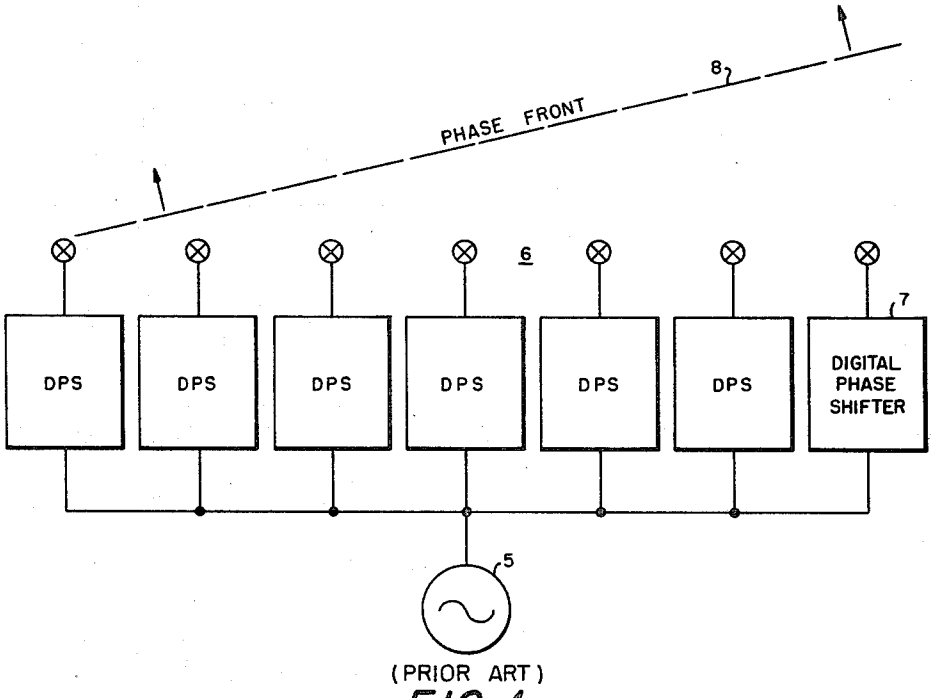
CONJUGATE PAIR FEED SYSTEM FOR ANTENNA ARRAY

Filed Nov. 30, 1965



(PRIOR ART)

FIG. 1

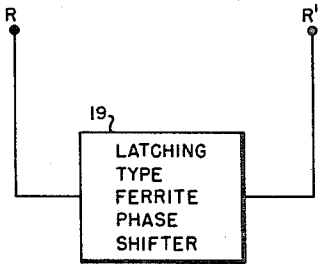


FIG. 3

INVENTOR
ARTHUR E. MARSTON

BY

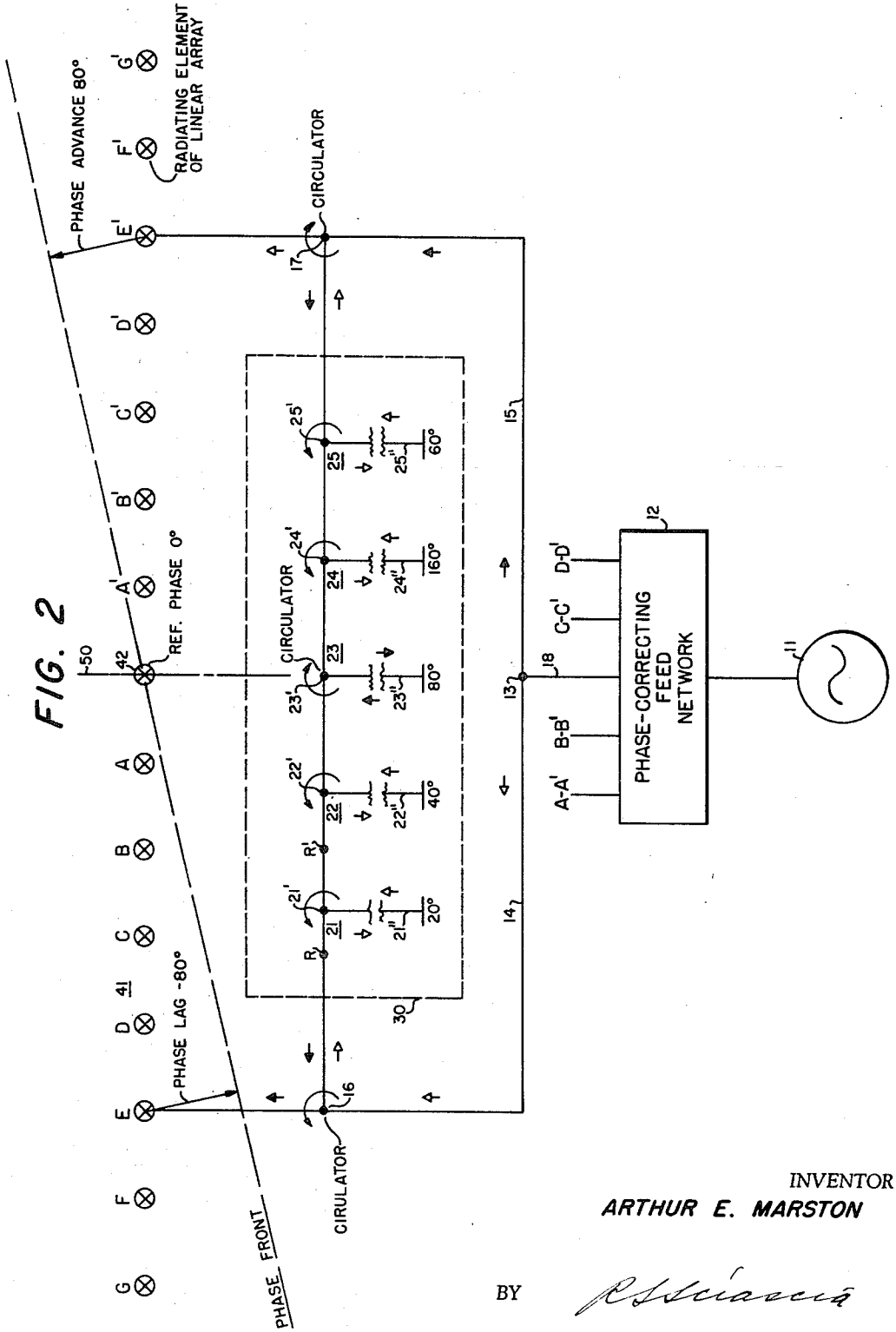
ATTORNEY

Jan. 14, 1969 A. E. MARSTON 3,422,438

CONJUGATE PAIR FEED SYSTEM FOR ANTENNA ARRAY

Filed Nov. 30, 1965 Sheet 2 of 3

FIG. 2



INVENTOR
ARTHUR E. MARSTON

BY

ATTORNEY

CONJUGATE PAIR FEED SYSTEM FOR ANTENNA ARRAY

Filed Nov. 30, 1965 Sheet 3 of 3

FIG. 4

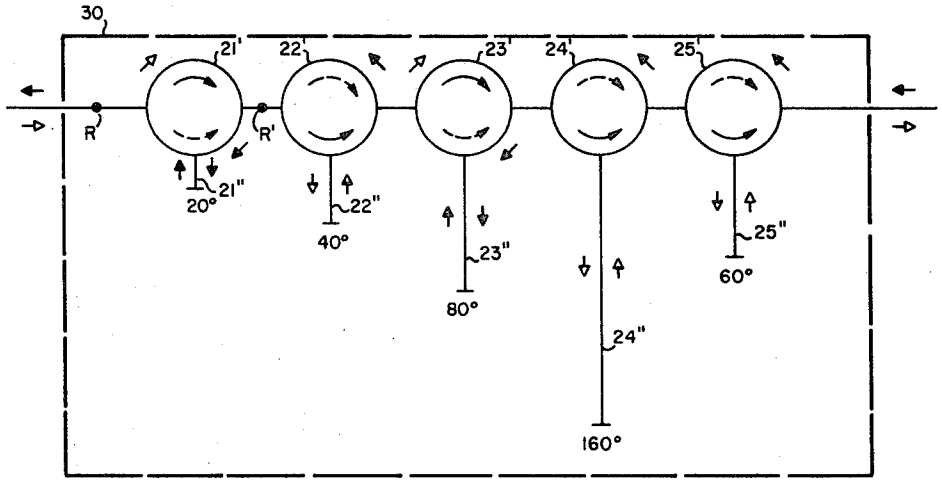
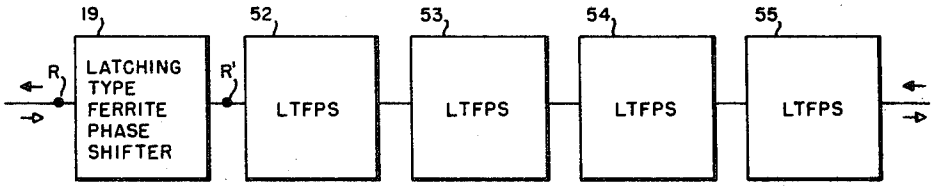


FIG. 5



INVENTOR
ARTHUR E. MARSTON
BY
ATTORNEY

United States Patent Office 3,422,438
Patented Jan. 14, 1969

3,422,438

CONJUGATE PAIR FEED SYSTEM FOR ANTENNA ARRAY

Arthur E. Marston, 718 Putnam Place, Alexandria, Va. 22302

Filed Nov. 30, 1965, Ser. No. 510,710
U.S. Cl. 343—854 6 Claims
Int. Cl. H01q 3/26; H01q 13/00

ABSTRACT OF THE DISCLOSURE

A feed system for an antenna array using non-reciprocal phase shifters. Each pair of radiating elements equidistance from the center of the array is connected to opposite ends of a variable non-reciprocal phase shifter. A signal to be radiated is divided to traverse the non-reciprocal phase shifters in opposite directions so that the phases of signals at each pair of radiating elements are conjugates of one another.

Specification

The present invention relates generally to improvements in microwave antenna array systems and the like and more particularly to new and improved microwave antenna array systems wherein non-reciprocal phase shifters are used in such a way as to decrease the number of phase shifters and phase-shift bits employed, as compared to the number of phase shifters and phase-shift bits employed in conventional antenna array systems, without degrading antenna performance, but rather with a simplification of the computer routines associated with the phase programmer that operates when the array is scanning.

In the field of microwave antenna array systems it has been the general practice to employ a variable phase shifter for each element of an antenna array in order to steer the radiation pattern of the antenna array. Although such devices have served the purpose, they have not proved entirely satisfactory under all conditions of service for the reason that considerable difficulty has been experienced in the synchronization of the variable phase shifters, which synchronization is necessary for the phase shifters to track with each other and to result in the desired radiation pattern from the antenna array. Considerable difficulties also have been experienced in the high cost of maintaining these complex systems and the related apparatus required to vary the phase shifters in synchronism.

The general purpose of this invention is to provide a microwave antenna array system which embraces all the advantages of similarly employed systems and possesses none of the aforedescribed disadvantages. To attain this the present invention contemplates the use of latching-type non-reciprocal phase shifters in microwave antenna array systems. A latching-type non-reciprocal phase shifter is one which requires no continuously applied electrical power in order to achieve a desired phase shift, but rather requires only an electrical pulse. These latching-type non-reciprocal phase shifters are used in such a way as to decrease the number of phase shifters and phase-shift bits employed as compared to the number employed in prior art microwave antenna array systems. This decrease in the number of components will lead to cost reduction in both the antenna and associated computer construction. Not only are no adverse effects produced by the invention as a result of the use of fewer components than are used in prior art systems, but the invention provides a reduction in the complexity of the computer elements of the phase programmer.

An object of the present invention is the provision of a microwave antenna array system which incorporates the use of latching-type, non-reciprocal phase shifters.

Another object is to provide a system of the above description which requires only a single non-reciprocal phase shifter for each antenna element pair.

A further object of the invention is the provision of a microwave antenna array system which operates with simpler phase programming computer routines.

Still another object is to provide a system of the above description which is less complex and less costly to maintain than previous microwave antenna array systems.

Yet another object is to provide a microwave antenna array system which attains better results with fewer components than previous systems of this type, and which produces no adverse effects as a consequence of the new arrangement.

Other objects and features of the invention will become apparent to those skilled in the art as the disclosure is made in the following description of a preferred embodiment of the invention as illustrated in the accompanying sheet of drawing in which:

FIG. 1 shows a block diagram of a prior art antenna array system;

FIG. 2 illustrates a schematic view of one embodiment of the invention;

FIG. 3 shows a block diagram of another embodiment of the invention;

FIG. 4 shows a schematic view of one type of non-reciprocal phase shifter; and

FIG. 5 shows how the non-reciprocal phase shifter may be composed of a plurality of latching type ferrite phase shifters.

Referring now to the drawings, there is shown in FIG. 1 a prior art antenna array system including a signal source **5** which supplies electrical power to the antenna array **6** through digital phase shifters, indicated as DPS, wherein one digital phase shifter is required for each element of the antenna array **6**. Such prior art systems require the digital phase shifters to be synchronized by computers (not shown) in such a manner as to track with each other and to result in the desired steered radiation pattern **8** from the antenna array **6**.

Referring now to FIG. 2, there is shown a signal source **11** the output of which is electrically connected to a conventional phase-correcting feed network **12**, which provides output signals that are in phase with each other. One output **18** of the network **12** is fed into T-junction **13** which divides into branch lines **14** and **15**, which may be cables or wave guides. The branch line **14** is connected to circulator **16** and the branch line **15** is connected to circulator **17**. Located between circulators **16** and **17** and electrically connected thereto is non-reciprocal phase shifter **30**. This phase shifter is non-reciprocal because a signal traversing it in one direction may undergo a different amount of phase shift than a signal traversing it in the opposite direction. The non-reciprocal phase shifter **30**, as illustrated, comprises five phase-shift bits **21**, **22**, **23**, **24** and **25**, totaling 360°, each including a circulator **21′**, **22′**, **23′**, **24′**, and **25′**, respectively, and a shorted transmission line **21″**, **22″**, **23″**, **24″** and **25″**, respectively, each of which lines acts as a phase shifter and which is connected to one port of its respective circulator. As shown in FIG. 2 each phase shift unit is a two port non-reciprocal device which either shifts or does not shift the phase of a signal depending upon the direction of circulation of the circulator and the port to which the signal is applied. Referring specifically to unit **21** it can be seen that circulator **21′** is set to have a counter-clockwise direction of circulation and therefore signals applied to port R undergo a phase shift of 20° before they arrive at port R^1. This phase shift is due to the particular length of shorted transmission line **21″**. Signals applied to port R^1 pass through circulator **21″** to port R without

traversing line **21''** and therefore do not undergo the 20° phase shift.

Any number of phase-shift bits of any magnitude may be used as long as they total 360°, and phase shifters other than the shorted transmission line-circulator combinations could be used, such as latching-type ferrite phase shifters. The shorted transmission line-circulator combination is shown for the purpose of illustration, and in practice the latching-type phase shifters would be used.

One port of circulator **21** is electrically connected to a port of circulator **16** and a second port of circulator **21** is electrically connected to a port of circulator **22**. A second port of circulator **22** is electrically connected to a port of circulator **23**, and circulator **23** is similarly connected to circulator **24**, which in turn, is similarly connected to circulator **25**, and one port of circulator **25** is electrically connected to a port of circulator **17**.

The circulator **17** is then electrically connected to radiating element E^1, and circulator **16** is electrically connected to radiating element E, which elements are located in the linear antenna array **41** an equal distance from the center **50** of the array.

If there is a center element **42** located at the center **50** of the array, the elements of each antenna element pair will be equidistant from the element **42**, and the center element will be energized directly from the phase-correcting feed network **12** by a transmission line (not shown).

With reference to FIG. 3, latching-type ferrite phase shifter **19** is shown electrically connected between the points R and R^1 of FIG. 2 thus replacing the shorted transmission line-circulator combination **21** in FIG. 2. In the event that latching-type ferrite phase shifters are used they will replace each of the shorted transmission line-circulator combinations **21–25** of FIG. 2. Such an embodiment, using a series of latching-type ferrite phase shifters **19, 52, 53, 54,** and **55**, is shown in FIG. 5.

In the operation of the microwave antenna array system of FIG. 2 the signal entering at **11** is passed through the phase-correcting feed network **12**, which allows the electrical power to be in phase at the various inputs to the non-reciprocal phase shifters of the system, one of which is provided for each of the various antenna element pairs of the array ($A–A^1$, $B–B^1$, $C–C^1$, etc.), as exemplified by non-reciprocal phase shifter **30** which is provided for the antenna element pair E and E^1.

The signal from one output **18** of the phase-correcting feed network **12** is shown divided equally to left and right at T-junction **13** which passes the signals through branch lines **14** and **15** and into ports of circulators **16** and **17**, respectively. The circulators **16** and **17** turn the two signals into the non-reciprocal phase shifter **30** which comprises the series of phase-shift bits **21–25**, which in turn include circulators **21'–25'** and phase shifters **21''–25''**.

By the use of a computer (not shown) switching the action of the circulators **21'–25'** from right to left, or left to right, as may be necessary, can result in a phase shift equal to any multiple of 20°. For example, as shown in FIG. 2 the direction of circulation of circulators **21'**, **22'**, **24'**, and **25'** has been set counterclockwise while the direction of circulator **23'** has been set clockwise. With these circulator settings the signal indicated by the white arrow starts on line **14** and enters block **30** from the left. It undergoes a delay of $(20°+40°+160°+60°)=280°$ and arrives at antenna element E' with a phase delay of 280° which is equivalent to a phase advance of 80°. Likewise the signal indicated by the black arrow starts on line **15** and enters block **30** from the right. It undergoes a delay of 80° and arrives at antenna element E with a phase lag of 80°. It can be seen that since the sum of all the discrete phase shifts in the several phase shifters **21** through **25** equals 360°, the signal going from right to left in block **30** will always be given a phase shift which is the conjugate of the phase shift imparted to the signal moving from left to right in block **30** and therefore, the signals radiating from antenna elements E and E^1 will always be the conjugates of one another, where phase advance and lag are measured relative to center element **42** the phase of which is assumed to be constant at 0°. To take another example (as illustrated in FIG. 4) assume that circulators **21'** and **23'** are switched clockwise by the computer (not shown) while circulators **22'**, **24'** and **25'** remain counterclockwise. The schematic of each circulator in FIG. 4 has both a solid and a dashed arrow representing the direction of circulation in the two states of applied magnetic field. In this case the signal traveling from left to right through block **30** will undergo a delay of $(40°+160°+60°)=260°$ or a phase advance of 100° while the signal traveling from right to left experiences a phase lag of $(80°+20°)=100°$. The discrete phase jumps (chosen here for the purpose of illustration to be 20°) could of course be any value as long as the sum thereof totals 360°.

FIG. 5 illustrates how other types of latching ferrite phase shifters could be used in place of the circulator/transmission line units depicted in block **30** of FIGS. 2 and 4. Various types of appropriate digital latching phase shifters are discussed in an article entitled "A Digital Latching Ferrite Strip Transmission Line Phase Shifter," by L. R. Whicker and R. R. Jones appearing in IEEE Transactions on Microwave Theory and Techniques, vol. MTT–13, No. 6, November 1965, pp. 781–784. An appropriate circulator for use in FIGS. 2 and 4 is disclosed in an article entitled "Pulse-Operated Circulator Switch," by L. Frieberg in IEEE Transactions on Microwave Theory and Technique, May 1961, p. 266. Further uses of circulator switches are disclosed in an article entitled "Reciprocal and Non-reciprocal Switches Utilizing Ferrite Junction Circulators," by Alvin Clavin in IEEE Transactions on Microwave Theory and Technique, May 1963, pp. 217–218.

Because the conjugate phasing of antenna element pairs, e.g. elements E and E^1, automatically achieved by the arrangement of the phase shifters and circulators the system provides a very considerable simplification of the phase-programming computer sub-system which, by virtue of the arrangement of phase shifters specified by this invention, has only half as many phase shifters to program as in the case in conventional arrangements of phase shifters. The synchronization of the signals radiated from any two elements in an antenna element pair of this invention, e.g. element pair E and E^1, is automatically achieved.

When a signal is received back from the direction in which it was radiated it is necessary by means of a computer (not shown), to reverse the sense of the circulators **16** and **17** in addition to the circulators employed in the non-reciprocal phase-shift bits, **21–25**.

It can, therefore, be seen that the invention very effectively provides for the use of non-reciprocal phase shifters, and particularly for the use of latching-type non-reciprocal phase shifters, in microwave antenna array systems in such a way as to materially reduce the number of phase shifters and associated equipment required in these systems. In reducing the number of components required the system is less complex and less costly to maintain than prior art systems of this type.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood, that within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. In a microwave antenna array, the combination comprising:

a pair of antenna elements predeterminedly spaced from the center of said array,

a non-reciprocal phase-shifting means having a first port and a second port,

a first signal path for connection to a signal source,

a second signal path for connection to said signal source,

first directional connecting means connecting said first port to a first of said elements and to said first signal path to couple signals from said first signal path to said first port while blocking signals from said first signal path to said first of said elements and also to couple signals from said first port to said first of said elements so that signals arriving at said first of said elements have passed through said non-reciprocal phase-shifting means in a first direction, and

second directional connecting means connecting said second port to a second of said elements and to said second signal path to couple signals from said second signal path to said second port while blocking signals from said second signal path to said second of said elements and also to couple signals from said second port to said second of said elements so that signals arriving at said second of said elements have passed through said non-reciprocal phase-shifting means in a second direction opposite to said first direction.

2. The combination of claim **1**, wherein

said first directional connecting means comprises a first circulator, and

said second directional connecting means comprises a second circulator.

3. The combination of claim **1**, including:

an additional plurality of pairs of antenna elements

with each pair symmetrically spaced about the center of said array,

an additional plurality of non-reciprocal phase-shifting means, and

directional connecting means connecting each of said additional pairs of antenna elements to a respective one of the additional non-reciprocal phase-shifting means.

4. The combination of claim **1** wherein said phase-shifting means includes:

a number of phase-shift bits which total 360°.

5. The combination of claim **4** wherein each of said phase-shift bits includes:

a three-port circulator, and

a phase-shifter electrically connected to one port of said circulator.

6. The combination of claim **4** wherein said phase-shift bits include:

latching-type ferrite phase shifters.

References Cited

UNITED STATES PATENTS

3,258,774	6/1966	Kinsey	343—854
3,308,465	3/1967	Tamama	343—854

ELI LIEBERMAN, *Primary Examiner.*

U.S. Cl. X.R.

343—778