Application of Butler Matrix to a Tree Structure of Microstrip Antenna Array

Tomader Mazri[1,2], Fatima Riouch[1] and Najiba El Amrani El Idrissi[2]

[1] The microwave laboratory
National Institute of Posts and Telecommunications Rabat, Morroco

[2] The signals, systems and components laboratory
FST-Fez morocco

Abstract

The aim of this investigation is to realize a Butler matrix for a multibeam base station antenna dedicated to a U MTS application; this matrix has been realized with microstrip technology. The antenna associated with this application is a network of patches distributed in a tree structure and fed by electromagnetic coupling. The patch distribution structure used in this experiment allowed a g reat improvement of gain, directivity as well as the adaptation level of the studied array. The following work was done between the signals, systems and components laboratory of FST-Fez and the microwave laboratory of the National Institute of Posts and Telecommunications.

Keywords: *Butler Matrix, Adaptive Antenna, Microstrip Antenna array, Multibeams Antenna, Coupler.*

1. Introduction

The UMTS (Universal Mobile Telecommunications System) is the cellular standard for mobile telecommunication systems of the third generation [1]. It has been adopted worldwide in 1998 but its service has been delayed due to the implementation costs. Its special feature is the simultaneous transmission of voice and data with higher rates than those permitted by previous generations.

The development of these systems requires technological advances in electronic components, computer software, coding techniques and antennas. Indeed, the antenna is one of the key points of wireless network since it represents the last link in the chain that allows emission, transmission and reception of the signal and therefore the information contained in it [1].

The potential of multibeams antennas has been recognized since the implementation of the first antenna reflector. In 1888 the German physicist Heinrich Hertz demonstrated the existence of electromagnetic waves imagined by James Maxwell in 1873 and produced the first reflector. The multibeams antennas always consist of the organs below:

- The radiating sources.
- The beamforming network (Butler Matrix).
- The control circuit (or calculator).

The ultimate goal of this work is to design an adaptive microstrip antenna for base stations of UMTS telecommunication networks, and to improve its cover.

To reach this purpose, the parameters of our antenna (resonant-frequency, geometry and bandwidth) will be considered for an UMTS application. The circuit will be made with FR4, a co mmonly used material for the manufacture of printed circuit with the following characteristics (thickness: 1.6 mm εr: 4.5 and tgδ: 0.02).

2. Butler Matrix

The theory of Butler Matrix goes back to the 1960s; these matrices are increasingly studied today for the implementation of beam-forming network for active or phased array antennas. We look to achieve the pointing angle of one or more beams in predetermined directions. To perform a radiation in a direction θ, we must apply a constant phase gradient on the radiating sources. This phase gradient can compensate the path difference due to the Butler matrix used to impose the phase gradient. The path difference of the spokes that exist between two radiating sources in the θ direction [2].

$$I_1 = A_1 e^{j0} \quad (1)$$

$$I_2 = A_2 e^{j\pi/2} \quad (2)$$

And

$$A_1 = A_2 \quad (3)$$

$I_1' = I_1 + I_2 e^{j\pi/2}$
Or
$I_1' = A_1 e^{j0} + A_2\ e^{j\pi}$ (4)
$I_2' = I_1 e^{j\pi/2} + I_2,$
$I_2' = A_1 e^{j\pi/2} + A_2 e^{j\pi/2},$
Or $I_2' = (A_1 + A_2)\ e^{j\pi/2}$ (5)

With A_1 and A_2 are the amplitudes of antenna currents. I_1 and I_2 are the Input antenna currents. I_1' and I_2' are the output antenna currents [3].

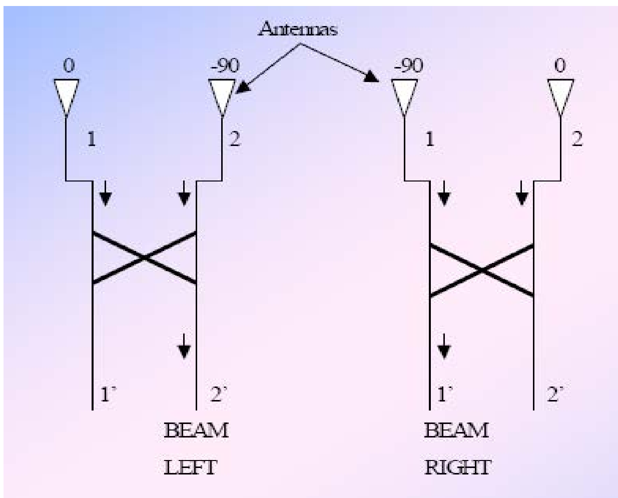


Fig. 1 dephased antennas.

2.1 Definition

First of all it's necessary to set the desired number of beams which is equal to the number of entry ports of the matrix. The various stages of division of power couplers and phase shifters compounds are then used to obtain the phase increments to impose on the network of N elements to achieve the pointing desired. From a network of N elements, the Butler matrix can create a maximum of N different scores. The number of network elements is a power of 2 (N = 2n). The power of n is equal to the number of division levels of power in the Butler matrix. In addition, the top floor is consisting solely of couplers who can excite N/2 elements. As each module has 2 outputs decoupled, the number of couplers on this floor is N / 2 [2].

2.2 Types of the Butler matrix

The Butler matrixes are divided into two types: standard and nonstandard matrixes. Standard matrixes, using 90 ° hybrids, produce beams located on either side of the normal to the plan containing the radiating elements. Nonstandard matrixes, employing 180 ° hybrid, using beams located on either side of the normal to the plan containing the radiating elements, but they also have an extra beam in the principal axis corresponds to the normal of antennas network.

2.3 Components of the Butler matrix

The Butler matrix consists of three components that are the phase shifters, crosses and 3dB couplers. The following figure shows an example of a structure of standard Butler matrix allowing to produce four beams.

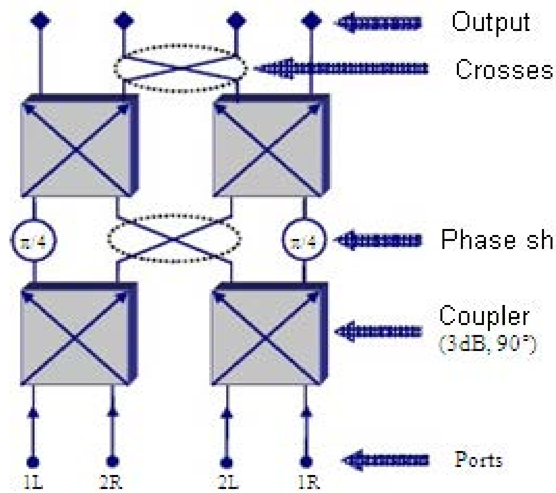


Fig. 2 4*4 Butler Matrix.

- The phase shifters:

We use a passive phase shifter in microstrip technology, to create a phase delay□with a microstrip line over another it's enough to add an extra line length ΔL.

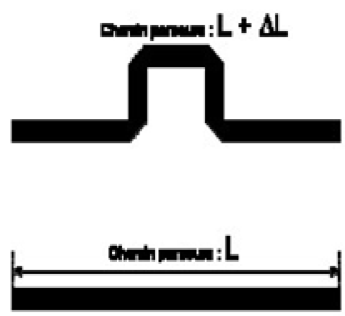


Fig.3 Phase shifters.

- (3 dB, 90 °) Couplers :

These couplers are used to send the half of the input power to each of two output ports, but in phase quadrature. This phase shift is due to the line section of quarter-wave length (λg/4) between ports 3 and 4. The hybrid couplers are often made in microstrip technology.

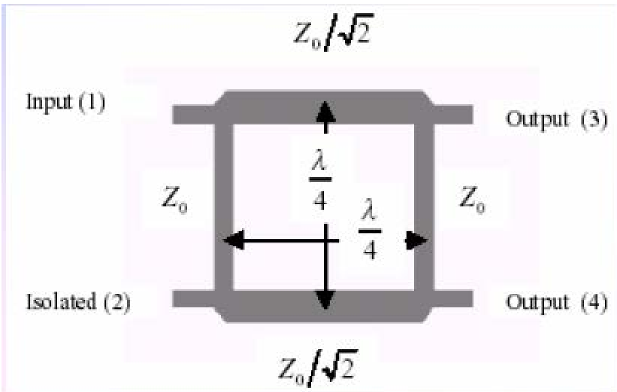


Fig. 4 Branch line coupler.

The different quarter wave sections are present to ensure impedance matching. There are two different sections of quarter-wave line which form the structure of the coupler [4].

- Crosses:

The crosses are replaced by two hybrid couplers (3 dB, 90°) placed end to end. This type of coupler is also called 0dB coupler.

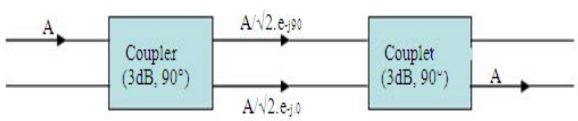


Fig. 5 Hybrid couplers placed end to end.

3. Simulations and Results

The purpose of this part is Application of Butler Matrix to a Tree Structure of Microstrip Antenna Array for a multibeams base station dedicated to a UMTS use. Abor all we will start by simulating the Butler Matrix 4*4.The simulation will be performed using the ADS tool. The substrate used for this simulation is FR4 for a resonant frequency of 2GHz.

3.1 4*4 Butler Matrix

The Butler matrix 4 * 4 consists of four couplers, two phase shifters and a cross (Fig. 2). So we may very well modeled with ADS according to the scheme given in Figure 6.

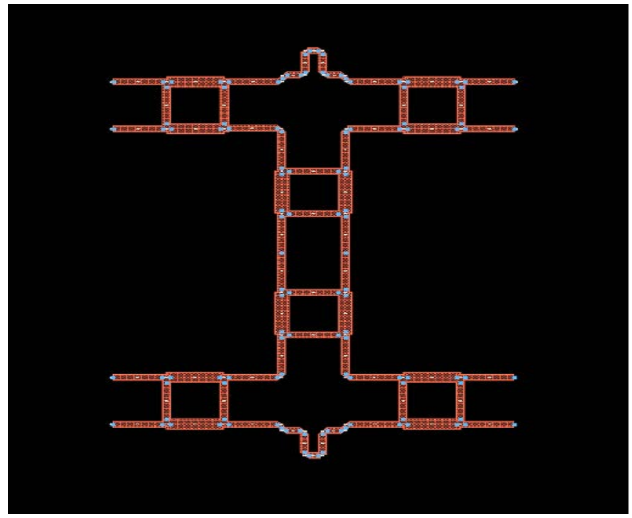
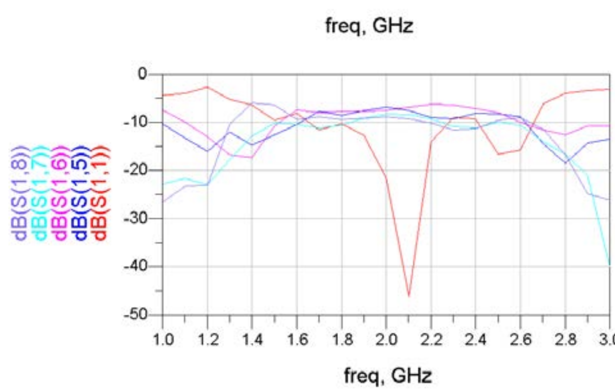


Fig. 6 Layout of 4*4 Butler Matrix.

We judge the functioning of a Butler matrix by its S parameters, although there must have minimum reflection coefficients and transmission coefficients up to verify proper signal transmission.



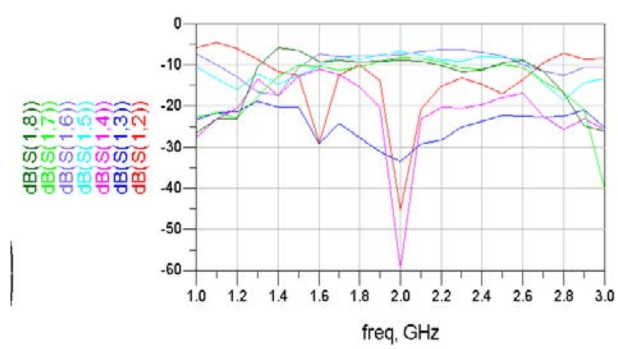


Fig. 7 Simulation results of 4*4 Butler Matrix.

The simulation results show that has a reflection coefficient of -45dB but with an offset frequency of 100 MHz that can be easily adjusted by resizing the matrix.
So for the port 1 the values of the matrix S are given by:

Table 1: S Parameter

S	dB
S11	-21
S12	-45
S13	-33
S14	-59
S15	-6.8
S16	-7.5
S17	-8.3
S18	-8.8

We note that reflection coefficients S11 S12 S13 S14 values are less than -20 dB and transmission coefficients S15 S16 S17 S18 are beyond -10dB which is good for our application. We can also view the phase (figure8) which shows the existence of the phase shift between the different ports.

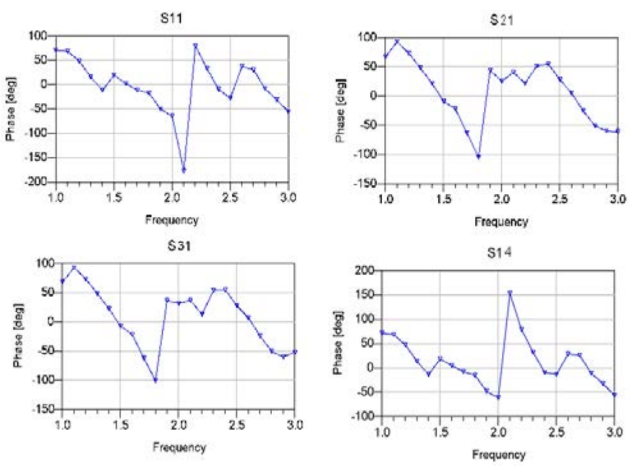


Fig. 8 Phase port for 4*4 Butler Matrix.8.

3.2 The application of the Matrix to the antenna network

In this simulation the antenna array has been developed by introducing circular patches arranged in a t ree structure and supplied by electromagnetic coupling (Figure 9). This array presents an electromagnetic coupling in the E and H planes [5].

This array is considered as a first step to design an adaptive microstrip antenna for UMTS use [6]. The patch distribution structure used in this experiment allowed a great improvement of gain, directivity as well as the adaptation level of the studied array [7].

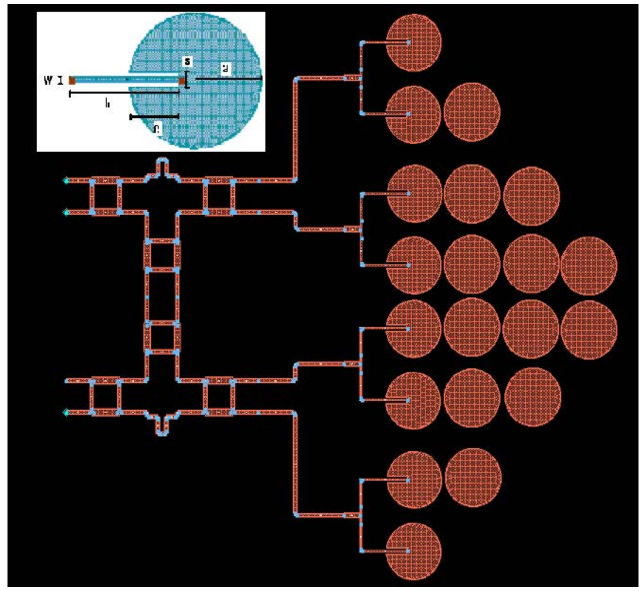


Fig. 9 Microstrip antenna arrays with a tree structure of Patches.

The values of the different parts of the patch and the connecting lines are: a = 20.70mm, b = 34.00mm, c = 15.40mm, w = 1.25mm and s = 4.40mm.
The adaptation quality of an antenna is defined by giving either its characteristic impedance (usually 50 ohms) or its reflection coefficient; Figure 10 shows its value for our array of eight patches at 2 GHz.

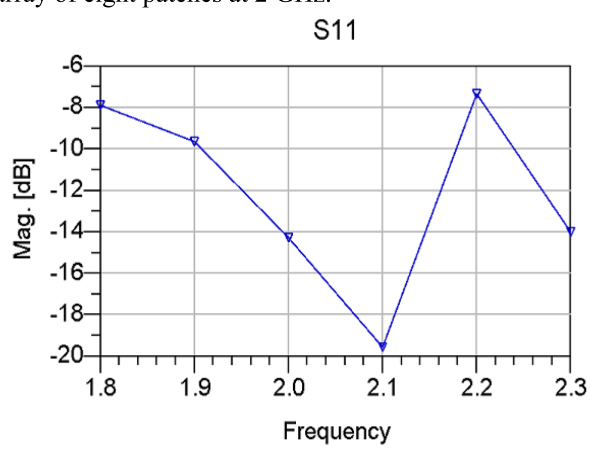


Fig. 10 Simulation results of Microstrip antenna arrays with a tree structure of Patches.

The simulation results show an adaptation coefficient of -14 dB. This array allows a bandwidth of 290 MHz. The graph of phase (figure11) shows the existence of four phase shift between the different ports.

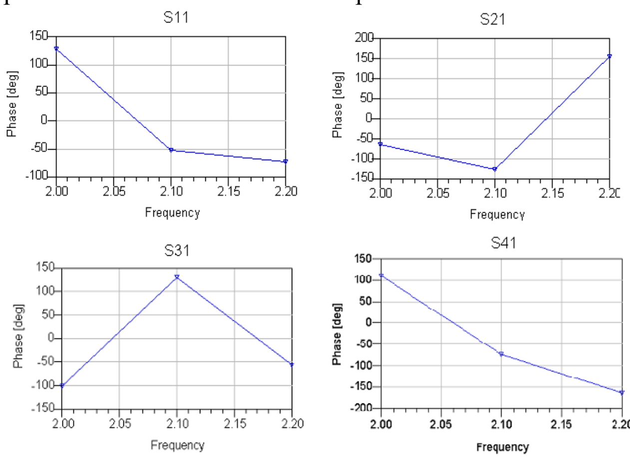


Fig. 11 Phase simulation results of Microstrip antenna arrays with a tree structure of Patches.

The values of different phase shift are given by:

Table 2: values of different phase shift en degrees

Port	***1***	***2***	3	4
Freq 2 GHz	125	-75	-100	110
Freq 2.1GHz	-125	-50	125	-75

The results show the existence of four different scores or the existence of four beams.

4. Conclusions

The ultimate goal of our work is the design of a microstrip adaptive antenna for a base station. This antenna will enable two intelligent functionalities; the electronic scanning and the distribution of the signal as needed for the environment [7]. Until now we could validate the backbone of our antenna and beamformer with a v ery favorable simulation results for our application. In what follows, we still have the validation of the distribution network that role will be awarding the signal according to user needs.

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Tomader Mazri Masters Degree in Microelectronics & Telecommunication systems 2007, Bachelors Degree in Telecommunication 2005. She is currently working toward the Ph.D degree between the signals, systems and components laboratory of FST-Fez and the microwave laboratory of the National Institute of Posts and Telecommunications. His major research interests microwave system and antennas.

Fatima Riouch graduated Engineer in CENAC Toulouse. She is a professor in the National Institute of Posts and Telecommunications Rabat, Morroco. Her major research interests microwave system and antennas.

Najiba El Amrani El Idrissi Received the Ph.D. degrees in Electrotechnics and power electronics from the Mohammedia School of Enginneering in Morocco 2004. She graduated Engineer in the Electrical Engineering specialty Computer Systems in 1984. She is a professor in electrical engineering department at Faculty of sciences and techniques, Fes, Morocco when she obtained the Doctor Title in physics.