

Feb. 1, 1944.

R. E. SCHOCK

2,340,432

PHASE MODULATION RECEIVER

Filed May 23, 1942

3 Sheets-Sheet 1

Fig. 1.

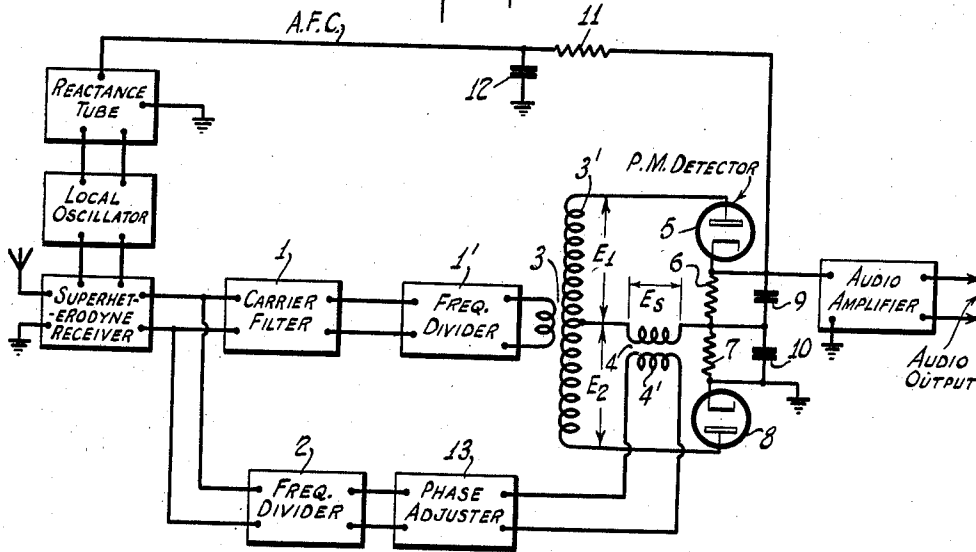
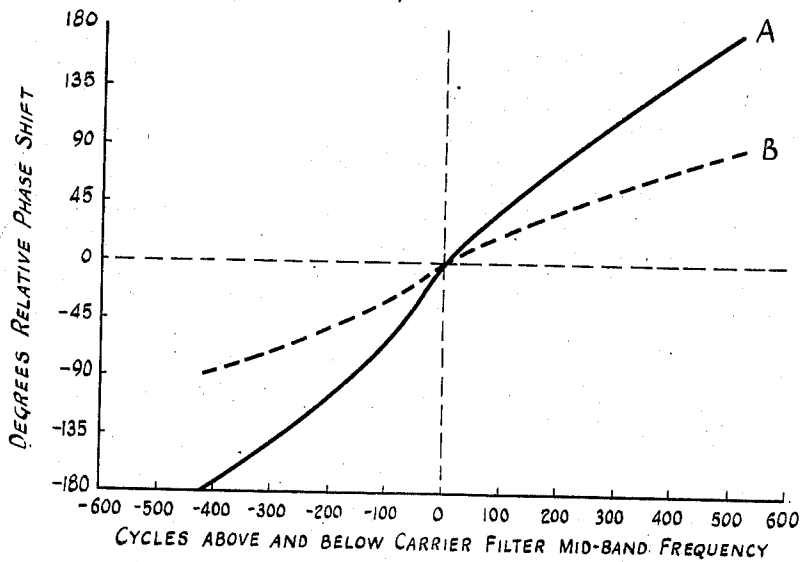


Fig. 2.



INVENTOR.
ROBERT E. SCHOCK.

BY *H. S. Grover*
ATTORNEY

Feb. 1, 1944.

R. E. SCHOCK

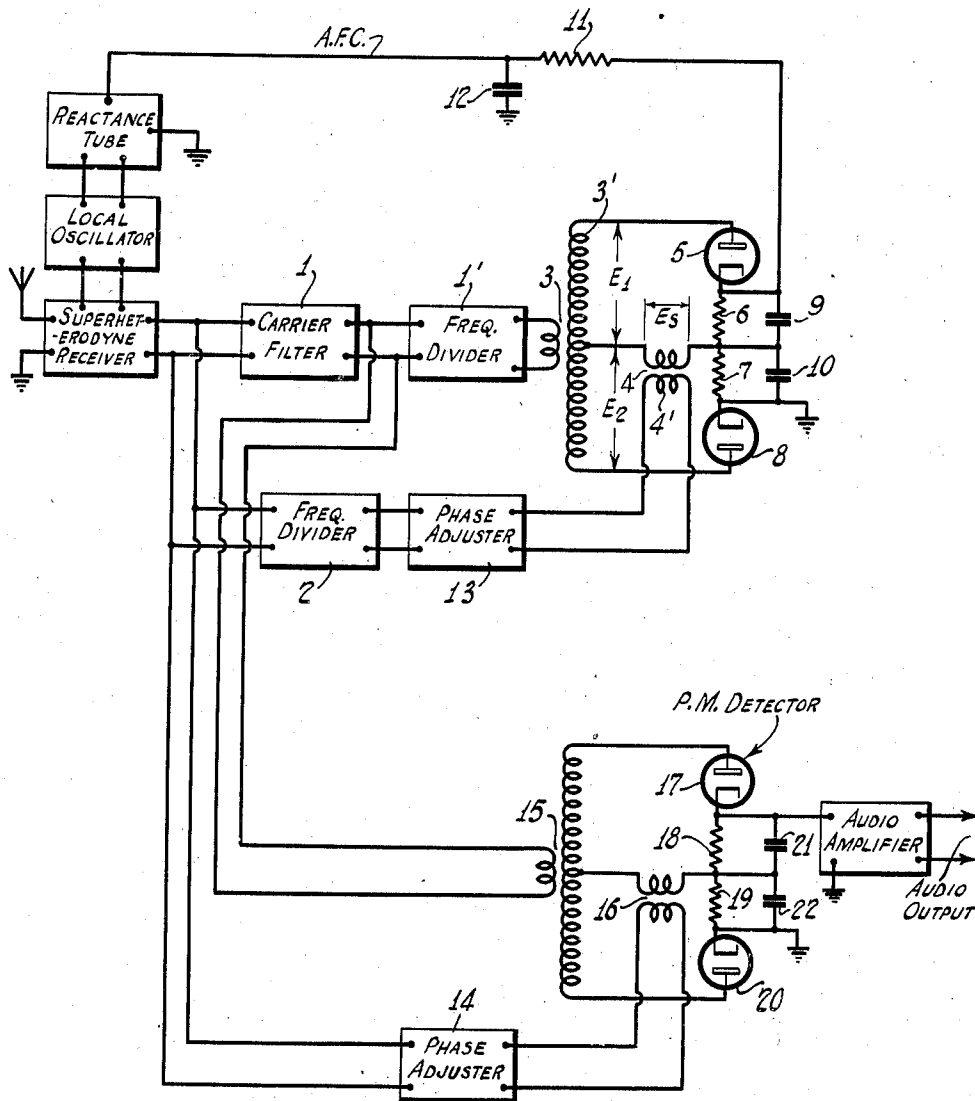
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Fig. 3.



INVENTOR.
ROBERT E. SCHOCK.
BY *H. S. Brown*
ATTORNEY

Feb. 1, 1944.

R. E. SCHOCK

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3 Sheets-Sheet 3

Fig. 4a.

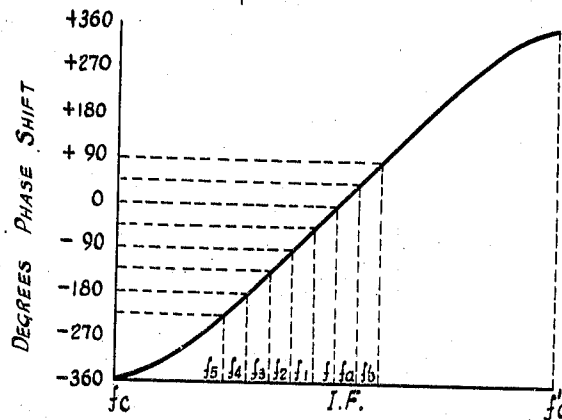


Fig. 4c.

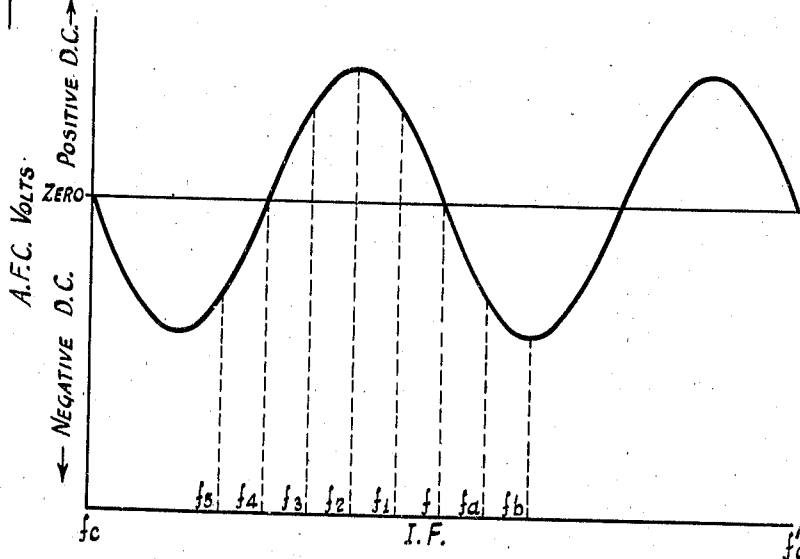
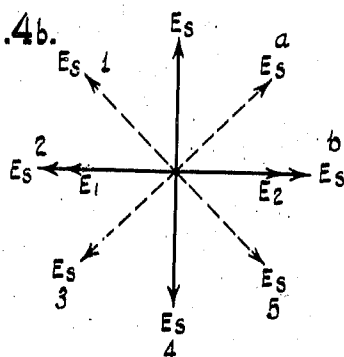


Fig. 4b.



INVENTOR.
ROBERT E. SCHOCK.
 BY *H. S. Brover*
 ATTORNEY

UNITED STATES PATENT OFFICE

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PHASE MODULATION RECEIVER

Robert E. Schock, Riverhead, N. Y., assignor to
Radio Corporation of America, a corporation of
Delaware

Application May 23, 1942, Serial No. 444,177

5 Claims. (Cl. 250—20)

My present invention relates to phase modulated carrier wave (PM) receivers, and more particularly to improvements in PM receivers of the type employing carrier exaltation.

One of the main objects of my invention is to provide a method of PM reception of the carrier filter type; wherein the carrier filter may have more than 180 degrees of relative phase shift to either side of the midband frequency, and frequency division being used to insure proper functioning of an automatic frequency control (AFC) circuit when used.

Another important object of my invention is to provide a PM receiver of the superheterodyne type employing an auxiliary carrier, or exalted carrier, network to provide demodulation of the PM waves; the normal modulated carrier path and auxiliary carrier path to the detector each including a frequency divider device for reducing the effective phase shift of the auxiliary carrier to a degree such that automatic frequency control (AFC) is readily usable in the system.

Another important object of my invention is to provide in a PM receiver of the superheterodyne type an automatic frequency control, means being employed in the carrier paths to the AFC rectifier to insure that the relative phase shift of the carrier filter is not in excess of 90 degrees either side of the mid-frequency of the filter.

Other objects of my invention are to improve, and to render more efficient and flexible, PM receivers.

The novel features which I believe to be characteristic of my invention are set forth in 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 drawings, in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawings:

Fig. 1 shows a PM receiver system, in schematic form, embodying the invention,

Fig. 2 graphically shows the frequency-phase shift characteristics of the carrier filter path to the detector,

Fig. 3 shows schematically a modification of the PM receiver of Fig. 1,

Figs. 4a, 4b and 4c show various characteristics useful in explaining the invention.

Referring now to the accompanying drawings, wherein like reference characters in the

figures designate similar circuit elements, the superheterodyne receiver system of Fig. 1 is generally a PM receiver of the type described on page 131 of Proceedings of the I. R. E., for February 1939, in an article by M. G. Crosby entitled "Communication by phase modulation." The receiver, in general, comprises a superheterodyne receiver which may be of any conventional and well-known construction. The rectangle designated "Superheterodyne receiver" is to be understood as comprising the usual tuned radio frequency amplifiers, tuned first detector, and one or more stages of intermediate frequency (IF) amplifiers. The rectangle designated "Local oscillator" is to be understood as an oscillator circuit adapted to be tuned to a frequency different from the received PM waves by the operating IF value. In this connection it is to be understood that the PM waves may have a carrier, or midpoint, frequency located in the ultra-high frequency range.

As is well known to those skilled in the art, and as described in the aforesaid article, PM waves are produced by deviating the transmitter carrier frequency in proportion to modulation frequency. The radio frequency deviation for the higher modulation frequencies is relatively greater than at the lower modulation frequencies. In this respect PM waves differ from frequency modulated carrier waves. In order to demodulate the PM waves at the reduced, or I. F. value, there is employed a detector circuit which comprises a pair of diode rectifiers 5 and 8 arranged in opposition. The cathodes of the diodes are connected by the series-arranged load resistors 6 and 7, and the midpoint of these resistors is connected to the midpoint on the secondary winding 3' of the detector input transformer 3. Each of resistors 6 and 7 is bypassed for I. F. currents by the respective bypass condensers 9 and 10.

The anodes of diodes 5 and 8 are connected to respective opposite ends of the winding 3'. The cathode end of load resistor 7 is grounded. The modulation signal voltage is taken off from the cathode end of resistor 6, and fed through an audio amplifier to any desired type of audio output circuit. The lead connecting the midpoint of winding 3' to the junction of resistors 6 and 7 includes the secondary winding of transformer 4. There is developed across the secondary winding of transformer 4 signal voltage designated E_s . To develop this voltage, the primary winding 4' is connected in the output of a path which comprises a frequency divider 2 and

a phase adjuster 13. Disregarding for the time being the action of the frequency divider 2, and assuming that the phase adjuster 13 is the only network included in the path feeding winding 4', it will be understood that in the type of PM receiver shown in the aforesaid Crosby article there is fed to transformer 4 the PM waves whose midband frequency is of I. F. value. A second path is provided to feed the secondary winding 3' of transformer 3. This path comprises a carrier filter 1 and a frequency divider 1'. The primary winding of transformer 3 is connected in the output of divider 1'. Here, again, let it be assumed that the divider 1' is not included in the carrier filter path. The function of the carrier filter 1 is to remove the modulation side bands of the modulated carrier wave and leave the carrier.

In order to receive a wave which is phase modulated, a converting circuit which converts the phase modulation into amplitude modulation must be used. Then, in a manner similar to the process used in frequency modulation reception, the amplitude modulation is detected by ordinary methods. As explained in the aforesaid Crosby article, the vector relations between the carrier and side band frequencies in amplitude modulation may be represented by the carrier vector being at right angles to each of the lower and upper side bands. In phase modulation, the relation of the carrier and side band frequencies over a given instant of time is such that the carrier of the PM wave has been shifted 90° with respect to the carrier of the amplitude modulated wave. In other words, the carrier vector is in phase with one of the modulation side-band vectors. In view of this phase relation existing between the carrier and side frequencies of phase modulation, it is obvious that for detection it is first necessary either to phase shift the carrier relative to the side-bands, or phase shift the sidebands relative to the carrier, to convert the PM wave into an amplitude modulated wave.

In a system of the type shown in Fig. 1 part of the incoming PM wave is fed to the carrier filter 1 which removes the modulation side-bands, and makes available an unmodulated auxiliary carrier which may be combined with the PM wave so as to produce a resultant voltage which is amplitude modulated. The phase adjuster 13 in the normal PM path is adjusted so that the two components of the filtered carrier E_1 and E_2 are 90° out of phase with the unfiltered PM wave voltage E_s . This produces resultant voltages between each diode anode and the junction of resistors 6 and 7 which are balanced in amplitude for the unmodulated condition. When the phase of the incoming wave E_s is shifted, one of the resultants is modulated down in amplitude and the other up. A phase shift in the opposite direction produces differential amplitude modulation in the opposite sense.

When this differential modulation is detected on the diode rectifiers, one of the diode resistors is reversed with respect to the other so as to combine the detector outputs in push-pull relation. Differential voltage for AFC action is also available, and is taken off from the cathode end of resistor 6. The resistor-condenser network 11-12 is a time constant circuit which removes alternating current components. The AFC bias is applied to a reactance tube which controls the frequency of the resonant tank circuit of the local oscillator of the receiver. This AFC action is very well known, and need not be described in

any further detail. Any well known form of reactance tube circuit may be used. Due to the high selectivity of the carrier filter 1, AFC is practically a necessity in this type of receiver.

It is necessary for proper functioning of the AFC circuit that the relative phase shift of carrier filter 1 be not more than 90° on either side of the mid-frequency of this filter. Thus, mid-frequency would be the operating I. F. value. There are certain types of carrier filters (such as a band pass crystal filter) which are very suitable for this type PM receiver, but which have more than 90° relative phase shift on either side of the midband frequency.

The following discussion, in connection with Figs. 4a, 4b, and 4c, should more clearly show how it is that the AFC operation is impaired by the use of a carrier filter with more than 90 degrees of phase shift-with-frequency either side of midband, and how the AFC action may reverse if the carrier filter has more than 180 degrees of phase shift-with-frequency either side of the midband frequency. Referring to Fig. 1, let us assume, for this discussion, that the frequency dividers 1' and 2 are omitted. Let us also assume that, in order to obtain a high degree of sideband attenuation in the carrier filter path, two band-pass carrier filters are used in series in the carrier filter position 1. Also, assume that each of these two band-pass filters is of a type which has 180 degrees of phase shift-with-frequency either side of midband. This will result in an overall phase shift-with-frequency of 360 degrees below midband frequency, and 360 degrees above midband frequency. Such a characteristic is represented by Fig. 4a. Inspection of this characteristic shows the phase shift to be zero at midband frequency f , 360 degrees in a negative direction at cut-off frequency f_c , and 360 degrees in a positive direction at cut-off frequency f'_c , etc.

The voltages E_1 , E_2 , and E_s of Fig. 1 are shown vectorially in Fig. 4b by solid vectors for the condition where the incoming I. F. signal is at midband frequency f in Fig. 4a. The amplitude and polarity of the AFC voltage developed across diode resistors 6 and 7 of Fig. 1 over the frequency range of the carrier filter considered are shown by the curve of Fig. 4c. Now with the I. F. signal at midband, f of Fig. 4a, there is no phase shift of E_s with respect to E_1 and E_2 . Fig. 4b, and zero AFC volts is developed as shown by Fig. 4c. If the I. F. shifts from f to f_a , Fig. 4a, shows that the filtered signal will then be phase shifted 45 degrees in a positive direction. This is represented vectorially by the dashed vector E_s in position a Fig. 4b, and with this phase relationship of E_s with respect to E_1 and E_2 a negative AFC voltage is developed across the diode resistors 6 and 7 of Fig. 1. This is represented on the curve of Fig. 4c for frequency position f_a . (The manner in which this voltage is developed is more fully discussed under the heading "Auxiliary-carrier receivers" in the Crosby paper "Communication by phase modulation.")

Similarly a shift of frequency to position f_1 , Fig. 4a, results in a negative phase shift of the filtered carrier of 45 degrees so that its vector E_s of Fig. 4b, is now represented by dashed vector E_s in position 1 , and, as shown in Fig. 4c, a positive AFC voltage is developed. From the foregoing discussion it may be seen that when a frequency shift to a higher frequency takes place in the I. F., and produces a negative AFC voltage, the AFC must act in such a manner as to lower the frequency of the I. F. signal. Con-

versely, when a frequency shift to a lower frequency of the I. F. signal takes place, thus causing a positive AFC voltage to be generated, this positive voltage must drive the AFC to raise the frequency of the I. F. signal if the AFC is to fulfill its purpose. Now, it is seen from Figures 4a, 4b and 4c that if the frequency of the I. F. signal should shift from midband frequency f down to the frequency designated as f_2 , the filtered carrier would experience a 90 degree shift in the negative direction which would cause the maximum amount of positive AFC voltage to be developed according to Fig. 4c.

A further decrease in frequency, say to f_3 , would cause a decrease in the amount of AFC voltage, and at frequency f_4 the filtered carrier phase shift of 180 degrees sets up the condition by which no AFC voltage is developed. At frequency f_5 the phase shift experienced by the filtered carrier is more than 180 degrees, and, as seen in Fig. 4c, the voltage developed has reversed from positive to negative which will act on the AFC to drive the frequency of the I. F. signal still lower in frequency instead of driving it back to frequency f . Actually, if the carrier filter has slightly more than the 720 degrees considered in Figures 4a, 4b, and 4c, and, if the frequency suddenly shifts to a frequency beyond f_4 , the reversed AFC action will carry the frequency of the I. F. signal to f_6 , and the AFC will hold it at that point. From this discussion it may be seen that if the carrier filter imparts a phase shift of more than 90 degrees either side of midband frequency, there results an undesirable condition in which the amplitude of the AFC voltage, generated at a frequency beyond the 90 degree shift point, decreases; and, if the carrier filter imparts 180 degrees, or more, of phase shift it is possible for the AFC voltage to be zero or the reverse. By the use of frequency subdivision, as set forth herein, the phase shift imparted by the carrier filter may be reduced to an amount satisfactory for AFC use.

I propose by the use of frequency division to cut the effective phase shift of the filtered carrier to a degree which renders it readily usable. By passing the filtered carrier output through the frequency divider 1', the carrier frequency is sub-divided to a sub-multiple of its original frequency. In this way the carrier attains a phase vs. frequency relation, relative to the phase vs. frequency relation of the unfiltered PM wave, which is not more than 90 degrees either side of the filter midband, or center, frequency. The PM wave passing through the other path is transmitted through a frequency divider 2, whereupon the carrier frequency is subdivided to the same frequency as that of the subdivided filtered carrier.

The subdivided PM wave energy leaving divider 2 is passed through the phase adjuster 13. The function of the phase adjuster is to adjust the phase of E_s , appearing at 4, to be 90 degrees out of phase with the two filtered carrier components E_1 and E_2 appearing across 3'. The curve A (full line) of Fig. 2 shows the relative phase shift with frequency of a carrier filter of the typical band-pass crystal filter type. If this latter type of filter were used at 1 in Fig. 1, and the networks of this invention were omitted, the filtered carrier and unfiltered modulated wave energy arriving at the PM detector would have a phase relationship varying with frequency as in curve A of Fig. 2. However, if this same fil-

ter is used in the carrier filter position of Fig. 1, and if frequency dividers 1' and 2 halve the midband frequency before passing them on to the detector, the filtered and unfiltered modulated wave energy will have a phase-frequency characteristic as illustrated by the dashed curve B of Fig. 2.

It will be seen from curve B that the phase shift of the auxiliary carrier energy is now 90 degrees either side of the midband frequency of the filter. Of course, in the above illustration the phase deviation of the PM wave energy will, also, be halved in the frequency division process. However, in the aforesaid Crosby article it has been pointed out that relatively low levels of modulation are required in this type of receiver if low distortion is desired, since receivers of this type inherently distort on higher levels of deviation. Frequency division would, therefore, be an improvement in many cases. It will be understood, of course, that the carrier filter may be of any desired type; even those exhibiting 180 degrees of phase shift with frequency either side of the center, or midband, frequency.

Among the various types of carrier filters which might be used, and which have more than 180 degrees of phase shift-with-frequency, are the following band-pass filters:

- Constant k type
- Mid-shunt derived m -type
- Mid-series derived m -type
- Mid-shunt derived mm -type
- Mid-series derived mm -type

These, and other, filters and their characteristics are described in the article, "Extensions to the theory and design of electric wave-filters," by O. J. Zobel, which appeared in the April 1931 Bell System Technical Journal. All the types above listed have a phase shift of minus 180 degrees below midband and plus 180 degrees above midband, or a total of 360 degrees.

The frequency dividers may be of any well-known type. Those skilled in the art are fully acquainted with the manner of designing these dividers. Frequency dividers which may be used are the oscillating converter type (see application Serial No. 385,800, filed March 29, 1941, by M. G. Crosby), and the multi-vibrator type.

If it is desired to utilize the full phase deviation at the audio detector, the system of Fig. 3 may be used. One detector 5-8 is employed for the AFC bias production. The other detector provides the audio signals, and makes no use of frequency division. Thus, the audio detector comprises opposed rectifiers 17 and 20 having respective load resistors 18 and 19. The audio detector is arranged as in the case of the AFC detector. Carrier bypass condensers 20 and 21 respectively shunt resistors 18 and 19. The output of carrier filter 1 feeds directly to input transformer 15, while the unfiltered PM energy is fed to transformer 16 through the phase adjuster 14. The latter insures impression of the filtered carrier and unfiltered PM energy upon the PM detector in phase quadrature relation.

The novel features which I believe to be characteristic of my invention are set forth in 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 drawings in which I have indicated diagrammatically several circuit organ-

izations whereby my invention may be carried into effect.

What I claim is:

1. The method of demodulating phase-modulated carrier energy which includes, concurrently reducing the midband frequency and degree of phase modulation of the modulated carrier energy, removing from a portion of the phase-modulated carrier energy all modulation sidebands, imparting to the carrier, as a result of said removal, a phase shift in excess of 90 degrees on either side of the midband frequency, reducing the phase shifted carrier frequency to the frequency of said reduced midband frequency thereby to reduce said phase shift so as not to exceed 90 degrees, and combining the resulting reduced carrier energy with the reduced modulated carrier energy to provide the original modulation signals.

2. In a superheterodyne receiver employing a local oscillator, means to combine phase modulated carrier energy with local oscillations to produce beat energy, a carrier filter for removing all modulation sidebands from the beat energy, said filter having a phase shift-frequency characteristic in excess of 90 degrees, means for demodulating the beat energy, a first frequency divider coupling the carrier filter to the demodulating means, a second frequency divider coupling said beat energy producing means to said demodulating means, means for securing application of both frequency divider output energies to said demodulating means in phase quadrature.

3. In a superheterodyne receiver employing a local oscillator, means to combine phase modulated carrier energy with local oscillations to produce beat energy, a carrier filter for removing all modulation sidebands from the beat energy, said filter having a phase shift-frequency characteristic in excess of 90 degrees, means for demodulating the beat energy, a first frequency divider coupling the carrier filter to the demodu-

lating means, a second frequency divider coupling said beat energy producing means to said demodulating means, means for securing application of both frequency divider output energies to said demodulating means in phase quadrature, and means regulating the frequency of said oscillator with the demodulated voltage.

4. In a superheterodyne receiver employing a local oscillator, means to combine phase modulated carrier energy with local oscillations to produce beat energy, a carrier filter for removing all modulation sidebands from the beat energy, said filter having a phase shift-frequency characteristic in excess of 90 degrees, means for demodulating the beat energy, a first frequency divider coupling the carrier filter to the demodulating means, a second frequency divider coupling said beat energy producing means to said demodulating means, means for securing application of both frequency divider output energies to said demodulating means in phase quadrature, a second demodulating means, and means for applying the filtered carrier energy and beat energy without frequency division to said second demodulating means.

5. In a phase modulated carrier wave receiver of the superheterodyne type employing an automatic frequency control circuit for the oscillator, said receiver employing a carrier filter path and an unfiltered modulated carrier wave path to feed respective energies thereof to a demodulator in phase quadrature; the improvement comprising a frequency divider in the carrier filter path, said divider being located between the carrier filter of said last-named path and said demodulator, a second frequency divider in the unfiltered path, said dividers reducing the carrier frequencies in both paths by the same amounts whereby the filtered carrier has an effective phase shift on either side of the midband frequency which is not in excess of 90 degrees.

ROBERT E. SCHOCK.