Study of a Planar Topology Butler Matrix for Printed Multibeam Antenna

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Abstract

Different structures of multiple-beam networks (beam-formers) have been proposed, such as the Blass matrix , the Nolen , the Rotman lens , and the Butler matrix [1]. The most important beamforming networks used for multiple beams with lineaire array are based on the Butler matrix. In this paper, the design of a planar new 8x8 Butler matrix were designed to form the orthogonal beamforming generates by 8 linear rectangular mirostrip antenna array, and the design procedure of matrix and its components: hybrids and phase shifters are prersented and descussed.

Keywords: *Microstrip,Multibeam antennas, Butler matrix, printed antenna, phase shifters, couplers..*

1. Introduction

The main advantages of Butler matrix as distributors are their ability to generate orthogonal beams with a constant level of aggregation using few components and ease of design. They have achieved a multibeam antenna Cited example is in the application of these matrix in the commercial satellite transponders (transponders multichannel), the inclusion of non-linear amplifiers are identical between two matrix set end to end to make a significant reduction in interference (IMP intermodulation product). They are found in the geostationary INMARSAT-3 as for mobile communication systems, where the use of 4x4 matrix in microstrip technology (stripline) operating at 1.542 GHz leads to a maximum power of 20 W signals to one or more antennas. To this list we can add the satellites in low orbits, such as Iridium system created by Motorola that provide comprehensive service for customers primarily making international calls. Butler matrix then generate up to 16 beams simultaneously with minimal transmission losses [2].

In the case of GSM (Global System Mobile) operating around 900 MHz for both base stations type using PCS CDMA systems for communications interior (indoor) around 60 GHz, Butler matrix are present and offer a good compromise in terms of coverage, the number of beams.

This is a circuit reciprocal passive symmetrical N input ports and N output ports that drives N radiating elements producing N different orthogonal beams, which is composed of joints that connect the input ports to output ports via lines transmission path length equal. The Butler matrix is composed of three components that are the 3-dB couplers, the phase shifters and crossings. Since there are two main types of coupler, the coupler (3-dB, 90°) codirectifs and couplers (3-dB, 180 °) contradirectifs respectively in phase 90° and 180°. Then we distinguish two types of matrix Butler binary [1,3,4]:

- Matrix standard, employing 90° hybrids, of which the beams generated are located either side of the normal to the plane containing the radiating elements.
- Matrix nonstandard employing 180° hybrid, which generated beams are also located on either side of the normal to the plane containing the radiating elements, but with a further beam in the reference axis corresponding to the normal antenna array.

2. Principle of operation of the couplers

The directional couplers are passive devices with four ports and outputs allowing to obtain an output proportional to the input: these are power dividers. We can distinguish between broad classes of directional couplers as couplers are close by (contra-directional) and couplers junctions (co-directional).

Indeed, in a Butler matrix, they are couplers (3-dB, 90°) codirectifs and couplers (3-dB, 180°) contradirectifs which are often used. These two types of 3-dB coupler, respectively phase 90° and 180° used in Butler matrix standard and non-standard will now be examined. The matrix expression for the transfer function3-dB coupler, respectively phase 90° and 180° respectively is given by:

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & e^{-j\pi/2} \\ e^{-j\pi/2} & 1 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} S_1 \\ S_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 1 \\ e^{-j\pi} & 1 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \end{bmatrix}$$

S_i outputs of the coupler and E_i its inputs.

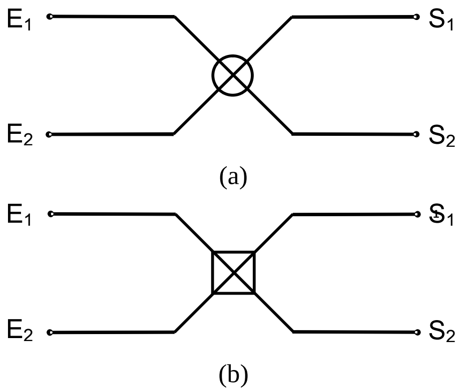


Fig. 1 Functional representation (a) 3 dB coupler 90 °,(b) 180 ° 3dB couplers.

Note that, unlike the coupler (3-dB, 90°), the coupler (3-dB, 180°) is not symmetric, also according to the input port chosen phase will take place or not (if the input 1 is selected, there is a 180° phase shift between the output ports 3 and 4).

3. Description and relationship with the of Butler matrix

A Butler matrix in its standard or non-standard is composed of 3 dB couplers, phase shifters and has N input ports and N output ports connected to an antenna array. This set constitutes the multibeam antenna. The signal which feeds each port is then divided into N signals equal in amplitude and recombined by the antenna array to produce the corresponding beam of which the phase for each misalignment depends mainly on the type of coupler selected. The expression of radiation in a direction θ (angle between the viewing direction and the normal to the grating) is obtained by applying the superposition theorem by summing the contributions of each source wireten:

$$\vec{F}(\vec{u}) = \sum_{n=0}^{n=N-1} a_n \times \vec{f}(\vec{u}) \times e^{j\frac{2\pi}{\lambda} \times \vec{A}_0 \vec{A}_n \times \vec{u}} \quad (2)$$

with $\vec{f}(\vec{u})$ the radiation pattern of each source, a_n the illumination law which feeds each source in phase and amplitude, $A_0, A_1, \ldots A_{N-1}$ are the phase centers of each source.

$$\vec{F}(\vec{u}) = \vec{f}(\vec{u}) \sum_{n=0}^{n=N-1} a_n \times e^{j.n.\frac{2\pi}{\lambda} \times d.\sin\theta} = \vec{f}(\vec{u}) \times AF(\vec{u}) \quad (3)$$

$AF(\vec{u})$ is known as the array factor since this term is purely a function of the excitation coefficients and the positions of the radiating elements. Hence it characterizes the array independently of the radiating elements used.

In the particular case for linear networks made of identical radiating elements, the field radiated by the array in a direction $\vec{u}$ is given by the product of the array factor $AF(\vec{u})$ multiplied by the radiation of an elementary source $\vec{f}(\vec{u})$.

Here we consider the case of uniform illumination normalized ($|a_n| = 1$) and a constant phase gradient, we can write:

$$a_n = e^{-j.n.\varphi} \quad (4)$$

The array factor can be written:

$$AF(\theta) = \sum_{n=0}^{n=N-1} e^{j.n\left(\frac{2\pi}{\lambda} \times d.\sin\theta - \varphi\right)} \quad (5)$$

The phase gradient φ ($\varphi = k.d.\sin(\theta_0)$) now becomes a variable that changes the orientation of the main lobe of the array factor. In the case of the, the array factor therefore simplifies as follows [5]:

$$AF(\theta) = \frac{\sin N\left(\frac{\pi}{\lambda} d \sin\theta - \sin\theta_0\right)}{N \sin\left(\frac{\pi}{\lambda} d \sin\theta - \sin\theta_0\right)} \quad (6)$$

3.1 Description of the Butler matrix with 3dB / 90° couplers

After expanding mathematical expression of the array factor of a linear array fed by a Butler matrix N×N using couplers (3 dB, 90˚) is as follows[5]:

$$AF(\theta)=\frac{\sin N\left(\frac{\pi}{\lambda}d\sin\theta-\frac{(2m-1)}{2N}\pi\right)}{N\sin\left(\frac{\pi}{\lambda}d\sin\theta-\frac{(2m-1)}{2N}\pi\right)} \qquad (7)$$

$\varphi=(2m-1)\frac{\pi}{N}$, m entier, m $\in\left[1-\frac{N}{2},\frac{N}{2}\right]$

Where:

- φ : The phase difference which indicates a direction of aiming of the beam,
- d : distance between elements
- θ : angle formed by the viewing direction and the normal to the grating.

3.1 Description of the Butler matrix with 3dB / 180° couplers

Similarly, the offset values for matrix NxN using couplers 180° are of the form:

$\varphi=2m\frac{\pi}{N}$, m entier, m $\in\left[1-\frac{N}{2},\frac{N}{2}\right]$

The array factor can be written:

$$AF(\theta)=\frac{\sin N\left(\frac{\pi}{\lambda}d\sin\theta-\frac{m}{2N}\pi\right)}{N\sin\left(\frac{\pi}{\lambda}d\sin\theta-\frac{m}{2N}\pi\right)} \qquad (8)$$

4. Design procedure of Butler matrix

4.1 Number positions and couplers

The number of coupling needed for the design of a Butler matrix of order N, where N is a power of two, such as N = 2n. This number n is the number of levels of couplers used in the matrix. The number of couplings per level is half of the order of the matrix, N/2. For example, for a matrix 8x8, n = 3 Therefore, this matrix has three levels of four couplers 3 dB, couplers or twelve in total. The number of coupling does not depend on the type of coupler used.

4.2 Positions and values shifters

The first column contains all the input ports of the matrix is divided into groups of two, four and eight. The two inputs of each pair are combined by a 3dB coupler and the next column contains the phase shifters. In this column the phase shifters are placed opposite the ends of each group of four, the values of the phase shifters are equal to 90 least the phase gradient φ_n between the radiating elements associated with the input ports in the same line ($90-\varphi_n$).The column containing the phase shifters is followed by another column which contains couplers 3 dB and therefore, there will be a second column that has phase shifters. In this second column, the phase shifters are placed in front of the ends of each group of eight values and are equal to 90 least twice the phase gradient φ_n between the radiating elements associated with the input ports in the same line ($90-2\times\varphi_n$).On the same column other phase shifters are placed on adjacent to those located at the ends of each group of eight, and they have the same values as those of adjacent, that is to say $90-2\times\varphi_n$. Another column couplers which will be followed by a third phase shifter column for values that will $90-4\times\varphi_n$. The number of phase shifters required depends on the type of couplers used. For a matrix using couplers 90°, there (n-1) line de N/2 phase shifters, a total of N(n-1)/2 shifters. In general, the phase gradients in a matrix using couplers (3dB, 90˚) are of the form [4]:

$$\varphi_n=\pm(2p-1)\times\frac{\pi}{N} \text{ with p } \in\left[1,\frac{N}{2}\right] \text{ (p integer)} \qquad (9)$$

The same way as the previous procedure for the new topology of the Butler matrix using couplers (3 dB 180°), there (n-1) levels, but the number of phase shifters vary from one level to another. Considering that k is the number of the line from the outputs, then the number of phase shifters for k^{ème} levels is :N/2 – $2^{(k-1)}$.

The first phase shifter is always placed on the second line of the matrix. Values and positions of its shifters are completely different from the previous one. The latter allows to use $s=2^{(n-1)}-1$ less than a matrix phase shifters using couplers 3dB 90°. To understand the mechanism design matrix 8x8 is analyzed in the simulation. The whole procedure has already been an article [3,4].

5. Simulation result

5.1 Choice of the radiating element

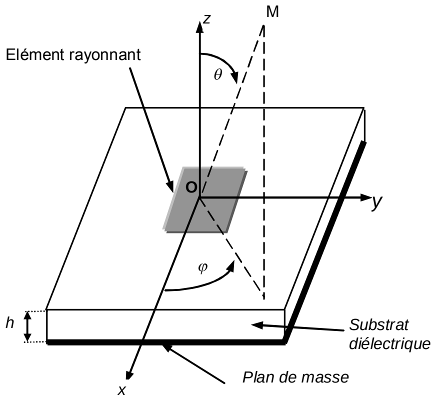


Fig. 2 Microstrip patch antenna

For the simulation we chose the elementary source as a printed antenna, the antenna is composed of a plate of dielectric substrate known which one face is fully metallized, the ground plane, the other side having a metallization forming the partial element radiant. A distance to the point M of the space, the field induced by the source is located in the plane, it is expressed by [6]:

$$\vec{E}(M) = E_\theta(\theta,\phi).\vec{U}_\theta + E_\phi(\theta,\phi).\vec{U}\phi \quad (10)$$

$$E_\theta(\theta,\varphi) = F(\theta).[\cos\varphi.J_x(\theta,\varphi) + \sin\varphi.J_y(\theta,\varphi)] \quad (11)$$

$$E_\varphi(\theta,\varphi) = G(\theta).[-\sin\varphi.J_x(\theta,\varphi) + \cos\varphi.J_y(\theta,\varphi)] \quad (12)$$

with:

$$F(\theta) = \frac{-jw\mu_0 T.\cos\theta}{T - j\varepsilon_r \cos\theta.\cot g(k_0 Th)} \quad (13)$$

$$G(\theta) = \frac{-jw\mu_0 T.\cos\theta}{\cos\theta - jT\cot g(k_0 Th)} \quad (14)$$

Surface currents decompose as follows:

$$J_x = L_x L_y I_1.\frac{\sin[(k_0 L_y(\sin\theta\sin\varphi)/2].2\pi\cos[(k_0 L_x(\sin\theta\cos\varphi)/2]}{[k_0 L_y(\sin\theta\sin\varphi)/2].[\pi^2 - (k_0 L_x \sin\theta\cos\varphi)^2]} \quad (15)$$

$$J_y = L_x L_y I_2.\frac{\sin[(k_0 L_x(\sin\theta\cos\varphi)/2)].2\pi\cos[(k_0 L_y(\sin\theta\sin\varphi)/2)]}{[k_0 L_x(\sin\theta\cos\varphi)/2].[\pi^2 - (k_0 L_y \sin\theta\sin\varphi)^2]} \quad (16)$$

$$T = \sqrt{\varepsilon_r.(1 - j\tan\delta) - \sin^2\theta} \quad (17)$$

The antenna element is square and operates in the band (f = 10 GHz), The main characteristics of this substrate are:

- Dielectric constant : $\varepsilon_r = 2.55$; $tg\delta = 0.01$
- Thickness of the dielectric:h=1.59
- The length of the patch Wx= 1.8 mm ;
- The width of the patch Wy= 1.8 mm.

Figure (3) shows the radiation pattern of a printed antenna with rectangular θ variable et φ =0 (plan E). The antenna does not have secondary lobes and the field amplitude is almost constant regardless of the value of the angle θ.

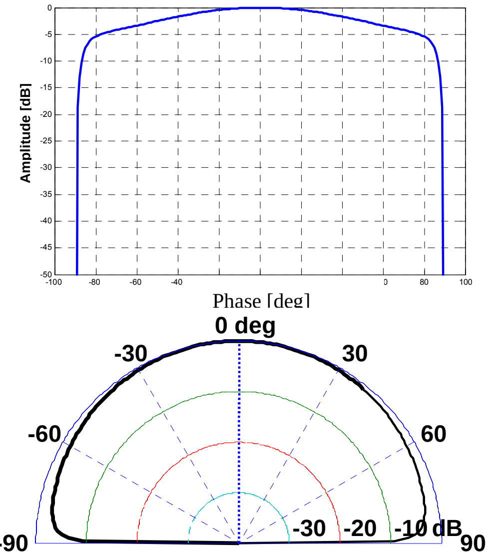


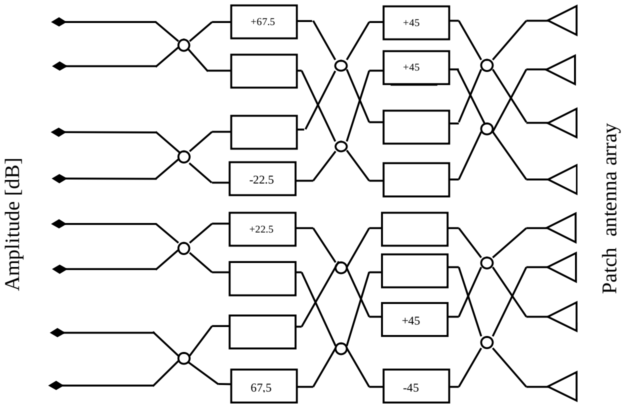
Fig. 3 Radiation pattern of a printed antenna at 10 GHz (a): Radiation pattern of a printed antenna (b): in polar coordinates

5.2 Simulation results

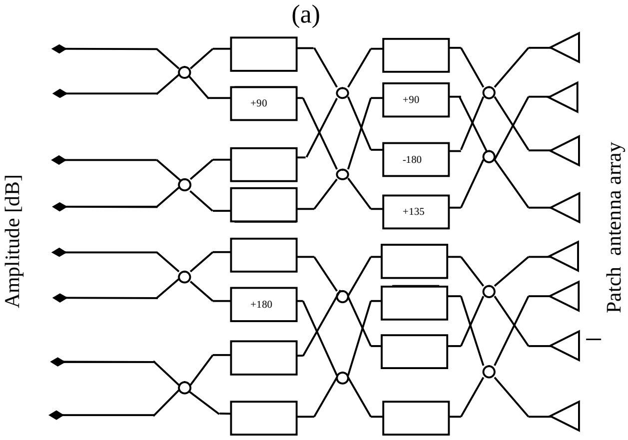
Butler matrix of order 8 offers the possibility of controlling 8 beams. It consists of 3 dB couplers 12, 16 crosses and eight phase shifters for the standard matrix and only 5 shifters for non-standard matrix, the internal architecture of these matrix is shown in Figure 4.

Butler matrix standard is composed of three levels of couplers. Can disassociate into two matrix of order four juxtaposed identical with a level of 4 sensors located just above. It may also be noted that the values of its phase shifters are multiple π/8. The new architecture is identical to the previous position and the exception values of the phase shifters that are multiples of π/4. The employees are all couplers couplers (3-dB,180°). Found within this topology 4x4 Butler matrix non-standard. The values of the phase shifters are multiples of π/4 for the matrix using couplers (3-dB, 90°) et de π/2 couplers for using the (3-dB, 180°).

Different radiation patterns obtained by the Butler matrix standard and nonstandard according to the selected input port are represented in the figure above. These results do not take into account the external environment to the network antennas, such as the power supply circuit of the matrix.

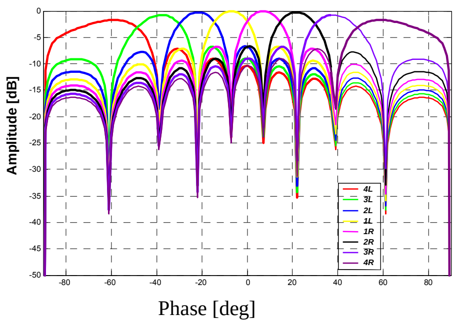


(a)

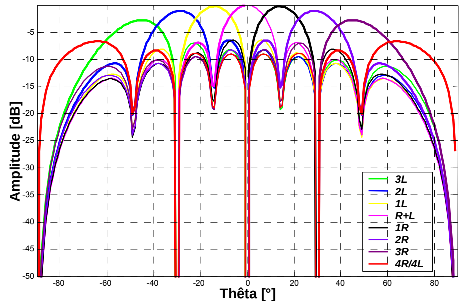


(b)

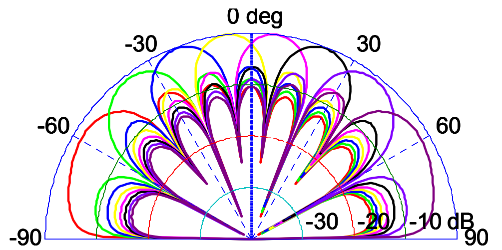
Fig. 4 Functional schematic Butler matrix (a):with 3 dB/90° couplers (b) :with 3 dB/180° couplers



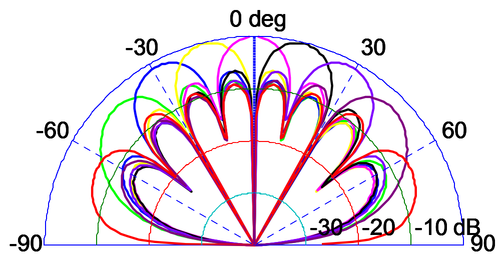
(a)



(b)



(c)



(d)

Fig. 5 Performance of the Butler matrix 8x8 standard (a),(b): Simulated radiation pattern in Cartesian coordinates respectively 3 dB/90° couplers and 3 dB/180° couplers (c),(d) : Simulated radiation pattern in polar coordinates3 dB/90° couplers and 3 dB/180°

6. Simulation result matrix Butler Plan

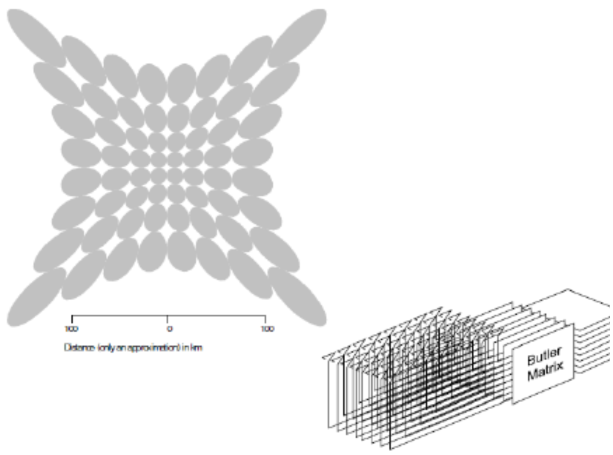
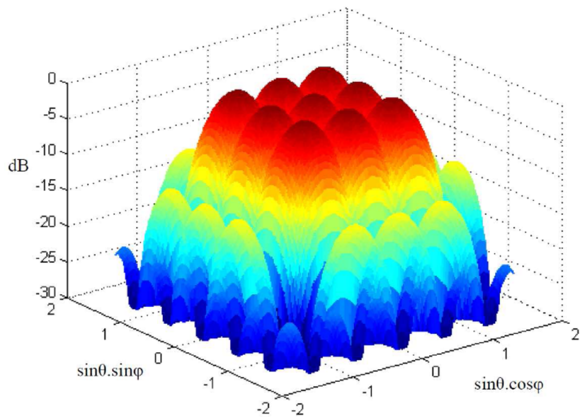
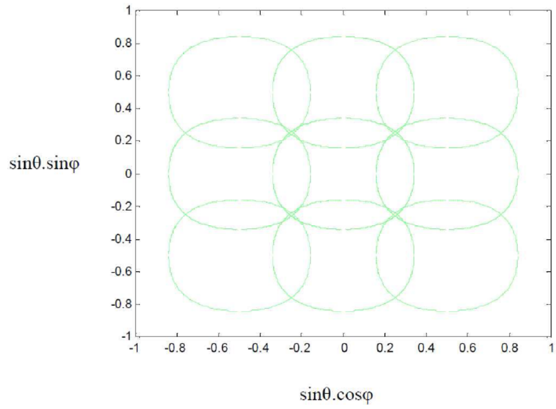


Fig .6 A two-dimensional Butler matrix producing orthogonal beams[7]

Curves that follow represent the different network coverage level using Butler matrix NxN as beam splitter. The matrix has as many ports 4 Entry output, so in this case we have a square lattice. since network plan includes several cascaded linear networks, we will have several main lobes output determined by applying the superposition theorem.



(a)



(b)

Fig. 7 Performance of the Butler matrix plan 4x4 standard (a): Three-dimensional radiation pattern (b) Two dimensional amplitude distribution on the aperture

The Figure (7) is the three-dimensional representation of the diagram radiation of plantar networks powered by Butler matrices 4x 4. They provide more effective network coverage antennas throughout the space. The main lobes represent the largest amount energy (gain) facing the antenna array, and each is associated with the main lobe with small energies focused in unwanted directions, they are considered as interference with its levels should be minimized to increase the performance the beam forming network.

7. Conclusions

This article presents the performance of Butler matrix. Beam forming networks for multiple beam antennas are a very important antenna sub-system as they enable to reuse the same radiating aperture to produce all the beams [8]. The Butler matrix was studied, simulated successfully. The complete analysis of 3-D Butler matrix for planar antenna array is carried out. The radiation patterns that result as progressive phase shifts produced by 3-D configuration of Butler matrix are presented. The simulated results show that the butler matrix produces orthogonal beams in the required directions. It is therefore the best choice to begin a detailed study of power networks with multiple beams in the millimeter range in microstrip technology [9,10,11].

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