HOMODYNE RECEIVER

Filed March 4, 1939

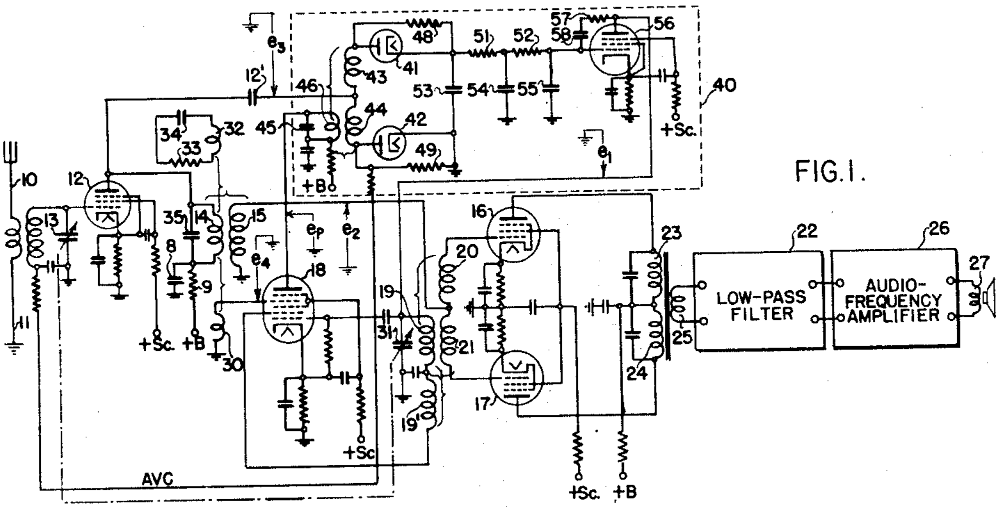

FIG. 1.

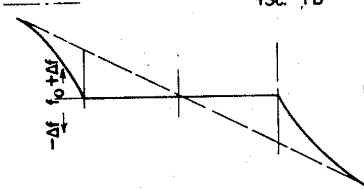

FIG. 2a.

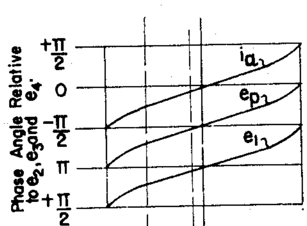

FIG. 2b.

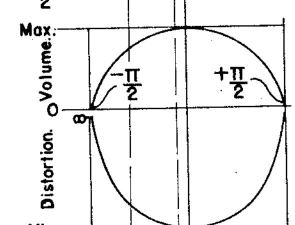

FIG. 2c.

FIG. 2d.

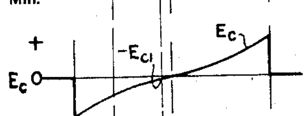

FIG. 2e.

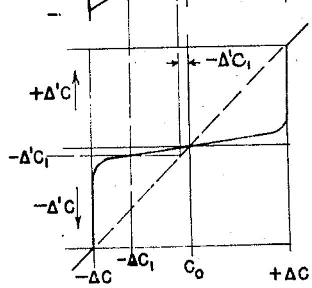

FIG. 2f.

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UNITED STATES PATENT OFFICE

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HOMODYNE RECEIVER

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Application March 4, 1939, Serial No. 259,735

22 Claims. (Cl. 250—20)

This invention relates to modulated-carrier signal receivers of the homodyne type and particularly to such receivers in which the locally-generated oscillations are controlled, both as to frequency and to phase, with respect to the carrier wave of the desired received signal.

In a modulated-carrier signal receiver of the homodyne type, locally-generated oscillations of the frequency of the carrier wave of the desired signal are heterodyned with the desired received signal to reproduce the desired modulation signal. If the frequency of the locally-generated oscillations differs slightly from that of the carrier wave of the signal to be reproduced, audible beat-frequency signals result, producing intolerable distortion. Prior art homodyne receivers, therefore, commonly have been provided with an arrangement responsive to the desired received signal for maintaining the desired frequency of the locally - generated oscillations. However, such prior art synchronizing arrangements are relatively sensitive to variations in amplitude of received signals, rendering reception unsatisfactory under certain conditions of operation.

Furthermore, even though the frequency of the locally-generated oscillations is exactly maintained at the desired value, considerable distortion in the reproduction of the received signal and a considerable reduction in the volume of the reproduced signal may result, due to an improper phase relationship between the signal-carrier wave and the locally-generated oscillations. It has been determined that there is a critical phase relation between the desired received carrier wave and the locally-generated oscillations at which there is little or no distortion in the reproduced signal. Distortion, due to improper phase relation between these two waves, increases rapidly with departure from this critical or optimum value, while the volume of the reproduced signal simultaneously decreases rapidly. While some prior art homodyne receivers have incorporated in the system, for maintaining the desired frequency of the locally-generated oscillations, an arrangement the purpose of which is to maintain a constant phase angle between the desired received signal and the locally-generated oscillations, as mentioned above, the operation of such systems of phase control have been materially affected by the amplitude of the received signals. Obviously, with such an arrangement and under such conditions, a phase control arrangement is almost entirely ineffective.

Furthermore, such systems of the prior art have been ineffective to maintain the critical or optimum phase displacement even under normal conditions of reception, the operation of such receivers thereby being not entirely satisfactory due to distortion caused by improper phase relation between the two high-frequency waves. It is, therefore, highly desirable to provide a modulated-carrier signal receiver of the homodyne type in which the frequency of the locally-generated oscillations is maintained at the correct value even though the amplitude of the received signals varies over relatively wide limits and in which there is also provided an additional arrangement for maintaining the phase relationship between the locally-generated oscillations and the desired signal-carrier wave substantially at the optimum value for all values of amplitude of received signals within the synchronizing range of the receiver.

Furthermore, there are present in the detector of most homodyne receivers undesired components of detection of the signal to be reproduced, which are not properly homodyne detection components and which usually result in a faulty reproduction. However, these undesirable components are reduced materially if a square-law detector is utilized in the receiver. Square-law detectors, however, have a disadvantage in that no automatic amplification control or A. V. C. source is available without the use of additional tubes. It is, therefore, further highly desirable to provide a receiver of the homodyne type comprising a square-law detector in which the above-mentioned critical or optimum phase relationship is maintained and in which an automatic amplification control source is provided without the use of additional tubes. There are also some components of detection, which are undesirable for homodyne reception, which are not eliminated by a detector of the square-law type. These additional undesired components may be eliminated by the use of a balanced detector system.

It is, therefore, an object of the invention to provide an improved modulated-carrier signal receiver of the homodyne type in which one or more of the above-mentioned disadvantages of homodyne receivers of the prior art are eliminated.

It is a further object of the invention to provide a modulated-carrier signal receiver of the homodyne type including an arrangement for controlling the phase of locally-generated oscillations with respect to the desired received carrier wave independently of the amplitude of received signals.

In accordance with the invention, a modulated-carrier signal receiver of the homodyne type comprises means for selecting a desired modulated-carrier signal and a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced. The receiver also includes means responsive to the frequency of the carrier wave of a desired received signal, which is preferably relatively insensitive to variations of its amplitude, for maintaining the locally-generated oscillations in synchronism with the first-named carrier wave. There is also provided additional means responsive to the phase difference between the carrier wave of the signal to be reproduced and the locally-generated oscillations for maintaining the above-mentioned phase difference within predetermined limits for all values of amplitude of the received signal within the synchronizing range of the receiver. The receiver additionally includes means for combining the modulated-carrier signal to be reproduced with the locally-generated oscillations to derive the modulation-frequency components of the desired received signal.

In the preferred embodiment of the invention, the phase difference is maintained substantially at the optimum value to minimize distortion and to provide maximum volume of, the reproduced signal. Also, in a preferred embodiment of the invention, the receiver comprises a balanced detector system of the square-law type, thereby to eliminate undesired components of detection. There is preferably provided, with this last-mentioned modification of the invention, means, including the above-mentioned additional means for maintaining the desired phase relationship, for controlling the amplification of the receiver in response to the amplitude of received signals.

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

In the drawing, Fig. 1 is a circuit diagram, partly schematic, of a modulated-carrier signal receiver of the homodyne type incorporating the invention; while Figs. 2a–2f, inclusive, illustrate certain of the operating characteristics of the receiver of Fig. 1 to aid in an understanding of the invention.

Referring now more particularly to Fig. 1 of the drawing, there is shown a modulated-carrier signal receiver of the homodyne type comprising an antenna-ground circuit 10, 11 coupled to a radio-frequency amplifier 12 through a tunable selector circuit including a variable condenser 13. The radio-frequency output of amplifier 12 is coupled through transformer 14, 15 to the input circuit of a balanced detector comprising square-law detector tubes 16, 17 connected in a balanced circuit. There is also provided a local oscillator for generating oscillations of the frequency of the carrier of the signal to be received comprising an oscillator tube 18, a frequency-determining circuit comprising an inductance 19 and an adjustable tuning condenser 31 coupled to the input grid of tube 18, and a feed-back inductance 19′ coupled to an anode grid of tube 18, these grids comprising the oscillator electrodes of this tube. The inductance 19′ also is coupled to inductance 19, the condenser 31 being connected for unicontrol with condenser 13. An output from oscillator 18 is coupled from inductance 19, by means of inductances 20, 21 coupled thereto, to the input circuits of detector tubes 16 and 17 with opposite polarity. The homodyne audio-frequency output of detector tubes 16 and 17 is coupled with additive polarity to the input circuit of a low-pass filter 22 through a transformer including primary windings 23, 24 and a secondary winding 25. The low-pass filter 22 may be of any type and is preferably designed to have a high attenuation at 10 kilocycles, the frequency of interfering signals developed from a channel adjacent the channel of the desired received signal. The audio-frequency components of modulation are further amplified in audio-frequency amplifier 26 and are reproduced by loudspeaker 27 in a conventional manner. Unidirectional potentials for tubes 12, 16, 17, and 18 are supplied from suitable sources indicated as +B and +Sc in a conventional manner.

The components of the receiver which have so far been described are well understood in the art, rendering a detailed description of the operation thereof unnecessary. In general, however, desired signals intercepted by antenna 10, 11 are selected by selector means including variable condenser 13, are amplified in radio-frequency amplifier 12, and are applied in the same polarity to each of the detector tubes 16 and 17. Local oscillations generated by oscillator tube 18 of the frequency of the carrier wave of the desired received signal and bearing a predetermined phase relationship to the desired received signal, as will be explained hereinafter in more detail, are coupled with opposite polarity to detector tubes 16 and 17. The audio-frequency modulation signal developed in detector tubes 16 and 17 is passed by low-pass filter 22, amplified in audio-frequency amplifier 26, and reproduced by sound reproducer 27 in a manner well understood in the art.

Coming now to the parts of the system comprising the present invention, transformer 14, 15 is provided with an additional winding 30 for the purpose of applying to a negatively biased grid of tube 18, preferably an electrode additional to the oscillator electrodes of this tube, the desired received signal in order to provide synchronization of the locally-generated oscillations with the carrier wave of the desired received signal through the inherent interelectrode or electronic coupling within tube 18. Transformer 14, 15, 30 thus comprises means for coupling the carrier-signal selecting means comprising variable condenser 13 to the additional electrode of tube 18 to maintain the locally-generated oscillations in synchronism with the carrier wave. There is also coupled to primary winding 14 an additional winding 32 across which are connected in series a resistor 33 and a condenser 34. Elements 32, 33, and 34, together with primary winding 14, shunted by a condenser 35, comprise a two-terminal dead-end filter for passing a wide band of frequencies in a manner fully described in the copending application of Harold A. Wheeler, Serial No. 203,598, filed April 22, 1938, now Patent 2.167.137, dated July 25, 1939. The provision of this broad-band selector renders the provision of a tunable selector at this point of the receiver channel unnecessary.

While the incoming signal, applied to oscillator 18 by means of winding 30, serves to maintain the frequency of the locally-generated oscillations exactly equal to the frequency of the carrier wave of the desired received signals for settings of variable condenser 31 which are close to the correct setting, it is necessary also to provide an additional means for maintaining the phase of the locally-generated oscillations at the optimum relationship with respect to the carrier wave of the received signal. This phase control is provided by the control system 40 including a phase-discriminator circuit including diodes 41 and 42 to which the incoming signal is applied in the same phase through inductances **43** and **44** and to which an output voltage of oscillator **18** is applied to one of the diode rectifiers with one phase and to the other of the diode rectifiers with opposite phase by means of a coupling circuit comprising a condenser **45** and an inductance **46** inductively coupled to inductances **43** and **44** and included in the anode circuit of tube **18**. The phase-discriminator circuit is thus jointly responsive to voltages derived from the signal-carrier wave and from the oscillator. Equal load resistors **48** and **49** are provided for diodes **41** and **42**, respectively. The differential resultant unidirectional output voltage of diodes **41** and **42** is applied through a filter circuit including series resistors **51**, **52** and shunt condensers **53**, **54**, and **55** to bias the input circuit of a control vacuum tube **56**, the purpose of which is to adjust the phase of oscillator **18** to the desired value. A series-connected resistor **57** and blocking condenser **58** are connected between the anode and control grid of tube **56**. The anode circuit of tube **56** is connected in shunt to the frequency-determining circuit **19**, **31** and its grid-anode coupling is such that, by proper proportioning of resistor **57** and condenser **58**, it simulates a shunt inductance across the circuit **19**, **31** variable in magnitude in accordance with the control potential applied to its control electrode.

Before considering the operation of the portions of the circuit of Fig. 1 constituting the present invention, it is desirable first to consider the fundamental principles of operation of a homodyne receiver. The components of rectification of such a receiver may be obtained by substituting the sum of the received signal voltages and the voltage of a local oscillator for e in Equation 1 following, which is the equation for the anode current of any homodyne detector tube:

$$i_p = A_0 + A_1 e + A_2 e^2 + A_3 e^3 + \dots A_n e^n \qquad (1)$$

In which

i_p = detector output current,
A_0 to A_n = coefficients depending upon the detector tube characteristic,
$e = e_s + e_i + e_o$ = the input voltage to the detector.

The voltage e_s, applied to the detector tube, representing the desired signal, may be expressed by Equation 2 as follows:

$$e_s = E_s (1 + m \cos at) \cos \omega_o t \qquad (2)$$

Where

E_s = peak voltage of the carrier wave of the desired signal,
m = modulation factor of the desired signal,
$\frac{a}{2\pi}$ = modulation frequency of the desired signal, and
$\frac{\omega_o}{2\pi}$ = frequency of the carrier wave of the desired received signal and of the local oscillator.

The voltage e_i, representing an undesired signal applied to the detector tube, may be expressed by Equation 3 as follows:

$$e_i = E_i (1 + n \cos bt) \cos \omega_i t \qquad (3)$$

Where,

E_i = peak voltage of the carrier wave of the undesired signal,
n = modulation factor of the undesired signal,
$\frac{b}{2\pi}$ = modulation frequency of the undesired signal, and
$\frac{\omega_i}{2\pi}$ = frequency of the carrier wave of the undesired signal.

The oscillator voltage e_o applied to the detector may be expressed by Equation 4 as follows:

$$e_o = E_o \cos (\omega_o t + \phi) \qquad (4)$$

Where

E_o = peak voltage of the oscillator, and
ϕ = phase angle between the carrier wave of the desired signal and the oscillator voltage.

When Equations 2, 3, and 4 are substituted in the right-hand member of Equation 1, the expansion contains direct-current terms, high-frequency terms, and audio-frequency terms. Only those terms representing audio-frequency currents are capable of developing audio-frequency voltages in the detector load circuit. When all other terms are rejected, the expansion of the first three terms of Equation 1 produces Equation 5 representing the audio-frequency plate current:

$$\begin{aligned} i = A_2 \Big[& E_s^2 m \cos at + \frac{E_s^2 m^2}{4} \cos 2at \\ & + E_i^2 n \cos bt + \frac{E_i^2 n^2}{4} \cos 2bt \\ & + E_s E_i \cos (\omega_o - \omega_i) t \\ & + \frac{E_s E_i}{2} m \cos (\omega_o - \omega_i + a) t \\ & + \frac{E_s E_i}{2} m \cos (\omega_o - \omega_i - a) t \\ & + \frac{E_s E_i}{2} n \cos (\omega_o - \omega_i + b) t \\ & + \frac{E_s E_i}{2} n \cos (\omega_o - \omega_i - b) t \\ & + E_o E_i \cos (\omega_o t - \omega_i t + \phi) \\ & + \frac{E_o E_i}{2} n \cos (\omega_o t - \omega_i t + bt + \phi) \\ & + \frac{E_o E_i}{2} n \cos (\omega_o t - \omega_i t - bt + \phi) \\ & + E_o E_s m \cos \phi \cos at \Big] \end{aligned} \qquad (5)$$

It will be noted that the first nine terms of the right-hand member of Equation 5 are independent of E_o, the oscillator voltage. They may be called the products of ordinary detection, and appear for both desired and undesired signals. The second term of Equation 5 is at double the original desired modulation frequency and represents distortion. The third and fourth terms of Equation 5 are respectively at the fundamental and second harmonic frequencies of the modulation of the undesired signal wave and represent interference. The fifth to twelfth terms, inclusive, of Equation 5 are not ordinarily in the range of frequencies reproduced by the audio-frequency amplifier and loud-speaker. If, however, the desired and undesired signals are on adjacent broadcast channels, the fifth and tenth terms represent the beat response at 10,000 cycles and the sixth, eighth, and eleventh terms or, alternatively, the seventh, ninth, and twelfth terms, depending on whether the interfering signal has a carrier frequency above or below the desired signal, represent additional interferences below 10,000 cycles.

The last term in Equation 5 depends on the product of the desired signal voltage E_s, the modulation factor m, and the oscillator voltage

E_o and is, therefore, the desired product of homodyne detection. By making E_o large relative to E_s and ϕ equal to zero, the last term of Equation 5 becomes greater than the first nine terms, thereby materially reducing the percentage of both the distortion and the interference.

The foregoing are the fundamental principles upon which the operation of the simple homodyne receiver is based; that is, by making the oscillator voltage E_o sufficiently large, the harmonic output is decreased and the ratio of the amplitude of desired signal components to undesired signal components is increased, since the former is produced mostly by homodyne detection and the latter by detection of the ordinary type.

In the foregoing analysis, the terms beyond the third term of Equation 1 were not considered. The fourth term contributes no audio-frequency components. The fifth term A_4e^4, however, contributes, in addition to the fundamental of the modulation frequency, harmonics up to and including the fourth. It is thus indicated that for a detector to supply components resulting in a minimum of distortion, the coefficients A_4 to A_n of its characteristic should be negligible. A square-law detector fulfills this condition since its anode current is ideally represented by the first three terms of the right-hand member of Equation 1. For this reason detector tubes 16 and 17 are preferably of the square-law type.

An improved detector circuit is provided by the use of the balanced detector system of Fig. 1. In the ideal case, that is, with a perfectly balanced square-law detector system, all except the last four terms of Equation 5 are eliminated by cancellation in the push-pull output circuit of the system; that is, Equation 5 becomes:

$$\begin{aligned} i = & 2E_oE_i \cos(\omega_o t - \omega_i t + \phi) \\ & + E_oE_i m \cos(\omega_o t - \omega_i t + bt + \phi) \\ & + E_oE_i m \cos(\omega_o t - \omega_i t - bt + \phi) \\ & + 2E_oE_s m \cos\phi \cos at \end{aligned} \quad (6)$$

Inasmuch as an undesired signal on an adjacent channel produces in the detector output a heterodyne frequency equal to the difference frequency between the local oscillator and the undesired signal, represented by the first term of Equation 6, a low-pass filter 22, designed to have a high attenuation of 10 kilocycles, is preferably provided immediately following the detector. Either the second or the third term of Equation 6 may contain interfering modulation-frequency terms within the range of audio-frequency reproduction, if the interfering signal is on a channel adjacent to the desired signal, but, in this case, the interfering signal component is within the band of desired signals and may not be eliminated by any means which does not also reduce the response at the desired signal frequencies. As a result of the discrimination against undesired signals provided by balanced homodyne detection and by the low-pass filter 22, the selectivity requirements of the radio-frequency channel of the receiver of Fig. 1 are greatly reduced so that the single tunable selector circuit comprising variable condenser 13 is sufficient.

When $(\omega_o - \omega_i)/2\pi$ is greater than the frequency separation between adjacent channels, the first three terms of Equation 6 represent components above audibility and the equation reduces to:

$$i = 2E_oE_s m \cos\phi \cos at \quad (7)$$

According to Equation 7, the output of a perfectly balanced square-law detector is proportional to the amplitudes of the signal-carrier and local oscillator voltages and to the cosine of the phase angle between them. When the phase angle ϕ is zero, the output is a maximum and when it is $\pi/2$, the output is zero.

Reference is now made to Figs. 2a–2f, inclusive, the curves of which are all plotted against values of condenser 31 as abscissae, for a complete explanation of the operation of the circuit of Fig. 1. In the absence of a synchronizing voltage on the tube of oscillator 18, the variation of the oscillator frequency as a function of capacitance C of tuning condenser 31 is given by the dashed line in Fig. 2a. For the value C_o of the condenser C, the frequency of the oscillator is assumed to be f_o. If, under these conditions, a synchronizing voltage of frequency f_o is applied to the grid of tube 18 through inductance 30, the oscillator frequency remains unchanged. Furthermore, as tuning condenser 31 is adjusted within the limits $C_o+\Delta C$ and $C_o-\Delta C$, the oscillator frequency remains at the desired frequency f_o. This operation is indicated by the solid horizontal line in Fig. 2a. Beyond the values $C_o\pm\Delta C$, however, synchronization is not maintained and the full-line curve of Fig. 2a becomes asymptotic to the dashed line. The greater the synchronizing voltage applied through inductance 30, the wider the region $2\Delta C$ over which synchronization is maintained although, as compared to most synchronizing arrangements of the prior art, the synchronizing arrangement of the invention is relatively insensitive to changes in amplitude of the desired received carrier.

The diagrams of Fig. 2b illustrate the phase relations which exist between several of the circuit voltages and the anode current as a function of the tuning capacitance C. The voltages e_2, e_3, and e_4, respectively, represent the radio-frequency carrier voltage applied through inductances 20 and 21 to the input electrodes of detector tubes 16 and 17, the carrier voltage applied through inductances 43 and 44 to the phase-control diodes 41 and 42, and the carrier voltage applied from winding 30 to oscillator 18. These voltages all have the same phase which, for convenience, has been selected as the reference phase, and i_a and e_1 represent, respectively, the anode current of oscillator 18 and the voltage across the frequency-determining circuit 19, 31 as determined by tests of a typical circuit. As shown by Fig. 2b when $C=C_o$, the current i_a is in phase with the synchronizing voltage e_4 while e_1 is opposite in phase to e_4. As C is decreased by ΔC, i_a lags e_4 by $\pi/2$. The central portions of the phase curves are approximately linear so that, for these regions, the phase angles are substantially proportional to variations in the value of condenser 31.

As will be explained more in detail hereinafter, it is necessary for the oscillator voltage e_p, applied to the phase-discriminator circuit including diodes 41 and 42, to be in quadrature with the signal-frequency voltage e_3, also applied thereto, when the value of capacitance of tuning condenser 31 is $C=C_o$. Since the anode current i_a is then in phase with said signal voltage e_3, the desired phase relation for e_p may be obtained by allowing the current i_a to flow through a reactive load circuit. This is provided by condenser 45 and inductance 46 adjusted to resonate below the band of frequencies to be received by the receiver. The resulting phase relation for the voltage e_p is also shown in Fig. 2b.

As explained above, the rectified output of a balanced homodyne detector is proportional to the cosine of the phase angle at the detector between the locally-generated oscillations and the carrier wave of the signal to be reproduced. Fig. 2c depicts this variation in output resulting from a phase deviation within the limits $\pm\pi/2$, corresponding to values of tuning condenser 31 of $C_o+\Delta C$ and $C_o-\Delta C$, respectively, which would exist if no control were present. Outside the region between $C_o\pm\Delta C$, the oscillator is unsynchronized and modulation-frequency signals are masked by beat-frequency signals developed between the signal-carrier wave and the local oscillations.

Fig. 2d illustrates the variation of distortion as a function of variation of capacitance C, primarily due to lack of perfect balance. It will be noted that the maximum distortion is obtained for the condition giving minimum volume and vice versa, as shown by Fig. 2c. Tests indicate that phase modulation in the oscillator also contributes materially to the production of the distortion indicated by the curve of Fig. 2d.

It is evident from Figs. 2c and 2d that the desired setting of condenser 31 must be such that the deviation of its capacitance from the value C_o is small and preferably zero. Since, in manually varying tuning condenser 31, it can only be expected that the oscillator will be brought to some point within the range of synchronization and not necessarily to the exact point required for optimum signal reproduction, an automatic means is required for decreasing the effective departure of the value of condenser 31 from its desired value. This is accomplished by means of unit 40 of Fig. 1. The resultant unidirectional voltage output developed by the phase-responsive circuit including diodes 41 and 42 is shown in Fig. 2e. By a method similar to that used for obtaining the audio-frequency components, it may be shown that the direct current in diode 41 is given by Equation 8 as follows:

$$i_1=A_2\left[\frac{E_3^2}{2}+\frac{T^2E_p^2}{2}+TE_3E_p\cos\psi\right] \quad (8)$$

Where

A_2=the coefficient in the expression for diode current,

E_3=peak voltage of the carrier wave of the signal,

E_p=peak anode voltage of the oscillator,

T=voltage transformation ratio of transformer 46, 43, 44, and

ψ=phase angle between the above voltages.

In a similar way the direct current in diode 42 is given by Equation 9 as follows:

$$i_2=A_2\left[\frac{E_3^2}{2}+\frac{T^2E_p^2}{2}-TE_3E_p\cos\psi\right] \quad (9)$$

Since these currents develop unidirectional voltages in resistors 48 and 49 which are in opposition, the net unidirectional voltage output of the two diodes is:

$$E_c=2RA_2TE_3E_p\cos\psi \quad (10)$$

where R is the resistance of each of resistors 48 and 49.

If Ψ is made $\pm\pi/2$ when the value of $C=C_o$, then the voltage E_c is zero but assumes increasing positive or negative values for departures of C from C_o. Since e_p is arranged to lag i_a by $\pi/2$, and ϕ is the angle between the oscillator and signal voltages at the signal detector, Equation 10 may be rewritten as Equation 11 as follows:

$$E_c=\pm 2RA_2TE_3E_p\sin\phi \quad (11)$$

The tube 56, biased by unidirectional voltage E_c, therefore, supplies an increasingly larger effective susceptance for phase correction as C departs from C_o. The action of this susceptance, supplied by the control tube 56, is very similar to that of the operation upon the frequency-determining circuit of the local oscillator of the corresponding tube of an automatic frequency control system of a conventional superheterodyne receiver.

By way of illustration, if E_c is made negative, due to an arbitrary setting of $C=C_o-\Delta C_1$, the negative susceptance which the control tube 56 supplies across the tuned circuit 19, 31 is less than for $C=C_o$. This reduces the resonant frequency of the circuit 19, 31 plus the control tube 56. A similar change in tuning might have been obtained by manually increasing the value of C, which, as shown by Fig. 2b, brings the voltages more nearly to the desired phase. The action continues until the effective remaining departure $-\Delta'C_1$ is just sufficient to produce the voltage $-E_{c1}$ required to shift the equivalent effective capacitance by an amount $\Delta C_1-\Delta'C_1$.

Fig. 2f shows this relationship. The dashed diagonal line of Fig. 2f provides a means for transferring the values of $\Delta'C$ to the scale of abscissae of Figs. 2a–2e, the value $-\Delta'C_1$ on the scale of abscissae being indicated in Fig. 2f. The vertical line through $-\Delta C_1$ represents the conditions in Figs. 2b–2f, inclusive, for the illustrative manual setting alone. The vertical line drawn through $-E_{c1}$ represents the conditions in Figs. 2b–2f, inclusive, after the automatic control acts.

If the original manual setting had been for a value of $C=C_o+\Delta C_1$, the operation would have been similar except that the developed voltage E_c would have been positive and the shift in tuning would have been in the opposite direction. In other words, the phase of oscillator voltage input to detectors 16, 17 remains nearly constant (0 or π radians) with respect to the signal-input voltage e_2 thereto, as the value of condenser 31 is adjusted between the limits $C_o\pm\Delta C$, which is the range of synchronization. Specifically, for a setting of condenser 31 corresponding to a value of $C_o-\Delta C_1$, it is seen that the actual variation of the effective value of condenser 31 from its desired value is only $-\Delta C_1$, and that the distortion is only a small amount while the volume is near its maximum value.

It is thus seen that the phase-controlling arrangement of the invention is effective to reduce the deviation of the uncontrolled phase difference between the desired received signal and the locally-generated oscillations from its optimum value by at least 2:1 for values of said uncontrolled phase difference displaced with respect to the optimum value of the phase difference for distortionless reception, as shown by the phase differences corresponding to $-\Delta C_1$ and $-\Delta'C_1$ on the curves of Figs. 2b–2f, inclusive, and that the device is thus effective to maintain the controlled phase difference substantially within the range of $\pm\pi/4$ with respect to the optimum value for distortionless reception. In the preferred embodiment of the invention, the above-mentioned reduction is much greater than 2:1, being at least of the order of 10:1. It is seen from curve 2c, therefore, that the volume output of the receiver remains substantially constant and, from curve 2d, that the distortion remains near the minimum value over the operating range of the system. Outside the range of synchronization, the phase-control circuits exert no controlling influence on the circuit of the oscillator. In the region outside the range of synchronization, beat-frequency signals are produced between the oscillator and the desired signal voltages and unsatisfactory operation results.

It will be understood that various silencing arrangements known to the prior art can be utilized to silence the receiver while tuning and that the automatic phase-control arrangement of the invention can be made to be inoperative while tuning the receiver.

Inasmuch as no satisfactory source of automatic volume control is available in the balanced detector of Fig. 1, the voltage developed across diode load resistor **49** of the phase-discriminator unit **40** is utilized as a control bias and is applied to the input electrode of tube **12** and any other similar stages that may be included in the receiver, thereby to maintain the signal input to detectors **16** and **17** within a relatively narrow range of amplitude for a wide range of received signals, in a manner well understood in the art.

While applicant does not wish to be limited to any particular circuit values for the embodiment of the invention described, there follows a set of representative values which may be utilized in the circuit of Fig. 1:

Tube **18**	Type 6A8
Tubes **41** and **42**	Type 6H6
Tube **56**	Type 6J7
Tubes **16** and **17**	Type 6J7
Inductance **32**	1.6 millihenries
Inductance **14**	1.6 millihenries
Inductance **15**	20 microhenries
Coefficient of coupling between inductances **14** and **32**	0.8
Coefficient of coupling between inductances **14** and **15**	0.12
Capacitance **45**	30 micro-microfarads
Inductance **46**	10 millihenries
Inductance **43**	5 millihenries
Inductance **44**	5 millihenries
Coefficient of coupling between inductance **46** and inductances **43** and **44**	0.8
Resistor **48**	0.5 megohm
Resistor **49**	0.5 megohm
Resistor **52**	1 megohm
Resistor **57**	50,000 ohms
Capacitance **58**	0.001 microfarad
Capacitance **55**	100 micro-microfarads
Inductance **19**	200 microhenries
Inductance **19'**	200 microhenries
Inductance **20**	35 microhenries
Inductance **21**	35 microhenries
Coefficient of coupling between inductance **19** and inductances **20** and **21**	0.5

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

What is claimed is:

1. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

2. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal and relatively insensitive to variations of its amplitude for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

3. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the said carrier wave and substantially independent of its amplitude for maintaining the said locally-generated oscillations in synchronism with said carrier wave, additional means responsive to the phase difference between the said carrier wave and said locally-generated oscillations for maintaining said phase difference substantially at the optimum value for distortionless reproduction, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

4. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within a range of plus or minus $\pi/4$ radians with respect to the optimum value of said phase difference for distortionless reception, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

5. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations for reducing the deviation of the uncontrolled phase difference from its optimum value by a ratio of at least two to one for values of said uncontrolled phase difference substantially displaced with respect to the optimum value of said phase difference for distortionless reception, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

6. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations for reducing the deviation of the uncontrolled phase difference from its optimum value by a ratio of at least ten to one for values of said uncontrolled phase difference substantially displaced with respect to the optimum value of said phase difference for distortionless reception, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

7. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator including a vacuum tube for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means for electronically coupling said selecting means to said vacuum tube for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

8. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator including a vacuum tube having oscillator electrodes and an additional electrode, said oscillator being provided to generate oscillations of the frequency of the carrier wave of the signals to be reproduced, means for coupling said selecting means to said additional electrode to maintain said locally-generated oscillations in synchronism with said carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

9. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, means for deriving a first voltage from said oscillator and a second voltage from said desired received signal, a phase-discriminator means responsive jointly to said first and second voltages for maintaining the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

10. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two rectifiers, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers, one of said voltages being applied in the same phase to each of said rectifiers and the other of said voltages being applied to one of said rectifiers with one phase and to the other of said rectifiers with opposite phase, means responsive to the differential output of said rectifiers for maintaining the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

11. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, means for deriving a first voltage from said oscillator and a second voltage from said desired received signal, phase-discriminator means responsive to said first and second voltages for developing a bias voltage varying in accordance with the difference in phase between said first and said second voltages, means for utilizing said bias to maintain the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the

modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

12. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two rectifiers, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers, said voltages being relatively displaced 90 degrees in phase under normal operating conditions of said system and one of said voltages being applied in the same phase to each of said rectifiers and the other of said voltages being applied to one of said rectifiers with one phase and to the other of said rectifiers with opposite phase, means responsive to the differential output of said rectifiers for maintaining the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

13. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator including a frequency-determining circuit for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two diode rectifiers, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers, one of said voltages being applied in the same phase to each of said rectifiers and the other of said voltages being applied to one of said rectifiers with one phase and to the other of said rectifiers with opposite phase, means responsive to the differential output of said rectifiers effectively varying the reactance of said frequency-determining circuit to maintain the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

14. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator including a frequency-determining circuit for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two diode rectifiers, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers, one of said voltages being applied in the same phase to each of said rectifiers and the other of said voltages being applied to one of said rectifiers with one phase and to the other of said rectifiers with opposite phase, electronic reactance means controlled by the differential output of said rectifiers and coupled to said frequency-determining circuit to maintain the phase difference between said carrier wave of said signal to be reproduced and said locally-generated oscillations within predetermined limits, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

15. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two rectifiers comprising a load circuit, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers to develop a bias voltage varying in accordance with the phase difference of said last-mentioned voltages, means for utilizing said bias voltage to maintain the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, means comprising said load circuit for maintaining the volume of the reproduced signal within relatively narrow limits for a wide range of received signal amplitudes, and means for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of said desired received signal.

16. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, and means including a square-law detector for combining the modulated-carrier signal to be reproduced and said locally-generated oscillations to derive the modulation-frequency components of the desired received carrier signal.

17. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, two vacuum-tube de-

tectors, means for applying a voltage derived from said signal to be reproduced and a voltage derived from the output of said oscillator to each of said detectors, one of said voltages being applied to both of said detectors in the same phase and the other of said voltages being applied to one of said detectors in one phase and to the other of said detectors in opposite phase, thereby to derive the modulation-frequency components of said desired received signal.

18. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, two vacuum-tube detectors, means for deriving a voltage from said signal to be reproduced and a voltage from the output of said oscillator, said voltages being substantially of the same phase and one of said voltages being applied to both of said detectors in the same phase and the other of said voltages being applied to one of said detectors in one phase and to the other of said detectors in opposite phase, thereby to derive the modulation frequencies of the said desired received signal.

19. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, two square-law vacuum-tube detectors, and means for applying a voltage derived from the desired received signal and a voltage derived from the output of said oscillator to each of said detectors, one of said voltages being applied to both of said detectors in the same phase and the other of said voltages being applied to one of said detectors in one phase and to the other of said detectors in opposite phase, thereby to derive the modulation frequencies of said desired received signal.

20. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signals to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of the said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, a signal detector, means for applying a voltage derived from a desired received signal and a voltage derived from the output of said oscillator to said detector to derive the modulation frequencies of said desired received signal, and a low-pass filter coupled to the output circuit of said detector to attenuate undesired signals appearing in channels adjacent that of the desired signal.

21. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a signal-transmitting channel including one or more amplifier stages, a local oscillator including a tunable frequency-determining circuit for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, a tunable signal selector included in said channel preceding the first amplifier of said receiver, unicontrol tuning means for said tunable frequency-determining circuit and said tunable selector, means responsive to the frequency of the carrier wave of the desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, additional means responsive to the phase difference between the carrier wave of said signal to be reproduced and said locally-generated oscillations for maintaining said phase difference within predetermined limits, a detector in said signal-translating channel, and a low-pass filter in said signal-translating channel at a point succeeding said detector to eliminate undesired signals appearing in channels adjacent to the channel of said desired received signal.

22. A modulated-carrier signal receiver of the homodyne type comprising, means for selecting a desired modulated-carrier signal, a local oscillator for generating oscillations of the frequency of the carrier wave of the signal to be reproduced, means responsive to the frequency of the carrier wave of a desired received signal for maintaining said locally-generated oscillations in synchronism with said first-named carrier wave, two rectifiers, means for applying an output voltage from said oscillator and a voltage derived from said desired received signal to said rectifiers, one of said voltages being applied in the same phase to both of said rectifiers and the other of said voltages being applied to one of said rectifiers with one phase and to the other of said rectifiers with opposite phase, means responsive to the differential output of said rectifiers for maintaining the phase difference between the carrier wave of the signal to be reproduced and said locally-generated oscillations within predetermined limits, two vacuum-tube detectors, means for applying a voltage derived from said signal to be reproduced and a voltage derived from the output of said oscillator to each of said detectors, said last-named voltage derived from said oscillator and said voltage derived from said signal to be reproduced being 90 degrees displaced in phase, and one of said voltages applied to said detectors being applied to both of said detectors in the same phase and the other of said voltages applied to said detectors being applied to one of said detectors in one phase and to the other of said detectors in opposite phase, thereby to derive modulation-frequency components of said desired received signal.

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