Feb. 21, 1939. W. T. WINTRINGHAM 2,147,728

PHASE CHANGER

Filed July 3, 1937

FIG. 1

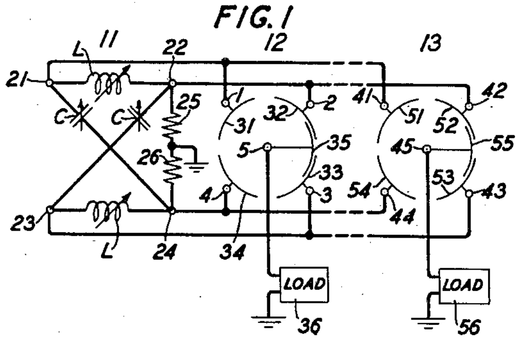



FIG. 2

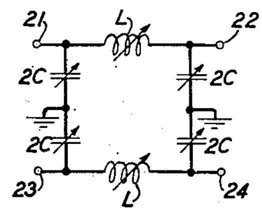


FIG. 3

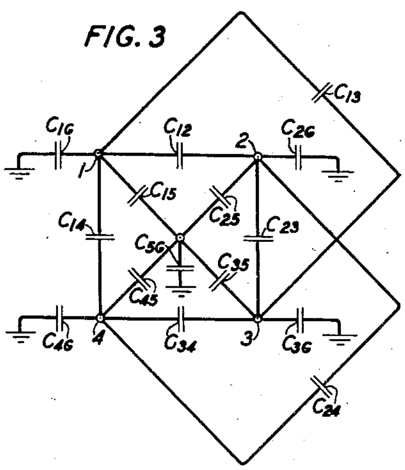


FIG. 4

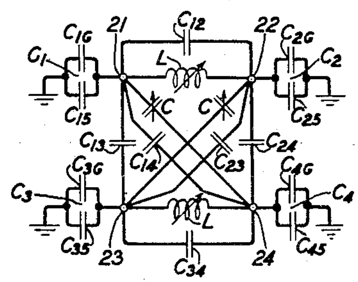


FIG. 5

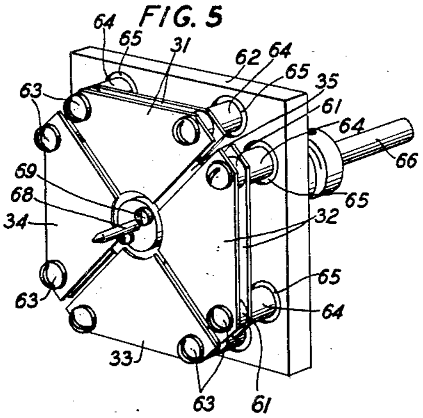
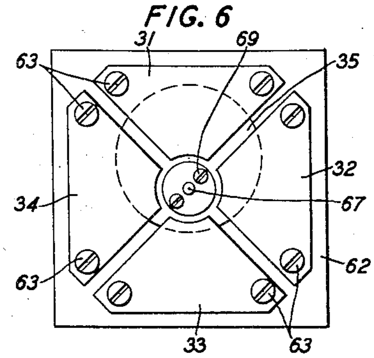


FIG. 6



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2,147,728

# UNITED STATES PATENT OFFICE

2,147,728

## PHASE CHANGER

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25 Claims. (Cl. 178—44)

This invention relates to phase control circuits and more particularly to a variable phase changer.

An object of the invention is to change the relative phase of an alternating current by any desired amount.

Another object is to keep the output potential constant with adjustment of phase.

Another object is to make the phase change proportional to the angular rotation of the variable element in the phase shifter.

A further object is to provide a plurality of different phase shifts with a single phase changer unit.

The phase changer in accordance with the invention comprises a phase splitter and one or more variable phase shifters. The phase splitter is preferably a quarter-wave artificial line from which four equal quadrantal voltages are derived from the input signal. The phase shifter is of any suitable type in which variable portions of these voltages are combined to produce an output potential having any desired phase relative to the input signal. In the preferred embodiment the component impedances comprising the phase splitter are adjusted in value as required in order to compensate for the passive reactances associated with the phase shifter. This compensation is of special importance when several phase shifters are used with a single phase splitter.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, of which:

Fig. 1 is a schematic circuit of a phase changer in accordance with the invention in which the phase splitter is an artificial line of the lattice type;

Fig. 2 shows schematically an artificial line of the ladder type suitable for use in the phase changer of Fig. 1;

Fig. 3 shows the network of capacitances associated with the phase shifter of Fig. 1;

Fig. 4 shows how these capacitances appear effectively between the terminals of the phase splitter, and between these terminals and ground;

Fig. 5 is a perspective view of a suitable form of phase shifter; and

Fig. 6 is a plan view of the phase shifter shown in Fig. 5.

As shown by the schematic diagram of Fig. 1, the phase changer of the invention comprises a phase splitter **11** and one or more phase shifters, such as **12** and **13**. The phase splitter **11** is a quarter-wave artificial line, having a phase shift of 90 degrees at a frequency $f$. The input signal of frequency $f$ is applied at terminals **21** and **23**, and at terminals **22** and **24** the line is terminated in two equal resistances **25** and **26**, the sum of which is equal to R, the characteristic impedance of the line. The artificial line shown in Fig. 1 is a lattice structure comprising two equal series inductances L, L and two equal capacitances C, C connected diagonally between the input and output terminals. The values of L and C are found from the following equations:

$$L=\frac{R}{2\pi f} \qquad (1)$$

$$C=\frac{L}{R^2} \qquad (2)$$

Alternatively, the artificial line may be of the balanced ladder type, with either mid-series or mid-shunt termination. The necessary transformation formulas are given, for example, on page 281 of K. S. Johnson's "Transmission Circuits for Telephonic Communication", published by D. Van Nostrand Company. Fig. 2 shows a balanced mid-shunt terminated ladder-type artificial line which may be substituted for the lattice-type line used as the phase splitter in Fig. 1. The two inductances L, L have the same value in both networks. In Fig. 2 each shunt branch consists of two capacitances, each equal in value to 2C, connected in series and grounded at the mid-point.

The phase splitter just described will provide four equal quadrantal voltages for exciting the phase shifter. These voltages are effective between the terminals **21**, **22**, **23** and **24** and ground, and have the relative phase angles of zero 90 degrees, 180 degrees and 270 degrees, respectively. As shown in Fig. 1, these potentials are impressed, respectively, upon the terminals **1**, **2**, **3** and **4** of the phase shifter **12**. These terminals are connected respectively, to the stator plates **31**, **32**, **33** and **34**. The rotor plate **35** is arranged so that in any position it will provide electrostatic coupling with a plurality of the stators. The load **36** is connected between terminal **5**, associated with the rotor, and ground. By manipulation of the rotor, the phase angle of the output potential, relative to that of the input to the phase changer, may be continuously varied between zero and 360 degrees, and the phase is directly proportional to the angle of rotation of the rotor.

The phase splitter **11** may be used to excite additional phase shifters, such as **13**, having stator plates **51**, **52**, **53** and **54**, and a rotor plate **55**. The quadrantal potentials are impressed upon the terminals **41**, **42**, **43** and **44**, and the load

56 is connected between terminal 45 and ground. The physical construction of a suitable phase shifter is described in more detail hereinafter.

In accordance with the invention, the unwanted reactances associated with the phase shifters are compensated for by adjusting the component impedances of the phase splitter. These unwanted reactances may be called passive reactances, since they remain constant in magnitude regardless of the setting of the phase shifter. For the phase shifter 12 the passive reactances are represented by the network of capacitances shown in Fig. 3.

The capacitance between each of the stators and the rotor varies with the setting of the phase shifter. Each capacitance may, therefore, be thought of as made up of a passive portion, which is the average value over a rotation cycle, and an active portion, which represents the plus or minus variation about this average. The passive stator-to-rotor capacitances, represented by $C_{15}$, $C_{25}$, $C_{35}$ and $C_{45}$, are taken into account in designing the phase splitter, as set forth more fully below.

The remaining capacitances shown in Fig. 3 are passive, having constant values regardless of the setting of the phase shifter. The capacitances to ground from the four stators are $C_{1G}$, $C_{2G}$, $C_{3G}$ and $C_{4G}$, and the rotor-to-ground capacitance in $C_{5G}$. The capacitances to ground of the wiring between the phase splitter and the phase shifter are directly in parallel with these stator-to-ground capacitances, and these latter are assumed to include such capacitances. Similarly, the wiring capacitance on the output side of the phase shifter is in parallel with the rotor-to-ground capacitance, and is included in $C_{5G}$. The stray capacitances between the stators are $C_{12}$, $C_{23}$, $C_{34}$, $C_{14}$, $C_{13}$ and $C_{24}$.

The capacitance $C_{5G}$ is in parallel with the load impedance, and in practice the latter is so chosen that the combination is anti-resonant at the frequency $f$. Under these conditions the impedance of the combination will be substantially a pure resistance. The relative voltages at the four terminals of the phase splitter are practically unchanged whether the rotors of the phase shifters are grounded directly or through normal resistance loads. If the rotors are considered grounded, however, a number of phase shifters connected in parallel may be represented by the same mesh of capacitances shown in Fig. 3 for one phase shifter. In this case, the value of each capacitance is equal to the sum of the corresponding capacitances in all of the phase shifters and, when appropriate, of the associated wiring capacitances.

The passive capacitances associated with all of the phase shifters and the interconnecting wiring will, therefore, effectively appear between the terminals of the phase splitter 11, and between these terminals and ground, as shown in Fig. 4. In accordance with the invention, the component impedances of the phase splitter are adjusted to compensate for all of these passive capacitances. For this purpose it is convenient to make the inductances and the capacitances variable.

If the phase splitter is of the lattice type, as shown in Fig. 4, the stator-to-stator capacitances $C_{14}$ and $C_{23}$ are directly in parallel with the two diagonal capacitances C, and the latter are reduced in magnitude to take into account the former. Between each terminal and ground there appear two capacitances effectively in parallel. These are the passive part of the stator-to-rotor capacitance, and the stator-to-ground capacitance, the latter including also the associated wiring capacitance. Thus, the total capacitances $C_1$, $C_2$, $C_3$ and $C_4$ between the terminals 21, 22, 23 and 24, respectively, and ground are given by the expressions

$$C_1=C_{15}+C_{1G} \quad (3)$$

$$C_2=C_{25}+C_{2G} \quad (4)$$

$$C_3=C_{35}+C_{3G} \quad (5)$$

$$C_4=C_{45}+C_{4G} \quad (6)$$

These terminal-to-ground capacitances are compensated for by further decreasing the magnitude of each capacitance C by an amount equal to half the average of the four capacitances $C_1$, $C_2$, $C_3$ and $C_4$.

The stator-to-stator capacitances $C_{13}$ and $C_{24}$ appearing in shunt at the ends of the network are corrected for by decreasing each capacitance C by an additional amount equal to the average of $C_{13}$ and $C_{24}$. In the lattice-type phase splitter of Fig. 4, therefore, the adjusted value C' of one diagonal capacitance C will be given by

$$C'=C-C_{14}-\frac{C_1+C_2+C_3+C_4}{8}-\frac{C_{13}+C_{24}}{2} \quad (7)$$

The adjusted value of the other diagonal capacitance will be the same as that given by Equation (7) except that $C_{23}$ is substituted for $C_{14}$. In most cases $C_{14}$ and $C_{23}$ will be substantially equal, but if they are not equal it is seen that in the lattice structure they may be allowed for separately.

If the phase splitter is of the balanced ladder type shown in Fig. 2, the terminal-to-ground capacitances $C_1$, $C_2$, $C_3$ and $C_4$ may be corrected for individually. In this case each of the capacitances 2C is decreased in magnitude by the value of the associated terminal-to-ground capacitance. In addition, each capacitance 2C on the left side is reduced by an amount equal to twice $C_{13}$, and each capacitance on the right is decreased by twice $C_{24}$. The diagonal capacitances $C_{14}$ and $C_{23}$ are compensated for by a further reduction of each capacitance 2C by an amount equal to the sum of $C_{14}$ and $C_{23}$. The adjusted value 2C'' of the capacitance between terminal 21 and ground will therefore be given by the expression

$$2C''=2C-C_1-2C_{13}-C_{14}-C_{23} \quad (8)$$

The adjusted values of the other three capacitances in Fig. 2 are found from similar equations.

In both the ladder network of Fig. 2 and the lattice network of Fig. 4 the effects of the stator-to-stator capacitances $C_{12}$ and $C_{34}$ are largely compensated for by an adjustment of the associated inductances L. These capacitances are in parallel with the inductances, and each inductance L is decreased to a new value such that the inductance-capacitance combination has the same impedance at the frequency $f$ as the inductance alone.

A phase shifter suitable for use in the phase changer of the invention is shown in perspective in Fig. 5. The stator plates 31, 32, 33 and 34 are triangular in shape and are provided in pairs, separated from each other by the spacers 61. All of the pairs of stators are mounted upon the base 62 by means of the screws 63 and the supports 64. The supports 64 are insulated from the base by the insulating collars 65. The rotor plate 35 is located between the stators and mounted upon but insulated from the shaft 66 which has a bearing in the base 62 and is arranged for rotation through an angle of 360 degrees. An indicating device, not shown, may be attached to the shaft **66** for showing the angular position of the rotor. As shown in the plan view of Fig. 6, the rotor plate is circular in shape and is eccentrically pivoted at the point **67**. Electrical connections to the stator plates may be made through the supports **64** or the screws **63**, and to the rotor through the pin **68** which is fastened to the rotor by the screws **69**. An electrostatic and electromagnetic shield, not shown, may be provided for the phase shifter if required.

When the phase splitter is an artificial line, with component impedances adjusted as explained above, the device will operate substantially as if no passive reactances were present. As a result, the quadrantal voltages obtainable at the terminals of the network will be equal in magnitude and will differ from each other by 90 degrees within close limits. When such a phase splitter is used in connection with a properly designed phase shifter there is obtained a phase changer having greatly improved operating characteristics. The phase shift introduced by the combination is substantially proportioned to the angle of rotation of the rotor, and the voltage across the load 36 is substantially constant for all settings of the rotor plate. The improvement in performance attributable to the compensation for passive reactances is of greater importance as the number of phase shifters associated with a single phase splitter is increased. In a multiple unit steerable antenna radio receiver, for example, where perhaps four phase shifters are excited by one phase splitter, such compensation becomes almost indispensable.

What is claimed is:

1. A phase changer comprising a phase splitter and a phase shifter, said phase splitter comprising a quarter-wave artificial line for deriving from an input signal four equal quadrantal voltages for the excitation of said phase shifter, said phase shifter being adapted to combine said voltages to provide an output potential substantially constant in amplitude but adjustable in phase relative to the phase of the input signal, and said phase splitter comprising a plurality of lumped impedances certain of which are adjusted in magnitude to compensate for passive reactances associated with said phase shifter.

2. A phase changer comprising a quarter-wave artificial line for deriving four equal quadrantal voltages from an input signal, and a phase shifter for combining said voltages to provide an output potential the phase angle of which, relative to the phase angle of said input signal, may be adjusted to any desired value.

3. A phase changer comprising a phase splitter for providing four equal voltages differing in phase by 90 degrees and a phase shifter for combining said voltages to provide an output potential which is substantially constant in magnitude but variable in phase relative to the input signal, said phase splitter comprising an artificial line having a phase shift of 90 degrees.

4. A phase changer comprising an artficial line having a phase shift of 90 degrees for deriving from an input signal four equal voltages differing in phase by 90 degrees, and means for combining said voltages to produce an output potential which remains substantially constant in amplitude while its phase angle, relative to the phase angle of said signal, is adjusted to any desired value.

5. A phase changer in accordance with claim 4 in which said artificial line is of the lattice type.

6. A phase changer in accordance with claim 4 in which said artificial line is of the ladder type.

7. A phase changer comprising a plurality of phase shifters and a phase splitter for exciting all of said phase shifters, said phase splitter comprising an artificial line having a phase shift of 90 degrees for deriving from an input signal four equal voltages differing in phase by 90 degrees, and each of said phase shifters being adapted to combine said voltages to provide an output potential which is substantially constant in amplitude but adjustable in phase relative to the phase of the input signal.

8. A phase changer comprising a phase splitter for deriving four equal quadrantal voltages from an input signal, and a phase shifter for combining said voltages to produce an output potential having a phase angle adjustable with respect to the phase angle of said input signal, said phase splitter comprising a plurality of lumped impedances, and certain of said impedances being adjusted in value to compensate for the effects of passive reactances associated with said phase shifter.

9. A phase changer in accordance with claim 8 in which said phase splitter comprises an artificial line having a phase shift of 90 degrees at the frequency of said input signal.

10. A phase changer in accordance with claim 8 in which said phase splitter comprises a lattice-type network.

11. A phase changer in accordance with claim 8 in which said phase splitter comprises a ladder-type network.

12. A phase changer comprising an artificial line for deriving four equal quadrantal voltages from an input signal, and a phase shifter of the condenser type having four separate stator plates and a single rotor plate for combining said voltages, said artificial line comprising a plurality of impedances certain of which are adjusted in value to compensate for passive capacitances between said plates and between said plates and ground.

13. A phase changer in accordance with claim 12 in which said artificial line is of the lattice type.

14. A phase changer in accordance with claim 12 in which said artificial line is of the ladder type.

15. A phase changer comprising a phase splitter for deriving four equal quadrantal voltages from an input signal, and a plurality of phase shifters for combining said voltages to produce output potentials having phase angles independently adjustable with respect to the phase angle of said input signal, said phase splitter comprising a plurality of lumped impedances, and certain of said impedances having their magnitudes adjusted to compensate for passive reactances associated with said phase shifters.

16. A phase changer in accordance with claim 15 in which said phase splitter comprises an artificial line having a phase shift of 90 degrees at the frequency of said input signal.

17. A phase changer in accordance with claim 15 in which said phase splitter comprises a network of the lattice type.

18. A phase changer in accordance with claim 15 in which said phase splitter comprises a network of the ladder type.

19. A phase changer comprising an artificial line for deriving four equal quadrantal voltages from an input signal, said line having a phase

shift of 90 degrees and being terminated in its characteristic impedance, and a plurality of phase shifters of the condenser type for combining said voltages, each of said phase shifters having four separate stator plates and a single rotor plate, all of said phase shifters being excited from said artificial line, said line comprising a plurality of lumped impedances, certain of said impedances being adjusted in value to compensate for passive capacitances associated with said phase shifters, and each of said phase shifters having an output potential the phase angle of which, relative to the phase angle of said input signal, is directly proportional to the angle of rotation of the associated rotor plate.

20. A phase changer in accordance with claim 19 in which said artificial line is of the lattice type.

21. A phase changer in accordance with claim 19 in which said artificial line is a mid-shunt terminated ladder-type network.

22. A phase changer comprising in combination a four-terminal artificial line having a phase shift of 90 degrees, an impedance element connected between two of the terminals of said line, a tap to the electrical midpoint of said impedance element, a variable condenser comprising a rotor and four stators, electrical connections from each of the four terminals of said line to a respective one of said stators, and two pairs of terminals for said phase changer, one pair comprising the other two terminals of said line and the other pair comprising said tap to the midpoint of said impedance element and a connection to said rotor, whereby rotation of said rotor varies the phase of the output from said phase changer with respect to its input.

23. A phase changer in accordance with claim 22 in which said artificial line is of the lattice type.

24. A phase changer in accordance with claim 22 in which said artificial line is of the ladder type.

25. A phase changer in accordance with claim 22 in which said artificial line comprises a plurality of lumped impedances certain of which are adjusted in value to compensate for passive capacitances associated with said variable condenser.

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