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Sheleg

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[54] CIRCULAR ARRAY WITH BUTLER SUBMATRICES

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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
[51] Int. Cl. H01q 3/26
[58] Field of Search 343/777, 778, 854

[56] **References Cited**

UNITED STATES PATENTS

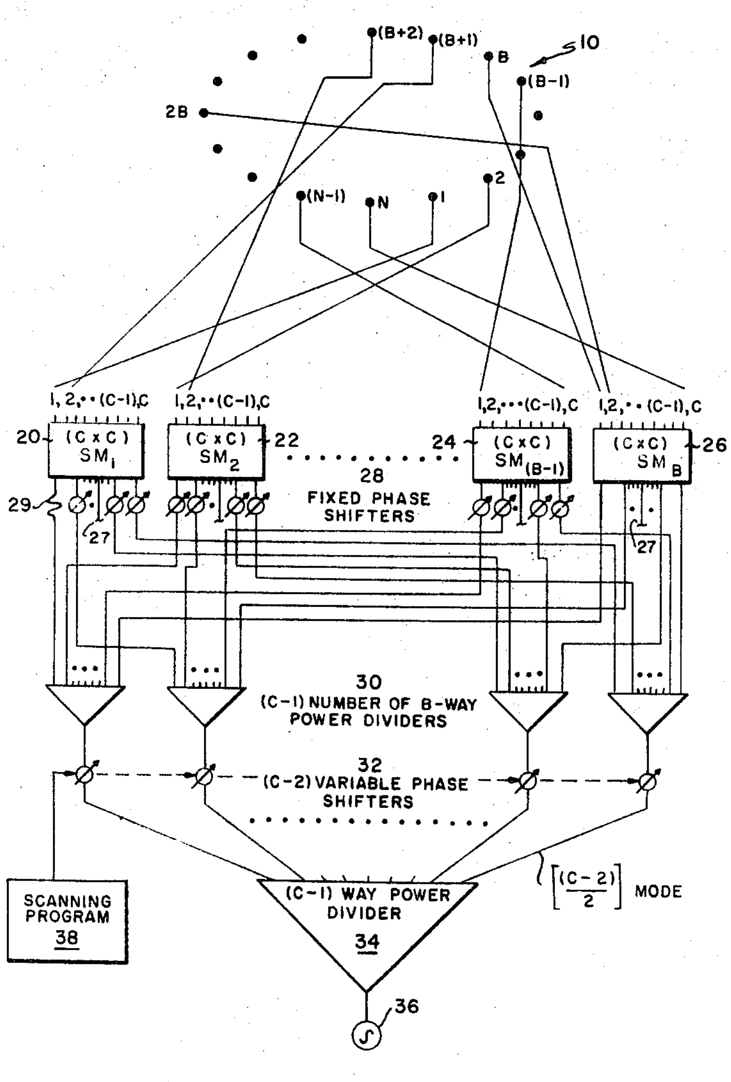
3,653,057 3/1972 Charlton 343/854

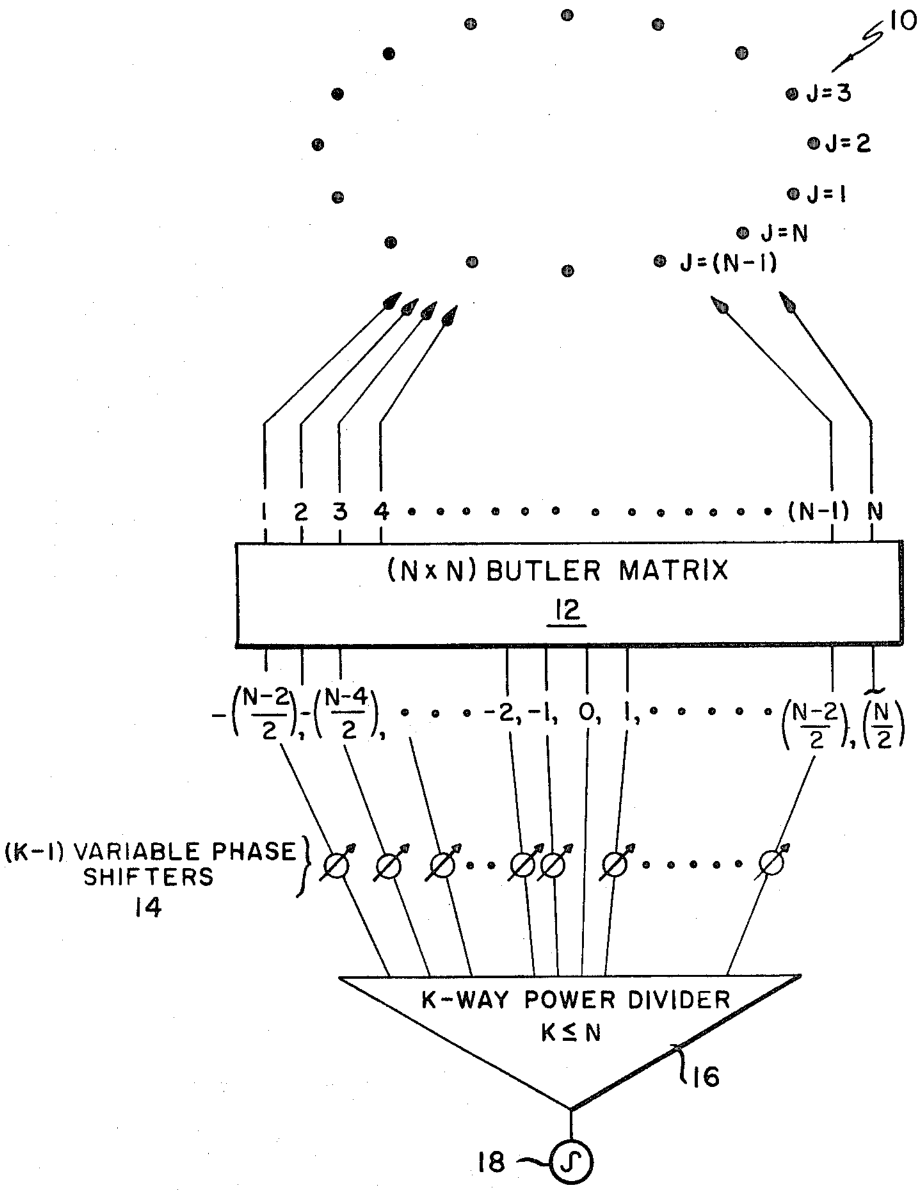
Primary Examiner—Eli Lieberman
Attorney—R. S. Sciascia et al.

[57] **ABSTRACT**

Several small Butler matrices are interconnected in a manner to replace a large Butler matrix employed in a beam forming and scanning network for a circular antenna array. This system of Butler submatrices (a set of low order Butler matrices simulating a single higher order Butler matrix) permits a reduction in the size of an existing feed system without any sacrifice in the 360° beam steering capability. Also this system produces only a minimal loss in beamwidth. A major difference between this system and the systems of the prior art is the number of modes available. For this instant submatrix feed system, the number of available modes is at most, one-half of that in the well known single Butler matrix system. The additional modes in the single Butler matrix system of the prior art are "-high order" modes and have generally produced poor quality far field patterns. As a result only a small percentage of these modes could be used in practice. Hence for most applications, the two systems provide essentially the same performance with the submatrix feed system being more economical since it is simpler, requires less hardware, and is more efficient in that all but one of the available modes are high quality modes.

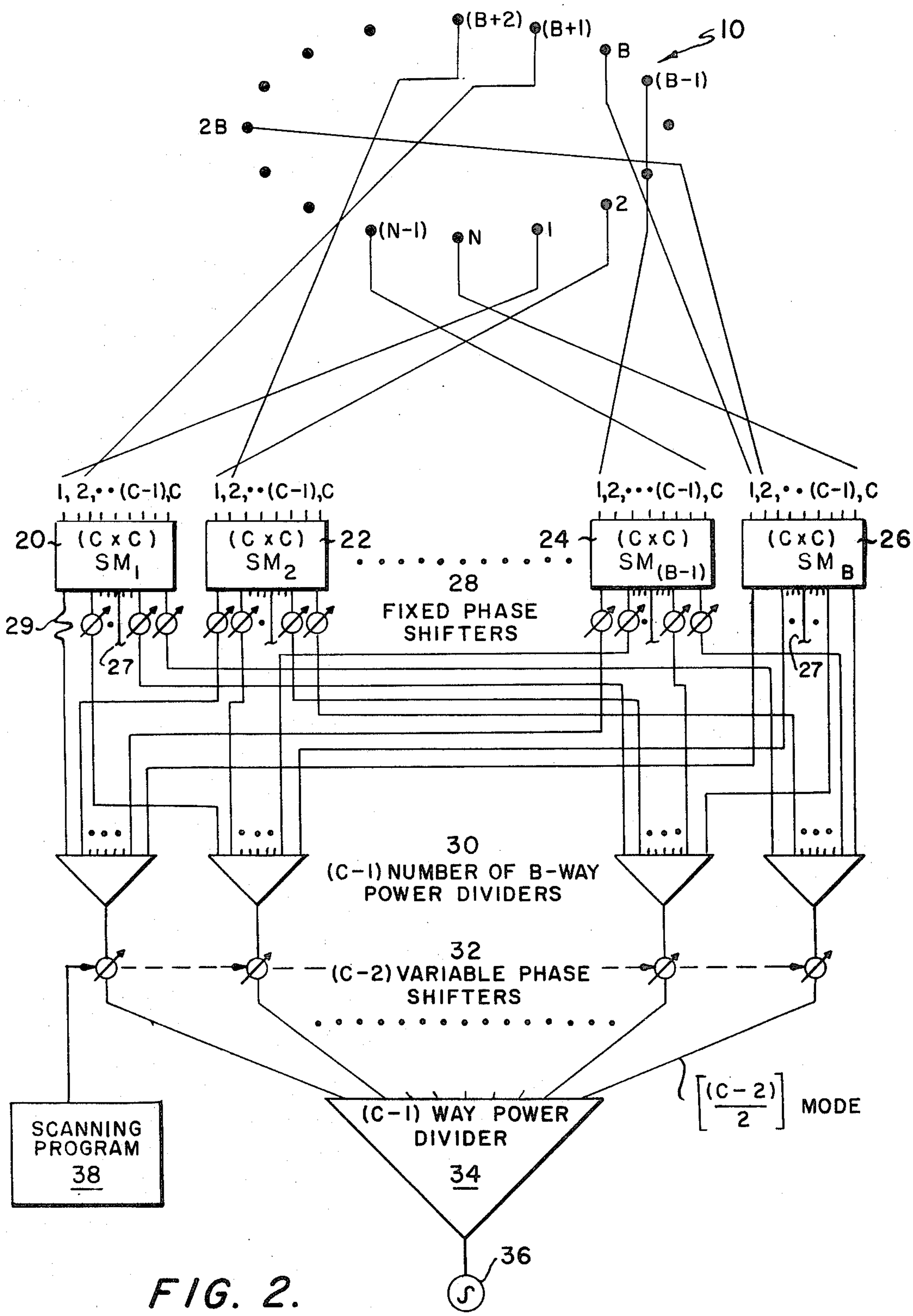
4 Claims, 2 Drawing Figures





PRIOR ART

FIG. 1.



(B+2)
(B+1)
B
10
(B-1)
2B
2
(N-1)
N
1
1, 2,•• (C-1),C
1,2,••(C-1),C
1,2,•••(C-1),C
1,2,•• (C-1),C
20
(C x C)
SM_1
(C x C)
SM_2
22
24
(C x C)
$SM_{(B-1)}$
(C x C)
SM_B
26
28
FIXED PHASE
SHIFTERS
29
27
27
30
(C-1) NUMBER OF B-WAY
POWER DIVIDERS
32
(C-2) VARIABLE PHASE
SHIFTERS
$\left[\frac{(C-2)}{2}\right]$ MODE
(C-1) WAY POWER
DIVIDER
34
SCANNING
PROGRAM
38
36

FIG. 2.

CIRCULAR ARRAY WITH BUTLER SUBMATRICES

BACKGROUND OF THE INVENTION

A butler matrix and its associated feed system have been recognized as an effective beam forming network for circular antenna arrays. The Butler matrix is a lossless passive network with N inputs and N outputs, where N is usually some power of 2. The inputs are isolated from one another, and a signal into any input results in currents of equal amplitude on all the outputs with phase varying linearly across the elements. Considering a large Butler matrix, the construction becomes extremely difficult and, other than the sheer massiveness of the structure, the mechanical and electrical tolerances become very stringent as the order of the matrix increases. Most Butler matrices are of shielded stripline construction and for large networks the number of transmission line corners, bends, and cross-overs encountered in this type of fabrication becomes a prime source of error. Hence, matrices of orders greater than 64 (2^6) are very expensive and considered high risk components. In addition, the higher order current modes generate deleterious aperture current distributions with drastic linear phase progressions (I.e., where the element to element phase progression approaches π radians). Such linear phase progressions give rise to poor far field pattern modes and very often cannot be used in the beam forming network.

Accordingly, when considering a large Butler matrix, the use of only two-thirds of the available modes are practical when the matrix is employed as a directional beam scanning antenna system.

Therefore with the above disadvantages in mind, I have developed a simplified feed system to replace the standard beam forming Butler matrix system in a circular array. The system presented herein may replace the large complicated Butler matrix used in the circular or cylindrical array as described in "Proceedures of the IEEE" Vol. 56, p. 2016–2027, Nov. 1968, entitled "A Matrix-Fed Circular Array for Continuous Scanning" by Boris Sheleg.

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 Butler matrices so as to result in an effective equivalent network which provides almost the full performance capability of the conventional Butler matrix feed network; the difference being that a somewhat narrower beam width can be obtained with a single Butler matrix. Furthermore, this system allows departure from the standard circular arrays of N-elements when $N = 2^n$ ($n = 1, 2, 3, \ldots$) wherein the number of elements N in this system equals the product of the number of submatrices in "parallel" times the order of the matrices. The result of this Butler submatrix beam forming network is a substantial savings in circuitry due to smaller, less complex design layouts, and it should be noted that for matrix orders of 16 and less shielded stripline cross-overs are not necessary.

OBJECTS OF THE INVENTION

An object of the present invention is to provide a comparable yet more reliable circular antenna scanning network employing two or more Butler matrices, of the same order, instead of a single matrix.

Another object of this invention is to provide a circular array beam forming and scanning network which approximates the function of a single Butler matrix.

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

Other objects, advantages and novel features of the invention will become 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 circular array driven by the well known Butler (multimodal) matrix beam forming and scanning network;

FIG. 2 shows the circular array driven by a number of lower order submatrices, and a particular method of connection

DETAILED DESCRIPTION

Referring to FIG. 1, a well-known circular scanning antenna system is shown. Basically such a device includes the circularly symmetric antenna system **10**, the Butler multimodal network **12**, receiver or signal source **18**, variable phase shifters **14**, and K-way power divider(s) **16**.

The antenna system **10** is usually composed of N number of similar radiating elements such as horns, slots, or dipoles. The elements are symmetrically spaced around the periphery. The array is usually restricted to a common plane but a two dimensional grid may also be used to provide three dimensional scanning.

The order of the Butler matrix **12** has been selected in accordance with the size of the antenna system **10**. The ($N \times N$) matrix is especially adapted for directional beam steering through selective phasing of signals and is discussed in my above-mentioned article. Each output port of the Butler matrix is connected to an antenna element with prescribed length transmission lines such as equal length transmission lines. The I^{th} output port of the Butler matrix connects to the I^{th} radiator of the circular array **10**. All but one of the ($N-1$) excited current modes have a variable in-line phase shifter **14** to provide modal phase adjustments for beam forming and scanning for the signal originated by source **18**.

FIG. **1** shows ($N-1$) mode terminal (input ports) of the matrix connected to a $K = (N-1)$ way power divider **16** by RF lines with ($N-2$) variable phase shifter **14** to provide a particular scanning pattern for the signal originated by source **18**.

The inherent drawback of this system is the size and complexity of the Butler matrix **12**. That is to say, the large Butler matrix **12** is extremely difficult to build as can be seen in U.S. Pat. No. 3,255,450 issued to Jesse

L. Butler. This invention therefore seeks to maintain the vital characteristics of the circular scanning array system, as shown in FIG. 1, while employing a simplified feed system in lieu of the massive Butler matrix 12.

Referring to FIG. 2, a number of Butler matrices such as 20, 22, 24, and 26 are shown. All matrices are of the same order (e.g., all $C \times C$) 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, $SM_{(B-1)}$, and SM_B, respectively. The order C of the submatrix times the number of individual matrices B must equal the number of radiators N (i.e., $N = B \cdot C$) in the circular array 10. Each output port of each submatrix is connected to one of the radiators in the array 10 by an equal length transmission line.

The total phase variation around the periphery of the antenna must be a whole multiple of 2π radians, and in order that a particular modal progression is generated, a particular method of interconnection between the submatrices and the N radiators must be maintained. As shown in FIG. 2, the first terminal of each submatrix is sequentially connected around the antenna 10 until the first terminal of submatrix B (26) is connected to terminal B on the antenna. The (B+1) element on the circular array 10 is connected to the second terminal of the first submatrix 20, and the second terminal of each subsequent matrix is sequentially connected around the antenna until the second terminal of the last submatrix B (26) is connected to element ($2B$). This method of interconnection continues until the last terminal C of the last submatrix B is connected to the last antenna element N of the circular array 10. The connections should be made with $2F$ lines of equal length so as to maintain the correct phasing.

Each Butler submatrix has C number of mode terminals, typically, for a (4 × 4) order Butler matrix, there are four modes: 0, 1, 2, and −1. The highest mode terminal (mode 2) is useless in the manipulation of the particular modes around the the circular array since the element to element phase progression varies in a 0, π, 0, π manner which produces a scalloped far field pattern. Therefore each of these highest modes is not utilized and are terminated in a matched load typified by termination 27. The result of losing the highest mode leaves only (C−1) mode terminals available from a ($C \times C$) Butler submatrix, which is the same as with any Butler matrix. All but one set of the (C−1) mode ports from the B submatrices is connected to a fixed phase shifter 28 which may typically be a fixed line length 29. The fixed phase insertion is determined by

$$\phi_K = [2\,\pi\,(SM_n)\,K]/B \cdot N$$

where K is the mode number, SM_n is the particular submatrix board, B is the total number of submatrices and N is the number of radiators in the antenna. The purpose of these fixed phase shifts is to establish the proper modal phase progressions around the periphery of the antenna system 10.

Similar mode ports from the Butler submatrices 20, 22, 24, and 26 are connected to the appropriate B-way power divider 30. A variable phase shifter 32 precedes all but one of the power divider 30. These (C−2) variable phase shifters are used to form a highly directional beam and then to scan it. The phase settings can be controlled by any scanning program 38 for a particular scan rate and sector coverage. Finally, all the lines leading to the submatrix network connect to power divider 34 which shapes the beam by establishing an amplitude taper across the current modes. For the same radiating antenna, fed with the single Butler matrix and Butler submatrix network, there is no difference in operation or performance so long as only modes common to both feed systems are used.

Obviously many modifications and variations of the present invention are possible in 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 circular array of antennas, each antenna being connected to an output of multimodal means, a plurality of the input means of said multimodal means being serially coupled to fixed phase shifters, power dividers, and variable phase shifters, the improvement comprising:
   a plurality of discrete Butler matrices employed as said multimodal means between the antennas and fixed phase shifters.

2. In a beam forming and scanning network for a circular array of N antennas, each antenna being connected to an output terminal of multimodal means, a plurality of input mode terminal means of said multimodal means being serially coupled to fixed phase shifters, power dividers, and variable phase shifters, the improvement comprising:
   B number of ($C \times C$) order discrete Butler submatrices having C number of outputs employed as said multimodal means between the antennas and fixed phase shifters wherein $B \cdot C = N$.

3. The device as claimed in claim 1 wherein the highest mode terminal is terminated in a matched load.

4. The device as claimed in claim 1 wherein the first terminal of each submatrix is sequentially connected around the circular array until the first terminal of submatrix B is connected to terminal B of the array;
   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 around the array 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.

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