

July 3, 1945.

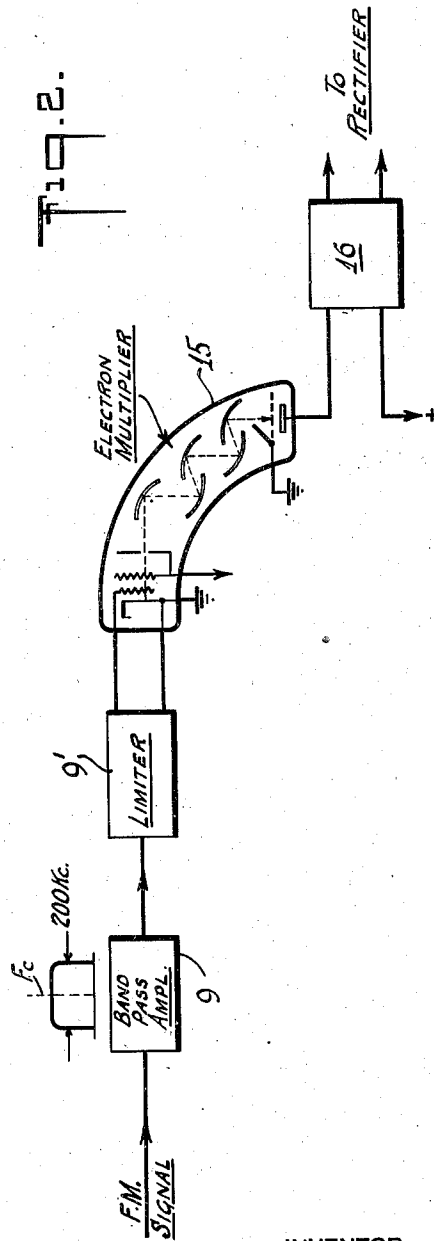
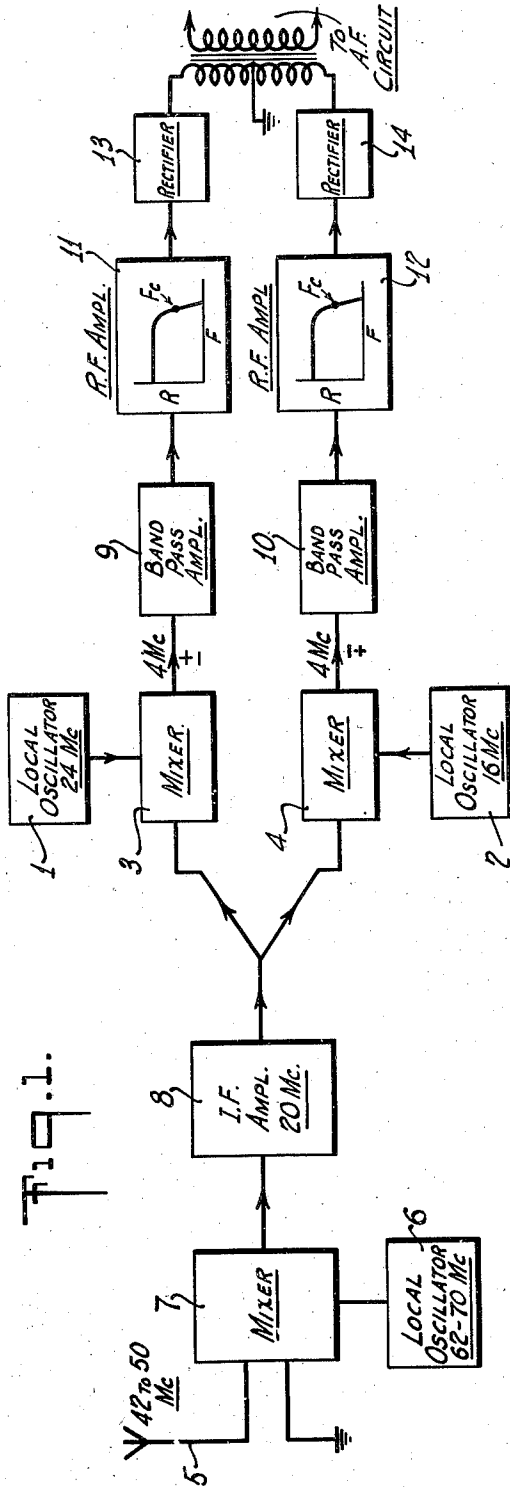
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FREQUENCY MODULATION DETECTOR CIRCUIT

Filed Sept. 22, 1942

2 Sheets-Sheet 1



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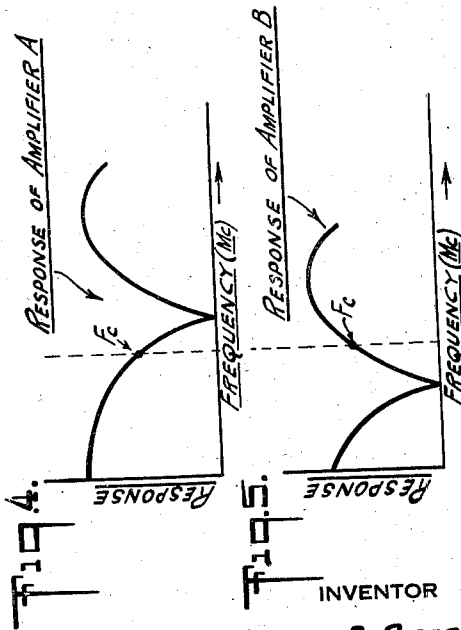
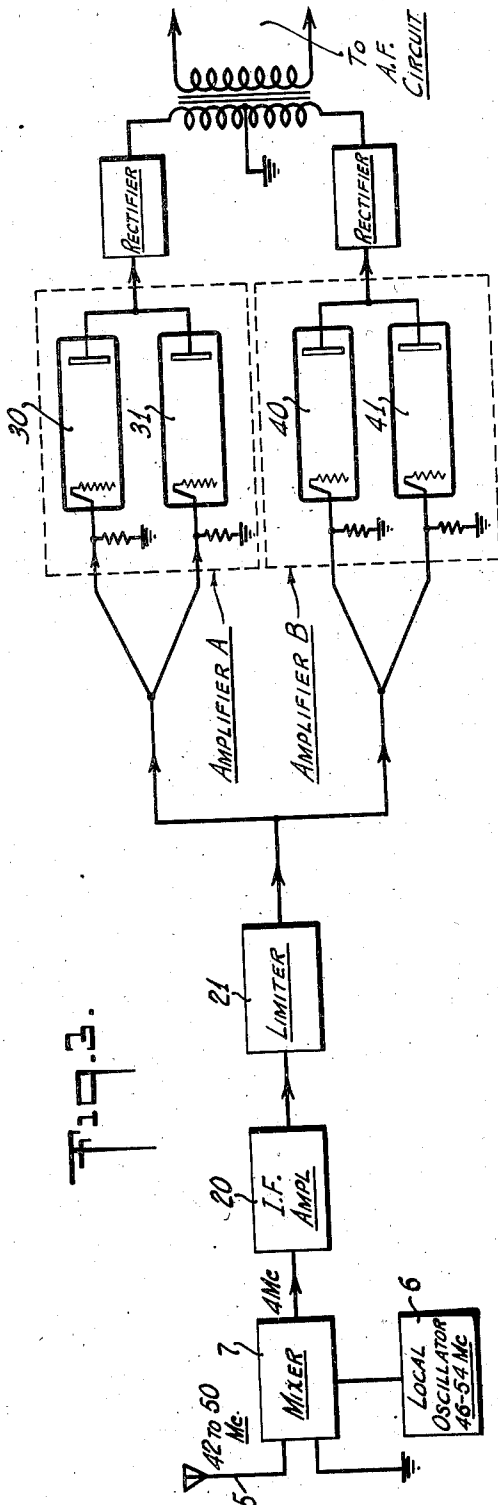
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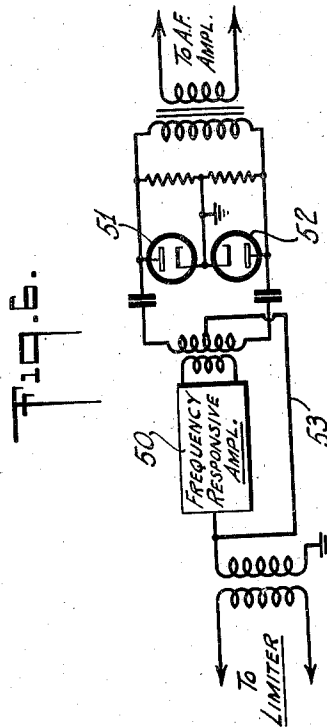
FREQUENCY MODULATION DETECTOR CIRCUIT

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2 Sheets-Sheet 2



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FREQUENCY MODULATION DETECTOR
CIRCUITSWalter van B. Roberts, Princeton, N. J., assignor
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of Delaware

Application September 22, 1942, Serial No. 459,228

7 Claims. (Cl. 250—27)

My present invention relates generally to detectors of angular velocity-modulated carrier wave energy, and more particularly to frequency modulation detectors.

One of the main objects of my present invention is to provide detectors of angular velocity-modulated carrier wave energy, and which detectors are characterized by the absence of any frequency discriminator reactance networks, but which detectors have an output balance against amplitude modulation.

Another important object of the invention is to provide in a receiver of frequency modulated wave energy (FM) an electron discharge device having appreciable transit time, and which is characterized by an output current that depends upon input voltage frequency, there being derived modulation voltage from the output of said electronic device, and the effect of amplitude modulation of said wave energy being balanced out in the absence of frequency modulation of the input waves.

Yet another object of my invention is to provide a receiving system wherein a pair of intermediate frequencies of the same value is produced, but which vary in value in opposite senses, the intermediate frequencies being subjected to amplifiers of like frequency response characteristics, and said characteristics being such that the amplifier outputs are dependent upon the frequency of input whereby the outputs of the amplifiers become unequal as the received signal departs from its mean, or center, frequency value.

Another object of the invention is to provide an FM receiving system wherein a single intermediate frequency is employed, but a pair of amplifier networks of different frequency response characteristics is employed whereby detection of the FM wave energy is secured.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claims; the invention itself, however, as to both its organization and method of operation will best be understood by reference to the following description taken in connection with the drawing in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawings:

Fig. 1 schematically shows a receiving system embodying one form of the invention.

Fig. 2 illustrates schematically the electron discharge device that may be employed in the detector circuit of Fig. 1.

Fig. 3 schematically shows another embodiment of the invention.

Figs. 4 and 5 show the respective characteristics of amplifiers A and B of Fig. 3.

Fig. 6 shows a further modification.

Referring now to the accompanying drawings, wherein like reference characters in the various figures designate similar circuit elements, Fig. 1 schematically represents one form of my present invention. In this system there are provided a pair of independent local oscillators 1 and 2. For example, oscillator 1 operates at 24 megacycles (mc.), while oscillator 2 operates at 16 mc. Each oscillator feeds an associated mixer stage. Thus, mixer 3 is fed by oscillator 1, while mixer 4 is fed by oscillations from oscillator 2. The input signal energy to each of mixers 3 and 4 may be either the original FM signal energy, or, if desired, there may be provided signal energy produced by prior heterodyne action.

In this case the signal collector 5, such as a grounded antenna, has applied to it FM signal energy located in the 42–50 mc. band; the latter is the assigned FM broadcasting band. A local oscillator 6, which is variable through a range of 62–70 mc., feeds its oscillations to a mixer 7. Of course, the input circuit of the mixer 7 will be tunable with the tuning circuit of oscillator 6 so that desired FM signals can be received. The intermediate frequency (I. F.) amplifier 8 amplifies the resulting 20 mc. energy which is fed to the input circuits of each of mixers 3 and 4.

It will be noted that the oscillator 1 operates above the mean, or center, frequency of the I. F. energy fed to mixer 3, while the oscillator 2 operates below the mean frequency of the energy fed to mixer 4. Hence, in the absence of modulation on the received carrier, current components of equal frequency are produced by the mixers 3 and 4. Those skilled in the art are fully aware of the fact that in FM transmission, the carrier frequency at the transmitter is varied in frequency with respect to its mean, normal, or center value in response to the modulation voltage, the frequency deviation being proportional to the instantaneous value of said voltage. In the assigned FM band the overall frequency deviation has a maximum value of 150 kilocycles (kc.). Of course, the frequency values given in this application are purely illustrative, and may be varied in accordance with the use to which the system is put.

The I. F. energies of mixers 3 and 4 may be respectively amplified in separate amplifiers. Thus, the I. F. band pass amplifier 9 is coupled to the output of mixer 3, while the band pass

amplifier 10 is coupled to the output of mixer 4. Each of the amplifiers 9 and 10 has its pass band designed to transmit the entire frequency deviation range of the applied signal energy. It will be noted, as shown in Fig. 1, that one of the normally equal intermediate frequencies increases with increase of signal wave frequency, while the other decreases. In other words, if the instantaneous frequency of the applied FM signal energy has a value such that it exceeds the mean value of 20 mc., then the I. F. energy output of mixer 3 is less than 4 mc., while the I. F. energy output of mixer 4 is greater than 4 mc. Hence, it will be seen that the I. F. energy outputs of each of mixers 3 and 4 vary in opposite magnitude senses, as the instantaneous frequency of the applied FM signal energy varies with respect to the mean, or center, frequency.

The I. F. energies, amplified at 9 and 10, may be subjected to amplitude limiting thereby to remove amplitude modulation effects. Subsequently the amplified energies are applied to networks 11 and 12. These networks are shown in generalized form as rectangles. Within each rectangle there is shown the characteristic thereof. Each characteristic is that of response (R) versus frequency (F). The center frequency F_c is located at substantially the central portion of the downwardly sloping portion of each characteristic. In general, then, the devices 11 and 12 are so constructed that the outputs thereof are equal in the absence of modulation on the received carrier, becoming unequal as the instantaneous frequency of the signal energy deviates from the value F_c .

Accordingly, if the outputs of the devices 11 and 12 be direct current, a differential connection of the output currents to a load, such as a loud speaker or audio amplifier, will provide the load with modulation voltage. On the other hand, if the outputs of the devices 11 and 12 are in the form of radio frequency currents, these outputs may be separately rectified. Such rectifiers are schematically designated by numerals 13 and 14. The rectifiers may be of any desired form, and it is to be understood that they are non-discriminatory networks. The outputs of these rectifiers are differentially connected to the audio frequency utilization circuit. The devices 11 and 12 may be a pair of identical electron discharge devices which act as radio frequency amplifiers. These amplifiers are preferably characterized by a rapidly falling off of amplification with increasing frequency over a certain range of frequencies.

In Fig. 2 I have schematically represented such an amplifier device. It is not believed necessary to show the device in more than schematic fashion, since it is substantially that designated by L. Malter in an article entitled "The behavior of electrostatic electron multipliers as a function of frequency." This article was published in the Proceedings of the Institute of Radio Engineers for November, 1941. Reference is made to pages 592, 593 and 594 thereof in particular. The device 15 shown in Fig. 2 is a schematic representation of a multiplier device described in the aforesaid article.

In Fig. 2 I have shown the FM signal energy, supplied by mixer 3 of Fig. 1, which is fed through the amplifier 9. Above the rectangle representing the amplifier 9 there is shown the pass band characteristic thereof. It will be observed that the band is 200 kc. in width, so as efficiently to transmit the entire frequency deviation. A lim-

iter 9' is schematically represented as acting as the actual input circuit for the input electrodes of multiplier tube 15. The electron path through the multiplier 15 is represented by the dotted line. It will be clear from the schematic representation in Fig. 2 that the electrons are subjected to a series of multiplications, and that the output voltage is developed across the output circuit 16. The circuit 16 will be non-discriminatory, and may be the rectifier if desired.

The falling frequency response characteristic, secured with an electron multiplier tube of the type shown at 15 in Fig. 2, is caused in part by small unintentional variations in the initial velocity of electrons from the cathode. By deliberately increasing such variations, the frequency at which rapid falling off of amplification occurs can be made much lower. For example, if two devices of the type shown as 15 in Fig. 2 are connected in parallel as to their input and output circuits, but operated at different electrode potentials, the common output can be arranged to fall off rapidly at a conveniently lower frequency. This is because the phase shift is greater in the device operating at the lower potentials, so that as frequency is increased a frequency will ultimately be reached at which the outputs of the two devices will be in phase opposition. At this frequency, if equal amounts of the two outputs are added, the result will be zero. At a slightly higher frequency there will again be some output, but of reversed polarity.

The resultant output thus has an amplitude which first decreases to zero, and then increases again as the frequency is increased. Furthermore, the polarity of the resultant output reverses as the amplitude passes through zero, and, in addition to both of the above effects, the phase of the resultant output varies with frequency at frequencies on each side of the zero point. Reference is made to the characteristic shown in Fig. 4 for an illustration of the type of characteristic which can be secured with such an arrangement. Further description of such an arrangement will be given at a later point. The action is exactly similar to that of a pair of transmission lines of different lengths. When the frequency is high enough so that one line is half a wave-length longer than the other, the output vanishes.

The various effects here described will be referred to separately. At first, however, it will be assumed that the devices indicated at 11 and 12 of Fig. 1 are so arranged and operated that their amplification changes rapidly with changing frequencies throughout a frequency range which includes the mean frequency of the input signal voltage. It is, of course, evident that one such device is sufficient to provide FM detection, but this does not provide an output which is balanced against amplitude modulation. Such use of a single device requires no further explanation.

It is not necessary to use separate oscillators 1 and 2 since these oscillations may be obtained as different order harmonics of a single oscillator. It will be understood that each of band pass amplifiers 9 and 10 may have a band pass characteristic as shown above amplifier 9 of Fig. 2. The rectifiers 13 and 14 are substantially non-selective over the range of variation of signal frequencies. These rectifiers may be of any well known type, as for example, of the diode type. The outputs of the rectifiers are differentially connected to the primary winding of an audio output transformer. It will be seen that on

account of complete symmetry, there will be no output due to amplitude modulation when the applied signal energy is at its mean value F_c . As the signal frequency changes, the frequency of one channel increases while that of the other channel decreases. Hence, one of the amplifier devices 11 and 12 amplifies more strongly, while the other amplifies less. As a result a differential output is obtained from the rectifiers 13 and 14.

It has been shown in Fig. 1 that the devices 11 and 12 have identical characteristics. It is the signal energies supplied thereto which have frequencies varying in opposite senses, in accordance with the frequency modulation of the received signal energy. However, the devices 11 and 12 may be arranged to show an increase of amplification over a range of frequencies. Hence, if one of the devices 11 is adjusted to give a falling characteristic in the vicinity of the mean frequency F_c , while the other device 12 has a rising characteristic in the same range, the necessity for the dual channel of Fig. 1 is avoided, and the somewhat simpler arrangement of Fig. 3 can be employed.

Referring specifically to Fig. 3 the signal collector antenna 5 feeds the mixer 7, and local oscillations are fed to the mixer from oscillator 6. In this case, the operating I. F. value is 4 mc., and, hence, the oscillator 6 is operated over a range of 46 to 54 mc. An I. F. amplifier 20 amplifies the energy, and, after limiting at limiter 21, the I. F. energy is fed to the two transmission networks shown as enclosed in the dotted rectangles. One of these rectangles is designated as "amplifier A," while the other rectangle is designated as "amplifier B." The characteristic shown in Fig. 4 is the frequency response characteristic of the amplifier A, while the frequency response characteristic of Fig. 5 is that of amplifier B.

As explained previously, each of these amplifiers is composed of a pair of parallel electron discharge devices such as shown at 15 in Fig. 2. In other words, it will be understood that the numeral 30 in Fig. 3 corresponds to a device such as shown by numeral 15 in Fig. 2, and that numeral 31 is a similar device. The input electrodes and output electrodes of the devices 30 and 31 are respectively in parallel. The remaining electrodes are not shown, because they are similar to that shown in Fig. 2. It will be understood that proper energization of the electrodes at devices 30 and 31 will result in the production of the substantially V-shaped characteristic of Fig. 4. The operating frequency F_c is chosen so as to be located at substantially the center of the falling slope to the left of the zero point of the characteristic of Fig. 4.

In the same way, the devices 40 and 41 are constructed so as to provide the response characteristic of Fig. 5. Here, the value F_c is chosen so as to be located at substantially the center portion of the rising slope to the right of the zero point. However, amplifiers A and B are so relatively constructed and designed that the zero points of their response characteristics are sufficiently displaced so that the value F_c of each response characteristic is in alignment. It will now be seen that even though the I. F. energy is fed through a single channel to the two amplifiers, the amplifiers have oppositely sloping response characteristics with respect to the center frequency of the applied signal frequency energy. The outputs of the two amplifiers are then rectified as described in Fig. 1 to produce the differ-

ential audio voltage output. It is noted that where opposite characteristics of the two amplifiers are obtainable with respect to their direct current outputs, the rectifiers can be omitted and the direct current components may be differentially combined.

In Fig. 6 I have shown a further modification of the invention. In this modification, the numeral 50 designates a frequency responsive amplifier, such as previously described, whose radio frequency output varies in phase and/or polarity with frequency change. For example, a single electron multiplier like 15 of Fig. 2 gives phase variation, while a pair of them, as in either dotted rectangle of Fig. 3, produces polarity reversal as described in connection with the output curves of Figs. 4 and 5. In such a case, by combining the radio frequency output with a voltage derived from the input voltage by a translating device which provides dissimilar treatment of phase or amplitude from that provided by the device 50, a resultant voltage is obtained which is amplitude modulated, and is, therefore, susceptible to rectification.

In Fig. 6 such a system is shown wherein balanced diode rectifiers 51 and 52 are used. If a varying phase of the output of the device 50 is depended upon, then the phase of this output is chosen to be normally in quadrature with the phase of the input applied by way of non-discriminatory lead 53. The balanced detectors then operate in a manner quite similar to the discriminator circuit well known to the prior art. On the other hand, if the polarity of the output reverses in accordance with the direction of the departure from the mean frequency while the amplitude increases in proportion to said departure, then the phase of the output is chosen to be co-linear with that of the input over lead 53.

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, as set forth in the appended claims.

What I claim is:

1. In a detector for angular velocity-modulated carrier wave energy, at least one electron discharge device having appreciable electron transit time between the electron emitter and output electrode, said device being constructed and arranged to have a characteristic wherein output current depends upon input voltage frequency and falls sharply over a range of input frequencies, means to apply said modulated wave energy upon the input of said device, means for deriving modulation voltage from the output of said device, and a load circuit adapted to be supplied with said modulation voltage.

2. In a detector for angular velocity-modulated carrier wave energy, at least one electron discharge device having appreciable electron transit time between the electron emitter and the output electrode, said device being constructed and arranged to have a characteristic wherein output current depends upon input voltage frequency, said characteristic having a sharply decreasing portion over a predetermined frequency range, means to apply said modulated wave energy upon the input of said device, means for deriving modulation voltage from the output of said device, a load circuit adapted to be supplied with said modulation voltage.

3. In a detector network for waves modulated in frequency, a pair of electron discharge devices having input and output electrodes, each device having appreciable transit time, and each device being constructed and arranged to have a characteristic whose output current depends upon input voltage frequency and which has a substantially downward sloping portion, means for applying frequency modulated wave energy of the same mean frequency value to the input electrodes of each of said devices, and means for deriving modulation voltage from the output electrodes of each of said devices.

4. In a detector for angular velocity-modulated carrier wave energy, at least one electron discharge device of the multiplier type having appreciable transit time, said device being constructed and arranged to have a characteristic wherein output current depends upon input voltage frequency and decreases above a predetermined frequency; means to apply said modulated wave energy upon the input of said device, means for deriving modulation voltage from the output of said device, a load circuit adapted to be supplied with said modulation voltage, and substantially the midpoint of the decreasing portion of the characteristic being at the center frequency of said wave energy.

5. In a detector network for waves modulated in frequency, a pair of electron discharge devices having respective input and output electrodes in parallel, each device being constructed and arranged to have appreciable transit time, one device having a frequency response characteristic which has a substantially downward sloping portion, the other device having a reverse frequency response characteristic, means for applying frequency modulated wave energy of the same mean

frequency value to the input electrodes of each of said devices, and means for deriving from the output electrodes of each of said devices modulation voltage.

6. In combination with a source of angular velocity-modulated carrier wave energy, at least two amplifier tubes having respective input and output terminals in parallel, means for applying said modulated wave energy to the input terminals of said tubes, each of said networks having a substantially V-shaped frequency response characteristic such that the output current of each tube is substantially zero at a predetermined intermediate point of its frequency range, and the operating frequency points of said tubes being located on respectively opposite slopes of their response characteristics.

7. In combination with a source of frequency modulated wave energy having a predetermined center frequency value, means for deriving from said source a pair of frequency modulated wave energies whose center frequency values are equal to the first mentioned value but which vary in frequency in opposite senses, at least two transmission networks provided with input and output terminals, said transmission networks having identical frequency response characteristics, said frequency response characteristics having the upper frequency portion thereof decreasing at a relatively rapid rate, and said center frequency being located at an intermediate point of said decreasing characteristic portions, and means coupled to the output terminals of said transmission networks for deriving from the output currents of the networks the modulation on said modulated wave energy.

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