Sept. 9, 1947. W. M. GOODALL 2,426,996

FREQUENCY MODULATION

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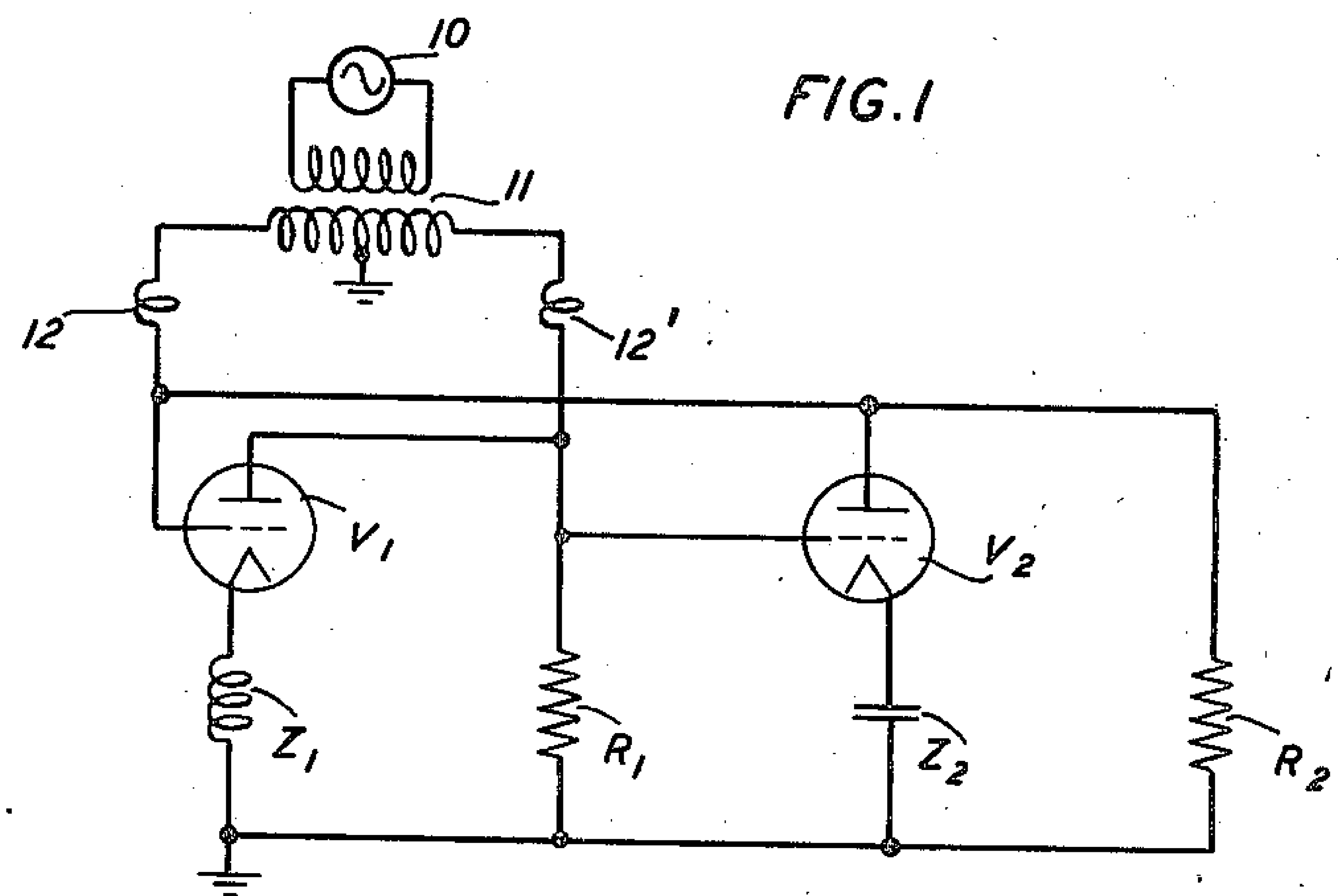

FIG. 1

FIG. 2

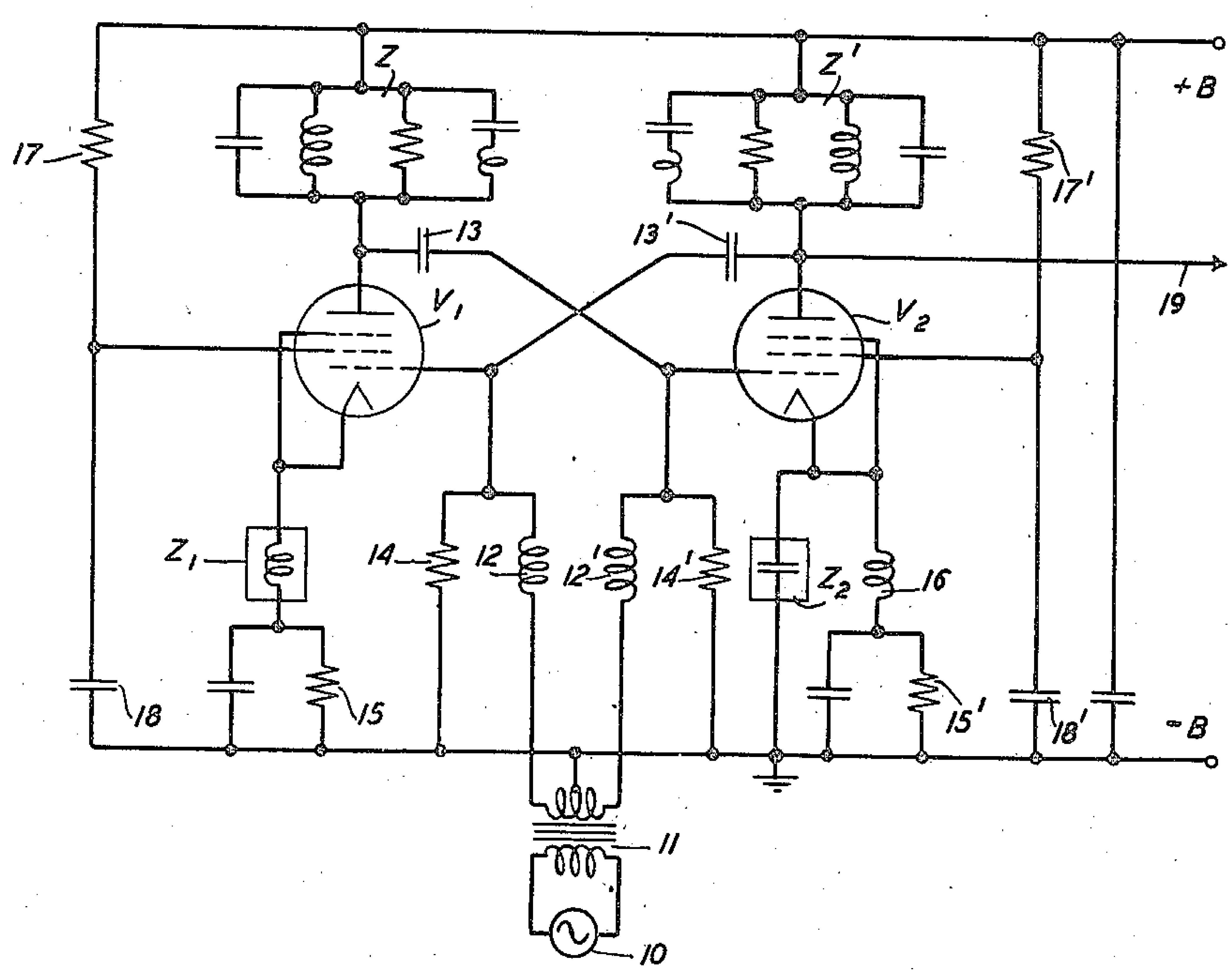

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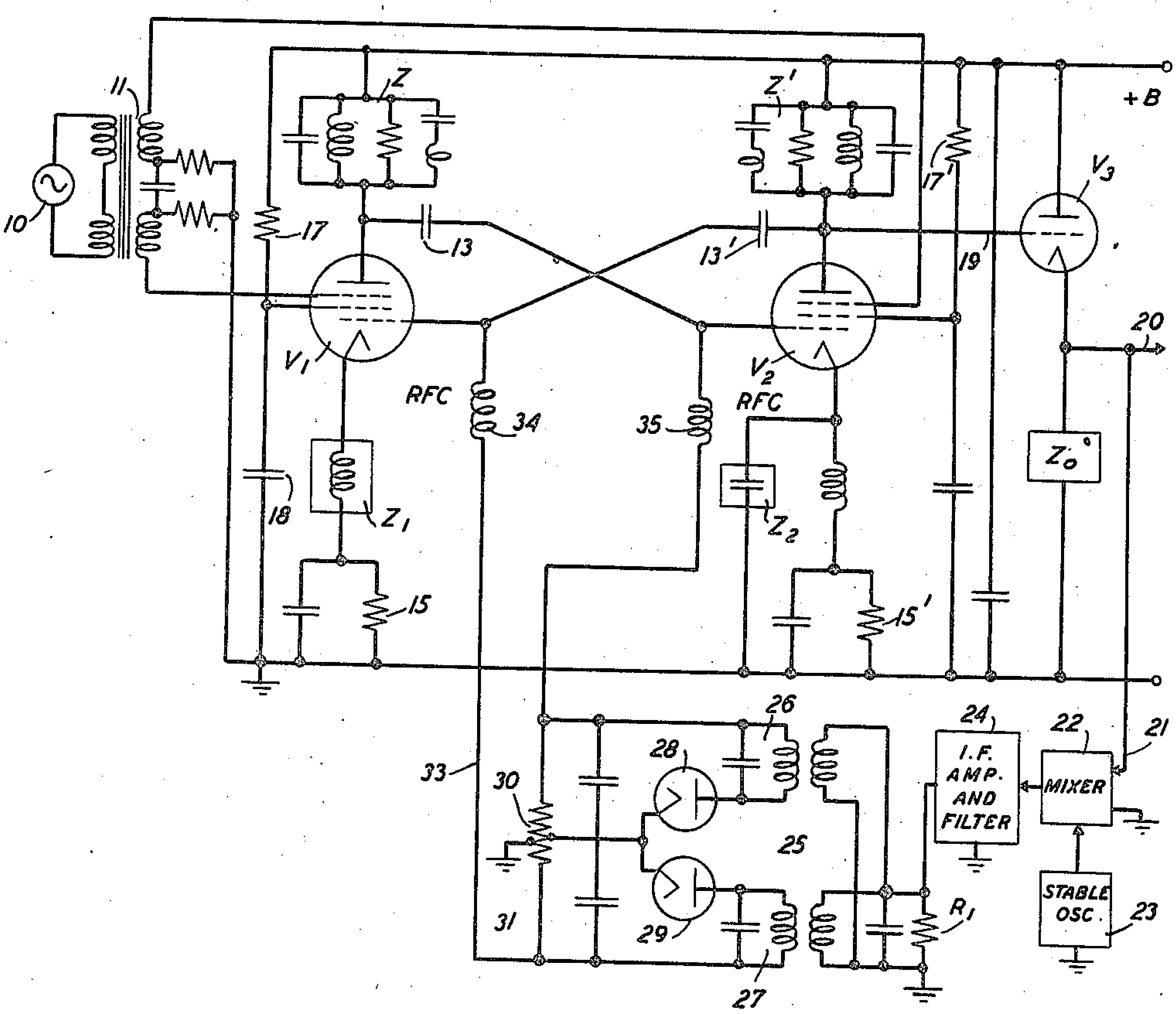
FIG. 3



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Patented Sept. 9, 1947

2,426,996

UNITED STATES PATENT OFFICE

2,426,996

FREQUENCY MODULATION

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Application August 17, 1944, Serial No. 549,853

6 Claims. (Cl. 179—171.5)

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This invention relates to an improved arrangement for generating high frequency oscillators and modulating their frequency by speech or other signal waves.

Among the objects of the invention are to increase the range or degree of modulation and to minimize amplitude variations of the frequency modulated wave.

In accordance with the invention, two vacuum tube amplifying stages, each provided with local negative feedback, are connected in tandem, the output circuit of each being coupled to the input circuit of the other so as to form a closed loop in which oscillations are generated. The local feedback circuits for the two tubes are so arranged, by means of appropriate impedance elements, that the two stages have rising and falling gain characteristics respectively and, consequently, produce phase shifts in opposite directions. The frequency of oscillation of the system is determined by the characteristics of the local feedback circuits and by the mutual conductances of the two tubes. Variation of the frequency is accomplished by applying signal voltages of opposite phases to the tubes so that the conductance of one is increased and that of the other is simultaneously reduced by a corresponding amount. By this means large frequency swings can be produced for quite small values of the modulating signal voltages. Further, the loop gain of the system remains constant at the different oscillation frequencies, with the result that factors tending to produce amplitude variations are substantially eliminated.

The invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, of which:

Fig. 1 is a simplified schematic of the invention;

Fig. 2 is a more detailed circuit of one form of the invention; and

Fig. 3 illustrates a modified form of the invention.

The circuit shown in Fig. 1 represents an elementary form of the invention and is intended primarily to illustrate the general principles by virtue of which large degrees of frequency modulation are obtained with negligibly small amplitude variations. For this reason only those elements necessary for the explanation of the principles are shown. Energizing circuits and blocking and by-pass impedances may be included where necessary in accordance with familiar practice.

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The oscillation generator comprises two vacuum tubes V_1 and V_2, preferably screen grid tubes or pentodes, which are coupled together serially by equal resistors R_1 and R_2 to form a closed feedback loop. Reactive impedances Z_1 and Z_2 consisting of an inductance and a capacity respectively provide local degenerative feedback around each tube and together establish a definite frequency of oscillation. For the purpose of modulation a source 10 of speech or other signals is connected through a transformer 11 having two secondary windings to the grids of the two tubes in such a way as to apply thereto signal voltage substantially equal in magnitude and opposite in phase. High frequency chokes 12, 12' serve to isolate the signal circuits from the high frequency oscillation path.

The properties of the circuit readily appear from a consideration of the loop gain around the oscillator feedback path. This quantity, which will be denoted by $\mu\beta$, has the value for the circuit shown

$$\mu\beta=\frac{g_1g_2R^2}{(1+g_1Z_1)(1+g_2Z_2)} \tag{1}$$

where g_1 and g_2 are the transconductances of tubes V_1 and V_2 respectively and R is the resistance of equal resistors R_1 and R_2. For the case illustrated where Z_1 and Z_2 consist of an inductance L and a capacity C respectively, Equation 1 becomes

$$\mu\beta=\frac{g_1g_2R^2}{1+g_1g_2\frac{L}{C}+j\left(g_1\omega L-\frac{g_2}{\omega C}\right)} \tag{2}$$

where ω denotes 2π times frequency.

The frequency at which the system oscillates is that for which the phase angle of $\mu\beta$ is zero or for which the imaginary term in Equation 2 disappears. Its value, denoted by $\omega_0\div 2\pi$, is given by

$$\omega_0=\sqrt{\frac{g_2}{g_1}\frac{1}{LC}} \tag{3}$$

The magnitude of the loop gain at this frequency has the value

$$\mu\beta_0=\frac{g_1g_2R^2}{1+g_1g_2\frac{L}{C}} \tag{4}$$

which must be at least as great as unity to ensure sustained oscillation.

From Equations 3 and 4 it is evident that the frequency can be varied by varying the ratio of the transconductances of the tubes and that, if this variation be effected in such a way as to maintain the product substantially constant, the loop gain at the oscillation frequency will remain independent of the value of the latter. A consequence of this is that the amplitude of the oscillations remains substantially constant as the frequency is varied and hence that frequency modulation is effected without concurrent amplitude modulation.

Assuming the tubes to be similar and equally biased so that in the absence of signal voltages their transconductances are substantially equal, then the application of equal signal voltages in phase opposition to the two grids will change the transconductances by about equal amounts in opposite senses. So long as the variation is relatively small, for example 10 per cent or less, the product of the transconductances will remain very nearly constant.

The frequency variation is closely proportioned to the applied signal voltage and, as follows from Equation 3, is substantially proportional to the percentage change in the transconductance of either tube. Thus a signal voltage which produces a five per cent increase in the transconductance of one tube and a decrease of five per cent in the other will produce a frequency swing of substantially five per cent. Since variations as great as ten per cent or even more can be readily accomplished in commercial vacuum tubes, very large degrees of frequency modulation may be achieved.

To insure an adequate amount of over-all feedback so that the loop gain as expressed by Equation 4 will be greater than unity at the oscillation frequency, it is desirable to make the local feedback impedances Z_1 and Z_2 small relatively to the coupling impedances R_1 and R_2 and to make the latter fairly high.

The system shown in Fig. 2 is similar in general to that of Fig. 1, but the circuit is shown in more complete detail and includes certain modifications for better operation at high frequencies. Tubes V_1 and V_2 are similar pentodes and are coupled serially to form a closed feedback loop by means of similar tuned impedances Z, Z' blocking condensers 13, 14', and grid leak resistors 14, 14'. Local feedback impedances Z_1 and Z_2 consist of an inductance and a capacity respectively as in Fig. 1. A resistance 15 shunted by a by-pass condenser is included in series with inductive impedance Z_1 and a similar by-passed resistance 15' in series with a high frequency choke coil 16 is shunted around the capacitive impedance Z_2. These circuits provide bias voltages for the control grids of the two tubes in a well-known manner. Plate potentials are supplied to the tubes through the coupling impedances Z, Z', as indicated. The screen grids are energized through resistors 17 and 17' and are by-passed to ground through condensers 18, 18'. Modulating potentials are supplied to the control grids in phase opposition through audio transformer 11 and high frequency chokes 12, 12' as in Fig. 1. The modulated output may be taken from the system by a circuit connected to the plate of either tube, for example, between conductor 19 and the negative terminal, —B, in the figure.

The substitution of the tuned coupling impedances Z, Z' for resistors R_1 and R_2 of Fig. 1 has the advantage that the magnitude of the impedance may be kept high at high oscillation frequencies in the presence of parasitic tube capacities. It is desirable that the impedance should have a broad-band characteristic in the sense that it should have very little reactance and should have substantially constant resistance at all frequencies in the operating range. There are many ways of realizing such a characteristic, for example, by the use of resistance terminated band-pass filters as two-terminal impedances. The arrangement illustrated comprises a series resonant circuit and an antiresonant circuit connected in parallel and both tuned to the mean oscillation frequency of the system. A high resistance added in parallel with the resonant circuit as shown serves to smooth out the frequency characteristic of the impedance and to reduce its reactance. If desired these resistors may be omitted and their smoothing effect may be obtained by giving the grid leak resistors 14, 14' appropriate resistance values.

In Fig. 3 is shown a modified form of the invention in which the modulating signals are applied to the suppressor grids of the vacuum tubes instead of to the control grids. The figure shows also how the central frequency of the oscillator may be held substantially constant.

The oscillator circuit is similar to that of Fig. 2 in most respects and need not be described further. The output from the plate of V_2 is taken by conductor 19 to cathode follower tube V_3 in the cathode lead of which is included a tuned impedance Z_0 which may be similar to the coupling impedances Z, Z'. The output of the system is taken from the terminals of this impedance between conductor 20 and ground.

For the purpose of frequency control part of the output is taken by conductor 21 to a mixer tube 22 which is also supplied with oscillations from a stable frequency oscillator 23. The difference frequency oscillations resulting from the mixing operation are supplied to intermediate frequency amplifier 24 and from thence to a discriminator 25. This discriminator may be of any of a number of well-known types, but it is desirable that the detectors and their output circuits be balanced with respect to ground so that two equal control voltages of opposite sign may be obtained. In the arrangement shown the discriminator comprises two slope circuits 26 and 27, preferably of very steep slope, whose characteristics intersect at the desired intermediate frequency, rectifiers 28 and 29, and equal output resistances 30 and 31 together with suitable filtering condensers. The balanced control voltages, which appear when the oscillator mean frequency departs from its assigned normal value, are applied through conductors 32 and 33 and high frequency chokes 34, 35 to the control grids of the tubes so as to produce symmetrical changes in the transconductances tending to restore the frequency to its proper value.

What is claimed is:

1. A generator of frequency modulated oscillations comprising two amplifying vacuum tubes having input terminals and output terminals, separate circuits coupling the output of each tube to the input of the other to form a closed transmission loop in which high frequency oscillations are generated, reactive impedances coupling the input and the output circuits of each tube and producing degenerative feedback therein, said impedances comprising reactances of unlike signs at the oscillator frequency and jointly constituting the principal frequency-determining elements of the oscillating system, a source of signal oscillations and circuit means for impressing signal

voltages from said source upon the two tubes in phase opposition whereby their transconductances are varied simultaneously in opposite senses.

2. A generator of frequency modulated oscillations comprising two vacuum tubes each having an anode, a cathode and a control grid, circuits coupling the anode of each tube to the grid of the other to form a closed loop in which high frequency oscillations are generated, a reactive impedance connected to the cathode of each tube and coupling the grid and anode circuits thereof, said impedances comprising reactances of unlike signs at the oscillation frequency and serving jointly to determine the frequency of oscillation, a source of signal oscillations, and circuits coupling said source to the grids of said tubes in phase opposition.

3. A generator of frequency modulated oscillations in accordance with claim 2 in which each of the said vacuum tubes is provided with an additional control grid isolated electrostatically from the other control grid by a screen grid and in which the signal oscillations are applied to said additional control grids.

4. A generator of frequency modulated oscillations according to claim 2 in which the frequency determining reactances consist respectively of an inductance and a capacity.

5. A generator of frequency modulated oscillation comprising two screen grid vacuum tubes, resistive impedances coupling the anode circuit of each tube to the grid circuit of the other to form

a closed oscillation circuit, reactive impedances connected respectively to the cathodes of said tubes and degeneratively coupling the input and output circuits thereof, said impedances having reactances of opposite sign at the oscillation frequency and together determining the frequency of oscillation, a source of signal oscillations, and circuits coupling said source and said tubes for impressing signal voltages in phase opposition thereon whereby their transconductances are varied simultaneously in opposite senses.

6. A system in accordance with claim 5 in which the resistive coupling impedances comprise multiple tuned circuits with damping resistance providing a broad resonance characteristic centered in the operating frequency range and in which the reactances of the local feedback impedances are small relatively to the resonance resistances of the coupling impedances.

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