Feb. 6, 1962 M. L. KALES ET AL 3,020,549

MATCHED ANTENNA ARRAY

Filed Aug. 20, 1959 2 Sheets-Sheet 1

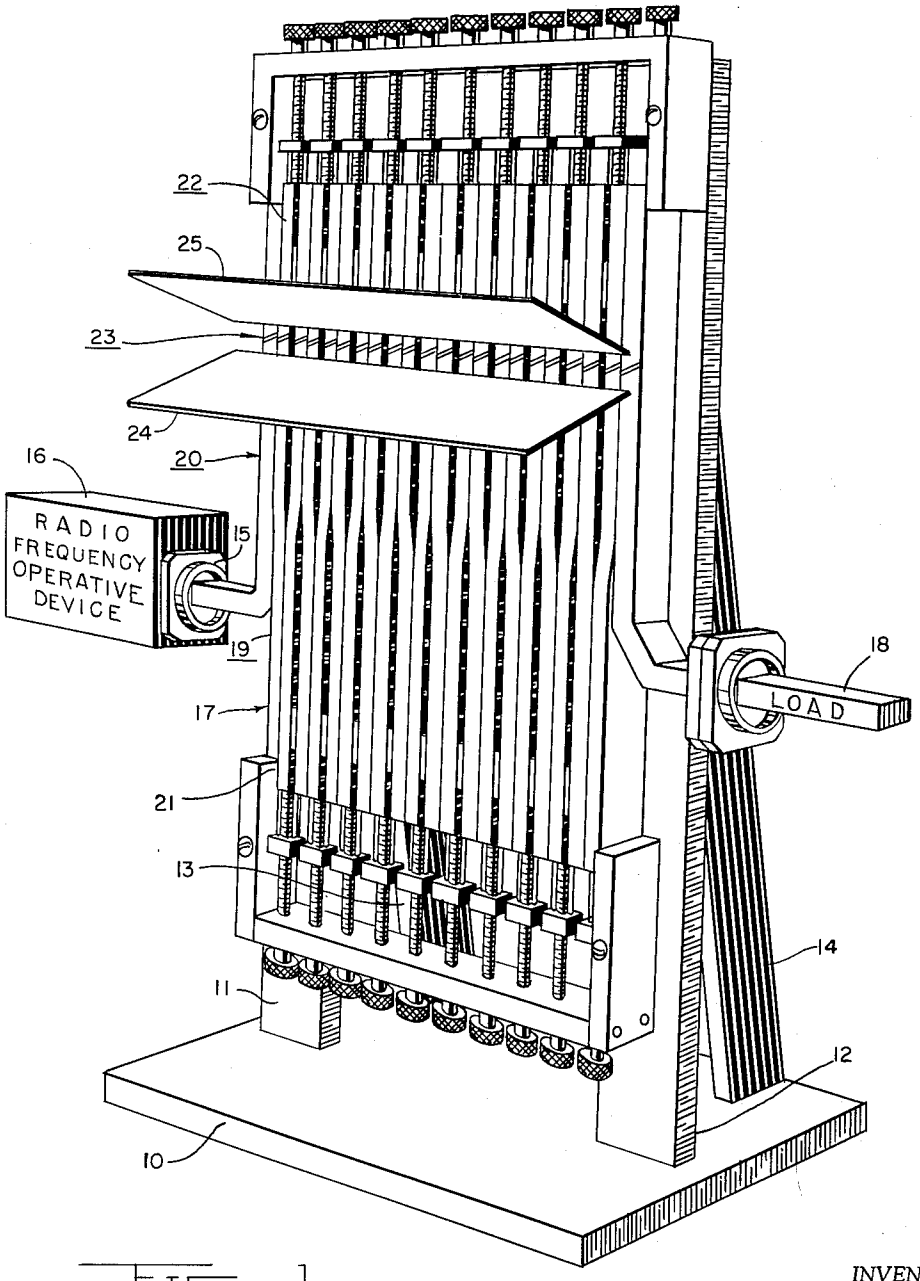


FIG. 1

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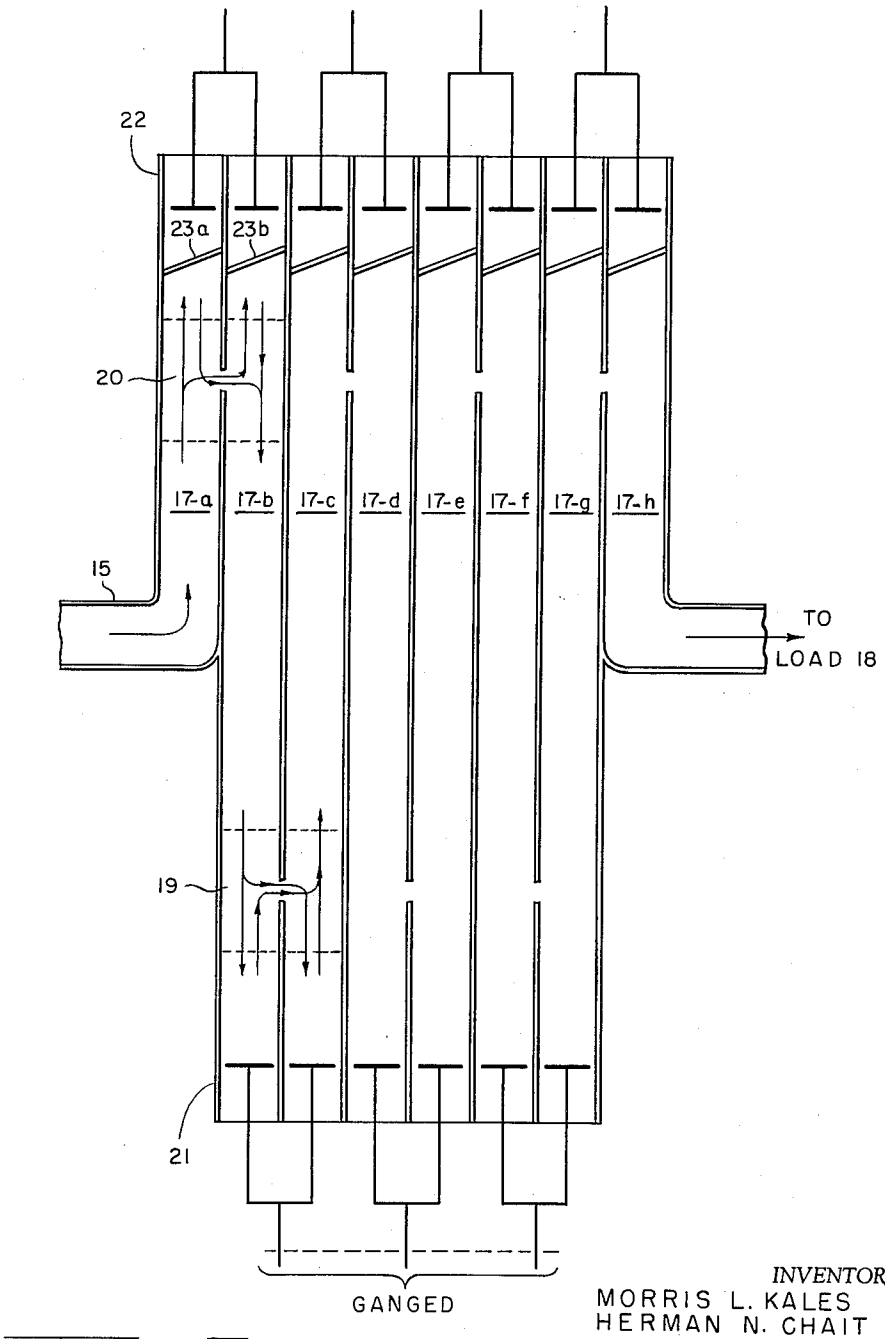


FIG. 2

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3,020,549
MATCHED ANTENNA ARRAY

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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 antenna systems in general and in particular to directive antennas wherein the axis of directivity is caused to scan through a sector of space by electrical variation as contrasted to mechanical variation. In greater particularity the invention relates to antennas employing a plurality of radiating elements which are series fed.

Direct radiator antenna arrays used for narrow beam operation, such as conventional forms of radar systems, generally must employ a plurality of antenna elements, spaced critical distances apart, and radiating in phase so that the energy from the elements is additive in the broadside direction providing a peak that falls off rapidly away from the broadside direction. In such systems, if the elements do not radiate in phase, but progressively differ in phase across the array, the maximum does not occur in the broadside direction but rather at some angle with respect thereto. Thus the basis of an electrical scanning antenna is set forth wherein the direction of major response of the antenna can be swept across a sector of space without requiring physical motion of the antenna.

In general the plurality of antenna elements must be fed from a single source of energy or connected to a single receiver depending upon whether the device is used for transmission or reception. In either case the problem of connecting many elements to one utilization device still exists. One way to accomplish this requires a symmetrically arranged plurality of tiers of T-junctions, each branch of each junction of one tier feeding two subsequent junctions in the subsequent tier, until finally each of the last tier of junctions feeds two antenna elements. This is referred to as parallel feed.

A second form of feed and that to which the device of the present invention is directed is termed a series feed because of the fact that it is in effect a single line that goes to each element in sequence, each such element withdrawing a portion of the energy in the line, the balance of the energy continuing down the line.

The matching of impedances and phasing of the elements in such arrays requires careful consideration if undesired reflections are to be avoided and the desired directivity obtained. In general the series fed system achieves in-phase excitation of the elements by spacing the feed points for the elements one wavelength apart along the line or a half wavelength apart with some arrangement for introducing 180 degree phase change. Either arrangement achieves scanning by the insertion of similar controllable phase shifters in the line between each such feed point. Such a system is subject to a particular disadvantage however in that when the in-phase condition exists, reflections from all similar components are additive at the input end of the line, producing serious impedance mismatch. This mismatch is of such proportions that prior art devices were seldom operated through the broadside condition in scanning, the scanning being deliberately limited so as to result in scanning only to one side or the other of the broadside condition. Such operation provides results which to some extent can be considered advantageous, however constant effort is being expended

to increase the possible scan angle so that some arrangement for avoiding the undesired reflections in the broadside condition would substantially increase the practical scan angle.

It is accordingly an object of the present invention to provide a series fed multi-element antenna system wherein the foregoing impedance mismatch in the broadside condition is avoided.

Another object of the present invention is to provide an antenna feed system wherein reflections from the elements do not occur regardless of whether the elements are matched to their feed line.

Other and further objects and features of the present invention will become apparent upon consideration of the accompanying description and drawings, wherein:

FIG. 1 shows an antenna system embodying the teachings of the present invention.

FIG. 2 shows details of the internal structure of the antenna system of FIG. 1.

In accordance with the present invention, an antenna system is provided employing a plurality of radiator elements wherein beam positioning is obtained by varying the relative phasing of excitation of the elements, the elements being coupled in sequence (series) to a single lead-in circuit. In-phase excitation of the elements is made possible in this antenna, a condition not practical in the prior art, by placing the elements in branches of directive couplers each of which has the property of providing overall matched transmission therethrough without reflection independent of actual element impedance. Phase variation of element excitation is provided by combining into the system phase shifters each of which has the property of providing overall matched transmission therethrough regardless of the amount of phase shift.

With reference now to FIG. 1 of the drawing, the apparatus shown therein indicates in general a radio frequency system including an antenna structure having a base member **10** carrying supports **11** and **12** and braces **13** and **14**. Mounted upon this framework is a waveguide structure having a connector **15** for connection to a radio frequency operative device **16**. Typically the radio frequency operative device **16** can be either a transmitter or a receiver, or both, provided that it include appropriate transmit-receive switching to provide alternation between the transmit and receive phases. To facilitate the description of the antenna however the following description will be directed primarily to a situation wherein the device **16** is a high frequency transmitter which produces energy to be radiated by the antenna system.

Energy applied to the antenna system at connector **15** travels through a series of parallel waveguides **17** toward load **18**. The waveguides are connected through two banks of couplers indicated generally as to location by the numerals **19** and **20** which are internal to the waveguides being shown in greater schematic detail in FIG. 2. The individual waveguides **17** further are adjustably short circuit terminated at the ends **21** and **22** and include a series of slots **23** in the side walls by means of which energy leaves the waveguides and is radiated. The beam is sharpened in the plane passing through the slots by virtue of the multiplicity of the slots and is restricted in the other plane by the members **24** and **25**. Energy not radiated by the slots **23** continues through the waveguides where it is absorbed in load **18**, load **18** being constructed in a suitable manner so as to provide a matched impedance termination for the waveguides so that reflection of energy back to source **16** does not occur.

With reference now to FIG. 2 of the drawing, the apparatus shown therein indicates the internal structure of the waveguide slot antenna of FIG. 1, similar reference numerals indicating similar parts. For simplicity, sub-

stantially fewer waveguides and slots are indicated in the apparatus of FIG. 2, it being understood however that a larger number of waveguides could be placed side by side in the same manner. Thus the device of FIG. 2 has waveguides **17**–*a*, **17**–*b*, **17**–*c*, **17**–*d*, **17**–*e*, **17**–*f*, **17**–*g*, and **17**–*h* which are all supplied by energy from input **15** and which are connected to an energy absorptive terminating device or load **18** as indicated. The combination of waveguides acts as a matched transmission line terminated by load **18**, however in regions near the ends of each of the waveguides, from each one of the couplers **19** and **20** to the respective near end, standing waves do exist and are utilized to control the amount and phasing of radiation from each slot, by adjustment of the position of the short circuit members at the ends **22** and **21**, respectively, to produce variation of the direction of major response of the antenna.

The couplers **19** and **20** as shown may be given for convenience the generic name "duplex coupler" and refer to devices well known in the art of radio frequency transmission lines. A typical duplex coupler is shown in FIG. 2 as that known in the art as a 3-db coupler, however other equivalents, namely, a four port junction having the property that if two ports are terminated in suitably placed shorts, all the energy entering a third port is transmitted to the fourth port, may be used. The so-called "magic-T" could also be used to advantage as a duplex coupler.

In operation of such a coupler, typically coupler **20** between waveguides **17**–*a* and **17**–*b*, energy traveling upward in waveguide **17**–*a* from input **15** splits into two equal parts at the coupler **20** with half the energy transferring and proceeding upward in waveguide **17**–*b*. One important distinction in the two portions of energy exists, however, and that is that the two are at 90-degree phase relationship to each other. Above the coupler **20**, the waveguides **17**–*a* and **17**–*b* are not operated in a matched impedance condition but are terminated in adjustable short circuit plungers at the ends **22** which can be varied to control the radiation or "loss" from slots **23**–*a* and **23**–*b*. It is important however that the waveguides **17**–*a* and **17**–*b* be identical in this regard so that the portions of energy reflected by the short circuit termination and traveling downward in the two waveguides are equal. When these reflected energy portions reach coupler **20**, equal amplitude splitting and 90 degree phase change again occur. Thus the portion of downward traveling energy of waveguide **17**–*a* becomes additive in waveguide **17**–*b* with the downward traveling energy of waveguide **17**–*b* which did not transfer to waveguide **17**–*a* and the downward traveling energy of waveguide **17**–*b* which does transfer to waveguide **17**–*a* is at 180 degree phase relationship to the downward traveling energy in waveguide **17**–*a*, and being equal, cancel each other. Thus there is no return of energy toward input **15** beyond the coupler **20** so that the coupler **20**, the slots **23**, and the short circuit termination all appear to be a matched impedance to the waveguide **17**–*a*. This condition further prevails regardless of the actual impedance presented by the radiating elements, the slots **23**.

Waveguide **17**–*b*, as thus fed by coupler **20** operates in matched impedance with the energy therein traveling downward to coupler **19**. Coupler **19** operates similar to the previously described coupler **20**, being used to feed two short sections of waveguide which are terminated in adjustable shorting members, which introduces an adjustable phase shift in the transmission of energy to waveguide **17**–*c*. This phase shift arrangement does not provide reflections upward in waveguide **17**–*b* beyond the coupler **19**, regardless of the amount of phase shift introduced as long as the waveguides **17**–*b* and **17**–*c* between the coupler **19** and ends **21** thereof are identical, but it does provide control over the phase of the energy delivered to waveguide **17**–*c* from coupler **19**.

The balance of the apparatus of FIG. 2 is constructed in a continuation of the foregoing principles, with the output from the last waveguide **17**–*h* going to a matched impedance load **18** where it is absorbed without reflection. The result is a device wherein reflections from the various components do not return to feed **15** so that broadside operation is not accompanied by the additive reflections producing large mis-match so that scanning through the broadside condition by operation of the phase shifters at ends **21** is possible and practical.

It is thus seen that the antenna system contains a plurality of slots **23** which may be considered as primary radiating elements which are fed by a single waveguide, each deriving its energy at a point along said waveguide and effectively therefore being fed in series rather than a parallel feed arrangement whereby a plurality of elements are fed from a plurally branched circuit. The in-phase reflections which were described as normally being produced in the broadside condition of prior art antennas are not produced by this antenna because of the fact that the couplers prevent the return of energy back toward the feed **15** from the slots **23**, the slots **23** withdrawing only a certain amount of energy and the balance passing on down the system to succeeding slots **23** or the load **18**.

From the foregoing it is apparent that an antenna feed system having desired characteristic is provided. Obviously many modifications and variations of the present invention is possible in the light of the above teachings. It is therefore understood that within the scope of the appended claims that the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers each having four ports; means for short circuit terminating first and second ones of said ports of each duplex coupler; means individually connecting an antenna element between each of said first and second ports and the terminations thereof; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

2. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers each having four ports; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the frequency operative device.

3. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers each having four ports; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; said first and second ports, transmission line, antenna elements and means connecting being in matched pairs for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the

series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

4. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers each having four ports; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means for varying the electrical length of each transmission line between the short circuit termination and the point of connection of an antenna element thereto; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio operative device.

5. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers each having four ports; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means for varying the electrical length of each transmission line between the short circuit termination and the point of connection of an antenna element thereto; said first and second ports, transmission lines, antenna elements, means connecting, and means for varying the electrical length of each transmission line being in matched pairs for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

6. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means for varying the electrical length of each transmission line between the short circuit termination and the point of connection of an antenna element thereto; said first and second ports, transmission lines, antenna elements, means connecting, and means for varying the electrical length of each transmission line being in matched pairs for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

7. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; means individually connecting an antenna element between each of said first and second ports and the terminations thereof; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

8. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship, means for short circuit terminating first and second ones of said ports of each duplex coupler; means individually connecting an antenna element between each of said first and second ports and the terminations thereof; adjustable phase control means for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series through said adjustable phase control means; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

9. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means for varying the electrical length of each transmission line between the short circuit termination and the point of connection of an antenna element thereto; said first and second ports, transmission lines, antenna elements, means connecting, and means for varying the electrical length of each transmission line being in matched pairs for each coupler; adjustable phase control means for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series through said adjustable phase control means; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

10. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that then the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; means individually connecting an antenna element between each of said first and second ports and the terminations thereof; adjustable phase control means for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the

succedent coupler of the series through said adjustable phase control means; means ganging the adjustable phase shift control means for the couplers whereby substantially equal phase shifts are produced simultaneously in the coupling between adjacently connected couplers; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

11. An antenna system for a radio frequency energy operative device comprising; a plurality of antenna elements; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; an individual section of transmission line connecting each said first and second ports to the corresponding short circuit termination thereof; means individually connecting an antenna element to each section of transmission line; means for varying the electrical length of each transmission line between the short circuit termination and the point of connection of an antenna element thereto; said first and second ports, transmission lines, antenna elements, means connecting, and means for varying the electrical length of each transmission line being in matched pairs for each coupler; adjustable phase control means for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series through said adjustable phase control means; means ganging the adjustable phase shift control means for the couplers whereby substantially equal phase shifts are produced simultaneously in the coupling between adjacently connected couplers; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

12. An antenna system for a radio frequency energy operative device comprising; a plurality of duplex couplers having four ports interconnected such that when the third port is terminated in a matched impedance; energy applied to the fourth port is delivered to the first and second ports in equal amplitude and 90-degree phase relationship; means for short circuit terminating first and second ones of said ports of each duplex coupler; a plurality of sections of transmission line, each having a portion that provides substantially more electromagnetic coupling to surrounding space than other portions thereof, said sections of transmission line individually connecting each said first and second ports to the corresponding short circuit termination thereof; means for varying the electrical length of each section of transmission line between the short circuit termination and the adjacent coupler port; said first and second ports, corresponding sections of transmission line, and corresponding means for varying the electrical length of each transmission line section being in matched pairs for each coupler; adjustable phase control means for each coupler; means connecting said couplers in series wherein the third port of a preceding coupler of the series is connected to the fourth port of the succedent coupler of the series through said adjustable phase control means; means ganging the adjustable phase shift control means for the couplers whereby substantially equal phase shifts are produced simultaneously in the coupling between adjacently connected couplers; means providing a matched impedance termination connected to the third port of the last coupler of the series; and means connecting the fourth port of the first coupler of the series to the radio frequency operative device.

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