April 1, 1941. D. B. PENICK 2,236,856

MODULATING SYSTEM

Filed March 29, 1939

FIG. 1

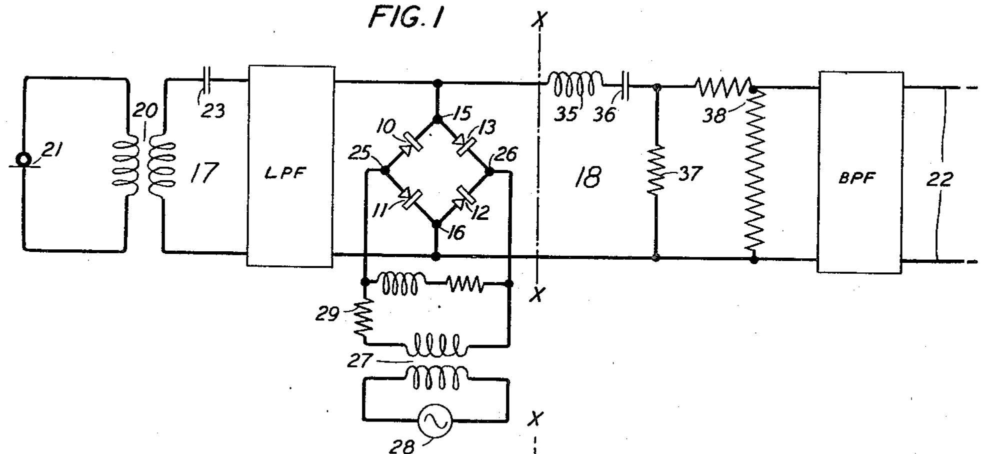


FIG. 1A

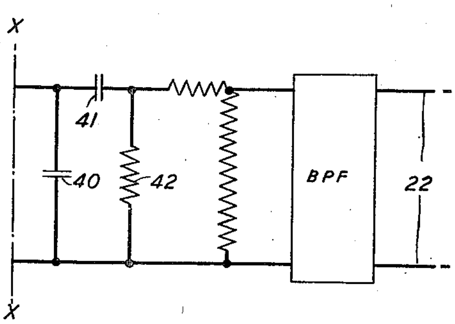


FIG. 2A

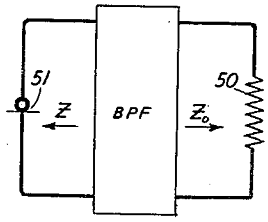


FIG. 2B

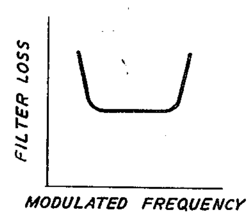


FIG. 2C

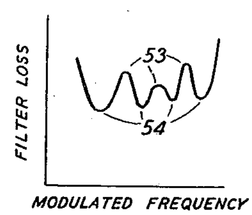
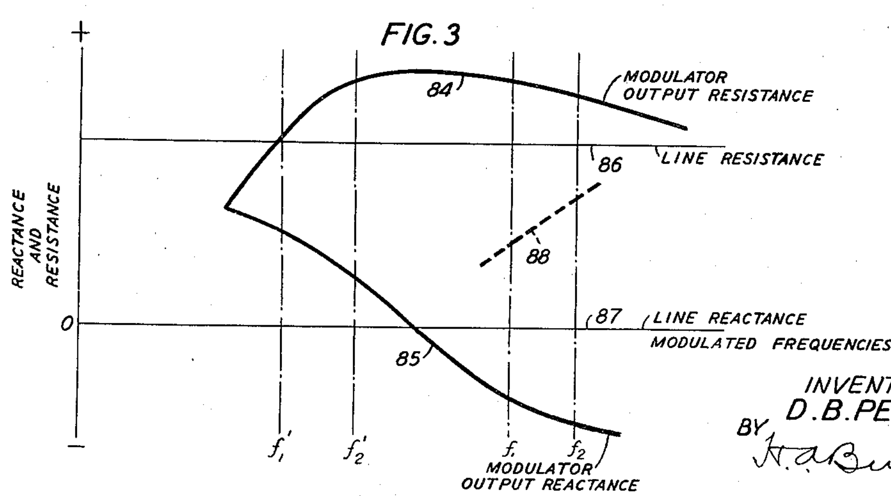


FIG. 3



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MODULATING SYSTEM

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6 Claims. (Cl. 179—171.5)

This invention relates to frequency changers which may be either modulators, demodulators, or detectors for use in signaling transmission systems, and more particularly to such frequency changers embodying non-linear resistance elements.

Heretofore non-linear resistance elements have been used in modulator and demodulator systems as illustrated in the patents of F. A. Cowan No. 1,959,459 and L. R. Cox No. 1,998,119. As disclosed in the patent of L. R. Cox, supra, arrangements have been devised to improve the efficiency of such systems, that is, to improve their economy of operation, particularly with reference to power consumption so that maximum desired side-band power is supplied to a line for transmission thereover.

It is an object of the invention to improve the fidelity of operation of modulator and demodulator systems.

It is another object of the invention to enable in such systems the transmission of all frequencies in a certain band of modulated frequencies substantially with the same losses.

It is a further object of the invention to provide optimum modulator impedance terminations to a band selecting filter embodied in the output of such systems.

In one type of well-known modulator or demodulator system a plurality of non-linear resistance elements are arranged in the form of a bridge which has connected to one diagonal an input circuit including a source of modulating waves and an output circuit including a filter network for applying a desired band of modulated frequencies to a line for transmission thereover. To the opposite diagonal of the non-linear bridge is connected a source of carrier waves so that the carrier and modulating waves are combined to produce desired modulated waves.

In accordance with the invention, a network comprising reactive and resistive elements is interposed in the output circuit between the non-linear bridge and the band filter network to so modify the impedance of the modulator comprising the input and output circuits and the non-linear bridge that the modulator presents optimum terminating impedance to the band filter network at all frequencies within its pass-band, thereby providing substantially equal over-all losses for all modulated frequencies.

The nature of the invention will be more fully understood from the following description of a system having it embodied therein and by reference to the accompanying drawing in which:

Fig. 1 is a schematic representation of a modulator system embodying a preferred form of the invention;

Fig. 1A is a modification of Fig. 1;

Figs. 2A, 2B and 2C include curves and a schematic representation of a circuit explaining the action of the system illustrated in Figs. 1 and 1A; and

Fig. 3 is also a curve explaining the action of the system illustrated in Figs. 1 and 1A.

Referring to Fig. 1, a plurality of physically inert non-linear resistance elements **10**, **11**, **12** and **13** are arranged in the form of a bridge whose one diagonal **15**, **16** is connected in shunt relation to an input circuit **17** and an output circuit **18**. The input circuit includes a modulating input transformer **20** and a low-pass filter LPF for applying a plurality of modulating frequencies from a suitable source **21** to the output circuit which embodies a band-pass filter BPF which impresses a desired band of modulated frequencies across a line **22** for transmission thereover. The low-pass filter serves to block from the modulating source noise and harmonics of the modulating frequencies while the band-pass filter selects the desired modulated frequencies.

A condenser **23** connected in one side of the input circuit between the secondary winding of the input transformer **20** and the low-pass filter serves to prevent a circulation of rectified current in the input circuit. In this connection it is to be understood that the design of the low-pass filter is such as to preclude bridging of the input circuit in a manner that the rectified current is transmitted thereover. Also condenser **23** serves to improve the impedance presented by the non-linear bridge to the modulating source.

To the other diagonal **25**, **26** of the bridge is connected a carrier input transformer **27** for applying thereto a source **28** of carrier waves. A resistance **29** connected in series in one side of the carrier circuit serves to eliminate odd harmonics of the modulating frequencies circulating in the carrier circuit. As resistance **29** tends to upset the impedance termination of the non-linear bridge to the carrier source, a network **30** comprising in series an inductance and an adjustable resistance is connected in shunt of the secondary winding of the carrier transformer so as to improve such impedance termination while at the same time the resistance in the network serves to reduce further whatever odd and even harmonics of the modulating frequencies are circulating in the carrier circuit.

The operation of a non-linear bridge in a modulating system is well known and briefly consists in applying modulating waves from the source 21 across the diagonal 15, 16 and simultaneously therewith impressing carrier waves from the source 28 across the diagonal 25, 26. These waves together with the non-linear resistance elements produce an action whereby the modulating and carrier waves are combined to effect modulated waves having a desired range of frequencies for application by the band-pass filter to the line 22 for transmission thereover.

As only a certain amount of modulated energy is available for transmission over the line, it is imperative to conserve such energy by avoiding energy losses in unwanted products of modulation due to a circulation of such products in certain portions of the system. One arrangement for limiting circulation of unwanted modulation products and thereby promoting efficiency in modulating systems is disclosed in the patent of L. R. Cox, supra. This, however, embodies no provisions for improving the fidelity of the system.

In Fig. 1 the low-pass filter and the band-pass filter serve to prevent circulation of unwanted products of modulation in the respective input and output circuits and thereby tend to conserve the modulated energy for transmission over the line. The effectiveness of the band-pass filter for this purpose is reduced considerably when other networks are interposed between the former and the non-linear bridge. It would be possible to design a band-pass filter so as to possess satisfactory transmission characteristics when terminated on the output side by the transmission line 22 and on the input side by the non-linear bridge.

However, for reasons of economy, flexibility and simplicity of filter design, it is frequently preferable to design a band-pass filter to function between equal terminating impedances and for this purpose it is usually preferable to select the impedance of the transmission line as the working impedance. In certain types of band-pass filters the transmission characteristic may be critical to the terminating impedance. This is illustrated in Fig. 2A which is a simplified circuit embodying a typical band-pass filter BPF, a load 50 having an impedance Z_0 and a source 51 of modulating frequencies having an impedance Z which is adjustable. When Z_0 provides optimum terminating impedance for the typical band-pass filter and Z is made equal to Z_0, the filter transmission characteristic is that shown in Fig. 2B. From an inspection of the latter it is seen that components of all frequencies within the desired band are transmitted to the load 50 substantially with the same losses. When, however, impedance Z differs from the impedance Z_0, the filter transmission characteristic is that shown in Fig. 2C. From an inspection of the latter it is noted that components of certain frequencies in a desired wave, such as those indicated at 53, are transmitted to the load 50 with higher losses than those indicated at 54. Thus, distortion occurs in the transmitted modulated wave. Consequently, a system whose action is according to Fig. 2C possesses relatively poor fidelity.

Ordinarily it is not practicable to provide in a non-linear bridge a predetermined impedance for all desired frequencies. In other words, it is not feasible to provide a non-linear bridge whose impedance is substantially equal to the load impedance throughout an entire range of frequencies. Fig. 3 illustrates the impedance of a modulating system such, for example, as the one shown in Fig. 1 measured at the line X—X so as to include the modulating and carrier circuits and the non-linear bridge. If the frequencies to be transmitted are included in the band f_1—f_2 or the band f'_1—f'_2, it is obvious that the modulator impedance, that is, the modulator resistance and reactance indicated by the respective curves 84 and 85 is not equal to the line impedance whose components are line resistance and line reactance both of which are illustrated by the respective curves 86 and 87. Thus, if a band-pass filter having pass-bands of f_1—f_2 or f'_1—f'_2 and designed to work between terminations equal to the line impedance is connected in Fig. 1 directly between the non-linear bridge and the line 22, the over-all modulator loss would approximate the form of the curve shown in Fig. 2C. Such arrangement would introduce into the system distortion which is due to the fact that the band-pass filter is terminated on the side of the non-linear bridge by an impedance comprising resistive and reactive components represented by the curves 84 and 85 and on the line side by an impedance comprising resistive and reactive components represented by the respective curves 86 and 87. As previously mentioned, such distortion is undesirable as it impairs the fidelity of the system.

Assuming a resistance pad of proper nominal impedance ($Z=Z_0$, Fig. 2A) to be disposed in Fig. 1 between the non-linear bridge and the band-pass filter BPF, then the impedance of the modulator including that of the resistance pad may be made to substantially match the impedance of the filter so as to provide an over-all frequency characteristic similar to that shown in Fig. 2B. In other words, the impedance termination on each side of the band-pass filter would be substantially an impedance having resistive and reactive components represented by the respective resistive and reactive curves 86 and 87 in Fig. 3. Such arrangement is often employed in communication systems. However, the outstanding disadvantage of this arrangement lies in the fact that the effectiveness of the resistance pad as an impedance matching device is directly related to its effectiveness as an attenuator. In the latter connection a resistance pad of high attenuation involves a direct loss in transmitted energy to such extent that transmission efficiency is seriously impaired.

Thus, it is seen that the design of a band-pass filter to meet individual circuit requirements entails complex structures and considerable initial expense while the use of a resistance pad to adjust the modulator impedance termination occasions an unnecessary impairment of efficiency.

In accordance with this invention, the terminating impedance of the modulator comprising modulating and carrier circuits and the non-linear bridge to the impedance of the band-pass filter is adjusted to optimum value by a three-element network embodying inductance, capacity and resistance so as to be substantially equal to a predetermined line impedance into which the band filter is working. For ordinary circuit requirements such three-element terminating network has been found to be satisfactory, although a more complex network may be designed for circuits requiring a precise impedance terminating adjustment. Still, in other situations a network involving one or two of the elements in combination may be found to be adequate. Such optimum impedance termination to the filter network enables the latter to apply to the line for transmission thereover modulated wave components of all frequencies in a desired modulated wave substantially with uniform losses.

Fig. 1 shows for a transmitted frequency band extending between f_1—f_2 in Fig. 3 a three-element modulator terminating impedance network comprising in one side of the output circuit in series an inductance **35** and a capacity **36** while in bridge thereof is a resistance **37** and an L-shaped resistance pad **38**. The elements **35**, **36** and **37** may be adjusted until the impedance termination of the modulator to the band-pass filter is such that the characteristic of the latter substantially attains the form shown in Fig. 2B. If the impedances of the modulator and of the band-pass filter are sufficiently well matched the effect of the L-shaped resistance pad **38** may be made as small as desired or omitted entirely without impairing the fidelity of the system. Consequently, the filter characteristic shown in Fig. 2B may be attained for any value of pad attenuation down to and including zero.

The operation of the terminating network comprising elements **35**, **36** and **37** in Fig. 1 is as follows: The elements **35** and **36** are adjusted until the combined series reactance thereof substantially approaches the form of the dotted curve **88** in Fig. 3 so that the combined reactance of elements **35** and **36** and of the modulator as represented by the curve **85** (negative value) substantially coincides with the curve **87** which is zero and therefore the desired reactance value for the modulator. As the combined resistance of the modulator and of the elements **35** and **36** is then substantially that indicated by the curve **84**, the shunt resistance **37** is then adjusted until the aforementioned combined resistance substantially coincides with the value represented by the curve **86**. Consequently, the combined impedance of the modulator (comprising modulating and carrier circuits and the non-linear bridge) and the terminating network (elements **35**, **36** and **37**) is substantially the impedance having resistive and reactive components represented by the respective curves **86** and **87**. Having thus adjusted the terminating network comprising elements **35**, **36** and **37**, the over-all frequency characteristic of the system is substantially the same as that shown in Fig. 2B. That is, the filter network applies to the line for transmission thereover modulated wave components of all frequencies in the desired modulated waves substantially with uniform losses.

Capacity **36** also serves the purposes of (1) blocking a flow of rectified current from the non-linear bridge so as to enable maintenance of a balanced condition in the latter and thereby holding carrier leaks to a minimum, and (2) increasing the impedance of the output circuit to modulating frequencies thereby promoting transmission efficiency in the system.

For a transmitted band of frequencies extending between f'_1—f'_2 in Fig. 3, the modulator impedance to be matched with that of the band-pass filter is different from that for the transmitted band f_1—f_2, particularly in that the reactance component is now positive whereas in the latter it is negative. Therefore, it is preferable for a transmitted band of frequencies extending between f'_1—f'_2 to use a network of the type shown in Fig. 1A. This comprises a bridging capacity **40**, a series capacity **41** and a bridging resistance **42**. It is to be understood that the circuit portion shown to the left of the line X—X in Fig. 1 is to be connected to the circuit portion shown to the right of the line X—X in Fig. 1A.

The operation of the terminating network comprising the elements **40**, **41** and **42** in Fig. 1A is as follows: Capacity **40** is adjusted until the numerical value of the negative reactance thereof is approximately equal to the numerical value of the equivalent parallel modulator reactance which is positive. This parallel combination of capacity **40** and the modulator (comprising modulating and carrier circuits and the non-linear bridge) forms an anti-resonant circuit whose reactance coincides substantially with the curve **87** in Fig. 3 and whose resistance is the equivalent parallel modulator resistance which is higher than a series resistance component as indicated by the curve **84** in Fig. 3. The shunt resistance **42** is then adjusted to reduce the resistance of the anti-resonant circuit to coincide substantially with the value represented by the curve **86**. Consequently, the combined impedance of the modulator and the terminating network is substantially an impedance comprising the resistive and reactive components represented by the respective curves **86** and **87**. Having thus adjusted the terminating network the overall frequency characteristic of the system is now substantially identical with that shown in Fig. 2B, as explained above in connection with Fig. 1.

Capacity **41** may modify the combined impedance of the modulator and terminating network in Fig. 1A to a relatively small extent and compensation therefor may be effected by readjusting capacity **40**. Capacity **41** serves the purposes (1) to block a flow of rectified current from the non-linear bridge so as to enable the maintenance of a balanced condition in the latter and thereby to hold carrier leak to a minimum, and (2) to increase the impedance of the output circuit to modulating frequencies thereby promoting transmission efficiency. Capacity **41** may also favorably affect the slope of the impedance characteristic in the transmitted band of frequencies.

The configuration of the terminating network depends on the characteristics of the two impedances that are to be matched. Usually it is preferable to substantially terminate the impedance of the modulator at the same impedance value at which the band-pass filter is terminated. In other words, it is the common practice in communication circuits to design a filter network to work into a transmission line having a predetermined impedance and therefore it is preferable to terminate the modulator impedance at a value which is substantially equal to the predetermined impedance of the line.

What is claimed is:

1. In a modulating system comprising a plurality of non-linear resistance elements arranged in the form of a bridge, an input circuit for modulating waves and an output circuit including a filter network having a predetermined impedance-frequency characteristic for selecting a desired modulated wave both of which are connected to one diagonal of the bridge, and a carrier wave source connected to the opposite diagonal of the bridge so that the modulating and carrier waves are combined in the desired modulated waves; means comprising an impedance network interposed in the output circuit between the non-linear bridge and the filter network for providing the bridge output circuit over the range of

selected frequencies with an effective impedance-frequency characteristic which is substantially identical with the impedance-frequency characteristic of the filter network to transmit wave components of all frequencies in the desired modulated waves substantially with uniform losses.

2. In the modulating system according to claim 1 in which the impedance network comprises resistive and reactive elements.

3. In the modulating system according to claim 1 in which the impedance network comprises an inductance and a capacity in series in one side of the output circuit and a shunting resistance.

4. In the modulating system according to claim 1 in which the impedance network comprises a shunting capacity and a shunting resistance.

5. In combination, a source of signal waves, a source of carrier waves, a non-linear bridge to combine the signal and carrier waves in desired modulated waves, a load connected to the output of the bridge and having substantially flat resistive and reactive-frequency characteristics to select a predetermined range of frequencies, and means comprising an impedance network connected between the bridge output and the load and proportioned over the predetermined range of frequencies to provide the bridge output with effective resistive and reactive-frequency characteristics that substantially conform with said load characteristics to transmit wave components of all frequencies in the predetermined range of frequencies substantially with equal attenuation.

6. In combination, a source of signal waves, a source of carrier waves, a non-linear bridge to combine the signal and carrier waves in desired modulated waves, a load connected to the output of the bridge and having a substantially flat impedance-frequency characteristic to select a predetermined range of frequencies, and means comprising an impedance network in the bridge output to provide the bridge output with a substantially flat effective impedance-frequency characteristic that corresponds to said load characteristic to transmit wave components of all frequencies in the predetermined range of frequencies substantially with equal attenuation.

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