from the various grids to the negative supply lead 179 and bypass condensers 181, 182, and 183 to the cathodes of the three tubes. These condensers are arranged again to have such values relative to the capacities of the tubes as to form the capacity bridges for securing the correct operating potentials on the various elements in accordance with the considerations discussed in connection with Figure 5D. The circuit may be, thereby, rendered inherently oscillatory. But I have provided, in addition, a further feed back arrangement, by providing

inductive coupling between the inductance 170 and the tuning coil 175, as indicated by the arrow 184.

Since the condenser 171 isolates the cathode of tube 172 from the negative supply line 179, it is necessary to supply a bypass around the condenser 171, which may be an inductance or a resistance. But I have shown as a preferred form a tube 185, the cathode of which is connected through the resistor 186 to the negative line 179, and the anode of which is connected to a tap 187 on the coil 170.

The tube 185 is, therefore, in series with the tubes 172, 173, and 174 and will cooperate with those tubes to form a series amplifier for modulating of the series oscillator. For this purpose a modulating transformer 188, the primary of which may be supplied with suitable modulating currents and the secondary of which is connected to the negative line 179 and the grid of tube 185 may be used. Thus, the applied modulating potentials are amplified in the tubes 172, 173, and 174 and applied across the choke coil 189 in the positive lead 180, in such a way that the oscillator is subject to a modulating variation of potential. A bypass condenser 190 permits the audio frequency variations to return from the positive lead 180 to the negative lead 179. A coil 191 may be coupled to the coil 175 and utilized either for further amplification or for transmission purposes. I have thus combined in the same series connected tubes, the functions of an oscillator, an amplifier for modulating currents, and the modulator.

The arrangement of Figure 8 can be conveniently utilized for the purpose of suppressing at least one of the side bands of the modulated radio frequency signals. For this purpose, the same principles as were discussed in connection with Figure 4 may be employed. That is, the ratio between the impedance of the tuned circuit and that corresponding to the tube impedance is taken into account and the frequency impedance characteristics of the tuned circuits 175 and 176 is modified in a manner exactly similar to that of the tuned circuit 104, and 105 of Figure 4 by inclusion of a resistor similar to resistor 106 of Figure 4.

However, the suppression of the carrier wave can be accomplished independently of such a change in the frequency characteristic of circuit 175 and 176. Instead, the tuned circuit 170 and 171 may be adjusted to have its resonance point about the center of one of the side band ranges. Then, at the other side band range, this same tuned circuit imposes a relatively high impedance in series with the tube impedances and prevents any oscillations of this second half of the side band range in the oscillator. In such a form of operation, I would prefer to omit the feed back arrangement illustrated by the arrow 184 which would necessarily tie up the tuning characteristics of the two tuned circuits.

The operation of such an oscillator modulator combination with suppressed side band may be explained, for example, as follows: The normal connection of the oscillator including the tuned circuits 175 and 176, the three tubes 172, 173, and 174, and their capacity bridges, will have a definite oscillating frequency. The modulating tube 185, acting through the same tubes 172, 173, and 174 as amplifiers at modulating frequency, will modulate the output of oscillations so that theoretically all of the side bands will be present in this modulated wave.

However, as the tuned circuit consisting of inductance 170 and condenser 171 is impressing a high impedance for the side band frequencies on one side of the carrier, these particular side bands will be reduced in amplitude or completely suppressed, thus modifying the output oscillations to contain only the carrier wave and one side band range.

It has been the experience with this type of transmission that the suppression of one half of the side bands results in an increased output of the whole transmitting system without any sacrifice of the clarity of reception provided at the receiving circuit the suppressed range of side bands is re-established.

Referring to Figure 9, I have shown another arrangement for modulating a series amplifier in which the modulating circuit is connected in series with the series oscillator. I have shown a two tube oscillator comprising the tubes 200 and 201 in series with a tuned circuit consisting of inductance 202 and a tuning condenser 203.

I have also shown a radio frequency return condenser 204 which connects to the cathode of tube 200 through a bias resistor 205. I have also shown a capacity bridge consisting of condensers 206, 207, and 208 by means of which the distributed capacity of the tube elements is included in the oscillating circuit.

The feed back arrangement in this case is shown by means of a coil 209 connected between the return to the cathode of tube 200 and the grid of the same tube, and the arrow 210 indicates that this coil is inductively coupled to the inductance 202 of the tuned circuit. A potentiometer 211 is also connected from the return lead 212 to the positive lead 213. There is also a radio frequency condenser 214 to supply the grid of tube 201 with proper radio frequency potential. This grid is also connected to a suitable tap 215 on potentiometer 211 to supply it with a proper steady potential.

The above description covers a complete two tube series oscillator. It is seen from the diagram that this oscillator is directly in series with tubes 216, 217 which constitute a series modulating amplifier. This amplifier utilizes the tubes 200 and 201 as a resistance coupling element for its molulations and has a return audio frequency path through the condenser 218 and the biasing resistor 219. The latter may also be bypassed by suitable condenser 220. The grid of tube 216 may be supplied from a modulating transformer 221, the primary of which is fed with suitable modulating currents, and the secondary of which is connected to the negative line 222 and the grid of tube 216. The grid of the tube 217 is connected to a tap point 223 on a potentiometer 224' which, as can be readily seen, is in series with the potentiometer 211 and an audio frequency choke coil 224. Of course, instead of connecting the potentiometer 224 in series with 211, it is also possible to extend this potentiometer and supply with a positive potential from the terminal 213. Choke coils 225 and 226 isolate the modulating amplifier from the radio frequency oscillator, audio frequency bypass condensers 227 and 228 may be also supplied to steady the potential on the potentiometer 224.

In the operation of this system it is evident that the modulating potential from the transformer 221 will be amplified in the modulating series amplifier tubes 216, 217 and that on lead 212 there will be a variation of potential corresponding to the modulating frequencies. Thus, between the

lines 212 and 213 a potential is applied to the series oscillator varying in accordance with the modulated frequency, and the oscillator output will be accordingly varied. The tuning coil 202 may be coupled to an output coil 229 for further amplification, or for use in a transmitting antenna.

Figure 10 shows another modification of a series modulating arrangement in which the oscillator is of a push-pull type; that is, the oscillator is split into two parallel channels and arranged so that while the current in one of these channels is increasing, the current in the other channel is decreasing.

I have shown an oscillator consisting of tubes 230, 231, 232, and 233 and a tuning circuit consisting of inductance 234, and a tuning condenser 235. The tubes 230 and 231 constitute one channel of the oscillator while the tubes 232 and 233 the other channel of the oscillator, and the two are connected respectively to the opposite points of the tuning circuit 234 and 235. A center tap 236 on the coil 234 connects the oscillator to the positive supply 237. In this oscillator it is not necessary to supply any potentiometer for grid potentials. The diagram shows that the grid of tube 231 is directly connected to the anode of tube 232 and the grid of tube 233 to the anode of tube 230.

Similarly, the grid of tube 230 is connected to the negative terminal of oscillator channel 232, 233 at point 238 while the grid of tube 232 is connected to the negative terminal of the oscillator channel 230 and 231 at the point 239. Biasing resistors 240, 241, 242, and 243 are respectively connected to the cathodes of the tubes 230, 231, 232, and 233. In this way, for a steady condition, the grid of each of the tubes is receiving a biasing potential from a tube in the other channel. But when the oscillations are established while the cathode of, say, tube 231 is rising in potential the cathode of tube 233 and the anode of tube 232 are falling in potential, and therefore the grid of tube 231, which is connected to the anode of tube 232, is receiving a potential in the opposite phase to the cathode of tube 231, and a condition is established for powerful oscillations, since on each of the tubes the cathodes and anodes are driven to opposite potentials.

It may be desirable in this case to have different voltage ratings on tubes 230 and 232 as compared with 231 and 233 for the same reason as was explained in connection with Figure 7. Capacity bridges, consisting of condensers 244, 245 on the channel 230 and 231, and consisting of condensers 246, 247 on the channel 232 and 233, is also supplied to take care of the capacitative current. An interchannel condenser 248 is arranged between points 239 and 238 by means of which a return path is formed for the capacitative currents that may circulate through the capacity bridges. I have also shown coils 249 and 250 and a connection at point 260 through which the negative potential is applied to the push-pull oscillator.

For modulating purposes, tubes 261 and 262 are connected in a series amplifier circuit with the cathode of tube 261, supplied from the negative lead 263 and a biasing resistor 264 while the grid of tube 261 is fed from a modulating transformer 265 with suitable modulating potentials. The grid of tube 262 is connected to a suitable tap on a potentiometer 266 across the power supply.

It is seen, therefore, that the modulating potentials applied through the transformer 265 are amplified by modulating series amplifiers 261 and 262 and applies a potential varying at the frequency of modulating potential to the point 260 of the series push-pull oscillator. The oscillations will be, therefore, modulated in accordance with these potential modulations and the output oscillations as modulated will be impressed on inductance 234, and coil 267 coupled to coil 234 may serve for output purposes.

Referring to Figure 11, I have shown a further modification using a push-pull series oscillator and a push-pull series modulator, the modulator comprising tubes 270 and 271 in one channel and tubes 272 and 273 in the other channel, each series connected to the negative supply 274 and a positive supply 275. The negative supply leads contain a biasing resistor 276 for the first channel and a biasing resistor 277 for the second channel. The positive supply lead 275 is connected to a center tap on a push-pull transformer primary 278. The two ends of the transformer 278 are connected directly to the anodes of tubes 271 and 273. A potentiometer 279 is also connected to the center tap and serves to supply the correct biasing potentials to grids of tubes 271 and 273 from a tap 280. The grids of tube 270 and 272 are, on the other hand, supplied with the modulating potentials of opposite phases from a transformer 281, the primary of which is supplied with suitable modulating currents. The secondary 282 of the modulating transformer is connected on one side to the positive supply lead 275 and on the other side to the input tap 283 of the push-pull series oscillator.

This series oscillator, includes the tubes 284 and 285 in one channel and the tubes 286 and 287 in the other channel. The anodes of tubes 285 and 287 are respectively connected to opposite ends of the tuning inductance 288 of which point 283 forms the center tap and a tuning condenser 289 is also connected across these opposite ends. The center tap 283 supplies also a potentiometer 290, the other end of which is connected to the negative supply lead 274. Biasing resistor 291 is supplied for the first channel and biasing resistor 292 for the other channel. Capacity bridges similar to those of Figure 9 are shown for each of the channels and serve the same purpose. The grids of tubes 284 and 286 may be supplied from a feed back coil 293, which may be inductively coupled to the tuning coil 288. The center tap of the coil 293 may be connected to the negative lead 274 so that the opposite ends will supply opposing potentials to the grids of tubes 284 and 286. The arrow 294 indicates the magnetic coupling between 288 and 293 which must be, of course, of such a sense that the potential of the grid of, say, the tube 284 is in the opposite phase to the potential of the anode of tube 285.

The feed back coil 293 may be omitted if the capacity bridges are arranged to have feed back in accordance with the principle discussed with respect to Figure 5. To supply the correct potentials in accordance with Figure 5D to the grids of tubes 285 and 287, two resistors 295 and 296 are connected to a tap on resistor 290, and the other end of these resistors being connected respectively to the grids of tubes 285 and 287. I have further supplied a condenser 297 between these two grids chosen of such a value that it will form, in connection with the capacity of tube elements of tubes 285 and 287, a bridge circuit across the tuned circuit 288 and 289 to secure the correct potential on each of the grids

corresponding to diagram Figure 5D. Thus, the oscillations in the series oscillator will be in opposite phase but of full magnitude in the two channels.

In this way I secure a powerful oscillator which needs no return circuit, as the oscillations are confined within the circuit so that the output lead and the secondary **282** need not carry any radio frequency current.

As a further protection, however, I interpose a choke coil **298** in this supply lead. The coil **288** may be coupled to an output coil **299** for further amplification or transmission.

Although I have illustrated my invention as applied to an oscillator, it will be understood that it has other adaptations in electrical circuits and these come within the scope of my invention.

I claim

1. An oscillation generator comprising a plurality of discharge devices having anode, cathode and control electrodes; a source of current therefor; a resonant circuit; said devices, said circuit and said source being in series through the anode of one device being connected to the cathode of the succeeding device and a potentiometer connected across said source provided with tap connections to said control electrodes to maintain predetermined fixed potentials thereat.

2. An oscillation generator comprising a plurality of discharge devices having main electrodes; a source of current therefor; a predetermined resonant circuit; said devices, said circuit and said source being connected in series; control electrodes for said devices; a potentiometer connected across said source and tap connections from said potentiometer to said control electrodes to secure predetermined fixed biasing potentials thereat; and a feedback circuit connection from said resonant circuit to the control electrode of the first discharge device.

3. An oscillation generator comprising a plurality of thermionic discharge tubes having cathode, anode and control electrodes; a source of current therefor; a parallel resonant circuit; said tubes, said resonant circuit and said source being connected in series with the anode of one tube being directly connected to the cathode of the succeeding tube; a feedback circuit connection from said resonant circuit to the first tube; means for maintaining constant predetermined direct potentials relative to said source at the control electrodes of said tubes; and further means for securing proper relative high frequency potentials at the various electrodes of said tubes, said first means consisting of a potentiometer connected across said source and tap connections from said potentiometer to the control electrodes of said tube, and said further means comprising an impedance bridge connected across said resonant circuit and tap connections from said bridge to the electrodes of said tubes.

4. An oscillation generator comprising a plurality of thermionic discharge tubes having cathode, anode and control electrodes; a source of current therefor; a parallel resonant circuit; said tubes, said resonant circuit and said source being connected in series with the anode of one tube being directly connected to the cathode of the succeeding tube; a feedback circuit connection from said resonant circuit to the first tube; means for maintaining constant predetermined direct potentials relative to said source at the control electrodes of said tubes; and further means for securing proper relative high frequency potentials at the various electrodes of said tubes; said last means comprising a series of condensers connected across said resonant circuit and connections from said condensers to the cathode electrodes of said tubes.

5. An oscillation generator comprising a plurality of thermionic discharge tubes having cathode, anode and control electrodes; a source of current therefor; a parallel resonant circuit; said tubes, said resonant circuit and said source being connected in series with the anode of one tube being directly connected to the cathode of the succeeding tube; a feedback circuit connection from said resonant circuit to the first tube; means for maintaining constant predetermined direct potentials relative to said source at the control electrodes of said tubes; and further means for securing proper relative high frequency potentials at the various electrodes of said tubes, said last means comprising a series of condensers connected across said resonant circuit and connections from said condensers to the control electrodes of said tubes.

6. An oscillation generator comprising a plurality of thermionic discharge tubes having cathode, anode and control electrodes; a source of current therefor; a parallel resonant circuit; said tubes, said resonant circuit and said source being connected in series with the anode of one tube being directly connected to the cathode of the succeeding tube; a feedback circuit connection from said resonant circuit to the first tube; means for maintaining constant predetermined direct potentials relative to said source at the control electrodes of said tube; and further means for securing proper relative high frequency potentials at the various electrodes of said tubes, said last means comprising a series of condensers connected across said resonant circuit and connections from said condensers to the anodes of said tubes.

7. An oscillation generator comprising a plurality of discharge devices, each having cathode, anode and a control electrode; a source of current therefor; a plurality of resonant circuits each tuned to a different frequency; said devices, said circuits and said source being in series with the anode of one device being directly connected to the cathode of a succeeding device; means for maintaining the control electrodes of said devices at predetermined fixed potentials and feedback circuit connections from said resonant circuits to the first of said devices whereby said series circuit is maintained in multiple oscillating condition.

ALEXANDER NYMAN.