

Sept. 27, 1966

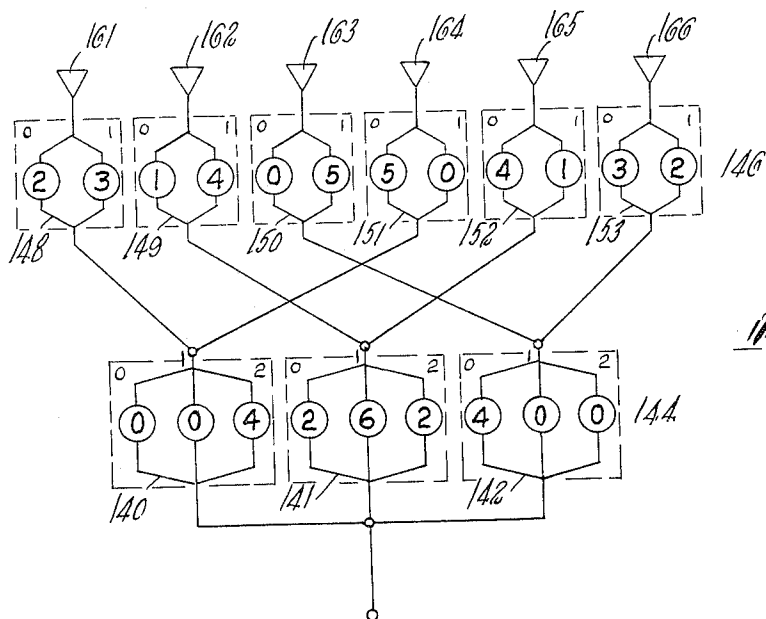
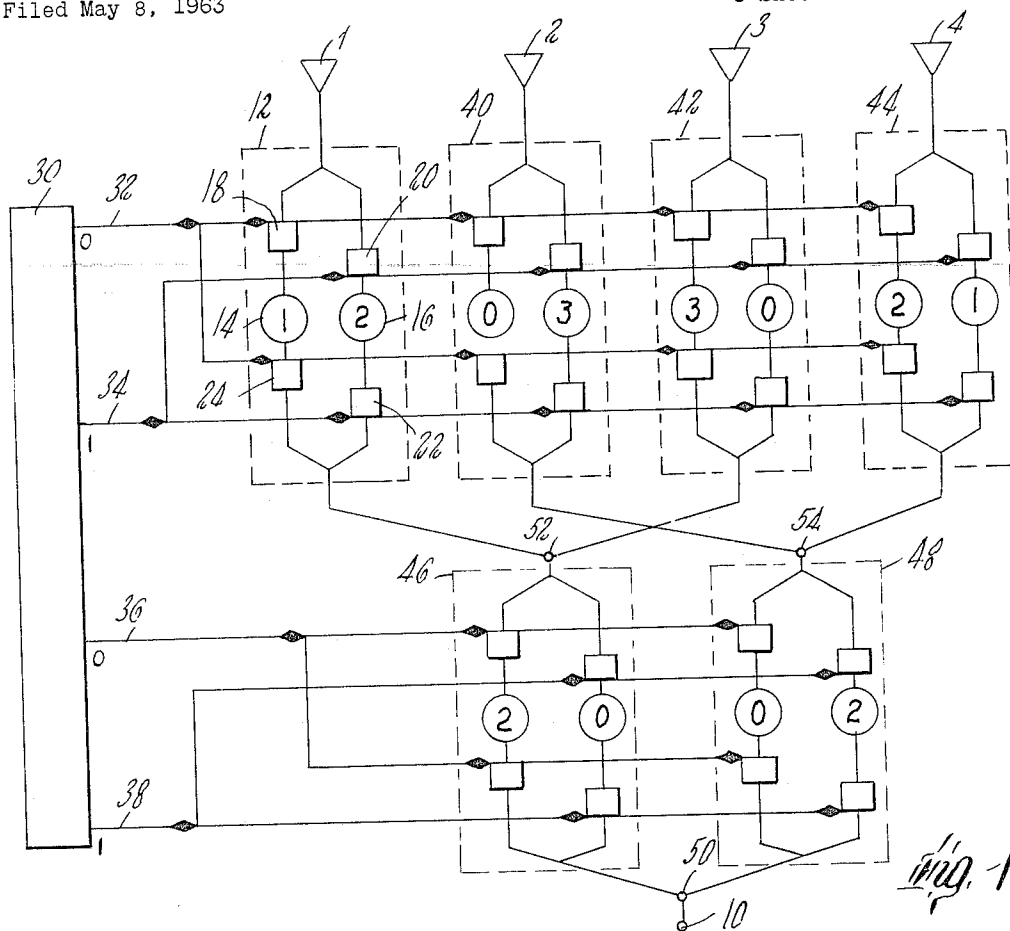
J. L. BUTLER

3,276,018

PHASE CONTROL ARRANGEMENTS FOR A MULTI-PORT SYSTEM

Filed May 8, 1963

5 Sheets-Sheet 1



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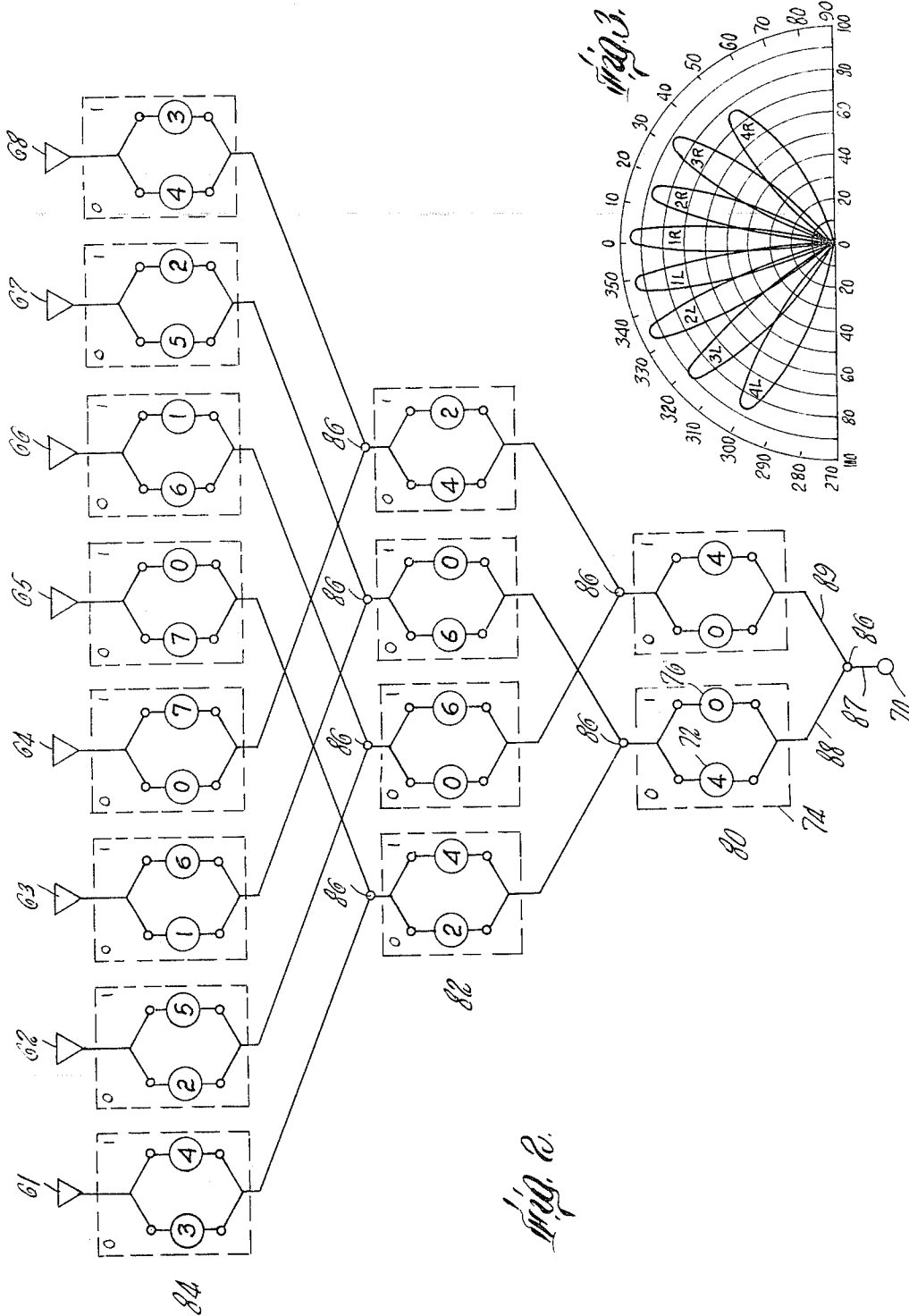
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PHASE CONTROL ARRANGEMENTS FOR A MULTI-PORT SYSTEM

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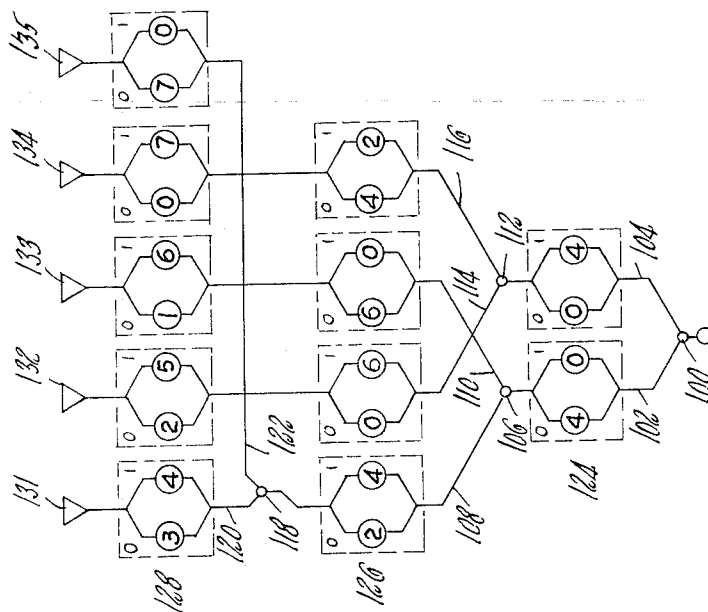


Fig. 5.

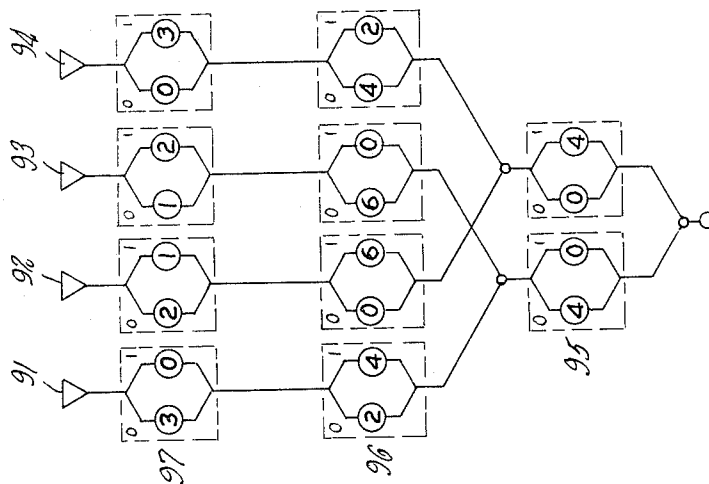


Fig. A.

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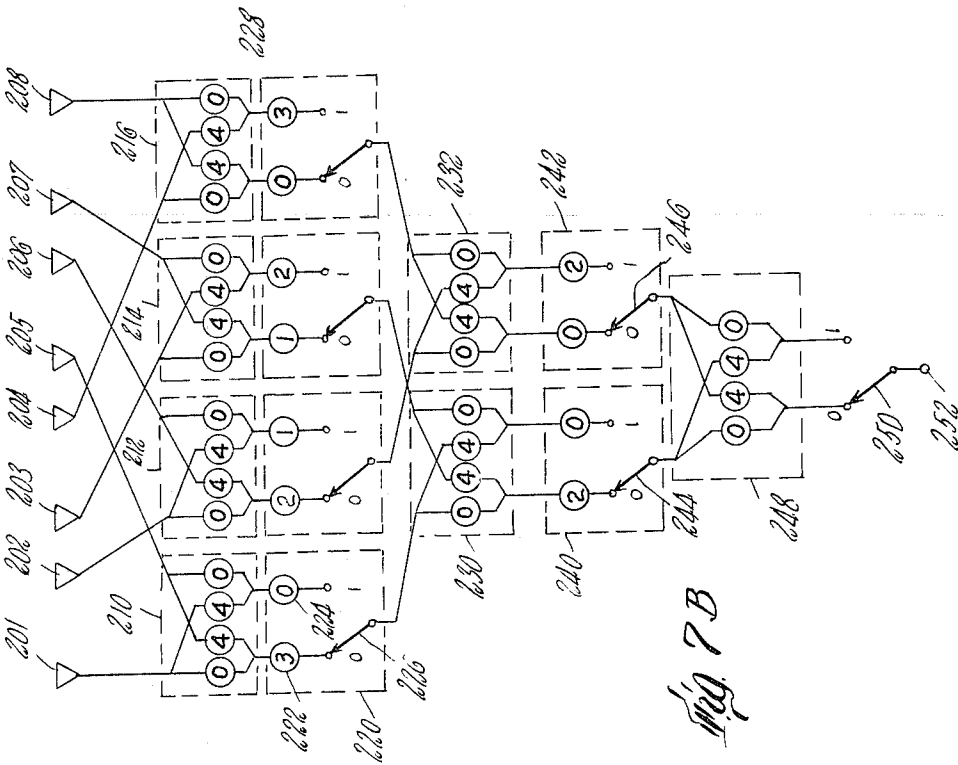


Fig. 7B

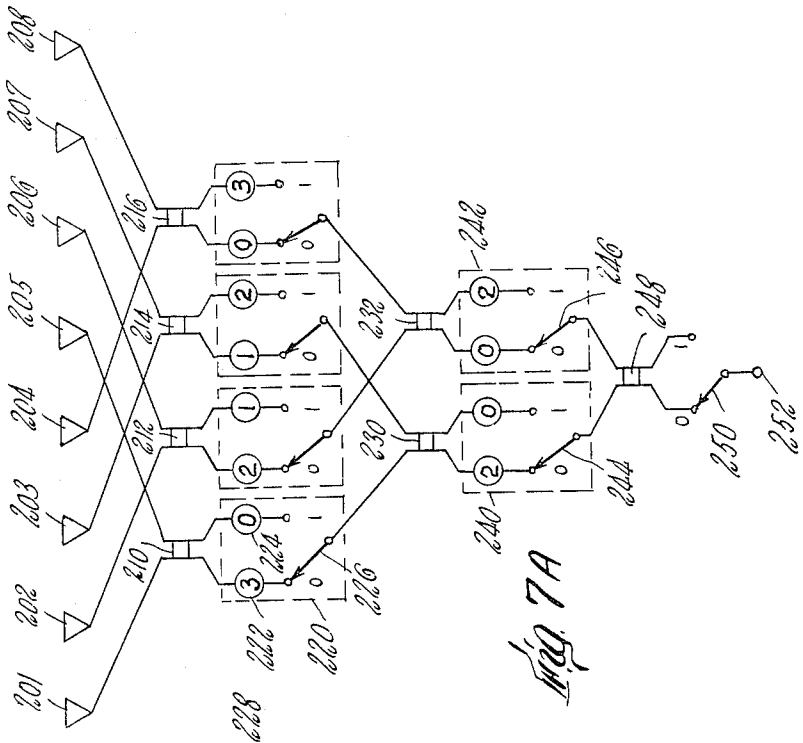


Fig. 7A

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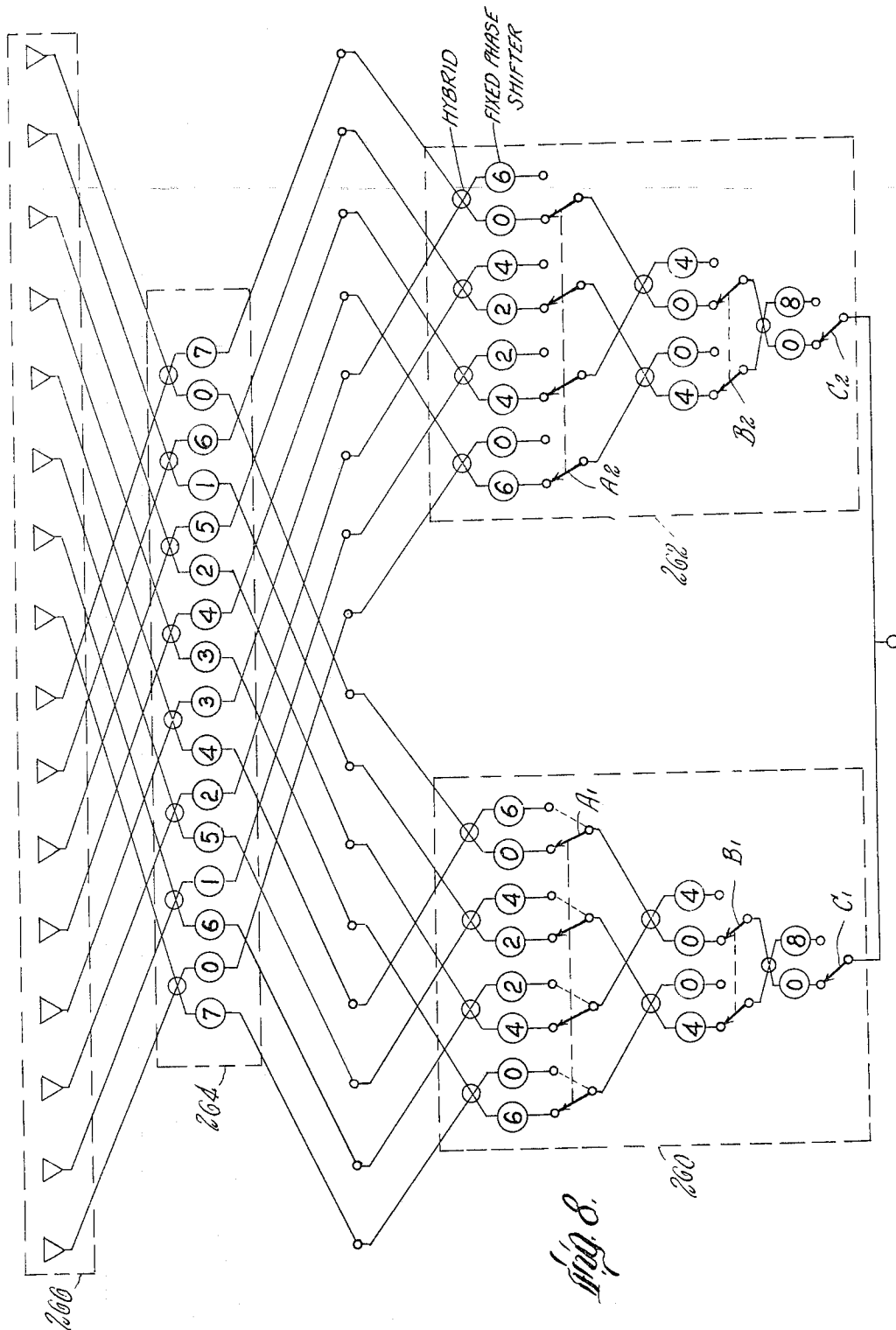
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PHASE CONTROL ARRANGEMENTS FOR A MULTIPOINT SYSTEM

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3,276,018 PHASE CONTROL ARRANGEMENTS FOR A MULTIPOINT SYSTEM

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Filed May 8, 1963, Ser. No. 278,854
17 Claims. (Cl. 343-100)

This invention relates to phase control arrangements and more particularly to phase control arrangements particularly useful in the control of directional properties of antenna arrays of the type used in a radar system, for example.

The directional characteristics of certain antenna arrays are a function of the relative phases of the signals applied to the individual antenna elements of the array wherein a uniform phase gradient is provided across the aperture of the array. Stable but adjustable phase shift components are required for accurately controlling this phase gradient. One method of varying the directional characteristics of such an array would be to employ a group of variable phase shifters which are coordinately controlled. However, variable phase shifters having rapid response (which in general requires no moving parts) and accurately predictable phase control characteristics are very difficult to achieve, particularly the ultra high and microwave frequencies employed in radar systems. Alternative proposals suggest the use of fixed phase shifters and control arrangements to selectively connect the phase shifters in the energized circuit to provide the several different desired phase gradients, each of which produces a beam with different directivity characteristics. As the phase of each signal applied to an array element must be varied as a function of the phase of the signal applied to the adjacent elements in order to change the phase gradient while maintaining a uniform phase difference between adjacent antenna elements, these proposals have required the use of astronomical quantities of control hardware. In particularly sophisticated antenna systems which produce a very narrow beam and consequently employ a great number of radiating elements and have a multitude of beam positions to be covered, such arrangements appear to be economically unfeasible.

Accordingly, it is an object of this invention to provide a novel and improved antenna array beam control system.

Another object of the invention is to provide a novel and improved control system for an antenna system of the phased array type which enables accurate and rapid phase gradient switching to control the directivity characteristics of the antenna system.

Another object of the invention is to provide a new and improved electronic beam forming and steering antenna system.

Still another object of the invention is to provide a novel and improved phase control system that is more economical to manufacture and use than phase control systems of this type that have been heretofore proposed.

A further object of the invention is to provide a novel and improved phase control system that is particularly susceptible to digital control.

This invention provides a digitally controlled phase shifting system which employs a plurality of fixed phase shifters with phase shifter isolating means associated with each phase shifter to control the transfer of energy to or from a plurality of array elements (energy coupling ports). While the invention has particular use in antenna arrays, its use is not limited thereto, and it may be used, for example, in frequency analysis where the array elements are coupling elements spaced along a delay line. The phase shifters are arranged in modules, each module including a plurality of phase shifters corresponding in number to the radix of digital control employed. For example,

where the digital control information is in binary radix each phase module includes two phase shifters. The modules in a level of control corresponding to an order of the digital control word are arranged so that the phase shifter of one module imparts a phase shift ϕ radians different from the corresponding phase shifter in the immediately adjacent module and the other phase shifters in that module impart phase shifts $K\phi$ radians different from the corresponding phase shifters in the immediately adjacent module. A phase shifter of each module is connected in circuit as selected by digital control information and the module matrix distributes the energy so that a uniform phase difference between the array elements is produced. This controlled phase gradient characteristic enables a beam with the desired directivity characteristics to be produced at an antenna array for example.

Numerous array configurations are possible through phase module, power divider combinations. In certain embodiments of the invention combined power divider-phase shifting devices are employed in conjunction with phase module arrangements to produce the digitally controllable phase gradient characteristics of the antenna array. Further, the illumination of the array aperture may be uniform or tapered, as a cosine distribution, as desired. The invention provides precise control of phase gradient characteristics of an antenna array in response to digital control signals, and enables the generation of and rapid switching between a plurality of different beams of accurate directivity characteristics with a substantial reduction in the cost and complexity of the required control components.

Further objects, features and advantages of the invention will be seen as the following description of embodiments thereof progresses, in conjunction with the drawings, in which:

FIG. 1 is a diagrammatic illustration of a phased array antenna beam controlling matrix constructed in accordance with the invention;

FIG. 2 is a diagram of a larger phase control matrix of the same type as shown in FIG. 1;

FIG. 3 is a diagrammatic illustration of the several beam positions that may be generated with the antenna array as controlled by the matrix shown in FIG. 2;

FIGS. 4 and 5 are diagrams of phase control matrices which feed four and five antenna elements respectively;

FIG. 6 is a diagram of a modified phase control matrix constructed in accordance with the invention which employs two legged and three legged phase modules;

FIGS. 7A and B are diagrams of still another embodiment of a phase control matrix constructed in accordance with the invention which employ phase module arrangements that include hybrid couplers; and

FIG. 8 is a diagram of a phased antenna array control matrix which provides a cosine distribution array aperture illumination.

The antenna array shown in FIG. 1 has four antenna elements 1-4 which are energized from a source 10 through a phase control matrix so that radiated beams of four different directional characteristics may be produced. The matrix comprises six similar phase control modules 12, each of which includes two fixed phase shifters 14, 16 and four control switches 18, 20, 22, 24. When control switches 18 and 24 are energized, phase shifter 14 is connected in the circuit and when switches 20 and 22 are energized, phase shifter 16 is connected in circuit.

The energization of the control switches is in response to digital control information from source 30, which has four output lines 32, 34, 36, 38. Lines 32 and 34 represent the "zero" and "one" values of the lowest order of digital control information and lines 36 and 38 represent the "zero" and "one" levels of the next more

significant order of digital control information. For example, when line 32 is energized, indicating the value of the lowest order of digital control information is "zero," control switches 18 and 24 are conditioned to connected phase shifter 14 in the circuit to antenna element 1. At the same time the left branches of the other three modules 40, 42, 44 in the upper level are also conditioned to connect the phase shifter in the left branch of each module to the antenna elements 2, 3 and 4 respectively. Should line 34 be energized, control switches 20 and 22 would be conditioned and connect phase shifter 16 in circuit with antenna element 1 and correspondingly the phase shifters in the right branches of the modules 40, 42, 44 in the upper level would be connected to the antenna elements. Only one line 32 or 34 is energized at any one time so that unambiguous control is provided.

A similar control over the two phase shifters 46, 48 of the second level are provided by signals on lines 36 and 38. A signal on line 36 conditions the switches to connect the phase shifters in the left branches of the phase modules 46, 48 in circuit, and a signal on line 38 conditions corresponding switches to connect the phase shifters in the right branch of the phase modules in circuit.

The source 10 is connected to the inputs of phase modules 46 and 48 through a power divider 50. The output of phase module 46 is connected to the inputs of phase modules 12 and 42 through a power divider 52 and the output of phase module 48 is connected to the inputs of phase modules 40 and 44 through a power divider 54. These power dividers 50, 52 and 54 split the power applied on the input equally to the two output branches. Thus power from a source connected at terminal 10 is divided for application to the antenna elements 1, 2, 3 and 4 equally.

The phase shift imparted to the power transmitted from terminal 10 to the antenna elements is indicated in the following table:

TABLE I

Digital Control	Antenna Elements				Phase Differential ($\Delta\phi$)
	1	2	3	4	
00.....	3	0	5	2	-3
01.....	4	3	2	1	-1
10.....	1	2	3	4	+1
11.....	2	5	0	3	+3

It will be noted that there is uniform phase gradient ($\Delta\phi$) imparted across the four antenna elements imparted by the phase control matrix. For the digital control value 00, a phase gradient of -3 units is imparted (each unit being in terms of $\pi/4$ radians). For the digital control signal 01 a phase gradient of -1 unit is imparted; for the digital control signal 10, a phase gradient of +1 unit is imparted; and for the signal 11 a phase gradient of +3 units is imparted.

An extension or enlarged antenna array of similar configuration is shown in FIG. 2. This array has eight antennas 61-68 which may be energized from a source 70 through a three level phase control matrix to produce beam of directional characteristics of the type indicated in FIG. 3. The phase control matrix employs a plurality of phase control modules of the same type as those employed in the arrangement of FIG. 1. Each includes two phase shifters and four control switches which are adapted to isolate one or the other phase shifter from an energy transmission path depending on the nature of the binary control signal applied thereto. As in the case of FIG. 1, the phase shift introduced by each phase shifter in the matrix is indicated on the corresponding phase shifter symbol, in this case in terms of $\pi/8$ radians. For example, the phase shifter 72 in the left leg of module

74 introduces a phase shift of $4\pi/8$ radians or 90° , while the phase shifter 76 in the right leg of that module introduces a phase shift of 0° .

The phase shifter matrix shown in FIG. 2 has three control levels 80, 82 and 84, each level corresponding to an order of the digital control word that is to be employed to select the phase shifters for connection in circuit. One phase shifter in each module is connected in circuit in accordance with binary information. Thus phase shifter 72 is connected in circuit of the binary control signal at level 80 is "zero" and phase shifter 76 is connected in circuit if the control signal at level 80 is "one."

It will be noted that the phase shifter arrangement in the matrix, as was the case in FIG. 1, is symmetrical and that the phase shifters are arranged in identical series on either side of the center. At level 80 either a shift of 0 or 90° ($\pi/2$) is introduced; at level 82 45° increments ($\pi/4$) are employed; and at level 84 the phase shifters are symmetrically arranged in 22.5° increments ($\pi/8$). The phase shift increments at level 84 increase outwardly from the center to the outside phase shift module on the "zero" legs and then continue to increase from the outside module back to the center module on the "one" legs. A similar symmetry is employed in levels 80 and 82. This symmetry is consistent with the fixed phase difference of corresponding branches or legs of adjacent modules. Thus the "zero" legs at level 84 differ by $-\pi/8$ radians and the "one" legs differ by $+\pi/8$ radians. Similarly, the "zero" legs at level 82 differ by $-\pi/4$ radians and the "one" legs by $+\pi/4$ radians, while the "zero" legs at level 80 differ by $-\pi/2$ radians and the "one" legs by $+\pi/2$ radians.

Each phase module is connected to the next module through a power divider 86. In the matrix of FIG. 2 all the power dividers are of equal value—splitting the power applied on input leg 87 equally to each output leg 88, 89. This matrix thus supplies equal power to all of the antenna elements 61-68.

The phase shift introduced to the signal from terminal 70 by the branching matrix for application to the antenna elements 61-68 is indicated in the following Table II as a function of the binary control signals applied to the levels of the matrix.

TABLE II

Digital Control			Antenna Elements								$\Delta\phi$	Beam (Fig. 3)
80	82	84	61	62	63	64	65	66	67	68		
0	0	0	9	2	11	4	13	6	15	8	-7	4L
0	0	1	10	5	16	11	6	1	12	7	-5	3L
0	0	0	11	8	5	2	15	12	9	6	-3	2L
0	0	1	12	11	10	9	8	7	6	5	-1	1L
1	0	0	5	6	7	8	9	10	11	12	+1	1R
1	1	0	1	6	9	12	15	2	5	8	+3	2R
1	1	1	0	7	12	1	6	11	16	5	+5	3R
1	1	1	8	15	6	13	4	11	2	9	+7	4R

From this table it will be observed that when all three binary control signals are "zero" (000) the phase differential applied to the antenna elements is $7\pi/8$ which produces a beam position denominated 4L in FIG. 3. When the digital control signal is changed to 001 the phase differential at the radiating elements is changed to $5\pi/8$ producing the radiated beam denominated 3L in FIG. 3. The other beams indicated in the table may similarly be correlated with FIG. 3.

The phase differences that are applied to the antenna elements may be determined directly from FIG. 2. For example, when the input digital control signal is 000, antenna element 64 has a signal applied to it through a 0°

phase shift at level 80, a 90° phase shift at level 82 and a 0° phase shift at level 84 producing a total phase shift of 90° or $4\pi/8$ radians. On the same antenna element when the input signal is 111 the phase shift introduced at level 80 is 90°, at level 82 is 45° and at level 84 is 157.5°—a total of 292.5° ($13\pi/8$ radians). While the above analysis is stated in terms of a signal being applied at a supply terminal to the modules, the components of an incoming wave front which produces the indicated phase gradient at the modules will be combined in similar manner at terminal 70. Thus these control matrices provide digitally controlled phase differentials with resulting beam directivity characteristics. The number of beam positions are a function of the digital control signals.

The number of antenna elements may be varied as indicated in FIGS. 4 and 5 which are illustrative of a radiating matrix producing eight beam positions (three binary levels) as does the matrix of FIG. 2. Table III which is similar to Table I but refers to FIG. 4 indicates the phase shift for an array having four antenna elements 91-94 which produces eight beam positions.

TABLE III

Digital Control			Elements Antenna				$\Delta\phi$
			91	92	93	94	
0	0	0	9	2	11	4	-7
0	0	1	6	1	12	7	-5
0	1	0	11	8	5	2	-3
0	1	1	8	7	6	5	-1
1	0	0	5	6	7	8	+1
1	0	1	2	5	8	11	+3
1	1	0	7	12	1	6	+5
1	1	1	4	11	2	9	+7

In this arrangement, as in the arrangement shown in FIG. 1, power splitters having outputs of equal value are employed. Levels 95 and 96 have phase shift modules arranged in the same manner as levels 80 and 82 in the matrix of FIG. 2. Level 97, however, has a modified arrangement—3-0, 2-1, 1-2, 0-3, which, it will be noted, is symmetrical with a fixed difference between corresponding legs of the modules of ± 1 units. Other ± 1 unit module differences can also be employed—for example, 3-4, 2-5, 1-6, 0-7, which is obtained by eliminating antenna elements 65-68 from the matrix of FIG. 2.

Where a different number of antennas are employed, however, power dividers of different values may be utilized as shown in FIG. 5. In this case the power divider 100 applies $\frac{3}{8}$ of the power on line 102 and $\frac{2}{8}$ of the power on line 104. Power divider 106 splits the power $\frac{2}{8}$ on line 108 and $\frac{1}{8}$ on line 110. An equal power split is provided by divider 112, $\frac{1}{2}$ to each of lines 114 and 116. The power divider 118 also supplies $\frac{1}{2}$ power to line 120 and $\frac{1}{2}$ to line 122. Thus this arrangement supplies equal power to the five antenna elements. The phase gradient across these antenna elements for the digital control signals is indicated in the following table:

TABLE IV

Digital Control			Antenna Elements					$\Delta\phi$
			131	132	133	134	135	
0	0	0	9	2	11	4	13	-7
0	0	1	10	5	16	11	6	-5
0	1	0	11	8	5	2	15	-3
0	1	1	12	11	10	9	8	-1
1	0	0	5	6	7	8	9	+1
1	0	1	6	9	12	15	2	+3
1	1	0	7	12	1	6	11	+5
1	1	1	8	15	6	13	4	+7

Again, a symmetry is employed in which the module leg phase differences at level 124 are ± 4 units; at level 126 ± 2 units; and at level 128 ± 1 unit.

In FIG. 6 there is shown a phase shifting arrangement in which three three-legged phase modules 140, 141, 142 are employed at level 144 in combination with a set of two-legged phase modules at level 146. Again as in the above examples, this phase matrix employs a symmetrical arrangement with the connections between levels interlaced so that each module in the lower level 144 is connected to the two corresponding modules in the upper level 146. In the level 146 six two-legged phase shift modules 148-153 are symmetrically arranged with ± 1 unit phase differences between corresponding legs of adjacent modules (in terms of $\pi/6$ radians). In the level 144 the phase difference between the "zero" legs is two units; between the "one" legs is six units; and between the "two" legs is ten (or minus two) units. The six antenna elements 161-166 receive equal energy in this embodiment. This matrix produces six different beam positions at the six antennas as indicated in the following table:

TABLE V

Digital Control		Antenna Elements						$\Delta\phi$
114	146	161	162	163	164	165	166	
0	0	2	3	4	5	6	7	
0	1	3	6	9	0	3	6	+1
1	0	2	7	0	5	10	3	+3
1	1	3	10	5	0	7	2	+5
2	0	6	3	0	9	6	3	+7
2	1	7	6	5	4	3	2	+9
								+11

As indicated in the table, equal phase gradients are produced by the various combinations of control signals applied to the phase modules. By appropriately combining modules in this manner a wide variety of phase shift increments between adjacent antenna elements may be obtained.

Still another arrangement is illustrated in FIGS. 7A and B in which a symmetrical arrangement of phase shift modules are interlaced with hybrid couplers (three db directional couplers) and single pole-double throw switches. In this arrangement eight phase shift modules are replaced by seven hybrid couplers (with a slight additional modification in the nature of the phase modules) to produce a scanning system equivalent to that shown in FIG. 2. In this arrangement eight antenna elements 201-208 are arranged in two sections. The corresponding array elements in each section are fed from the same hybrid. For example, elements 201 and 205 are fed from the output ports of hybrid 210. Similarly, elements 202 and 206 are fed from the output ports of hybrid 212.

The input ports of each hybrid are connected to a phase shift module 220 which has two fixed phase shifters 222, 224 of phase shift values as indicated which are fed by a digitally controlled single pole-double throw switch 226. The corresponding modules in the two sections at level 228 are fed from the output ports of hybrids 230, 232 and the input ports of those hybrids are connected to phase modules 240, 242. These two phase modules are connected to the output ports of hybrid 248 and the input ports of that hybrid are connected through single pole-double throw switch 250 to terminal 252. The phase shifts imparted by this matrix are indicated in FIG. 7B and the several phase differentials for this matrix, which are a function of the position of the digitally controlled switches, are indicated in the following table:

TABLE VI

Digital Control			Antenna Elements								$\Delta\phi$
			201	202	203	204	205	206	207	208	
0	0	0	5	6	7	8	9	10	11	12	+1
0	0	1	6	9	12	15	2	5	8	11	+3
0	1	0	7	12	1	6	11	16	5	10	+5
0	1	1	8	15	6	13	4	11	2	9	+7
1	0	0	9	2	11	4	13	6	15	8	+9 (-7)
1	0	1	10	5	16	11	6	1	12	7	+11 (-5)
1	1	0	11	8	5	2	15	12	9	6	+13 (-3)
1	1	1	12	11	10	9	8	7	6	5	+15 (-1)

A limitation on the use of this arrangement is that the hybrid couplers must give equal power division and hence the energy distribution at the array aperture must be uniform in amplitude. Tapered aperture distributions are often preferred in order to reduce the side lobes of the array pattern. A modified arrangement of the hybrid coupler-phase module arrangement is shown in FIG. 8 which enables a "cosine" distribution to be obtained. In this arrangement two sets of control matrices 260, 262 are employed which are digital programmed separately, and their outputs are applied to a combined phase module hybrid circuit 264 for application to the array elements 266. By the separate programming of two sets of control matrices 260, 262 the resulting aperture distribution may be caused to be the sum of two uniform linear amplitude distributions which have incremental phase differences that differ by the function $2\pi/K$.

Where the switches are set as shown in solid lines, the left hand network 260 produces a phase differential between adjacent antenna elements of $\pi/16$ and the right hand network 262 produces an element phase differential of $3\pi/16$. The resulting distribution on the array has a phase differential of $\pi/8$ with a cosine amplitude distribution. If the A_i switches in the left hand control section are changed to the dashed position, the left hand network 262 is set for a distribution with a phase differential of $5\pi/16$ to produce a total phase differential across the elements of the array of $-\pi/8$. Again the result amplitude distribution is "cosine" in nature in which the amplitude of the excitation on the center elements of the array is the greatest and decreases outwardly in accordance with the relationship $\cos(XL/2)$ where X is the distance of the element from the center of the array and L is the length of the array.

While preferred embodiments of the invention have been shown and described, various modifications thereof will be apparent to those skilled in the art and therefore it is not intended that the invention be limited to the disclosed embodiment or to details thereof and departures may be made therefrom within the spirit and scope of the invention as defined in the claims.

I claim:

1. Phase control apparatus for a system having a plurality of energy coupling ports, said system being responsive to digital control words, comprising a multiplicity of phase control modules arranged in a plurality of levels in a matrix, each said phase control module in each level having N branches where N is the radix of said digital control word applied to that level, each said branch including a phase shifter which imparts a fixed and predetermined amount of phase shift to a signal applied to that branch and selection means for connecting that branch in circuit, each said level corresponding to an order of said digital control word, power divider means for connecting the modules in one level to the modules in the succeeding level, and means to actuate said phase shifter selection means in accordance with the digital control words to connect each said port through a phase module in each level so that said matrix produces a corresponding

uniform phase differential between said ports in said system.

2. The phase control apparatus as claimed in claim 1 wherein each level includes N times as many phase modules as the preceding level where N is the radix of the digital control of that level.

3. The phase control apparatus as claimed in claim 1 wherein each said selection means includes two phase shifter isolating devices,

one disposed on either side of the phase shifter connected in the branch controlled by the selection means.

4. The phase control apparatus as claimed in claim 1 wherein said digital control words are in the binary radix and each said phase control module further includes a hybrid coupler connected to the two phase shifters in each module.

5. Phase control apparatus for a system having a plurality of energy coupling ports,

said system being responsive to binary control words, comprising a multiplicity of phase control modules arranged in a plurality of levels in a matrix,

- each said level corresponding to an order of said binary control word,

power divider means for connecting the modules in one level to the modules in the succeeding level,

- each said phase control module in each level having two branches,

each said branch including a phase shifter which imparts a fixed and predetermined amount of phase shift to a signal applied to that branch and selection means for connecting that branch in circuit,

- the phase shifter in one branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of the immediately adjacent module in the same level and the phase shifter in the other branch of each module imparting a shift $K\phi$ radians different from the phase shifter in the corresponding branch of said immediately adjacent module, where K is an integer,

and means to actuate said phase shifter selection means in accordance with the binary control words to connect each said port through a phase module in each level so that said matrix produces a corresponding uniform phase differential between said ports in said system.

6. The apparatus as claimed in claim 5 wherein said power divider means includes a four port coupler associated with each module, said coupler having two input ports and two output ports,

means connecting each input port to a corresponding phase shifter in the associated module and means connecting each output port to a phase module in the succeeding level.

7. The apparatus as claimed in claim 6 wherein said selection means includes a single pole-double throw switch device for connecting one of said phase shifters in each module in circuit in response to the binary control signal applied to that level.

8. Phase control apparatus for a system having a plurality of ports, said apparatus being responsive to digital control words,

comprising a plurality of phase control modules arranged in a level corresponding to an order of said digital control words,
 each said phase control module having N branches where N is the radix of said digital control words,
 each said branch including a phase shifter which imparts a fixed and predetermined amount of phase shift to a signal applied to that branch and selection means for connecting that branch in circuit,
 the phase shifter in one branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of the immediately adjacent module and the phase shifter in another branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of said immediately adjacent module, the shifts imparted by the phase shifters in said one branches of the modules being in inverse relation to the phase shifts imparted by the phase shifters in said another branches of the modules,
 and means to actuate said phase shifter selection means in accordance with the digital control words to connect each module so that said apparatus produces a uniform phase differential between said ports in said system.

9. The phase control apparatus as claimed in claim 8 wherein each said selection means includes two phase shifter isolating devices, one disposed on either side of the phase shifter connected in the branch controlled by the selection means.

10. The phase control apparatus as claimed in claim 8 wherein said digital control words are in the binary radix and each said phase control module further includes a hybrid coupler connected to the two phase shifters in each module.

11. Phase control apparatus for a system having a plurality of ports,
 said apparatus being responsive to binary control words, comprising a plurality of phase control modules arranged in a level corresponding to an order of said binary control words,
 each said phase control module having two branches, each said branch including a phase shifter which imparts a fixed and predetermined amount of phase shift to a signal applied to that branch and selection means for connecting that branch in circuit,
 the phase shifter in one branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of the immediately adjacent module in the same level and the phase shifter in the other branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of said immediately adjacent module, the shifts imparted by the phase shifters in said one branches of the modules being in inverse relation to the phase shifts imparted by the phase shifters in said another branches of the modules,

and means to actuate said phase shifter selection means in accordance with the binary control words to connect each said port through a corresponding phase module so that said apparatus produces a uniform phase differential between said ports in said system.

12. A digitally responsive phase control system comprising a plurality of phase control modules,
 each said phase control module having an input, an output, and N branches where N is the radix of digital control,

each said branch including a fixed phase shifter, said phase shifters being arranged so that one set of corresponding branches in said phase modules imposes a phase gradient ϕ on the signal transmitted through said phase modules,

and another set of corresponding branches imposes a

phase gradient of $K\phi$ on the signal transmitted through said phase modules where K is an integer, said one set imposing a phase gradient that is inversely related to the phase gradient imposed by said another set,

and means responsive to digital control to connect all the phase shifters in one set in circuit between said module inputs and said module outputs in accordance with the value of the control to impose a predetermined phase gradient as a function of the control on the signal transmitted through said modules.

13. A beam control system for an antenna array having a plurality of antenna elements,
 comprising a source of digital control words, a multiplicity of phase control modules arranged in a plurality of levels in a branching matrix,
 each said level corresponding to an order of said digital control words,

power divider means connected between succeeding levels for coupling power applied to said matrix between levels so that each antenna element in said array responds to the same amount of power,
 each said phase control module having N branches where N is the radix of said digital control words, each said branch including a phase shifter which imparts a fixed and predetermined amount of phase shift to a signal applied to that branch,

the phase shifter in one branch of each module imparting a shift ϕ radians different from the phase shifter in the corresponding branch of the immediately adjacent module in the same level and the phase shifter in another branch of each module imparting a shift $K\phi$ radians different from the phase shifter in the corresponding branch of said immediately adjacent module, where K is an integer,

and digital control word selection means coupled between said source and each branch for connecting that branch in circuit so that each antenna element is connected to a matrix terminal through a phase module in each level with a uniform phase differential between said antenna elements in said array being produced by said matrix.

14. The system as claimed in claim 13 wherein the modules in at least one level are arranged in two groups and the selection means for each group are independently controllable in response to said digital control words so that a tapered aperture illumination may be produced.

15. The beam control system as claimed in claim 13 wherein each level includes N times as many phase modules as the preceding level where N is the radix of the digital control of that level.

16. The beam control system as claimed in claim 15 wherein each said selection means includes two phase shifter isolating devices, one disposed on either side of the phase shifter connected in the branch controlled by the selection means.

17. The apparatus as claimed in claim 15 wherein said power divider means includes a four port coupler associated with each module,

means connecting each input port to a corresponding phase shifter in the associated module and means connecting each output port to a phase module in the succeeding level.

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