Sept. 12, 1944. C. W. EARP 2,358,152

PHASE AND FREQUENCY MODULATION SYSTEM

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Fig. 1.

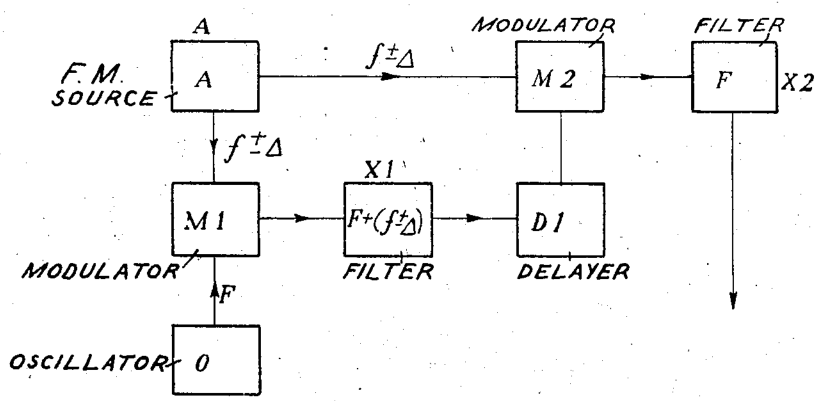
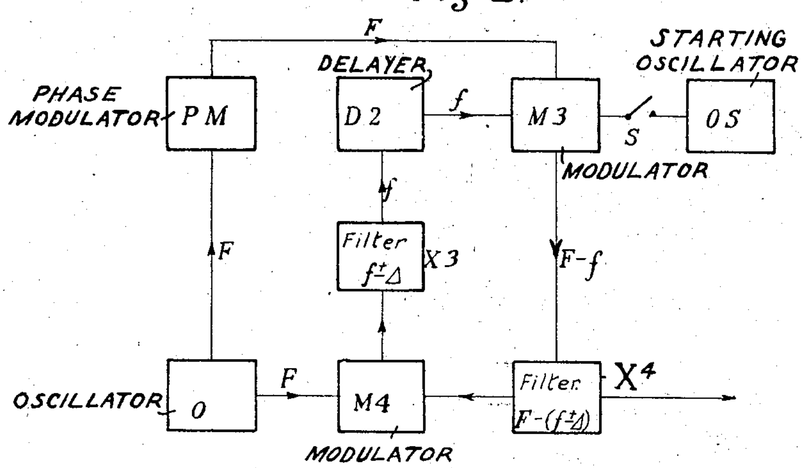


Fig. 2.



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PHASE AND FREQUENCY MODULATION SYSTEM

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6 Claims. (Cl. 179—171.5)

The present invention relates to an arrangement for the conversion of frequency modulation to phase modulation and vice versa, and the application thereof to the production of a frequency modulated wave from a frequency stable oscillator such as a crystal controlled oscillator.

An ultimate object of the invention is to provide a simple and economic arrangement for producing a frequency modulated wave of large excursion, that is, a large range between the limits of frequency variation, from a frequency stable oscillator such as a crystal controlled oscillator.

According to one feature of the invention, an arrangement for the conversion of frequency modulation to phase modulation of stable frequency comprises a first modulator to which the frequency modulated wave and the stable frequency are fed and a second modulator to which are fed the frequency modulated waves and one of the side bands in the output from said first modulator, the paths between the source of phase modulated waves and said second modulator being so designed as to have a linear frequency versus differential phase shift characteristic, the output of said second modulator being passed through a filter designed to pass said stable frequency.

From another aspect of this feature of the invention an arrangement for the conversion of a frequency modulated wave to a phase modulated wave is characterised in that a beat frequency is produced between a stable frequency and the frequency modulated wave, the said beat frequency being given a phase shift in accordance with its deviation from a mean frequency and then combined with the original frequency modulated wave to produce a phase modulated wave of said stable frequency.

According to another feature of the invention an arrangement for the conversion of a phase modulated wave to a frequency modulated wave comprises a modulator and a circuit arrangement for producing a frequency linearly variable in accordance with the phase of said phase modulated wave, said phase modulated wave and said variable frequency being fed to said modulator for producing the frequency modulated wave, said circuit arrangement comprising a second modulator to which are fed one of the side-bands of the output of the first-mentioned modulator and the unmodulated frequency of the phase modulated wave, the beat frequency in the output of said second modulator being fed to the input of said first modulator, the feed-back path of the first modulator thus produced being designed to have a total phase delay linearly variable with frequency.

In its application for producing a frequency modulated wave of stable mean frequency an arrangement according to this latter feature comprises an arrangement for producing a phase modulated wave of a stable frequency, and an arrangement for producing a frequency linearly variable in accordance with the phase of said phase modulated wave, the said phase modulated wave and said variable frequency being fed together to a first modulator for producing in the output thereof the frequency modulated wave, the arrangement for producing said variable frequency comprising a second modulator to which are fed one of the side-bands of the output of the first modulator and the said stable frequency, the beat frequency in the output of said second modulator being fed to the input of said first modulator, the feed-back path of said first modulator thus formed being designed to have a total phase delay linearly variable with frequency.

In order to attain the ultimate object of the invention, the phase modulated wave of stable frequency is first produced by the modulating wave and the phase modulated wave is then converted to a frequency modulated wave by an arrangement according to the above features of the invention.

The invention will be more clearly understood from the following description taken in conjunction with the accompanying drawing which shows schematically in

Fig. 1 a circuit arrangement for converting a frequency modulated wave to a phase modulated wave, and

In Fig. 2 a circuit for producing a frequency modulated wave and utilising the arrangement shown in Fig. 1 for first producing a phase modulated wave.

Referring to Fig. 1 of the drawing, a source of frequency modulated waves is shown at A, the normal unmodulated frequency being f and the frequency excursion being represented by $\pm\Delta$. The wave energy from A is fed along two paths, namely directly to modulator M2 and to modulator M1 which is supplied with a carrier wave of stable frequency F from the oscillator O. The output of M1 is fed to a filter X1 in order to select one sideband of the modulation, for instance $(F+f)$ which is then passed to the modulator M2. A delay device is represented at D1 but this should be understood to represent generally the circuit elements producing the total delay over the path from M1 to M2, the phase shift being linear with frequency. In actual practice a separate delay network may not necessarily be required since the requisite delay may be introduced by proper design of the filter X1 automatically. A well designed filter giving a flat frequency-amplitude characteristic over the pass-band provides the necessary linear phase shift with frequency and has all the characteristics of a simple delay device for all frequencies contained within the pass-band of frequencies.

There is thus fed to the modulator M2 two waves differing in frequency by F which is selected by a final filter X2. The amount of phase modulation of the output from M2 or filter X2 is determined by the differential delay between the two signal paths between A and M2, and delay devices may be inserted in the direct path from A to M2, between A and M1, or between M1 and M2.

The delay network D1 (or X1) is such that a linear phase shift of θ radians per Δ cycles is introduced in the path from M1 to M2 and may, of course, be comprised by the filter X1. If the frequency of the signal increases from f to $(f+\Delta)$ the phase distortion produced by the delay network will be advanced by θ radians and consequently the output of F from M2 will also be advanced by θ radians. Similarly any other frequency change between $+\Delta$ and $-\Delta$ will produce a corresponding phase modulation between + and $-\theta$ on the frequency F from oscillator O. In other words a frequency excursion $\pm\Delta$ is translated to a phase modulation of $\pm\theta$ on the frequency F.

Fig. 2 shows an arrangement for producing a frequency modulation of a frequency stable oscillator. This circuit arrangement is a simple inversion of the circuit arrangement shown in Fig. 1, that is, a source of phase modulated waves is substituted for the wave source A in Fig. 1. This is shown in Fig. 2 by the rectangle PM. In Fig. 2, O is an oscillator of stable frequency F, which may for instance be crystal controlled. The output from O is phase modulated in PM and the output from PM is fed to a modulator M3. Output from the oscillator O is also fed to the modulator M4 where it is modulated by one of the side bands $[F\pm f\pm\Delta)]$ whose frequency is dependent upon the phase modulation and is obtained as described later via a filter X4 of mean pass frequency $(F+f)$ or $(F-f)$. The output of M4 contains the frequency $(f\pm\Delta)$ which is passed by the filter X3 of mean pass frequency f and fed to the modulator M3, which as already stated is also supplied with the phase modulated frequency F. The output from M3 thus includes the side bands $F\pm(f\pm\Delta)$ one of which, e. g. $F-(f\pm\Delta)$ is passed by the filter X4 and is the frequency modulated wave required and is of mean frequency $F-f$ in the example. Part of the output of X4 is, as already stated, fed back to the modulator M4. A delay network D2 is shown between X3 and M3 but, as in the case of Fig. 1 this represents elements of the feedback path (X4—M4—X3) of M3 which produce phase shifts. A phase delay network may be used to make the total phase shift of the feedback path linear with frequency or the filters X3 and X4 may be properly designed in known manner to carry out this function.

If the amplification around the circuit is sufficiently great oscillations are set up and these must be of mean frequency f in order to pass through filter X3 and $(F-f)$ in the example to pass through X4. The delay network D2 (or X3 and/or X4) is/are designed to give a linear phase distortion of $\pm\theta$ radians over a frequency band $f\pm\Delta$. If a certain frequency f is produced when the frequency F injected into M3 has a definite phase relationship to the output from O injected into M4 and if a change in this phase relationship occurs, the correct phase relationship for oscillation round the loop has now been upset and the frequency f will rise or fall to accommodate itself to the new conditions. For instance, if the phase of the injected frequency F into M3 is advanced with respect to the direct injection of the same frequency from O into M4, oscillations can only be maintained in the loop if the frequency f is increased to $(f+\Delta)$ and the frequency $(F-f)$ to $[F-(f+\Delta)]$. Oscillation on these new frequencies is quite stable.

In certain cases it may be necessary to initiate the loop oscillations by injecting into the feedback circuit an oscillation of frequency fo lying within the limits of the frequency modulation of $F-f$ (or $F+f$).

An oscillator OS of frequency fo is shown in Fig. 2, coupled up to the modulator M3 by means of a switch S. When the switch S is closed the starting oscillator OS feeds the modulator M3 with the frequency fo for example, and the output from M3 is then $(F-fo)$. If frequency $F-fo$ were used it would be introduced into the circuit at or between the output of M3 and the input of M4.

Taking the case when frequency fo is introduced into M3 it beats with frequency F from the phase modulation source PM, to produce frequency $F-fo$ which is passed to M4. Here frequency $F-fo$ beats with frequency F directly fed from the oscillator O to produce the difference frequency fo which is passed via the filter X3 and delay network D2 to modulator M3, reinforcing the initial oscillation from the starting oscillator OS. The starting oscillator may now be switched out of circuit, and the oscillations continue. The oscillator O at frequency F thus produces a frequency $(F-f)$ in the output of the filter X4 and a frequency f in the forward path from M4 to M3. Suppose now the phase of the frequency F injected into M3 is advanced with respect to the wave directly injected into modulator M4, due to its phase modulation, and as previously stated the correct phase relationship for maintaining the oscillations at frequency f and $(F-f)$ has been upset and oscillations can only be maintained by an increase of frequency from f to $f+\Delta$ and from $(F-f)$ to $(F-f-\Delta)$. Similarly a retardation of the phase of F fed to M3 produces a change in the loop frequency from f to $(f-\Delta)$ and from $(F-f)$ to $(f-f+\Delta)$.

Thus a phase modulation of $\pm\theta$ on the oscillator O produces two frequency modulated waves $(f\pm\Delta)$ and $[F-(f\pm\Delta)]$.

If the phase modulation is linear, since the time delay network gives linear phase distortion with frequency, the output wave is linear in frequency with the original modulating wave.

What is claimed is:

1. A system for producing a frequency modulated wave of stable mean frequency which comprises a source of stable frequency, means to phase modulate the frequency from said source, a first modulator, means to deliver the phase modulated wave to said first modulator, a second

modulator, means to impress the stable frequency from said source on said second modulator, means to impress a portion of the output of said first modulator on said second modulator, means to impress the output of said second modulator on said first modulator, means to provide a total phase delay linearly with frequency between said second modulator and said first modulator, and means to utilize a remaining portion of the output of said first modulator as the desired frequency modulated wave.

2. A system as defined in claim 1, in which a filter is provided in the output circuit of each modulator which will pass one side band only of the output of said modulator.

3. A system as defined in claim 1, in which a filter is provided in the output circuit of each modulator which will pass one side band only of the output of said modulator, the filter in the output circuit of said second modulator having a linear frequency vs phase shift characteristic and is the means to provide the phase delay.

4. A system as defined in claim 1 in which an oscillator is provided to inject energy into the loop circuit between the two modulators to start the system functioning.

5. A system for the conversion of a phase modulated wave to a frequency modulated wave which comprises a first modulator, means to deliver a phase modulated wave to said first modulator, a source of stable frequency at the frequency of said modulated wave, a second modulator, means to impress on said second modulator a portion of the energy from said source of stable frequency, means to impress a portion of the output of said first modulator on said second modulator, means to impress the output of said second modulator on said first modulator, means to provide a total phase delay linearly with frequency between said second modulator and said first modulator, and means to utilize a remaining portion of the output of said first modulator as the desired frequency modulated wave.

6. The method of producing a frequency modulated wave of stable mean frequency which comprises producing a wave of stable frequency, phase modulating a portion of said wave, beating said phase modulated wave with a wave having a frequency linearly variable in accordance with the phase of said phase modulated wave, beating a portion of the resultant modulated wave with another portion of said stable frequency wave, delaying the phase of the resultant wave linearly with frequency, utilizing said phase delayed wave as said aforementioned wave having a frequency linearly variable in accordance with the phase of said phase modulated wave which is used to beat with said phase modulated wave, and utilizing the remaining portion of the resultant of said first beating for the desired frequency modulated wave.

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