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Sheleg

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[54] **BUTLER SUBMATRIX FEED FOR A LINEAR ARRAY**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy**

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[52] **U.S. Cl.**....................................**343/854,** 343/778
[51] **Int. Cl.**..**H01q 3/26**
[58] **Field of Search**......................343/776, 777, 778, 343/779, 854

[56] **References Cited**

UNITED STATES PATENTS

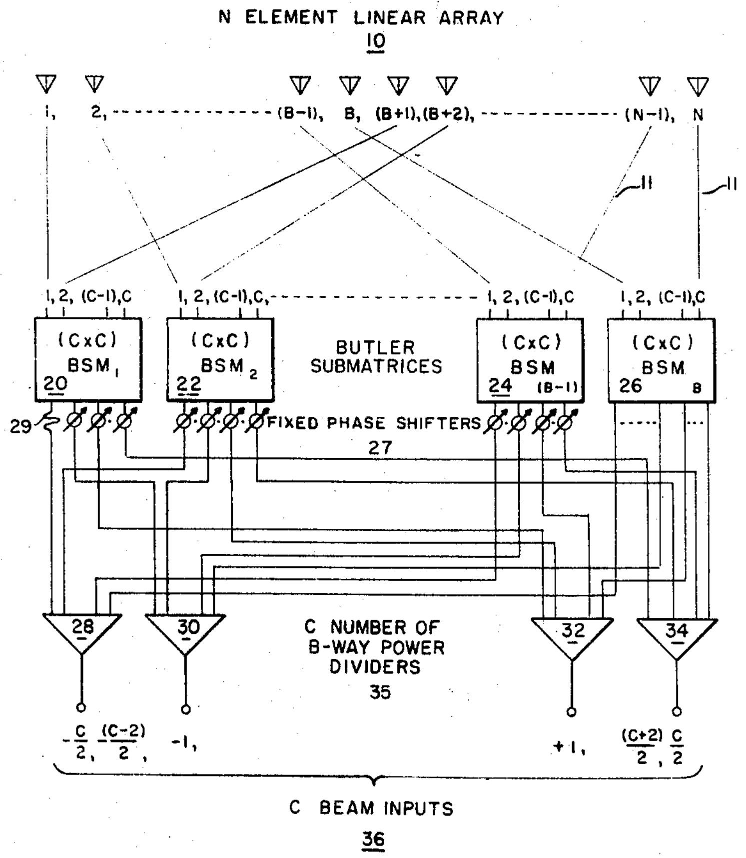
3,295,134	12/1966	Lowe	343/854

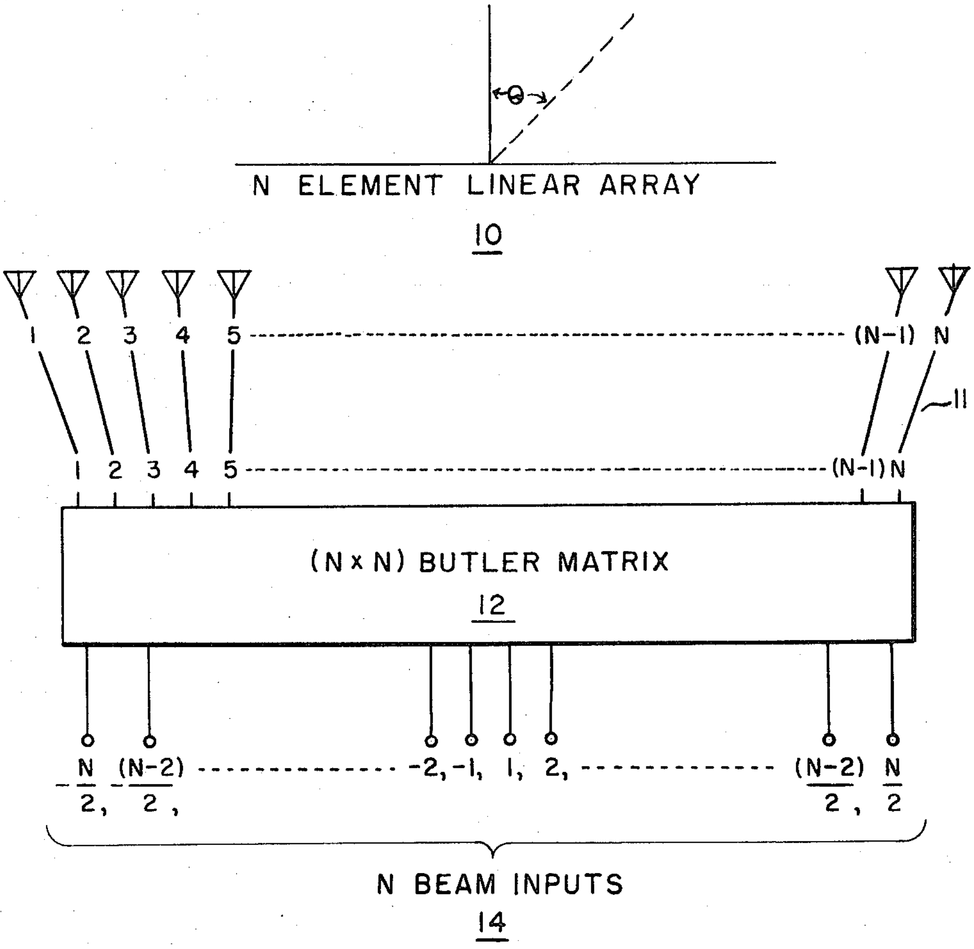
Primary Examiner—Eli Lieberman
Attorney—R. S. Sciascia et al.

[57] **ABSTRACT**

Several small Butler matrices are interconnected in a manner to replace a large single Butler matrix employed in a beam forming and scanning network for a linear array. This system of Butler submatrices (a set of low order Butler matrices simulating a single higher order Butler matrix) permits reduction in the size of existing feeding systems, which results in a substantial savings of system components and hardware. The function of this submatrix feed system is substantially identical to that of the single multibeam matrix network in most respects except for a fewer number of available beams. Also, this submatrix feed system is capable of exciting linear arrays which cannot presently be excited by a single Butler matrix. Also, the system has application in satellite communications and direction finding equipment.

5 Claims, 2 Drawing Figures





PRIOR ART

FIG. 1.

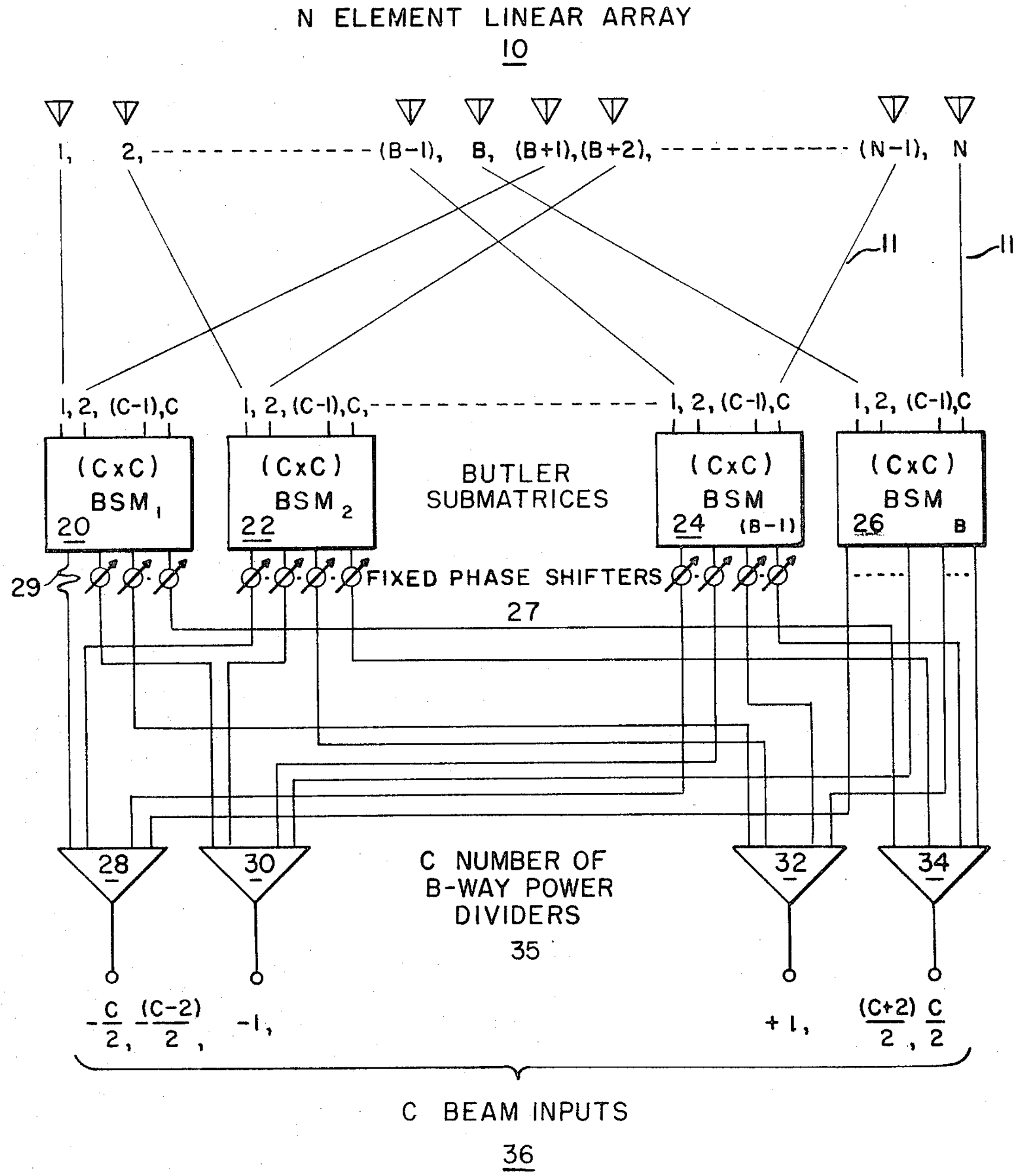

N ELEMENT LINEAR ARRAY
10
1,
2,
(B-1),
B,
(B+1),
(B+2),
(N-1),
N
11
11
1, 2, (C-1), C
1, 2, (C-1), C,
1, 2, (C-1), C
1, 2, (C-1), C
(CxC) BSM1
20
(CxC) BSM2
22
BUTLER SUBMATRICES
(CxC) BSM (B-1)
24
(CxC) BSM B
26
29
FIXED PHASE SHIFTERS
27
28
30
32
34
C NUMBER OF B-WAY POWER DIVIDERS
35
-C/2, -(C-2)/2,
-1,
+1,
(C+2)/2, C/2
C BEAM INPUTS
36

FIG. 2.

BUTLER SUBMATRIX FEED FOR A LINEAR ARRAY

BACKGROUND OF THE INVENTION

Butler matrices and associated feed systems have long been employed as an effective means for electronically scanning a linear array. The Butler matrix is a lossless passive network having N inputs and N outputs, where N is usually some power of **2**. The inputs are isolated from one another, and a signal into a single input results in a set of currents of equal amplitude on all the outputs with a linear phase progression across this linear array. Thus, each of the N input ports give rise to an independent directive beam. The construction of a large Butler matrix becomes extremely difficult and linear arrays having more than 64 elements are very uncommon. Also the mechanical and electrical tolerances become very stringent as the order of the matrix increases. Furthermore, for large networks, the number of transmission line corners, bends, and cross-overs encountered in fabrication become a prime source of system error. Hence, matrices of orders greater than 64 (2^6) are very expensive and are considered high risk components.

When a single Butler matrix of order N is employed in a beam forming and scanning network for a linear array it generates N beams in the space defined by $-90° < \theta < +90°$; where the scan angle $\theta = 0$ is broadside to the array. Since the effective aperture of an array is proportional to the factor cos θ, large values of θ [$\theta > (\pi/4]$ provide very poor antenna performance. In fact, most linear arrays do not scan beyond ± 45°. Hence, because these beams are normally dropped, seldom is the full capability of a single Butler matrix feed system utilized.

Therefore, with the above disadvantages in mind, I have developed a simplified feed system to replace the beam forming Butler matrix in a linear array. The system herein may replace the large complicated Butler matrix used in the linear array described in "Institute of Radio Engineers" Vol. PGAG Ap-9, 1961, pp 154–161, by J. Shelton and K. Kelleher.

SUMMARY OF THE INVENTION

The beam forming and scanning function of a single Butler matrix is replaced by a network of two or more lower order matrices so as to result in an equivalent network for driving a linear or planar array. This system appreciably reduces the amount of circuitry from that required in the prior art in exchange for a more limited scanning sector. Also, the system allows departure from the standard linear array having a number of elements equal to the order of the Butler matrix. Here the number of antenna elements equals the product of the number of submatrices "in parallel" times the order of the matrices. Therefore a number of N elements, not merely restricted to $N = 2^n$, is now possible. Also this instant Butler submatrix beam forming network system inherently has less complex design layouts and fewer general fabrication problems.

OBJECTS OF THE INVENTION

An object of the present invention is to provide a comparable yet more reliable linear array beam forming and scanning network employing two or more Butler matrices, of the same order in lieu of a single matrix.

Another object of the present invention is to provide a linear array with a Butler submatrix beam forming and scanning network which results in substantial savings in the cost of system components and hardware.

A further object of this invention is to provide an N element linear array which need not necessarily be a multiplier of 2^n.

Another object of the present invention is to limit the space coverage to approximately a ± 45° scan such that every beam which is generated is usable.

Another object of the present invention is to provide a feed network for a linear array which is economical and offers an appreciable savings in circuitry and hardware in exchange for the present inefficient 180° sector coverage offered by the prior art.

Other objects, advantages and novel features of the invention will become readily apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings wherein:

THE DRAWINGS

FIG. **1**, prior art, depicts a linear array driven by the well known (N × N) Butler matrix.

FIG. **2** shows the linear array driven by a number of lower order submatrices, and particular method of interconnection between the linear array and the outputs of the submatrices.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. **1**, N element linear array **10** of the prior art is shown with its associated (NXN) Butler matrix **12**. The N element array usually consists of equally spaced horns, dipoles, or possibly other linear arrays and are arranged along a common line. Although a linear array is shown, it should be understood that the element configuration could form a planar array wherein a number of linear arrays such as array **10** are disposed in columns. There are only a few requirements regarding the actual physical placement of a particular antenna, and the well known antenna placement principles control. As is well known in the prior art, interconnecting RF lines which connect the individual antenna element to an output terminal of the single Butler matrix must be of a prescribed length which maintains a uniform phase relationship between the array **10** and the single Butler matrix **12**.

As previously mentioned, a Butler matrix **12** is a lossless passive network having N inputs and N outputs where N is usually some power of **2**. The inputs are isolated from each other and a signal into any particular beam terminal input results in currents of equal amplitude on all the outputs with phase varying linearly across the elements. Therefore, if a unit voltage is applied to beam terminal [$+N/2$] a directional beam will be generated in the furthermost scan position $\theta_{[+N/2]}$ direction where $\theta_{[+N/2]} = \text{Sin}^{-1}[N-1/N]$. Similarly, if a unit voltage is applied to input mode terminal [$-N/2$], a beam will be generated in the $\theta_{[-N/2]}$ direction. The N beam terminals as shown in FIG. **1** can be used independently or connected together in different combinations so as to establish an amplitude taper illumination on the radiating aperture or to obtain simultaneous beams. This system described above is well known in the prior art and is set forth in detail in U. S. Pat. No. 3,255,450 issued to Jesse L. Butler. Also, it should be noted that the gain of the system shown in FIG. **1** drops off substantially for beam scans greater than $\theta = 45°$. This is due to a decrease of the effective aperture by a factor cos θ. These beams have little value in most applications and result from the higher aperture current modes. Therefore the scanning sector is effectively limited to $\theta \approx \pm 45°$. As a result the single Butler matrix feed system is inefficient since all the inputs are not used. Hence the matrix **12** becomes unnecessarily large and as I have discovered may be replaced by a number of smaller order Butler matrices.

Referring to FIG. **2** a number of Butler submatrices such as **20**, **22**, **24** and **26** are shown. All the matrices are of the same order (e.g., all C × C) and are conceptually identical to Butler matrix **12** except that in a similar system, the matrices of FIG. **2** are of much lower order. Because of the fact that a number of lower order Butler matrices are used in lieu of a larger order matrix the matrices **20**, **22**, **24** and **26** are designated as submatrices $SM_1, SM_2 \ldots SM_{(B-1)}$, and SM_B, respectively. The order C of the submatrix times the number of individual matrices B equals the number of radiators N in the array **10**. As a result one is not restricted to a power of 2 number of radiators as was required in the prior art. It should be noted that each output port of each submatrix is connected to one of the radiators in the array **10** by a transmission line which maintains the relative phase between the output ports and the radiators.

Using the principles of geometrical optics, it can be easily shown that the element spacing and the phase differences between adjacent elements determines a wave front at a particular angle with respect to the array. Thus, when the elements of the array **10** are fixed the angle of the wave front will be substantially determined by the phase distribution across the array. A particular linear phase progression is established by providing a unit voltage to one of C beam inputs **36**.

In order to establish a particular linear phase progression across the linear array **10**, while employing a number of Butler submatrices in lieu of the single Butler matrix, a particular method of element interconnection must be maintained. As shown in FIG. **2**, the first terminal of each submatrix is connected across the array **10** from left to right until the first terminal of submatrix B (**26**) is connected to element B of the array. The (B + 1) element of the linear array **10** is connected to the second terminal of the first submatrix **20**, and the second terminal of each subsequent terminal of each submatrix is sequentially connected from left to right until the second terminal of the last submatrix B (**26**) is connected to terminal 2B (not shown). This method of interconnection continues across the array until the last terminal C of the last submatrix B is connected to the last antenna element N of the linear array **10**. The connections may be made with RF lines of prescribed electrical length to maintain the established phase properties.

Each Butler submatrix has C number of beam terminals. Typically for a (4 × 4) order Butler submatrix which is used to drive a linear array there are four particular beam terminals which may be designated as **1**, **2**, **−1**, and **−2**. In order to have each of the (B·C) beam terminals correspond to an independent directional beam, the N linear phase progressions must be established across the array. This may be accomplished by using submatrix B as a reference and inserting fixed phase shifts in each of the C input ports of the remaining (B −**1**) submatrices. As shown in FIG. **2**, the phase shifters **27** may typically be a fixed line length **29**. The phase insertion of any particular phase shifter is determined by:

$$\phi_K = \frac{(SM_n - B)\,(2k-1)\pi}{N \cdot B}$$

where K is the particular beam terminal under consideration, SM_n is the particular submatrix board, B is the total number of submatrices and N is the number of radiators in the array.

FIG. **2** shows the submatrices connected to power dividers **35**. Similar beam terminals from the set of B submatrices are connected to a common power divider. For example, considering power divider **28**, the first submatrix input terminal of each of the submatrices **20**, **22**, **24**, and **26** are connected thereto. Similarly all the second beam terminals of each of the Butler matrices are connected to power divider **30**. Therefore, C number of B-way power dividers are responsible for the proper current distribution.

When the far field radiation patterns of the device of FIG. **2** is compared to the prior art in FIG. **1**, it can be seen that the conventionally fed array has a greater number of independent beams available. However, these additional beams are the ones directed farthest away from broad side, and since the sector coverage for most linear arrays is less than ±45°, the loss of these beams is inconsequential.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed and desired to be secured by Letters Patent of the United States is:

1. In a beam forming and scanning network for a linear array of antennas, each antenna being connected to an output of multibeam network means, a plurality of the input means of said multibeam means being serially coupled to fixed phase shifters and power dividers, the improvement comprising:

a plurality of discrete Butler matrices employed as said multibeam network means between the antennas and fixed phase shifters.

2. In a beam forming and scanning network for a linear array of N antennas, each antenna being connected to an output terminal of multibeam network means, a plurality of input beam terminal means of said multibeam network means being serially coupled to fixed phase shifters and power dividers, the improvement comprising:

B number of (C × C) order discrete Butler submatrices having C number of outputs employed as said multibeam network means between the antennas and fixed phase shifters wherein B·N = N.

3. The device as claimed in claim **2** wherein the first terminal of each submatrix is sequentially connected across the linear array until the first terminal of submatrix B is connected to terminal B of the array and,

the B + 1 element of the array is connected to the second terminal of the first submatrix and;

the second terminal of each subsequent submatrix is sequentially connected until the second terminal of submatrix is connected to array element 2B; and

until the C terminal of submatrix B is connected to array element N.

4. The device as claimed in claim **2** wherein the fixed phase shifter comprises:

B—1 sets of prescribed line lengths for establishing a phase:

$$\phi=\frac{(SM_n-B)(2k-1)\pi}{N\cdot B}$$

where k is the particular beam terminal of said multibeam means, and SM_n is the particular submatrix means.

5. The device as claimed in claim **2** wherein:

B equals 2.

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