A 4 × 4 Butler Matrix for 28 GHz Switched Multi-Beam Antenna

Stella Ifeoma Orakwue [#1], Razali Ngah[#2], T. A. Rahman[#3], and Hamza M. R. Al-Khafaji[# 4]

[#]Wireless Communication Centre, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia
[1] ifystan2007@yahoo.com
[2] razalin@fke.utm.my
[3] tharek@fke.utm.my
[4] hamza@utm.my

Abstract— In this paper, a 4 × 4 Butler matrix (BM) switched-beam patch antenna array is designed and discussed. The design is developed on a single layer of Rogers material; RO 5880 with dielectric constant 2.2 and thickness 0.254mm.This makes the designed antenna low cost and easy of fabrication. The four rectangular patches fed by inset microstrip lines are connected to the outputs of the BM. The results show wide bandwidth that covers from 24.67 GHz to 30.2 GHz in all the four inputs, and the highest array gain performance of 10.8 dBi at 28 GHz. The designed switched beam antenna provides a cost effective approach to implement at 28 GHz wireless communications.

Keyword- Butler matrix, microstrip patch antennas, millimeter wave antenna arrays, switched beam antenna.

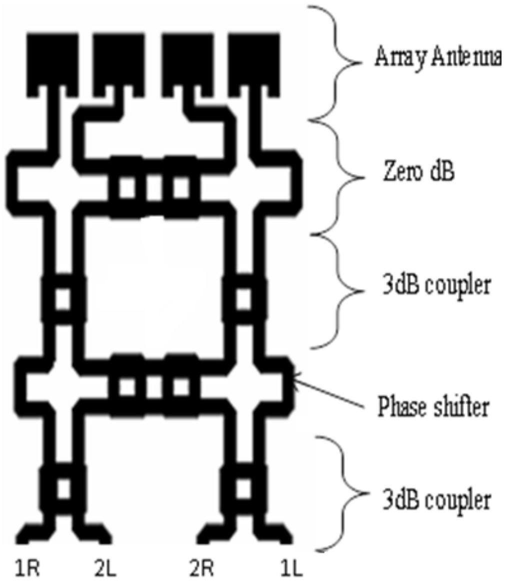
I. INTRODUCTION

The continuous growth of traffic in mobile communication has recently leads to recommendation of millimetre wave frequency band for 5G wireless applications [1-3]. Due to the high propagation losses at millimetre wave, it will be difficult to use either omnidirectional antenna or fixed beam antenna [4]. To overcome these problems, several studies have recently been conducted using switchable antennas for increasing signal in the desired direction while rejecting the interfering signals thereby enhancing capacity and quality of service [5]. Smart antenna can be divided in two categories: adaptive antenna array and switched beam systems. An adaptive antenna array uses digital signal processing and adaptive algorithm to automatically steer the beam to the desired direction, while creating nulls to the interferer which results in a better signal to interference ratio but at the expense of high cost due to the complexity of implementation. However, switched beam antenna can be implemented at less cost to achieve most of the features of adaptive array including the beam steering capability [6]. A switched beam system produces multiple narrow beams and selects from them the appropriate beam that gives the strongest signal level.

The application of Butler matrix (BM) beamformer in millimetre wave, has been proposed by many researchers due to its simplicity and low power loss [7-9]. BM is a widely known beamformer network in switched beam antenna system. Patch antenna with attribute of light weight, low profile and easy of fabrication are highly desired for wireless communication. In this paper, the conventional BM is adapted but the input ports are amended to allow free connection of the ports because at very high frequency, the size of the BM is too small that the ports are too close to each other. The proposed BM is integrated with four elements of a microstrip array patch antenna structure. The achieved return loss range from 24.67 GHz to 30.2 GHz and the highest gain performance is 10.8 dBi at 28 GHz. Section II presents the implementation of BM and the designed antenna. Then, Section III shows the results and discussions. Finally, conclusions are offered in Section IV.

II. IMPLEMENTATION OF BUTLER MATRIX AND ANTENNA

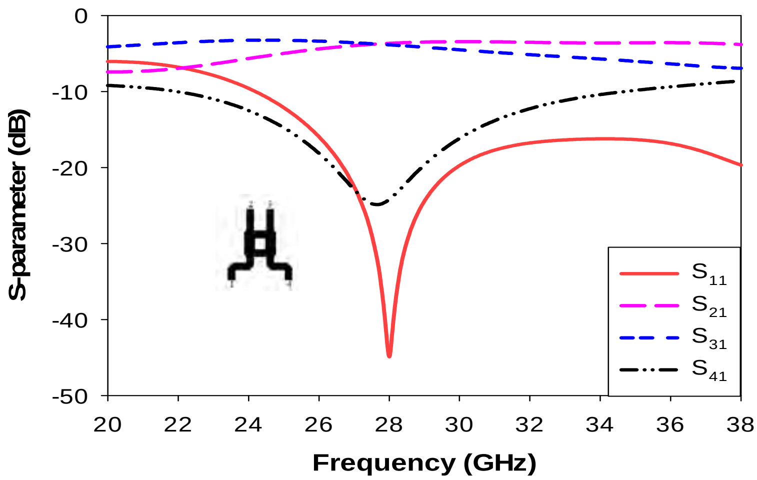
BM commonly employs the combination of directional couplers, crossovers, and phase shifters to control phases and amplitudes of the excitation for the beam forming network. The layout of the designed antenna with BM beamformer is shown in Fig. 1. It is a 4 × 4 BM and consists of four directional coupler, two phase shifters, and a crossover. The conventional branch-line coupler structure is adapted but the input ports are extended to apply it in millimetre wave frequency. The transmission lines of the input ports are extended to accommodate the feed connectors. Extending the transmission lines of the input ports, changes the phase but the branch parameters are adjusted to achieve the desired result. Rogers material RO5880 substrate with dielectric constant of 2.2 and thickness of 0.254 mm is applied to achieve BM at 28 GHz frequency. The conductor coating thickness is 0.0175 mm. The transient field analysis and radiation pattern calculations are done by the transient solver in computer simulation technology (CST) microwave studio.



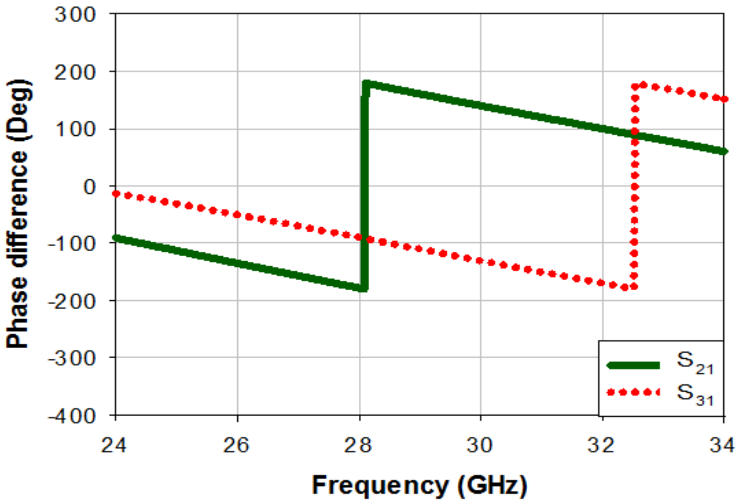
III. RESULTS AND DISCUSSIONS

The required magnitude and phase are obtained starting from the coupler to the crossover and then the 45 degrees phase shifter. The designed individual components are integrated together to form the BM beamformer of Fig. 1. Fig. 2 shows the magnitude and phase of the designed branch line coupler (BLC). The design adapts the conventional BLC but modified the input ports. By extending the input port, there is a change in phase which was accommodated by changing the branch parameters.

Fig. 2(a) shows the simulated return loss, coupling, insertion loss and isolation of the proposed BLC. The coupling and insertion loss (S_{31} and S_{21}) are 3.84 dB and 3.64 dB respectively at the operating frequency of 28 GHz which are within the acceptable limits. The return loss and isolation (S_{11} and S_{41}) of 44.9 dB and 24.2 dB are obtained which is far better than S11 of less than 38 dB that shown in [10]. Furthermore, the phase differences between port 2 and port 3 is 88.8 degrees at the designed frequency.



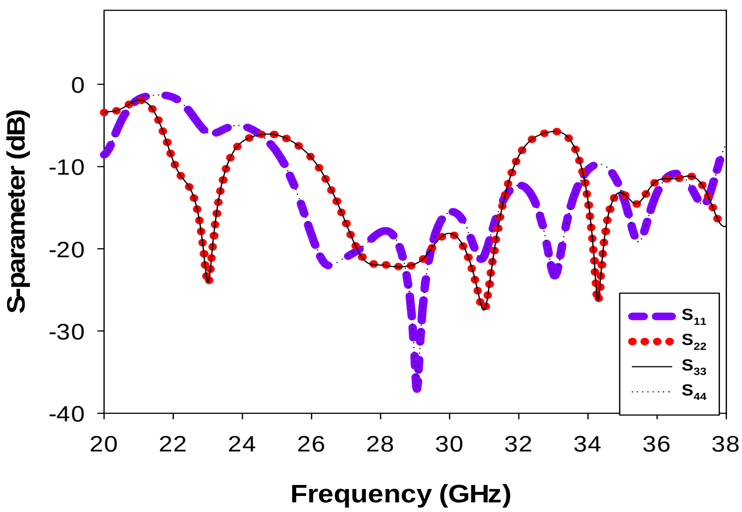
(a)



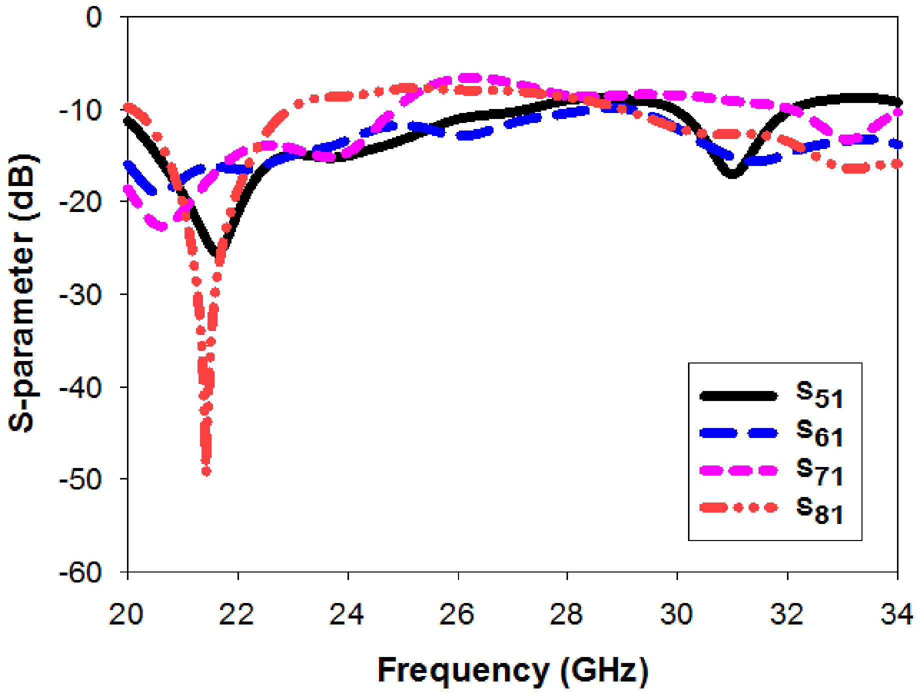
(b)

Fig. 2. The frequency characteristics of the designed antenna:
(a) magnitude, (b) phase difference.

Fig. 3 shows the simulated return loss and transmission coefficients of port1 of the BM. From Fig. 3(a), the return loss is better than 10 dB from 24.67 GHz to 30.2 GHz in all the input ports. Fig. 3(b) presents the insertion loss when fed to port 1. As can be seen the insertion loss are approximately constant across the operation frequency. There are little differences due to different path lengths and possible mismatches along the line.



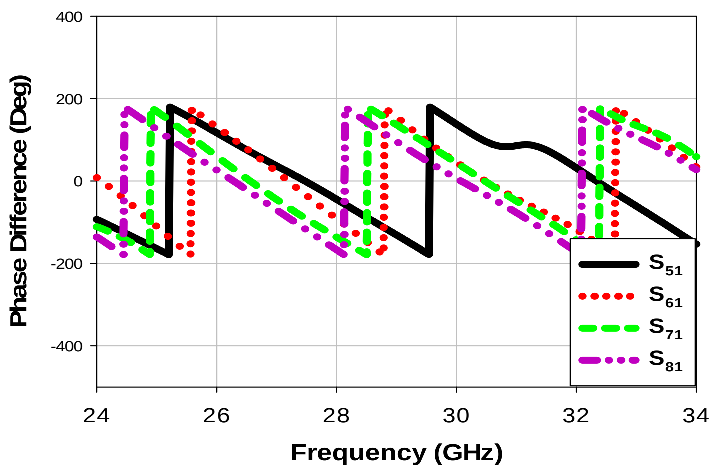
(a)



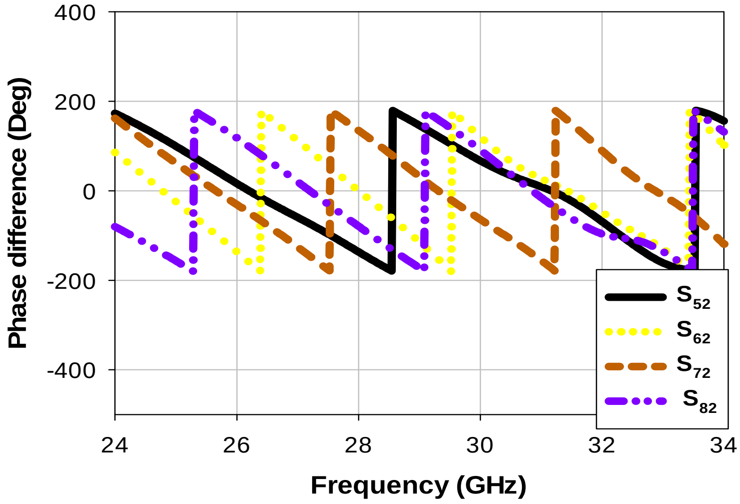
(b)

Fig.3 Simulated S-parameter of the proposed BM:
(a) return loss , (b) insertion loss.

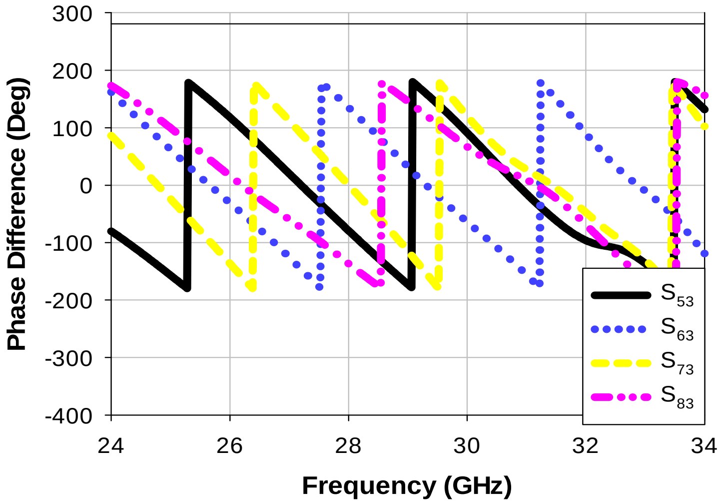
Fig. 4 shows the simulated phase shift characteristics at the different output ports. The phase difference of 88.8 degree is achieved at the designed frequency.



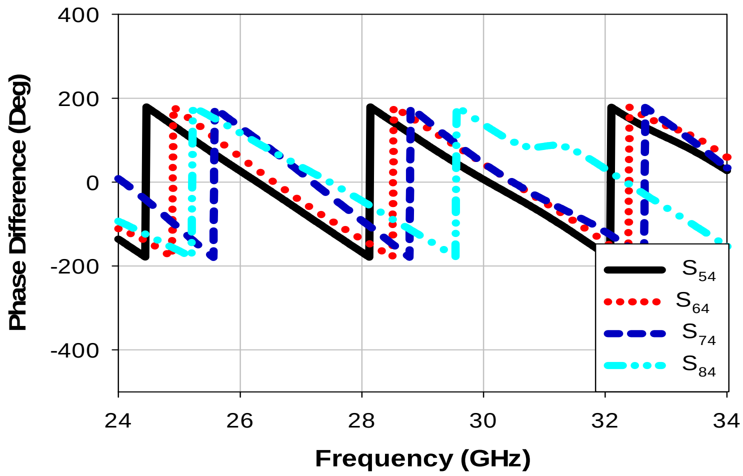
(a)



(b)



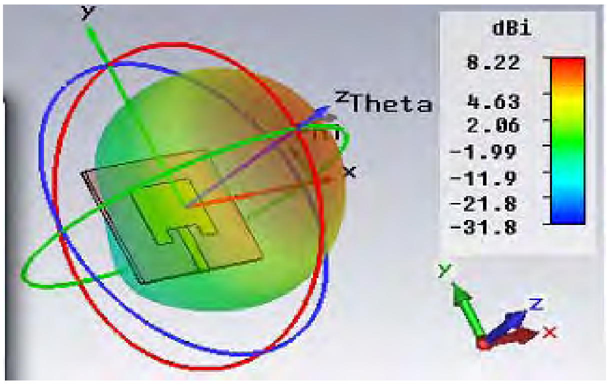
(c)



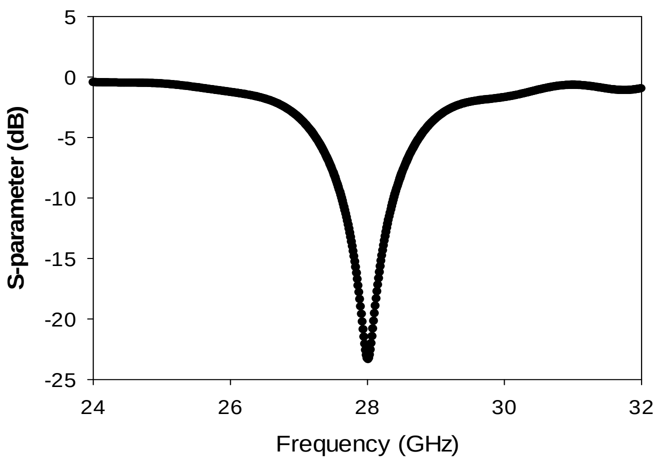
(d)

Fig. 4 Simulation phase difference results of the output ports of the BM:
(a) output ports with respect to input port 1, (b) output ports with respect to input port 2,
(c) output ports with respect input port 3, (d) output ports with respect of input port 4.

A single antenna is designed with the same material to operate at 28 GHz and also integrated to the beamformer and simulated. The inter element distance of 0.5λ is used. Fig. 5 shows the radiation pattern and return loss of the designed antenna at 28 GHz operation frequency. The gain of 8.22 dBi is obtained for a single patch antenna, but when integrated as an array the maximum gain of 10.8 dBi is achieved.



(a)



(b)

Fig.5 Performance of patch antenna designed at 28 GHz:
(a) Radiation pattern (b) the return loss.

IV. Conclusions

A 28 GHz switched beam antenna with BM beamformer has been demonstrated. The obtained result showed that the antenna can cover from 24.67 GHz to 30.2 GHz with the highest array gain performance of 10.8 dBi at 28 GHz. The simulated results of the designed 4 × 4 BM demonstrated a good performance at the 28 GHz operating frequency in terms of S-parameters and phase differences. The beam can be switched toward different directions by switching any of the input ports.

Acknowledgment

The authors would like to express their gratitude to Ministry of Higher Education (MOHE) in Malaysia and UTM for providing the financial support for this research through the GUP Grant (Q.J130000.2523.05H00). The grant is managed by Research Management Centre (RMC) at UTM.

Reference

[1] 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.

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

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

[4] K.-C. Huang and D. J. Edwards, "Millimetre Wave Antennas for Gigabit Wireless Communications: A Practical Guide to Design and Analysis in a System Context" John Wiley & Sons, 2008.

[5] H. Wonbin, B. Kwang-Hyun, L. Youngju, K. Yoongeon, and K. Seung-Tae, "Study and prototyping of practically large-scale mmWave antenna systems for 5G cellular devices", IEEE Communications Magazine, vol. 52, pp. 63-69, 2014.
[6] C. A. Balanis, "Antenna theory analysis and design", John Wiley & Sons, 2012.
[7] Y. S. Jeong and T. W. Kim, "Design and Analysis of Swapped Port Coupler and Its Application in a Miniaturized Butler Matrix", IEEE Transactions on Microwave Theory and Techniques, vol. 58, pp. 764-770, Apr 2010.
[8] M. Elkhouly, Y. F. Mao, C. Meliani, J. C. Scheytt, and F. Ellinger, "A G-Band Four-Element Butler Matrix in 0.13 mu m SiGe BiCMOS Technology", IEEE Journal of Solid-State Circuits, vol. 49, pp. 1916-1926, Sep 2014.
[9] C. J. Chen and T. H. Chu, "Design of a 60-GHz Substrate Integrated Waveguide Butler Matrix-A Systematic Approach", IEEE Transactions on Microwave Theory and Techniques, vol. 58, pp. 1724-1733, Jul 2010.
[10] T. Chao-Hsiung, C. Chih-Jung, and C. Tah-Hsiung, "A Low-Cost 60-GHz Switched-Beam Patch Antenna Array With Butler Matrix Network", IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 432-435, 2008.

AUTHOR PROFILE

\ 

Stella Ifeoma Orakwue obtained B.E in Electrical Electronic Engineering and M.E in Electronic and Communication Engineering from UAM and Nnamdi Azikiwe University, Awka, Anambra State Nigeria in 1998 and 2005 respectively. She had worked with Radio Nigeria and Anambra State University Uli, both in Nigeria. She is presently undergoing PhD research at Universiti Teknologi Malaysia with study leave from her present place of work at University of Portharcourt, River State Nigeria. Her research interest is on application of machine learning in antenna beam steering, and antenna design for future generation wireless communication.

Assoc. Prof. Dr. Razali Ngah received the B.E. degree in Electrical Engineering from Universiti Teknologi Malaysia (UTM), Malaysia, M.Sc. degrees in Radio Frequency Communication Engineering from University of Bradford, United Kingdom, in 1989 and 1996, respectively, and the Ph.D. degree from the University of Northumbria, United Kingdom, in 2005. Since 1989, he has been with the Faculty of Electrical Engineering, UTM, where he is currently an Associate Professor. He is also the Deputy Director of Wireless Communication Centre in UTM. His research interests include antennas and propagation for communications, radio over fiber and photonic networks.

Prof. Dr. Tharek Abd Rahman is a Professor at Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM). He obtained his BSc. in Electrical & Electronic Engineering from University of Strathclyde UK in 1979, MSc in Communication Engineering from UMIST Manchester UK and PhD in Mobile Radio Communication Engineering from University of Bristol, UK in 1988. He is the Director of Wireless Communication Centre (WCC), UTM. His research interests are radio propagation, antenna and RF design and indoors and outdoors wireless communication. He has also conducted various short courses related to mobile and satellite communication to the Telecommunication Industry and government body since 1990. He has a teaching experience in the area of mobile radio, wireless communication system and satellite communication. He has published more than 250 papers related to wireless communication in national/international journal and conference.

Dr. Hamza Mohamed Ridha Al-Khafaji was born in 1982, in Baghdad. He received the B.Sc. degree in electronic and communications engineering and the M.Sc. degree in modern communications engineering in 2004 and 2007, respectively, from Nahrain University, Baghdad, Iraq. In 2014, he obtained his Ph.D. degree in communications engineering from Universiti Malaysia Perlis (UniMAP), School of Computer and Communication Engineering. He has five years working experience as a senior BSS engineer in Huawei Technologies and Omnnea Wireless Telecom, Iraq from 2006 until 2010. He has published scientific papers and also served as a reviewer in many international journals and conferences. He is a member of IEEE, IEICE, IAENG, IACSIT, and the editorial board in several international journals. His research interests are in both wireless and optical fiber communications systems. Currently, he is a post-doctoral research fellow in Wireless Communication Centre (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Malaysia. He is continuous in bringing new ideas to scientific research, combating the limitations, and seeking the next big things!