United States Patent [19]

Barker

[11] **3,893,124**

[45] **July 1, 1975**

[54] **R-F ANTENNA APPARATUS FOR GENERATING CONICAL SCAN PATTERN**

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[73] Assignee: **General Electric Company**, Utica, N.Y.

[22] Filed: **Apr. 26, 1974**

[21] Appl. No.: **464,430**

[52] **U.S. Cl.** **343/768;** 343/854; 343/858

[51] **Int. Cl.** **H01q 13/10**

[58] **Field of Search** 343/768, 771, 854, 858

[56] **References Cited**

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Primary Examiner—Eli Lieberman

[57] **ABSTRACT**

A four quadrant antenna is connected to r-f receiving and/or transmitting means by an arrangement including five 180° hybrid couplers (magic tee waveguides), a 90° hybrid coupler and a single 360° phase shifter. The branching arms of two of the 180° couplers are respectively connected to the four antenna quadrant elements while a third 180° coupler has its branching arms connected to the E-plane arms of the first mentioned couplers. The H-plane arms of the latter are connected to the branching arms of a fourth 180° coupler. Input/output to the circuit is coupled through a fifth 180° hybrid coupler which in turn is connected via its branching arms to the fourth 180° coupler and a 360° phase shifter. The latter is connected to the H-plane arm of the third 180° coupler through a 90° hybrid coupler, the latter also being connected to the E-plane arm of the fourth 180° coupler. Rotation of the phase shifter causes the axis of the antenna beam pattern to follow a path describing a cone. Modified arrangements include a duplexer connected to the fifth 180° hybrid coupler such that an r-f transmitter feeding the duplexer with signal pulses causes the antenna to broadcast corresponding pulses in either a scanned or a fixed beam pattern. A receiver also connected to the fifth 180° coupler operates during the intervals between transmission pulses to detect radiation received by the antenna from a conically scanned field.

8 Claims, 11 Drawing Figures

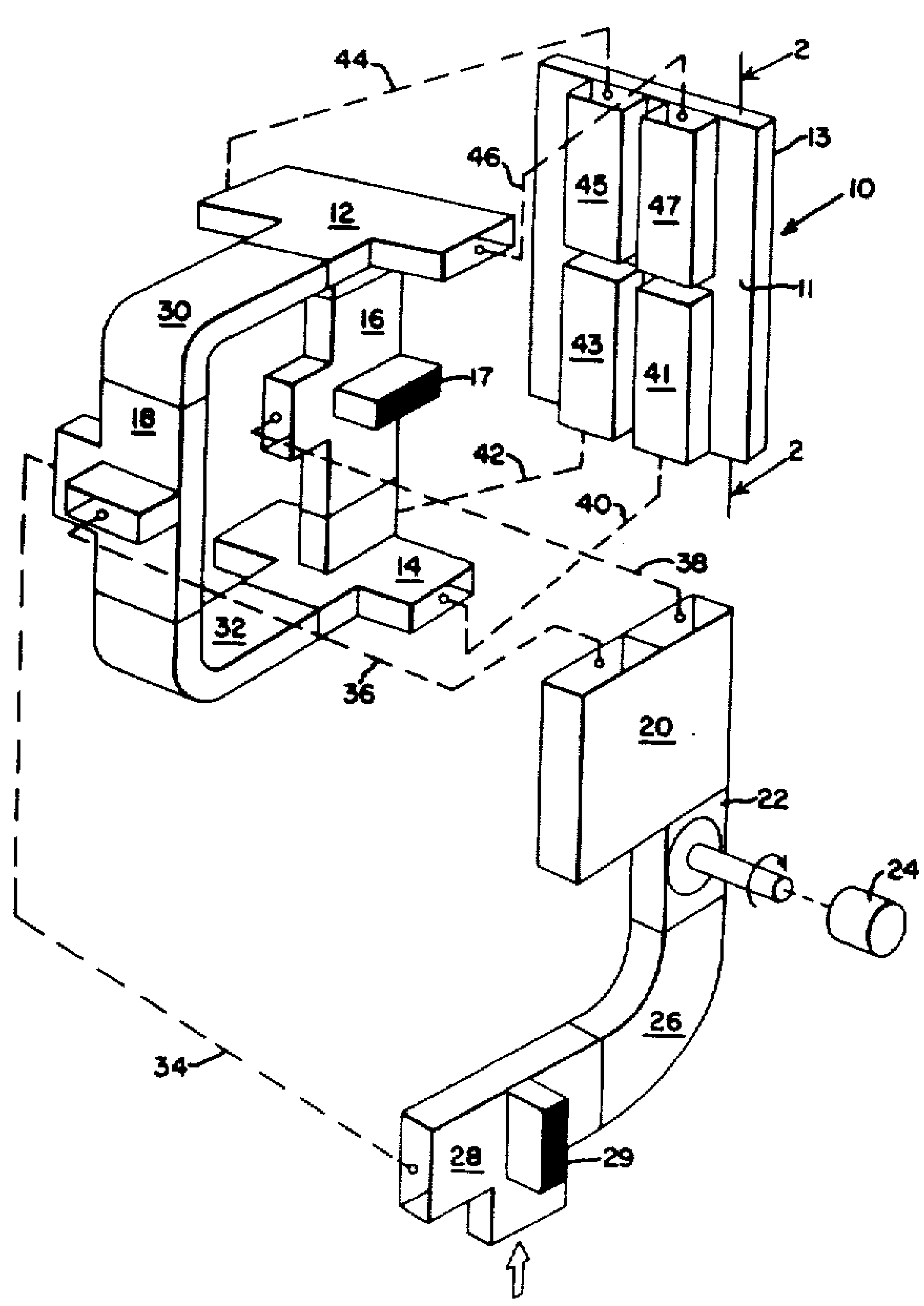
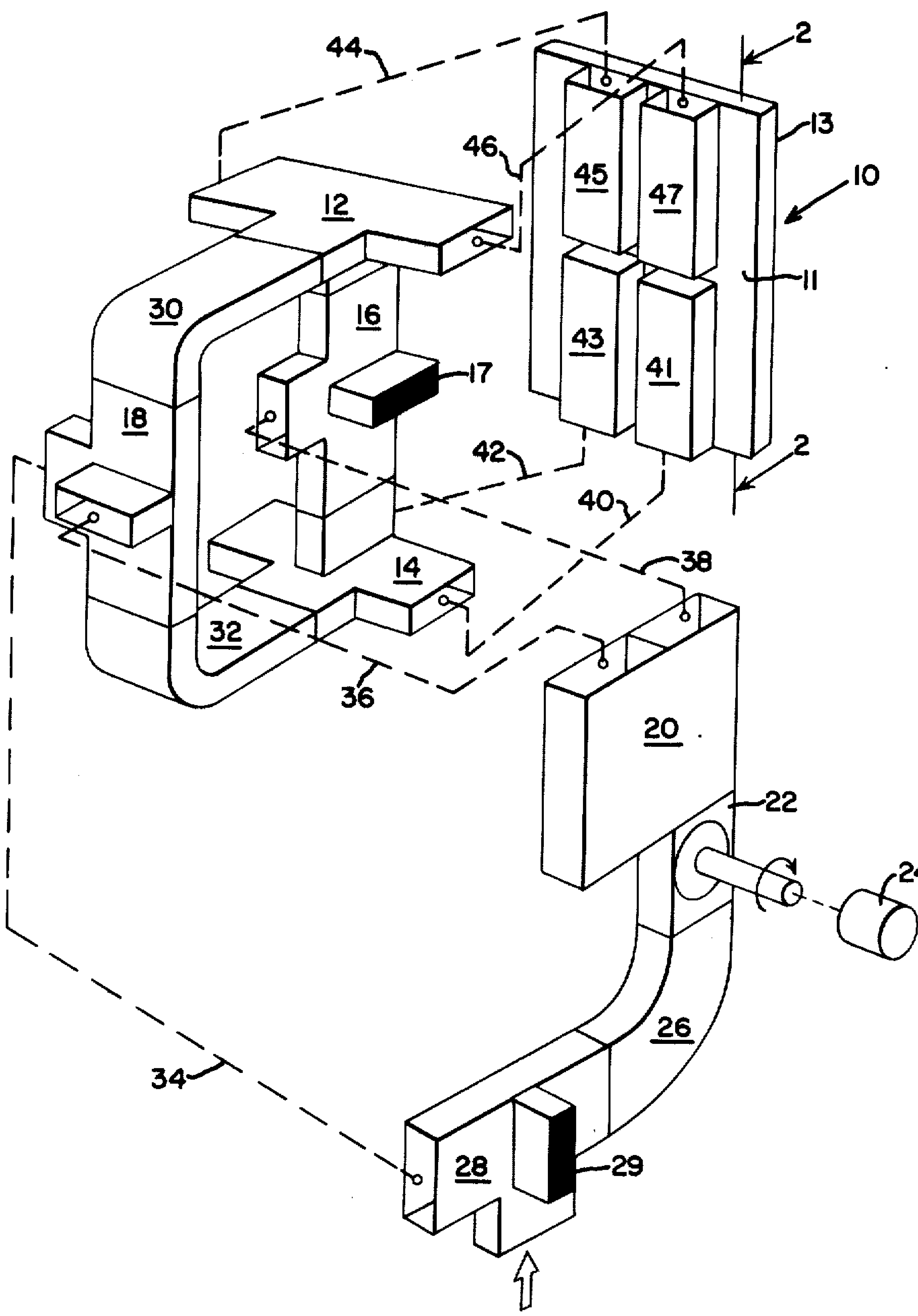


FIG.1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46
2
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16
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22
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29

FIG.2

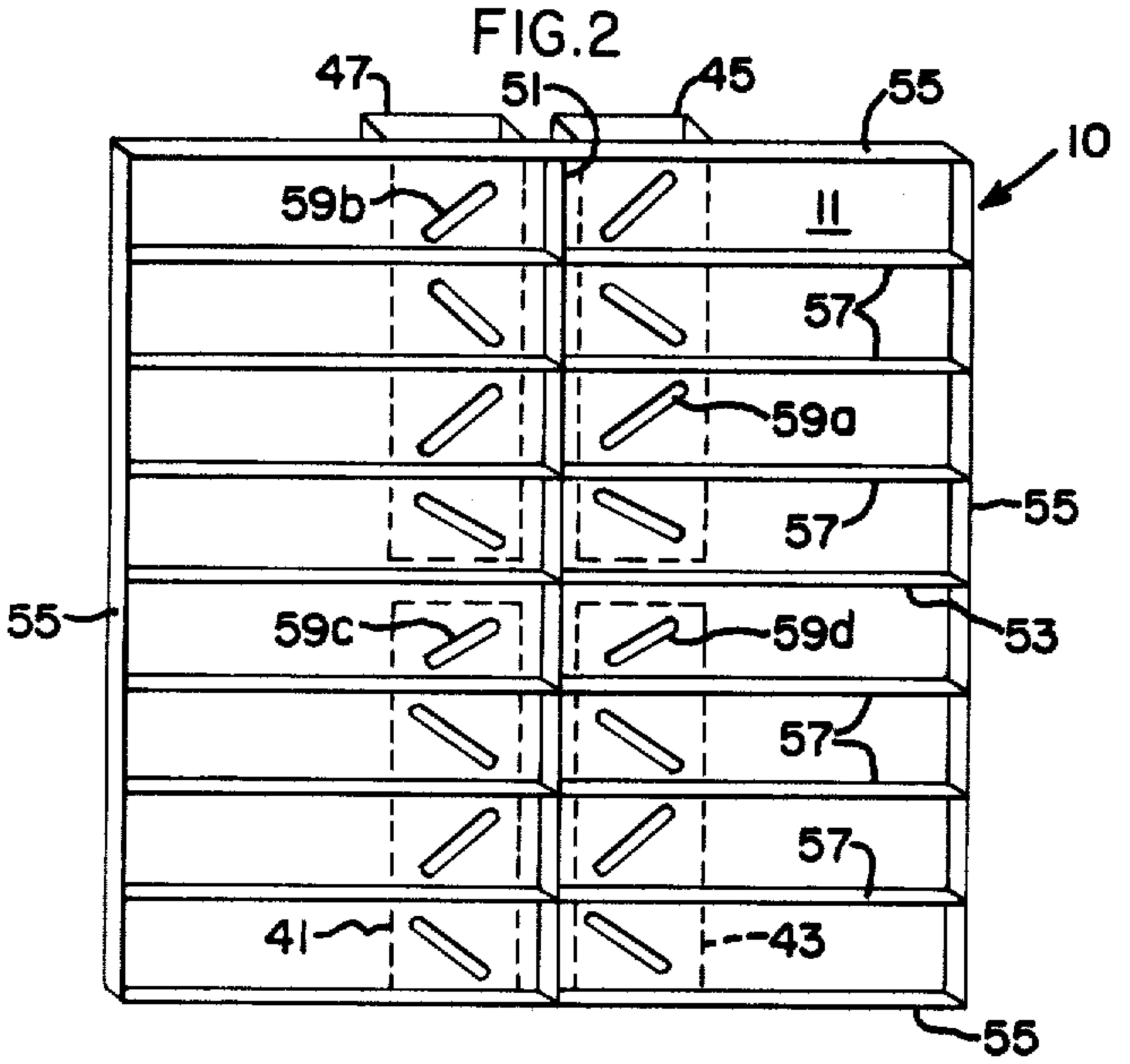


FIG.3

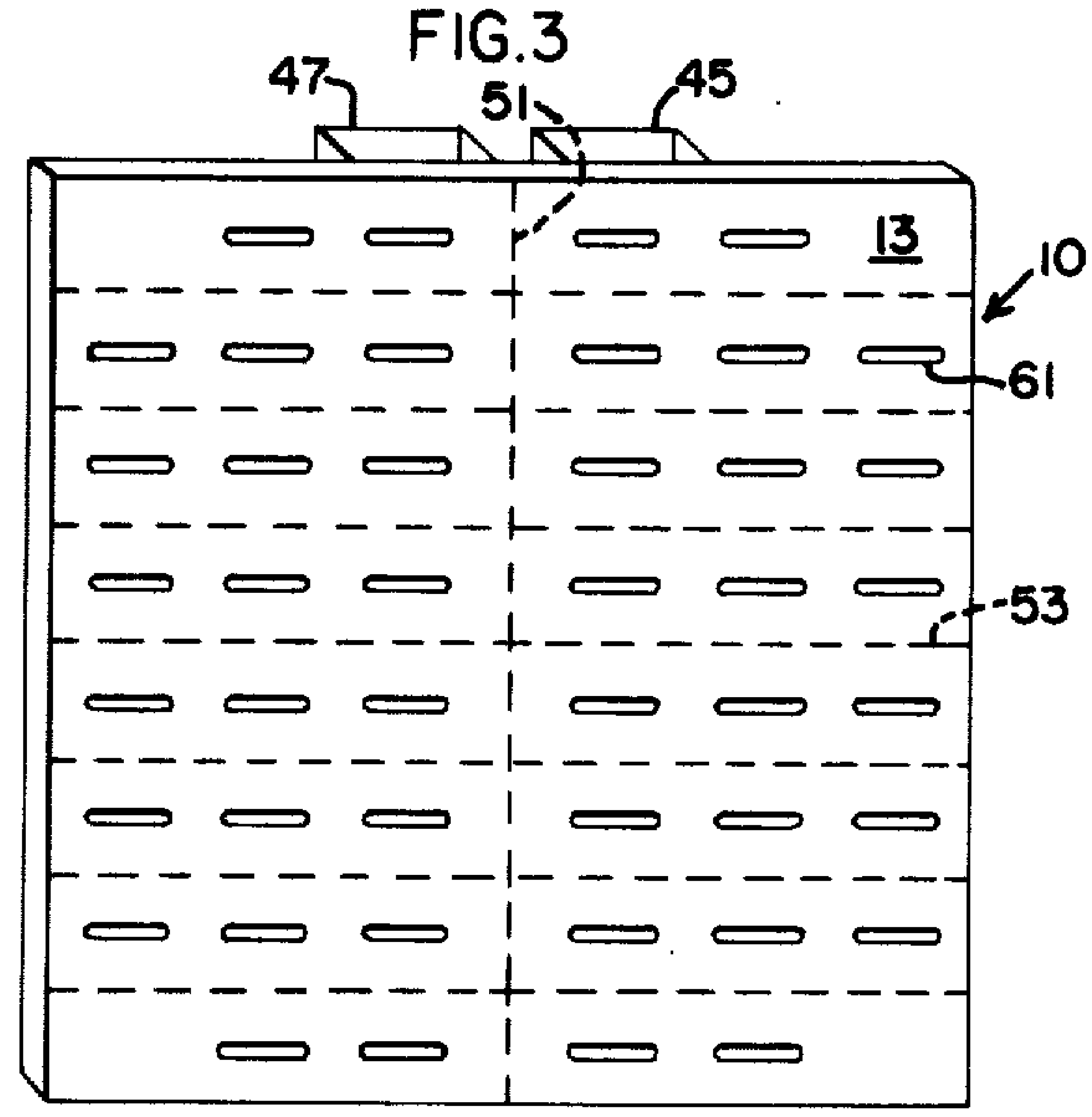


FIG.4

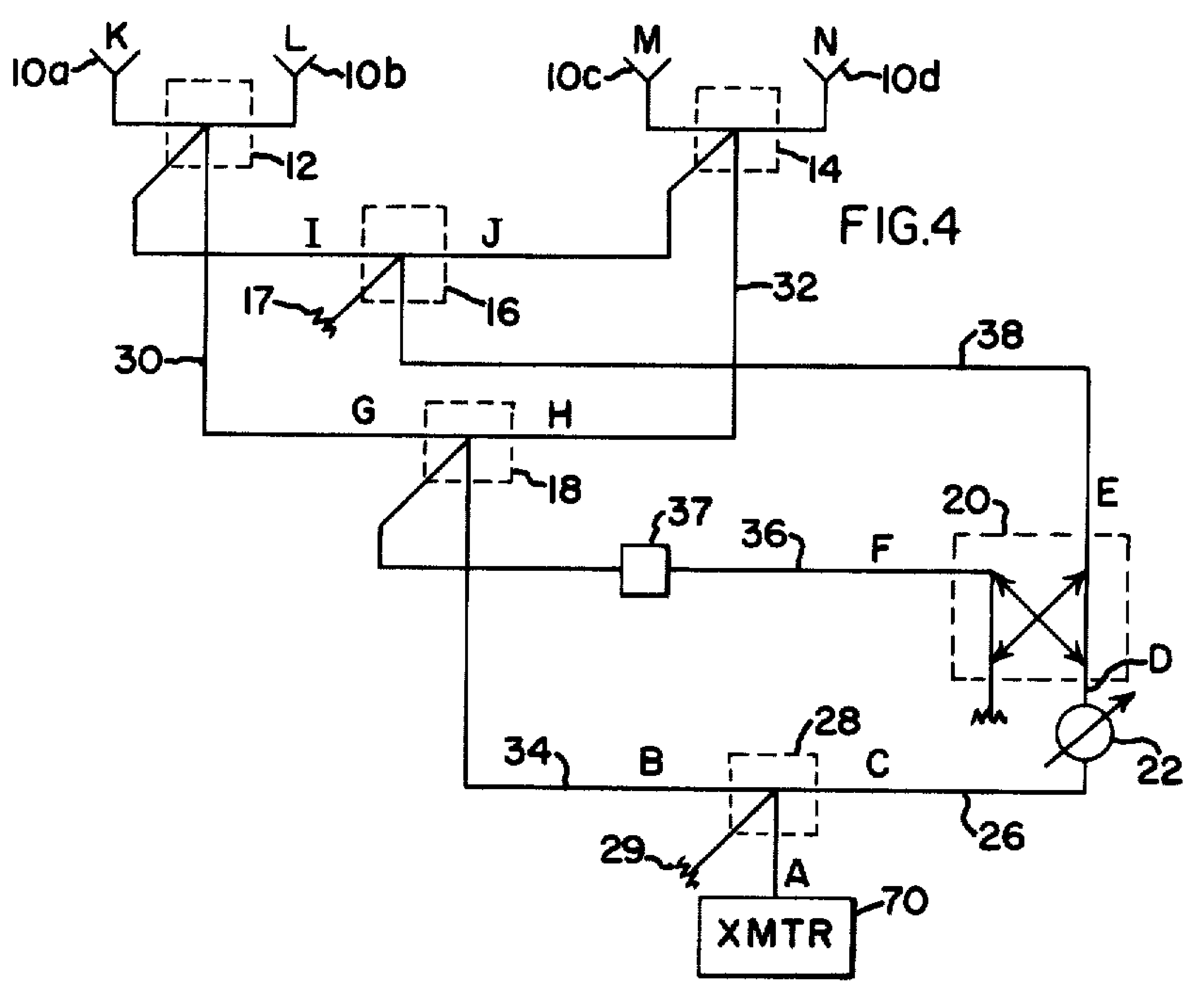
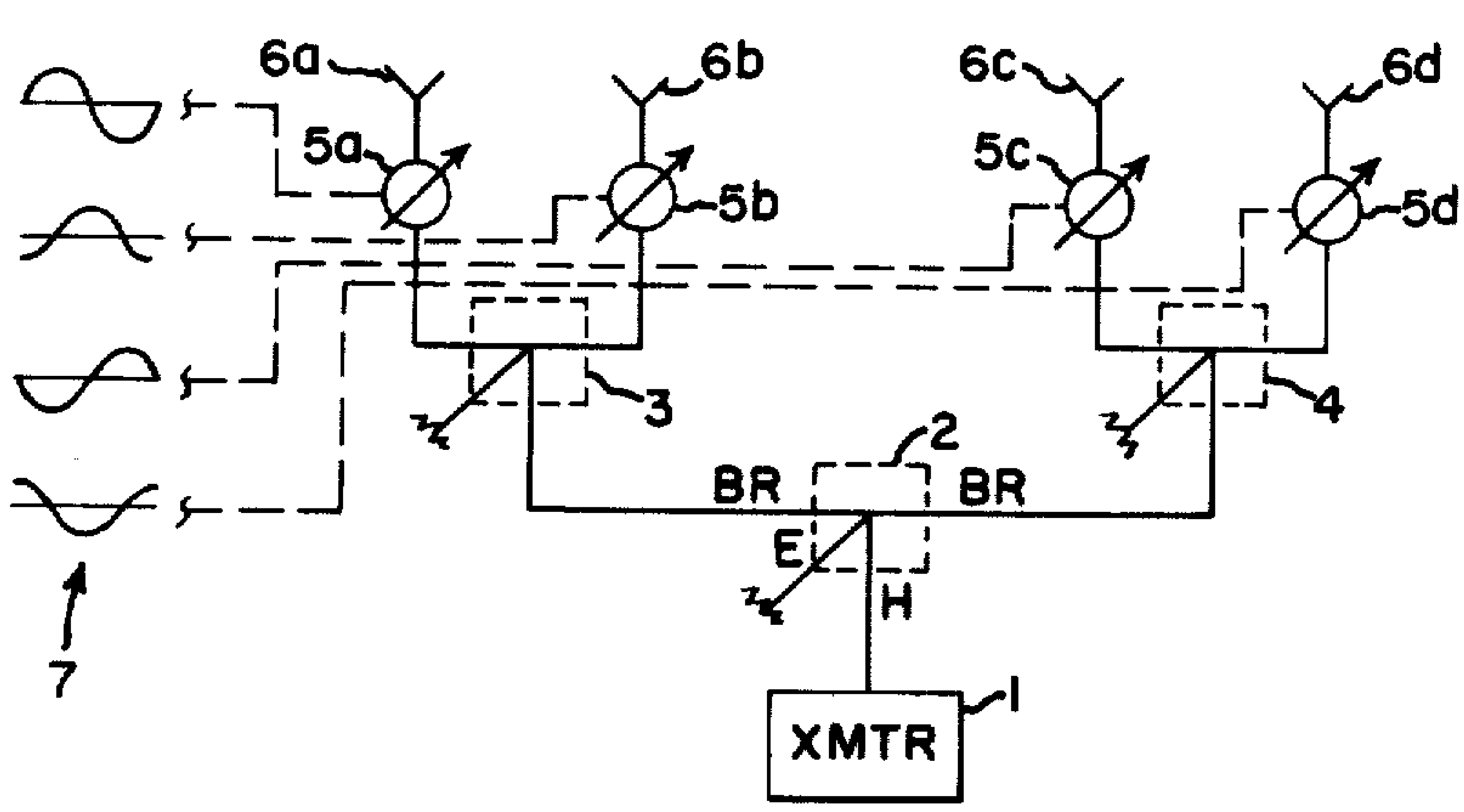


FIG.5
(PRIOR ART)



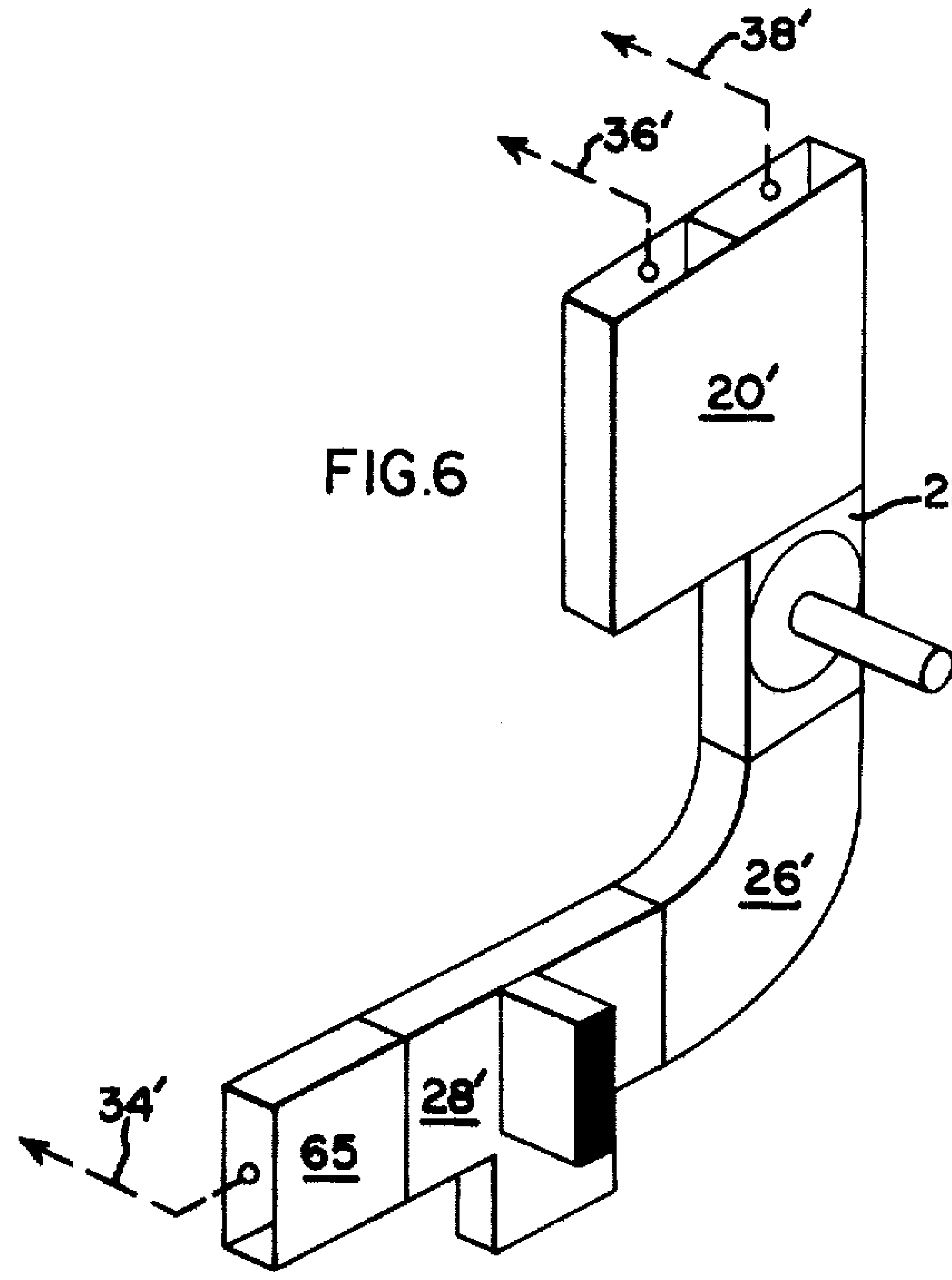

38′
36′
20′
22′
26′
34′
65
28′

FIG.6

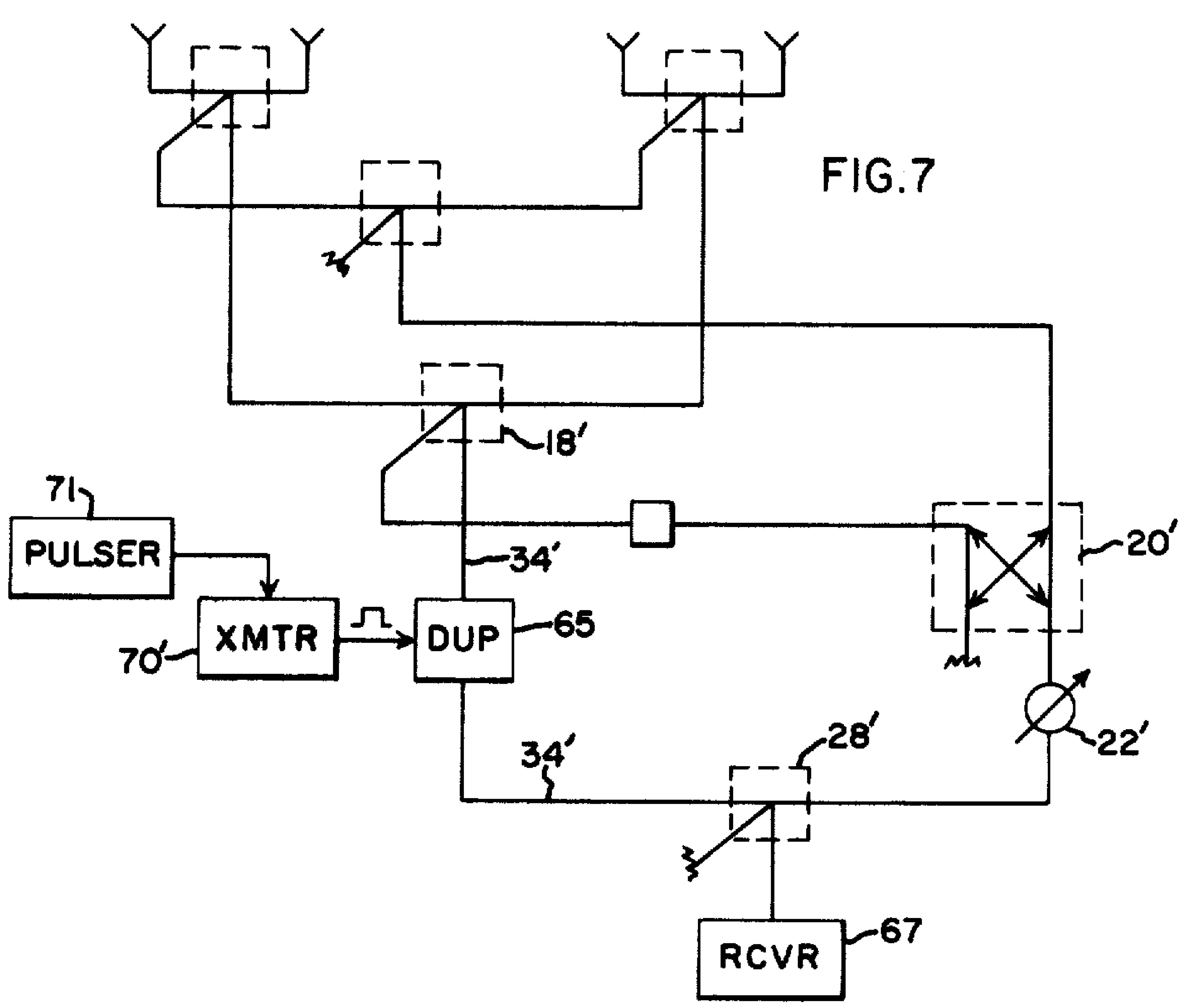

18′
71
PULSER
XMTR
70′
DUP
65
34′
20′
22′
28′
RCVR
67

FIG.7

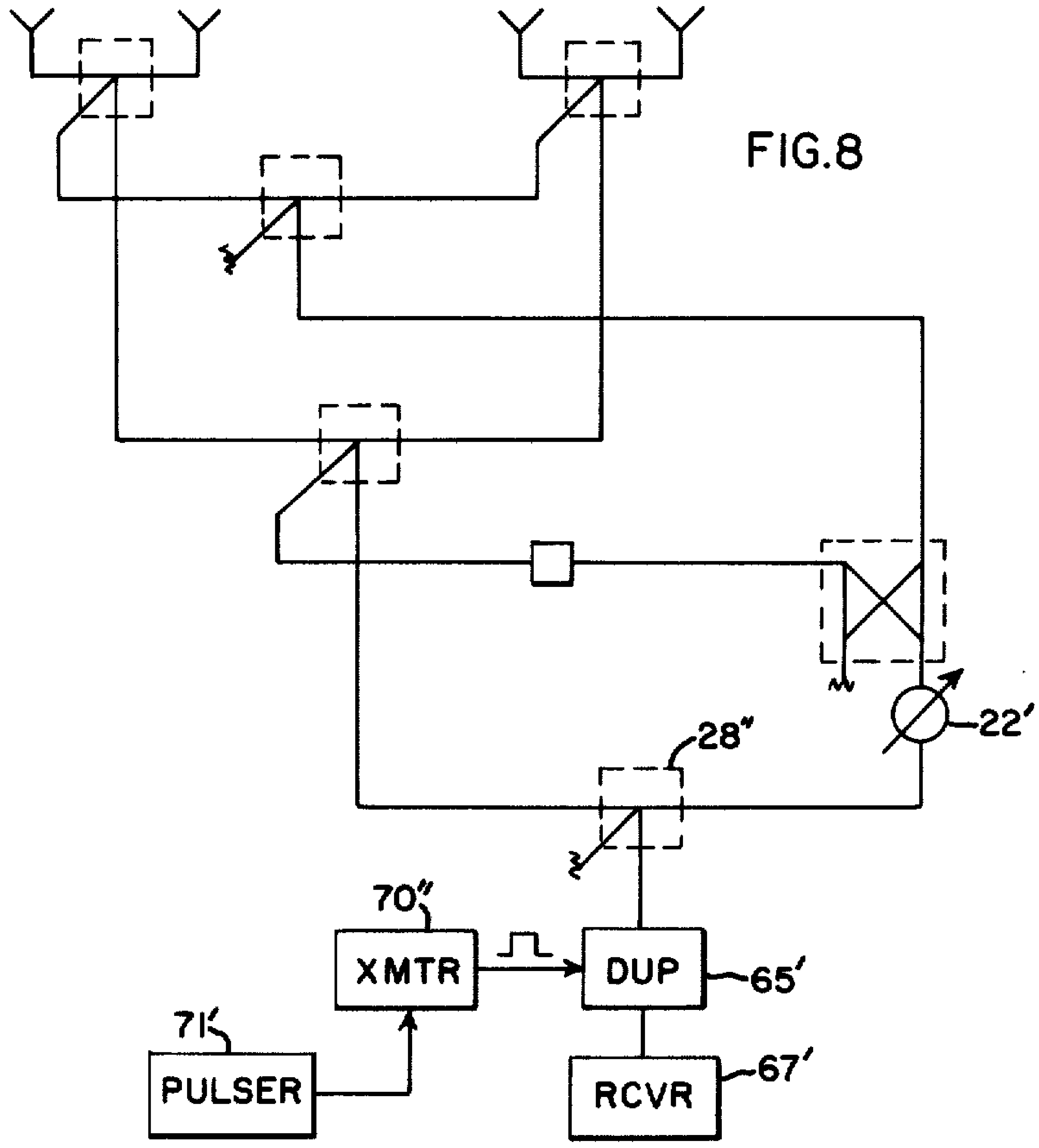


FIG.8

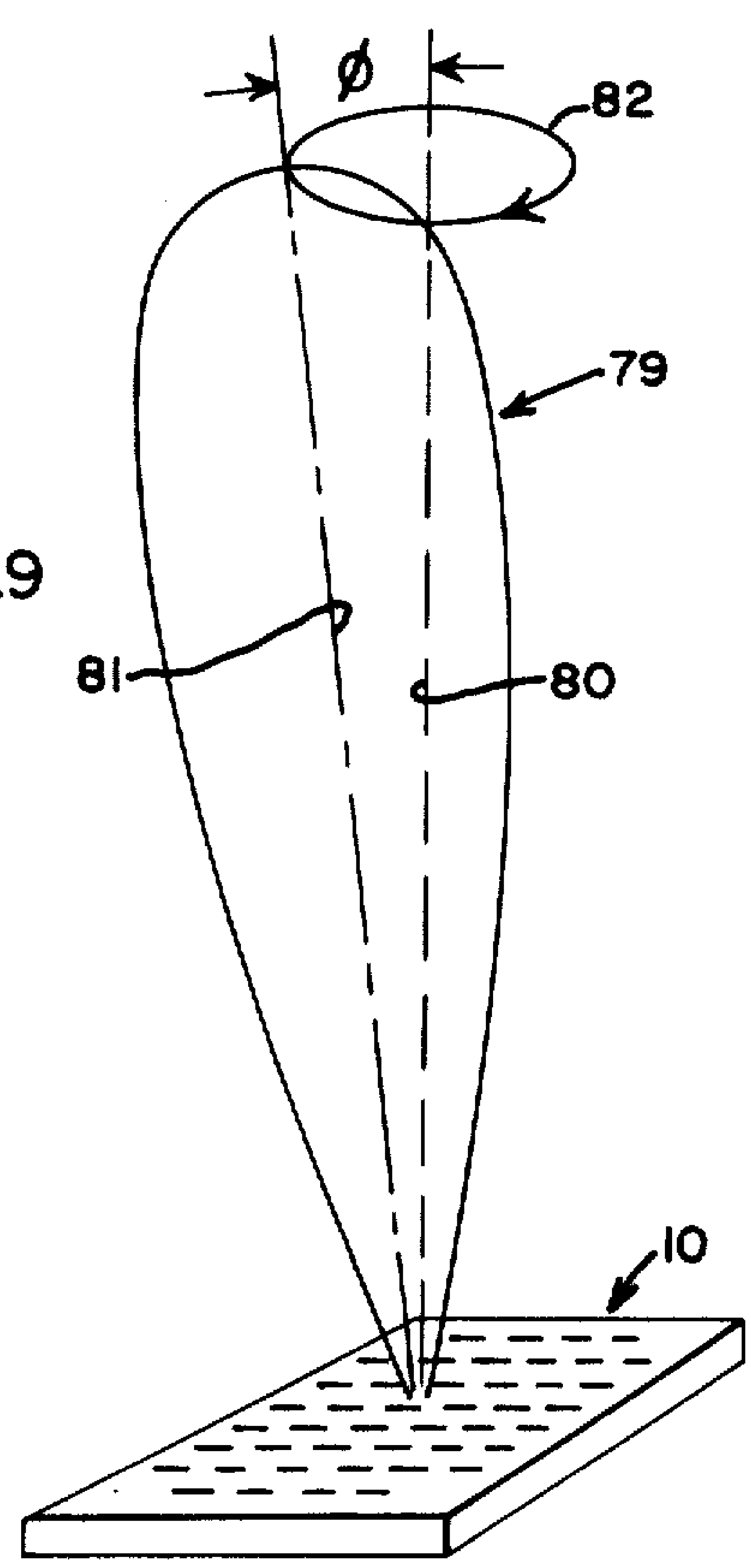


FIG.9

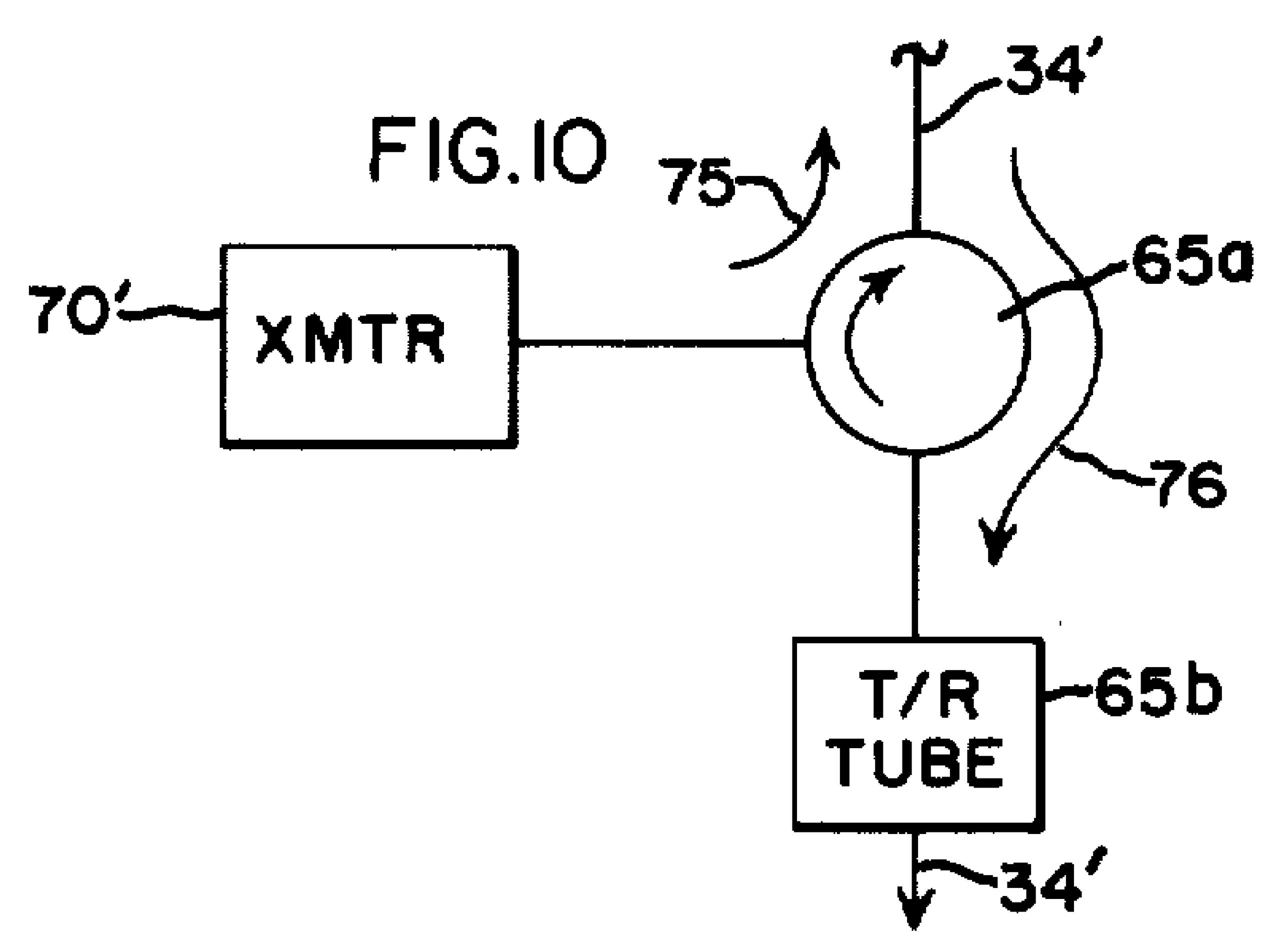


FIG.10

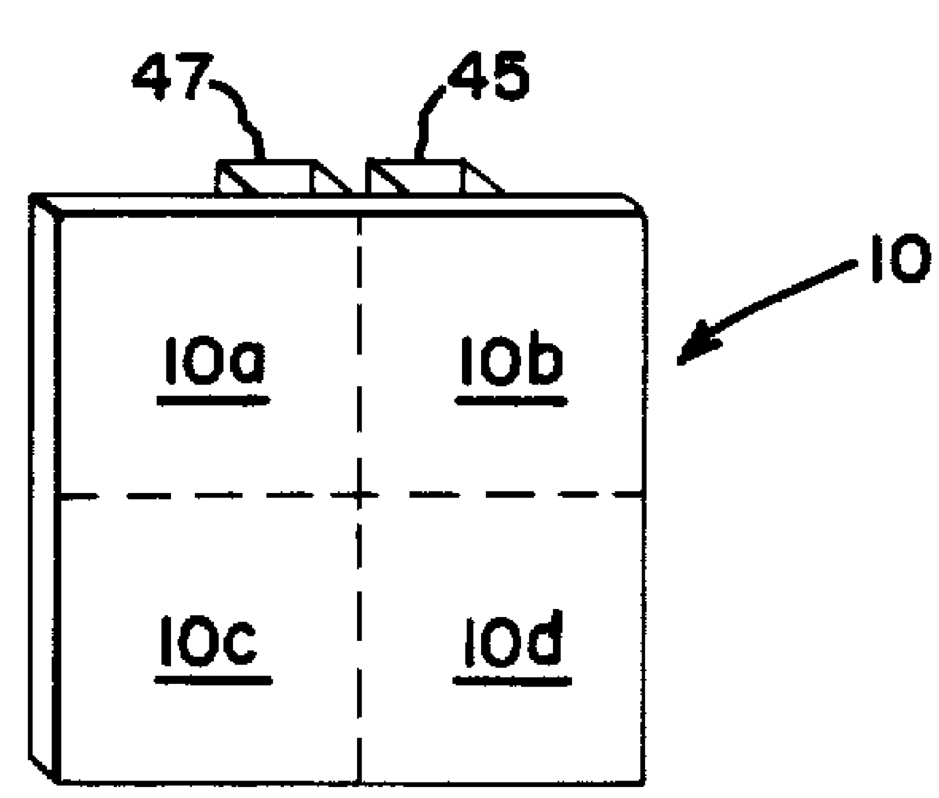


FIG.11

R-F ANTENNA APPARATUS FOR GENERATING CONICAL SCAN PATTERN

BACKGROUND OF THE INVENTION

The invention relates to r-f antenna arrangements and, more particularly, to a phase-scanned antenna arrangement for scanning a beam through a conical scan pattern. The invention herein described was made in the course of or under a contract or subcontract thereunder, with the Department of Defense.

In the past, generation of conical patterns through the use of stationary, phase-scanned multiple antenna arrangements has required the use of multiple phase shifting or attenuation elements. One such arrangement, for example, employs a four quadrant flat plate array antenna wherein each of the antenna quadrants is coupled to a single I/O device through a series of 180° hybrid couplers. A phase shifter is included in each portion of the circuit which connects to one of the antenna elements. The phase shifters are operated at a common frequency by individual actuation inputs which are progressively offset by a quarter wavelength. The result is conical scanning of the antenna beam pattern at a scan frequency equal to the common actuating frequency.

The requirement for four separate phase shifters makes such an arrangement complicated and expensive to manufacture due to the complexities of the phase shifters themselves and unless the shifters are closely matched in operating characteristics a high degree of scan accuracy is difficult to obtain.

OBJECTS AND SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide an improved r-f antenna arrangement for producing a phase-scanned conical beam pattern through use of relatively simple and inexpensive circuit elements.

It is a further object to provide an improved r-f antenna arrangement of the type described which employs but a single phase shifting element.

Still a further object is to provide an improved r-f antenna arrangement of the type described which is capable of intermittent transmit and receive operations wherein both such operations may utilize scanning or wherein only one of such operations undergoes scanning while the other does not.

In accordance with the first aspect of the invention a four element antenna is connected to an I/O 180° hybrid coupler (magic tee) by a series of circuit elements including four additional 180° hybrid couplers, one 90° hybrid coupler and a single 360° phase shifter. The four antenna elements are respectively connected to the branching arms of two of the additional 180° couplers. The latter have their E-plane arms connected to the branching arms of another of the additional couplers and have their H-plane arms connected to the branching arms of the fourth additional 180° coupler. The I/O coupler has its branching arms connected respectively to the H-plane arms of the aforementioned third and fourth 180° couplers and to the phase shifter, the connection going to the third coupler including the 360° phase shifter and the 90° hybrid coupler. A second port of the 90° coupler is connected to the E-plane arm of the aforementioned fourth additional 180° coupler. Rotation of the phase shifter through 360° degrees scans the antenna beam pattern through a conical path.

In accordance with a second aspect of the invention the H-plane arm of the I/O coupler is connected to a receiver while a duplexer is inserted between the fourth additional 180° coupler and the associated branching arm of the I/O coupler. A transmitter is connected to feed intermittent pulses to the antenna through the duplexer. The result is the emission from the antenna of a fixed beam during the transmission cycles while in the intervals between transmission pulses the receiver is fed energy from the antenna under the influence of the rotating phase shifter with the result that the system is conically scanned in the receive mode but not in the transmit mode. In a variation of this aspect of the invention the duplexer/transmitter is inserted at the input to the receiver resultng in the scanning of both transmit and receiver beam patterns.

These and other objects, features and advantages will be made apparent by the following description of preferred embodiments of the invention, the description being supplemented by drawings as follows:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective, semi-schematic view, partially exploded, of an r-f antenna arrangement constructed in accordance with the principles of the invention. Dashed lines are employed to represent conventional waveguide elements which have been omitted for purposes of simplifying the drawing.

FIG. **2** is a front elevation sectional view of the antenna taken along line **2**—**2** of FIG. **1**.

FIG. **3** is a full front elevation view of the antenna.

FIG. **4** is a schematic circuit diagram of the antenna arrangement of FIG. **1**.

FIG. **5** is a schematic circuit diagram depicting one form of prior art antenna arrangement.

FIG. **6** is a perspective view of a portion of the antenna arrangement of FIG. **1**, illustrating a first modification thereto.

FIG. **7** is a schematic circuit diagram of the complete antenna arrangement in accordance with the modification suggested by FIG. **6**.

FIG. **8** is a schematic circuit diagram of a second modified form of the invention.

FIG. **9** is a schematic diagram illustrating the antenna beam pattern and scanning motion associated with the arrangement of FIG. **1**.

FIG. **10** is a schematic circuit diagram of the duplexer/transmitter circuits shown in connection with FIGS. **7** and **8**.

FIG. **11** is a front elevation view of the antenna as shown in FIG. **3**, illustrating the correlation between the four antenna quadrants thereof and the four antenna elements schematically represented in FIG. **4**.

DETAILED DESCRIPTION OF THE EMBODIMENT

Referring first to FIG. **5** a typical prior art phase-scanned antenna arrangement is described. The antenna itself comprises a fixed four element array including the elements **6***a*, 6*b*, 6*c* and **6***d*. The antenna structure may be, for example, a four quadrant flat plate slotted array of the type employed with the embodiments of the invention hereinafter disclosed in connection with FIGS. **1**, **2** and **3**. In FIG. **5** *a* r-f transmitter **1** operating, for example, in the X-band frequency spectrum, feeds the antenna through a network of three 180° hybrid couplers (magic tees) **2**, **3** and **4**. The convention employed herein to illustrate such couplers is shown in connection with coupler **2**. A horizontal line is employed to designate the branching arms BR while a vertical line H indicates the H-plane arm of the coupler and a diagonal line E denotes the E-plane arm.

Transmitter **1** is connected to feed the H-plane arm of the coupler **2** while the branching arms of the latter are connected respectively to the H-plane arms of couplers **3** and **4**. The E-plane arms of all three couplers are terminated. The branching arms of coupler **3** are connected to feed the antenna elements **6***a* and **6***b* through a pair of phase shifters **5***a* and **5***b* respectively. Coupler **4**, through its branching arms, feeds antenna elements **6***c* and **6***d* through the phase shifters **5***c* and **5***d*. Actuating means (not shown) actuate the phase shifters through continuous sinusoidal cycles with each actuation input being offset from the other by 90° as illustrated by the sinusoidal wave forms shown at **7**.

The result, shown in FIG. **9**, is a beam pattern **79** projected by the vertically pointing antenna **10** along a beam axis **81** which is tilted by an angle θ away from the mechanical boresight **80** of the antenna. As the phase shifters rotate the beam axis **81** rotates through a circular path **82** centered about the antenna boresight. The path of the beam axis thus describes a cone.

This arrangement has the disadvantage of requiring four separate phase shifters. These are somewhat complex devices which are difficult to match very closely. This means that the antenna system is difficult and expensive to manufacture when the goal of close tolerance scanning is desired.

Another type of prior art arrangement includes a sum and difference network connected to feed a four quadrant phase-array antenna of the type described above. The sum and difference network is the same as the network of couplers shown in FIG. **5** except that a fourth 180° hybrid coupler is connected through its branching arms to the E-plane arms of the two output couplers. The E-plane arm of this fourth coupler is terminated.

This sum and difference feed network is driven by a circuit including a pair of ferrite modulators employing variable resistances. These modulators must be driven in sync to achieve an accurate conical scan of the type depicted in FIG. **9**. However, this arrangement also requires extremely close matching of the dynamic elements (variable resistors) and thus it is difficult economically to achieve high accuracies. This leads not only to high cost of manufacturing but also to reduced reliability due to the increased number of complex, dynamic elements. The use of variable resistors also leads to a power loss problem.

Further discussion of the general principles involved in the construction of electronic phase-scanned antennas may be found in the text *Introduction to Monopulse* by D. R. Rhodes (McGraw-Hill, 1959), reference particularly being directed to pages 62–68 thereof.

The present invention, hereinafter described, eliminates the aforementioned problems by reducing the number of dynamic circuit elements to a single 360° phase shifter. Since the remaining antenna elements comprise nothing more than passive waveguide structures, which can be fabricated to relatively high tolerances at reasonable cost levels, the end result is a low cost antenna system of improved reliability capable of generating an extremely accurate conical scan pattern.

Referring to FIGS. **1** and **4**, an antenna **10** of the flat plate, slotted array type is connected to an r-f (e.g., X-band) operating device, which may be either a transmitter or receiver, through the microwave network shown. As seen in FIG. **1** antenna **10** is viewed from the rear. Assuming, for purposes of explanation, that the antenna **10** is being employed in the transmission mode, an X-band r-f transmitter **70** (FIG. **4**) is connected to feed a signal to the H-plane arm of an input 180° hybrid coupler **28**. The E-plane arm of this coupler is terminated at **29**.

The coupler **28** is connected at one of its branching arms through a waveguide **26** to a 360° mechanical phase shifter **22**. The output of the phase shifter is connected to the lower right-hand port of a 90° hybrid coupler **20**. A drive motor **24** is connected to continuously rotate the shifter **22** through 360°.

The upper ports of the 90° coupler **20** and the other branching arm of the 180° coupler **28** are connected to a sum and difference network comprising four 180° hybrid couplers **12, 14, 16** and **18**. The branching arms of coupler **18** are connected to the H-plane arms of the couplers **12** and **14** by a pair of wave guides **30** and **32** respectively. The E-plane arms of couplers **12** and **14** are connected to the branching arms of coupler **16**, the E-plane arm of the latter being terminated at **17**.

The H-plane arm of coupler **16** is fed by the upper right-hand port of the 90° coupler **20** while the upper left-hand port of the latter is connected to feed the E-plane arm of coupler **18**. The lower left-hand port of coupler **20** is terminated. The final input connection to the sum and difference network is through waveguide **34** which connects the left-hand branching arm of input coupler **28** to the H-plane arm of coupler **18**.

As previously mentioned the dashed lines **34, 36, 38,** 40, 42, 44 and **46** of FIG. **1** represent conventional waveguide connections which connections for purposes of clarity have been omitted from the drawing.

The branching arms of couplers **12** and **14** are connected to feed the four quadrants of antenna **10**. Four closed-ended waveguide elements **41, 43, 45** and **47** are mounted on the rear plate **11** of antenna **10** to couple energy to the antenna through a series of coupling slots described in more detail subsequently in connection with FIGS. **2** and **3**. The branching arms of coupler **12** are connected to waveguides **45** and **47** by waveguides **44** and **46** respectively. Similarly, the branching arms of coupler **14** are connected to waveguides **41** and **43** by waveguides **40** and **42** respectively.

Referring to FIGS. **2** and **3**, the specific structure of antenna **10** is hereinafter described in detail. FIG. **2** is a cross section of the antenna structure view from the front of the antenna along the line **2—2** of FIG. **1**. FIG. **3** is a front elevation view of the full antenna with front plate **13** in place.

As shown in FIG. **2** the rear plate **11** and the front plate **13** of the antenna are spaced apart by a series of waveguide partitions **51, 53** and **57**. The outer periphery of the structure is enclosed by side walls **55**. Partitions **51** and **53** divide the antenna into four equal quadrants. An additional series of horizontally running partitions **57** divides each quadrant into four sections. Each of the four antenna quadrants is depicted in the schematic circuit diagram of FIG. **4** as one of the four antenna array elements **10***a*, 10*b*, 10*c* and **10***d*. FIG. **11** illustrates the manner in which the four array elements correspond to the four quadrants of the structure of FIGS. **2** and **3**.

Waveguide **45** (FIG. **2**) is coupled to the four sections of quadrant **10***a* by a series of coupling slots **59***a* formed in the rear plate **11.** Similarly, waveguide **47** is coupled to the four sections of quadrant **10*b*** by a series of coupling slots **59*b*** while waveguide **41** is coupled to quadrant **10*c*** through the four slots **59*c*** and waveguide **43** is coupled to quadrant **10*d*** by the four slots **59*d*.** The front plate **13** of the antenna (FIG. **3**) is provided with a series of parallel radiating slots **61** associated with the several quadrant sections.

As shown in FIG. **4,** a phase adjuster **37** may be inserted in the waveguide **36** which connects the 90° coupler with the E-plane arm of 180° coupler **18** to facilitate the electrical equalization of waveguides **36** and **38** (i.e., enables the nulling of any relative phase shifts imposed by the waveguides).

In operation, the application by transmitter **70** (FIG. **4**) of X-band radiation to the antenna system results in the transmission by the antenna of a beam such as illustrated at **79** in FIG. **9.** The beam **79** is tilted from the mechanical boresight **80** of the antenna by an angle θ and rotates through a conical path defined by the circle **82** as the phase shifter **22** rotates. Each full revolution of the shifter results in one complete scan (revolution) of the bean. The simplest manner of completely describing the operation of the various circuit elements of the embodiment depicted in FIG. **4** is to mathematically describe the vector voltage present at each significant point of the circuit as denoted by the letters A through N shown in FIG. **4.** The point A taken at the output of transmitter **70** represents the antenna system input voltage E. The voltages at the remaining circuit points are as follows:

$$B = \sqrt{2/2}\,E$$

$$C = \sqrt{2/2}\,E$$

$$D = \phi\sqrt{2/2}\,Ee^{j}$$

$$E = E/2\,e^{j\phi}$$

$$F = E/2\,e^{j(\phi - \pi/2)}$$

$$G = E/2 - \sqrt{2/4}\,Ee^{j(\phi - \pi/2)}$$

$$H = E/2 + \sqrt{2/4}\,Ee^{j(\phi - \pi/2)}$$

$$I = -\sqrt{2/4}\,Ee^{j\phi}$$

$$J = +\sqrt{2/4}\,Ee^{j\phi}$$

$$K = \sqrt{2/4}\,E(1+e^{j(\phi + \pi/4)})$$

$$L = \sqrt{2/4}\,E(1-e^{j(\phi - \pi/4)})$$

$$M = \sqrt{2/4}\,E(i-e^{j(\phi + \pi/4)})$$

$$N = \sqrt{2/4}\,E(1+e^{j(\phi - \pi/4)})$$

where ϕ = instantaneous phase of the rotating phase shifter

It should be noted that the output voltage at each of the four antenna elements includes a constant term and a variable term of equal magnitude to the constant term but which varies in phase in accordance with the operation of the phase shifter **22.** The phase variance of the voltage at the antenna elements K, L, M and N progressively differs by voltage at the antenna elements K, L, M and N progressively differs by 90°. The net result is the conical scan pattern illustrated in FIG. **9.** It should be further noted that the characteristics of the circuit are fully reciprocal and that a receiver may be substituted for transmitter **70.** The response characteristics of the antenna to received radiation, as "seen" from the receiver, will be conically scanned. Also, the scan angle θ (FIG. **9**) may be adjusted by varying the ratio

of energy directed to waveguides **26** and **34** from the transmitter **70.** To this end a directional coupler having the desired characteristics may be substituted for 180° hybrid coupler **28** (which divides the input energy equally). Channelling all the energy to waveguide **34** results in a beam axis coinciding with the mechanical boresight of the antenna. Channelling most (but not all) the energy into waveguide **26** results in a maximum scan angle.

FIGS. **6** and **7** illustrate a first modified embodiment of the invention wherein the system is arranged to receive as well as transmit. During transmission a fixed (non-scanned) beam pattern is directed along the mechanical boresight of the antenna and during the receive operation (between transmission intervals) the response pattern of the antenna is conically scanned.

FIG. **6** shows only the modified portion of the structure. The remainder of the circuit is identical to that shown in FIG. **1.** The modification comprises addition of a duplexer **65** which is connected to the left branching arm of 180° hybrid coupler **28′**. The remaining primed reference numerals shown in FIG. **6** indicate structural identity between the associated elements and those represented by corresponding numbers in FIG. **1.** As shown in FIG. **7** the duplexer **65** is inserted in waveguide **34′** which connects the left branching arm of coupler **28′** to the H-plane arm of coupler **18′**. A receiver **67** is connected to the H-plane arm of coupler **28′** and a transmitter **70′** is connected to feed an input to the duplexer. A pulsing circuit **71** cooperates with transmitter **70′** so that the ouptut from the latter is a series of signal pulses. With the duplexer in the position shown the effects of the continuously rotating phase shifter **22′** are not imposed on the transmitted energy and the result is generation of an antenna beam pattern which has its axis in alignment with the antenna boresight and which does not rotate.

However, when the transmission pulse terminates the operation of duplexer **65** is to return received energy through waveguide **34′** to the left branching arm of coupler **28′** in the same manner as previously described in connection with FIG. **4,** just as though the transmitter was not in the circuit. Thus, the aforedescribed conical scanning operation is realized during the receive mode.

FIG. **10** schematically illustrates the structure and operation of the duplexer **65.** A ferrite circulator **65*a*** rotates input energy in a clockwise direction so that the output from transmitter **70′** is coupled upwards in the direction of arrow **75** into the section of waveguide **34′** which connects to coupler **18′**. When the transmitter is not operating, energy received from coupler **18′** is coupled through the circulator in the direction of arrow **76** into a transmit/receive tube **65*b*** and thence to the lower section of waveguide **34′** which connects to the coupler **28′**. Transmit/receive tube **65*b*** isolates the receiver from the high level energy generated by the transmitter **70′**.

A second modified embodiment of the invention is shown in FIG. **8.** The circuit there illustrated is identical to that of FIG. **4** except a duplexer **65′** is inserted in front of the H-plane arm of input/output coupler **28‴**. The duplexer **65′**, as with the duplexer **65** shown in FIG. **7,** allows the antenna system to operate in both a transmit and receive mode. However, with the duplexer positioned as shown in FIG. **8** both the transmitted and received energy is conically scanned. The operation of the pulser **71'**, transmitter **70''**, duplexer **65'** and receiver **67'** is identical to that set forth above for the pulser **71**, transmitter **70'**, duplexer **65** and receiver **67**. The only difference is that due to the position of the duplexer **65'** both the transmitted as well as the received signals are acted upon by the rotating phase shifter **22''** in the manner previously described in connection with FIG. **4**.

It will be appreciated that various additional changes in the form and details of the above-described preferred embodiments may be effected by persons of ordinary skill without departing from the true spirit and scope of the invention.

I claim:

1. A phase-scanned r-f antenna comprising, in combination:

a four quadrant antenna;

first and second 180° hybrid couplers connected to said antenna, the four branching arms of said couplers being connected to different ones of said antenna quadrants;

a third 180° hybrid coupler having its branching arms connected to the E-plane arms of said first and second couplers;

a fourth 180° hybrid coupler having its branching arms connected to the H-plane arms of said first and second couplers;

a 90° hybrid coupler having one pair of adjacent ports connected to the H and E-plane arms of said third and fourth 180° hybrid couplers respectively;

a fifth 180° hybrid coupler having its branching arms connected respectively to the H-plane arm of said fourth 180° coupler and to a port of said 90° coupler which is opposite the port connected to said third 180° coupler.

a phase shifter connected in the circuit between the branching arm of said fifth 180° coupler and said 90° coupler;

r-f energy operating means connected to the H-plane arm of said fifth 180° coupler; and

means for actuating said phase shifter whereby the axis of the beam pattern of said antenna is caused to scan in a path describing at least a segment of a cone.

2. The phase-scanned r-f antenna set forth in claim **1** wherein said actuating means operates said phase shifter through 360° whereby the axis of the beam pattern of said antenna is caused to scan in a path describing a cone.

3. The phase-scanned r-f antenna set forth in claim **1** wherein said r-f energy operating means comprises a transmitter.

4. The phase-scanned r-f antenna set forth in claim **3** wherein said transmitter is constructed and arranged to transmit r-f energy in the X-band frequency range.

5. The phase-scanned r-f antenna set forth in claim **1** wherein said r-f energy operating means comprises a receiver.

6. The phase-scanned r-f antenna set forth in claim **5** wherein said receiver is constructed and arranged to receive and detect r-f energy in the X-band frequency range.

7. The phase-scanned r-f antenna set forth in claim **5** further comprising:

a duplexer connected between said H-plane arm of said fourth 180° hybrid coupler and the branching arm of said fifth 180° hybrid coupler;

an r-f transmitter coupled to said duplexer to feed a signal to said antenna; and

means for intermittently energyzing said transmitter to cause said antenna to emit a fixed beam pattern, said receiver operating during the intervals between said transmissions to receive and detect signals from a field which is conically scanned by the operation of said phase shifter.

8. The phase-scanned r-f antenna set forth in claim **5** further comprising:

a duplexer connected between said receiver and said H-plane arm of said fifth 180° hybrid coupler;

an r-f transmitter coupled to said duplexer to feed a signal to said antenna; and

means for intermittently energyzing said transmitter to cause said antenna to emit a beam pattern which is conically scanned by the operation of said phase shifter, said receiver operating during the intervals between said transmissions to receive and detect signals from a field which is also conically scanned by the operation of said phase shifter.

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