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STEERABLE ANTENNA SYSTEM

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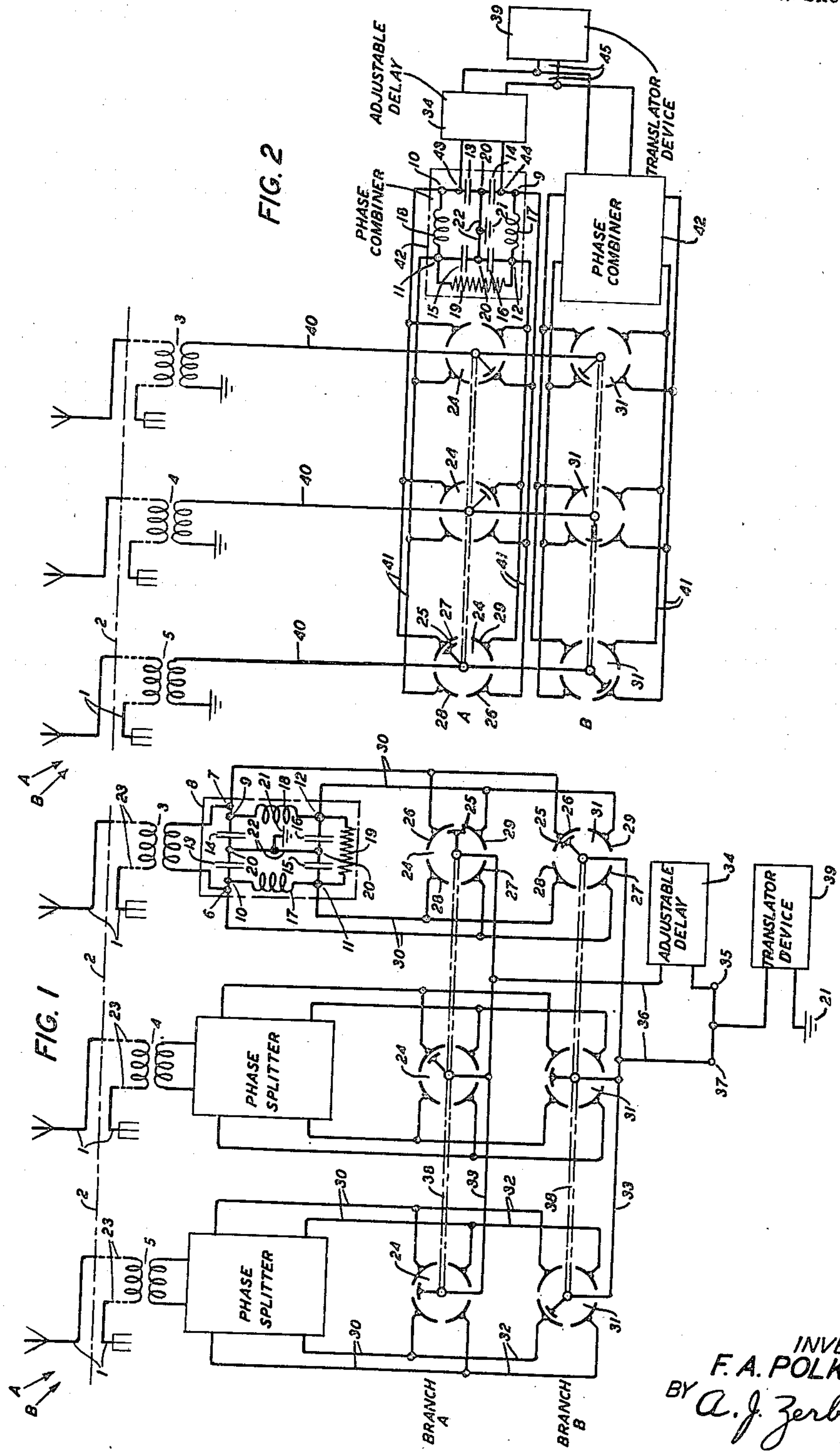

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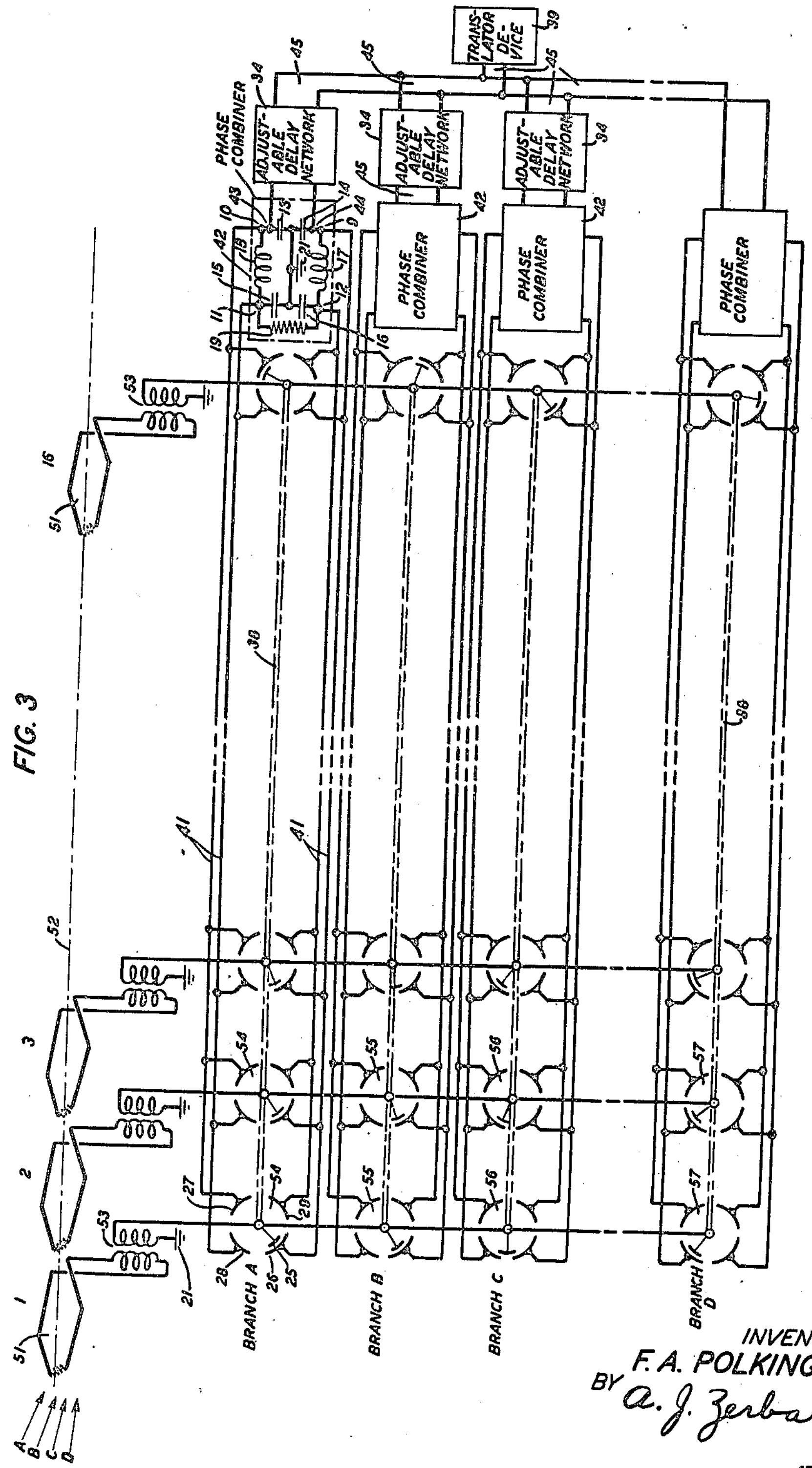

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STEERABLE ANTENNA SYSTEM

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7 Claims. (Cl. 250—11)

This invention relates to phase control circuits and more particularly to multichannel phase control circuits especially adapted for use in systems having a plurality of input circuits and one or more output circuits.

As disclosed in Patent 2,041,600, H. T. Friis, May 19, 1936, highly efficient radio reception or transmission may be secured utilizing an array comprising a plurality of antenna units connected through adjustable individual phase shifters to the receiver. In this system or method the phases of the antenna currents are adjusted for the purpose of aligning the maximum directive lobe of the array with the optimum direction of transmission or reception, and it has been suggested that a phase shifter of the type illustrated by Fig. 1 of Patent 2,147,728, W. T. Wintringham, February 21, 1939, and comprising a variable condenser and a phase splitting network included between each antenna unit and associated condenser, be employed in order to secure an accurate phase and amplitude control and a constant uniform loss in the phase shifter with adjustment of phase. Thus, in a large practical receiving system comprising sixteen antenna units and sixteen phase shifting variable condensers, sixteen phase splitting networks would be utilized. If reception is desired over several paths or diversity branches a group of sixteen condensers is required for each diversity branch and several condensers, one for each diversity branch, may be connected to the output terminals of the phase splitting network associated with each unit. It now appears desirable to simplify greatly the phase control arrangement described above and particularly to achieve a substantial reduction in cost, both in initial and maintenance expense, for multichannel control circuits used in a multiunit steerable array, hereinafter referred to simply as MUSA, comprising a large number of antenna units. More particularly it appears desirable to employ a minimum number of networks in receiving systems comprising a given plurality of antenna units or input circuits and a different plurality of diversity branches or output circuits.

It is one object of this invention to control the phase relation of several currents in a simple and economical manner.

It is another object of this invention to utilize a minimum amount of equipment for adjusting or controlling, without change of amplitude, the phase relation of several currents.

It is still another object of this invention to steer or adjust for optimum operation one or more directive characteristics of a multiunit antenna array without attenuating upon change of adjustment the antenna currents, and utilizing a minimum amount of equipment.

It is a further object of this invention to control, in a transmission system included between a plurality of input circuits or energy sources and a plurality of output circuits or load devices and comprising a plurality of distinct transmission paths, the phase relation of the currents in an efficient and inexpensive manner.

According to this invention, in a system having a plurality of input circuits and one or more output circuits and employing phase control circuits of the type described above, a minimum number of networks may be utilized when the number of input circuits exceeds the number of output circuits, by including a phase combining network between each output circuit and a separate set of condensers connected to the input circuits; and, when the number of output circuits is greater than the number of input circuits, by connecting a phase splitting network between each input circuit and a separate set of condensers connected to the output circuits. When the number of input circuits and the number of output circuits are equal either arrangement may be utilized. Thus, in a four-angle diversity MUSA system comprising sixteen antenna units and sixty-four control condensers, four control networks may be employed instead of sixteen as previously suggested.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawings in which like reference characters denote elements of similar function and in which:

Fig. 1 illustrates a two-angle diversity, three-unit MUSA system arranged in accordance with prior art suggestions;

Fig. 2 illustrates a two-diversity, three-unit MUSA system constructed in accordance with the invention; and

Fig. 3 illustrates an embodiment of the invention as incorporated in a large MUSA system.

Referring to Fig. 1, reference numerals 1 designate antenna-counterpoise units which may each have a directive characteristic or a non-directive characteristic and which together constitute an array for receiving an incoming signal over the two diversity paths or branches A and B, the units being spaced along the array axis 2. Each unit is coupled through input transformer 3 or 4 or 5, to the input terminals 6 and 7 of a phase splitting network 8 having four terminals 9, 10, 11 and 12 and comprising connected condensers 13, 14, 15 and 16, coils 17 and 18, and resistance 19. The junction points 20 of the condensers 13, 14 and of condensers 15 and 16 are connected to ground 21, respectively, through conductors 22. The transformers 3, 4 and 5 represent intermediate frequency input circuits, a frequency conversion circuit being included, as indicated by dotted line 23 between each antenna and the associated transformer 3, 4 or 5. Reference numerals 24 designate phase control variable condensers for diversity branch A, each of these condensers having a rotor 25 and four stator plates 26, 27, 28 and 29 which are connected, respectively, to network terminals 9, 10, 11 and 12 through conductors 30. A similar set of three condensers 31, one for each input circuit, is provided for diversity branch B, the stators of each being connected by conductors 32 to the stators of the condenser 24 and to the four terminals of the network 8 associated with the same input circuit or antenna. Thus, each of condensers 24 and 31 and the associated phase splitting network constitutes a distinct phase control circuit.

The rotors 25 of condenser 24 for diversity branch A are connected together by conductor 33 and through adjustable delay device 34 to the input terminal or circuit 35 by means of conductors 36; and the rotors 25 of condensers 31 for diversity branch B are similarly connected together and directly connected to output terminal 37. The rotors for the condensers in each diversity branch are preferably unicontrolled through graded gears, in accordance with the disclosure in the above-mentioned Friis patent, as indicated schematically by line 38. The output terminals 35 and 37 are connected to ground 21 through the receiver 39. Hence, input circuits 3, 4 and 5 are connected to the two output circuits 35 and 37 through a six-channel transmission system each including a phase control condenser. It should be noted that the phase control networks are directly associated with the input circuits, and that the number of networks is equal to the number of input circuits and greater than the number of output circuits.

In operation, the components of a desired wave as received over the two paths A and B on the several antennas 1 are conveyed through transformers 3, 4 and 5 to the input terminals 6 and 7 of each of the three networks 8. As explained in the Friis patent mentioned above, the components intercepted by adjacent units differ in phase by an amount related to the wave arrival angle A or B. Since the network 8 is in effect a quadrature phase shifter, each network functions to impress quadrature potentials on the four stator plates of each condenser 24 and 31 associated therewith, whereby the potential impressed on the condenser rotor 25 may have any phase and is determined solely by the rotor position. As ordinarily used the rotors 25 of condensers 24 are simultaneously adjusted so as to secure thereon in-phase potentials for waves having the incoming direction A; and the rotors 25 of condenser 31 are similarly adjusted to secure in-phase potentials for components following direction B. Delay device 34 is then adjusted for the purpose of rendering the output potentials or the currents for the two branches in phase agreement on terminals 35 and 37.

Referring now to Fig. 2 which illustrates a multi-channel system having the same number of input circuits, output circuits and transmission channels as the system of Fig. 1, it will be seen that in accordance with the invention the connections for each variable condenser are reversed with respect to those in the system of Fig. 1, and that instead of phase splitting networks, one for each input circuit, phase combining networks, one for each output circuit, are utilized. The phase combining networks 42 are the same in construction as the phase splitting network 8 of Fig. 1. Thus considering each diversity branch or output circuit and the three condensers therefor, the input circuits 3, 4 and 5 are each connected to the rotors 25 and the stators are connected through a single combining network to the output circuit; whereas in Fig. 1, the input circuits are connected through separate splitting networks to the stators and the rotors are connected to the output circuit. It may be noted here that each condenser and associated network, as used in the systems of Figs. 1 and 2, constitute a passive network, and, as is known, the output and input terminals of such a network may be interchanged. More particularly, referring to Fig. 2, the secondary windings of transformers 3, 4 and 5 are each connected by a conductor 40 to the rotors 25 of a condenser 24 and a condenser 31; and the stators 26 and 27, 28 and 29 of the three condensers in each diversity group are connected by the conductors 41, respectively, to the terminals 9, 10, 11 and 12 of a network 42, each network comprising condensers 13 and 14, condensers 15 and 16, coils 17 and 18 and a resistance 19. The output terminals 43 and 44 of each network 42 are connected to the receiver 39 by line 45, a delay device 34 being included in branch A between the phase combining network 42 and the receiver 39. Thus, as in the system of Fig. 1 the transmission system comprises six channels and each condenser and associated network constitute a phase control circuit.

In operation, out-of-phase wave components received over each of paths A and B by the antenna units 1 are impressed on the rotors 25 of the condensers 24 and on the rotors of condensers 31. The rotors of condensers 24 and the rotors of condensers 31 are adjusted so that in-phase potentials are secured, respectively, for directions A and B on the output terminals of the respective network 42. More specifically, the rotors 25 of condensers 24 are adjusted so that the out-of-phase potentials impressed thereon by the antenna units 1 produce in-phase potentials on the output terminals 43 and 44 of the network for waves having the direction A and the rotors 24 of condensers 31 are adjusted to secure in-phase output potentials for a wave having direction B. As in the circuit of Fig. 1, the delay circuit 34 is then adjusted so that the energies received over branches A and B are rendered in phase agreement before being supplied to the receiver 39. In a sense, in the system of Fig. 1, each rotor selects from the phase splitter terminals a properly phased potential whereas, in the system of Fig. 2, each rotor impresses on the phase combiner terminals properly phased potentials.

It is therefore apparent that, in accordance with the invention, a reduction in the number of networks required is realized, the number being equal to either the number of input circuits or the number of output circuits, whichever is smaller. Comparing the prior art system of Fig. 1 with applicant's system, Fig. 2, each system having three input and two output circuits, three networks are used in the prior art arrangement whereas only two networks are employed in applicant's system. Ordinarily in steerable antenna systems of the type referred to above the number of input circuits exceeds the number of output circuits, and, in accordance with the invention, a considerable economical saving is effected.

Fig. 3 illustrates a large practical MUSA system especially suited for transoceanic communication and designed for four-angle diversity reception. The system comprises sixteen highly unidirectional rhombic antennas **51** spaced along the array axis **52** and connected each through a transformer **53** to the rotors **25** of four condensers **54**, **55**, **56** and **57**, each of the four condensers being included in a different diversity branch. Thus, sixteen condensers **54** are provided for branch A, sixteen condensers **55** for branch B, sixteen condensers **56** for branch C and sixteen condensers **57** for branch D. As in Fig. 2, the stators **26**, **27**, **28** and **29** for the condensers for each branch are connected by conductors **41** in parallel and to the four terminals of a phase combining network **42** one of which is provided for each branch. The output terminals **43** and **44** of all networks, except the network **42** for branch D, are connected by lines **45** through a separate delay device **34** to the input terminals of receiver **39**. The network **42** for branch D is directly connected to the receiver **39**. If desired, one of the sets of sixteen condensers and associated network may be used for monitoring purposes instead of for service reception, as disclosed in Patent 2,173,858 of N. J. Pierce and F. A. Polkinghorn, granted September 26, 1939.

The directive operation of the MUSA system of Fig. 3 is fully explained in the Friis patent. Moreover, in view of the discussion given above in connection with Fig. 2, the operation of the phase control multichannel system of Fig. 3 is believed to be apparent. It should be noted that while sixteen input circuits or antenna units, four output circuits or branches and sixty-four variable condensers are utilized only four control networks are employed, whereas if the arrangement illustrated by Fig. 1 were utilized, sixteen networks, each relatively expensive both in structural cost and installation cost, would be required. It may be added that, as described in the above-mentioned patent of Pierce-Polkinghorn, the receiver **39** in network **42** may be located at the center of the array and the two halves of the array may, if desired, be separately or jointly used. In this case each subarray of eight antenna units would require four phase combining networks, and for the whole system, a saving of eight networks would be realized as compared to the prior art arrangement. It should be added also that the invention is equally suited for use in transmitting and receiving systems and may be used in MUSA systems arranged for directive steering in a plurality of planes.

Although the invention has been described in connection with certain embodiments, it should be understood that it is not to be limited to the embodiments described since other apparatus may be successfully employed without exceeding the scope of the invention. Thus, the number of stator plates in each variable phase shifting condenser may be other than four, as for example, eight; and again, instead of a variable condenser a variable inductance may be satisfactorily employed in each phase control circuit.

What is claimed is:

1. In an electrical system, a plurality of energy sources each connected through a separate transmission channel to a load circuit and means for adjusting with uniform loss the phase relation of the currents in said channels, said means comprising a variable phase splitter included in each channel for deriving from the channel current two sets of opposite phase components, and a common phase combiner included between all of said phase splitters and said load circuit and comprising a phase shifter for changing the phase relation between the two sets of components in each channel.

2. In a radio system, an antenna array comprising a plurality of antenna units, a translation device, a set of adjustable phase changers each having a constant loss with adjustment, each changer comprising an individual variable condenser having a rotor connected to a different antenna unit and four stator plates, a common quadrature phase shifter connected to the translation device and having four terminals each connected to a different set of corresponding stator plates.

3. In an angle diversity radio receiving system, a multiunit steerable antenna array, a receiver and a set of adjustable phase changers for each diversity branch, each changer having uniform loss with adjustment and each set comprising a separate variable condenser connected to each unit and a common quadrature phase shifter included between the receiver and said condensers.

4. In a radio receiving system, a multiunit antenna array, a receiver and means for obtaining a plurality of steerable and independent space factor directive characteristics included between said array and said receiver, said means comprising a plurality of sets of variable reactances, one set for each characteristic, each reactance in each set being connected to a different antenna unit, and a plurality of phase combining networks, a different one for each characteristic, each network being connected between the receiver and all the reactances of the associated set of condensers.

5. In a radio system, a steerable antenna array comprising a plurality of antenna units connected through separate transmission channels to a receiver, and means for adjusting without change of attenuation the phase relation of the antenna currents included in said channels, said means comprising a plurality of variable condensers, each having a rotor and a plurality of stator plates, said units being connected to separate rotors and the corresponding stator plates being connected together, and a phase combining network having four terminals each connected to a different set of corresponding stator plates, and said receiver being coupled to said network.

6. A method of securing, in a radio system comprising a multiunit antenna array, a plurality of steerable space factor characteristics for receiving energy over diverse paths, utilizing a separate variable reactance between each unit and the receiver for each diversity path, which comprises the step of including a network between each unit and the reactances connected thereto when the number of paths exceeds the number of units, including a network between the reactances for one path and the receiver when the number of units is greater than the number of paths, and including the network between each unit and the associated reactances or between the reactances for one path and the receiver when the units and paths are equal in number.

7. A method of receiving radio energy over a first given plurality of paths, utilizing an array

comprising a second given different plurality of antenna units, a plurality of variable condensers equal to the product of said given pluralities, a plurality of phase control networks and a receiver, which comprises connecting in parallel between each unit and the receiver a group of variable condensers, one for each path, selecting a particular number of networks equal to the smaller of said given pluralities and including a network between each antenna and the condensers connected thereto when the first given plurality is larger than the second given plurality, and including a network between the receiver and the corresponding condensers utilized for the same path when the second given plurality exceeds the first given plurality, whereby each condenser and associated network constitute an independent phase control circuit and a minimum of networks is utilized.

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