March 29, 1949. E. H. B. BARTELINK 2,465,782

FREQUENCY MODULATION RECEIVER

Filed Jan. 30, 1943 2 Sheets-Sheet 1

Fig. 1.

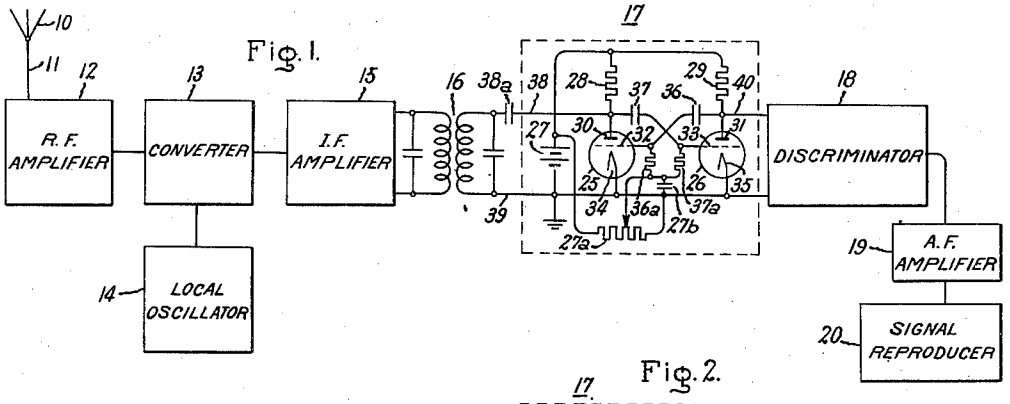


Fig. 2.

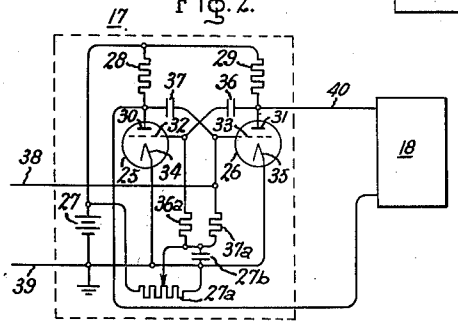


Fig. 3.

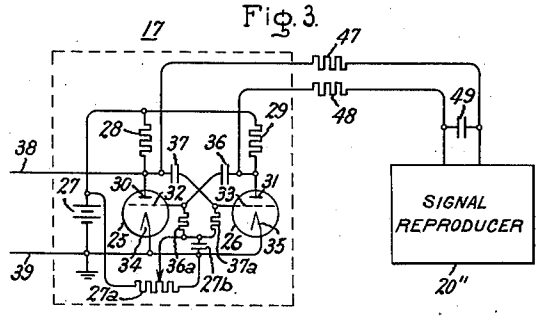
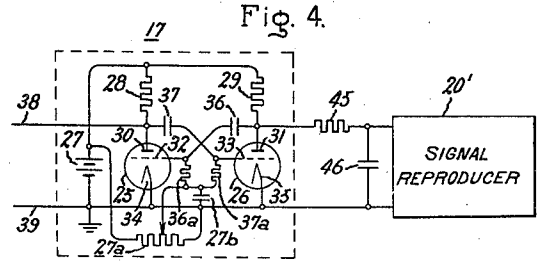


Fig. 4.



Inventor:
Everhard H. B. Bartelink,
by Harry E. Dunham
His Attorney.

March 29, 1949. E. H. B. BARTELINK 2,465,782

FREQUENCY MODULATION RECEIVER

Filed Jan. 30, 1943 2 Sheets-Sheet 2

Fig. 5.

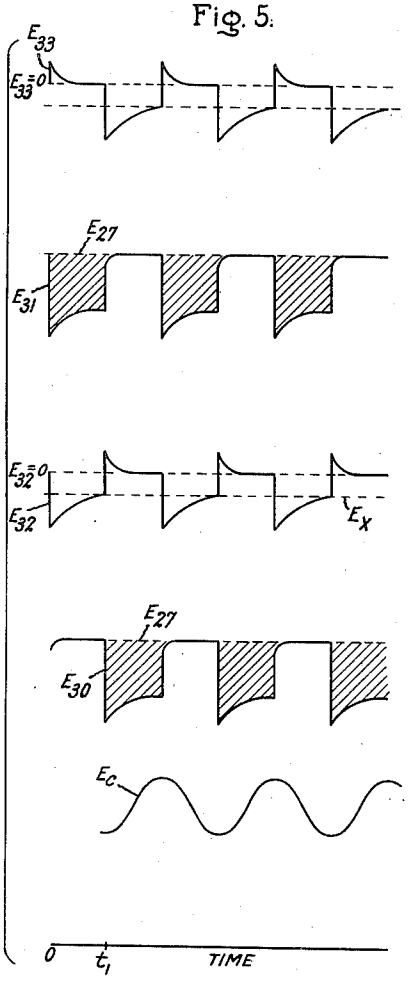
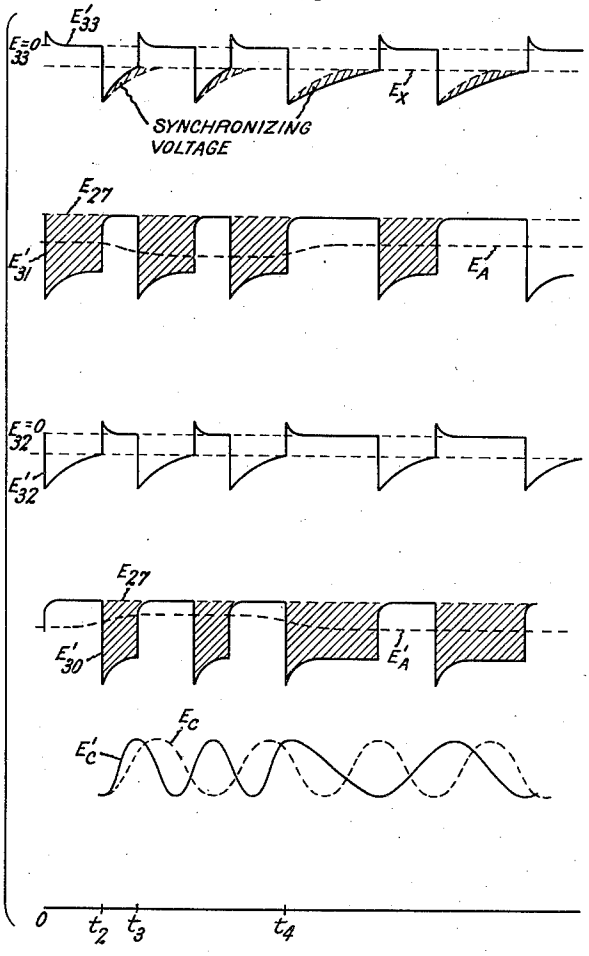


Fig. 6.



Inventor:
Everhard H. B. Bartelink,
by Harry E. Dunham
His Attorney.

Patented Mar. 29, 1949 2,465,782

UNITED STATES PATENT OFFICE

2,465,782

FREQUENCY MODULATION RECEIVER

Everhard H. B. Bartelink, West Milton, N. Y., assignor to General Electric Company, a corporation of New York

Application January 30, 1943, Serial No. 474,114

7 Claims. (Cl. 250—20)

1

My invention relates to frequency modulation receivers and particularly to frequency modulation limiters and detectors.

This application is a continuation in part of my copending application, Serial No. 342,321, filed June 25, 1940, now Patent No. 2,338,395 issued Jan. 4, 1944, and assigned to the same assignee as the instant application.

In frequency modulation or FM receivers it is customary to use a limiter to eliminate so far as possible any components of amplitude modulation appearing in the signal modulated carrier wave. A frequency modulated carrier wave of uniform amplitude is then supplied to a frequency discriminating apparatus for converting frequency variations into amplitude variations of a unidirectional potential. Heretofore it has been common to use as a limiter a diode or triode which saturates at a control voltage greater than a predetermined minimum or threshold signal voltage. Thus so long as the signal voltage is above the threshold value, the limiter output is of substantially constant amplitude.

While limiters of the above type are quite satisfactory and have certain advantages in some applications, it is well recognized that there is an unavoidable loss of signal strength in passing through the limiter due to the fact that to obtain limiting action the gain through the limiter is necessarily less than unity. The practice of discarding a portion of the signal voltage in this manner requires additional amplification in the signal channel, either in the form of additional intermediate frequency amplifiers preceding the limiter or additional audio frequency amplifiers following the discriminator.

I have discovered that the loss of gain in a limiter may be avoided and, in fact, that a substantial gain may be obtained in conjunction with the limiting action by providing a multivibrator device arranged to be triggered by carrier wave voltages above a threshold value. The triggered multivibrator releases, at intervals determined by the signal modulated carrier frequency, current pulses of a predetermined amplitude, the amplitude of the current pulses being determined solely by the multivibrator characteristics and independently of the amplitude of the signal modulated carrier wave. A device of this character may be so arranged that the current pulses in one multivibrator tube are of equal amplitude and duration and occur at intervals determined by the frequency of the carrier wave, while the current pulses in the other multivibrator tube are of constant amplitude and are spaced apart by

2

equal time periods but have a duration dependent upon the carrier frequency. The current pulses of uniform magnitude and varying frequency may either be supplied to any conventional frequency discriminating circuit to obtain an audio voltage having an instantaneous amplitude proportional to the frequency of the incoming signals, or may be combined directly into an undulating current having an average value proportional to signal frequency, the alternating component of such undulating current providing an audio signal.

Accordingly, it is a general object of my invention to provide a new and improved limiter for frequency modulated carrier waves.

Furthermore, it is a principal object of my invention to provide new and improved means for limiting the amplitude of frequency modulated carrier waves without incurring a loss of gain in the limiting process.

It is still another object of my invention to provide means for simultaneously limiting and amplifying frequency modulated carrier waves.

My invention also has for its object the provision of new and improved means for demodulating the frequency modulated carrier waves.

Still another object of the invention is to provide new and improved means for simultaneously limiting and demodulating a frequency modulated carrier wave.

My invention itself, together with further objects and advantages thereof, will be more fully understood by referring now to the following detailed specification taken in conjunction with the accompanying drawings of which Fig. 1 is a schematic circuit diagram, partially in block form, of a radio receiving apparatus of the frequency modulation type embodying my invention in one form; Figs. 2, 3 and 4 are schematic circuit diagrams showing other embodiments of my invention; and Figs. 5 and 6 are graphical representations of certain of the characteristics of an apparatus embodying my invention.

Referring now to the drawings, and particularly to Fig. 1, I have shown my invention by way of illustration as applied to a frequency modulation radio receiving apparatus of the superheterodyne type comprising an antenna 10 connected by a suitable transmission line 11 to a radio frequency amplifier 12 where incoming signals are amplified and supplied to a mixer or converter 13. In the converter 13 the frequency modulated carrier wave of radio frequency is mixed with an unmodulated wave of different frequency generated in a local oscillator 14 thereby to provide a fre-

quency modulated carrier wave of predetermined intermediate mean or center frequency which is supplied to an intermediate frequency amplifier 15. The output of the intermediate frequency amplifier 15 is supplied through a tuned coupling transformer 16 to a multivibrator 17 for limiting and, if desired, for demodulation. In the embodiment of the invention illustrated in Fig. 1 the output of the multivibrator 17 is supplied to a frequency discriminator or demodulator 18 and thence through an audio frequency amplifier 19 to a suitable signal reproducing device 20 such as a recorder, loudspeaker, headphone, or the like.

The multivibrator device 17 comprises a pair of electric discharge devices 25 and 26 each connected in parallel circuit relation between the terminals of a suitable source of unidirectional electric current supply such as a battery 27. The electric discharge devices 25, 26 are connected in series circuit relation with associated anode load resistors 28 and 29, respectively. The discharge devices 25 and 26 are provided with anodes 30 and 31, control electrodes 32 and 33 and cathodes 34 and 35, respectively. The cathodes 34 and 35 are connected together and to the grounded negative terminal of the battery 27. The control electrode or grid 32 of the tube 25 is connected through a capacitor 36 to the anode 31 of the tube 26 and through a grid resistor 36*a* to a suitable source of positive bias such as a potentiometer 27*a*. The grid 33 of the tube 26 is connected through a capacitor 37 to the anode 30 of the tube 25 and through a grid resistor 37*a* to the potentiometer 27*a*. The common terminal of the grid resistors 36*a* and 37*a* is also grounded through a suitable bypass capacitor 27*b*. The secondary winding of the coupling transformer 16 is connected through a series coupling condenser 38*a* and a lead 38 to the grid 33 of the tube 26 and through a ground lead 39 to the common cathode connection of the tubes 25 and 26. The lead 38 is connected to the grid 33 through the grid capacitor 37 so that the carrier wave potential appearing upon the lead 38 is amplified in the tube 26 and impressed through the grid capacitor 36 upon the grid 32 of the tube 25. While I prefer to supply the signal potential to the control electrode of one of the multivibrator discharge devices in the manner described, it will be understood by those skilled in the art that, if desired, the signal voltage may be supplied directly to the grid of one of the tubes as shown in the illustrated embodiment of Fig. 2. Referring back, however, to the embodiment of the invention illustrated in Fig. 1 the multivibrator connection is connected to the discriminating apparatus 18 through the cathode lead 39 and a lead 40 from the anode 31 of the controlled discharge tube 26.

Referring now to Fig. 5 and assuming for the moment that no carrier potential is impressed across the leads 38 and 39, the multivibrator 17 may be set in oscillation between its two limiting stable conditions at a fundamental frequency determined by the exponential discharge characteristics of the grid circuits of the tubes. Let it be assumed by way of example that the tubes 25 and 26 are substantially identical in their characteristics and that the grid resistors 36*a* and 37*a*, the grid capacitors 36 and 37, and the anode load resistors 28 and 29, respectively, are substantially identical. If now the potential of the battery 27 is suddenly impressed across both tubes 25 and 26, both tubes will tend to conduct simultaneously due to the fact that both grids are assumed to be at a slight positive potential. This condition, however, is unstable for, due to unavoidable inequalities in the tube circuits, the grid potentials in both tubes cannot change at exactly the same rate. For example, if the grid 33 becomes slightly more positive than the grid 32 the current in the tube 26 will increase with respect to that of the tube 25. The increasing current in the tube 26 and resistor 29 will transfer a slight negative impulse to the grid 32 through the grid capacitor 36, thereby decreasing the current in the resistor 28 and the tube 25. The decreased current in the resistor 28 will increase the potential of the anode 30 and thereby give a slight positive impulse through the grid capacitor 37 to the grid 33. This positive impulse will further increase the current in the tube 26. It will be evident that this amplification process involves a number of frequency components much higher in frequency than the fundamental frequency of the multivibrator plate current pulses, and that it will continue until the tube 25 is cut off or the tube 26 reaches saturation, or both. In practice it is found that this condition of equilibrium is attained almost instantaneously as illustrated at Fig. 5 at the instant $T=0$. In Fig. 5 the voltage of the anode 31 of the tube 26 with respect to the battery voltage E_{27} is represented by the curve E_{31}, and the potential of the grid 33 is illustrated by the curve E_{33}. In this condition of equilibrium the grid 32 of the tube 25 is highly negative, as indicated by the curve E_{32}, due to the negative impulse transferred through the grid capacitor 36 when the potential of the anode 31 decreased upon the current rise. While the potential of the grid 33 will quickly decay to zero and thus slightly reduce the current in the tube 26 thereby slightly to increase the plate voltage E_{31}, the tube 26 will continue to conduct until the negative charge on the condenser 36 has decayed sufficiently to raise the potential of the grid 32 in the non-conducting tube 25 slightly above its cutoff point E_x. The decay of negative potential on the condenser 36 is exponential in form and is determined by the R. C. characteristic of the grid circuit including the load resistor 29, the capacitor 36 and the grid resistor 36*a*. As shown upon the curve E_{32} of Fig. 5 the potential of the grid 32 will reach the cutoff value at a time t_1. At this time the tube 25 will begin to conduct and the increasing current in the tube 25 will rapidly bias the grid 33 of the tube 26 to cutoff. The voltage of the anode 30 in the tube 25 is indicated by the curve E_{30} of Fig. 5.

It will be apparent that the anode voltage curves E_{30} and E_{31} of Fig. 5 may also be taken to represent qualitatively the respective anode currents in the tubes 25 and 26, respectively, since in each case the decrease in plate voltage below the battery voltage E_{27} is simply the I. R. drop in the plate resistors 28 and 29 and is thus directly proportional to plate current. This also applies to the current curves E'_{30} and E'_{31} of Fig. 6 to be discussed hereinafter.

At Fig. 5 I have shown a curve E_c which represents the intermediate frequency carrier potential at mean or center frequency impressed upon the grid 33 of the tube 26. By way of simplification of the illustration I have shown the center frequency of the carrier wave to be the same as the fundamental or natural frequency of the multivibrator oscillations. It will be evident that so long as the carrier mean frequency is the same as the multivator natural frequency, or is of the same general order of magnitude and an even harmonic of the natural frequency, it will

not interfere with the balanced operation at natural frequency of the 50% multivibrator described, that is ,the firing periods of the two tubes will remain equal and alternate in spite of the fact that the carrier potential is superposed upon the grid potentials obtained through the grid capacitors 36 and 37. I prefer in each case to set the natural frequency of the multivibrator equal to the mean intermediate frequency of the receiver, and it is for this purpose that I provide the positive bias potentiometer 27*a*. It will be understood that by changing the amount of positive bias on the multivibrator grids the natural frequency of the multivibrator may be controlled as desired and thereby set at substantially the same value as the mean intermediate frequency of the receiver. It will, of course, be understood that, if desired, other means may be used to set the natural MV frequency.

From the above description it may now be noted that the rapid amplification of the grid voltages when switching of current from one tube to the other occurs is accomplished at a frequency much higher than and independently of the fundamental frequency of the multivibrator. It is well understood by those skilled in the art that with any predetermined grid bias the fundamental frequency of the multivibrator in its free running condition is determined solely by the R. C. characteristic of the grid discharge circuits and very much lower in frequency than the frequency components involved in the buildup of the positive and negative grid bias voltages at the instant of switching. Furthermore, while the timing of switching operations depends upon when the grid voltage in the non-firing tube rises to the cutoff point, the amplitude of the current pulses through the multivibrator tubes is substantially constant and is entirely independent of the amplitude of the grid voltage.

It is also well known that multivibrator oscillations may be synchronized with control voltages of slightly different frequencies than the natural frequency of the multivibrator by impressing such voltages upon one of the multivibrator grids. In such a case the synchronizing grid voltage acts only to trigger the multivibrator circuit by controlling the instant at which the grid voltage of the non-conducting tube initiates switching operation. Once switching operation has begun the grid has substantially no control of the amplitude of the resulting plate current pulse. Thus the multivibrator plate current pulses are of constant amplitude and are independent of the amplitude of the synchronizing voltage within certain limits. However, the amplitude of the synchronizing voltage does determine, and is in fact substantially directly proportional to the range of frequency deviation from the fundamental frequency over which multivibrator can be made to operate. Thus the maximum frequency deviation of the signal from the center frequency determines the minimum necessary synchronizing voltage by reason of the fact that the amplitude of the synchronizing voltage must be at least sufficient to maintain control of the multivibrator frequency, or to hold the multivibrator in step over the entire range of signal frequency deviation.

Referring now to Fig. 6, let it be assumed that at a time t_2 the frequency of the carrier wave appearing at the transformer 16, being modulated to a frequency in accordance with the desired signal, increases as indicated by the curve E'*c*. Now as indicated upon the curve E'$_{33}$ the superposition of the control voltage E'*c* on the grid causes the grid 33 to rise to the cutoff potential Ex more rapidly than normal and to attain this potential at a time t_3. Thus the firing period of the tube 25 is reduced as indicated by the curve E'$_{30}$ and the off period of the tube 26 is reduced as indicated by the curve E'$_{31}$. Following the time t_3 switching is controlled by decay of the grid voltage on the tube 25 as indicated by the curve E'$_{32}$ of Fig. 6. Since this grid voltage is not controlled by the carrier potential, the off period of the tube 25 is unaffected and the firing period of the tube 26 is likewise unaffected. Thus Fig. 6 shows that when the frequency of the carrier voltage impressed upon the grid 33 is increased the current pulses through the tube 26 are increased in frequency but unaffected in amplitude and duration while the current pulses through the tube 25 are unaffected in amplitude and periodicity but are of shortened duration. Similarly it will be clear from the foregoing explanation that, if at a time t_4 the frequency of the modulated carrier wave is decreased, the current pulses through the tube 26 will remain unaffected in amplitude and duration but will occur less frequently while the duration of the current pulses through the tube 25 will be increased.

From the foregoing explanation of Figs. 5 and 6 it is clear that the curves E$_{31}$ or E'$_{31}$ may be taken to represent either the current pulses through the tube 26 or the potential of the tube anode 31 referred to the cathode potential. Thus the output voltage of the multivibrator tube 26 taken between the anode and the cathode consists of a wave of definitely limited amplitude having a frequency controlled by the frequency of the signal modulated carrier wave appearing at the input transformer 16. It will be evident that this output voltage of the tube 26 may be impressed upon a discriminator 18 of any well-known type and demodulated to provide an audio signal in accordance with the frequency variations of the carrier wave but independent of any amplitude modulations of the carrier. Since the curve E'$_{31}$, as drawn, shows the voltage of the anode 31 with respect to the positive battery potential, it represents the voltage drop across the anode resistor 29. It is evident that, if desired, this resistor voltage drop may be used to supply the load in place of the voltage between the anode and the cathode of the tube 26.

From the analysis of Fig. 6, and particularly the curves E'$_{31}$ and E'$_{30}$, it will be evident that the current pulses through the tubes 25 and 26 are of constant amplitude and of a duration varying in a complemental manner under the control of the frequency modulated carrier wave superposed upon the grid of one of the discharge devices. The anode voltage characteristics are complemental to the current characteristics as determined by the plate resistor I. R. drops. At Fig. 2 I have illustrated an embodiment of the invention which makes use of these characteristics to obtain increased output from the multivibrator limiter. At Fig. 2 I have shown the discriminator 18 connected between the anodes 30 and 31 of the tubes 25 and 26 respectively to supply equal and opposite voltages to the discriminator for "push-pull" operation. By way of variation I have also shown at Fig. 2 the manner in which the modulated carrier wave may be impressed through the lead 38 directly upon the grid 33 of the tube 26. In all other respects the embodiment of the invention

illustrated in Fig. 2 is similar to that illustrated in Fig. 1 and like parts have been assigned the same reference numerals.

Referring now more particularly to the curve E'_{31} of Fig. 6 it will be noted that the average voltage upon the anode **31** of the tube **26** is indicated by the broken line curve E_A, and that this average current increases as the carrier frequency increases and decreases as the carrier decreases. Similarly, the average voltage at the anode **30** of the tube **25** is indicated by the curve E'_A, and obviously decreases with increasing carrier frequency and increases with decreasing carrier frequency. Thus it appear that the average potential across either of the discharge tubes or either of the anode load resistors represents of itself a demodulated wave varying in amplitude in accordance with the frequency of the signal modulated carrier. Thus, as shown at Fig. 4, such a voltage, for example the anode-cathode voltage of the tube **26**, may be supplied directly to a suitable signal reproducing apparatus. At Fig. 4 I have shown such a signal reproducer at **20'** connected to the anode of the tube **26** through a high pass filter comprising a series resistor **45** and a shunt capacitor **46** for integrating the signal output. In all other respects the embodiment of Fig. 4 corresponds to that of Fig. 1 and like parts have been assigned the same reference numerals.

At Fig. 3 I have shown a further embodiment of the invention in which a signal reproducer **20''** is connected through a high pass filter network **47**, **48**, **49** to the demodulated multivibrator output but in push-pull relation in the manner of Fig. 2. In all other respects the embodiment of the invention illustrated in Fig. 3 is similar to that illustrated at Fig. 1 and like parts have been assigned the same reference numerals.

From the foregoing detailed description it will now be evident that I have provided a new and improved limiter for a carrier wave modulated in frequency in accordance with a desired signal such as voice, music, or the like. The limiter may, if desired, also be used simultaneously as a demodulator. My limiter has the further advantage that it necessarily produces a gain rather than a loss of amplification of the carrier wave in passing through the limiter. The amplification function is inherent in the multivibrator circuit, in that it is a necessary condition of multivibrator oscillation that the loop gain be greater than unity. The circuit is, therefore, by nature an oscillator of such a nature that a small amount of synchronizing voltage is able to control the frequency of oscillation but not the amplitude, the amplitude being many times larger than that of the synchronizing signal. Furthermore, my invention may be embodied in apparatus characterized by the greatest simplicity in design, manufacture and ease of adjustment. In the illustrative examples a single multivibrator connected in a new and novel manner for synchronization with the frequency modulated carrier wave of a frequency modulation receiver performs all the desired functions. As contrasted with its extreme simplicity of construction and arrangement, the arrangement possesses numerous advantages in that it may be used simultaneously to perform the functions of limiting, demodulating and amplifying.

While I have described and illustrated only certain preferred embodiments of my invention

by way of illustration, many further modifications thereof will undoubtedly occur to those skilled in the art. I, therefore, wish to have it understood that I intend by the appended claims to cover all such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In an amplitude limiter for carrier waves modulated in frequency about a predetermined center frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having control electrodes, said multivibrator device having a natural frequency of oscillation of the same general order of magnitude as said center frequency, and means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize oscillations of said multivibrator with said frequency modulated carrier wave over the desired range of frequency modulation.

2. In an amplitude limiter for a carrier wave modulated in frequency about a predetermined center frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having control electrodes, said multivibrator device being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, the amplitude of said current pulses being independent of the voltage upon said control electrodes, and means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize the frequency of current pulses through the controlled discharge device with said frequency modulated carrier wave over the desired range of frequency modulation.

3. In a limiter and demodulator for carrier waves variable in frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having anodes and control electrodes, said multivibrator being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, the amplitude of said current pulses being independent of the voltage upon said control electrodes, means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize the frequency of current pulses through the controlled discharge device with said frequency modulated carrier wave over the desired range of frequency modulation, and signal reproducing means connected to the anode of said controlled discharge device.

4. In a limiter and demodulator for carrier waves variable in frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having anodes and control electrodes, said multivibrator being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, means for impressing potentials of carrier frequency upon one of said control electrodes, said carrier fre-

quency potentials having an amplitude at least sufficient to control the instant of alternation of said current pulses and thereby to synchronize the current pulses in the controlled discharge tube with said frequency modulated carrier wave over the desired range of frequency modulation, and signal reproducing means connected between the anodes of said discharge devices.

5. In a receiver for carrier waves modulated in frequency about a predetermined center frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having anodes and control electrodes, said multivibrator being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize the current pulses of the controlled discharge device with said frequency modulated carrier wave over the desired range of frequency modulation and to control the period of current pulses in the other of said discharge devices, and frequency discriminating means connected to the anode of one of said discharge devices to convert frequency variations of the voltage wave at said anode into corresponding amplitude variations of a unidirectional electric potential.

6. In a receiver for carrier waves modulated in frequency about a predetermined center frequency in accordance with the desired signal, a multivibrator device including a pair of electric discharge devices having anodes and control electrodes, said multivibrator being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize the current

pulses in the controlled discharge tube with said frequency modulated carrier wave over the desired range of frequency modulation, and frequency discriminating means connected to the anode of said controlled discharge device.

7. In a receiver for carrier waves modulated in frequency about a predetermined center frequency in accordance with a desired signal, a multivibrator device including a pair of electric discharge devices having anodes and control electrodes, said multivibrator device being so arranged that said discharge devices alternately conduct current pulses of a predetermined limited and substantially constant amplitude at a natural frequency of oscillation of the same general order of magnitude as said center frequency, means for impressing upon one of said control electrodes potentials of carrier frequency having an amplitude at least sufficient to synchronize the current pulses in the controlled discharge device with said frequency modulated carrier wave over the desired range of frequency modulation without affecting the amplitude or period of said pulses and complementally to control the period of current pulses in the other of said discharge devices, and frequency discriminating means connected between the anodes of said discharge devices to translate variations in frequency of said current pulses into corresponding amplitude variations of a unidirectional electric potential.

EVERHARD H. B. BARTELINK.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,061,734	Kell	Nov. 24, 1936
2,064,106	Crosby	Dec. 15, 1936
2,262,838	Deloraine et al.	Nov. 18, 1941
2,271,203	O'Krent	Jan. 27, 1942
2,286,377	Roberts	June 16, 1942
2,305,842	Case	Dec. 22, 1942
2,323,596	Hansell	July 6, 1943