Oct. 19, 1937. J. C. McNARY 2,095,998

DEMODULATING CIRCUIT AND METHOD

Filed March 1, 1934 2 Sheets-Sheet 1

FIG. 1.

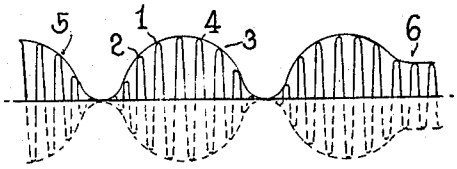


FIG. 2.

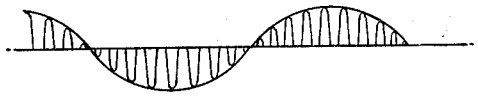


FIG. 3.

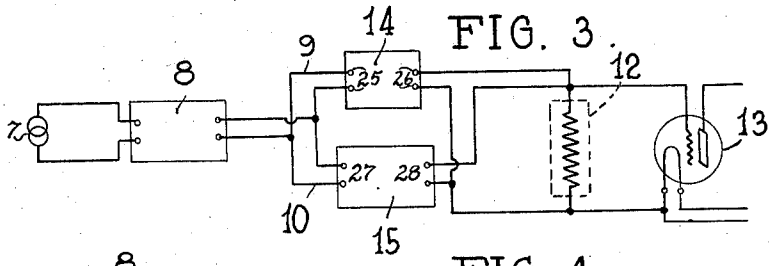


FIG. 4.

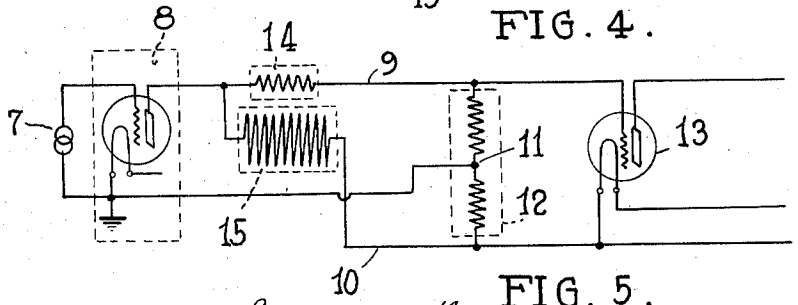


FIG. 5.

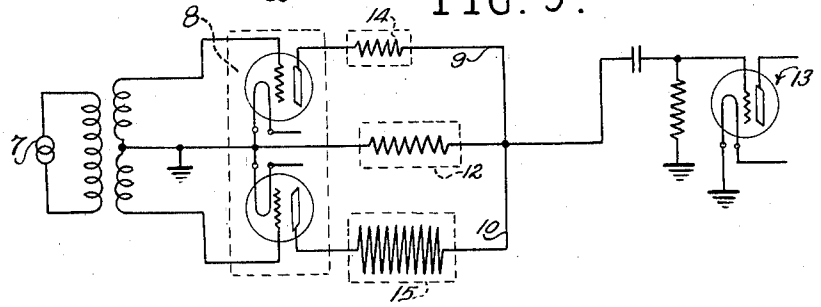
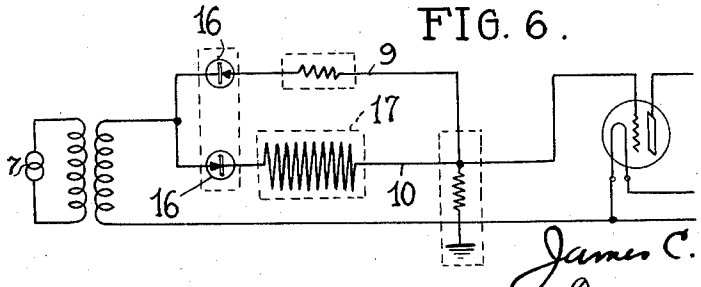


FIG. 6.



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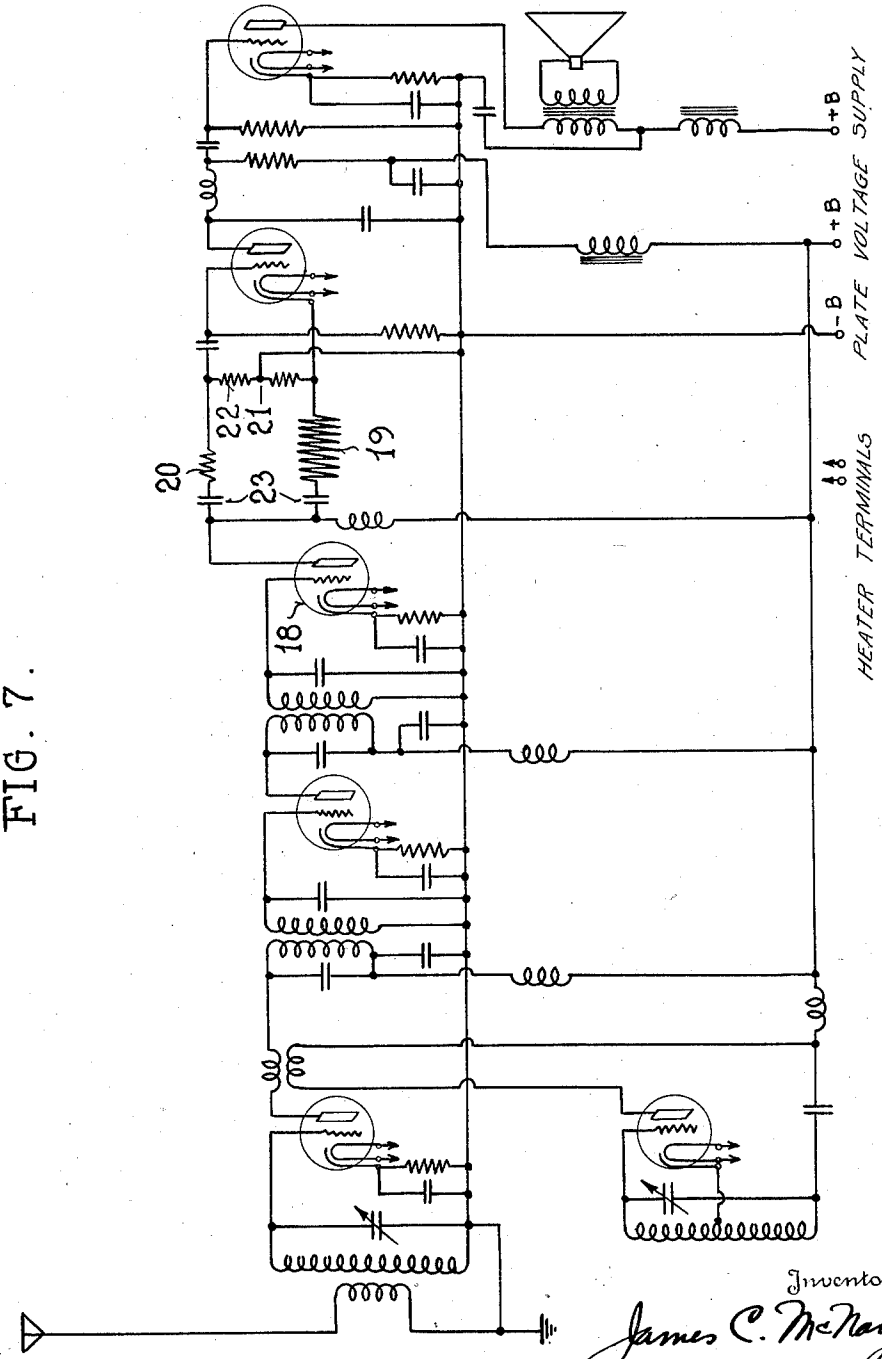
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Oct. 19, 1937. J. C. McNARY 2,095,998

DEMODULATING CIRCUIT AND METHOD

Filed March 1, 1934 2 Sheets-Sheet 2

FIG. 7.



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DEMODULATING CIRCUIT AND METHOD

James C. McNary, Washington, D. C.

Application March 1, 1934, Serial No. 713,579

13 Claims. (Cl. 250—21)

My invention relates to the demodulation of amplitude modulated carrier waves, with particular but not exclusive reference to the carriers used in radio telegraphy and telephony.

The invention will be illustrated in terms of its application to modulated waves in radio reception. As is well known, the received carrier wave is normally characterized by a constant amplitude, and becomes modulated as signals are impressed on it. The portions of the carrier which carry no signals, for example, those portions transmitted before a broadcast begins, or continuing during the momentary pauses common to all spoken or musical programs, are received as a wave of unmodulated amplitude. In many cases reception of the unmodulated wave is not objectionable, but in other cases serious difficulty results from the beating of the wave with another wave of a differential frequency. In the latter cases the advantage of removing from the receiving circuit the unmodulated portions of the carrier is obvious.

An object of the present invention is to provide a method and a circuit for removing the carrier wave when it becomes unmodulated and for restoring it as modulations appear. A primary advantage of the invention is an improvement of the ratio of signal to noise.

Broadly considered, the foregoing object is attained by providing a plurality of circuit branches for dividing the wave, so acting on the components of the wave in one of the branches that their passage through the branch is delayed, and then recombining these delayed components with the components which traversed the other branch. Preferably the delay is such as to deliver the affected division of the wave to the junction of the delay branch and what may be called the unretarded branch at a relative displacement of just the number of electrical degrees sufficient to cause prior and subsequent amplitude values of the wave to oppose each other.

When the divisions of the wave are recombined in opposite phase the resultant wave is the vector sum of the divisions. Consequently a wave of constant amplitude is completely removed, and a wave of varying amplitude is delivered from my novel circuit as a wave having an amplitude equal to the difference between lobes of the original wave spaced apart a distance equal to the wave length value of the delaying means, which, as has been indicated, may conveniently be one wave length or one half wave length, according to the circuit arrangement. It is evident that the wave resulting from a modulated carrier modified by practice of the invention will have its amplitude reduced, but this is readily corrected, if correction is necessary, by increasing the amplification in the audio circuit. Most radio receiving sets have abundant available amplification, so that this apparent difficulty presents no problem whatever.

With the foregoing and other objects in view, the invention comprises certain novel arrangements of circuit elements and certain novel sequences of method steps which will now be briefly described. However, it is to be understood that the following specific description is by way of illustration only and not limitation, the invention being of wide application and capable of being embodied in other and differently modified forms, all of which are considered to be within the spirit of the invention to the extent that they embody the principles thereof as pointed out by the appended claims.

In the accompanying drawings, which illustrate certain preferred embodiments of the invention,

Figure 1 shows a modulated wave, half of the wave being represented as removed by rectification;

Fig. 2 shows the same wave on a larger scale for clarity of illustration after modification by practice of my invention;

Fig. 3 is a block diagram of a typical circuit embodying certain principles of the present invention;

Fig. 4 is a diagram showing a type of circuit including one rectifier;

Figs. 5 and 6 are diagrams showing two types of circuits for full wave rectification; and

Fig. 7 is a diagram showing an elementary super-heterodyne circuit to which the invention has been applied.

Referring now to the drawings, it is evident that the modulated radio-frequency wave of Fig. 1 comprises successive lobes of varying amplitude, such as those indicated at **1**, **2**, **3**, **4**, where **1** is larger than the next succeeding lobe **2**, and **3** is smaller than the next succeeding lobe **4**, all of the lobes defining an audio-frequency envelope **5**. Each lobe differs in intensity from its adjacent lobes by a small amount. Let it be assumed that the bottom half of the wave be removed by rectification, as indicated by the broken lines. It will be apparent that the remainder, the rectified full line wave, will be transformed into the wave of Fig. 2 if each lobe of Fig. 1 be subtracted from the next succeeding lobe, e. g., if lobe **1** be subtracted from **2**, lobe **3** from **4**, etc. Where suc-

cessive lobes are of equal value, i. e., where the carrier is unmodulated, as indicated at 6, the wave will be completely removed.

An object of the present invention is to transform the wave of Fig. 1 into the wave of Fig. 2, and I accomplish this purpose by dividing the wave into a plurality of divisions, say two in number, subjecting one of the divisions of the wave to a time delay capable of retarding the affected portion of the wave until the unretarded division has made a relative advance of the required amount, say one wavelength, and then recombining the divisions in such a way (as for example in opposite phase) that the recombining divisions oppose each other and the resultant is the vector sum of the divisions.

It may be noted that the resultant wave of Fig. 2 may be smoothed out by use of by-pass condensers according to well understood practice, so that the final resultant will be an approximation of the envelope at the modulating frequency.

Figs. 3, 4, 5, and 6 illustrate practical embodiments of the invention, and Fig. 7 shows the invention applied to a conventional super-heterodyne circuit.

In these figures 7 designates a source of amplitude modulated carrier waves. A half-wave rectifier of any convenient type is shown at 8 in Figs. 3 and 4, and the output circuit of this rectifier contains an unretarded branch 9 and a time delay branch 10, which join at 11, conveniently the mid-point of a load resistance 12, to which the grid 13 of an audio amplifier tube is connected. In some cases it is desirable to interpose in the unretarded branch 9 a compensating impedance 14 to balance the retarding element 15 of the time delay branch.

The retarding element 15 may consist of an appropriate length of wire or other conductor folded back and forth on a card for economy of space. The conductor may be provided with taps of any sort engaged by a suitable contactor, or made variable in any well understood manner if desired, but of course for use in a heterodyne receiver a time delay of fixed value is sufficient. Optionally I may use a time delay element comprising a combination of impedances arranged in any well known configuration.

The operation of the circuit thus described is briefly as follows: The output from the rectifier is divided between the branches 9 and 10, and the value of the time delay element 15 is such that when the divisions recombine at 11 the retarded portion of each impulse becomes combined with the portion of the succeeding impulse which traversed the unretarded branch. Recombining such divisions in opposite phase produces a resultant equal to the vector sum of the divisions, effecting complete removal of the wave when the received carrier is unmodulated.

In Fig. 3 double connections 25 indicate the input terminals and double connections 26 the output terminals of a generalized compensating impedance 14. Similarly the double connections 27 indicate the input terminals and the connections 28 the output terminals of a generalized retarding element 15.

The arrangement shown in Fig. 5 is generally similar but differs in that two rectifiers are used. In this circuit the output of one rectifier is delivered to the unretarded branch, and the output of the other traverses the time delay branch. The mode of operation and effect are otherwise as described above in connection with the explanation of Fig. 4.

In Fig. 6 two rectifiers 16 are shown, each in a branch of the coupling transformer output circuit, the rectifiers being arranged to pass impulses of different polarity. One rectifier branch, designated 9, is unretarded, and the other, shown at 10, contains a time delay element 17 preferably of a value substantially equal to one-half wave length or any odd multiple thereof, such as 1½, 2½, 3½, etc. Due to the arrangement of the rectifiers waves of opposite phase and relatively displaced one-half wave length are produced in the branches 9 and 10. The time delay element 17 in branch 10 retards the wave in this branch sufficiently to cause it to coincide at the junction 11 with the portion of a succeeding wave (the next succeeding wave if the value of the delay be one-half wave length) which passed through branch 9.

It will be observed that the rectifiers 16 are shown as of the copper oxide type, while in Figs. 4 and 5 vacuum tubes are used. The invention in its various embodiments may be practiced equally well with any conventional rectifying means.

Fig. 7 shows a typical super-heterodyne circuit in which a demodulating circuit embodying the principles of the present invention is incorporated. Oscillations from the source 18 enter branch circuits containing a time delay element 19 and, if desired, a compensating impedance 20, respectively, and are recombined at the junction 21 in the load impedance 22. The output is passed through the audio frequency and power amplifier circuits according to conventional practice. A by-pass condenser 23 is provided in each of the branches merely for the purpose of isolating the demodulating circuits from the plate potential of the associated vacuum tube.

The invention may be mathematically explained and proved as follows:

The voltage applied to the linear rectifier, which may be, for example, a signal received from a broadcasting station, represents a carrier wave and its two second-order side-bands. It may be expressed as

$$V=P\cos pt(1+k\cos qt) \quad (1)$$

where

V=instantaneous voltage
P=carrier amplitude
$p=2\pi\times$carrier frequency
k=factor representing depth of modulation
$q=2\pi\times$modulating frequency.

The linear rectifier suppresses the negative lobes of the wave. To determine the wave components of the output of the linear rectifier, it is clear that such an objective is attained if the expression for V, above, is multiplied by a function which is unity when cos pt is positive, and zero when cos pt is negative. This is equivalent to replacing cos pt by the result of linear rectification of cos pt. This function is well known, by Fourier analysis, to be

$$f(t)=\frac{1}{\pi}+\frac{1}{2}\cos pt+\frac{2}{3\pi}\cos 2pt-\frac{2}{15\pi}\cos 4pt+\ldots \quad (2)$$

The rectified wave may then be written as

$$V_r=f(t)[1+k\cos qt] \quad (3)$$

This may be expanded to read

$$V_r=\frac{1}{\pi}+\frac{k}{\pi}\cos qt+\frac{1}{2}\cos pt+\frac{k}{4}\cos(p\pm q)t+\frac{2}{3\pi}\cos 2pt+\frac{k}{3\pi}\cos(2p\pm q)t+\ldots \quad (4)$$

The output circuit of the linear rectifier may be divided into two sections. If a time delay of Δt be applied to the currents flowing in one of the sections, it may be represented by

$$I=\frac{1}{\pi}+\frac{k}{\pi}\cos q(t+\Delta t)+\frac{1}{2}\cos p(t+\Delta t)+\frac{k}{4}\cos (p\pm q)(t+\Delta t)+\frac{2}{3\pi}\cos 2p(t+\Delta t)+\frac{k}{3\pi}\cos (2p\pm q)(t+\Delta t)+\ldots \quad (5)$$

When the currents flowing in the two sections are of equal amplitude and combined in an out-of-phase relation, the resulting potential is proportional to the difference of the two currents whose wave components are represented in Equations (4) and (5), which is

$$E=\frac{k}{\pi}\cos qt-\frac{k}{\pi}\cos q(t+\Delta t)+\frac{1}{2}\cos pt-\frac{1}{2}\cos p(t+\Delta t)+\frac{k}{4}\cos (p\pm q)t-\frac{k}{4}\cos (p\pm q)(t+\Delta t)+\frac{2}{3\pi}\cos 2pt-\frac{2}{3\pi}\cos 2p(t+\Delta t)+\frac{k}{3\pi}\cos (2p\pm q)t-\frac{k}{3\pi}\cos (2p\pm q)(t+\Delta t)+\ldots \quad (6)$$

When Δt is made equivalent to a phase shift of 360°, or integral multiple thereof, at the carrier frequency, Equation (6) becomes

$$E=\frac{k}{\pi}\cos qt-\frac{k}{\pi}\cos\left(\{q(t)\}+\frac{q\times 360^\circ}{p}\right)+\frac{k}{4}\cos(p\pm q)t-\frac{k}{4}\cos\left(\{(p\pm q)(t)\}+\frac{(p\pm q)360^\circ}{p}\right)+\frac{k}{3\pi}\cos (2p\pm q)t-\frac{k}{3\pi}\cos\left(\{(2p\pm q)(t)\}+\frac{(2p\pm q)360^\circ}{p}\right)+\ldots \quad (7)$$

Now it so happens that the demodulating system is intended to reproduce the components of the "q" frequency from the modulated carrier wave. This is usually relatively low frequency so that such components may be easily separated from the components of carrier frequency, or of harmonics and modulation products thereof. Interest is centered, therefore, on the components of "q" frequency in Equation (7), as all the higher frequency components may be removed by the familiar use of by-pass condensers and other devices at appropriate places in the circuit. The demodulation product of interest is

$$E=\frac{k}{\pi}\cos qt-\frac{k}{\pi}\cos\left(qt+\frac{q\times 360^\circ}{p}\right) \quad (8)$$

which may be expanded to read

$$E=\frac{k}{\pi}\left(1-\cos\frac{q\times 360^\circ}{p}\right)\cos qt+\frac{k}{\pi}\sin qt\sin\frac{q\times 360^\circ}{p} \quad (9)$$

which represents the useful voltage appearing across the output terminals of the demodulating system.

It will be observed that the output voltage amplitude of "q" frequency, as represented by Equation (9), varies directly as the factor k, the depth of modulation, and more or less inversely as the ratio of the q and p frequencies. Therefore, to obtain a flat response-frequency characteristic for the demodulating system, an equalizer must be used to increase the relative amplitudes of the lower "q" frequencies.

It is to be noted that carrier frequency components have disappeared entirely from Equation (7). Hence, an interfering signal has nothing to heterodyne with when no modulation is present on the desired carrier wave, and the result is a substantial reduction of noise.

The foregoing represents an analysis of the particular case wherein a 360° time delay, with opposite-phase recombination, is used. It is obvious that a similar analysis is applicable to other embodiments of the invention, wherein other choices of circuit elements are used.

I claim:

1. The method of removing intelligence from a received modulated carrier wave which comprises dividing the wave, retarding one of the divisions thereof until another of the divisions has advanced substantially an integral multiple of one wave length at the frequency of the carrier wave over the first, and recombining the divisions while preserving substantially the original relative frequency response of the divisions.

2. The method of removing intelligence from a received modulated carrier wave which comprises rectifying the wave, dividing the rectified wave into at least two divisions, delaying the flow of the wave in one of the divisions until another of the divisions has advanced an integral multiple of one wave length at the frequency of the carrier wave over the first, and recombining the divisions in out of phase relation while preserving substantially the original relative frequency response of the divisions.

3. The method of demodulating an amplitude modulated carrier wave which comprises separately rectifying the positive and negative impulses, retarding the impulses of one polarity until the impulses of the other polarity have advanced substantially an odd multiple of one-half wave length over the impulses of the first named polarity, and recombining the impulses of both polarities.

4. A circuit for removing intelligence from a received modulated carrier wave comprising an unretarded branch and a branch including means for delaying the wave flowing therein substantially an integral multiple of one wave length, at the frequency of the carrier wave, with relation to the wave flowing in the unretarded branch, said branches having substantially identical frequency characteristics, and a junction of the branches.

5. A circuit for removing intelligence from a received modulated carrier wave comprising a rectifier, a rectifier output circuit including an unretarded branch and a branch including means for delaying the wave flowing therein substantially an integral multiple of one wave length, at the frequency of the carrier wave, with relation to the wave flowing in the unretarded branch, said branches having substantially identical frequency characteristics, and a junction of the branches.

6. A circuit for demodulating an amplitude modulated carrier wave comprising means for receiving modulated waves, a plurality of branches connected to said means, a rectifier in each branch, means in one of the branches for delaying the wave flowing therein substantially an odd number multiple of one-half wave length with relation to the wave flowing in another branch, and a junction of the branches.

7. The method of removing intelligence from a received modulated carrier wave which comprises rectifying the wave, dividing the rectified components, retarding one of the divisions thereof, and, while preserving substantially the origi-

nal relative frequency response of the divisions, recombining said divisions in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

8. The method of removing intelligence from a received modulated carrier wave which comprises dividing the wave, retarding one of the divisions thereof, and, while preserving substantially the original relative frequency response of the divisions, recombining said divisions in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

9. The method of removing intelligence from a received modulated carrier wave which comprises rectifying the wave, dividing the rectified components into at least two divisions, delaying the flow of the wave in one of the divisions, and, while preserving substantially the original relative frequency response of the divisions, recombining said divisions in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

10. The method of removing intelligence from a received modulated carrier wave which comprises separately rectifying the positive and negative impulses, relatively delaying the impulses of one polarity, and, while preserving substantially the original relative frequency response of the divisions, recombining said divisions in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

11. The method of removing intelligence from a received modulated carrier wave which comprises separately rectifying the positive and negative impulses, retarding the impulses of one polarity until the impulses of the other polarity have advanced substantially one-half wave length over the impulses of the first named polarity, and, while preserving substantially the original relative frequency response of the divisions, recombining said divisions in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

12. A circuit for removing intelligence from a received modulated carrier wave comprising an unretarded branch and a branch including a time delay, said branches having substantially identical frequency characteristics, and a junction of the branches for recombining the waves flowing through the branches in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

13. A circuit for removing intelligence from a received modulated carrier wave comprising means for receiving modulated waves, a plurality of branches connected to said means, a rectifier in each branch, a time delay means in one of the branches, said branches having substantially identical frequency characteristics, and a junction of the branches for recombining the waves flowing through the branches in such phase relation that the amplitude of the recombined carrier components varies in proportion to modulation.

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