Sept. 30, 1947. M. G. CROSBY 2,428,264

FREQUENCY DISCRIMINATOR CIRCUITS

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Fig. 1.

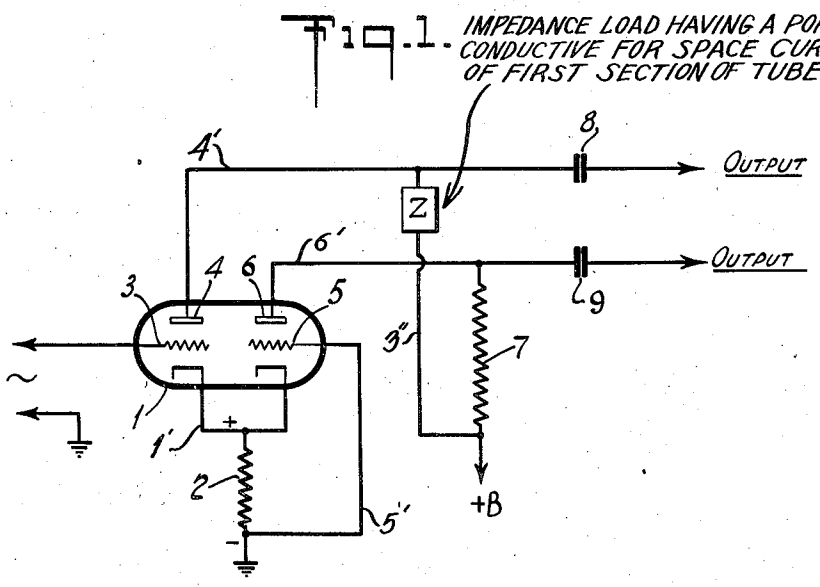
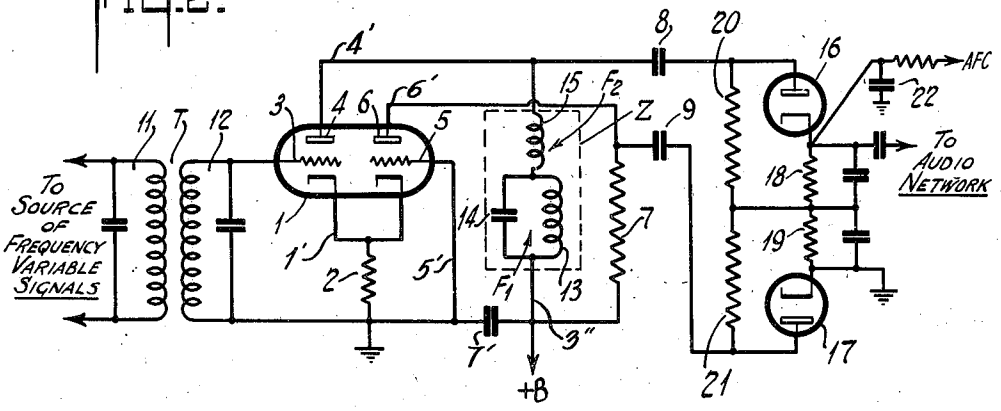


Fig. 2.



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Fig. 3.

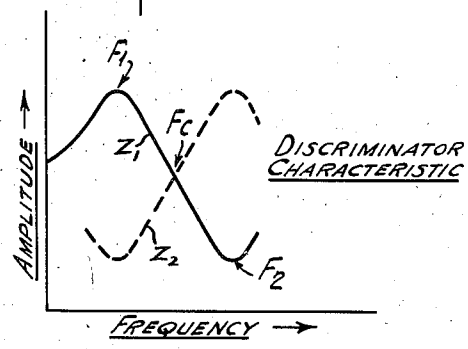


Fig. 3a.

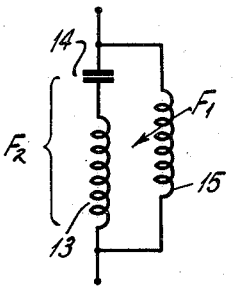


Fig. 4.

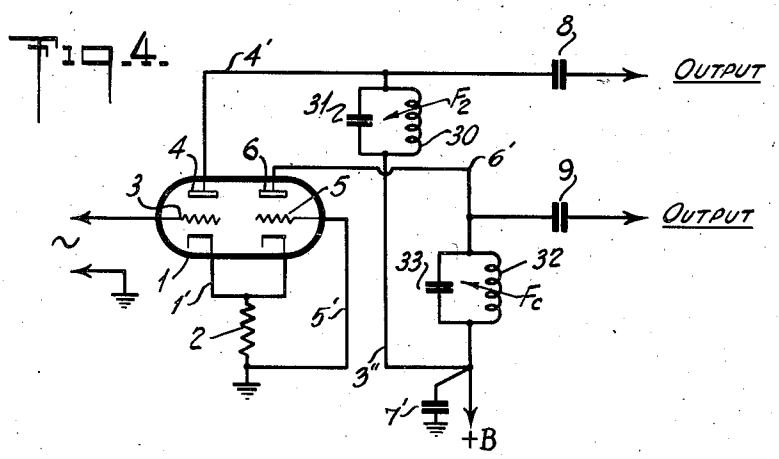


Fig. 5.

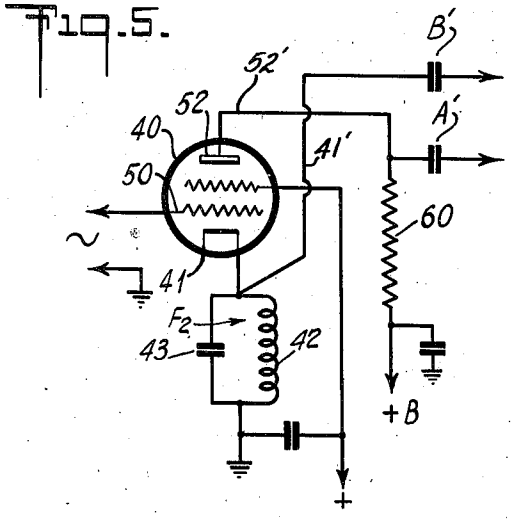
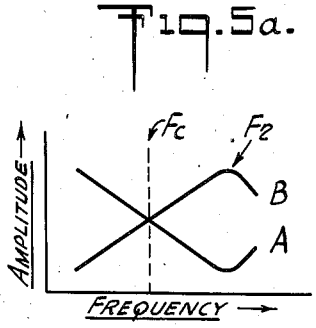


Fig. 5a.



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Patented Sept. 30, 1947 2,428,264

UNITED STATES PATENT OFFICE

2,428,264

FREQUENCY DISCRIMINATOR CIRCUITS

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Application April 27, 1943, Serial No. 484,703

9 Claims. (Cl. 250—27)

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My present invention relates to discriminator circuits for waves of variable frequency, and more particularly to frequency modulated wave energy discriminator circuits.

An important object of this invention is the provision of a novel method for converting an impedance characteristic into an output characteristic, wherein the characteristics bear an inverse proportionality relation to each other.

Another important object of my invention is to utilize the aforementioned conversion method in a frequency discriminator network, the latter being provided with input terminals to which are supplied frequency-variable waves, and the network having a pair of output impedances of respectively complementary amplitude-frequency characteristics.

Another object of my invention is to provide a method of translating frequency-variable waves into variable-amplitude waves, the method employing a novel network capable of converting a given amplitude-frequency characteristic into a complementary amplitude-frequency characteristic, and the two characteristics being caused to have a cross-over frequency at the mean frequency value of the frequency-variable waves.

Another object of the invention is to provide a frequency discriminator circuit using a single electron discharge device provided with a pair of output impedances, and the frequency-response characteristics of the impedances being of a complementary nature, the output impedances additionally being located in common in the space current path of said device.

Still another object of my invention is to provide a demodulator network for frequency modulated carrier wave energy wherein the discriminator section of the network comprises a pair of parallel electron discharge devices having a common cathode load, the output electrodes of the devices having parallel output impedances, the respective amplitude-frequency characteristics of these parallel impedances being complementary and having a cross-over frequency at the mean frequency of the frequency modulated energy which is to be demodulated.

Still other objects of my invention are to improve generally frequency discriminator circuits, and more particularly to provide various modifications of circuits employing the fundamental impedance inversion method disclosed in this application.

Other features will best be understood by reference to the following description, taken in connection with the drawing, in which I have

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indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 shows a generalized network embodying the invention,

Fig. 2 shows my invention embodied in a frequency discriminator for frequency-variable signals,

Fig. 3 shows the complementary amplitude-frequency characteristics of the output impedances of the circuit of Fig. 2,

Fig. 3*a* illustrates a modified form of impedance network which may be substituted for the output impedance of the first electronic section of the circuit of Fig. 2,

Fig. 4 illustrates a modified form of the invention,

Fig. 5 shows a further modification of the invention,

Fig. 5*a* shows the complementary frequency response characteristics for the circuit of Fig. 5.

Referring now to the accompanying drawing, wherein like reference characters in the different figures designate similar circuit elements, in Fig. 1 there is shown a pair of electron discharge devices whose electrodes are conveniently located in a common tube envelope 1. It is to be clearly understood that the electronic devices may be located in separate tube envelopes. Assuming that tube 1 is of the well known twin triode type, the common cathode lead 1′ is shown connected to ground by a purely resistive impedance 2 which is unbypassed. The input control grid 3 of the first electronic section is connected to a source of alternating current energy which is schematically represented. The source of alternating current energy may be a source of high frequency signals, either amplitude modulated, frequency modulated or phase modulated, and is shown connected between ground and the input grid 3. The plate 4 of the first electronic section is shown connected back to the +B terminal of the direct current energizing source (not shown) through lead 4′, an impedance Z and lead 3″. At least a portion of this impedance load is to be understood as being conducted for the direct current flowing through the closed space current path including the space current of the first electronic section.

The second electronic section has its control grid 5 connected by lead 5′ to the grounded end of cathode resistor 2. The plate 6 is connected to the +B terminal through a lead 6′ and a purely resistive impedance 7. The plate end of

impedance Z is connected by a coupling condenser 8 to an output circuit, while condenser 9 couples the plate end of output impedance 7 to a second output circuit. In other words, the impedances 7 and Z are the respective output impedances of the two electronic sections. In considering the electrical action of the circuit shown in Fig. 1, it is pointed out that the first electronic section of tube 1 is a so-called cathode follower stage.

This cathode follower applies alternating voltage between the grid and cathode of the second electron section by applying the voltage to the common cathode resistor 2. The fraction of the voltage applied at grid 3, which appears on the cathode resistor 2, is dependent on the degree of inverse feedback existing in the first electron section. The degree of inverse feedback is dependent on the ratio of the cathode resistance to the impedance Z in the plate circuit of the first section. If the impedance magnitude of load Z is high, a small voltage will be developed across resistor 2 from grid 3. If the impedance magnitude of load Z is low, a high voltage will be developed. Thus, at the frequency corresponding to a high impedance value for load Z, the voltage fed to grid 5 will be low so that the output appearing across resistor 7 will be low. At this same time, the high magnitude of impedance of load Z, appearing in the plate circuit of the first tube, causes a high output voltage to appear across load Z. Hence, when the value of impedance of load Z is high, the output at condenser 8 is high and that at resistor 7 is low. For the same reason, when load Z is low in impedance value the output at condenser 8 is low, and that at resistor 7 is high. It will thus be apparent that the impedance characteristic of load Z appears inverted in resistor 7.

In Fig. 2 I have shown a circuit for utilizing the system of Fig. 1 to provide frequency discrimination. Here the tube 1 has the input grid 3 of the first electron section coupled to the high potential side of the resonant secondary circuit of input transformer T. The resonant primary circuit 11 and the resonant secondary circuit 12 are each tuned to the mean frequency of the frequency-variable signal energy applied to circuit 11 from any well known source of frequency-variable signals. Such a source of signals, for example, could be intermediate frequency energy of a superheterodyne receiver, whether the receiver be utilized for amplitude modulated carrier energy or for frequency modulated carrier energy. Of course, in the case of the reception of amplitude modulated carrier energy the discriminator would be employed to produce automatic frequency control (AFC) bias to control the local oscillator in the well known manner. Where frequency modulated signal energy is applied to transformer T the discriminator network would then function, in cooperation with the usual opposed rectifiers, to provide demodulation for the purpose of producing the original modulation signals, as well as to produce AFC bias for control of the local oscillator. Let it be assumed, for the purposes of this application, that the signals applied to transformer T are frequency modulated (FM) carrier waves, and that the mean frequency of the applied FM energy is at an intermediate frequency value. Each of circuits 11 and 12 would then be tuned to the operating I. F. value.

The plate 4 in this case has connected in circuit therewith a complex impedance network which is shown within the dotted rectangle designated as Z. The impedance network comprises a resonant circuit consisting of coil 13 shunted by condenser 14, the parallel resonant circuit being in series with a coil 15. The lead 4' connects plate 4 to the upper end of coil 15. The parallel resonant circuit 13—14 is tuned to a frequency F_1 which is located on one side of the mean frequency F_c of the applied FM signal energy. On the other hand, the entire network 13—14—15 is tuned for series resonance to a frequency F_2 which is located on the opposite side of the mean frequency F_c. Referring to Fig. 3 the solid line curve Z_1 depicts the "Amplitude-Frequency" curve of the complex impedance network Z in Fig. 2. It will be seen that there is an output peak at F_1 and a second output peak at F_2. The frequencies F_1 and F_2 are on opposite sides of F_c, and are located at equal frequency distances from the latter mean frequency.

The plate 6 has connected in circuit therewith the resistor 7 which is an aperiodic element. The lead 6' connects plate 6 to the upper end of resistor 7. The unbypassed cathode resistor 2 is connected from the common cathode lead 1' to the grounded side of input circuit 12. The lead 5' connects grid 5 to the grounded end of resistor 2, and the low potential ends of resistor 7 and circuit 13, 14 are respectively returned to ground for signal frequencies by condenser 7'. The +B terminal is connected to the lower end of resistor 7 and by lead 3'' to the lower end of coil 13. It will be seen that these connections are generally similar to those shown in Fig. 1. The amplitude-frequency characteristic appearing across resistor 7 is represented by the dotted line Z_2 in Fig. 3. This amplitude characteristic Z_1 is complementary to the corresponding solid line characteristic of the complex network Z. In other words, at frequency F_1 the output voltage appearing at resistor 7 is a minimum, while at frequency F_2 it is a maximum. This action occurs by virtue of the fact that when the impedance in the plate circuit of the first electronic section is high, then the output across the cathode load resistor 2 is low. This means that the output at resistor 7 in circuit with plate 6 of the second electron section is a minimum.

On the other hand, when the impedance of network Z at F_2 is low, then the voltage developed across cathode resistor 2 is high and the output at resistor 7 is also high. It is to be understood that the explanation given in connection with Fig. 1, relative to the impedance inversion functions, applies equally well to the circuit of Fig. 2. It will, therefore, be seen that the amplitude characteristics at network Z and resistor 7 in Fig. 2 present to respective rectifiers complementary sloping filter characteristics as shown in Fig. 3. This is the type of network which provides frequency discrimination. In order to produce a differential rectified voltage output, which is representative of the frequency variations due to the modulating signal upon the carrier, it is necessary to provide a pair of opposed rectifiers 16 and 17.

These rectifiers are shown by way of illustration as being of the diode type. The coupling condenser 8 connects the anode of diode 16 to the plate end of impedance network Z. The coupling condenser 9 connects the anode of diode 17 to the plate end of aperiodic impedance 7. The cathodes of diodes 16 and 17 are connected together by series-arranged load resistors 18 and 19. Each of the load resistors 18 and 19 is shunted

by a respective carrier bypass condenser, and the cathode of diode 17 is grounded. The junction of resistors 18 and 19 is connected to the junction of respective direct current return resistors 20 and 21, each of which return resistors is associated with a respective one of diodes 16 and 17.

There may be taken off from the cathode end of resistor 18 modulation signal voltage as well as AFC voltage. Those skilled in the art are fully acquainted with the fact that the rectifiers 16 and 17 respectively function to rectify the instantaneous voltage appearing across the input impedance elements thereof. It will, therefore, be clear that when the voltage developed across impedance network Z is a maximum, the voltage developed at the same instant across impedance 7 will be a minimum. Hence, the differential resultant voltage of the rectified voltages developed across each of resistors 18 and 19 is fed to the utilizing audio network.

The slow variations in differential voltage are filtered out by the filter network 22 located in the AFC line leading to the local oscillator. At the mean frequency F_c of applied FM signals the voltages across each of network Z and resistor 7 are equal. Hence, the differential output voltage of the rectifiers 16 and 17 is zero at F_c. The spacing between F_1 and F_2 may exceed the overall frequency deviation of the FM signal energy, if desired. If the signal energy applied to circuit 11 is AM wave energy, then any shift of the carrier frequency of applied signals from F_c will provide AFC bias of a polarity and magnitude dependent upon the sense and extent of frequency shift. The complex impedance network Z may take the form shown in Fig. 3*a*, if desired. Here, the condenser 14 and coil 13 are series resonant to F_2. The coil 15 is arranged in shunt with circuit 14—13, and the entire network 13—14—15 is parallel resonant to F_1.

The modification of Fig. 4 is one wherein the plate impedance network in circuit with plate 4 is a tuned circuit 30—31 which is resonant to F_2. The plate load in circuit with plate 6 is a second tuned circuit 32—33 resonated to F_c. As in the case of the circuit shown in Fig. 2, lead 4' connects plate 4 to the high potential side of the impedance network 31, 30, and lead 3'' connects the low potential side of the latter to the +B terminal. The common cathode resistor 2 connects the common cathode lead 1' to ground. The lead 6' connects plate 6 to the high potential side of tuned circuit 32, 33, and the low potential side of the latter is connected to the +B terminal. Condenser 7' provides the signal frequency path back to the grounded end of resistor 2. Here, again, complementary amplitude-frequency characteristics would be presented to the opposed rectifiers 16 and 17. The voltage developed across circuit 30—31 is taken off by condenser 8, and fed to rectifier 16. Since this circuit is detuned from the carrier frequency, its amplitude-frequency characteristic is as shown by curve B in Fig. 5*a*. The voltage across tuned circuit 32—33 is fed to rectifier 17 by condenser 9. This output circuit provides a complementary amplitude-frequency characteristic as shown by curve A of Fig. 5*a*. Hence, the well known opposite sloping filter characteristics appear at respective condensers 8 and 9.

In Fig. 5 I have shown how to utilize a single electronic section in place of the two electronic sections of Figs. 1, 2 and 4. Here, the tube 40 is of the screen grid type, and has its cathode 41 connected to ground through a parallel resonant

circuit comprising the coil 42 shunted by condenser 43. The parallel resonant circuit is tuned to the frequency F_2 which is above the center frequency F_c. The signal input voltage is schematically represented as being applied to the input grid 50. The plate 52 is connected to the +B terminal of the direct current source through lead 52' and a relatively low magnitude output resistor 60. The cathode side of the resonant circuit 43—42 is connected by lead 41' to a coupling condenser B' which feeds one of the opposed rectifiers. In the same way the coupling condenser A', whose input electrode is connected to lead 52', feeds the voltage developed across the resistor 60 to the second of the opposed rectifiers. The complementary characteristics A and B of the impedances 60 and 43—42 respectively are shown in Fig. 5*a*.

The output across circuit 42—43 is obtained by virtue of the cathode follower action which depends upon the degree of inverse feedback in the tube. The degree of inverse feedback depends upon the ratio of the impedance of circuit 42—43 to the impedance of resistor 60. Thus, when the impedance of circuit 42—43 is high, the inverse feedback is high and a large output appears across circuit 42—43. At this instant of high inverse feedback, the amplification of the tube is low so that the output appearing across resistor 60 is low. It is thus seen that when the output across circuit 42—43 is high, that across resistor 60 is low. This produces the complementary amplitude-frequency characteristics as shown in Fig. 5*a*. These complementary characteristics are produced by the impedance-inverting characteristic existing between the cathode circuit and the plate circuit of the tube.

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

What I claim is:

1. In combination with a pair of electron sections having a common unbypassed cathode impedance, each electron section being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode impedance for varying the space current flow in the second electron section, an impedance network in circuit with the output electrode of the first electron section, said impedance network consisting of a resonant system having an amplitude-frequency characteristic provided with maximum and minimum frequency peaks respectively located on opposite sides of the mean frequency of said signal energy, a separate purely resistive impedance in circuit with the output electrode of the second electron section, and means for separately utilizing voltage developed across each of said impedance elements.

2. In combination with a pair of electron sections having a common unbypassed cathode impedance, each electron section being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode impedance for varying the space current flow in the second elec-

tron section, an impedance network in circuit with the output electrode of the first electron section, a separate impedance in circuit with the output electrode of the second electron section, means for separately utilizing voltage developed across each of said impedance elements, said first impedance element comprising a resonant network which has a maximum impedance at a frequency located on one side of the mean frequency of applied signal energy, and a minimum impedance at a frequency located on the opposite side of the mean frequency.

3. In combination with a pair of electron sections having a common unbypassed cathode impedance, each electron section being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode impedance for varying the space current flow in the second electron section, an impedance network in circuit with the output electrode of the first electron section, a separate impedance in circuit with the output electrode of the second electron section, means for separately utilizing voltage developed across each of said impedance elements, both of said impedance elements being resonant circuits, and one of said resonant circuits being tuned to the mean frequency of applied signal energy.

4. A demodulator network for frequency modulated carrier wave energy comprising a pair of parallel electronic devices each having respective input and output electrodes, said devices having a common cathode load, means impressing frequency modulated carrier wave energy upon the input electrodes of one of the devices, said devices being provided with output electrodes each having a respective output impedance, at least one of the output impedances being a resonant circuit, and the amplitude-frequency characteristics of the output impedances being complementary and having a cross-over frequency at the mean frequency of applied frequency modulated energy.

5. In a frequency discriminator network having a pair of input terminals to which are applied frequency-variable waves, an electron discharge system provided with input electrodes and two pair of output terminals, said input terminals being connected to said input electrodes, said network having a pair of independent output impedances of respectively complementary amplitude-frequency characteristics, means connecting each of said impedances in circuit with a respective pair of said output terminals so as to be traversed by oppositely phased space currents of the system, a separate rectifier connected to each of said output impedances, and means for connecting said rectifiers in polarity opposition to provide a differential rectified voltage output.

6. In combination with a pair of electron sections having a common unbypassed cathode resistor, said electron sections each being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode resistor for varying the space current flow in the second electron section, a tuned impedance network in circuit with the output electrode of the first electron section, a separate resistive impedance in circuit with the output electrode of the second electron section, and means for separately utilizing signal voltage developed across each of said impedance elements.

7. In combination with a pair of electron sections having a common unbypassed cathode impedance, said electron sections each being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode impedance for varying the space current flow in the second electron section, an impedance network in circuit with the output electrode of the first electron section, a separate impedance which is essentially resistive in circuit with the output electrode of the second electron section, and means for separately utilizing voltage developed across each of said impedance elements, said first impedance element comprising a resonant network which has a maximum impedance at a frequency located on one side of the mean frequency of applied signal energy, and a minimum impedance at a frequency located on the opposite side of the mean frequency.

8. In combination with a pair of electron sections having a common unbypassed cathode impedance, said electron sections each being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode impedance for varying the space current flow in the second electron section, a resonant impedance network in circuit with the output electrode of the first electron section, a resistor in circuit with the output electrode of the second electron section, and means for separately utilizing signal voltage developed across each of said impedance network and said resistor.

9. In combination with a pair of electron sections having a common unbypassed cathode resistor, said electron sections each being provided with respective input and output electrodes, means for applying frequency-variable signal energy to the input electrodes of the first section, means responsive to signal voltage variations developed across the cathode resistor for varying the space current flow in the second electron section, a tuned impedance network in circuit with the output electrode of the first electron section, a resistor in circuit with the output electrode of the second electron section, means for separately utilizing signal voltage developed across each of said impedance and resistor, said tuned impedance comprising a resonant network which has a maximum impedance at a frequency located on one side of the mean frequency of applied signal energy and a minimum impedance at a frequency located on the opposite side of the mean frequency.

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