

DESIGN OF A BUTLER MATRIX BEAMFORMING CIRCUIT  
AT 28 GHz FOR 5G MOBILE COMMUNICATION

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DESIGN OF A BUTLER MATRIX BEAMFORMING CIRCUIT  
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A project report submitted in partial fulfilment of the  
requirements for the award of the degree of  
Master of Engineering (Electronic And Telecommunication)

Faculty of Electrical Engineering  
Universiti Teknologi Malaysia

JUNE 2018

*Specially dedicated  
to my supervisor and family who encouraged  
me throughout my journey of  
education.*

## ACKNOWLEDGEMENT

I wish to express my deepest appreciation to all those who helped me, in one way or another, to complete this thesis.

First and foremost, I thank God almighty who provided me with strength, direction and showered me with blessings throughout. My sincerest gratitude to my supervisor Dr. Noor Asniza Murad for her continuous guidance and support. With her expert guidance and immense knowledge. I was able to overcome all the obstacles that I encountered during my journey of doing project. I could not have imagine having a better advisor and mentor who has been more like a motherly figure to me.

Secondly, thanks my family for their care and support for me. Thanks to my friends, thank everyone who gave me help and encouragement on my path to growth.

Finally, I would like to express my sincere gratitude to the experts, professors, and teachers who have reviewed this article in full time!

## ABSTRACT

Mobile communication has become prevalent nowadays. The demand for high speed data and information exchange urge on a better communication services. Furthermore, existing services may not able to satisfy the increasing data volume with increasing number of users. The current technology may suffer from congestion and spectrum shortage issue. Thus, 5G is introduced with new spectrum particularly at higher frequencies. However, at high frequencies, a higher propagation loss is expected. The solution is to have a high gain array antenna with particular beamforming features to compensate the high loss. Thus, this work proposes a Butler Matrix beamforming circuit to feed an array at particular 28 GHz for 5G mobile communication. However, the antenna part will not be in the scope of this work. The beamforming circuit will be design, simulate and optimize using CST software. The components namely the coupler, crossover and phase shifter are designed and analyzed separately before integrated to be one Butler Matrix network circuit. Conventional hybrid coupler is designed to operate at desired 28GHz with 90 degrees phase different and equal power divided between the output ports before it is improved with tee junction structure, which reduce the overall dimension without much sacrificing the performances. The coupler then combined to form a crossover with 0 degrees phase different and good isolation. A delay line which give 45 degrees phase shift is designed and connect the structure to form a Butler Matrix beamforming circuit.

## ABSTRAK

Komunikasi mudah alih telah menjadi lazim sekarang ini. Permintaan untuk data berkelajuan tinggi dan pertukaran maklumat menggesa perkhidmatan komunikasi yang lebih baik. Selain itu, perkhidmatan sedia ada mungkin tidak dapat memenuhi peningkatan jumlah data dengan peningkatan bilangan pengguna. Teknologi semasa mungkin mengalami masalah kesesakan dan kekurangan spektrum. Oleh itu, 5G diperkenalkan dengan spektrum baru terutama pada frekuensi yang lebih tinggi. Walau bagaimanapun, pada frekuensi tinggi, jangkaan penyebaran yang lebih tinggi dijangka. Penyelesaiannya adalah untuk mempunyai antena array keuntungan yang tinggi dengan ciri-ciri penyesuaian tertentu untuk mengimbangi kerugian yang tinggi. Oleh itu, kerja ini mencadangkan litar beamforming Butler Matrix untuk memberi makan pada 28 GHz khusus untuk komunikasi mudah alih 5G. Walau bagaimanapun, bahagian antena tidak akan berada dalam skop kerja ini. Litar beamforming akan merancang, mensimulasikan dan mengoptimumkan menggunakan perisian CST. Komponen-komponen seperti coupler, crossover dan shifter fasa direka dan dianalisis secara berasingan sebelum digabungkan menjadi satu litar rangkaian Matriks Butler. Penyambung hibrid konvensional direka untuk beroperasi pada 28GHz yang dikehendaki dengan 90 darjah fasa kuasa yang berbeza dan sama yang dibahagikan antara port keluaran sebelum ia dipertingkatkan dengan struktur simpang tee, yang mengurangkan dimensi keseluruhan tanpa banyak mengorbankan persembahan. Pemasangan itu kemudian digabungkan untuk membentuk crossover dengan 0 darjah fasa berbeza dan pengasingan yang baik. Barisan penangguhan yang memberi pergeseran 45 darjah fasa direka bentuk dan menyambung struktur untuk membentuk litar beamformasi Butler Matrix.

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**LIST OF ABBREVIATIONS**

CST	-	Computer Simulation Technology
BLC		Branch Line Coupler
BFN		Beamforming matrix network

**LIST OF SYMBOLS**

E	-	Energy
dB		Decibel
Hz		Hertz
GHz		Giga Hert
Mm		Millimetre
RF		Radio Frequency
L		Length
W		Width
Z <sub>0</sub>		Characteristic impedance
Z <sub>p</sub>		Load impedance
$\pi$		Pi
$\lambda$		Free-space wavelength
$\epsilon_r$		Dielectric constant of the substrate
t		Patch thickness

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 Background of study**

Future communication system such as 5G mobile communication is moving towards higher frequencies as the higher band may offer greater bandwidth with better speed. However, the system with higher capacity is expected to have higher loss from congestion and overlapping signal. As the mobile users is increasing, 5G must handle more traffic and higher speed. Thus, beamforming technology is believing to help with the new system. The beam can be directed to the desired direction, thus reducing the interference from nearby user. A high directive beam with high gain can be built in integration with massive antenna arrays.

With the rapid development of electronic technology, the smart antenna is playing an increasingly important role in radar and communication systems. The smart antenna technology not only can improve the communication capability of the system, but also can get a better signal to noise ratio system, smart antenna technology mainly includes: beam switching antenna technology [4] and the technology of adaptive antenna. The complex algorithm in adaptive antenna and signal processing technology to make its



response speed slow. And multi-beam antenna is relatively simple to implement and to make its more accurate used [1-5].

In this work, the focus is on the antenna beam forming circuit network. Power in certain proportion assigned to an output port and produces a constant phase difference between adjacent output port, but from different input ports input, The direction of the antenna under each port input phase is different so that lead to the phase difference is diverse.

There are many types of beamforming circuit network, in general, Radio Frequency Beamforming Networks (RF BFN) can be classified in to two types as quasi-optical and circuit types [3]. In this work, Butler matrix is chosen due to its simplicity.

## **1.2 Problem statement**

5G base stations can support large-scale antenna arrays, and the number of configurable antennas even reach 1024, so that there can be more users. To fully exploit the potential of these large-scale antenna arrays, 5G beamforming is absolutely essential. In the spatial propagation process, the quality of wireless signals will be attenuated. This kind of attenuation, called path-loss, can have a huge impact on the communication system. Especially for millimeter-band 5G communication systems, signal attenuation will up to ten times of dB that cause the system cannot work normally.

In this case, the beamforming technology can effectively combat the path loss and use multiple differently directed beams to completely cover the cell. The beamforming technology effectively superimposes signals by adjusting the phase of each antenna to generate stronger signal gain to overcome path loss, thus providing a powerful guarantee for the transmission quality of 5G wireless signals.

### 1.3 Project objectives

Due to the Butler matrix its own structure with the advantages such as flexible, easy to fabric, and its great application prospect. This article is based on the application background of the communication system, this paper proposes a Butler Matrix beamforming circuit to feed a 4x4 array at particular 28 GHz for 5G mobile communication using 28 GHZ butler, 3 dB directional coupler and 45 degree phase shifter, the bandwidth of the matrix feature is determined by the directional coupler and phase shifter. The cross structure, using of different metal layer of cable can solve this proposed design. Thus, the project objectives are:

- i. To design the Branch Line Coupler circuit at 28 GHz that can adapt to the Butler Matrix for antenna beamforming .
- ii. To simulate and analyze the 4x4 Butler Matrix performance of the designed Branch Line coupler by using of CST studio

### 1.4 Scope of work

This project contains of four parts. For the first phase, study the concept of beamforming network and butler matrix technique. In order to understand all the basic theory and concept of the related topic of this project, some research were made in beamforming network using design 4x4 Butler Matrix technique and exploring the function of CST studio 2015. All the material that related to the beamforming, butler matrix and other related this project in books, journals and articles have been collected.

Coupler is the main component in Butler Matrix. Thus, the coupler design was given priority at the beginning of the work. The branch line coupler is designed to have

90 degrees phase different at the output ports with equal power divided. The design parameters of transmission line such as width and length are calculated using standard equations. Two couplers then combined to form a cross-over. The phase shifter is also designed before all components are integrated to form a Butler Matrix network. The 4X4 beamforming network circuit are simulated by using CST studio 2015. The transmission coefficient, isolation and phase difference for each port have been analyzed. The results have been compared between the conventional structure and the improved with reduced size structure.

## **1.5 Project organization**

The following is the introductory chapter, the rest of the thesis organized as follow:

Chapter 2 introduce the recent works for the branch line coupler. An overview of the main and recent technologies used in the designing the BLC will be presented. In addition, an extensive literature review about the BLC and theory.

Chapter 3 introduce the project methodology, the design steps, and the calculations of certain parameters and the process of the design will be discussed.

Chapter 4 introduce the steps of the proposed BLC compared with the conventional BLC, the designed BFN compared with the conventional BFN, the simulation results for both design will be presented in this chapter.

Chapter 5 provides a conclusion of the project and suggestion for future works related to this project.

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