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ELECTRONICALLY CONTROLLED LOW IMPEDANCE PHASE SHIFTING DEVICE

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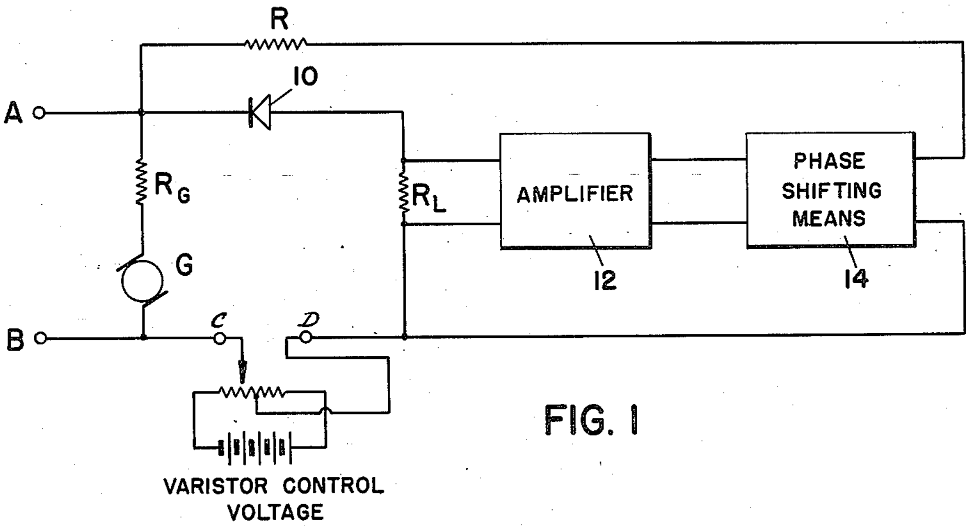

FIG. 1

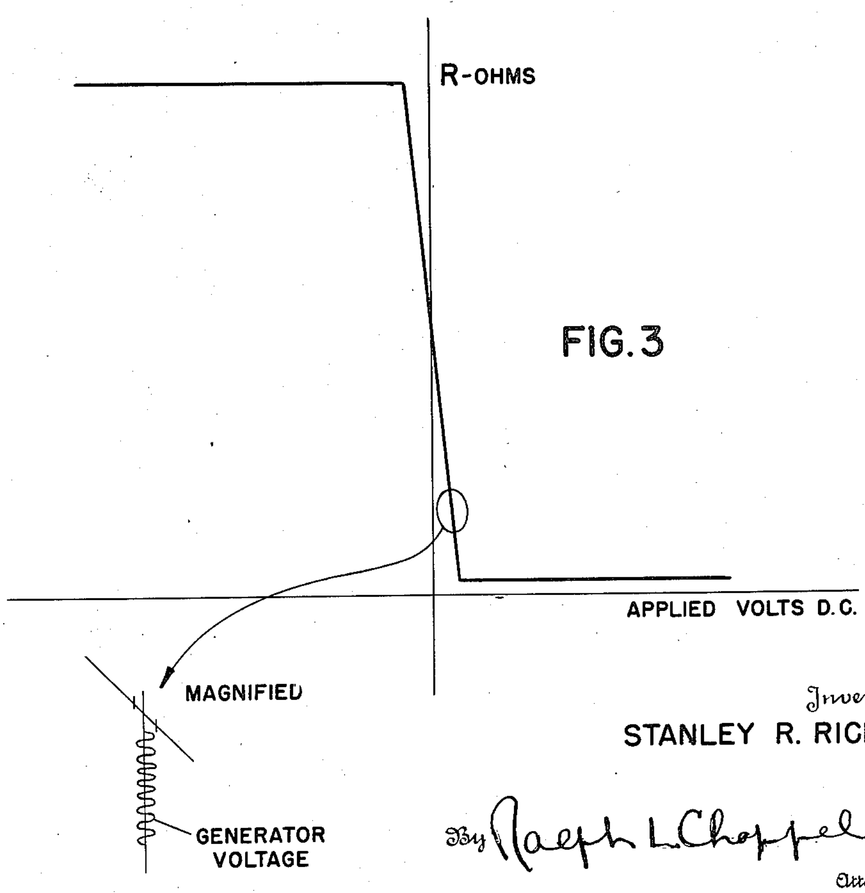

FIG. 3

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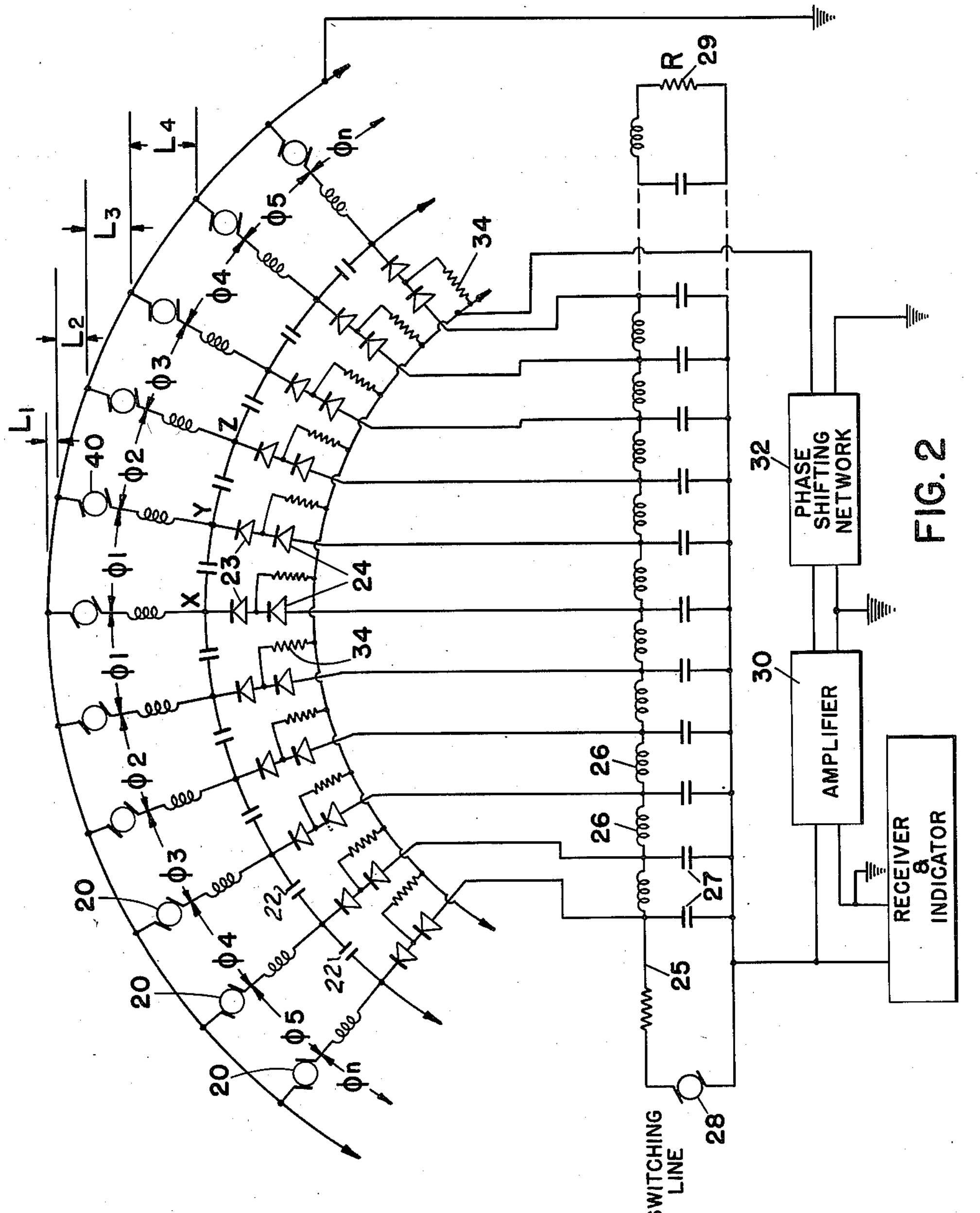

FIG. 2

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ELECTRONICALLY CONTROLLED LOW IMPEDANCE PHASE SHIFTING DEVICE

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4 Claims. (Cl. 177—386)

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This invention relates to means to control the phase shift in a transmission line or similar network and is particularly directed to a circuit which enables the use of varistors as low impedance variable reactance control elements.

The invention is of general application but will be described in the following specification in its specific aspect which adapts it to an electronically rotated scanning underwater sound echo ranging or "scanning sonar" system.

For the purpose of this disclosure it is necessary to understand the essentials of a scanning sonar system only to the extent that the system employs a transducer from which an omnidirectional sound pulse is periodically emitted, echoes from the sound pulses being picked up by the transducer acting as a multi-element receiving microphone the elements of which are scanned at intervals less than the pulse length. Scanning is accomplished in one form of the electronic rotation system by so biasing varistors associated in the receiving circuit of each transducer element as to permit the passage of current from successive transducer elements into the rest of the receiver system.

A switching line is used in the preferred form by which a pulse started down the line biases each varistor in turn, thus in effect, rotating a beam of sensitivity around the transducer the frequency being determined, of course, by the electrical length of the switching line. As soon as a pulse reaches the end of the line a new pulse is put into the beginning so that the rotation is continuous at the switching frequency which is preferably at least 200 cycles per second.

While it is possible to scan each transducer element in turn and as a unit, a much higher output and hence better system sensitivity can be attained by combining the outputs of a plurality of transducer elements. Since the transducer is generally of essentially cylindrical shape and a returning wave front is essentially plane there is a time difference between the instant when a given sound wave strikes one element and the instant when the same wave strikes successive pairs on either side of that element. Thus if the signals from the side pairs can be led in phase they can be made to add to the signal from the center element so that the transducer, in effect, operates as though it had a flat face containing all of the elements then conducting. In the electronic rotation scanning system, a permanently connected lead line is used to give the desired results.

In order to activate a number of receiving

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circuits simultaneously it is only necessary to broaden the pulse in the switching line so that several varistor elements have imposed on them sufficient voltage to render them conductive. If the switching pulse varies in amplitude from beginning to end, as will be the case if the pulse is the clipped peak of a sine wave, the activated varistors will have different voltages impressed so that they are in progressively increasing and then progressively decreasing stages of conductivity as a pulse passes down the line. Thus the signal contribution from the far side pairs is much less than the contribution from the instantaneous center element, the contribution increasing as the center element is approached. The receiving pattern thus includes a properly weighted sample from the activated transducer elements shifted in phase to approximate phase coincidence. This approximation is not as close as is desirable, however.

It will be apparent from the geometry of the transducer-wave front system that the phase shift required to bring signals in the first side pair of elements into phase coincidence with the center element is much less than that required to bring the signals in the second side pair into coincidence, and that successive pairs require greater phase shift. Thus, either a compromise must be effected and slightly out of phase signals tolerated if a constant phase shift lead line is used, or some means must be provided whereby the lead line characteristics are varied with pattern rotation.

It is the primary object of the present invention to provide means to vary the phase shift characteristics of a phase shifting network in accordance with the amplitude of an applied bias voltage.

Another object of the invention is to provide a low impedance means to vary the phase shift characteristics of a phase shifting network in accordance with the amplitude of an applied bias voltage.

Still another object of the invention is to provide a circuit wherein low impedance elements, such as varistors, can be utilized as reactors, so that the over all phase shift in the circuit is dependent on the bias voltage across the varistor.

Other objects and advantages of the invention will become apparent from the following detailed description of one application of the invention, reference being had to the accompanying drawings in which:

Fig. 1 is a circuit diagram illustrating the principles of the invention.

Fig. 2 is a diagrammatic illustration of one specific application of the invention.

Fig. 3 is a curve illustrating varistor characteristics.

Referring to Fig. 1 of the drawings, the invention is shown in its general application to control the phase and magnitude of the voltage between two terminals A and B. As there indicated, a generator G having an internal resistance R_G is disposed in series with a load R_L. If there were no other devices connected in the circuit a particular voltage E_0 would appear between A and B.

A varistor 10 is inserted in the circuit and a portion of the current flowing through the load R_L is amplified in an amplifier 12. The output of the amplifier is taken through a phase shifting means 14 back to the generator circuit in parallel with the generator. The phase shifting means may be capacitive or inductive, so that with the amplifier output in phase or 180° out of phase with the voltage across R_L there exists the possibility of the voltage which is placed in parallel with the original generator voltage being of any desired phase and amplitude relative thereto. Thus, if the phase shifting means 14 introduces a 90° phase lead and the output of amplifier 12 is 180° out of phase with its input, the voltage in parallel with the original generator voltage is a quadrature voltage lagging 90°. The quadrature voltage may be a leading voltage if no phase shift is introduced by amplifier 12 and if means 14 introduces a 90° lead. The parallel voltage may aid the generator voltage if the amplifier 12 and phase shifting means both introduce 180° phase shift, or it may buck the generator voltage if no phase shift is introduced by the amplifier and 180° by the means 14 or if the means 14 is omitted and a phase inverting amplifier used. The reintroduced voltage may have any desired phase relationship to the original voltage dependent upon the sum of the phase shifts in the amplifier 12 and phase shifting means 14.

The contribution introduced by the parallel source across points A and B is controlled in amplitude by any suitable means, the simplest form being a D. C. control voltage which biases and hence controls the conductivity of the varistor 10. The varistor 10 presents a substantially constant resistance, both forward and backward, to a small A. C. voltage from generator G. From an inspection of Fig. 3 it will be apparent that the generator voltage modulates the control voltage. If the D. C. control voltage is replaced by an A. C. voltage it will be apparent that the voltage across C and D will be the generator voltage whose magnitude is varied by the control voltage which, if desired, may be an audio frequency voltage derived from any source. The generator voltage may be derived from a microphone or signal transmission line while the control voltage may be derived from a sine wave oscillator or a switching lag line.

In Fig. 2 the invention is shown applied to an electronically rotated scanning sonar system comprising a transducer which is diagrammatically illustrated as a ring of generators 20. In effect each transducer element acts as a small generator on reception of a signal. The rotation of the pattern or successive connection of each transducer element is accomplished by means of a circuit including a pair of series-connected varistor elements associated with each transducer element which are successively rendered operative to effectively couple the transducer elements to the rest of the system by a control pulse fed thereto from switch line 25. Accordingly the varistors are connected between the respective transducer elements and successive points on a switching delay line 25 which may consist of series inductances 26 and shunt capacitors 27 into which a pulse is fed by a pulse generator 28. The line, is, of course, terminated in its characteristic impedance 29.

A portion of the transducer voltage obtained from switch line 25 voltage is taken to an amplifier 30 which corresponds in function to amplifier 12 in Fig. 1, so that its output passes through a phase shifting means 32 and back through isolating resistors 34 to the several points between varistors 23 and 24 in each set. By reintroducing the voltage between the varistors the effect of the feed-back voltage is confined to those varistors circuits which are presently biased to conduction by the switching delay line. The effect thus rotates in accordance with the pattern rotation.

In the system as used without the present invention the value of capacitors 22 is chosen to effect the best possible compromise to approximate a flat-face transducer on reception. The phase shift introduced by capacitor 22 has been made constant at about one radian per section. This value is slightly low for the outside sections to contribute most efficiently and slightly high for the most efficient contribution from the first and second side pairs of transducer elements.

In the operation of the present invention as applied to the specific case shown in Fig. 2, generator 40 produces a voltage at point Y which is advanced in phase by the line section XY so that at point X the phase of the voltage due to generator 40 is normally 1 radian ahead of the phase at point Y. When the varistor at point X is so biased that its resistance to the flow of signal currents is small, signal from point X is conducted to amplifier 30 through the associated varistors 23–24 and switch delay line 25. This signal is amplified and its phase shifted an appropriate angle. This amplified and phase shifted signal is then fed back into the circuit between varistors 23 and 24 so that a current flows into X due to the reintroduced voltage. This produces a new voltage at X, which, combined vectorially with the original voltage at this point from generator 40, results in a new final voltage. The phase difference between the new resultant voltage and the original voltage at point Y is now smaller than the phase difference originally existing between points X and Y. The new phase difference is now more nearly proportional to the actual delay in the arrival of signal from a source in the medium indicated by the distance L1.

Since the switching pulse is shaped to provide a lower bias voltage for successive side pairs of circuits associated with transducer elements flanking the instantaneous center, the varistors in these circuits are less conductive than the center varistors adjacent point X. Thus it can be seen that the voltage contributed to point X from point Z is less than that from point Y, and since this voltage is made up of what may be termed a "normal" component added vectorially to a phase shifted component which is the same in all of the varistor circuits the phase of the voltage will be more greatly changed. The greater change is due to the fact that the phase shifted component plays a larger part in determining the final phase of the voltage. The result is to bring the signal voltage from Z into more accurate phase coincidence with the signal voltage at X and to reduce the phase relation to a value very close to that of the actual delay in arrival time between the transducer elements at X and Z. The same effect is present in all the activated circuits; that is, the phase lead is changed from the compromised value to one more closely approaching the optimum.

Varistors are useful as control elements in the low impedance range from a few ohms up to about 500 ohms. Diodes may be employed successfully in the range from 500 to 5000 ohms; and triodes, pentodes, etc. for circuits above 5000 ohms.

What I claim is:

1. In a sonar scanner an arcuate array of transducer elements each coupled to a transducer output, a pulsed switching delay line terminating in a characteristic impedance and having a number of equal incremental line impedances corresponding to the number of said transducer elements, circuit means connecting the transducer element outputs to successive ones of said incremental line impedances, respectively, a varistor in each said circuit means, whereby a pulsed voltage progressing along said switch line causes voltages from successive transducer elements to be conducted through said varistors, respectively, an amplifier connected to said transducers through said varistors whereby the respective transducer outputs voltage is coupled to said amplifier upon conduction of the associated varistor, a phase shifting network in the output circuit of the amplifier, and means connecting the output circuit of said phase shifting network to said transducer output, whereby the output thereof is the vectorial sum of the shifted and unshifted voltage components.

2. A transducer scanning device for converting the reception pattern of an arcuate array of transducer elements from an arcuate to plane front comprising a plurality of transducer elements arranged generally along an arcuate line, a separate transmission path connecting each transducer element to a common circuit through a respective switch device having a normally high impedance condition and which is switchable to a low impedance condition, a delay line, a source of voltage pulses connected to said delay line for causing pulses to be sent down said line, means

connecting said respective switch devices to different points on said line for causing said switch device to assume a low impedance condition in response to a pulse on said delay line to progressively couple said transducer to said common circuit, a phase shifting circuit coupled between said common circuit and the side of said switch devices remote from said common circuit to feed back to said common circuit a phase shifted component of the signal therein only when the associated switch device is in the low impedance condition.

3. The combination of claim 2 characterized further by capacitor means coupled between said transmission paths for coupling a phase advanced component from one transducer transmission path to the adjacent transmission path, the said source of voltage pulses providing pulses which have a gradually diminishing amplitude at the leading and trailing edges thereof, the duration of said pulses being sufficiently long that at least three adjacent switch devices are simultaneously in a low impedance condition and hence operative to simultaneously couple a plurality of transducer elements to said common circuit, the impedance of said switch devices, and hence their coupling efficiencies being variable with the instantaneous amplitude of the pulses fed thereto from said delay line.

4. The combination of claim 2 characterized further by said switch devices each including two varistor elements in series circuit relation which are conductive in only one and the same direction, the connection of the switch device to the output of the said phase shifting circuit being made at a point between said varistor elements.

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