Planar SIW Diplexer Using Circular Cavity Resonator

N. H. Baba, member, IEEE, A. H. Awang, member, IEEE, M. T. Ali, Senior member, IEEE, and H. M. Hizan, member, IEEE

***Abstract*—This paper presents a new design of planar diplexer based on substrate integrated waveguide single mode filters with circular cavity. The diplexer consists of two bandpass filters. The design is based on Substrate Integrated Waveguide (SIW) substrate fabricated by printed circuit board technique. The individual bandpass filters using the TM_{010} mode SIW circular resonator were designed at 2.2 GHz and 2.4 GHz. The simulation return losses for the lower and upper channels are greater than 20.94 dB and 30.92 dB respectively. The minimum insertion losses obtained are 0.87 dB and 0.74 dB at each band. The diplexer provides isolation better than 15 dB at both channels. The simulation results are in good congruent with the ideal electrical modelling response. The proposed SIW diplexer has a promising application for the uplink/downlink RF front end subsystem that is essential for wireless communications systems.**

***Index Terms*— circular resonator, diplexer, power divider, substrate integrated waveguide**

I. Introduction

Waveguide diplexers or multiplexers are indispensable components in RF/microwave wireless communication systems. They are also widely employed to all types of communication systems such as microwave and millimeter-wave applications. Their applications are used to filter between wanted and unwanted signal frequencies. Diplexers and filters that are manufactured separately in conventional design are bulky in size thus uses more materials and space in fabrication process. In order for them to connect with each other, there is in need of transmission line and other matching circuits which will contribute to losses. This is when they come up with miniaturized filters and diplexers structure that are integrated into substrates resulting in smaller and compact but capable of operating with the same performance [2].

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N.H. Baba, Aziati H. Awang. M.T Ali are with Universiti Teknologi MARA Malaysia, Faculty of Electrical Engineering, 40450 Shah Alam, Selangor, Malaysia (e-mail: nhasimah@salam.uitm.edu.my).

H.M. Hizan is with Advanced Physical Technologies Lab, Telekom Research & Development SdnBhd, Cyberjaya, Selangor, Malaysia..

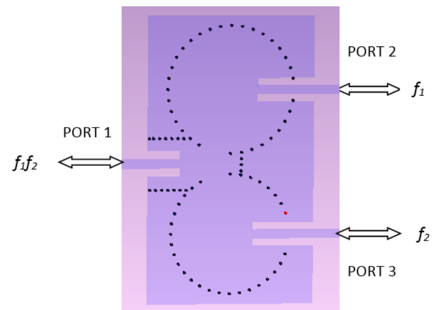


Fig. 1: Operation principle of the proposed SIW diplexer.

In general, the diplexer and its operation principle are shown in Fig. 1. Diplexer is a two-way three-port network used to separate a common input into two different output frequencies. In transmitting mode, two signals with different frequencies are injected in port 1: one of them exits from port 2, while the other one from port 3. In receiving mode, port 2 and 3 receive two different signals, which exit from port 1. A waveguide or its cavity, when it is synthesized in a planar substrate-based circuit and the propagating waves are constrained by linear arrays of metallic vias, is then referred to as a substrate integrated waveguide (SIW). Its basic structure is similar to a microstrip structure but it works in TE or TM modes, instead of the quasi-TEM mode of microstrip line.

Many work have been carried out to replace all-metallic waveguide structures to SIW circuits. The first device manufactured in SIW was a filter by Deslandes and Ke Wu [1]. Paper [2] presented a compact SIW diplexer design employing two cross coupling filters combined using a circulator designed with metal inductive window. In [3] a design of K-band SIW diplexer is introduced using an efficient Mode-Matching Technique which operates at a significantly higher frequency. The SIW offers advantages such as high Q factor, low insertion loss, low cost and high power-handling capacity [4,5]. Apart from the well-known advantages, this technique widely appears in various subsystems such as filters, couplers, power dividers, and antennas [6-11]. However, the main drawbacks of SIW are when a single row of vias is used, the leakage loss can be substantial. This leakage limits the isolation between adjacent resonators, producing small but non-zero coupling coefficients. In this paper, the performance of the first order diplexer was investigated by simulation. The electrical and physical modelling were attained using ADS software and the full-wave EM simulator CST, respectively. The results of simulation were compared.

II. DIPLEXER DESIGN

A. Circuit Synthesis

The synthesis and design techniques of a 2.2 GHz and 2.4 GHz diplexer is proposed and demonstrated employing SIW technology. The diplexer is synthesized from the generalized low-pass prototypes Chebyshev configurations. The working mode for the diplexer is TM_{010} mode. Firstly, individual bandpass filters using the TM_{010} mode SIW circular resonator were designed at 2.2 GHz and 2.4 GHz. Then, the two filters are combined together to work as diplexer. Normally, the diplexer employs a 3-port device to connect the two filters thus for feeding the two filters, a microstrip T-junction power divider is used. 50-Ohm microstrip lines with inset feed are used to directly excite the filters. Simulated results are presented and compared.

A network that meets Table 1 design specification is synthesized using standard filter theory starting with a low-pass filter [12]. Then the lowpass prototype is transformed into bandpass filter at the desired frequencies with -10 dB passband return loss bandwidth of 20 MHz. The lumped element equivalent circuit of the first-order diplexer is shown in Fig. 2. The circuit was built and simulated in ADS. This network consists of two bandpass filters coupled with the admittance inverters J01 and J12 used as the input and output coupling of the filter which is designed to operate from a normalized 1 ohm generator into a 1 ohm load.

TABLE 1. FIRST-ORDER TM_{010} SIW FILTER SPECIFICATIONS

Centre frequency, f_0	2.2 GHz and 2.4 GHz
Passband bandwidth (PBW)	20 MHz
Passband return loss (L_R)	≥ 10 dB
Stopband insertion loss (L_A)	> 10 dB at f_0 ±100MHz (SBW)
Order, N	1

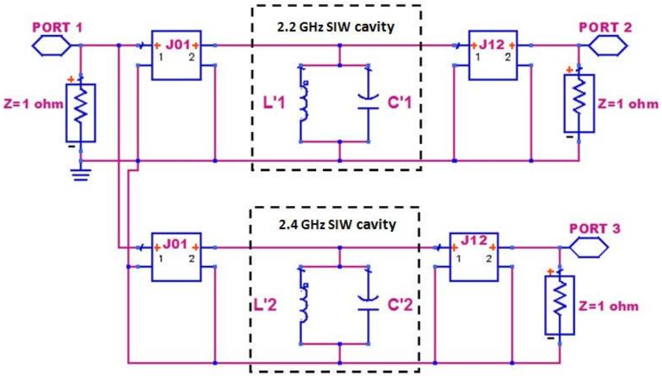


Fig. 2: Lumped element equivalent circuit for the diplexer

The shunt connected resonators are calculated using equations (1)-(4), as shown below:

$$L_1' = \frac{1}{\alpha C_{1\omega_0}} \quad (1)$$

$$C_1' = \frac{\alpha C_1}{\omega_0} \quad (2)$$

$$\alpha = \frac{f_0}{PBW} \quad (3)$$

$$\omega_0 = 2\pi f_0 \quad (4)$$

where α is the bandwidth scaling factor and ω_0 is the midband frequency. All the element values for the diplexer are shown in Table 2.

TABLE 2. ELEMENT VALUES FOR SINGLE-MODE DIPLEXER

Element	Value (2.2 GHz)	Value (2.4 GHz)
$L'_1 = L'_2$	**0.9865 pH**	**0.8289 pH**
$C'_1 = C'_2$	**5.3052 nF**	**5.3052 nF**
$J_{01} = J_{12}$	**1**	**1**

Based on the simulation results depicted in Fig. 3 and 4, both output ports (Ports 2 and 3) have more than 20 dB of isolation between each other and very good transmission (S_{21} and S_{31}) characteristics to input Port 1 having center frequencies at 2.2 GHz and 2.4 GHz with 10 dB passband return loss bandwidth of 20 MHz. The reflection characteristics in Fig. 5 suggest that only less than -10 dB of the input signal is reflected off of Port 1 for the two designed frequency bands.

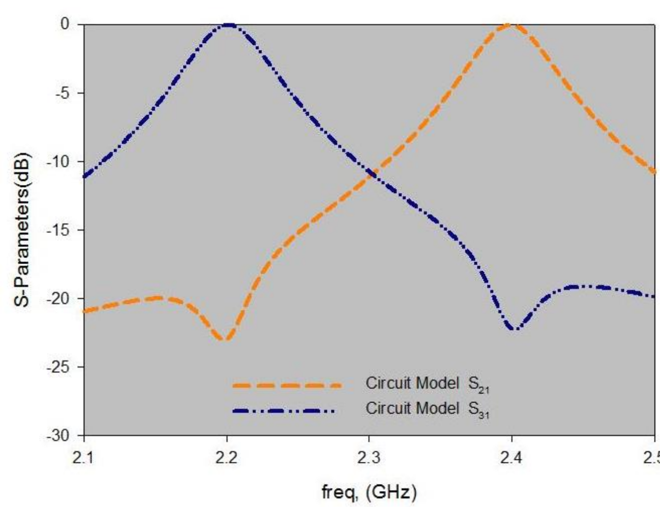


Fig. 3: Circuit model transmission between outputs and input

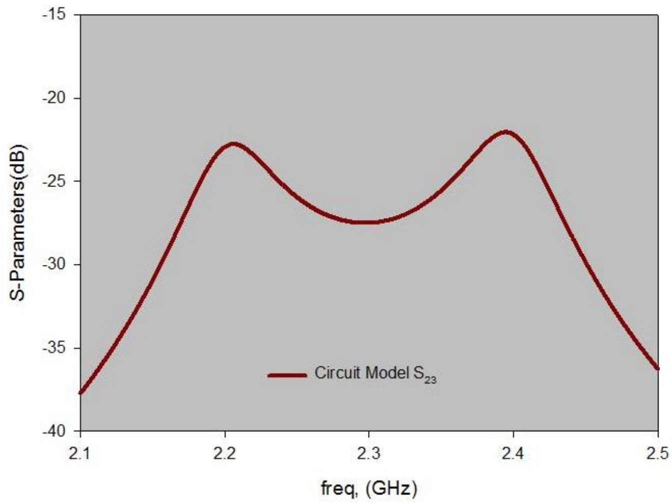


Fig. 4: Circuit model isolation between output ports

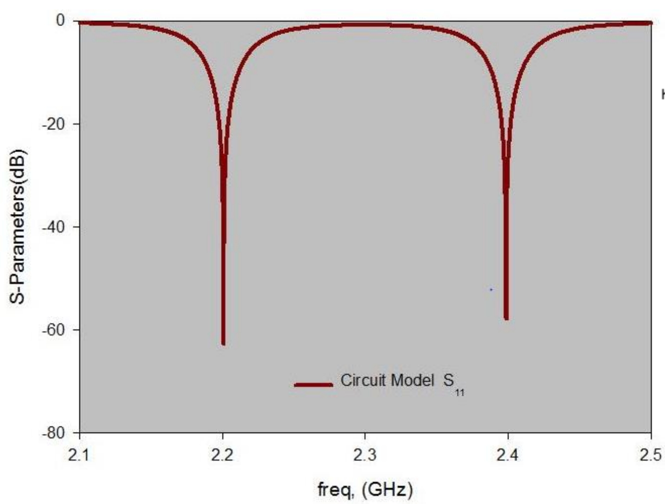


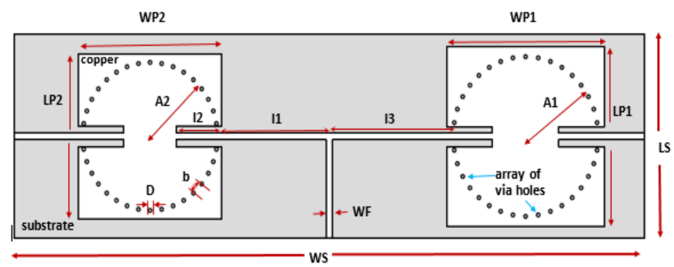
Fig. 5: Circuit model input port reflection

B. Electromagnetic Simulation

The fundamental parameter in designing the cavity of the SIW filter is the resonant frequency. The radius of the circular SIW cavity is approximated according to the resonant frequency using the following formula [13], and then the radius is optimized by electromagnetic software.

$$\left(f_r^{\,filter}\right)_{010}^{TM^z} = \frac{c}{2\pi\sqrt{\mu_r\epsilon_r}}\left(\sqrt{\frac{2.4049}{a_{filter}}}\right)^2 \qquad (5)$$

where c is the speed of light in free space; μ_r is the relative permeability while ε_r is the dielectric permeability of the substrate respectively. The value 2.4049 is the first zero of the Bessel function and a_{filter} is the radius of the SIW filter. The design rules related to the pitch and via diameters to ensure that the radiation loss is kept at negligible level are already given in literature [1]. In this design, the matching from 50-Ohm microstrip line to the SIW cavity resonator section is achieved by the inset excitation structure which converts quasi-TEM mode propagating in microstrip line to the TM_{010} mode of the SIW cavity resonator. The configurations of the proposed diplexer with the transitions are shown in Fig. 6. The optimized geometric parameter of the proposed structure is shown in Table 3. The topology comprises of a metallic top layer and a conductive ground layer (t1), two circular cavity resonators, inset couplings, and linear arrays of via holes to form a circular via wall around the cavity resonators.



(a)

(b)

Fig. 6: Configuration of the First-order SIW diplexer (a) top view, (b) side view.

TABLE 3. GEOMETRIC DIMENSIONS OF FIRST-ORDER DIPLEXER

Symbol	Value (mm)	Symbol	Value (mm)
A1	**20.75**	***LP1***	**11**
A2	**19.05**	***LP2***	**11**
b	**3.5**	***LS***	**53**
D	**1**	***WF***	**1.76**
h1	**1.28**	***WP1***	**45**
I1	**30.7**	***WP2***	**41**
I2	**11.5**	***WS***	**180**
I3	**30**	***t1***	**0.035**

The proposed diplexer was simulated and optimized using the full-wave EM simulator CST. The analysis for the parameter of radius for both SIW cavities was conducted and the results are shown in Fig. 7 and 8. Both figures show the response that change in S_{11} and S_{21} when the radius of the SIW cavities are varied. It can be observed that when the radius is increase, the frequency will decrease or shift to the left side. Referring to the theory given in equation 5, the radius is inversely proportional to the frequency. Thus, with the changes in the radius will result in changes of the resonance frequency and this will affect the frequency response as well.

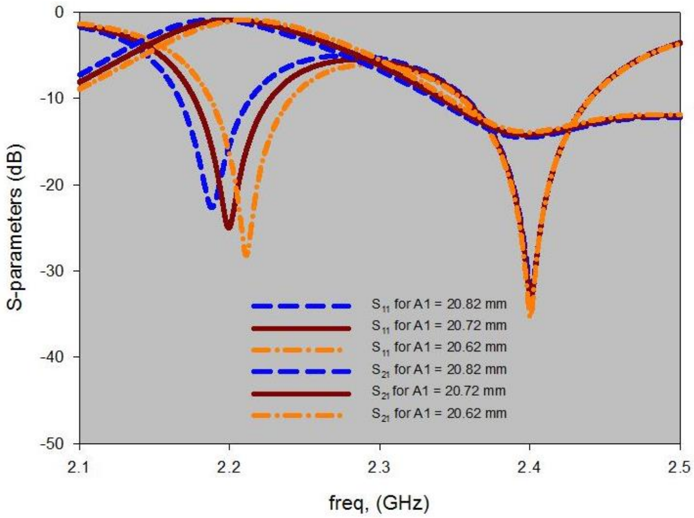


Fig. 7: Simulated $|S_{11}|$ and $|S_{21}|$ for the 2.2 GHz SIW cavity with different A1

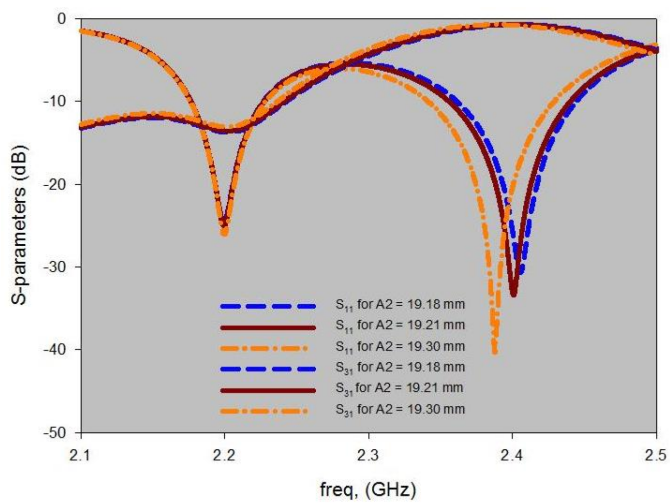


Fig. 8: Simulated $|S_{11}|$ and $|S_{31}|$ for the 2.4 GHz SIW cavity with different A2

The full-wave simulation S parameters results for the proposed diplexer are shown in Fig. 9, 10 and 11. According to the simulation results in Fig. 9, the transmission or minimum insertion losses obtained are 0.87 dB and 0.74 dB at each band. Also the bandwidth of the S21 and S31 are wider than in the lumped element circuit model. Fig. 10 shows that both output ports (Ports 2 and 3) have under 19 dB of isolation between each other which is similar to the circuit model. It could be observed that from Fig. 11 there were two resonant points namely 2.2 GHz and 2.4 GHz. From this plot, the simulation reflection or return losses for the lower and upper channels are greater than 20.94 dB and 30.92 dB respectively. The full-wave S parameter simulated responses show a good agreement with the lumped element circuit model responses. Fig. 12 revealed the corresponding E-field distribution in the cavity resonator at 2.2 GHz. The surface current distribution of the proposed diplexer is shown in Fig. 13. A strong current distribution is contained within the SIW cavity and port 2 at 2.2 GHz. Similarly in Fig. 14, the same observation is seen within the SIW cavity and port 3 at 2.4 GHz.

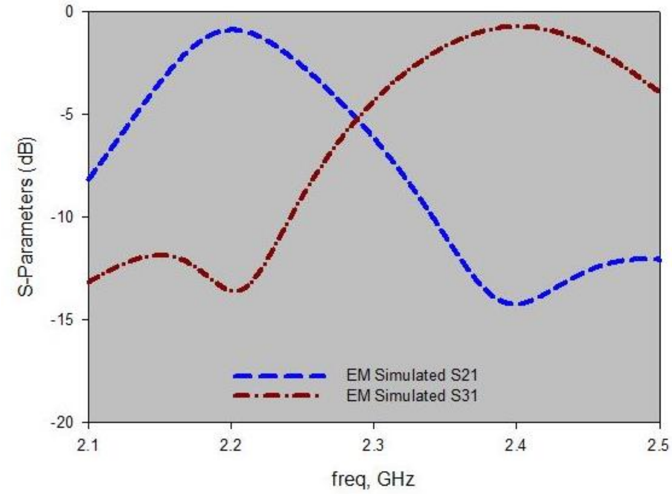


Fig. 9. Transmission responses of diplexer full-wave simulation

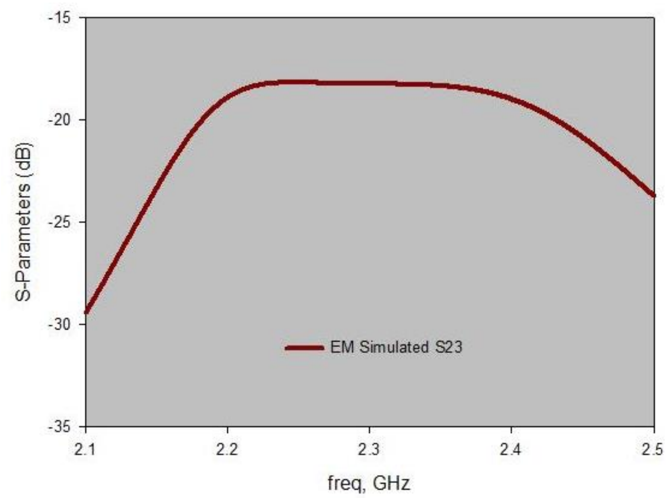


Fig. 10. Isolation between output ports of diplexer full-wave simulation

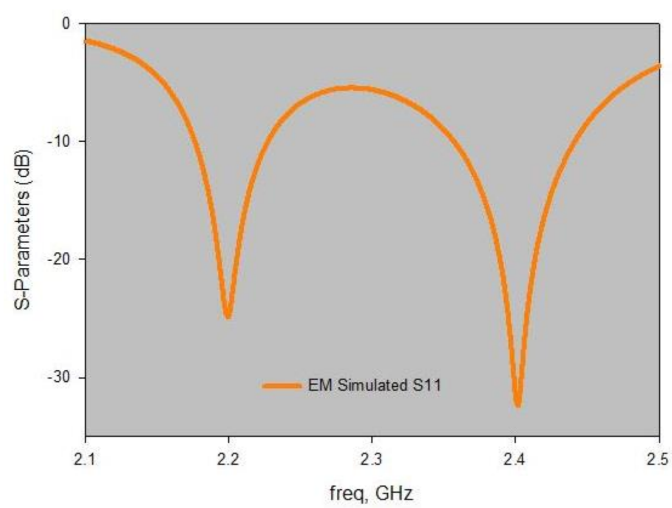


Fig. 11. Input port reflection responses of diplexer full-wave simulation

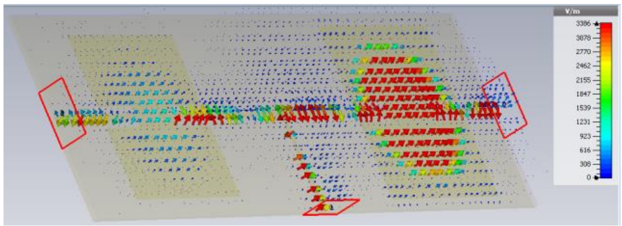


Fig. 12. The diplexer E-field distribution in the cavity at 2.2 GHz.

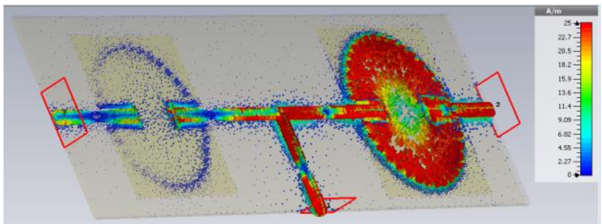


Fig. 13. The diplexer surface current distribution in the cavity at 2.2 GHz.

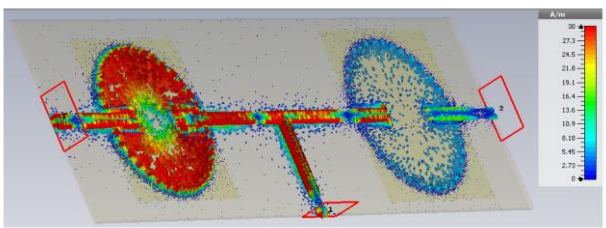


Fig. 14. The diplexer surface current distribution in the cavity at 2.4 GHz.

III. CONCLUSIONS

A planar SIW diplexer is proposed employing single-mode circular cavity resonators having center frequencies at 2.2 GHz and 2.4 GHz, and which is proposed for LTE/WiFi applications. The EM simulated response shows a good agreement with the ideal electrical modelling response. The diplexer features low insertion loss, compact, simple structure and easy to connect to other circuits. This design provides an alternative solution for the uplink/downlink RF front end subsystem that is essential for wireless communications systems. The functionality of the presented results will be validated experimentally in near future.

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Noor Hasimah Baba is a Senior Lecturer at the Universiti Teknologi MARA (UiTM), Selangor, Malaysia. She received the B. Sc. degree in electrical engineering from the University of New Haven, Connecticut USA and M.Sc. degree in electrical engineering (Microwave) from the Universiti Teknologi MARA, Selangor, Malaysia (2005). She is currently working toward the Ph. D. degree in electrical engineering at Universiti Teknologi MARA. Upon graduation, she joined SIEMENS SDN BHD and ONKYO MALAYSIA as an R&D Engineer involved in various consumer electronic products research and development. In 2005, she started joining the academic field. Her research interests are in microwave and millimeter-wave passive devices, antennas and microwave non-destructive testing. She is a member of IEEE (MTT/AP/EMC) and Board of Engineers Malaysia.

Aziati Husna Awang is a Senior Lecturer at the Universiti Teknologi MARA (UiTM), Malaysia. She received the B. Eng. (with Honors) in Electrical and Electronic Engineering from the Universiti Tenaga Nasional in 2000, M.Sc. in Personal, Mobile and Satellite Communication Engineering from the University of Bradford, U.K. in 2003 and Ph.D. in Electronic and Electrical Engineering (Development of a system for coherent continuous-wave detection of radiation from a terahertz quantum cascade laser) from University of Leeds, U.K. in 2013. Upon graduation, she joined MAXIS Communication Bhd as an Engineer involved in various products technologies from 2G to 3G, teletraffic projections and planning. In 2004, she started joining the academic field. Her research projects include millimeter and microwave devices, photonic devices and THz and optical detection systems. Some of the projects which he has involved had been awarded the Winner of Diamond, Gold and Silver Medal in the Innovation, Invention and Design Competition in the national and international level. Dr. Aziati is an executive committee member of IEEE (MTT/AP/EMC).

Mohd Tarmizi Ali received the B.Eng. degree in electrical engineering from the Universiti Teknologi Mara (UiTM), Shah Alam, Malaysia, in 1996, the M.Sc. degree in electrical engineering from the University of Leeds, Leeds, U.K., in 2002, and the Ph.D. degree in electrical engineering from the Universiti Teknologi Malaysia (UTM), Johor, Malaysia, in 2010. Since 2012, he has been an Associate Professor with the Microwave Technology Center (MTC), UiTM, and the Group Leader of the Antenna Research Group, UiTM, in 2010. He has authored more than 100 journal papers and conferences proceedings on various topics related to antennas, microwaves, and electromagnetic radiation analysis. He has also filed five patent applications on communication antennas. To date, his publications have been cited 237 times with the H-index of 8 (Source: Google Scholar). He is currently handling several research projects from the Ministry of Science, Technology and Innovation (MOSTI) and the Ministry of Higher Education Malaysia (MOHE). His research interests include the areas of communication antenna design, radio astronomy antennas, satellite antennas, and electromagnetic radiation analysis.

Dr. Ali was the Chair and Technical Program Chair of the IEEE Symposium on Wireless Technology and Applications, between2011and2012He has been a very promising as a Researcher, with the achievement of several International Gold Medal Awards, a Best Invention in Telecommunication Award, and a Special Chancellor Award from UTM for his contribution to research and innovation and was the recipient of Postgraduate Best Student Award 2011 from UTM

Hizamel Mohd Hizan is a Senior Researcher at Communication Technologies Division, Telekom Malaysia Research and Development (TM R&D). He received the B. Eng. (with Honors) in Electronic and Communication Engineering from the University of York, U.K. in 1999, M.Sc. (with Distinction) in RF and Communication Engineering from the University of Bradford, U.K. in 2003 and Ph.D. in Electronic and Electrical Engineering from University of Leeds, U.K. in 2011. Upon graduation, he joined Telekom Malaysia as an Engineer involved in various technologies from WCDMA to WDM systems. He is an Editorial Board member of TM R&D publication committee. His research projects include integrated microwave filters and antenna, millimeter wave transceivers system, Radio-over-fiber (RoF) and WiFi technologies. He has been a member of Industrial Advisory Board (IAB) at Centre on Optical Wireless Application (COWA), National Science Foundation at Georgia Institute of Technology, Atlanta, USA. Some of the projects which he has involved had been awarded the Winner of Best Broadband Partnership at Broadband Infovision Awards on Green Collaboration Optical Radio Network at Amsterdam, Netherland (2014) and Merit Award on Green Fiber Wireless Technology in Asia Pacific ICT (APICTA 2013), Malaysia. Dr. Hizamel is a member of IEEE (MTT/AP/EMC) and Board of Engineers Malaysia.