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CARRIER-SIGNAL FREQUENCY DETECTOR

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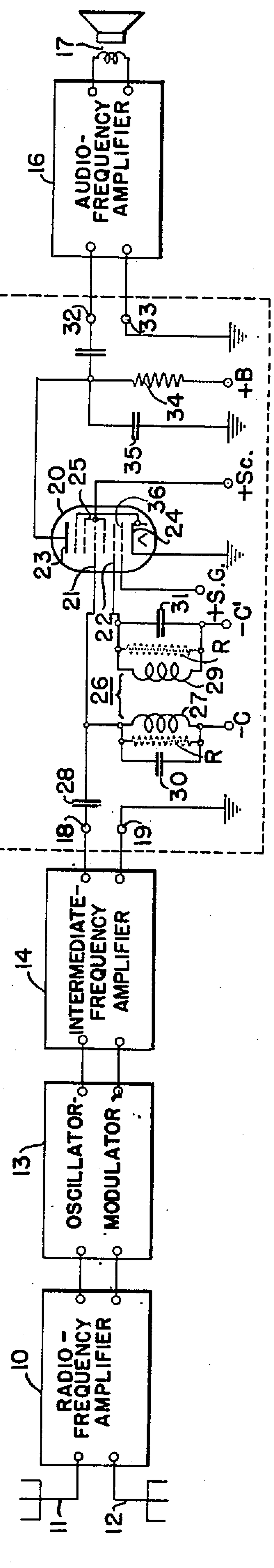

FIG. 1

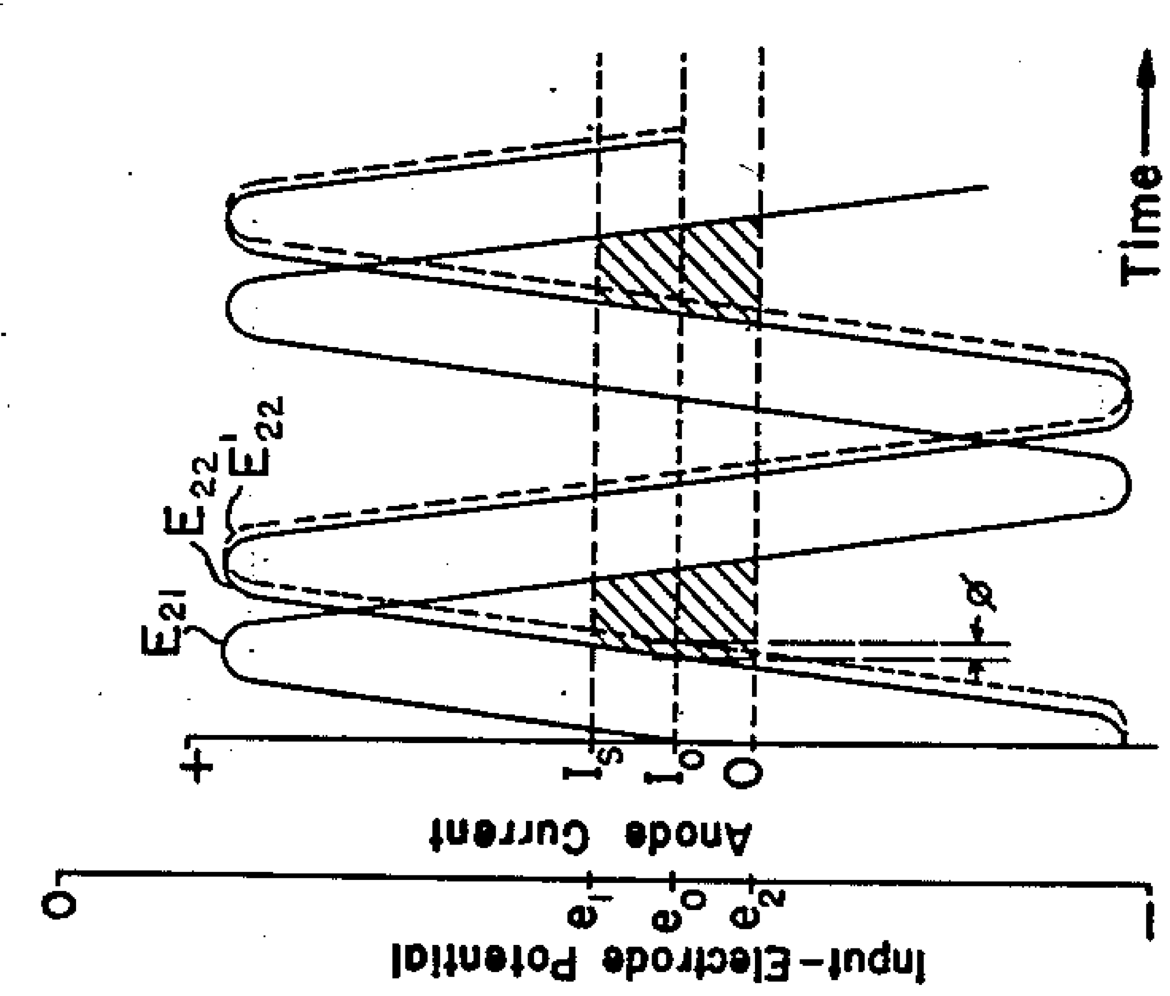

FIG. 2

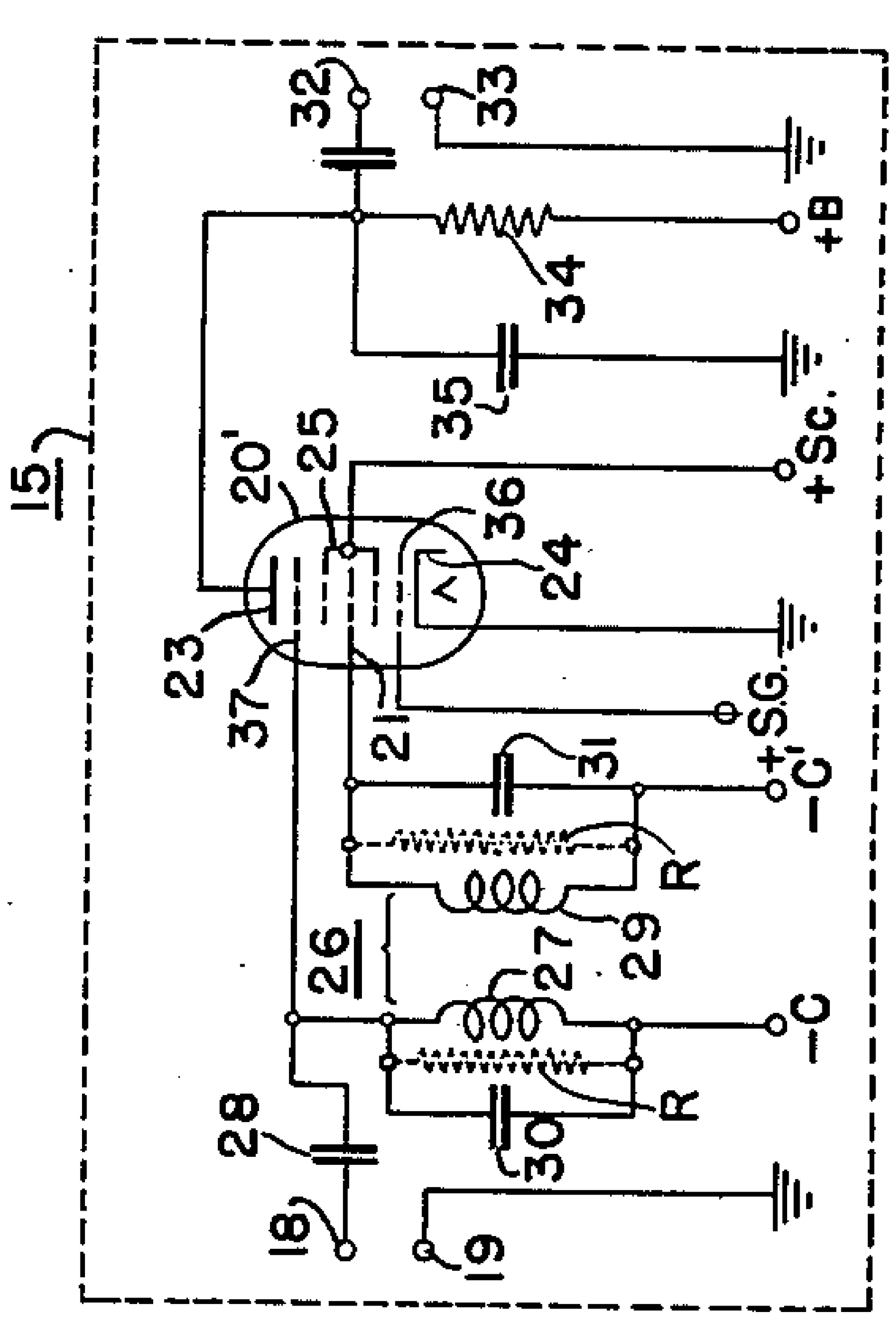

FIG. 3

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CARRIER-SIGNAL FREQUENCY DETECTOR

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10 Claims. (Cl. 250—27)

The present invention relates to carrier-signal frequency detectors and, particularly, to frequency detectors which convert frequency variations of a carrier signal to amplitude variations of the same carrier signal or the signal derived therefrom. While not limited thereto, the invention is particularly suited for use in a frequency-modulation carrier-signal receiver to derive the modulation components of a received carrier signal and will be described in that connection.

In frequency-modulation carrier-signal receivers, it is customary to change a received frequency-modulated carrier signal at some point in the receiver to an amplitude-modulated carrier signal to provide a form of carrier signal suitable for detection by a conventional amplitude-modulation detector to derive the modulation components thereof. Such change of form of the carrier signal and the subsequent detection thereof are effected in the receiver by a frequency detector which includes a frequency-selective network or frequency discriminator and means for rectifying the carrier signal of changed form to derive the modulation components thereof. Such frequency detectors in general are responsive to undesired spurious amplitude variations of the received carrier signal, such amplitude variation being due for example to atmospheric conditions or electrical disturbances, and, therefore, the frequency detector is sometimes preceded by a limiting system by which the undesired amplitude variations of the received carrier signal may be removed. The use of a separate frequency detector and limiting system has numerous disadvantages, for example the increased cost and complexity of the receiver, the fact that additional vacuum tubes are required with attendant increased maintenance costs, and the increased power required to operate the receiver. Both the prior art limiting systems and frequency detectors have additional limitations individual to each relating primarily to their design and adjustment to effect the operation desired of each.

In order to avoid the disadvantages attendant upon the use of separate limiting systems and frequency detectors, it has been proposed in accordance with one prior art arrangement that a frequency detector having somewhat reduced response to undesired amplitude variations of a received carrier signal be provided by the use of a single multi-electrode vacuum tube. In this arrangement, the vacuum tube includes two input electrodes and there are derived from the received frequency-modulated carrier signal, and individually applied to the control electrodes, two carrier signals having a relative phase which varies with the frequency deviation of the frequency-modulated carrier wave from a predetermined frequency. The circuit of each of the control electrodes includes a self-bias network. In this arrangement, an effective limiting action results from operation of the tube between grid-current rectification and anode-current cutoff. This arrangement has the disadvantage that the extent of the effective limiting action is dependent upon the values of time-constants of the self-bias networks included in the control-electrode circuits, with the result that undesired amplitude variations of brief duration and transient character are not efficiently limited. There is the additional disadvantage with this arrangement that the operating characteristic of the frequency detector is dependent upon the intensity of the received carrier signal, since it is the intensity which determines the points on the operating characteristics of the vacuum tube at which the control electrodes are biased. Due to the self-bias feature of this prior art arrangement, the action of the arrangement is so complex that it is difficult to obtain both linear-frequency detection and effective limiting, especially over a wide range of intensities of the received carrier signal.

It is an object of the present invention, therefore, to provide a new and improved carrier-signal frequency detector which avoids one or more of the disadvantages and limitations of the prior art devices.

It is an additional object of the invention to provide a carrier-signal frequency detector which possesses a greatly improved effective limiting characteristic and a detector characteristic having a high degree of linearity.

It is a further object of the invention to provide a carrier-signal frequency detector of simple and improved circuit arrangement and one having an effective limiting characteristic which is fixed by the circuit parameters and is entirely independent of the intensity of a carrier signal applied to the detector.

In accordance with the invention, a carrier-signal frequency detector comprises an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation. The detector also includes a vacuum tube including two input electrodes and an anode, and means coupled to the input circuit for deriving from the applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of the applied carrier signal from a predetermined frequency and for individually applying the derived carrier signals to the input electrodes. There is also included in the detector means for effecting anode-current saturation of the tube to render the detector substantially unresponsive to amplitude variations of the applied carrier signal, and an output circuit coupled to the aforesaid anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of the applied carrier signal from the aforesaid predetermined frequency.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims.

Referring now to the drawing, Fig. 1 is a circuit diagram, partly schematic, of a complete frequency-modulation carrier-signal receiver embodying the present invention; Fig. 2 is a graph used as an aid in explaining the operation of the Fig. 1 arrangement; and Fig. 3 is a circuit diagram of a portion of the carrier-signal receiver of Fig. 1 and represents a modified form of the invention.

Referring now more particularly to Fig. 1, there is represented schematically a complete frequency-modulation carrier-signal receiver of a conventional design embodying the present invention in a preferred form. In general, the receiver includes a radio-frequency amplifier 10 having an input circuit connected to an antenna system 11, 12 and having an output circuit connected to an oscillator-modulator 13. Connected in cascade with the oscillator-modulator 13, in the order named, are an intermediate-frequency amplifier 14 of one or more stages, a frequency detector 15, more fully described hereinafter, an audio-frequency amplifier 16 of one or more stages, and a sound reproducer 17.

It will be understood that the various units just described may, with the exception of the frequency detector 15, be of a conventional construction and operation, the details of which are well-known in the art, rendering detailed description thereof unnecessary. Considering briefly the operation of the receiver as a whole, and neglecting for the moment the operation of the frequency detector 15 presently to be described, a desired frequency-modulated carrier signal is selected and amplified by the radio-frequency amplifier 10, converted to an intermediate-frequency carrier signal by the oscillator-modulator 13, amplified in the intermediate-frequency amplifier 14, and effectively limited in amplitude and detected by the frequency detector 15, thereby to derive the audio-frequency modulation components. The audio-frequency components are, in turn, amplified in the audio-frequency amplifier 16 and are reproduced by the sound reproducer 17 in a conventional manner.

Referring now more particularly to the portion of the system embodying the present invention, the detector 15 includes an input circuit comprising input-circuit terminals 18, 19 adapted to have applied thereto from unit 14 a frequency-modulated intermediate-frequency carrier signal, the frequency of which deviates from a predetermined mean or nominal frequency over a predetermined range of frequency deviation in accordance with a modulation signal. The detector also includes a vacuum tube 20 having two input electrodes or control grids 21, 22, an anode 23, a cathode 24, and a screen electrode or grid 25. There is included in the tube 20 means for effecting anode-current saturation thereof to render the detector 15 substantially unresponsive to amplitude variations of the carrier signal applied to the detector. This means comprises an additional or space-charge electrode or grid 36 adjacent the cathode which is positively energized from a biasing source indicated as +S.G.

The detector additionally includes means coupled to the input circuit comprising terminals 18, 19 for deriving from the applied carrier signal two carrier signals having a relative phase which varies with the frequency deviations of the applied carrier signal from a predetermined frequency and for individually applying the derived carrier signals to the input electrodes 21, 22. This means comprises an input transformer 26 having a primary winding 27 coupled to the input terminals 18, 19 through a condenser 28 and having a secondary winding 29, the primary and secondary windings of transformer 26 being tuned by a pair of condensers 30, 31, respectively, to the nominal frequency of the applied carrier signal. The transformer 26 is thus double-tuned to the mean frequency of the applied carrier signal and the signal potentials developed across transformer windings 27 and 29 have a quadrature phase relationship at this frequency. The relative phase relationship of these signal potentials, however, varies with the frequency of the applied carrier signal over its range of frequency deviation. In order that the detector 15 shall have an output which varies linearly with the frequency deviations of the carrier signal applied thereto, it is necessary that the relative phase of the carrier-signal potentials developed across the transformer windings 27 and 29 shall vary linearly with the frequency deviations of the applied carrier signal over a predetermined range of frequency deviation, the precise value of which will presently be considered in greater detail. This linear phase-frequency characteristic is obtained by reducing the Q, that is, the ratio of inductive or capacitive reactance to resistance, of the tuned circuits 27, 30 and 29, 31 to a sufficiently low value either by proportioning the constants of the circuit elements themselves, or by the provision of damping resistors R, R connected in shunt to one or both of the tuned circuits and shown in dotted lines for the reason that they may be comprised in whole or in part by the resistance of the circuit elements 27, 29, 30 and 31, or by a combination of these methods.

The input electrode 21 of vacuum tube 20 is coupled to the primary winding 27 to have applied thereto the carrier-signal potential developed across this winding. Similarly, the input electrode 22 is coupled to the secondary winding 29 to have applied thereto the carrier-signal potential developed thereacross. Means are provided for individually biasing each of the input electrodes to a fixed operating potential, preferably on the linear portion of the operating characteristic of each, comprising the sources of biasing potentials indicated as —C, —C' which are connected to the input electrodes 21 and 22 through the respective transformer windings 27 and 29. The screen electrode 25 has a positive potential applied thereto from a source indicated as +Sc.

There is provided in the detector 15 an output circuit coupled to the anode 23 of vacuum tube 20 for deriving therefrom a signal, the amplitude of which varies substantially only with the deviations of frequency of the applied carrier signal from its nominal frequency. This output circuit comprises output-circuit terminals 32, 33 and includes a load impedance comprising a resistor 34 in the anode circuit of the vacuum tube 20. The anode 23 of vacuum tube 20 is energized from a source of space current, indicated as +B, through the resistor 34. The resistor 34 is bypassed to ground for currents of carrier-signal frequency by a condenser 35 effectively connected thereacross.

Considering now the operation of the circuit just described, and referring to the curves of Fig. 2, a carrier signal is applied from the output circuit of the unit 14 to the input-circuit terminals 18, 19 of the detector 15 to develop in the windings of the transformer 26 two carrier signals having a relative phase which varies substantially linearly with the frequency of the applied carrier signal from its nominal frequency. The transformer 26 thus comprises a frequency discriminator and provides for the input electrodes 21, 22 of vacuum tube 20 two carrier signals which it derives from the applied carrier signal.

The space-charge grid 36 has a constant bias applied thereto from the source +S.G. and is effective to produce a substantially constant-intensity electrostatic field adjacent to cathode 24, thereby to cause the anode current of vacuum tube 20 to saturate at a relatively low value of input-electrode voltage, as represented by the broken line I_s, Fig. 2, whenever both of the input electrodes 21 and 22 have an instantaneous potential greater than a value e_1. The level of zero anode current is represented in Fig. 2 by the broken line O corresponding to an input-electrode potential of e_2. The bias of the input electrodes 21 and 22 is preferably adjusted in the following manner. The electrode 21 is biased to a large positive potential at which it normally would produce anode-current saturation of tube 20 and the bias −C′ of electrode 22 is then adjusted to a value midway between the values at which electrode 22 biases tube 20 to anode-current cutoff and anode-current saturation. To adjust the bias of electrode 21, electrode 22 is biased so far positively that this electrode normally would cause anode-current saturation of tube 20 and the bias −C is then adjusted to a value approximately midway between the values at which electrode 21 biases vacuum tube 20 to anode-current cutoff and anode-current saturation. The carrier signal applied to one of the input electrodes, for example the electrode 21, is represented by curve E_{21}, and that applied to the other input electrode, for example the input electrode 22, is represented by curve E_{22}, it being assumed that the applied carrier signal under these conditions has its nominal value of frequency and, consequently, that the carrier signals applied to the input electrodes 21 and 22 have a quadrature phase difference.

Each of the input electrodes 21 and 22 is effective to bias the vacuum tube 20 to anode-current cutoff when its instantaneous potential is less than the value e_2. From this it will be evident that anode current flows only during the intervals when both of the input electrodes 21 and 22 have instantaneous potentials greater than the value e_2, which condition occurs only during a relatively short interval of each cycle of the applied carrier signal, as represented in Fig. 2 by the shaded area. The maximum value of the anode current is limited to its saturation value I_s and thus is substantially independent of the maximum amplitudes of the positive half-cycles of the carrier signals applied to the input electrodes 21 and 22. The minimum value of the anode current is, of course, limited by its zero value represented by the value O of Fig. 2, and thus is independent of the maximum amplitudes of the negative half-cycles of the applied carrier signals. Consequently, it will be seen that the carrier-signal voltage developed across the resistor 34 in the output circuit of the detector 15 does not vary substantially in amplitude with variations of amplitude of the applied carrier signal.

Assume now that the frequency of the applied carrier signal deviates from its mean frequency. The phase difference between the carrier signals applied to the input electrodes 21 and 22 now changes by a phase angle ϕ from the quadrature phase relationship normally existing between these carrier signals and, assuming this phase change adds to the initial quadrature phase difference as illustrated in Fig. 2, the carrier signal applied to the input electrode 22 under this condition is represented by the broken-line curve E'_{22}. It will be evident that the anode current of vacuum tube 20 now flows during a smaller interval of each cycle of the applied carrier signal. The following mathematical analysis of the detector operation indicates that the average value of the anode current, over one cycle of the applied carrier signal, varies linearly with the phase change of the carrier signals applied to the input electrodes 21 and 22 from their normal quadrature phase relationship.

As a starting point for this analysis, it may be noted that the total shaded area of Fig. 2 represents the integrated value of anode current flowing during each cycle of the applied carrier signal. It can be shown that this area, and thus the integrated anode current, has very nearly the value

$$I_p=\int_0^t i_p dt=\frac{\pi I_s}{2} \tag{1}$$

where:

I_p=the integrated value of anode current of tube 20,

i_p=the instantaneous value of anode current of tube 20,

t=the period of the carrier signal applied to detector 15, and

I_s=the value of anode current saturation of tube 20.

The average anode current during each cycle of the applied carrier signal is thus:

$$I_p(\text{av.})=\frac{\pi I_s}{4\pi}=\frac{I_s}{4} \tag{2}$$

If ϕ has any value other than zero, the integrated value of anode current is defined by the relation:

$$I'_p=\int_0^t i_p dt=I_s\left(\frac{\pi}{2}-\phi\right) \tag{3}$$

Thus, the average anode current over one cycle of the applied carrier signal now has the value:

$$I'_p(\text{av.})=\frac{I_s\left(\frac{\pi}{2}-\phi\right)}{2\pi}=\frac{I_s}{4}-\frac{I_s\phi}{2\pi} \tag{4}$$

It will be seen from a comparison of Equations 2 and 4 that the average anode current varies linearly with the phase change ϕ. The constants of the transformer windings 27 and 29, their coefficient of coupling, the constants of the condensers 30 and 31 and the Q, or ratio of inductive or capacitive reactance to resistance, of the tuned circuits 27, 30 and 29, 31, are proportioned such that the phase change ϕ varies linearly over a predetermined range, for example 20 degrees, with the frequency deviation of the carrier signal applied to the detector 15. The output of the detector 15 thus varies linearly with the frequency deviation of the carrier signal applied thereto and substantially independently of amplitude variations of the applied carrier signal, whereby the detector 15 is responsive only to the frequency deviations of the applied carrier signal and is substantially unresponsive to amplitude variations thereof.

From the foregoing description of the Fig. 1 arrangement, it will be apparent that the space-charge electrode 36 and source of energizing bias +S.G. therefor and the biasing sources —C, —C′ for the control electrodes 21, 22 comprise means for effecting anode-current saturation at a relatively low level of applied carrier-signal intensity and anode-current cutoff of the vacuum tube 20 to render the detector 15 substantially unresponsive to amplitude variations of the carrier signal applied thereto for carrier-signal intensities, greater than such low intensity level.

Fig. 3 is a circuit diagram representing a modified form of the invention which is essentially similar to the arrangement of Fig. 1, similar circuit elements being designated by similar reference numerals and analogous circuit elements by similar reference numerals primed. In the Fig. 3 arrangement, the two carrier signals derived by the transformer 26 are individually applied to the input electrode 21 and to a suppressor electrode 37 included in the vacuum tube 20′. This arrangement thus provides an alternative method of applying the two carrier signals to input electrodes of the vacuum tube 20. The arrangement and operation of the Fig. 3 modification are otherwise essentially similar to that of Fig. 1 except for the feature that the portion of the screen electrode 25 which is positioned between the input electrode 21 and the space-charge electrode 36 is effective with the latter to control the level of anode-current saturation I_s of the vacuum tube 20′. Consequently, the value of the potentials applied to the space-charge electrode 36 from the source +S.G. and that applied to the screen electrode 25 from the source +Sc are relatively proportioned to provide the desired value of anode-current saturation I_s. The operation is otherwise essentially similar to that of the Fig. 1 arrangement and will not be repeated.

While in both the arrangements of Figs. 1 and 3, the means for deriving the two carrier signals from that applied to the detector 15 comprises the transformer 26, it will be evident that any of the known forms of frequency discriminators other than the double-tuned transformer 26 may be used by which to derive from the carrier signal applied to the detector 15 two carrier signals having a relative phase which varies substantially linearly with the frequency of the applied carrier signal over the range of frequency deviation of the latter.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

2. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermind frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation and anode-current cutoff of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

3. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means included in said tube for effecting anode-current saturation thereof to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

4. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes, an additional electrode and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means including said additional electrode for effecting anode-current saturation of said tube to render said detector

substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

5. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes, a space-charge electrode and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means including said space-charge electrode for effecting anode-current saturation of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

6. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including an anode, a cathode, two input electrodes, and a space-charge grid adjacent said cathode and between said cathode and said input electrodes, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means including said space-charge grid and means for positively energizing said space-charge grid for effecting anode-current saturation of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

7. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation of said tube at a relatively low level of applied carrier-signal intensity to render said detector substantially unresponsive to amplitude variations of said applied carrier signal in excess of said low-level intensity, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

8. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, means for fixedly biasing said input electrodes to points on substantially linear portions of the operating characteristics of said vacuum tube, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

9. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal the frequency of which deviates over a predetermined range of frequency deviation, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation and anode-current cutoff of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, means for fixedly biasing said input electrodes to points on the operating characteristics of said vacuum tubes substantially midway between anode-current saturation and anode-current cutoff of said vacuum tube, and an output circuit coupled to said anode for deriving therefrom a signal the amplitude of which varies substantially only with deviations of the frequency of said applied carrier signal from said predetermined frequency.

10. A carrier-signal frequency detector comprising, an input circuit adapted to have applied thereto a carrier signal frequency-modulated over a predetermined range of frequency deviation in accordance with a modulation signal, a vacuum tube including two input electrodes and an anode, means coupled to said input circuit for deriving from said applied carrier signal two carrier signals having a relative phase which varies with the frequency deviation of said applied carrier signal from a predetermined frequency and for individually applying said derived carrier signals to said input electrodes, means for effecting anode-current saturation of said tube to render said detector substantially unresponsive to amplitude variations of said applied carrier signal, and an output circuit coupled to said anode and including means for deriving from the average space current thereof said modulation signal.

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