electronic goniometer

June 27, 1967 J. N. WARFIELD ETAL 3,328,798

DOUBLE BRIDGE NETWORK FOR PRODUCING SIGNALS HAVING A MODULATION ENVELOPE PHASE DIFFERENCE

Filed May 7, 1965 3 Sheets-Sheet 1

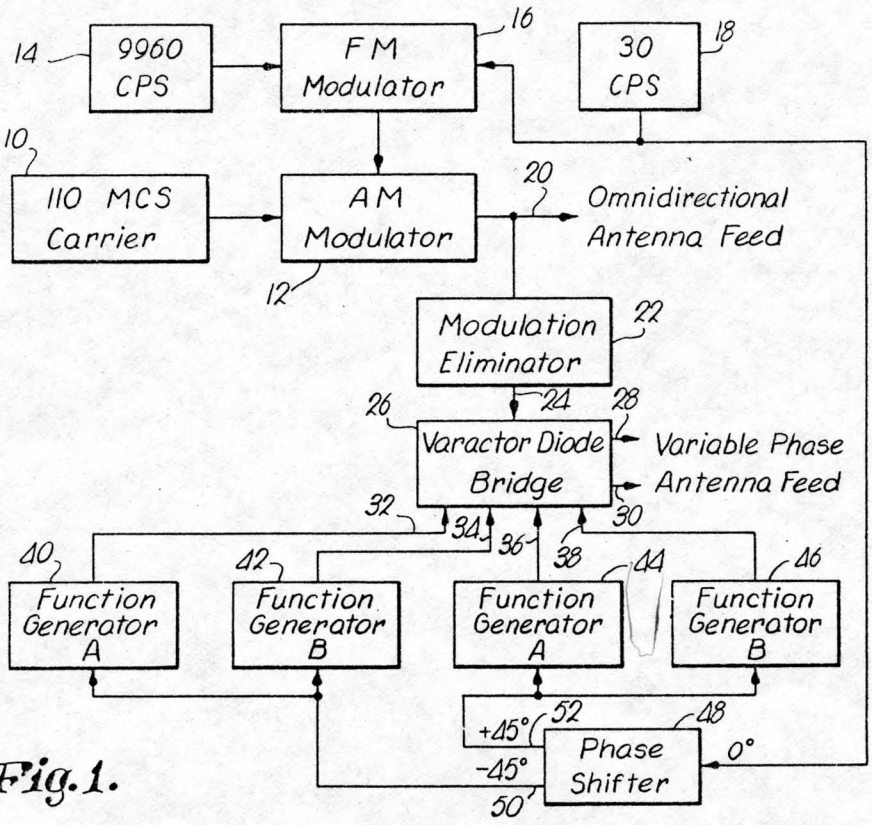


Fig. 1.

Fig. 4.

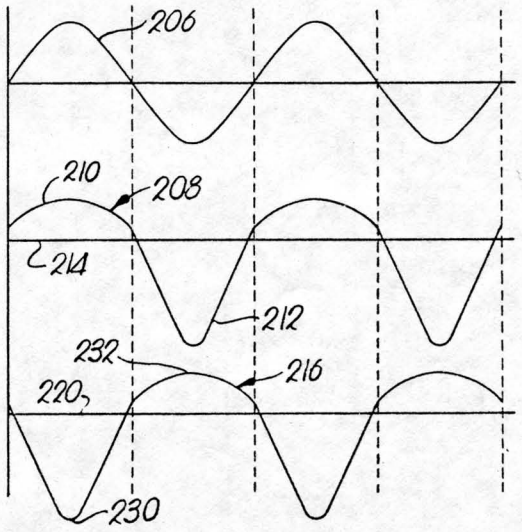
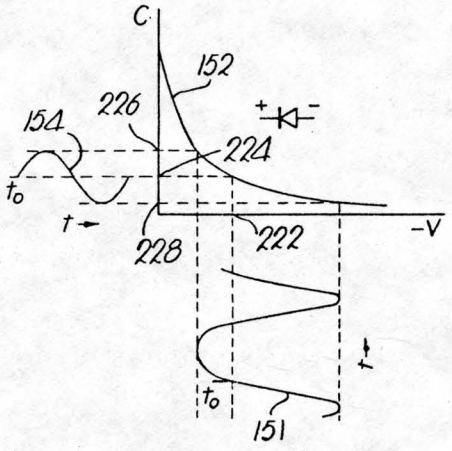


Fig. 3.



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Filed May 7, 1965 3 Sheets-Sheet 2

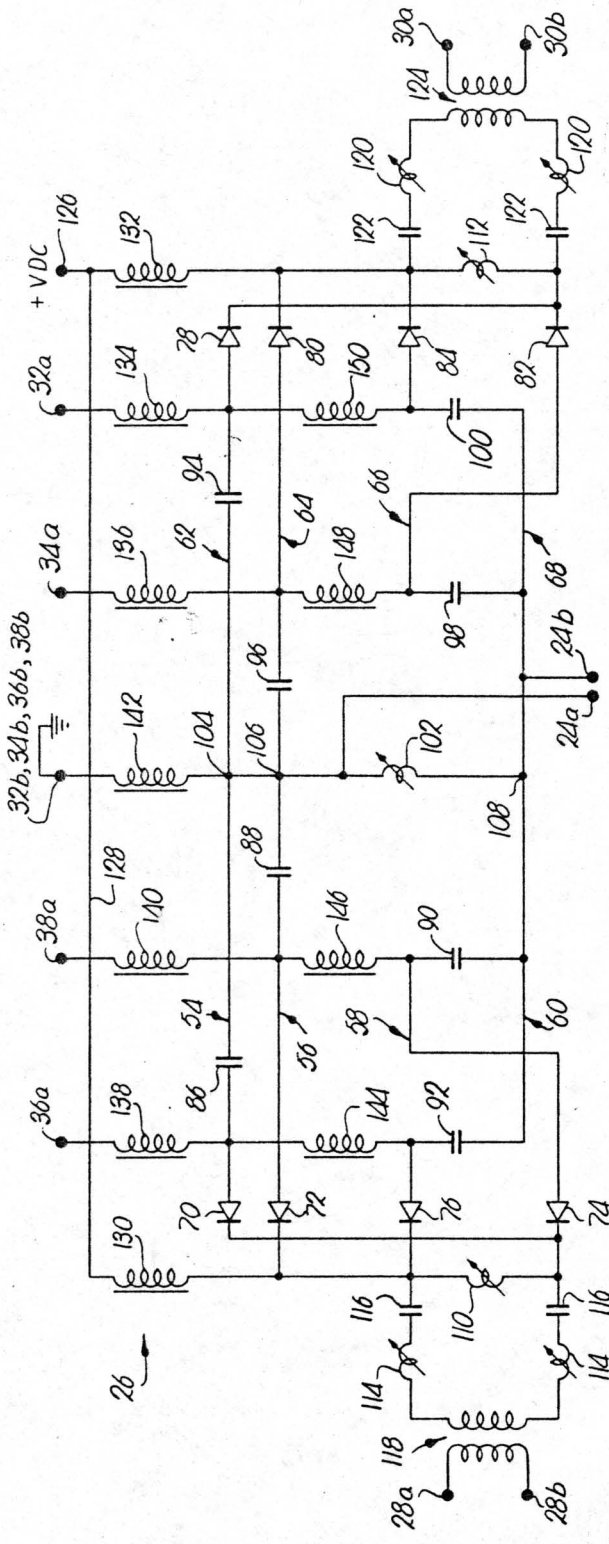

Fig. 2.

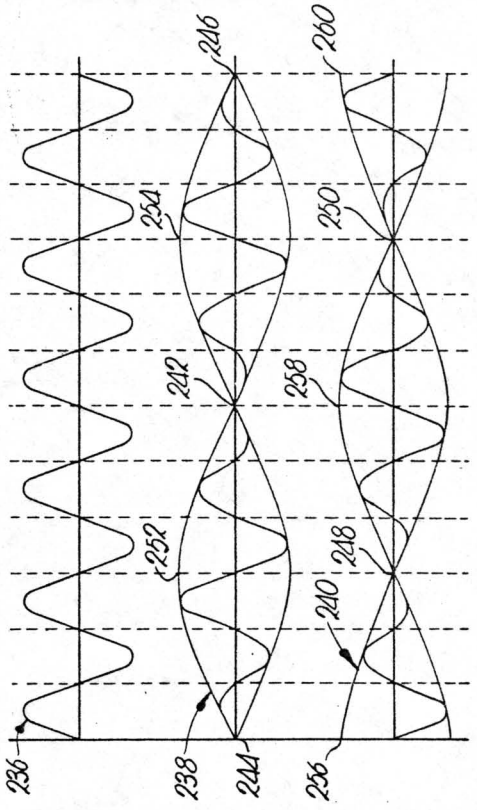

Fig. 3.

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Filed May 7, 1965 3 Sheets-Sheet 3

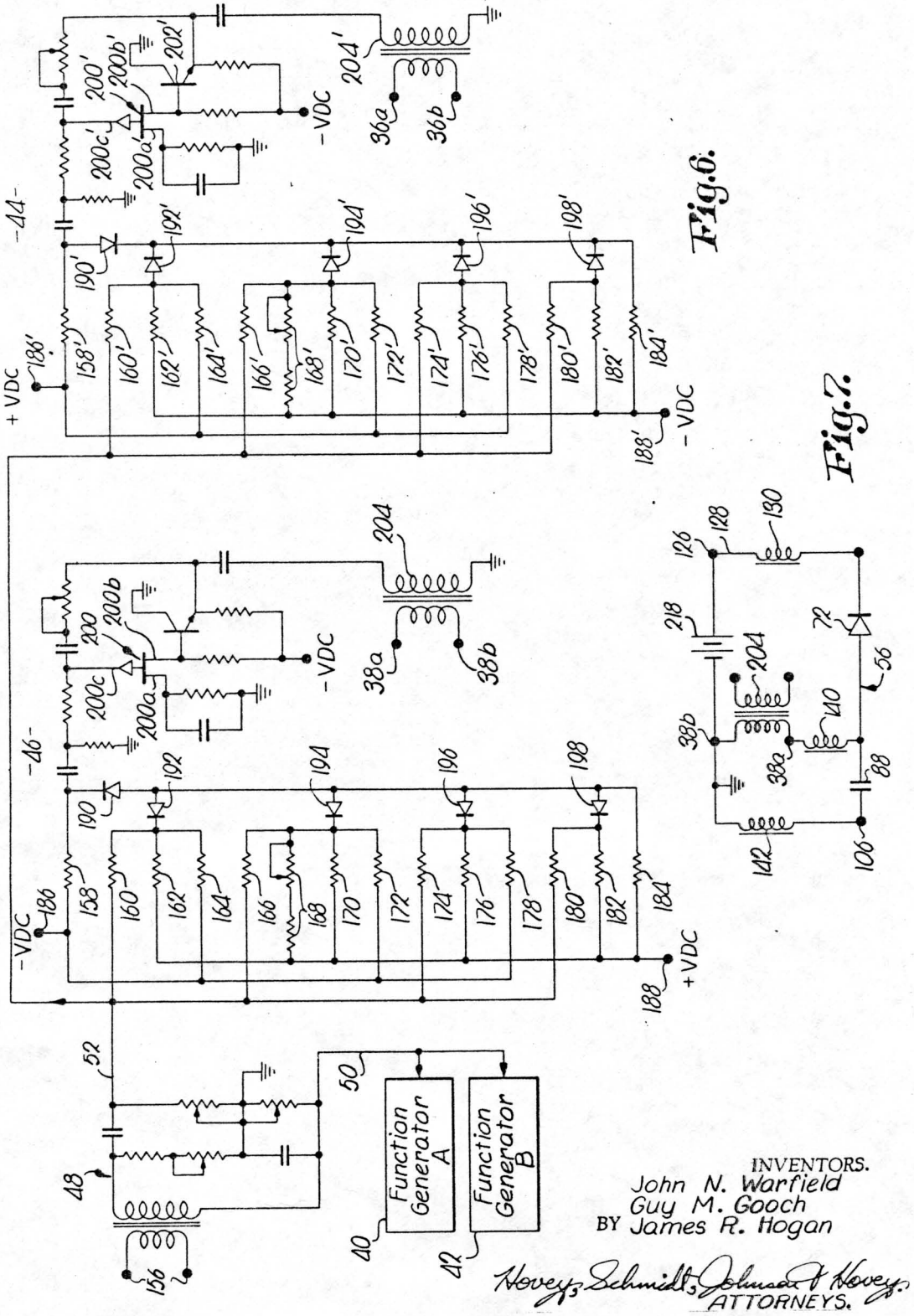

Fig. 6.

Fig. 7.

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DOUBLE BRIDGE NETWORK FOR PRODUCING SIGNALS HAVING A MODULATION ENVELOPE PHASE DIFFERENCE

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ABSTRACT OF THE DISCLOSURE

A double bridge network produces a pair of double side band, suppressed carrier signals having a modulation envelope phase difference. Each bridge arm contains a varactor diode, the two bridges being alternately balanced by the application of phased control signals to the diodes. The control signals are shaped to compensate for the nonlinear capacitance variation characteristics of the bridge arms, to which the characteristics of the diodes contribute, in order to effect a variation of the net capacitance of each arm corresponding to the modulation information to be imparted to the transmitted side bands.

This invention relates to modulation apparatus for producing a double side band, suppressed carrier signal and, more particularly, to a goniometer having no moving parts and operable to produce a pair of such signals with a predetermined modulation envelope phase difference therebetween.

In the radio navigation art, particularly VHF omnirange systems, mechanical goniometers have been employed for a number of years as a means of producing double side band, suppressed carrier signals. In one of the systems in common usage, two double side band signals having suppressed carriers are fed to the transmitting antenna with their modulation envelopes 90° out of phase. The antenna arrangement is such that these two out-of-phase signals are utilized in conjunction with an unmodulated omnidirectional R.F. signal to produce a unidirectional beam having a moving radiation pattern that is detected as a rotating beam, although the actual antenna structure is stationary. The omnidirectional signal is employed as a reference carrier and contains a frequency modulated signal which may be compared in phase with the rotating beam by a navigation receiver in an aircraft to determine the azimuth of the aircraft with respect to the transmitting station.

Although the mechanical goniometer has proven through the years to be a successful device, it possesses disadvantages inherent in any mechanical apparatus where moving parts subject to friction and wear are involved. Radio navigation systems must be operated on a continuous basis, and thus cannot be subject to periodic shutdowns for goniometer repair and maintenance. Manifestly, the rotors of the mechanical goniometer variable condensors are journaled in bearings which, ultimately, will wear out, thereby requiring replacement or substitution of new condensors.

A further problem with the mechanical goniometer is that tuning or trimming thereof cannot be effected during operation because of the movement of the components. Thus, to adjust the mechanical goniometer, it is necessary that the motor thereof be de-energized and system operation momentarily interrupted. This results in a trial and error adjustment technique since, of course, the effect of an adjustment on system operation cannot be observed until the goniometer is again rendered operative and the carrier and modulating signals applied thereto.

It is, therefore, an important object of this invention to provide a goniometer having no moving parts so that the problems inherent in mechanical goniometers will not be encountered.

It is another important object of the instant invention to provide an electronic goniometer which may be readily tuned or adjusted during operation without interrupting the transmission of the radio navigation signals.

It is a further object of this invention to provide an electronic goniometer which lends itself to automatic electronic error correction so that the lobe shape of the rotating beam may be compensated for azimuth errors when necessary.

Additionally, it is an object of the instant invention to provide a goniometer consisting of a double bridge network in which the arms of the bridges comprise electrically controllable, variable impedance devices which may be subjected to properly phased control signals to operate the bridges in a manner to produce the aforesaid double side band, suppressed carrier signals.

Yet another object of the instant invention is to provide the aforesaid double bridge network wherein the impedance variation of the bridge arms is accomplished by the use of varactor diodes, the capacitance of the diodes being electronically varied by nonsinusoidal control signals having wave forms which compensate for the nonlinear response of the diodes so that, ultimately, the side bands of the output signals contain sinusoidal modulation information.

Other objects will become apparent as the detailed description proceeds.

In the drawings:

FIGURE 1 is a block diagram showing the radio navigation system;

FIG. 2 is an electrical schematic diagram of the bridge network of the instant invention;

FIG. 3 is a graph showing the response of a back-biased varactor diode;

FIG. 4 is a graph showing the wave forms generated by the function generators in response to a sinusoidal input signal;

FIG. 5 is a graph showing the carrier wave input to the network of FIG. 2 and the modulated output signals obtained therefrom;

FIG. 6 is an electrical schematic diagram of the phase shifter and the two types of function generators; and

FIG. 7 is a fragmentary showing of one arm of the network of FIG. 2, illustrating the interconnection of a function generator and a varactor diode.

The navigation system in general

FIGURE 1 illustrates a VHF omnirange navigation system utilizing, for example, a carrier wave frequency of 110 mcs. The carrier wave generator is shown at **10**, the output thereof being fed to one input of an AM modulator **12**. A modulating signal having a frequency of 9960 c.p.s. is produced by signal source **14** and fed to one input of an FM modulator **16**. The 9960 c.p.s. signal may be considered a subcarrier since the same is frequency modulated by a 30 c.p.s. modulating signal generated by signal source **18**. FIGURE 1 clearly illustrates that the subcarrier and the 30 c.p.s. modulating signal are combined in the FM modulator **16** and then fed to the AM modulator **12** to serve as a modulating signal for the 110 mcs. carrier.

The output from AM modulator **12** is illustrated at **20**, it being apparent that the signal at such output comprises the 110 mcs. carrier which is amplitude modulated by the subcarrier delivered from the FM modulator output, such subcarrier having a center frequency of 9960 c.p.s. and being frequency modulated by the 30 c.p.s. signal from source **18**. This composite signal is fed to the omni-

directional feed of a VHF omnirange antenna to form one component of the propagated navigational signal.

The composite signal appearing at output **20**, however, is also coupled with a modulation eliminator **22** which delivers the 110 mcs. carrier free of modulation at its output **24**. Modulation eliminator **22** is conventional circuitry and may, for example, comprise a highly saturated vacuum tube amplifier stage having an AGC feedback. Under the effect of the automatic gain control, in conjunction with operation of the tube in the saturated state, the gain of the stage becomes an inverse function of envelope amplitude, resulting in a constant output at **24**.

The output **24** of the modulation eliminator is coupled with the input of a varactor diode bridge network **26** which, as will be discussed in detail later in this specification, comprises a pair of four arm bridges fed from a common input. Bridge network **26** has a pair of outputs **28** and **30** which are coupled with the variable phase feed of the VHF omnirange antenna.

The function of network **26** is to produce a pair of double side band, suppressed carrier signals at respective outputs **28** and **30** which have a 90° modulation envelope phase difference. These two signals are utilized by the antenna, in combination with the omnidirectional pattern, to produce a radiation pattern having a directional lobe which rotates about the antenna location at a rate of 30 revolutions per second.

Exemplary antenna systems suitable for use with the instant invention include a type 47898 VOR antenna, manufactured by Wilcox Electric Company, Kansas City, Missouri, assignee herein, or antenna structure as shown in Sprague, U.S. Letters Patent No. 2,746,039, owned by the assignee herein. Such antennas have an omnidirectional feed terminal for receiving the signal appearing at output **20** of AM modulator **12**, and two variable phase feed terminals for receiving the two double side band, suppressed carrier signals produced at outputs **28** and **30** of network **26**, the combined signals forming the sweeping or rotating directional lobe discussed above.

Network **26** has four control inputs **32**, **34**, **36** and **38** coupled with the outputs of function generators **40**, **42**, **44** and **46** respectively. As will become clear hereinafter, function generators **40–46** serve to control the operation of network **26** in a manner to impart the desired modulation to the 110 mcs. carrier. The function generators operate in response to the 30 c.p.s. signal produced by source **18**, such signal being referred to hereinafter as a primary signal. This primary signal is introduced into a phase shifter **48** which effectively splits the signal into a pair of secondary signals having a 90° phase difference. The secondary signals are sinusoidal and have the same frequency as the primary signal, one of said secondary signals appearing at output **50** of phase shifter **48** for coupling with function generators **40** and **42**, the other secondary signal appearing at output **52** of phase shifter **48** for coupling with function generators **44** and **46**.

It may now be appreciated that the utilization of modulation eliminator **22** to provide the 110 mcs. suppressed carrier for the variable phase antenna feed, rather than direct coupling of bridge network **26** with generator **10**, phase locks the omnidirectional and variable phase antenna feeds to eliminate any carrier phase difference that might occur due to the action of the intervening modulator stages.

The goniometer

FIGURE **2** is a schematic diagram of bridge network **26** showing input terminals **24***a* and **24***b*; output terminals **28***a* and **28***b*; output terminals **30***a* and **30***b*; control input terminals **32***a*, **34***a*, **36***a* and **38***a*; and a control terminal **32***b*, **34***b*, **36***b*, **38***b* forming a common return. It should be understood that the various terminals in FIG. 2 designated by a reference numeral and the "*a*" or "*b*" notation correspond to the reference numeral designations of FIG. 1 so that FIGS. 1 and 2 may be readily correlated.

Network **26** comprises a pair of four arm bridges having a common input coupled with terminals **24***a* and **24***b*. The two bridges have separate outputs represented by terminals **28***a*, **28***b* and **30***a*, **30***b* respectively. The left-hand bridge comprises arms **54**, **56**, **58** and **60**, while the right-hand bridge comprises arms **62**, **64**, **66** and **68**. Each arm has an electrically controllable, variable impedance device coupled therein, such devices comprising varactor diodes **70**, **72**, **74**, **76**, **78**, **80**, **82** and **84** in arms **54–68** respectively.

The arms of the two bridges also contain capacitors connected in series with respective diodes, such capacitors being designated **86**, **88**, **90**, **92**, **94**, **96**, **98** and **100** and disposed in arms **54–68** respectively.

A tunable inductor **102** is connected across the common bridge input, arms **54**, **56**, **62** and **64** being connected to one side of the input at junction points **104** and **106**, arms **58**, **60**, **66** and **68** being connected to the other side of the input at junction point **108**. Tunable inductors **110** and **112** are connected across the outputs of respective bridges, inductor **110** being coupled in a series loop with a pair of variable inductors **114**, a pair of blocking capacitors **116**, and one winding of a Balun transformer **118**. In a similar manner, inductor **112** is connected in a series loop with a pair of variable inductors **120**, a pair of blocking capacitors **122**, and one winding of a Balun transformer **124**. The Balun transformers **118** and **124** have 1:1 winding ratios, the secondary winding of each transformer being connected with the respective output terminals as illustrated.

A fixed DC bias voltage from a source (not shown) is applied between a positive terminal **126** and the common return or ground. The DC voltage is fed to the left-hand bridge of network **26** via conductor **128** and RF choke **130** to one side of the tunable inductor **110**. The DC voltage voltage is applied to the right-hand bridge through RF choke **132** to one side of tunable inductor **112**. RF chokes **134**, **136**, **138** and **140** are connected with control input terminals **32***a*, **34***a*, **36***a* and **38***a* respectively, and couple these terminals with arms **62**, **64**, **54** and **56**, respectively. An RF choke **142** is also connected in series with the common return, and RF chokes **144**, **146**, **148** and **150** are connected in the bridges as shown so that arms **58**, **60**, **66** and **68** are controlled by the same signals that control arms **56**, **54**, **64** and **62**, respectively.

Referring to FIG. 3, a graph is there shown illustrating the variable capacitance characteristic of a back-biased varactor diode. The graph is a plot of the reverse voltage applied across the cathode and anode of the diode, as abscissa, against the capacitance exhibited by the diode, as ordinate. It should be noted that FIG. 3 illustrates the application of an applied voltage **151** having a nonsinusoidal wave shape, the characteristic curve of the diode response being illustrated at **152**. It will be observed that curve **152** is quite nonlinear but that, when the nonsinusoidal voltage illustrated is applied to the diode, a sinusoidal capacitance response is obtained as illustrated by the sine wave **154**. The graph clearly shows that the applied voltage **151**, although periodic in nature, must have half cycles of unequal duration, as well as unequal instantaneous amplitude, in order to effect a sinusoidal variation of the capacitance of the varactor diode.

It should be understood at this juncture that modulation of the carrier wave by the bridge network **26** is effected by repeated balancing and unbalancing of the bridges in a fashion to be fully discussed hereinafter. Change of state of each bridge between its balanced condition and an unbalanced condition is effected by varying the capacitance of the arms thereof, such variation being effected electronically by time-varying control signals applied to the varactor diodes in the bridge arms. To effffect 30 c.p.s. sinusoidal suppressed carrier modulation of the carrier wave, it is requisite that the capacitance of the bridge arms be varied in a sinusoidal fashion at a frequency of

30 c.p.s., such frequency being the same as the frequency of the primary signal produced by source **18**.

It should be further understood that FIG. 3 illustrates the desired capacitance variation of the varactor diode if other bridge arm capacitance is negligible as compared with the capacity of the diode; therefore, the variation of diode capacitance is shown as sinusoidal. But, in practice, the capacity of the D.C. blocking capacitor in each arm and stray capacitance may be appreciable, necessitating that the diode capacitance variation be other than sinusoidal and selected so that the net capacitance of each bridge arm will undergo sinusoidal variation. For clarity of illustration, however, the existence of only negligible arm capacitance as compared with the diode is assumed herein.

The function generators which provide the necessary nonsinusoidal control signals for the bridges are illustrated in FIG. 6. Phase shifter **48** is shown at the left-hand end of the schematic diagram, the phase shifter being conventional in design and having a pair of input terminals **156** which are coupled with the output of the 30 c.p.s. source **18**. Terminals **156** thus receive the primary signal, the same being converted into the two secondary signals by operation of the RC components of the shifter network. One secondary signal appears at output lead **52**, this signal having a leading phase angle of 45° with respect to the primary signal. The other secondary signal appears at output lead **50** and has a lagging phase angle of 45° with respect to the primary signal.

Since the circuitry of function generators **40** and **44** and generators **42** and **46** is identical, only generators **44** and **46** are shown schematically in FIG. 6. Function generator **46** comprises a bank of resistors **158**, **160**, **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, **178**, **180**, **182** and **184** interconnected as shown and coupled with the output lead **52** from phase shifter **48**. Resistor **168** is shown split into two series connected resistors, one of which is variable and is utilized as a trimmer. It should be noted, however, that this arrangement adapts the variable section of resistor **168** for use as a part of automatic error correction apparatus to provide a means of compensating for lobe-shape errors during actual operation of the navigational system.

A D.C. supply voltage for function generator **46** is applied across terminals **186** and **188**, terminal **186** being negative, while terminal **188** is positive. Solid state diodes **190**, **192**, **194**, **196** and **198** are coupled with the resistor bank as shown to complete the wave shape forming portion of the circuitry. The output from diode **190** drives a field effect transistor **200** having a source **200***a*, a drain **200***b*, and a gate **200***c*. The field effect transistor **200**, in turn, drives an NPN transistor **202** which delivers the generator output to an output transformer **204**. The secondary winding of transformer **204** is connected across bridge control input terminals **38***a* and **38***b*.

Assuming that a Philco V–4091 is utilized as the varactor diode in each bridge arm and that other bridge arm capacitance is negligible as compared with the diode capacitance, values for resistances **158–184** which cause the production of the output signal of desired wave shape are as follows:

	Ohms
R158	200K
R160	52.3K
R162	10.5K
R164	11.3K
R166	28K
R168	39–64K
R170	15K
R172	12.4K
R174	13.3K
R176	15.0K
R178	17.4K
R180	9.09K
R182	32.4K
R184	100K

The circuit arrangement of function generator **44** is similar to that as described above for generator **46**. The difference between the two generators is in the polarity of the applied voltage at terminals **186'** and **188'**, and the reverse orientation of the diodes **190'–198'**. The circuit of generator **44** is otherwise identical to that as shown and described for generator **46**, including the values of the resistors **158'–184'**, with the exception that output transformer **204'** has its secondary winding connected across control input terminals **36***a* and **36***b* of the bridge network **26**.

FIGURE 4 illustrates the input and output wave forms of the function generators. The sinusoidal wave **206** depicts the wave form of the signal appearing at either of the outputs **50** or **52** of phase shifter **48**. Manifestly, if the signals at both of the outputs **50** and **52** were shown, such signals would be 90° out of phase with one another; therefore, it should be understood that FIG. 4 illustrates the phase relationship between the signal appearing at output **50** and the signals provided by function generators **40** and **42**, or the phase relationship between the signal appearing at output **52** and the signals provided by the function generators **44** and **46**. It may be seen that each of the type A function generators **40** and **44** produces a signal **208** phased as shown with respect to the corresponding sinusoidal secondary signal **206**. Signal **208** has a broad, relatively flat, positive excursion **210**, and a relatively sharp, negative excursion **212** of greater magnitude with respect to the reference line or axis **214**. Excursion **210** is of longer duration than excursion **212**, resulting in uneven half cycles, although the period of the signal **208** is the same as the period of the sinusoidal signal **206**.

Signal **216** from a B type generator **42** or **46** is identical to signal **208** except that the two signals are 180° out-of-phase with one another. Thus, it is apparent that the output signals from function generators **40** and **42** are 180° out-of-phase, and that the output signals from function generators **44** and **46** are also 180° out-of-phase. Furthermore, since the secondary signals appearing at outputs **50** and **52** of phase shifter **48** have a 90° phase difference, it is evident that function generators **40**, **44**, **42** and and **46** have relative phase angles of 0°, 90°, 180° and 270°, respectively.

Operation

The action of any one arm of either of the two bridges of network **26** may be readily understood with reference to FIG. 7. This figure shows arm **56** removed from the remainder of the network so that the action of the varactor diode **72** may be readily understood. A DC source **218** is illustrated connected between the positive supply terminal **126** and the negative return or common terminal **38***b*. The output transformer **204** of function generator **46** is shown with its secondary connected to terminal **38***b* and **38***a*. It will be appreciated that terminal **38***b* also forms the common return for the other three function generators which are not illustrated in FIG. 7.

Source **218** and the secondary of transformer **204** are effectively connected in series relationship so that the resulting potential difference across the cathode and anode of diode **72** will be the sum of the potentials delivered by these two voltage sources. Manifestly, the signal produced in the secondary of transformer **204** will alternately aid and oppose the constant voltage supplied by source **218**. This is illustrated clearly in FIG. 4 since the base line or reference axis **220** of signal **216** represents the level of the constant voltage supplied by source **218**. Thus, this constant negative voltage imparts a fixed reverse bias to the varactor diode which is varied when the function generator alternately opposes and aids source **218**. At the midpoint of the period of signal **216** corresponding in time to the zero crossing of the sinusoidal secondary signal **206**, a voltage illustrated in FIG. 3 at **222** causes the capacitance of the diode to assume a value indicated at **224** on the capacitance axis of the graph, the capacitance value at

224 being equal to the average value of the capacitance of the diode in its swing between the maximum value indicated at 226 and the minimum value 228.

The effect of the function generator output shown in FIG. 7 is to vary the applied voltage across diode 72 between a maximum negative value illustrated at 230 in FIG. 4, and a minimum negative value illustrated at 232. Thus, in accordance with the characteristic curve shown in FIG. 3, this causes the capacitance of diode 72 to vary sinusoidally over a period equal to the period of the output wave form appearing in the secondary of transformer 204. Manifestly, this sinusoidal variation of the diode capacitance will correspond in frequency to the secondary signal 206 appearing at output 52 of phase shifter 48 which, in turn, is identical in frequency to the 30 c.p.s. primary signal produced by source 18.

Due to the presence of capacitor 88, no direct or appreciable 30 c.p.s. current is permitted to flow to junction point 106 or through RF choke 142, the action of the function generator and source 218 being confined to the diode 72. The only current produced by this action is leakage current through the reverse junction of the diode. However, the capacitor 88 does not prevent passage of the carrier wave along arm 56, such wave entering the arm at junction point 106.

As may be seen in FIG. 2, the cathode of diode 72 is connected to the output of the bridge at the upper end of inductor 110; therefore, it will be appreciated that a path for the high frequency carrier wave is present from the input of the bridge to the output thereof through the sinusoidally varying capacitance presented by diode 72.

When the operation of the entire network is considered, it is evident that the capacitances of the various arms of the two bridges are constantly undergoing a sinusoidal variation which, in turn, is causing unbalancing of each bridge, first in one direction and then in another direction. The cumulative effect of this action in each bridge is to split the high frequency carrier into a pair of side bands containing the 30 c.p.s. modulation information imparted to the side bands by the varactor diodes. The carrier is thus suppressed, leaving only a double side band signal at each bridge output, such signal having a modulation envelope phase difference of 90° due to the 90° phase difference between the two secondary signals appearing at the outputs 50 and 52 of phase shifter 48.

Referring to FIG. 5, the input carrier wave is illustrated at 236, the double side band, suppressed carrier output signals obtained at bridge outputs 28 and 30 being shown at 238 and 240. The spaced, broken lines in FIG. 5 correlate the same points in time along the time axes of the respective wave forms, and clearly illustrate that the RF double side band signals are either in phase or 180° out-of-phase with respect to the RF carrier at all times. Looking particularly at wave form 238, it may be seen that phase reversal of the RF signal occurs at 242. If the plot of wave form 238 were extended in time beyond that shown in FIG. 5, it would be seen that a reversal also occurs at 244 and 246. Similarly, wave form 240 exhibits RF phase reversal at 248 and 250. The reversal points in time of wave form 238 correspond to the instants in time that the bridge comprising arms 54, 56, 58 and 60 is in balance. Likewise, the reversal points in time of wave form 240 correspond to the instants in time that the bridge comprising arms 62, 64, 66 and 68 is in the balanced condition. Looking at the wave form 238, the portion of the wave between points 244 and 242 illustrates unbalancing of the bridge in one direction, while the portion of the wave form between wave points 242 and 246 shows that the bridge has passed through the balanced condition and is in a state of unbalance in the opposite direction. The same is true for the other bridge of network 26, as evidenced by the phase reversals occurring at points 248 and 250 of wave form 240.

It will also be appreciated from viewing FIG. 5 that the modulation envelopes of wave forms 238 and 240 are 90° out-of-phase with one another, maximum amplitudes of the envelope of wave form 238 occurring at 252 and 254, while amplitude maximums for wave form 240 occur at 256, 258 and 260. This 90° phase difference between the modulation envelopes of the two double side band, suppressed carrier output signals of network 26 results from the 90° phase difference between the two 30 c.p.s. secondary signals applied to function generators 40, 42 and 44, 46 by phase shifter 48. The modulation envelopes, of course, carry the 30 c.p.s. modulation information, the carrier being added in space by the VOR antenna.

In the operation of the apparatus, the variable inductor 102 across the input of network 26 is adjusted to resonate with a value of capacitance equal to the average capacitance of one of the varactor diodes plus two times the minimum capacitance thereof. Such average capacitance is represented at 224 in FIG. 3, the minimum capacitance being represented at 228 on the capacitance axis of the graph. It is assumed, of course, that all of the varactor diodes of network 26 have similar characteristics.

Variable inductances 110 and 112 across the respective bridge outputs are each tuned to resonate with a value of capacitance illustrated at 228 in FIG. 3, or the minimum capacitance of one of the varactor diodes. Each pair of variable inductances 114 and 120 are tuned to resonate with a value of capacitance illustrated at 224 in FIG. 3 which, of course, corresponds to the average capacitance of one of the varactor diodes. It will be appreciated that the tuning of the various inductors may be effected during actual operation of the network and that, additionally, any adjustment of the function generators by variation of the value of resistance 168 (or 168') may also be effected during the network operation to assure optimum performance of the system.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. An electronic goniometer for subjecting a carrier wave to modulation information to produce a pair of double side band, suppressed carrier signals containing said information and having a predetermined, relative modulation envelope phase difference, said goniometer comprising:

a network including a pair of bridges having a common input for receiving said carrier wave and separate outputs, each of said bridges comprising a plurality of arms each having an electrically controllable, variable impedance device therein operable to vary the state of the respective bridge at the output thereof between a balanced condition and an unbalanced condition; and

modulation means coupled with said devices for applying control signals thereto to vary the impedances thereof in a manner to effect variation of the impedances of the arms of the bridges in accordance with the characteristics of said modulation information and to effect alternate balancing of said bridges, whereby to provide said suppressed carrier signals at respective bridge outputs.

2. The invention of claim 1, wherein each of said devices has a pair of electrical connection points between which the impedance at the frequency of said carrier wave is determined by the instantaneous magnitude of the respective control signal, said modulation means being coupled with the connection points of said devices.

3. The invention of claim 1, wherein each of said devices has a pair of electrical connection points between which the impedance at the frequency of the carrier wave varies as a nonlinear function of the potential difference across said connection points, said modulation means being coupled with the connection points of said devices and including means for providing said control signals with time-varying amplitudes defining wave shapes to compensate for the nonlinear response of said devices.

4. The invention of claim 3, wherein is provided means for producing an electrical signal comprising said modu-

lation information, said modulation means being coupled therewith and responsive to said modulation information signal for producing said control signals.

5. The invention of claim 3, wherein each of said devices presents an electrical capacitance between the connection points thereof having a value which varies as said nonlinear function of the potential difference thereacross.

6. An electronic goniometer for subjecting a carrier wave to modulation information to produce a pair of double side band, suppressed carrier signals containing said information and having a predetermined, relative modulation envelope phase difference, said goniometer comprising:

a network including a pair of bridges having a common input for receiving said carrier wave and separate outputs, each of said bridges comprising a plurality of arms each having an electrically controllable, variable impedance device therein operable to vary the state of the respective bridge at the output thereof between a balanced condition and an unbalanced condition; and

modulation means coupled with said devices for applying control signals thereto to vary the impedances thereof in a manner to effect variation of the impedances of the arms of the bridges in accordance with the characteristics of said modulation information and to effect periodic balancing of each of said bridges,

said modulation means including means for phasing said control signals to cause said balancing of the bridges to occur alternately, whereby to provide said suppressed carrier signals at respective bridge outputs.

7. An electronic goniometer for subjecting a carrier wave to modulation information to produce a pair of double side band, suppressed carrier signals containing said information and having a predetermined, relative modulation envelope phase difference, said goniometer comprising:

a network including a pair of bridges having a common input for receiving said carrier wave and separate outputs, each of said bridges comprising a plurality of arms each having an electrically controllable, variable impedance device therein operable to vary the state of the respective bridge at the output thereof between a balanced condition and an unbalanced condition;

first modulation means coupled with the devices of one of said bridges for applying first oscillatory control signals thereto having like periods to vary the impedances of the last-mentioned devices in a manner to effect variation of the impedances of the arms of said one bridge in accordance with the characteristics of said modulation information,

said first modulation means producing said first control signals with predetermined, relative phase relationships selected to effect momentary balancing of said one bridge at repetitive intervals equal to one-half of said period;

second modulation means coupled with the devices of the other bridge for applying second oscillatory control signals thereto, having the same periods as said first control signals, to vary the impedances of the last-mentioned devices in a manner to effect variation of the impedances of the arms of said other bridge in accordance with the characteristics of said modulation information,

said second modulation means producing said second control signals with predetermined, relative phase relationships selected to effect momentary balancing of said other bridge at repetitive intervals equal to one-half of said period; and

means operably coupled with said first and said second modulation means for phasing said first control signals relative to said second control signals to cause said balancing of the bridges to occur alternately, whereby to provide said suppressed carrier signals at respective bridge outputs.

8. The invention of claim 7, wherein said phasing means creates a phase difference between said first control signals and said second control signals equal to said modulation envelope phase difference.

9. The invention of claim 7, wherein said first modulation means produces a pair of said first control signals 180° out of phase with one another, said second modulation means producing a pair of said second control signals 180° out of phase with one another.

10. The invention of claim 9, wherein said plurality of arms comprise four in number in each bridge respectively, said first modulation means including circuit means for coupling each of said pair of first control signals with a different pair of the four arms of said one bridge, said second modulation means including circuit means for coupling each of said pair of second control signals with a different pair of the four arms of said other bridge.

11. In a radio navigation system:

first means for supplying a carrier wave;

a network including a pair of bridges having a common input and separate outputs, said common input being coupled with the output of said first supply means, each of said bridges comprising a plurality of arms each having an electrically controllable, variable impedance device therein operable to vary the state of the respective bridge at the output thereof between a balanced condition and an unbalanced condition,

each of said devices having a pair of electrical connection points, coupled in the respective arm, between which the impedance at the frequency of the carrier wave varies as a nonlinear function of the potential difference across said connection points;

second means for supplying a primary signal comprising modulation information;

a phase shifter coupled with said second supply means and responsive to said primary signal for splitting the latter into a pair of secondary signals out of phase with one another a preselected number of degrees;

a first pair of function generators coupled with the arms of one of said bridges and said phase shifter and responsive to one of said secondary signals for producing a first pair of bridge control signals having time-varying amplitudes defining wave shapes to compensate for the nonlinear response of said devices and vary the impedances thereof in a manner to effect variation of the impedances of the arms of said one bridge in accordance with the characteristics of said modulation information, and having a predetermined phase difference selected to effect momentary balancing of said one bridge at repetitive intervals; and

a second pair of function generators coupled with the arms of the other bridge and said phase shifter and responsive to the other of said secondary signals for producing a second pair of bridge control signals having time-varying amplitudes defining wave shapes to compensate for the nonlinear response of said devices and vary the impedances thereof in a manner to effect variation of the impedances of the arms of said other bridge in accordance with the characteristics of said modulation information, and having a predetermined phase difference selected to effect momentary balancing of said other bridge at repetitive intervals, whereby to provide a pair of double side band, suppressed carrier signals at respective bridge outputs having a modulation envelope phase difference caused by alternate balancing of said bridges.

12. The invention of claim 11, wherein said predetermined phase difference of said first and said second pairs of control signals equals 180°.

13. The invention of claim 12, wherein said plurality of arms comprise four in number in each bridge respectively, each of said devices comprising a varactor diode, there being first circuit means coupling the output of each of said first pair function generators, respectively, with a different pair of said arms of said one bridge, and second circuit means coupling the output of each of said second pair of function generators, respectively, with a different pair of said arms of said other bridge.

14. The invention of claim 12, wherein said preselected number of degrees equals substantially 90, whereby said network is fed with control signals substantially 90° out of phase with one another to provide said pair of suppressed carrier signals with a 90° modulation envelope phase difference.

15. An electronic goniometer for subjecting a carrier wave to modulation information to produce a pair of double side band, suppressed carrier signals containing said information and having a predetermined, relative modulation envelope phase difference, said goniometer comprising:

a network including a pair of bridges having separate outputs, each of said bridges being provided with an input;

means coupled with the bridge inputs for feeding said carrier wave thereto,

each of said bridges comprising a plurality of arms each having an electrically controllable, variable impedance device therein operable to vary the state of the respective bridge at the output thereof between a balanced condition and an unbalanced condition; and

modulation means coupled with said devices for applying control signals thereto to vary the impedances of the arms of the bridges in accordance with the characteristics of said modulation information and to effect alternate balancing of said bridges, whereby to provide said suppressed carrier signals at respective bridge outputs.

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