Nov. 28, 1967 H. N. CHAIT 3,355,735

RADAR SYSTEM WITH INDEPENDENT CONTROL OF TRANSMIT AND RECEIVE ANTENNA PATTERNS

Filed March 23, 1960

FIG. 1

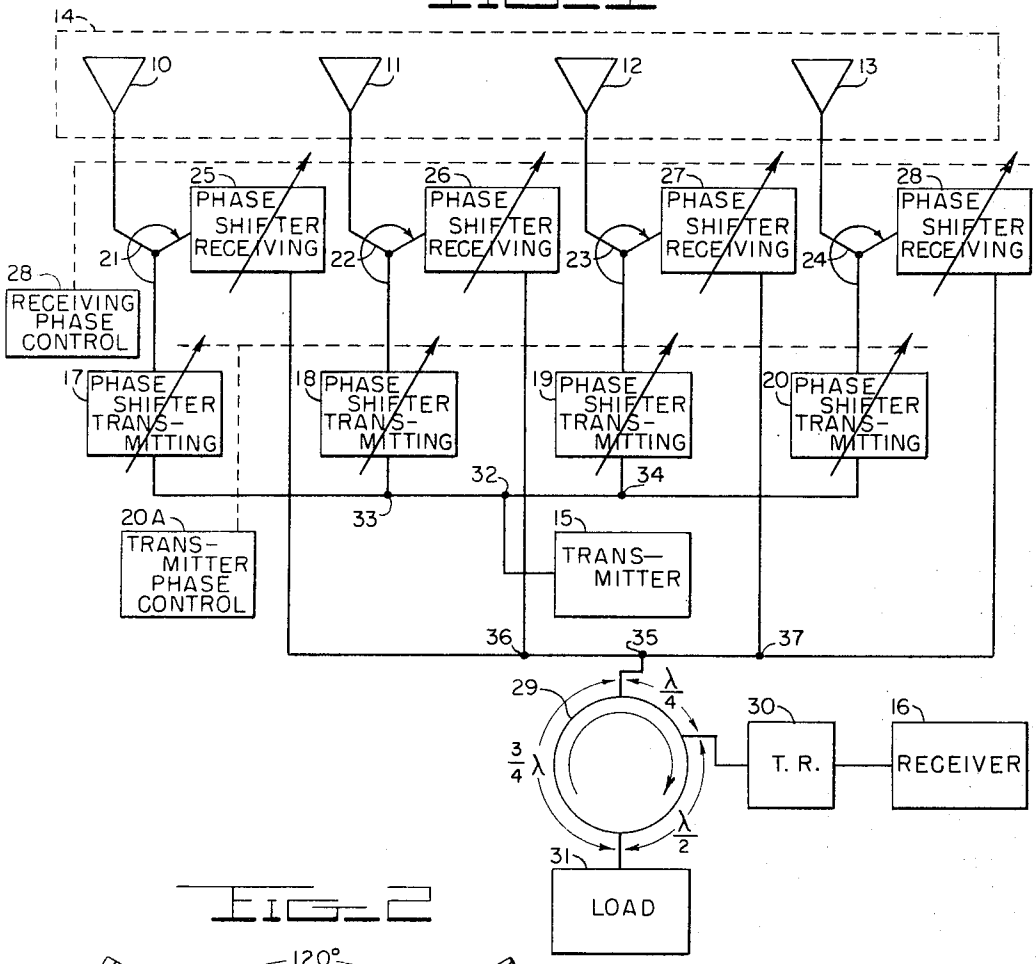
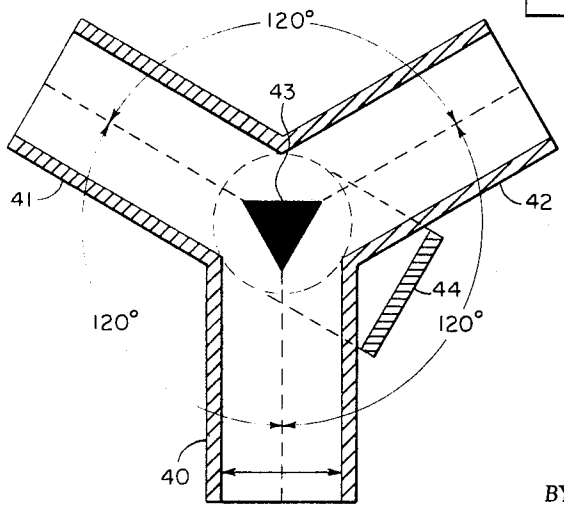


FIG. 2



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United States Patent Office 3,355,735 Patented Nov. 28, 1967

3,355,735

RADAR SYSTEM WITH INDEPENDENT CONTROL OF TRANSMIT AND RECEIVE ANTENNA PATTERNS

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Filed Mar. 23, 1960, Ser. No. 17,230
3 Claims. (Cl. 343—16)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to radio antenna systems in general and in particular to electrically steerable dual purpose directive antenna systems for transmission and reception such as may be employed in radar apparatus or the like. In greater particularity the invention relates to antennas having extremely narrow beamwidths as a result of using many elements.

In antenna systems of the foregoing type, a high degree of directivity or conversely a very narrow beamwidth is obtained by using many, perhaps several hundred, effective elements which cooperate to produce the narrow beam. In such an array, problems present themselves which are either nonexistent or inconsequential in systems of a wider beamwidth. In the first place, to obtain the narrow beamwidths without prohibitive production of side lobes, careful design and exact control of the phasing and amplitude of the energy emitted by the various elements is required. Thus impedance mismatches of the individual elements as well as reradiation of the energy from one element by coupling through the feed system to the other elements may have appreciable adverse effect.

A further complication with antennas of narrow beamwidths such as a degree or a fraction of a degree, is that with an substantial angular movement rate of the beam relative to a distant object, the antenna beam moves away from the direction of the object before the return energy reaches the antenna. Thus it is frequently necessary to employ somewhat different directions for transmission and reception, with the reception beam lagging the transmission beam. In electronically steered antennas, where mass of components is not a limiting factor, it is possible to achieve high angular scanning rates making the problem quite acute in some instances where high speed objects are to be located such as low altitude earth satellites or the like. To further complicate the foregoing picture, the careful initial design and adjustment of the energy phasing and distribution of the various elements is frequently upset by reradiation in which energy emitted by one antenna elemet couples directly to another antenna element or indirectly via some nearby reflecting object and is reradiated either by the second element or fed back through the transmission line feed system to reach other elements and is radiated thereby. Thus careful and precise design frequently does not work out in practice, the result being an antenna which does not possess the narrow beamwidth which calculations indicate should have resulted.

It is accordingly an object of the present invention to provide an antenna system of anrrow beamwidth.

Another object of the present invention is to provide an antenna system in which the direction of the maximum response for transmission and reception may be separately controlled.

Another object of the present invention is to provide an antenna system in which reradiation of energy by the elements is minimized.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a schematic diagram showing a typical embodiment of the teachings of the present invention.

FIG. 2 shows in partial section a circulator employed in the apparatus of FIG. 1.

In accordance with the basic teachings of the present invention, an antenna system having an extremely narrow bandwidth which may be directed separately for transmission and reception is provided employing a plurality of antenna elements to achieve the desired beamwidth, in combination with a plurality of directive coupling devices, one for each antenna element, in which the transmission energy is supplied to each element from a different line than that to which the received energy is delivered from the antenna. Separate phase shifting devices are included in the transmission and reception paths whereby the energy coupling of each element is controllable, and a matched coupling device to the receiver is included to produce absorption of energy which would normally be reradiated in a conventional system not so equipped.

With reference now to FIG. 1 of the drawings the apparatus shown therein contains an antenna system indicated typically as having the elements **10**, **11**, **12** and **13** mounted upon a suitable supporting structure indicated in general by the numeral **14** which may be a part of or include a suitable reflector device to provide, if desired, a measure of control over the radiation of the antenna elements **10** through **13**. For the typical radar type of operations employing a transmitter **15** and a receiver **16**, the elements must be connected to transmitter **15** during the operation of that transmitter and to the receiver **16** in oher periods. Thus the transmitter **15** is connected to the elements **10** through **13** hrough a series of phase shifting devices **17**, **18**, **19** and **20** controlled by control unit **20–A** and another group of devices identified as circulators **21**, **22**, **23** and **24** controlled by control unit **24–A**. The circulators **21** through **24** are described in greater detail in the copending application of Herman N. Chait and Morris L. Kales, Serial No. 796,183, filed February 27, 1959, now Patent No. 3,089,101, entitled "Field Displacement Circulator." For convenience a brief description of such a circulator is included in the present application at a subsequent point and the device is shown in FIG. 2 of the present application.

Return energy intercepted by the antenna elements **10** through **13** is separately delivered through the group of phase shifters **25**, **26**, **27**, **28** through hybrid junction **29**, and transmit-receive switching device **30**. In addition a load device **31** is connected to the hybrid junction **29**.

In operation of the device of FIG. 1, the separate operations of transmitting and receiving must be considered separately. In the transmitting operation, signals which typically are of a pulse nature are produced by the transmitter **15** in conventional fashion typical of radar devices. This energy is supplied to the transmitting phase shifters **17** through **20** by means of which the phasing of the energy delivered to each of the antenna elements **10** through **13** may be controlled and varied in accordance with a selected schedule to obtain a selected relative phasing of the antenna elements and hence electronic sweeping of the beam produced by the elements to cover a sector of space. Thus the transmitting phase shifters **17** through **20** are indicated as being connected together by a dotted line, such indicating coordination in the operation of the various phase shifters although not necessarily identical phase shift produced by all. In addition to the phase shifting of the signals delivered to the antenna elements **10** through **13**, it is usually desired to provide some control or adjustment in the amount of power delivered to each element for radiation thereby.

Such is normally done to assist in the production of a narrow beam having a minimum amount of side lobes which are normally undesired. Thus the transmission line between the transmitter **15** and the various phase shifters **17** through **20** may be proportioned with sections of various lengths and characteristic impedance so that the desired division takes place at the junction points which may be identified for the purpose of this discussion by numerals **32**, **33** and **34**. Normally it is a matter of engineering skill to select the various transmission line characteristic impedances to obtain the desired power division. Alternatively some form of attenuating devices could be inserted in each of the lines to the phase shifters **17** through **20** to obtain the desired power distribution between the various antenna elements **10** through **13** for transmission purposes.

The Y circulators **21** through **24** as described in greater detail in the copending application above referred to are of such a nature as to provide channeling of the transmitter energy from the transmitting phase shifters **17** through **20** to the branch of the circulators leading to the elements **10** through **13** with a minimum of that energy directly reaching the receiving phase shifters **25** through **28**.

In addition the Y circulators have the further properties when properly designed and constructed of channeling received energy intercepted by the antenna elements **10** through **13** in such manner as to cause the received energy to go via the paths containing the receiving phase shifters **25** through **28** with a minimum of the received energy being lost as it were through the transmitting phase shifters **17** through **20**. Thus the phase shifters **25** through **28** may be adjusted for scanning purposes again as indicated by coordinated control from some suitable device to obtain desired phase relationship between the received signals from each of the individual antennas which are delivered to the hybrid junction **29**. As with the transmission phase of the operation, it may also be desirable in certain instances to provide for variable coupling of the elements to the receiver **16** which again may be obtained by appropriate arrangement of the impedances of the transmission lines leading to the hybrid junction **29** typically of the impedances at the junction points **35**, **36** and **37**. Again an alternate form of arrangement might include impedance transformation devices additionally inserted in the individual leads between the receiving phase shifters **25** through **28** and the hybrid junction **29**.

With received energy thus delivered to the hybrid junction **29**, this energy is transmitted thereby through the transmit-receive switching device **30** to the receiver **16**. The transmit-receive switching device **30** is typically a gas tube protective device for the receiver **16**, ionizing to effectively short circuit the transmission line between the hybrid junction **29** and the receiver **16** in the periods during which the transmitter **15** is operative to prevent the delivery of damaging or blocking amounts of energy to the receiver **16**. When the transmission line to the receiver **16** is thus short circuited, the hybrid junction **29** is no longer properly matched for delivery of energy to the receiver **16** and hence the load **31** is provided for matched absorption of that energy. Normally the actual energy involved is a very small percentage of the total energy produced by the transmitter **15** but it is still sufficient to have adverse effect as far as the receiver **16** is concerned. When the transmit-receive switch device **30** is not ionized the paths of the hybrid junction **29** are balanced as far as the load **31** is concerned so that substantially no received energy is lost in the load **31**.

With the apparatus as thus described it is apparent that control of the direction of the beam from the elements **10** through **13** is possible in such a way that the received and the transmitted beams are independent of each other, thus it is possible to rapidly sweep the transmitted beam to cover a sector of space and likewise to rapidly sweep the received beam to cover the same sector of space with the received beam lagging the transmitted beam to permit the correspondence of the beams, or otherwise varying relative thereto to achieve a desired result.

The apparatus of the present invention achieves a high degree of isolation in the form of prevention of reradiation from the elements because of the load **31**. Thus during the transmitting phase of operation, for example, energy emitted by antenna element **10** striking a nearby object is quite likely to be reflected and picked up in substantial proportions by the antenna element **11** as well as the other elements. Such energy thus received by antenna element **11** is quite likely to be delivered through phase shifter **26** to junction point **36**. With the load **31** provided a matched impedance termination through the hybrid junction **29**, a large part of this energy is absorbed by the load **31** and is not thus available for reradiation by the antenna elements. Such an arrangement thus achieves a much higher degree of freedom from the reradiation difficulty in antenna systems not equipped as in the present system.

The Y circulator mentioned above is shown in FIG. 2 to which reference is now directed. This circulator contains typically three waveguides identified by the numerals **40**, **41** and **42** which are arranged in one plane with equiangular spacing thereof. The waveguides intersect in a common region which is actually a part of all of the waveguides. The common region contains a ferrite member indicated in general by the numeral **43** to which a magnetic field may be supplied by a magnet indicated in general by a numeral **44** which field can be either of a D.C. nature as obtained from a permanent magnet or an electromagnet or in some instances where desired may be of an alternating nature to produce variations in the operation thereof. In the apparatus of FIG. 2 utilization is made of the principle that the field distribution in a rectangular waveguide containing a ferrite subjected to a magnetic field can be asymmetrical even though the physical configuration is symmetrical. By properly selecting the ferrite and its proportions it is possible to concentrate the energy on one side of the waveguide. Reversing the field or changing the direction of propagation will cause the energy to concentrate on the other side of the waveguide. Using the principles of the circulator, channeling the energy is thus possible with energy typically applied to waveguide **40** being delivered to waveguide **41** and energy applied to waveguide **41** being delivered to waveguide **42**. Thus in correlation of FIG. 2 with FIG. 1 waveguide **40** would typically be connected to the transmitter device and waveguide **42** to the receiver device.

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 is:

1. In combination, a transmitter for producing recurrent pulses of energy, a receiver, an antenna array for said transmitter and receiver having a plurality of elements, a plurality of directive couplers for the elements connected to the transmitter and receiver whereby transmitter energy is delivered to the elements and energy intercepted by the elements is delivered to the receiver, first control means for varying the relationship of energy delivered to the individual elements, second control means for varying the relationship of coupling of the individual elements to the receiver, and a transmit-receive switch unit connected between the second control means and the receiver for blocking the delivery of energy to the receiver during the production of each pulse of energy by the transmitter.

2. In combination, a transmitter for producing recurrent pulses of energy, a receiver, an antenna array for said transmitter and receiver having a plurality of elements, a plurality of directive couplers for the elements

connected to the transmitter and receiver whereby transmitter energy is delivered to the elements and energy intercepted by the elements is delivered to the receiver, first control means for varying the relationship of energy delivered to the individual elements, second control means for varying the relationship of coupling of the individual elements to the receiver, and impedance matched receiver isolation means connected between said last named means and the receiver for providing matched absorption of energy existing therein during the production of each pulse of energy by the transmitter.

3. In combination, a transmitter for producing recurrent pulses of energy, a receiver, an antenna array for said transmitter and receiver having a plurality of elements, a plurality of directive couplers for the elements connected to the transmitter and receiver whereby transmitter energy is delivered to the elements and energy intercepted by the elements is delivered to the receiver, first control means for varying the relationship of energy delivered to the individual elements, second control means for varying the relationship of coupling of the individual elements to the receiver, a transmit-receive switch unit connected between the second control means and the receiver for blocking the delivery of energy to the receiver during the production of each pulse of energy by the transmitter, and an energy absorption load for absorbing the energy prevented from reaching the receiver by said transmit-receive switch unit.

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