

June 7, 1966

J. L. BUTLER
MULTIPLE BEAM ANTENNA SYSTEM EMPLOYING MULTIPLE
DIRECTIONAL COUPLERS IN THE LEADING

3,255,450

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4 Sheets-Sheet 1

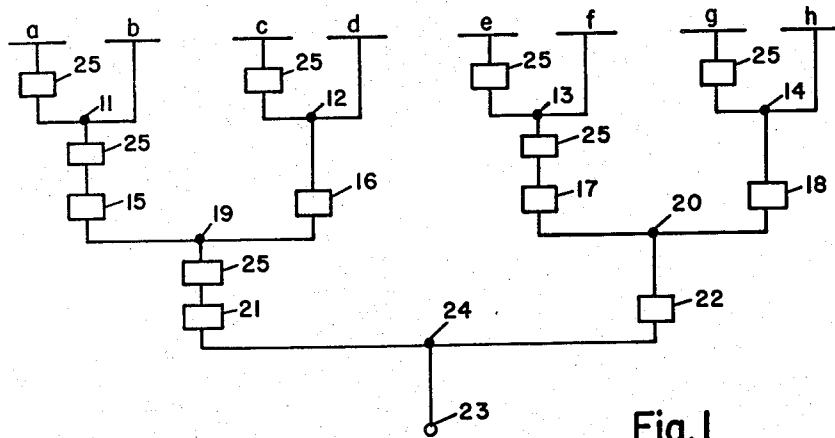


Fig. 1

PRIOR ART

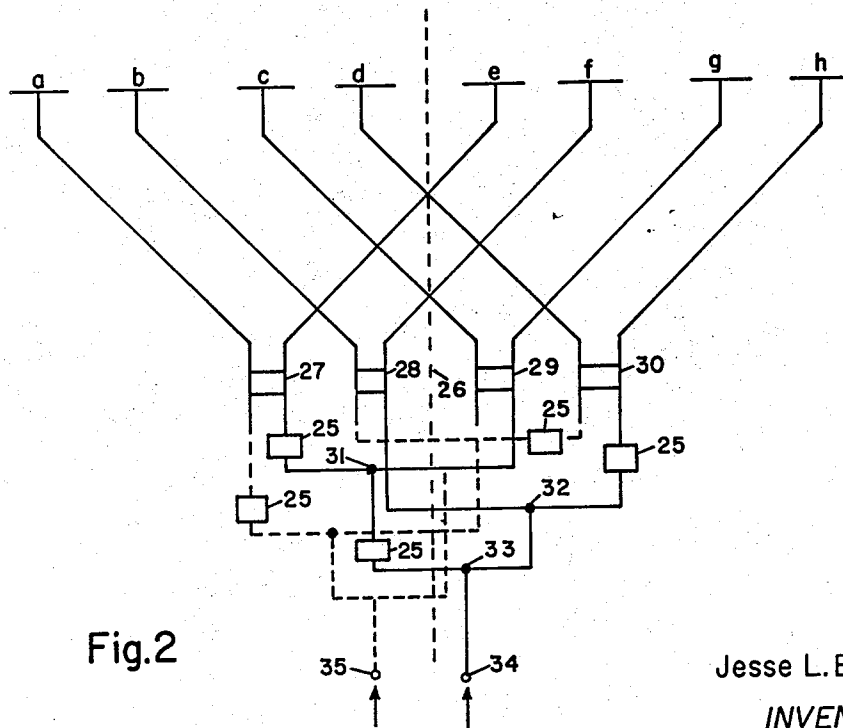


Fig. 2

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4 Sheets-Sheet 2

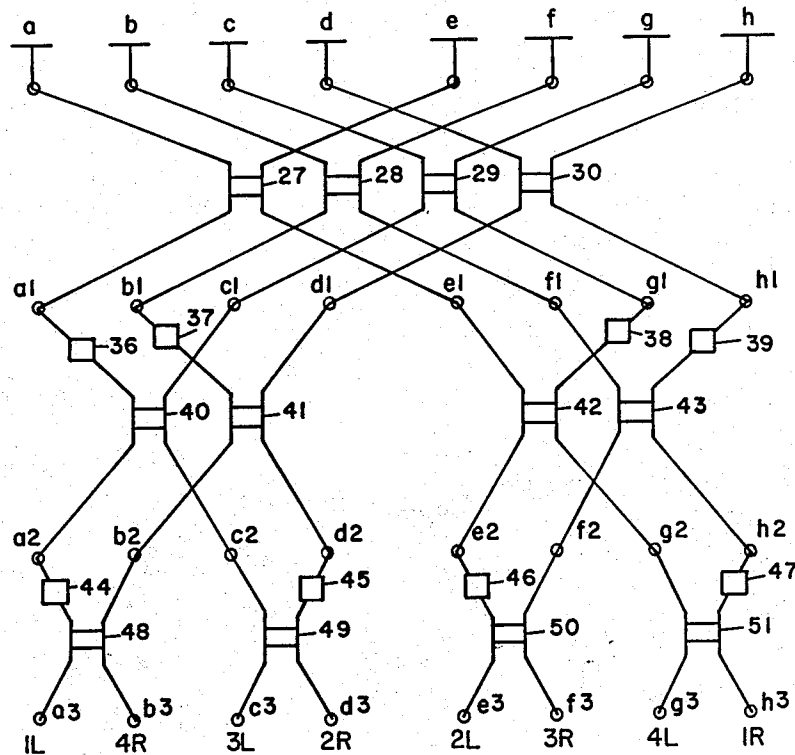


Fig.3

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4 Sheets-Sheet 3

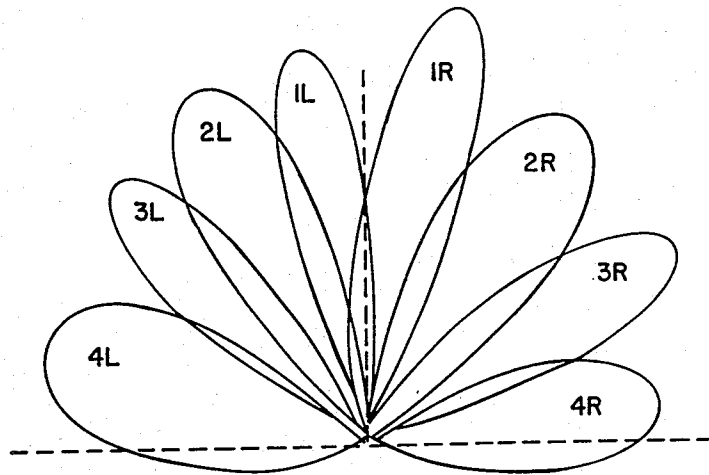


Fig. 4

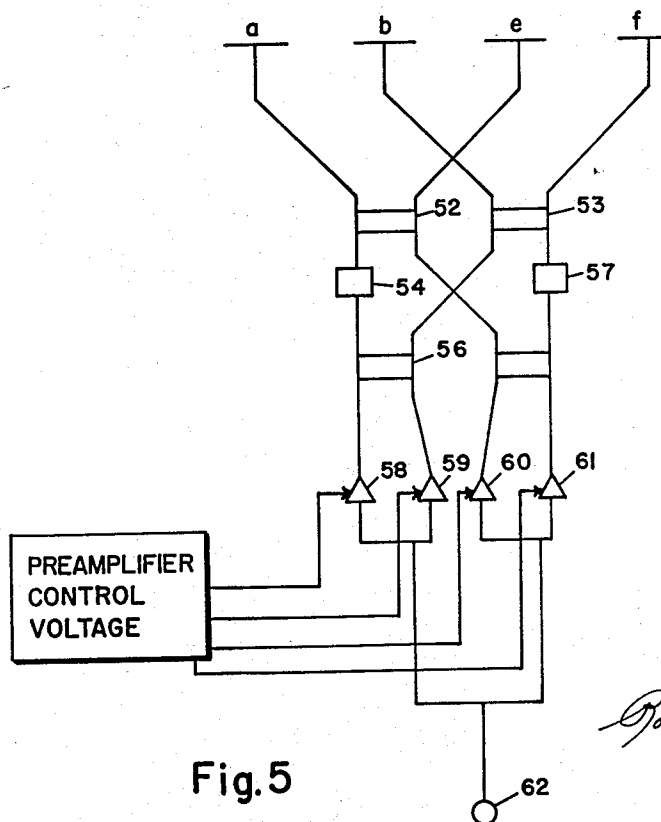


Fig. 5

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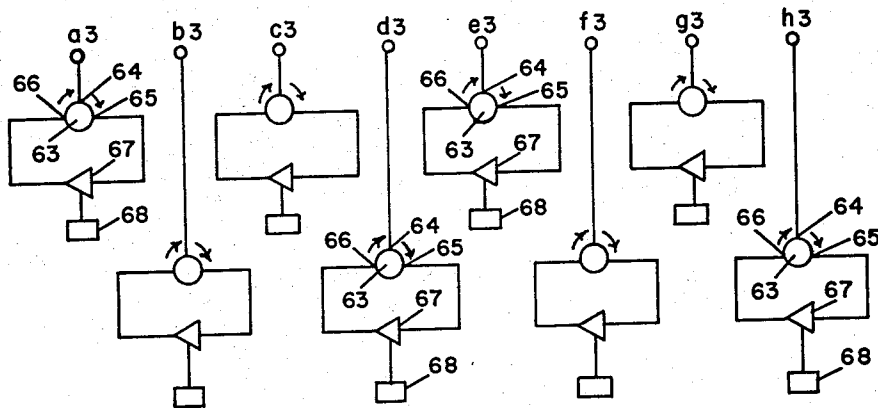


Fig. 6

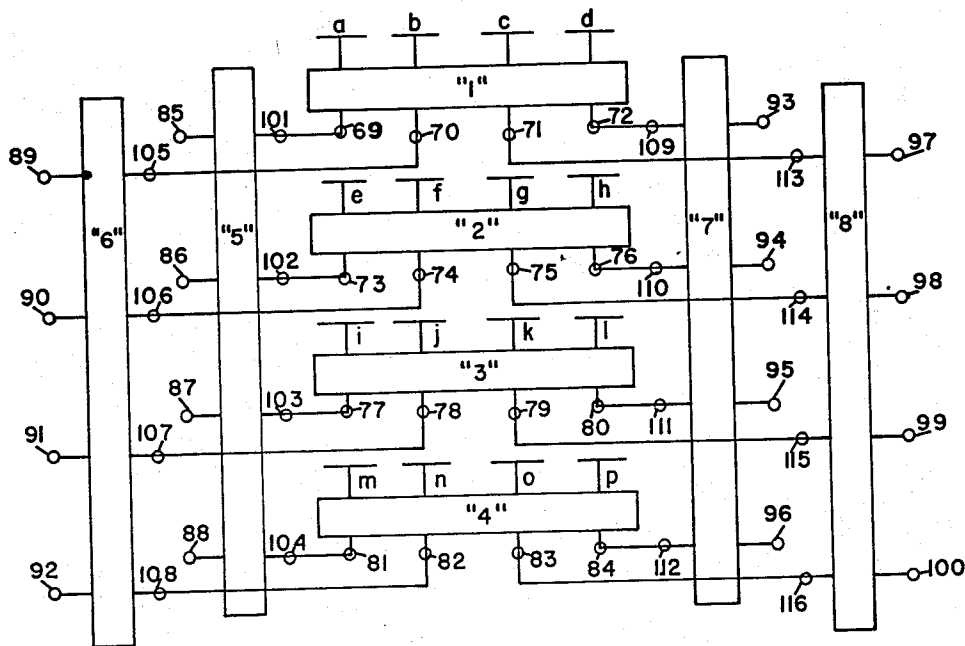


Fig. 7

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MULTIPLE BEAM ANTENNA SYSTEM EMPLOYING MULTIPLE DIRECTIONAL COUPLERS IN THE LEADIN

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7 Claims. (Cl. 343-100)

This invention relates to multiple beam antenna systems and more particularly to circuits and components comprising such systems for directional beam steering through selective phasing of signals from a plurality of antennas.

Directional beam steering through predetermined phasing of signals from a plurality of antennas is well known in the art. For example, an article entitled "Certain Factors Affecting the Gain of Directive Antennas" by G. C. Southworth was published in the Proceedings of the Institute of Radio Engineers, volume 18, Number 9, September 1930, on pages 1502 to 1536, wherein phasing of signals was discussed. In signal phasing, the energy from a single transmitter source was channelled into two or more antennas coupled by means of three port power dividers. These dividers have the characteristic that the in-phase components of signals fed to two ports will sum up and pass out the third port, whereas the out-of-phase components of the signals will continue beyond the junction and not be useful. This, of course, results in a loss of useful power in the power divider. In the same manner in receivers, a maximum range can be achieved in a predetermined fixed direction through phase shifting techniques, whereas if the system is adapted to receive from more than the one beamed direction, this maximum range becomes foreshortened due to the attenuation in the three port power dividers. It has been found that with a new circuit arrangement for connecting the antennas, a four port power divider can be used. In the four port divider the sum of the power into the two input ports substantially equals the sum of the power out of the other two ports regardless of the phase relationships of the signals. With additional connections to the fourth port another directional beam can be generated, utilizing the phase shifting and isolation characteristics of the divider. Moreover, with the four port power divider the impedance matching transformers may be eliminated. Thus, the multiple beam antenna system comprising this invention is more efficient, has additional directivity patterns, and requires fewer components than those heretofore used.

It is therefore an object of the present invention to provide for a four port power divider for use with a plurality of antennas for directional beam steering through phasing of feeder signals.

It is another object to provide for an improved connecting circuit in a multiple beam antenna system.

It is another object to provide for an improved multiple beam antenna system wherein four port power dividers are used in connecting circuits between a plurality of antennas and a plurality of associated receivers or transmitters.

Another object is the provision of a multiple beam antenna system wherein a plurality of beams may be fed at a time to the antennas or at the same time without substantial loss in beam range.

Another object is the provision of an improved switching means for signal beam steering by selectively ener-

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gizing the inputs of four port power divider circuits which interconnect a plurality of antennas.

Other objects will hereinafter become obvious as a description of the invention made wherein,

FIGURE 1 shows a typical prior art multiple beam antenna system for directional steering through signal phasing,

FIGURE 2 shows the multiple beam antenna system using the new components and order of connections featured in the present invention,

FIGURE 3 shows a specific system for providing eight directional beams from eight antennas, and

FIGURE 4 shows the relative orientation of the eight beam patterns for the circuit of FIGURE 3,

FIGURE 5 shows an arrangement of a four element array whereby transmitter beams may be switched in and out by preamplifier control voltages,

FIGURE 6 shows a transponder system whereby a reply may be made only in the direction from which wave energy is received, and

FIGURE 7 shows a system for both vertical and horizontal signal beaming.

Referring now to FIGURE 1, there is shown a typical eight antenna system wherein the eight antennas, *a* to *h*, are shown in a linear array wherein each antenna is considered as a spherical source of waves radiating equal power in all directions. Adjacent antennas are coupled through three port power dividers, 11 to 14, to impedance matching transformers, 15 to 18. Adjacent pairs of these transformers are coupled through three port power dividers, 19, 20, which in turn are coupled through transformers 21, 22 which in turn are connected to an energy source or receiver 23 through another three port power divider 24. Through suitable wavelength spacing of the antennas from each other and phasing of the signal paths, the directional patterns can be varied as desired. The phase shifters 25 may preferably be an extra length of transmission line to cause signals therethrough to lag those signals going through the parallel paths.

In FIGURE 2, instead of connecting adjacent antennas into pairs and connecting adjacent pairs until all antennas are connected to the same source as in FIGURE 1, the array is divided into right and left sections, separated by a dashed line 26 for reference purposes. Corresponding antennas in each section are coupled, for example, *a* and *e*, *b* and *f*, *c* and *g*, and *d* and *h*, through four port power dividers 27, 28, 29, and 30. In other words, if there are *x* numbered antennas, those *x*/2 apart are connected through these dividers. Corresponding power dividers in each section are in turn coupled, as at 31 and 32, and recoupled at 33 to energy source 34. Suitable phase shifters 25 are used as needed.

The four port power divider may be a wave guide top wall or sidewall coupler, a branch line coupler in wave guide, coax, or stripline, a stripline parallel-line coupler, or any of a number of coupler types which have the property of providing two outputs differing in phase by 90 degrees, and conversely of coupling all the power to one of two isolated ports when power is applied equally to two other ports with a 90 degree phase differential. This power divider may also be a branched directional double stub coupler as discussed in the October 1956, issue of the IRE Transactions on Microwave Theory and Techniques, volume MII-4, Number 4, pages 246 to 252, in an article by Reed and Wheeler entitled "A Method of Analysis of Symmetrical Four-Port Networks." These dividers differ from the three port dividers in that regardless of

the phase relationship of the signals fed into the inputs, the power leaving the outputs is substantially equal to the power into the inputs. Thus, it is possible to use the fourth ports of the dividers in FIGURE 2 for making similar connections to another signal source 35 as shown by the dotted lines. In this manner the number of directional beams for the system may be doubled. As used herein, the term "power divider" is used in its ordinary sense, that is, to denote a device in which energy applied to an input port is divided between two other ports.

The basic building block component in FIGURE 2 of a four port power divider and a fixed phase shifter can be adapted readily to any array of two to the n th power elements where n is an integer, indicating the number of stages to be used. Thus, in FIGURE 3 where eight antennas are to be used and eight directional beams are desired this integer would be three, since $2^3=8$. Here is shown schematically the feed structure for an eight element array with eight independent feed terminals and designed to produce eight patterns which will overlap at the three db points. If halfwave lengths spacing is used between the elements the patterns will cover a 180-degree sector as shown in FIGURE 4. In the first stage the output terminal ports of the power dividers are connected to those antennas $n/2$ apart, where n is the number of antennas to be used.

In FIGURE 3 the antennas a to h are connected to dividers 27 to 30 with each divider connected to corresponding antennas in the left and right sections in the same manner as in FIGURE 2. Following the basic formula of connecting those elements together which are $n/2$ apart, where n is the number of elements, this constitutes the first stage with the input terminals of the dividers connected in the same manner to terminal points of the first stage $a1$ through $h1$. A second stage of power dividers 40, 41, 42, and 43 likewise connect to these terminal points since there were four divider elements in the first stage with their input terminals connected at $a1$ through $h1$. The power dividers of the second stage, 40 to 43, are connected to these terminals in the same pattern of connecting those elements which are $n/2$ apart. Therefore, divider 40 will be connected to dividers 27 and 29 at points $a1$, $c1$, divider 41 will be connected to dividers 28 and 30 through terminals $b1$, $d1$, all being connected to the left input ports. Similarly, dividers 42 and 43 will be connected to the right hand input ports of dividers 27 to 30. Divider 42 is thus connected to divider 27 at terminal $e1$ and to divider 29 at terminal $g1$. Also, divider 43 is connected to divider 28 at terminal $f1$ and to divider 30 at terminal $h1$. Phase shifters 36, 37, 38, and 39 are connected to the outer output ports of dividers 40-43 as shown. Terminals $a2$ to $h2$ form the input connections for the power dividers of the second stage. The third stage power dividers 48, 49, 50, and 51 are connected to these terminals in a similar manner. However, in connecting the third stage dividers the dividers in the second stage must be considered as separate left and right sections, with dividers 40 and 41 being the left sections, since they connect to the left ports of the first stage dividers, and dividers 42 and 43 being considered the right section with their ports connected to the right ports of the dividers of the first section. Thus, with 40 and 41 considered as one section and following the formula for connecting those elements $n/2$ apart, divider 48 is connected to both left ports and divider 49 is connected to both right ports of dividers 40 and 41. In the same manner and considering dividers 42 and 43 to comprise one section, divider 50 is connected to the left ports and divider 51 is connected to the right ports of dividers 42 and 43. Connections $a3$ and $h3$ form the input connections for energy sources to produce the various beam patterns identified therewith and as shown in FIGURE 3.

In FIGURE 4 there is shown an array for eight directional beams. If all energy sources were used at once

all eight directional beam patterns would result, as well as each beam resulting from the energization of the particular energy source.

In FIGURE 5 for purposes of simplification four antennas a , b , e and f are shown to illustrate the use of a single energy source used to provide four directional beams through the use of separate preamplifier control voltages. Here preamplifiers 58 to 61 are each connected to the input ports of dividers 56 and 57, as shown. These amplifiers are all coupled to oscillator 62. Each preamplifier has a control voltage which may be used as a switching means to provide for an output in the desired preamplifier. In this manner the desired beam pattern may be achieved, using a single source and controlling the preamplifier outputs with a control voltage.

FIGURE 6 shows an arrangement of circuitry which may be connected to the terminals $a3$ to $h3$ in FIGURE 3. Here a circuit is connected to each terminal. This consists of a three port circulator 63 having one port 64 connected to the terminal and the other two, 65, 66 to an amplifier 67. This circulator has the characteristic that energy into one port will leave another port to the exclusion of a third. Circulators of this type are discussed in an article "The Elements of Nonreciprocal Microwave Devices" by C. Lester Hogan in volume 44, October 1956, issue of Proceedings of the IRE, pages 1345 to 1368. As shown by the direction of the arrows, energy from port 64 passes out port 65 to amplifier 67. This amplifier may be connected in such manner that the incoming signal may raise the amplifier signal level sufficiently to pass a new signal from signal source 68. This new signal from the amplifier output will enter port 66 and out port 64. This then becomes the signal source to terminal $a3$ to $h3$ in FIGURE 3. In this manner any incoming signal received by the antennas in FIGURE 3 will generate a return signal beamed in the same direction from which the original signal was received.

In FIGURE 7 there is shown an arrangement for phasing signals in a vertical as well as horizontal plane. Here four rows of four antennas each are used for purposes of illustration. For simplification, the complete phasing system for a four antenna array is shown in block form. Thus, the system in FIGURE 3, as applied to four antennas, a to d , is shown in FIGURE 7 as "1," with input terminals 69, 70, 71 and 72 for connection to similar systems. Four such systems "1" to "4" are shown in the center with systems "6" to "8" conveniently positioned vertically at the sides and without antennas. Instead of additional antennas, connecting terminals 101 to 116 are used. Terminals 101 to 104 of system "5" are connected to the input terminals 69, 73, 77 and 81 on the left of systems "1" to "4." Similarly, terminals 105 to 108 of system "6" are connected to the next terminals 70, 74, 78 and 82 of systems "1" to "4." The system "7" terminals 109 to 112 are connected to the right column of terminals 72, 76, 80 and 84 while system "8" terminals 113 to 116 are connected to terminals 71, 75, 79, 83.

A signal to any one of the input terminals of systems "1" to "4" will produce one of a possible four or sixteen directional beams in a horizontal plane, depending upon whether each system duplicates or varies from the beam projection of the others. However, by shifting the phase of signals fed into all four systems, the horizontal beam will become elevated in an amount indicative of the phase shift. For example, the output from system "5," which depends upon which input 85, 86, 87 or 88 is used, will establish a phase relationship of signals to terminals 69, 73, 77 and 81 of systems "1" to "4" thereby causing a predetermined elevation as well as a horizontal direction to the output beam. The other systems "6," "7" and "8" likewise contribute a vertical signal phasing to produce an elevated signal, although the horizontal direction will differ since they feed different terminals of systems "1" to "4."

If systems "1" to "4" each produce identical beam patterns and systems "5" to "8" also produce identical beam patterns, then the total system of FIGURE 7 will produce sixteen beams in four horizontal and four vertical patterns.

However, if each of the horizontal and vertical systems do not correspond with each other but are spaced in their beam projection, then the total system of FIGURE 7 will project a beam pattern sixteen beams horizontally and sixteen beams vertically.

It is to be understood that within the purview of this invention any number of antennas and associated dividers and phase shifters may be used. Although the antennas shown are in linear array, they may also be placed in other configurations as desired, provided suitable phase compensation is made.

The amount of phase shifting of the signals depends upon the desired direction of the beam to be received or transmitted. This system is equally adaptable to reception as well as transmission of signals. Other variations and modifications are likewise to be construed as part of the invention, which is not limited to the embodiments which were above described for purposes of illustration only.

What is claimed is:

1. A transmission system comprising, in combination, first, second, third and fourth transmission line couplers, each of said couplers having first, second, third and fourth ports and being adapted to couple a signal from either of said first and second ports to said third and fourth ports with a fixed phase difference between the signals at said third and fourth ports and with equal amplitude at said third and fourth ports, first transmission means connected between said fourth port of said first coupler and said first port of said fourth coupler, second transmission means connected between said third port of said second coupler and said second port of said third coupler, said first and second transmission means being of equivalent electrical length, third transmission means connected between said third port of said first coupler and said first port of said third coupler, fourth transmission means connected between said fourth port of said second coupler and said second port of said fourth coupler, said third and fourth transmission means being of equivalent electrical length, said first and third transmission means being of such different electrical lengths as to couple an input signal fed into one of said first and second ports of said first and second couplers equally to said third and fourth ports of said third and fourth couplers with a uniform phase difference between the signals coupled to said fourth ports of said fourth and third couplers, between the signals coupled to said third ports of said fourth and third couplers, and between the signals coupled to said fourth port of said third coupler and said third port of said fourth coupler.

2. The combination defined in claim 1 in which said fixed phase difference is an odd integral multiple, including unity, of 90 degrees.

3. The combination defined in claim 1 including an antenna connected to each of said third and fourth ports of said third and fourth couplers.

4. The combination defined in claim 3 including a source of radio frequency energy and means coupling said source to one of said first and second ports of said first and second couplers.

5. The combination defined in claim 1 further comprising

- (A) first, second, third and fourth spaced antennas, each of said antennas being connected to a different one of said third and fourth ports of said third and fourth couplers,
- (B) first, second, third and fourth preamplifiers, each of said preamplifiers being connected to a different one of said first and second ports of said first and second couplers,

- (C) a single signal source having an output terminal connected to each of said preamplifiers, and
- (D) means for rendering selected ones of said preamplifiers operative to thereby energize selected ones of said first and second ports of said first and second couplers, thereby beaming selected signal patterns from said antennas.

6. The combination defining claim 1 further comprising

- (A) first, second, third and fourth antennas, each of said antennas being connected with a different one of said third and fourth ports of said third and fourth couplers,
- (B) first, second and third and fourth signal sources,
- (C) first, second, third and fourth transponder means, each transponder means being connected between one signal source and one of said first and second ports of said first and second couplers, said transponder means being actuated by a signal incoming thereto from said couplers and upon being actuated coupling the source connected with it to the port connected with it, so that a signal source is coupled with said antennas to transmit signals in the direction from which a signal is intercepted by said antennas.

7. A multiple beam antenna system for selectively beaming signals in a direction selected along two orthogonal axes said system comprising in combination

- (A) a plurality of antennas arrayed in rows and columns,
- (B) a plurality of intermediate terminals equal in number to the number of antennas and schematically arranged in rows and columns,
- (C) means interconnecting said intermediate terminals in each row thereof to the antennas in a different row thereof in such manner that the beam direction of signals radiated from said antennas is dependent upon which intermediate terminal is energized,
- (D) a plurality of input terminals arranged in groups with the number of groups being equal to the number of columns of intermediate terminals and with the number of input terminals in each group thereof being equal to the number of intermediate terminals in a column thereof,
- (E) means interconnecting the input terminals in each group thereof with the intermediate terminals in a different column thereof,
- (F) each of said interconnecting means comprising at least first, second, third and fourth transmission line couplers, each of said couplers having first, second, third and fourth ports and being adapted to couple a signal from either of said first and second ports to said third and fourth ports with a fixed phase difference between the signals at said third and fourth ports and with equal amplitude at said third and fourth ports, first transmission means connected between said fourth port of said first coupler and said first port of said fourth coupler, second transmission means connected between said third port of said second coupler and said second port of said third coupler, said first and second transmission means being of equivalent electrical length, third transmission means connected between said third port of said first coupler and said first port of said third coupler, fourth transmission means connected between said fourth port of said second coupler and said second port of said fourth coupler, said third and fourth transmission means being of equivalent electrical length, said first and third transmission means being of such different electrical lengths as to couple an input signal fed into one of said first and second ports of said first and second couplers equally to said third and fourth ports of said third and fourth couplers with a uniform phase difference between the signals coupled to said third and fourth

ports of said third and fourth couplers and between said fourth port of said third coupler and said third port of said fourth coupler.

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