April 16, 1935. L. R. COX 1,998,119

FREQUENCY CHANGER AND CIRCUITS THEREFOR

Filed Aug. 19, 1932 2 Sheets-Sheet 1

FIG. 1

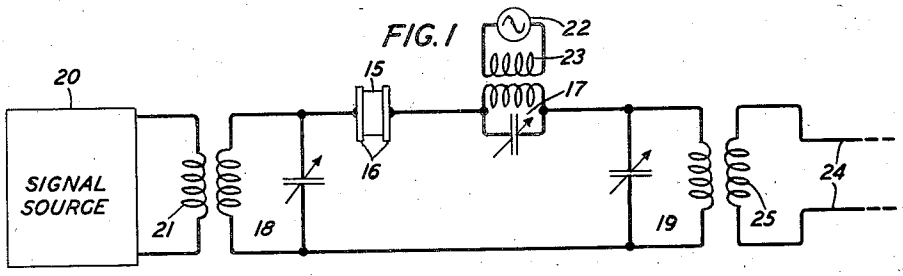


FIG. 2

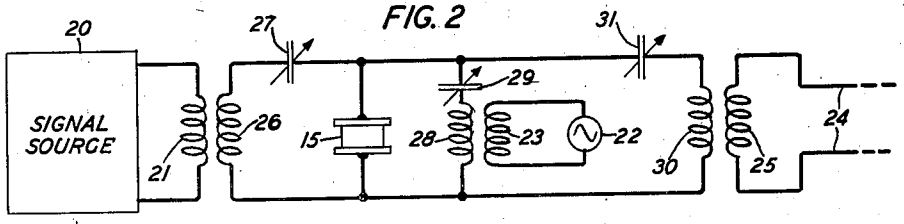


FIG. 3

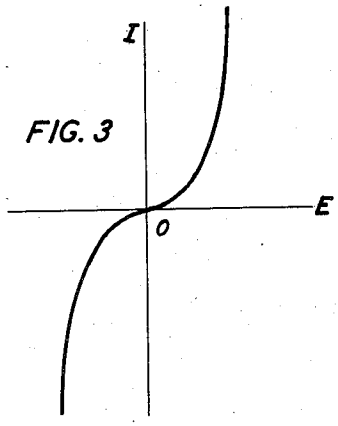
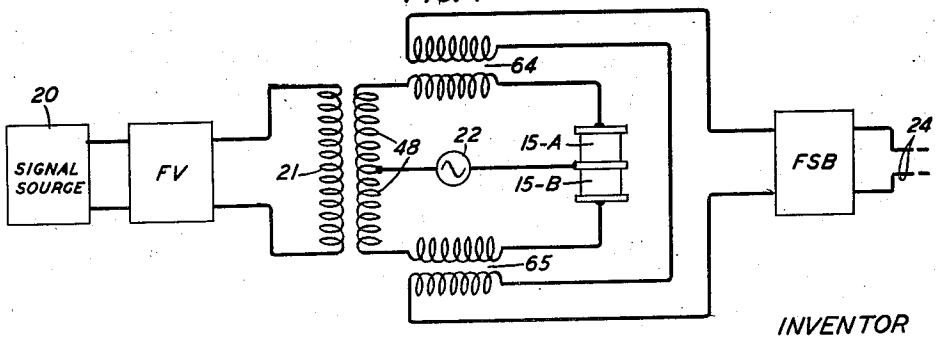


FIG. 4



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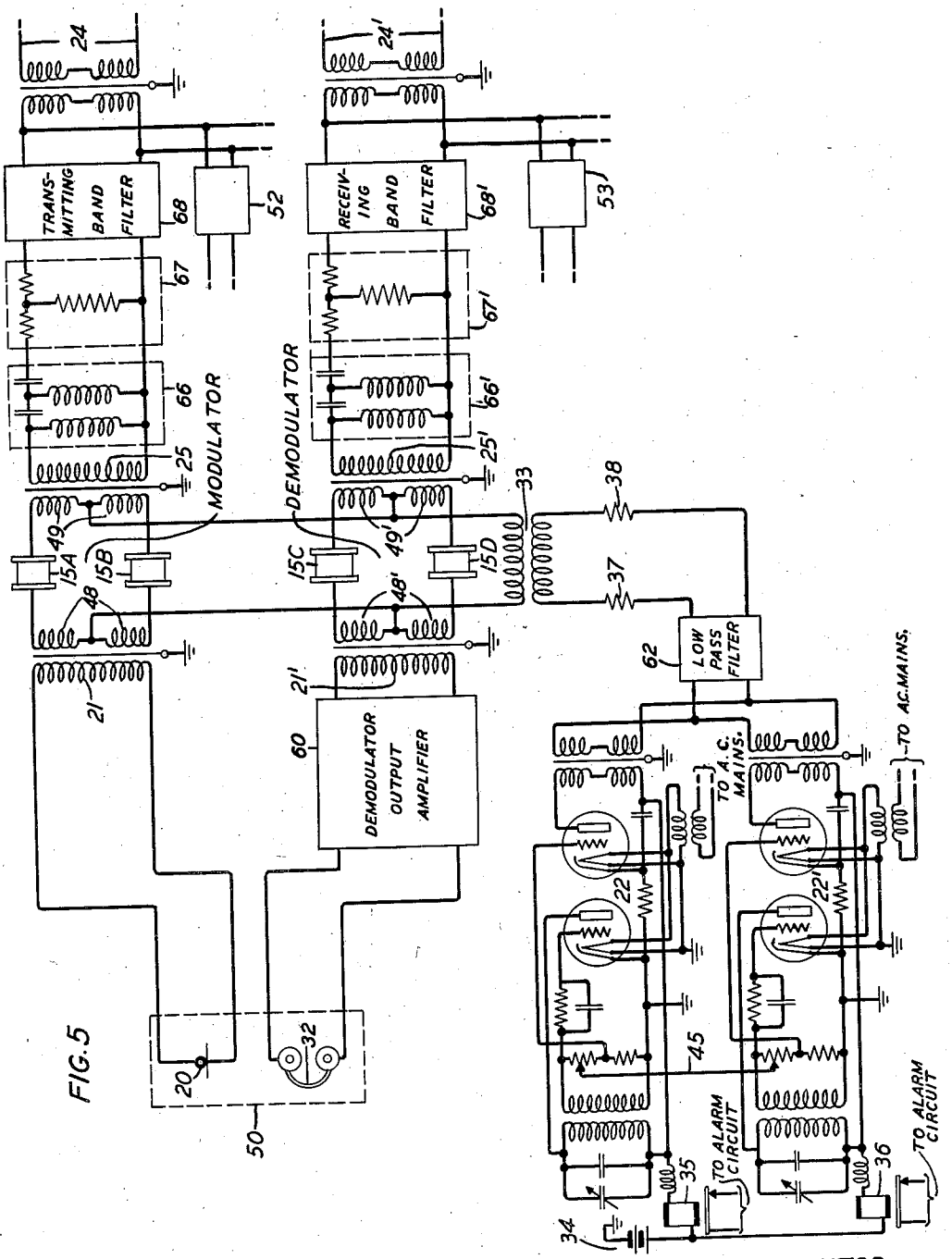


FIG. 5

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FREQUENCY CHANGER AND CIRCUITS THEREFOR

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Application August 19, 1932, Serial No. 629,487
Renewed December 12, 1933

12 Claims. (Cl. 179—171)

This invention relates to frequency changers which may be either modulators, demodulators or detectors, for use in electrical communication, and more particularly to devices in which an inert solid element is employed to effect modulation or demodulation.

An object of the invention is to obtain increased reliability and constancy in the operation of modulators, demodulators and the like.

Another object is to improve the economy in operation of such devices, with particular reference to power consumption.

A further object is to provide an increased degree of suppression of the unmodulated carrier in modulator output circuits.

In modulators of the space discharge type a considerable amount of energy is required for energizing the filaments and the plate circuits and, where a high degree of constancy in the operating characteristics is required, accurate control of the energy supply to these parts becomes necessary. In addition, when carrier suppression is desired, the achievement and the maintenance of balance in vacuum tube modulators for this purpose becomes difficult and costly.

It has been found that a mass of finely divided particles of certain crystalline substances held together in random contact within a matrix of insulating material forms an aggregate with a symmetrical, non-rectilinear current-voltage characteristic which makes it suitable for use as a modulating device. An element of this type may be used in the ordinary manner as a modulator, but on account of the symmetrical character of the current-voltage characteristic a polarizing voltage must be applied to the element to obtain the usual second order modulation products.

In accordance with the present invention a modulating system is provided using an element of the type described and having the associated circuits arranged to furnish modulation products of a higher order than the second, thereby making the use of a polarizing potential unnecessary and at the same time giving a modulated wave in which the carrier component is suppressed.

The nature of the invention will be more fully understood from the following detailed description of systems in which it is embodied and by reference to the accompanying drawings of which:

Figs. 1 and 2 are schematic representations of single element modulators embodying the invention;

Fig. 3 is a graphical diagram for explaining the action of the systems illustrated in Figs. 1 and 2;

Fig. 4 illustrates a two element modulator embodying the invention; and

Fig. 5 is a schematic representation of a complete carrier terminal equipment including modulators and demodulators embodying the invention.

Referring to Fig. 1, the modulating element comprises a plate 15 of material of the sort hereinafter described, held between a pair of terminal electrodes 16. In series with the modulating element are tuned circuits 17, 18 and 19 which are anti-resonant respectively at the impressed carrier frequency, the signal frequency, and a frequency equal to twice that of the impressed carrier. A source 20 of signal current is connected across a primary coil 21 which is in turn coupled to the inductive element of tuned circuit 18. A carrier current generator 22 is connected to a primary coil 23 which is inductively coupled to the tuned circuit 17. A secondary coil 25, coupled to tuned circuit 19, is directly connected to an outgoing line 24.

The essential part of the modulating element is the plate 15 of material which comprises a mass of finely divided conductive or semi-conductive crystalline particles held together in random contact in a binding matrix of insulating substance. One example of a suitable material of this kind is a mixture of silicon carbide and carbon with clay as a binder, made as specified in U. S. Patent 1,822,742, issued September 8, 1931 to K. B. McEachron. In order to provide good electrical contact between the material of the modulating element and the surfaces of electrodes 16 the contact surfaces of the material are coated with metal, as for example by some suitable spraying process. The electrodes 16 are pressed against the contact surfaces with sufficient pressure to make satisfactory electrical contact. Otherwise than to secure this contact the degree of pressure employed is not critical. A plate one-half inch square or less and having a thickness of from one-fiftieth to one-fourth inch has been found to be of suitable size for a modulator in a carrier system.

In the operation of the system of Fig. 1, a modulating current from signal source 20 and a carrier current from generator 22 cause superimposed voltage variations at the frequencies of the two respective currents to occur across the terminals of the modulating element 15. The element has the electrical qualities of a non-linear

resistance with conductivities in the two directions which are equally good and which nicely balance one another at all voltages. By a non-linear resistance is meant one for which the ratio of the voltage to the current is not independent of the magnitudes of voltage and current. The symmetrical non-rectilinear conductivity of the element is illustrated in Fig. 3 which shows a curve representing the relation between the current and voltage. The current through the element is designated by I and is plotted as a function of the voltage across the terminals, designated by E. When waves of two different frequencies are simultaneously impressed upon a non-linear impedance device of this character a variety of modulation products result. The balanced nature of the conductivities of the element gives an inherently high degree of suppression to all harmonics of even order. In particular the second harmonic of the carrier is suppressed, but sidebands of the double carrier frequency appear, as these latter are not prevented by the balanced condition. These sidebands are composed of frequencies equal to twice the carrier plus or minus the modulating frequency and are referred to as third order modulation products. Other sidebands of odd orders are also generated by the device, but substantially no even order sideband current is produced. The third order sidebands are usually produced with the greatest efficiency of any modulation product and for that reason a third order sideband is preferably selected for transmission over the line. For this purpose circuit **19** is tuned to a frequency equal to twice that of the impressed carrier, the resistance of the circuit preferably being such as to give a resonance broad enough to include the desired sidebands. If only a single sideband is to be transmitted the circuit **19** may be tuned to the desired sideband frequency or a band pass filter such as described in Campbell Patent 1,227,113 of May 22, 1917 may be used in place of the tuned circuit.

In accordance with one method of avoiding energy losses and thus promoting the highest efficiency in the modulating system, the anti-resonant circuits **17**, **18** and **19** are arranged in series connection with each other and with the element **15**. Each tuned circuit presents a high impedance at its own resonant frequency, but a very low impedance for frequencies considerably above or below the resonant point. The voltage generated by the modulating current in circuit **18** to which this current is resonant is developed principally across the element **15**, circuits **17** and **19** being virtually short-circuited at this frequency. Similarly, the voltage developed by the carrier generator in circuit **17** is impressed almost exclusively across element **15**. Circuits **17** and **18**, having very low impedance to the frequency of the desired modulation product, absorb very little power from the output current so that substantially the whole of the power developed in the output current is delivered to circuit **19** and transmitted thereby to the line **24**.

The system shown in Fig. 2 is similar to that of Fig. 1 except that the tuned circuits are arranged in parallel connection with the modulating element and with each other. The first tuned circuit, comprising an inductance **26** and a variable capacity **27**, is series resonant to the frequency of the modulating current, the inductance **26** being coupled to coil **21**. The second tuned circuit, comprising an inductance **28** coupled to coil **23** and tuned by means of a variable condenser **29**, is series resonant to the frequency of the carrier generator **22**. The third circuit comprises an inductance **30** coupled to coil **25** and tuned by means of a variable condenser **31** to the frequency of the desired modulation product. Each of the circuits **26—27**, **28—29**, and **30—31** being a series resonant circuit has a low impedance at its own resonant frequency, but a high impedance at all frequencies considerably above or below the resonant point. Due to the parallel connection of these circuits the high impedance of each substantially prevents shunt losses therein at frequencies which are off resonance. The operation is similar to that of the system of Fig. 1 third order sidebands free of unmodulated carrier being developed by the modulation process.

Fig. 4 shows a modulator employing two modulating units and having the carrier current supplied through a balanced circuit. The modulating units are designated by reference characters **15—A** and **15—B** and have a terminal in common. The units are serially connected with a signal input transformer comprising the primary winding **21** and a secondary winding **48**. In this series circuit are included two sideband output transformers **64** and **65**. The winding **48** is divided at its midpoint and the carrier generator **22** is connected between the midpoint of the winding and the common terminal of units **15—A** and **15—B**. The signal source **20** is connected through a filter FV to the primary winding **21**, to constitute the input circuit of the modulator. On the output side the secondary windings of the transformers **64** and **65** are connected in series aiding relation with a filter FSB which is in turn connected to the outgoing line **24**.

In the operation of the system of Fig. 4, signal currents from source **20** are supplied to the units **15—A** and **15—B** through the filter FV and transformer windings **21** and **48**. Carrier currents are supplied to the units **15—A** and **15—B** in parallel by generator **22**. Odd order modulation products are generated by the modulating units and a third order sideband is selected by filter FSB for transmission over line **24**. Because of the symmetry of the circuit, the currents originating in generator **22** are neutralized or balanced out in the output circuit of the modulator. This arrangement facilitates the connection of several modulating systems with a single carrier source, the balance of the elements preventing cross-talk currents from one system entering any of the others. If the signal source **20** is replaced by a suitable signal receiver, for example, a telephone, the circuits of Figs. 1, 2 and 4 may be used as demodulators for the reception and translation of signal modulated waves. Preferably the received wave should be a single sideband with the unmodulated carrier suppressed in which case the local carrier source would be adjusted to a frequency half that of the suppressed carrier of the incoming wave.

Fig. 5 represents the terminal circuits of one channel of a multiplex carrier wave transmission system in which the arrangements of the invention are used for both modulation and demodulation.

In the transmitting portion of the terminal, illustrated at the top of the figure, the signal source **20** is shown as a telephone transmitter connected to the primary winding **21** of the signal input transformer. Modulating elements **15—A** and **15—B**, selected to have substantially equal current-voltage characteristics, are connected between the secondary **48** of the signal input transformer, and the primary **49** of the

sideband output transformer. Windings 48 and 49 are divided at their respective midpoints to establish two balanced circuit branches, one of which comprises the upper half of winding 48, the element 15—A and the upper half of winding 49, and the other branch the element 15—B with the lower halves of the two windings. The midpoints serve as terminals to which is connected a carrier supply system hereinafter described. The secondary 25 of the sideband output transformer is connected to a high-pass filter 66 having its cut-off frequency located immediately above the frequency range of the impressed signals. The filter is shunt terminated at the input end in order to present a low impedance to the signal frequencies. The output end is connected to an attenuation pad 67 which causes further attenuation of any signal currents which may be incompletely suppressed in the filter 66. The output circuit for the sideband currents extends from the pad 67 through a transmitting band-pass filter 68 to the outgoing line 24.

The receiving portion of the terminal, represented directly below the transmitting portion in Fig. 5, differs in structure only slightly from the transmitting portion. An incoming line 24', separate from the outgoing line 24 to provide four-wire operation, is connected to a receiving band-pass filter 68'. The band filter is connected through a pad 67' and a high-pass filter 66' to a sideband input transformer having a primary winding 25' and a divided secondary winding 49'. A pair of balanced demodulating elements 15—C and 15—D, similar to the modulating elements 15—A and 15—B are connected between the sideband input transformer and a signal output transformer comprising a divided primary winding 48' and a secondary winding 21'. The respective midpoints of the divided windings 48' and 49' serve as terminals for connection to the carrier supply system. The secondary 21' is connected through a demodulator output amplifier 60 to the telephone receiver 32, which latter forms part of a telephone set 50 including the transmitter 20.

The carrier supply system comprises a pair of vacuum tube oscillators 22 and 22' forced to operate in synchronism by means of a tie connection 45 between corresponding points in their respective grid circuits. The output circuits of the oscillators are connected in parallel across the input terminals of a low-pass filter 62 which is proportioned to pass the oscillator frequency and to suppress the harmonics thereof. The filter output is connected through series resistors 37 and 38 to the primary winding of a transformer 33, the secondary of which is connected across the midpoints of windings 48 and 49 in the modulator and across the midpoints of windings 48' and 49' in the demodulator. A source of space current, represented by a battery 34, is connected to the plate electrodes of the vacuum tubes through parallel paths including current failure alarm relays 35 and 36 individual respectively to oscillator 22 and oscillator 22'. The contact circuit of each relay is connected to an alarm circuit of any desired form.

In the operation of the system of Fig. 5 for transmitting a modulating voltage from the source 20 is impressed upon the modulating elements 15—A and 15—B together with a carrier voltage from oscillators 22 and 22', thereby producing a variety of modulation products of which one of the third order sidebands corresponding to the double frequency carrier is selected in band filter 68 and transmitted into the outgoing line 24.

In receiving, sideband currents incoming over line 24' are passed through band filter 68' and combined with carrier waves in demodulating units 15—C and 15—D to form reproduced signal currents which are amplified in amplifier 60 and supplied to the telephone receiver 32.

Provision is made for emergency operation in case of failure of a carrier supply oscillator. Any trouble in oscillator 22 which is of such nature as to be reflected in a reduction or interruption of the space current causes the relay 35 to be released, thereby actuating an associated alarm circuit in any known manner, calling the attention of the attendant to the trouble and identifying oscillator 22 as the one that has failed. Similarly, a failure of oscillator 22' is indicated when relay 36 is released. Interruption of one oscillator reduces the available carrier supply to one-half of its normal value, but does not completely incapacitate the modulators and demodulators as would a complete failure of all carrier supply.

The operation of the modulators and demodulators is not very critical as to the amount of carrier current necessary within wide limits and it is found possible to secure satisfactory operation, with little, if any, impairment noticeable in the service, using half the normal supply of carrier. Thus, upon failure of one oscillator, the system will continue to operate satisfactorily during the period in which the faulty oscillator is being repaired and returned to service provided only that the other oscillator does not also fail before the first has been replaced. Under this plan of operation, the likelihood of actual interruption of service over the communication system due to oscillator failure is very small. The series resistors 37 and 38 serve to reduce the magnitude of the voltage change which occurs at the coil midpoints 48 and 49 when one oscillator stops or when a short-circuit occurs in another part of the carrier supply system.

If additional carrier channels are to be superposed upon the lines 24 and 24', the transmitting band filter of a second transmitting channel may be connected across the output terminals of filter 68, as illustrated by filter 52. The receiving band filter of a second receiving channel may be connected across the input of filter 68', as illustrated by filter 53. The terminal equipment for the added channels is similar to that in the channels illustrated. The inclusion of high-pass filters 66 and 66' and of pads 67 and 67' keeps signal currents out of the band filter, thus simplifying the design of the latter, and making the channel equipment uniform except for the band filter. Carrier current for the additional channel may be supplied by a carrier supply source similar to the one hereinbefore described but arranged to generate another carrier frequency.

If the carrier system is to be operated over a cable, the lines 24 and 24' may each be connected to a conductor pair within the cable, or if the system is to be operated over coaxial conductors, line 24 may be connected to one pair of coaxial conductors and line 24' may be connected to another coaxial pair.

What is claimed is:

1. A third order modulating system comprising a modulating element composed of a mass of finely divided conducting or semi-conducting particles held in random contact within a matrix of insulating material, said element having a non-linear conductivity, a source of signals, and

a source of carrier waves adapted to impress simultaneous voltage variations upon said modulating element to produce modulation products of order higher than the second, and an output circuit tuned to twice the frequency of the carrier waves for selecting from said modulation products a third order sideband.

2. A third order modulating system comprising a modulating element composed of a mass of finely divided semi-conducting crystalline particles held in random contact with each other by an insulating binder, said element having a non-linear conductivity, a source of modulating current and a source of carrier waves adapted to impress simultaneous voltage variations upon said modulating element to produce modulation products of order higher than the second, and an output circuit tuned to twice the frequency of the carrier waves for selecting from said modulation products a third order sideband.

3. A third order modulating system comprising a modulating element composed of a mass of finely divided conducting or non-conducting particles held in random contact within a matrix of insulating material, said element having a non-linear conductivity, a source of signals and a source of carrier waves adapted to impress simultaneous voltage variations upon said modulating element to produce modulation products of order higher than the second, and a filter having a pass band in a frequency range adjacent to twice the frequency of the carrier wave for selecting from said modulation products a third order sideband.

4. A third order modulating system of the suppressed carrier type comprising a source of carrier waves, a source of modulating current, a non-linearly conducting element composed of a mass of finely divided crystalline particles held in random contact in a matrix of non-conductor, means for simultaneously impressing upon said element voltage variations from said sources to produce modulation products of order higher than the second, said element having a symmetrical current-voltage characteristic whereby the even harmonics of the carrier are substantially suppressed, and a filter adapted to pass a band of frequencies adjacent to the second harmonic of the carrier for selecting from said modulation products a third order sideband.

5. A third order modulating system comprising a pair of balanced modulating elements each composed of a mass of finely divided conducting or semi-conducting crystalline particles held in random contact with each other by an insulating binder, said element having a non-linear conductivity, a source of modulating current and a source of carrier waves adapted to impress simultaneous voltage variations upon both of said modulating elements to produce modulation products of order higher than the second, and a filter adapted to pass a band of side frequencies lying immediately adjacent the second harmonic of the carrier frequency for selecting from said modulation products a third order sideband, said modulating elements being balanced with respect to the input circuit of said filter to substantially prevent transmission of unmodulated carrier waves of the fundamental carrier frequency from said carrier source to said filter.

6. A third order modulating system comprising a modulating element composed of solid conducting material having a symmetrical, non-linear current-voltage characteristic, a source of signal waves, a source of carrier waves, said modulating element being arranged in conductive relationship with said wave sources, and means whereby said sources are caused to impress simultaneous voltage variations upon said modulating element to produce third order modulation products of said carrier and signal waves.

7. A third order modulating system comprising a modulating element composed of solid conducting material having a symmetrical, non-linear current-voltage characteristic, a source of signal waves, a source of carrier waves, said modulating element being arranged in conductive relationship with said wave sources, means whereby said sources are caused to impress simultaneous voltage variations upon said modulating element to produce a plurality of modulation products, and an output circuit tuned to twice the carrier frequency for selecting from said modulation products a third order side band.

8. A third order modulating system comprising a modulating element composed of a solid conducting material with a symmetrical, non-linear current-voltage characteristic, a source of signal waves, a source of carrier waves, said modulating element being arranged in conductive relationship with said wave sources, means whereby said sources are caused to impress simultaneous voltage variations upon said modulating element to produce a plurality of modulation products, and a filter having a pass band in a frequency range adjacent to twice the frequency of the carrier wave for selecting from said modulation products a third order side band.

9. A third order modulating system comprising a source of carrier waves, a source of modulating current, a non-linearly conducting solid element arranged in conductive relationship with said sources, means for simultaneously impressing upon said element voltage variations from said sources to produce modulation products of order higher than the second, said element having a symmetrical current-voltage characteristic whereby the even harmonics of the carrier are substantially suppressed, and a filter adapted to pass a band of frequencies adjacent to the second harmonic of the carrier for selecting from said modulation products a third order side band.

10. A third order modulating system comprising a source of carrier waves, a source of modulating current, a non-linearly conducting solid element arranged in conductive relationship with said sources, and means for simultaneously impressing upon said element voltage variations from said sources to produce modulation products of order higher than the second, said element having a symmetrical current-voltage characteristic whereby the even harmonics of the carrier are substantially suppressed.

11. A third order modulating system comprising a pair of modulating elements, each composed of a solid non-linear conductor, a source of modulating current and a source of carrier waves adapted to impress simultaneous voltage variations upon both of said modulating elements to produce modulation products of order higher than the second, and a load circuit associated with said modulating elements, said elements being arranged in conductive relationship with said sources and being balanced with respect to the load circuit to substantially prevent transmission of unmodulated carrier waves of the fundamental carrier frequency from said carrier source to said load circuit.

12. A third order modulating system comprising a pair of modulating elements, each composed of a solid non-linear conductor, a source of

modulating current and a source of carrier waves adapted to impress simultaneous voltage variations upon both of said modulating elements to produce modulation products of order higher than the second and a filter adapted to pass a band of side frequencies lying immediately adjacent the second harmonic of the carrier frequency for selecting from said modulation products a third order side band, said modulating elements being arranged in conductive relationship with said sources and being balanced with respect to the input circuit of said filter to substantially prevent transmission of unmodulated carrier waves of the fundamental carrier frequency from said carrier source to said filter.

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