View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Universiti Teknologi Malaysia Institutional Repository

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

ZHANG BEI BEI

UNIVERSITI TEKNOLOGI MALAYSIA

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

ZHANG BEI BEI

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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
Z0		Characteristic impedance
Zp		Load impedance
π		Pi
λ		Free-space wavelength
&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.

Reference

[1] El-Tager, A. and M. Eleiwa. Design and implementation of a smart antenna using butler matrix for ISM-band. in Progress In Electromagnetics Research Symposium, Beijing, China. 2009.

[2] Djerafi, T., N.J. Fonseca, and K. Wu. Design and implementation of a planar 4× 4 butler matrix in SIW technology for wideband applications. in Microwave Conference (EuMC), 2010 European. 2010. IEEE.

[3] Ch n, C.-J. and T.-H. Chu, Design of a 60-GHz substrate integrated waveguide Butler matrix—A systematic approach. IEEE Transactions on Microwave Theory and Techniques, 2010. 58(7): p. 1724-1733.

[4] Wang, Y., et al., 5G mobile: Spectrum broadening to higher-frequency bands to support high data rates. IEEE Vehicular technology magazine, 2014. 9(3): p. 39-46.

[5] Ullah, H., F.A. Tahir, and M.U. Khan. Dual-band planar spiral monopole antenna for 28/38 GHz frequency bands. in Antennas and Propagation & USNC/URSI National Radio Science Meeting, 2017 IEEE International Symposium on. 2017. IEEE.

[6] Errifi, H., et al., DESIGN AND SIMULATION OF A PLANAR TOPOLOGY BUTLER MATRIX FOR 10 GHZ SWITCHED MULTIBEAM ANTENNA.

[7] Djerafi, T., N.J. Fonseca, and K. Wu, Design and implementation of a planar 4x4 butler matrix in SIW technology for wide band high power applications. Progress In Electromagnetics Research B, 2011. 35: p. 29-51.

[8] P. Wounchoum, D. Worasawate, C. Phongcharoenpanich, and M. Krairiksh, “A Switched-Beam Antenna Using Circumferential-Slots on a Concentric Sectoral Cylindrical Cavity Excited by Coupling Slots,” Progress in Electromagnetics Research-PIER, vol. 120, pp. 127-141, 2011.

[9] Z. Chen and Y. P. Zhang, “FR4 PCB grid array antenna for millimeter-wave 5G mobile communications,” in IEEE MTT-S International Microwave Workshop Series on RF and Wireless Technologies for Biomedical and Healthcare Applications (IMWS-BIO), pp. 1-3, 2013.

[10] M. R. Akdeniz, Y. P. Liu, M. K. Samimi, S. Sun, S. Rangan, T. S. Rappaport, "Millimeter Wave Channel Modeling and Cellular Capacity Evaluation," IEEE Journal on Selected Areas in Communications, vol. 32, pp. 1164-1179, Jun 2014.

[11] S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges," IEEE Proceedings, vol. 102, pp. 366-385, 2014.

[12] T.Rappapor, "The Cellular Concept System Design Fundamentals," Wireless Communications Principles and Practice, pp. 57-104, 2006.

[13] Djerafi, T. and K. Wu, Multilayered substrate integrated waveguide 4× 4 Butler matrix. International Journal of RF and Microwave Computer-Aided Engineering, 2012. 22(3): p. 336-344.

[14] D.Sanchez-Escuderos,M.Ferrando-Bataller,M.Baquero-Escudero, and J. I. Herranz, “Reconfigurable Slot-Array Antenna With RF-MEMS,” IEEE Antennas and Wireless Propagation Letters, vol. 10, pp. 721-725, 2011.

[15] F. Y. Zulkifli, N. Chasanah, Basari, and E. T. Rahardjo, "Design of Butler matrix integrated with antenna array for beam forming," in 2015 International Symposium on Antennas and Propagation (ISAP), 2015,pp. 1-4.

[16] M. Fernandes, A. Bhandare, C. Dessai, and H. Virani, "A wideband switched beam patch antenna array for LTE and Wi-Fi," in India Conference (INDICON), 2013

[17] H. Nachouane, A. Najid, A. Tribak, and F. Riouch, "Broadband 4× 4 Butler matrix using wideband 90° hybrid couplers and crossovers for beamforming networks," in Multimedia Computing and Systems (ICMCS), 2014 International Conference on, 2014, pp. 1444-1448.

[18] S. I. Orakwue, R. Ngah, T. Rahman, and H. Al-Khafaji, "A 4× 4 Butler Matrix for 28 GHz Switched Multi-Beam Antenna," International Journal of Engineering and Technology, vol. 7, 2015.

[19] N. C. T. Desmond, "Smart antennas for wireless applications and switched beamforming," University of Queensland, 2001.B. Sahu, "Design and Implementation of 4x4 Butler Matrix."

[20] M. M. Alam, "Microstrip antenna array with four port butler matrix for switched beam base station application," in Computers and Information Technology, 2009. ICCIT'09. 12th International Conference on, 2009,pp. 531-536.

[21] G. ADAMIDIS and I. VARDIAMBASIS, "Design and Implementation of a 4x4 Butler-Matrix Switched-Beam Antenna Array at the Microwave Communications and Electromagnetic Applications Lab of the Technological Educational Institute of Crete."

[22] Shaikh, F. and M. S. B. Akhade, “Smart Antenna System using 4x4 Butler Matrix switched beam network for 2.4 GHz ISM band."

[23] David M. Pozar, “Microwave Engineering”, Wiley, 3rd edition, New York, 2005.

[24] T. Djerafi, N. J. G. Fonseca, and K. Wu, "Design and implementation of a planar 4x4 butler matrix in SIW technology for wideband applications," in The 40th European Microwave Conference, 2010, pp.910-913.

[25] O. U. Khan, "Design of X-band 4x4 Butler Matrix for Microstrip Patch Antenna Array," in TENCON 2006 - 2006 IEEE Region 10 Conference,2006, pp. 1-4.

[26] S. Johnosono, T. Fujii, and I. Ohta (2006) , Design of broadband CPW Branch line 3~dB couplers, in Proc. 36th Eur. Microw. Conf., Sep. 2006 , pp. 36-39.

[27] D.Wang, A. Huynh, P. Hakansson, M. Li, and S. Gong (2008), Study of wideband microstrip 90 3-dB two-branch coupler with minimum amplitude and phase imbalance, in Proc. Int. Conf. Microw. Millim. Wave Technol., 2008, pp. 116-119.

[28] T. Kawai, H. Taniguchi, I. Ohta, and A. Enokihara (2010)，Broadband branch line coupler with arbitrary power split ratio utilizing microstrip series stubs, in Proc. 40th Eur. Microw. Conf., 2010, pp. 1170-1173.

[29] C. H. Ho, F. Lu，and K. Chang (1993)，Broad-band uniplanar hybrid-ring and branch-line couplers, DEEE Trans. Microw. Theory Tech., vol. 41, no. 12, pp. 2116—2125, Dec. 1993.

[30] 26 T Jensen, V. Zhurbenko, V. Krozer, and P. Meincke (2007)，Coupled transmission lines as impedance transformer, IEEE Trans. Microw. Theory Tech., vol. 55，no. 12, pp. 2957-2965, Dec. 2007

[31] Susmita Das (Smart Design/or Wireless Communication Adaptive Beam-forming Approach, Microwave, antenna, propagation and EMC Technologies for Wireless Communication (2009).

[32] Bow-Tie (2009), Antenna for GSM/CDMA and 3G/WLAN, Microwave, antenna propagation and EMC Technologies for Wireless Communication, 2007 International symposium on 16-17 Aug. 2007 Page(s): 504 — 507.

[33] Balasem S.S，S.K.Tiong, S. P. Koh (2012), Beamforming Algorithms Technique by Using MVDR and LCMV World Applied Programming, Vol (2), Issue (5), May 2012. 315-324.

[34] David M.Pozar (2012), Microwave Engineering, Vol 4，JohnWiley & Sons, Inc 2012.

[35] Kwok-Keung, M. Cheng (2004), A Novel Approach to the Design and Implementation of Dual-Band Compact Planar 90 Branch-Line Coupler, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 52, NO. 11, NOVEMBER 2004.

[36] Jyan-Han Vu, Ju-Ching Cheng, and Yi-Hsin Pang (2011)，Design of a Dual-Band Miniaturized 90° Branch Line Coupler with Coupled Lines, proceedings of the Asia-Pacific Microwave Conference 2011.

[37] F. T. Ulaby, E. Michielssen and U. Ravaioli (2010)，Fundamentals of Applied Electromagnetics (6th Edition), Prentice Hall, 2010.

[38] R. Ludwig and G. Bogdanov (2008)，RF Circuit Design: Theory & Applications (2ndEdition), Prentice Hall, 2008.

[39] S. S. Mohan, M. del Mar Hershenson，S. P. Boyd and T. H. Lee (1999)， Simple Accurate Expressions for Planar Spiral Inductances, IEEE Journal of Solid-State Circuits, pp. 1419-1424,1999.

[40] M. Muraguchi, T. Yukitake, and Y. Naito (1983)，Optimum design of 3 dB branch-line couplers using microstrip lines, IEEE Trans. Microw. Theory Technology MTT-31, no. 8，pp. 674-678, Aug. 1983.

[41] C. Montgomery, R. Dicke, and E. M. Purcell (1984)，Principles of Microwave Circuits，ser. Radiation Laboratory Series. New York: McGraw-Hill, 2008..

[42] 19 G P Riblet (1978), A directional coupler with very flat coupling, IEEE Trans. Microw. Theory Tech., vol. MTT-26, no. 2，pp. 70-74, Feb. 2007.

[43] 2q a. s. Wright and S. K. Judah (1987), Very broadband flat coupling hybrid ring, Electron. Lett" vol. 23，pp. 47-49, Jul. 1987.

[44] 21. B. Mayer and R. Knochel (1990)，Branch line-couplers with improved design flexibility and broad bandwidth, in IEEE MTT-S Int. Dig.，May 1990, vol. 1, pp. 391-394.