

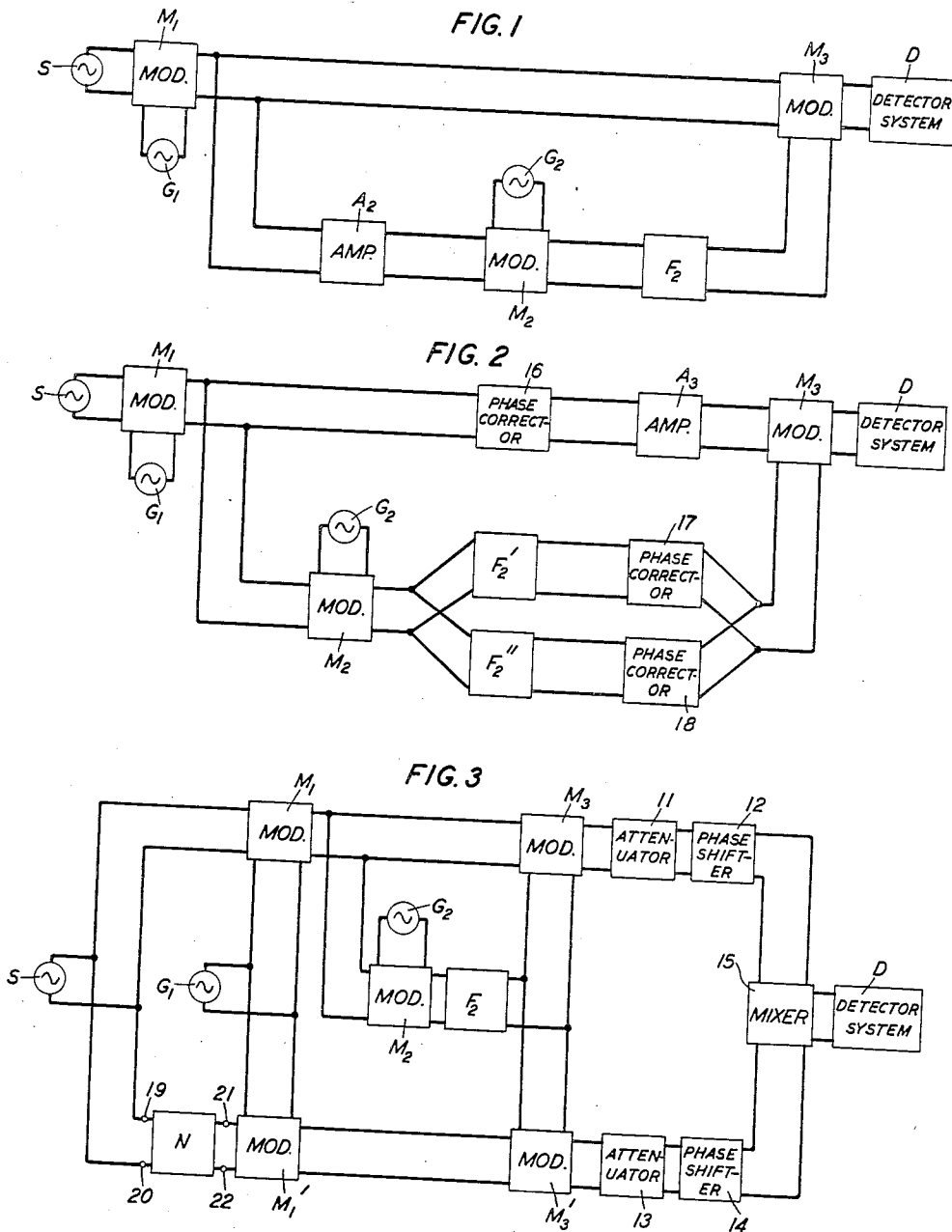
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ELECTRICAL RECEIVING AND MEASURING SYSTEM

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ELECTRICAL RECEIVING AND MEASURING
SYSTEM

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This invention relates to the utilization of a signal wave in receiving and measuring systems.

An object of the invention is to provide a stable intermediate frequency wave in the reception of a signal wave regardless of the frequency drift in the signal wave.

Another object is to provide a stable intermediate frequency wave in the reception of a signal wave regardless of frequency drift in the heterodyne current of the receiver.

A further object is to provide a stable intermediate frequency wave in an electrical measuring system regardless of frequency drift in the signal wave.

Another object of the invention is to provide a stable intermediate frequency wave in an electrical measuring system regardless of frequency drift in the heterodyne current of the system.

Heretofore difficulty has been encountered in the reception of signal waves because of changes in the frequencies of the signal wave and the heterodyne current. In accordance with the present invention this difficulty is overcome by the addition of one or more heterodyne stages, one of which employs an oscillator of fixed and stable frequency. The system is so arranged that the original signal wave is reproduced, the reproduced wave consisting of an intermediate frequency wave of high frequency stability. Thus frequency drift in the original signal wave or the heterodyne current does not affect the reception of the signal wave. Difficulties due to frequency drifts similar to those in receivers exist also in electrical testing circuits and these difficulties can be overcome by the same means as those employed in receivers. Specific embodiments of the invention are described in which it is applied to radio receivers and measuring systems.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing of which:

Fig. 1 is a schematic diagram used to explain the principles of the invention and to represent an embodiment of the invention in a receiving or measuring system;

Fig. 2 is a modification of the circuit of Fig. 1 in which two waves instead of one wave are supplied by one of the modulators; and,

Fig. 3 is another embodiment of the invention in a measuring system.

The principle involved in the invention will be explained in connection with the schematic diagram of Fig. 1, in which S is a source of signal

current of frequency f , G_1 is a source of heterodyne current of frequency f_1 and M_1 is a modulator. The currents of frequencies f and f_1 are combined in the modulator M_1 to produce an output current of frequency $f_a = (f - f_1)$, a part of which is supplied to a second modulator M_2 and another portion of which is supplied to a third modulator M_3 . The heterodyne current for the modulator M_2 is furnished by the source G_2 which has a fixed and stable frequency f_2 smaller than f_a . The output of the modulator M_2 is passed through a band-pass filter F_2 which transmits the frequency $(f_a + f_2)$ or $(f_a - f_2)$ but excludes undesired components, and this selected frequency is also supplied to the modulator M_3 . The currents of frequency f_a and $(f_a + f_2)$ or $(f_a - f_2)$ are combined in the modulator M_3 to produce an output current of frequency f_2 which is unaffected by frequency drift in the sources S and G_1 . The output of the modulator M_3 is supplied to the detecting system D.

An amplifier A_2 , having the same band width as the filter F_2 , and equipped with automatic or manual volume control if desired, may be inserted in front of the modulator M_2 or after M_2 . This amplifier may also be built in two sections, one of which is located before and the other one after modulator M_2 . The amplifier can also be placed in the link connecting M_1 and M_3 . In this way the relative levels of the inputs to the modulator M_3 can be controlled. The mid-frequency of the amplifier or amplifier section depends, of course, upon its location in the circuit.

It is preferable that modulator M_3 should have a linear plate current-grid voltage characteristic. The design of M_3 in other respects follows standard practice, and this is also true of the design of the modulators M_1 and M_2 . However, it may be desirable to place in the output of M_1 a filter having its transmission band properly centered and a band width equal to that of the filter F_2 .

Some relationships between the various frequencies involved which should be observed if the best results are to be obtained will now be considered. If f_0 is the nominal frequency of the output of the modulator M_1 and d is the permissible frequency drift, the actual output frequency f_a will always lie between the limits $(f_0 + d)$ and $(f_0 - d)$. Let the frequencies f_0 and f_2 be determined by the equations

$$f_0 = 3rd \quad (1)$$

$$f_2 = 6d \quad (2)$$

where r is an odd integer equal to or greater than 55

9. The output of M_2 will contain one frequency $(f_a - f_2)$ located within the frequency band

$$(f_0 - f_2 - d) \text{ to } (f_0 - f_2 + d), \quad (3)$$

5 another frequency $(f_a + f_2)$ located within the band

$$(f_0 + f_2 - d) \text{ to } (f_0 + f_2 + d) \quad (4)$$

and in addition undesirable modulation products
10 each of which is located within a certain band. Such undesirable products are:

$$\left. \begin{array}{l} f_a, f_2 \\ 2f_a, 2f_2 \\ 3f_a, (2f_a \pm f_2), (f_a \pm 2f_2), 3f_2 \end{array} \right\} \quad (5)$$

and so on. Let us limit our attention to products up to and including order r . There is only one undesirable product, namely

$$20 \quad f_a - (r-1)f_2, \text{ order } r \quad (6)$$

falling in the band (3). No product falls in the band (4). The products

$$\left. \begin{array}{l} 2f_a - \frac{r+1}{2}f_2, \text{ order } \frac{r+5}{2} \\ 2f_a - \frac{r+3}{2}f_2, \text{ order } \frac{r+7}{2} \end{array} \right\} \quad (7)$$

30 may fall on the upper edge of the first band (3) or the lower edge of this band, respectively, but never inside the band. The products

$$\left. \begin{array}{l} 2f_a - \frac{r-3}{2}f_2, \text{ order } \frac{r+1}{2} \\ 2f_a - \frac{r-1}{2}f_2, \text{ order } \frac{r+3}{2} \end{array} \right\} \quad (8)$$

40 may fall on the upper edge of the second band (4) or the lower edge of this band, respectively, but never inside this band. All other products fall outside the two bands at least a distance $2d$. By choosing r sufficiently large, the undesirable products (6), (7) and (8) can be made so small
45 that they can be safely neglected, and this is also true for products of order higher than r which may fall in the bands (3) and (4). The value required for r depends, of course, on the design of the modulator M_2 , and in particular on the vacuum tubes used therein.

50 It is now clear that the filter F_2 should have a band width equal to $2d$, with its band centered at the frequency $(f_0 + f_2)$ or $(f_0 - f_2)$. If the minimum allowable value of r is $r_{\min}$, a value of r greater than $r_{\min}$ may be chosen if desired. Similarly, if the minimum permissible value of d is $d_{\min}$, a value of d greater than $d_{\min}$ may be used. Then the band width of the filter F_2 may be given
55 any value between $2d_{\min}$ and $2d$.

60 It should be observed that the choice of the output frequency $f_a = (f - f_1)$ of the modulator M_1 is not the only one since it also is possible to use the output frequency $f_a = (f + f_1)$. The former possibility is advantageous in high frequency work where both f and f_1 usually are large compared to f_a , while the latter choice is convenient in low-frequency application where f_1 may be made large compared to f . For the purpose of illustration it is sufficient to limit the
65 subsequent discussion to the first possibility.

70 Fig. 2 shows a modification of the system of Fig. 1 in which the band-pass filter F_2 is replaced by two band-pass filters F_2' and F_2'' connected in parallel. One of the filters has its mid-band

frequency located at $(f_0 + f_2)$ and the other at $(f_0 - f_2)$. In this way, all of the undesired frequencies in the output of the modulator M_2 except $(f_a + f_2)$ and $(f_a - f_2)$ are suppressed, and these two frequencies are supplied to the modulator M_3 . The amplifier A_3 , if required, is located between M_1 and M_3 , and the phase correctors 16, 17 and 18 are placed in the circuit as shown. These modifications may be used when the invention is applied to the radio receiving circuit described hereinafter.

It will now be assumed that S in Fig. 1 is a source of signal current representing, for example, a modulated wave consisting of a carrier and the two accompanying side-bands of the type used in telephonic and telegraphic communication. In this case f is the carrier frequency of the signal current, f_a is the carrier frequency of the signal wave after M_1 , $(f_a + f_2)$ or $(f_a - f_2)$ is the carrier frequency of the signal wave after F_2 , and f_2 is the carrier frequency of the signal wave after M_3 . The band width of the filter F_2 is now determined by the permissible frequency drift d of the carrier frequency f_a as well as by the channel width of the signal current.

When S in Fig. 2 is a source of modulated signal current then f is the carrier frequency of the signal current, f_a is the carrier frequency of the signal wave after M_1 , $(f_a + f_2)$ and $(f_a - f_2)$ are the carrier frequencies of the signal waves after F_2' and F_2'' , and f_2 is the carrier frequency of the signal wave after M_3 .

The application of the invention to a receiving system intended for the reception of modulated waves will now be explained by reference to Fig. 1. Unmodulated waves may be considered to be special cases of modulated waves. The modulated signal current from the source S is delivered directly to M_1 or is delivered to M_1 after having passed amplifying and selective circuits which permit the signal current to pass in spite of its frequency drift.

The detecting system D may be designed in a variety of ways. For purpose of illustration it may be assumed that D consists of a selective circuit and a detector as well as amplifying means. The band width of the selective circuit in the detecting system can be made equal to that of the signal current from source S , and the signal wave after M_3 is then detected by the detector in D . The selective circuit can also be so designed that one side-band in the signal wave after M_3 is suppressed, the remaining side-band and the carrier in this wave being detected by the detector in D . The selective circuit can also be made to suppress one side-band and the carrier, the remaining side-band being detected by having in D a heterodyne detector supplied with a heterodyne current of frequency f_2 which may be obtained from the source G_2 . In this latter case, the selective circuit in D should have a band width equal to that of the useful side band. It is also possible to suppress the carrier only. Another possibility is to feed the signal wave after M_3 into a heterodyne detector, the output of which is fed into D , which then performs as before. This heterodyne detector may be supplied with a source of heterodyne current of suitable fixed and stable frequency.

The above illustrates the type of equipment to precede M_1 and to follow M_3 in a receiving system. In the receiving system shown in Fig. 2, the apparatus preceding the modulator M_1 and that

following the modulator M_3 may be of the type just described above in connection with Fig. 1.

Fig. 3 shows an application of the invention to a measuring system adapted to determine the insertion loss and phase shift introduced by electrical apparatus. Insertion loss is here used in its broad sense to include both loss and gain. In Fig. 3 the testing current of frequency f is furnished by the source S . This current is split into two parts, one of which is fed directly to the modulator M_1 and the other of which passes through the network N under test to the modulator M_1' . The network N is inserted into the test circuit by connecting its available terminals to the terminals 19, 20, 21 and 22. The modulators M_1 and M_1' are supplied with heterodyne current from the same source G_1 of frequency f_1 . These modulators will therefore have in their outputs a frequency $f_a = (f - f_1)$. The output of M_1' is fed into the modulator M_3' and part of the output of M_1 is fed into modulator M_3 . Another portion of the output of M_1 is supplied to the modulator M_2 , which has a heterodyne current of frequency f_2 furnished by the source G_2 . As explained previously, amplification may be employed at this point, if required, in the form of an amplifier which may either precede or follow M_2 .

The filter F_2 suppresses all of the modulation products in the output of M_2 except the frequency $(f_a + f_2)$ or $(f_a - f_2)$, which is supplied as heterodyne current to the modulators M_3 and M_3' . The outputs of M_3 and M_3' will each have a component of the frequency f_2 which is unaffected by drifts in the frequencies f and f_1 . The output current from M_3 passes through the variable attenuator 11 and the variable phase shifter 12, and likewise the output from M_3' passes through the variable attenuator 13 and the variable phase shifter 14, after which the two currents are combined in a suitable mixer 15.

The output current from the mixer is detected by the detecting system D . As an illustration, D may comprise a suitable amplifier, which is preceded and followed by filters, each having a narrow band width centered at the frequency f_2 , and a detector. The detector in this case may conveniently be a vacuum tube voltmeter with logarithmic response, or it may be a telephone receiver if the frequency f_2 is in the audible range. If this frequency is not in the audible range the output current from the mixer 15 may be supplied to a suitable heterodyne detector, the output of which is fed into the detecting system D , although this is not the only possibility. For instance, it is also possible to insert between M_3 and the attenuator 11 one modulator and between M_3' and the attenuator 13 a second modulator, these new modulators having a common source of heterodyne current of suitable fixed and stable frequency.

In the operation of the measuring circuit shown in Fig. 3 a null method is employed. The variable attenuators 11 and 13, and the variable phase shifters 12 and 14 are adjusted until the current entering the mixer 15 from the modulator M_3 is equal in magnitude but opposite in phase to the current entering from the modulator M_3' . This condition is indicated by a lack of response in the detecting system D . The system is first balanced while the unknown apparatus N is removed from the circuit, the terminals 19 and 20 being strapped respectively to terminals 21 and 22. The network N is then connected into the circuit, as shown in Fig. 3, and

the system again balanced. The differences between the settings of the variable attenuators and phase shifters for these two conditions will give directly the insertion loss and phase shift introduced by the network N under test, at the particular test frequency used. Other networks, as for example attenuators, may be inserted, if required, in one or both of the paths connecting the source S to the modulator M_1 and M_1' .

As long as the heterodyne voltages supplied to the modulators M_3 and M_3' in Fig. 3 are large, the amplitudes of these voltages need not be kept constant. However, it may improve the accuracy of the measuring system to maintain these voltages at substantially constant levels by means of a gain control. To minimize the changes in these voltages occurring when the network N is inserted into or removed from the circuit, it is preferable to connect M_2 to M_1 when N is connected to M_1' , as shown in Fig. 3. The circuit link connecting the modulators M_1 and M_3 , and the link connecting the modulators M_1' and M_3' , are so designed that as the frequency f_a drifts between its allowable limits the changes in phase shift and attenuation in the one link are equal to the changes in the other.

In order to illustrate the frequency relationships to be observed in the design of the measuring system shown in Fig. 3 a concrete set of frequencies will be assumed, although it will be understood that these frequencies are referred to merely by way of example. Let us assume that the highest signal frequency f is 30,000,000 cycles per second, that the total drift in the sources S and G_1 is one part in 10,000 per hour and the time required to obtain a balance is six minutes or one tenth of one hour. Then the frequency drift d during the interval required to make a measurement may be as much as

$$d = \frac{30,000,000 \times 0.1}{10,000} = 300 \text{ cycles per second.} \quad (9)$$

Taking r as 31, the nominal output frequency f_0 of the modulator M_1 is found from Equation 1 to be

$$f_0 = 3rd = 3 \times 31 \times 300 = 27,900 \text{ cycles per second.} \quad (10)$$

From Equation 2 the frequency f_2 of the source G_2 is found to be

$$f_2 = 6d = 6 \times 300 = 1800 \text{ cycles per second.} \quad (11)$$

The band-pass filter F_2 should thus have its transmission band centered at one of the alternative frequencies

$$f_0 + f_2 = 27,900 + 1800 = 29,700 \text{ cycles per second} \quad (12)$$

or,

$$f_0 - f_2 = 27,900 - 1800 = 26,100 \text{ cycles per second} \quad (13)$$

and a band width of

$$2d = 2 \times 300 = 600 \text{ cycles per second.} \quad (14)$$

The invention can also be applied to current analyzers which are used to determine the magnitude of the components of a complex wave. Fig. 1 illustrates an embodiment of the invention for this purpose. In this case S is the source

of the wave to be analyzed, and the component to be determined is selected by adjusting the frequency f_1 of the source G_1 . For the purpose of illustration, the detecting system D may consist of an amplifier preceded and followed by narrow band filters with transmission bands centered at the frequency f_2 , and a detector. This detector may be simply a current indicating instrument, such as a milliammeter in conjunction with a thermo-couple, a vacuum tube voltmeter, or the like. The detecting system may also include an attenuator. The component under test produces a response in D and the magnitude of this component is determined by disconnecting S from M_1 and by supplying to M_1 a known calibrating voltage of the same frequency as the component tested.

Analyzers of the type just described can be used not only for the purpose mentioned above but also as detectors and gain or loss measuring sets. The attenuator in the detecting system performs a particularly important function in gain or loss measuring sets, since by its aid it is possible to determine gain or loss at high frequencies without using calibrated high frequency attenuators, since these determinations can be made by the aid of the attenuator in D which operates at the relatively low frequency f_2 .

Some explanations required for a more complete understanding of the invention will now be made. The circuit shown in Fig. 1, when used to receive a modulated signal wave, will first be considered. In this case there is impressed on M_3 two modulated signal waves having the carrier frequencies f_a and $(f_a + f_2)$ or $(f_a - f_2)$. The output of M_3 is a modulated signal wave having f_2 as a carrier frequency. In order to insure a high quality of the output wave, the level of one of the input waves is made large compared to the level of the other input wave. In addition a linear plate current-grid voltage characteristic of the modulator M_3 is helpful. These statements can be verified by reference to a paper by Charles B. Aiken, "Theory of the Detection of Two Modulated Waves by a Linear Rectifier", I. R. E., Proceedings, April, 1933, particularly Equation 62.

Noise is associated with each input wave but since the band width of the selective circuit in the detecting system D is not greater than just required, as explained previously, there is under normal operating conditions no degradation or no appreciable degradation of the signal-to-noise ratio, provided the above means have been taken to insure high quality of the output signal, as can also be verified by reference to the paper just mentioned, and provided the permissible frequency drift does not exceed several hundred kilocycles, since otherwise there may be an increase in noise due to the very large input noise to M_3 . While the filter F_2 limits the amount of noise reaching M_3 with one input wave to the amount inevitable to take care of the frequency drift, the noise reaching M_3 with the other input wave may be limited by using a selective circuit after M_1 , although this circuit may not be required when selective circuits precede M_1 .

The receiver selectivity is limited to an extent determined by the permissible frequency drift. The selectivity is determined by the band width of the filter F_2 . When employed, the selective circuit inserted after M_1 assists the selectivity. The sensitivity however is not so limited since there is no degradation or no appreciable degradation in the signal-to-noise ratio as we pro-

ceed from the received signal through the receiver to the output of the detecting system D. Since the input to M_3 consists of two modulated waves each with its associated noise, the quality of the output of M_3 and the signal-to-noise ratio, have been discussed. The input to M_1 consists of one modulated signal wave and a single-frequency heterodyne current from G_1 and there is not necessarily any degradation in quality or signal-to-noise ratio in the output of M_1 , if standard practice is followed. A similar remark applies to the output of the modulator M_2 .

Fig. 1 will next be considered when used as a current analyzer. In this case the input waves to M_3 consist of two pure frequencies f_a and $(f_a + f_2)$ or $(f_a - f_2)$. The output of M_3 consists of a pure frequency f_2 . There are no quality considerations but the use of a linear modulator for M_3 , and adjustment of the level ratio of the input waves are still means helpful from the standpoint of noise, and in this respect the filter F_2 as well as the filter after M_1 , when provided, are also helpful. Since the band-pass filter in the detecting system D can be made as narrow as is permitted by the stability of the source G_2 , the effective noise can be limited by using extremely narrow filters in D. Hence, it may not be necessary to use a linear modulator, since an increase in noise in a non-linear modulator can be compensated for by narrowing the filter in D. In a receiver the corresponding selective circuits cannot be narrowed, since they must have a definite width to transmit the signals, and therefore the linear modulator is more essential in a receiver. Finally, it should be remarked that the large level ratio at the input to M_3 increases the modulating efficiency of M_3 .

In a current analyzer the source S delivers as a rule a number of components to M_1 , but it is assumed that none except the component to be measured is effective. This is realized by excluding the undesirable components by means of the filter F_2 and the filter after M_1 , when the latter is employed, assuming that no selective circuits precede M_1 . This means that the undesirable components must have a certain frequency separation from the component to be measured, which is the same as to say that the analyzer selectively is limited to an extent determined by the permissible frequency drift. Analyzer measurements can almost always be so arranged that the selectivity limitation is unimportant. The sensitivity is not limited.

When the analyzer shown in Fig. 1 is used as a detector or insertion loss measuring set what has just been said still holds, except that the selectivity limitation becomes even less important or is of no importance at all.

The insertion loss and phase measuring circuit shown in Fig. 3 will next be considered. In view of the above discussion of Fig. 1 as a measuring circuit, it would only involve repetition to discuss Fig. 3 in detail, and only a single remark will therefore be made. Since there are two modulators M_2 and M_3' , it would appear at first sight that more noise reaches the detecting system than that produced by a single modulator. However, by properly setting the attenuators 11 and 13, measurements can always be so arranged that the noise reaching D never exceeds that produced by a single modulator.

A discussion of the theory underlying the receiving circuit shown in Fig. 2 will now be pre-

sented. Let the modulated signal wave at the output of M₁ be represented by

$$\begin{aligned} & \epsilon \cos \omega_a t \left[1 + \sum_{i=1}^n m_i \cos (\delta_i t + \beta_i) \right] \\ & = \epsilon \cos \omega_a t + \frac{\epsilon}{2} \sum_{i=1}^n m_i \\ & [\cos ((\omega_a + \delta_i)t + \beta_i) + \cos ((\omega_a - \delta_i)t - \beta_i)] \quad (15) \end{aligned}$$

where

t = time

ϵ = amplitude of the carrier of frequency f_a

$\omega_a = 2\pi f_a$ = angular frequency of carrier

$\frac{\epsilon}{2} m_i$ = amplitude of side-band component

$\omega_a + \delta_i$ = angular frequency of upper side-band component

$\omega_a - \delta_i$ = angular frequency of lower side-band component

β_i = phase angle of upper side-band component

$-\beta_i$ = phase angle of lower side-band component

$$\begin{aligned} & \mu \epsilon \cos (\omega_a t + \lambda \omega_a) \left[1 + \frac{2\eta}{\mu} \cos (\omega_2 t + \phi + \lambda \omega_2) + \right. \\ & \left. \sum m_i \cos (\delta_i t + \beta_i + \lambda \delta_i) + \frac{\eta}{\mu} \sum m_i \cos ((\omega_2 + \delta_i)t + \phi + \beta_i + \lambda(\omega_2 + \delta_i)) + \right. \\ & \left. \frac{\eta}{\mu} \sum m_i \cos ((\omega_2 - \delta_i)t + \phi - \beta_i + \lambda(\omega_2 - \delta_i)) \right] \quad (22) \end{aligned}$$

While ω_a may be considered to be located in the radio frequency range, δ_i is in the audio range.

The expression (15) represents an exact reproduction of the signal wave received by M₁, at least if the circuits preceding M₁ are provided with suitable phase correcting networks. Let the heterodyne voltage supplied to M₂ by G₂ be

$$C_2 \cos (\omega_2 t + \phi) \quad (16)$$

where

C_2 = amplitude

$\omega_2 = 2\pi f_2$

ϕ = phase angle

The waves represented by (15) and (16) combine in the modulator M₂ to produce at the input of modulator M₃ a wave represented by

$$\begin{aligned} & \eta \epsilon \cos [(\omega_a + \omega_2)t + \phi + \lambda(\omega_a + \omega_2)] + \\ & \frac{\eta \epsilon}{2} \sum m_i \cos [(\omega_a + \omega_2 + \delta_i)t + \phi + \beta_i + \lambda(\omega_a + \omega_2 + \delta_i)] + \\ & \frac{\eta \epsilon}{2} \sum m_i \cos [(\omega_a + \omega_2 - \delta_i)t + \phi - \beta_i + \lambda(\omega_a + \omega_2 - \delta_i)] + \\ & \eta \epsilon \cos [(\omega_a - \omega_2)t + \phi + \lambda(\omega_a - \omega_2)] + \\ & \frac{\eta \epsilon}{2} \sum m_i \cos [(\omega_a - \omega_2 + \delta_i)t - \phi + \beta_i + \lambda(\omega_a - \omega_2 + \delta_i)] + \\ & \frac{\eta \epsilon}{2} \sum m_i \cos [(\omega_a - \omega_2 - \delta_i)t - \phi - \beta_i + \lambda(\omega_a - \omega_2 - \delta_i)] \quad (17) \end{aligned}$$

which can be written

$$2\eta \epsilon \cos (\omega_a t + \lambda \omega_a) \cos (\omega_2 t + \phi + \lambda \omega_2) [1 + \sum m_i \cos (\delta_i t + \beta_i + \lambda \delta_i)] \quad (18)$$

where η is a factor of proportionality. In Fig. 2 the phase corrector 17 is so designed that the entire phase shift suffered by a single component travelling from M₂ via F₂' to M₃ equals λ multiplied by the angular frequency of the component, where λ is another factor of proportionality. A similar phase corrector 18 is inserted after the filter F₂'.

The output of M₁ given by (15) after going through the link containing the phase corrector 16 and the amplifier A₃ is also impressed on M₃. This signal impressed on M₃ can be represented by

$$\begin{aligned} & \mu \epsilon \cos (\omega_a t + \lambda \omega_a) + \\ & \frac{\mu \epsilon}{2} \sum m_i [\cos ((\omega_a + \delta_i)t + \beta_i + \lambda(\omega_a + \delta_i)) + \\ & \cos ((\omega_a - \delta_i)t - \beta_i + \lambda(\omega_a - \delta_i))] \quad (19) \end{aligned}$$

which is the same as

$$\mu \epsilon \cos (\omega_a t + \lambda \omega_a) [1 + \sum m_i \cos (\delta_i t + \beta_i + \lambda \delta_i)] \quad (20)$$

In (20) μ is a factor of proportionality, and the phase shift suffered by a component travelling from M₁ via the phase corrector 16 and A₃ to M₃ is controlled by this phase corrector.

The total signal impressed on M₃ is the sum of (18) and (20), that is,

$$\epsilon \cos (\omega_a t + \lambda \omega_a) [1 + \sum m_i \cos (\delta_i t + \beta_i + \lambda \delta_i) [\mu + 2\eta \cos (\omega_2 t + \phi + \lambda \omega_2)]] \quad (21)$$

which can be written

If

$$\frac{\eta}{\mu}$$

is small compared to unity, then (22) represents a moderately modulated wave of the carrier frequency ω_a , provided the modulation of the original signal (15) is not too large. The ratio

$$\frac{\eta}{\mu}$$

is made small compared to unity by the aid of the amplifier A₃. Then, M₃ being a linear detector followed by a detecting system passing frequencies in the vicinity of $2\pi f_2 = \omega_2$ only, the output of interest from M₃ due to the input (22) will be proportional to

$$\begin{aligned} & 2\eta \epsilon \cos (\omega_2 t + \phi + \lambda \omega_2) + \\ & \eta \epsilon \sum m_i \cos [(\omega_2 + \delta_i)t + \phi + \beta_i + \lambda(\omega_2 + \delta_i)] + \\ & \eta \epsilon \sum m_i \cos [(\omega_2 - \delta_i)t + \phi - \beta_i + \lambda(\omega_2 - \delta_i)] \quad (23) \end{aligned}$$

which can be written

$$2\eta \epsilon \cos (\omega_2 t + \phi + \lambda \omega_2) [1 + \sum m_i \cos (\delta_i t + \beta_i + \lambda \delta_i)] \quad (24)$$

If

$$t + \lambda = \tau \quad (25)$$

then (24) can be written

$$2\eta \epsilon \cos (\omega_2 \tau + \phi) [1 + \sum m_i \cos (\delta_i \tau + \beta_i)] \quad (26)$$

which, it will be noted, is an exact reproduction of (15), the original signal.

If the wave represented by (26) is detected by a linear detector, the output of this detector will be proportional to

$$2\eta \epsilon \sum m_i \cos (\delta_i \tau + \beta_i) \quad (27)$$

whereas direct linear detection of (15) would have produced an output proportional to

$$\epsilon \sum m_i \cos (\delta_i t + \beta_i) \quad (28)$$

It will be seen that the two expressions (27) and (28) differ only by the constant factor 2η and a time delay represented by λ .

To preserve the quality of the signal the detecting system D itself may be furnished with suitable phase correcting networks, if required. Also, to the various phase correcting networks may be added amplitude correcting networks, if required.

The above theory in connection with Fig. 2 may be summarized by saying that the entire input to the modulator M_3 , consisting of three modulated waves having the carrier frequencies f_a , $(f_a + f_2)$ and $(f_a - f_2)$, can be considered as a single modulated wave of the carrier frequency f_a , provided certain phase and perhaps amplitude correcting networks are introduced. By making the level of the wave having the carrier frequency f_a large compared to the level of the waves having the carrier frequencies $(f_a + f_2)$ and $(f_a - f_2)$ the single modulated wave mentioned is not over-modulated as long as the received signal is not over-modulated. This single wave when not over-modulated permits an exact reproduction of the original signal wave by means of a linear detector.

What is claimed is:

1. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting one of said resultant waves, and combining said selected wave with a second portion of said signal wave to produce a second resultant wave, said second portion of said signal wave being unaltered as to its position in the frequency spectrum.

2. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting two of said resultant waves, and combining said selected waves with a second portion of said signal wave to produce a second resultant wave.

3. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting one of said resultant waves, combining said selected wave with a second portion of said signal wave to produce a second resultant wave, and making the relative volume levels of said selected wave and said second portion of said signal wave substantially different, said second portion of said signal wave being unaltered as to its position in the frequency spectrum.

4. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting two of said resultant waves, combining said selected waves with a second portion of said signal wave to produce a second resultant wave, and making the volume level of said second portion of said signal wave high compared to the volume level of said selected waves.

5. A method of utilizing a signal wave containing carrier and side-bands which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves each consisting of its carrier and side-bands, selecting two of said resultant waves, combining said selected waves with a second portion of said signal wave to produce a second resultant wave, and controlling the phases of said selected waves and said second portion of said signal wave.

6. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves which include two reproductions of said signal wave, the frequency of said heterodyne current and the carrier frequency of said signal wave being so related that said two reproductions fall within separate frequency bands while all disturbing portions of said resultant waves fall outside of said frequency bands, selecting one of said separate frequency bands, and combining the wave falling within said selected band with a second portion of said signal wave to produce a second resultant wave, said second portion of said signal wave being unaltered as to its position in the frequency spectrum.

7. A method of utilizing a signal wave which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves which include two reproductions of said signal wave, the frequency of said heterodyne current and the carrier frequency of said signal wave being so related that said two reproductions fall within separate frequency bands while all disturbing portions of said resultant waves fall outside of said bands, selecting both of said separate frequency bands, and combining the waves falling within said selected bands with a second portion of said signal wave to produce a second resultant wave.

8. In combination a source of signal current, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said modulator to produce resultant waves, means for selecting one of said resultant waves, a second modulator, and means for impressing said selected wave and a second portion of said signal current upon said second modulator to produce a second resultant wave, said second portion of said signal current being unaltered as to its position in the frequency spectrum.

9. In combination a source of signal current, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said modulator to produce resultant waves, means for selecting two of said resultant waves, a second modulator, and means for impressing said selected waves and a second portion of said signal current upon said second modulator to produce a second resultant wave.

10. In combination a source of signal current, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said modulator to produce resultant waves, means for selecting one of said resultant waves, a second modulator, means for impressing said selected wave and a second portion of said signal current upon said second modulator to produce a second resultant wave, and means for making the relative volume levels of said selected wave and said second portion of said signal current substantially different, said first mentioned portion of said signal current having the same frequency composition as said signal current, and said second portion of said signal current being unaltered as to its position in the frequency spectrum.

11. In combination a source of signal current, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said

modulator to produce resultant waves, means for selecting two of said resultant waves, a second modulator, means for impressing said selected waves and a second portion of said signal current upon said second modulator to produce a second resultant wave, means for making the volume level of said second portion of said signal current high compared to the volume level of said selected waves, and means for controlling the phases of said selected waves and said second portion of said signal current.

12. In combination a source of signal current, a first modulator, a second modulator, a source of heterodyne current, means for impressing a portion of said heterodyne current and a portion of said signal current upon said first modulator to produce a first resultant wave, means for impressing a second portion of said heterodyne current and a second portion of said signal current upon said second modulator to produce a second resultant wave, a third modulator, a second source of heterodyne current, means for impressing current from said second source and a portion of said first resultant wave upon said third modulator to produce a third resultant wave, a fourth modulator, means for impressing a portion of said third resultant wave and a second portion of said first resultant wave upon said fourth modulator to produce a fourth resultant wave, a fifth modulator, means for impressing said second resultant wave and a second portion of said third resultant wave upon said fifth modulator to produce a fifth resultant wave, means for controlling the amplitudes and phases of said fourth resultant wave and said fifth resultant wave, means for combining said fourth resultant wave and said fifth resultant wave to produce a sixth resultant wave, and means for detecting said sixth resultant wave.

13. In combination a source of signal current, a first modulator, a second modulator, an electrical path connecting said source with said first modulator, a second electrical path connecting said source with said second modulator, means for inserting an electrical network in one of said paths, a source of heterodyne current, means for impressing a portion of said heterodyne current upon said first modulator to produce a first resultant wave, means for impressing a second portion of said heterodyne current upon said second modulator to produce a second resultant wave, a third modulator, a second source of heterodyne current, means for impressing current from said second source and a portion of said first resultant wave upon said third modulator to produce a third resultant wave, a fourth modulator, means for impressing a portion of said third resultant wave and a second portion of said first resultant wave upon said fourth modulator to produce a fourth resultant wave, a fifth modulator, means for impressing said second resultant wave and a

second portion of said third resultant wave upon said fifth modulator to produce a fifth resultant wave, means for controlling the amplitudes and phases of said fourth resultant wave and said fifth resultant wave, means for combining said fourth resultant wave and said fifth resultant wave to produce a sixth resultant wave, and means for detecting said sixth resultant wave.

14. The method of utilizing a signal wave containing carrier and side-bands which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting two of said resultant waves each consisting of its carrier and side-bands, combining said selected waves with a second portion of said signal wave to produce a second resultant wave, and controlling the phase of at least one of said selected waves.

15. The method of utilizing a signal wave containing carrier and side-bands which comprises generating a heterodyne current, combining a portion of said signal wave with said heterodyne current to produce resultant waves, selecting two of said resultant waves each consisting of its carrier and side-bands, combining said selected waves with a second portion of said signal wave to produce a second resultant wave, and controlling the phase of said second portion of said signal wave.

16. In combination a source of signal current comprising carrier and side-bands, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said modulator to produce resultant waves, means for selecting two of said resultant waves each consisting of its carrier and side-bands, a second modulator, means for impressing said selected waves and a second portion of said signal current upon said second modulator to produce a second resultant wave, and means for controlling the phase of at least one of said selected waves.

17. In combination a source of signal current comprising carrier and side-bands, a modulator, a local source of heterodyne current, means for impressing said heterodyne current and a portion of said signal current upon said modulator to produce resultant waves, means for selecting two of said resultant waves each consisting of its carrier and side-bands, a second modulator, means for impressing said selected waves and a second portion of said signal current upon said second modulator to produce a second resultant wave, and means for controlling the phase of said second portion of said signal current.

18. An electrical system in accordance with claim 12 in which means are provided for filtering said third resultant wave.

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