

5G Coupler Design for Intelligent Transportation System (ITS) Application

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ABSTRACT

Aiming to achieve 3-dB coupling, operating in fifth generation (5G) technologies, this paper introduces a new design of tight coupling coupler that will be operated in 5G technologies. Two stubs and two slots have been implemented into the 3-dB coupler design in order to achieve impedance matching between the ports and to give better coupling performances, respectively. Moreover, a study on the stubs' and slots' effects towards the S_{31} of the 3-dB coupler has also been presented in this paper. The proposed coupler is designed on Rogers RO4003C substrate. The simulation results and the analytical study on the stubs and slots implementation show that both stubs and slots affect the performance of the coupling coefficient.

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1. INTRODUCTION

Recently, fifth generation (5G) mobile technology has been introduced, which expected to be deployed in year 2020 [1]. As it is still considered as a new technology, few encounters need to be attended in order to change from fourth generation (4G) technology to 5G [2-3]. These include the security for the system, limitation in the frequency spectrum resources, the choice among various wireless system, network infrastructure and QoS support, jamming and spoofing and last but not least, the multi-mode user terminals [4-5]. Few advantages of having 5G technologies in our lives such as this technology will provide better coverage, higher speed and enhanced spectral efficiency. In addition to the challenges mentioned above, limited resources and also lack of new designs have been noted in 5G technologies. This includes antenna and passive devices.

One of the most suitable applications for 5G technology is Intelligent Transportation System (ITS). However, due to 5G short-range, limited space can be covered during the transmission of the data. One way to overcome the problem is by using beam-forming system where by implementing beamforming system into 5G technology the range can be widen. One of the mostly used beamforming system is Butler Matrix [6]. Basically, Butler Matrix is an $N \times N$ network, where the N indicates the inputs and outputs of the network. By using Butler Matrix, it will be easy to produce various beams in different directions. Henceforth, those beams

can be used to provide a fast discrete electronic scanning of the antenna pattern when connected with the adaptive control unit in the antenna system [7].

By connecting $N \times N$ Butler Matrix to N -elements of array antenna, switched beam antenna system, which will be pointed at different angles and generate the orthogonal beams [8]. The development of the standard Butler Matrix composed of three main components which are, 45° phase shifters, crossovers and last but not least, 3-dB couplers [9-10]. When one of the Butler Matrix input was fed with signal, the output signal will have equal magnitudes and progressive phase shift between adjacent ports. Thus, different direction of radiation's beams can be formed when feeding the signal from different ports [11]. By constructing Butler Matrix into cascading side-by-side, short range and long-range radiation can be produced.

The combination of usage for short-range and long-range application at the same time for vehicle applications can successfully been done due to the development of CALM or known as a Continuous Air-Interface for Long and Medium range telecommunication [12]. CALM's concept can be employed into the Intelligent Transportation System (ITS) applications. ITS application can be accessed through more than one communication systems. When ITS application system is organized into a network, it can be a very powerful platform in sensing and avoiding collision. Up to date, CALM has been introduced widely in order to offer a wide area communications to support the ITS applications. ITS application can be seen to be functioning very well on a variety of network platforms, which includes the millimeter-wave and short-range technologies like wireless fidelity (Wi-Fi), Second Generation technology (2G), 3G technology, mobile communication, 4G technology, satellite, infrared and Worldwide Interoperability for Microwave Access (WiMAX) [13].

The main advantage of ITS system is that it has a great potential in providing a direct exchange messages between vehicles related to their speed, location, position and acceleration. Furthermore, emergency situations such as the presence of ice on the road, fog, animals and accident occurred nearby could also be send through this system. In addition to that, this system could also provide the driver with all of the information even though there is no information related to weather forecasts or traffic conditions [14]. Thus, due to its attractive main advantage, arousing of demand in Intelligent Transportation System (ITS) especially in vehicle communication system applications. Therefore, it can be realized by the implementation of this promising candidate of beam forming system that produces multiple beams.

Therefore, this paper aims to develop a new design of 5G coupler, which is one of the main components to build the 5G Butler Matrix. 15 GHz has been chosen in this study as an initial study for 5G technology. In the next section, the method on how the proposed designed coupler initiated is introduced. The configuration is practically approximately similar with a basic branch line coupler with $\lambda/4$ length with additional stub and slot. The design of the 5G coupler is designed by using CST Microwave Studio software version 2016. The proposed coupler is designed onto Rogers RO4003C. The analysis of the parametric study of the stubs and slots is explained in Section 3. The simulation results show that the designed 5G coupler achieves a good performance for application in 5G technologies.

2. 5G COUPLER DESIGN

Figure 1 and Figure 2 describe the proposed 5G coupler design both in top view and bottom view, respectively. As seen in Figure 3, two stubs have been implemented to the coupler which located between Port 1 and 2 and also between Port 3 and 4. The proposed coupler configuration is observed to be approximately similar with a basic branch line coupler with $\lambda/4$ length. However, as shown in Figure 3, additional stub and also additional slot has been introduced in the design. The stubs are located at the top layer, as seen in Figure 1. Meanwhile, the slot is located at the ground plane, as seen in Figure 2. The use of the stub is to improve the impedance matching between these ports. Besides, the stubs have also being an important role to reduce the size of the coupler. The slot is implemented into the design to provide impedance matching along the ports, Port 1 and 2 and also Port 3 and 4.

Table 1. Dimension of the Proposed Coupler's Parameter

Parameter	Dimension (mm)
W	24
L	33.5
wf	1.1
sl	2.4
sw	2
bll	8.8
blw	10
$slot_l$	9
$slot_w$	0.75

The design of the 5G coupler is initiated by using simple mathematical formula based on the conventional branch line coupler [15]. Subsequently, the method and mathematical equation on the implementation of stub and slot is employed. Table 1 lists the optimized dimension of all the coupler's parameters as shown in Figure 1 and Figure 2.

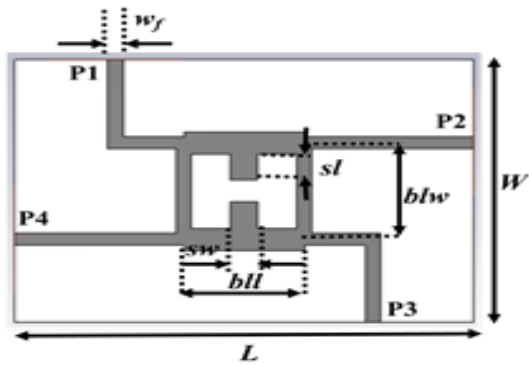


Figure 1. The proposed design of 5G coupler (top view)

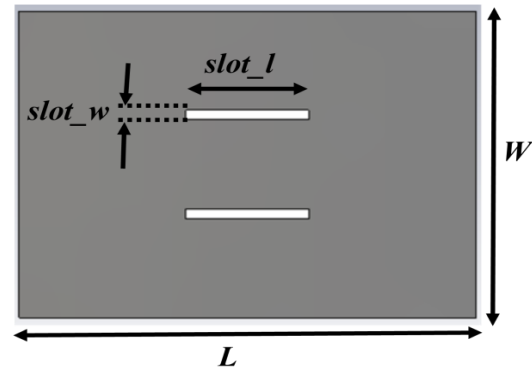


Figure 2. The proposed design of 5G coupler (bottom view, ground plane)

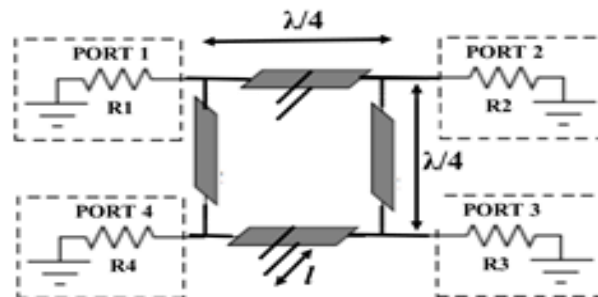


Figure 3. Circuit diagram of the proposed 5G coupler design

3. ANALYSIS OF S_{31} TRANSMISSION COEFFICIENT

For the analysis of the proposed coupler on regards of the transmission coefficient performances of S_{31} , parameters for the stub's length and also the slot's width; sl and $slot_w$ were varied accordingly. The results are divided into two analysis for clearer observation. Figure 4 and Figure 5 demonstrate the results analysis of the proposed 5G coupler for both different cases as follows.

3.1. Analysis 1: Different Stub's Length, sl

For the first analysis, the value for sl is varied from 1.1 mm to 3.1 mm. The variation steps of the analysis is 0.7 mm. From Figure 3, it can be observed that the best value of S_{31} occurred when the value of sl is at 3.1 mm.

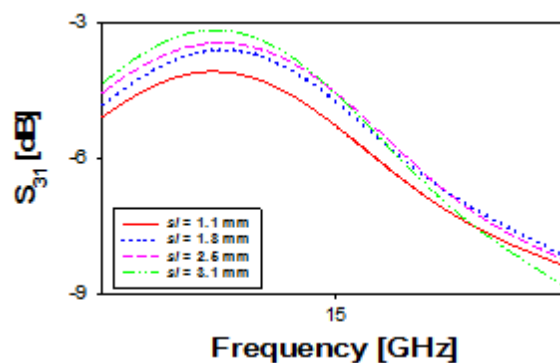


Figure 4. Coupling coefficient (S_{31}) for 5G coupler for different value of sl

3.2. Analysis 2: Different Slot's Width, $slot_w$

Meanwhile, for the second analysis, the value for $slot_w$ is varied from 0 mm, where there is no slot available in the design then followed by 1.5 mm to 5.5 mm with variation steps of 2 mm. From Figure 4, it can be seen that the best S_{31} occurred when the value of $slot_w$ is at 1.5 mm. However, when there is no slot implemented into the design, it can be noticed in Figure 5 that the performance of the coupling coefficient of the 5G coupler has been deteriorated.

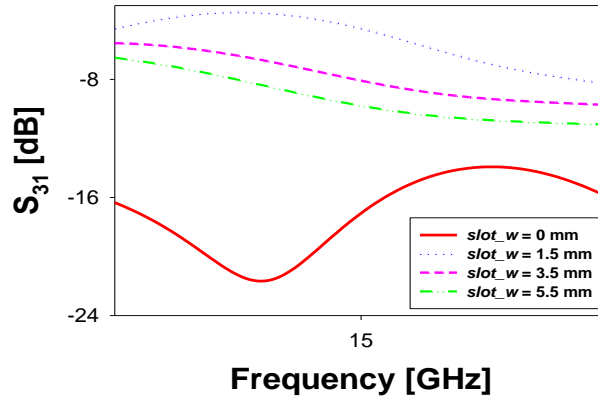


Figure 5. Coupling coefficient (S_{31}) for 5G coupler for different value of $slot_w$

From both analysis, it can be concluded that the introduction of the stub's and the slot's acquaintance have help in improving the coupling coefficient of the proposed coupler. As seen in Figure 5, when the slots have not been implemented into the design, the coupling coefficient of the 5G coupler's performance has been deteriorated. This situation happened due to the impedance matching towards the line from Port 1 to Port 2 and also Port 3 to Port 4 that have the stubs have been disturbed.

4. RESULTS AND DISCUSSIONS

Figure 6 and Figure 7 illustrate the simulated performance of the proposed 5G coupler in terms of S-parameters and phase difference, respectively. From the results, the bandwidth of the proposed 5G coupler is approximately 0.9 GHz covering from 14.3 up to 15.2 GHz. Across the stated operating frequency, the optimal S_{11} and S_{41} are better than 21.6 dB and 25 dB, respectively. Meanwhile, the optimal transmission coefficient of S_{21} and S_{31} are -4.3 dB and -3.4 dB, respectively. For the phase difference as depicted in Figure 7, the best phase difference performance along the operating frequency is at -90.7° . Table 2 includes the optimal results plotted in Figure 6 and Figure 7. It can be concluded that, based from these figures and Table 2, the proposed coupler exhibit good performance and can be used in 5G ITS application.

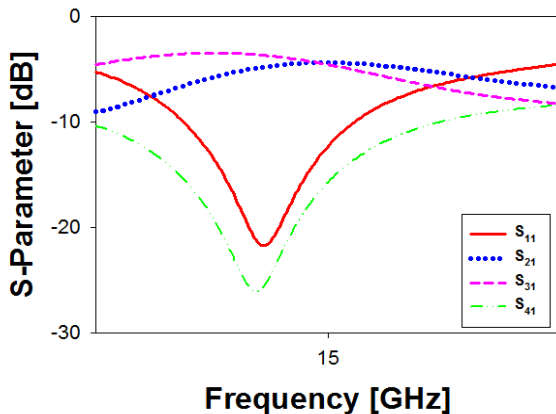


Figure 6. Simulated S-Parameter performances of the proposed 5G coupler

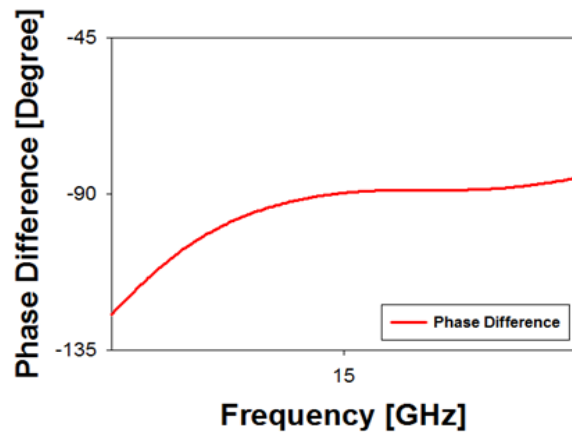


Figure 7. Simulated phase difference performance of the proposed 5G coupler

Table 2. Summary of the Best/Optimal Performance of the 5G Coupler Across the Operating Frequency (14.3 GHz to 15.2GHz).

Parameter	Performance
S_{11}	-21.6 dB
S_{21}	-4.3 dB
S_{31}	-3.4 dB
S_{41}	-25 dB
Bandwidth	0.9 GHz
Phase Difference	-90.7°

5. CONCLUSION

A new design of tight coupling coupler operating at 5G frequency range is introduced in this paper. The proposed designed implemented two stubs and two slots in order to achieve impedance matching between the ports and to give better coupling performances, respectively. In addition, an investigation on the effect of stubs and the slots towards coupling coefficient of the designed coupler has also been presented. The results of the investigation show that the coupling coefficient of the 5G coupler is deteriorated when there is no slots implemented into the design. This situation happened due to the impedance matching from Port 1 to Port 2 and Port 3 to Port 4 have been disturbed by the existing of the stubs. The scattering parameter and phase difference of the proposed designed coupler show good performance in the respective band. Therefore, the coupler is suitable to be used to construct a Butler Matrix for Intelligent Transportation System (ITS) applications.

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