Improvement of the Bandwidth and Scattering Parameter Performances of 5G Branch-Line Coupler Design for the Use in Intelligent Transportation System (ITS)

D.N.K.A.Zaidel[1], M.P.Attan[1], M.R.M. Sharip[1], D.A.A.Mat[1], A.S.W.Marzuki[1], N. Seman[2], and Y.L. Then[3]

[1]*Department of Electrical and Electronics Engineering, Faculty of Engineering, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak.*

[2]*Wireless Communication Center, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310, UTM Johor Bahru, Johor. Faculty of Engineering, Computing and Science.*

[3]*Faculty of Engineering, Computing and Science, Swinburne University of Technology (Sarawak Campus), 93350, Kuching, Sarawak.*

azdnorkhairunnisa@unimas.my

***Abstract*—This paper presents a design of 5G branch-line coupler that operates at 10 GHz frequency range. The proposed coupler is implemented with four stubs and two slots to improve the performances including the scattering parameter and also the bandwidth. Advanced Design System (ADS) software is used to design and perform the simulation stage. The proposed 5G coupler with stub and slot technique has enhances the bandwidth up to 60% as compared to the one proposed earlier in the literature. Additionally, the simulation results show that the scattering parameter and phase differences have also improved. The proposed design is suitable to be used later in Butler Matrix for Intelligent Transportation System (ITS) application.**

***Index Terms*—5G Technology; Branch-Line Coupler; Stub Technique; Wideband**

I. INTRODUCTION

Intelligent Transport System (ITS) is a system that utilises communication technology to improve the efficiency and safety in the transportation system. The idea of having the ITS in today's world is to provide every car on the road with the ability to communicate with each other. The communication includes sending location, speed and also traffic and danger occurring on the roads. Thus, this help in improving the performance and reliability of current conventional transportation system. Also, this ITS enable the vehicles to operate safely and well coordinate according to the given information. As ITS plays with number of input and output signals that leads to crowded data transferred, therefore, the most suitable communication technology to be used for this system is a 5th Generation (5G) technology. This technology is expected to have hundred times faster data rates especially for high mobility, massive connectivity in crowded areas, thousand times higher system capacity/km2, less than 1ms reduced latency (virtually zero latency), energy saving and cheaper especially for terminals [1]. By the year of 2020, it is estimated that 50 billion devices are connected to the internet with the foundation of the Internet of Things (IoT) and 75% of it consist of traffic, where 90% of it is vehicle [1].

The drawback of 5G technologies is, it offers short coverage range due to its high frequency. Thus, multi-input-multi-output (MIMO) technology is introduced to extend the range of 5G technologies by concentrating the signal in ultimate/one direction. Since MIMO technology has multiple antenna, signal can be transmitted and received from multiple direction [2],[3].

Beam-forming network is the example of MIMO technology used to concentrating the receiving or transmitting directional signal instead of broadcasting the signal to wide area [4]. To date, numerous number of beam-forming system that have been introduced which includes Butler Matrix [5]-[7], Blass Matrix [8] and Rotman Lens [9],[10]. The simplest among all is Butler Matrix where only few number of couplers used in its topology compare to other type of beam-forming network [7]. Butler Matrix consists of 3 main components, which are; the 3-dB coupler, 450 phase shifter and crossover. As yet, various design of 3-dB coupler has been presented [11]-[15], however, only a few of them operate in 5G technologies as it is still a new technology.

In [12], the authors implement the multilayer technique to design the 5G coupler and also, as reported, the effect of the stub and slot in the used technique also studied. The result shows that the stub and slot give effect towards the performance of the 5G coupler. The bandwidth coverage of this design is 2 GHz which is considered as wideband. However, as known, multilayer has issues during fabrication and realization where, the alignment of the substrate, patch and slot must be 100% aligned. A small misalignment will degrade the whole results and performances [16].

Hence, to solve the issue raised by using multilayer technique, in [13], the authors implement the most basic 3-dB coupler design, the branch-line coupler. The design consists of one single layer with implementation of two stubs and two slots to maintain the performance of the coupler. The advantage of using branch line coupler includes; simplest type of coupler, cheap to fabricate and many development and research have been done from it. Even though it solves the alignment issue, however, as known, the branch-line coupler concerning issue is the narrow bandwidth coverage [17]. The bandwidth performance of the coupler reported in [13] is only operating in 900 MHz.

Therefore, the purposes of this paper is improved the design of 5G coupler introduced in [13]. The coupler will be implemented with stub technique to improve the bandwidth and also to improve the scattering parameter performances. The difference between the proposed coupler and the coupler reported in [13] is that, four stubs, two stubs located from port 1 to port 2 and another two stubs located along port 3 to port 4, will be implemented in this proposed design. The coupler will be operated at 10 GHz. Rogers RO4003C is chosen as the substrate to design the 5G coupler. Advanced Design System (ADS) software is used for the design and simulation works. The results performance shows that the designed 5G coupler achieves greater bandwidth coverage up to 60% and better scattering parameter compares to the one reported in [13].

II. Design Theories And Analysis

Initially, the design of the basic branch line coupler circuit diagram is implemented with two stubs. The proposed equivalent structure and the quarter wavelength branch line are shown in Figure 1 and Figure 2, respectively. Based on Figure 1, an equivalent circuit for the quarter-wavelength transmission line is proposed, which consists of two stubs (jY), with an electrical length of θ and characteristic impedance of Z_A.

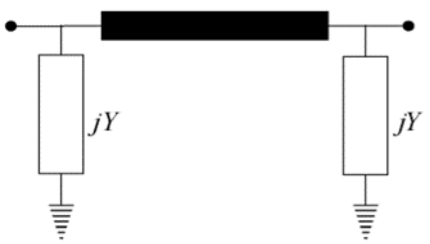


Figure 1: Proposed equivalent structure

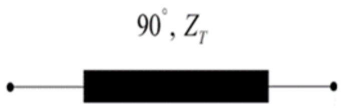


Figure 2: Quarter-wavelength branch line.

Thus, by applying the ABCD–parameters to the proposed structure shown in Figure 1, the matrix can be derived as in (1), which by then can be simplified to (2) [18],[19]:

$$\begin{bmatrix} 1 & 0 \\ jY & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & jZ_A\sin\theta \\ jY_A\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ jY & 1 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} \cos\theta - Z_A Y\sin\theta & jZ_A\sin\theta \\ jY_A\sin\theta\,(1 - Z_A{}^2Y^2 + 2Z_A Y\cot\theta & \cos\theta - Z_A Y\sin\theta \end{bmatrix} \tag{2}$$

Then, the following setting; shown in (3) and (4) will be added into (2). Thus the expression in (2) is then can be simplified into (5). Equation (5) proved that the proposed structure is equivalent to a transmission line that has characteristic impedance of Z_T and electrical length of ±90°.

$$Z_A\sin\theta = \pm Z_T \tag{3}$$

$$Y = \frac{\cot\theta}{Z_A} \tag{4}$$

$$\begin{bmatrix} 0 & \pm jZ_T \\ j\frac{1}{Z_A\sin\theta} & 0 \end{bmatrix} \tag{5}$$

Figure 3 represents the proposed quarter-wavelength transmission line or known as stub, that has been applied into the branch-line coupler. The value of Z_1, Z_2 and Z_3 can be determined by using (6) to (8) [20]:

$$Z_1 = \frac{Z_0}{\sqrt{2}} \times \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \tag{6}$$

$$Z_2 = Z_0 \times \frac{1}{\cos\left(\frac{\delta\pi}{2}\right)} \tag{7}$$

$$Z_3 = \frac{Z_0}{1+\sqrt{2}} \times \frac{1}{\sin\left(\frac{\delta\pi}{2}\right)\tan\left(\frac{\delta\pi}{2}\right)} \tag{8}$$

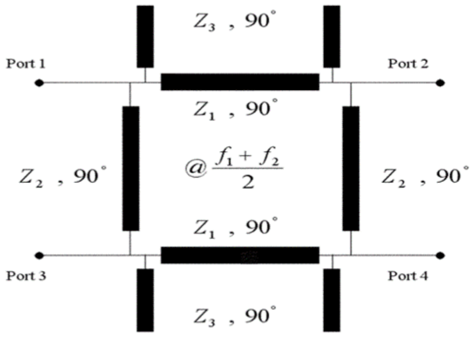


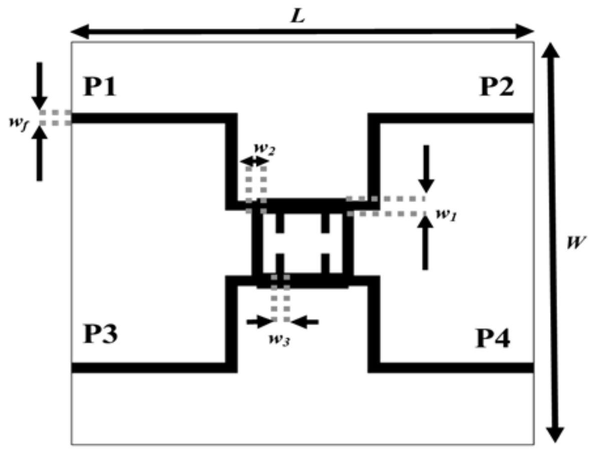
Figure 3: Branch Line Coupler with proposed structure

Based from the equation given, thus, the value obtained for Z_1, Z_2 and Z_3 are 37.2 Ω, 52.6 Ω and 92.2 Ω, respectively. From the value, it can be converted into microsrip line by using Tx line calculator. Once the initial dimension is determined, then the design is designed into ADS software to simulate the performance.

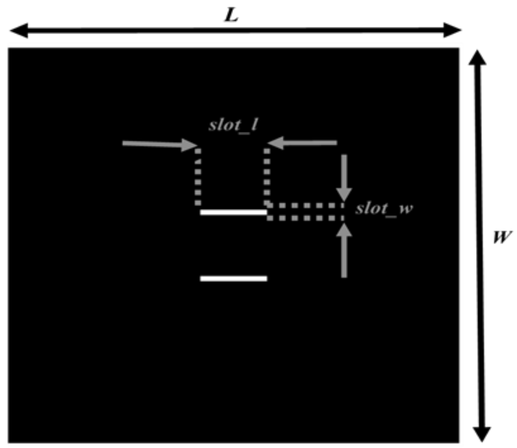
Figure 4(a) and Figure 4(b) describes the proposed 5G coupler design both in top view and bottom view, respectively. As seen in figures, a total of four stubs have been implemented to the coupler which two stubs located between Port 1 and 2 and another two stub between Port 3 and 4. The proposed coupler configuration is observed to be approximately similar with a basic branch line coupler with additional slot. The use of the stub is to improve the impedance matching between these ports. Besides, the stubs have also been 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 lists the dimension of all the coupler's parameters as shown in Figure 4(a) and Figure 4(b).

Table 1
The Dimension the Coupler's Parameter

Parameter	Dimension (mm)
W	25.3
L	18.3
w_1	1.1
w_2	0.4
w_3	0.1
w_f	0.4
slot_l	3.8
slot_w	0.4



(a)



(b)

Figure 4: The proposed design of 5G coupler from the (a) top view (b) bottom view

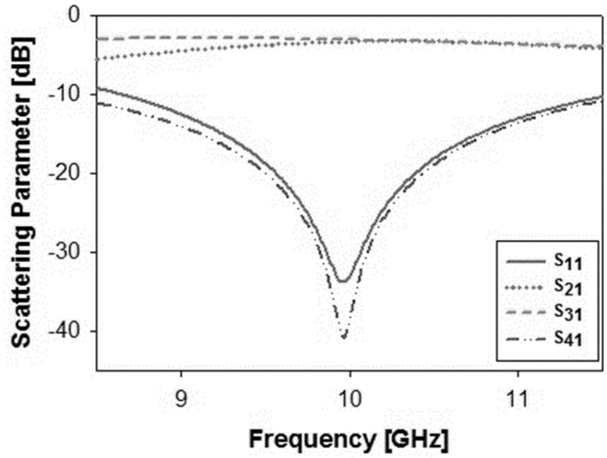


Figure 5: Scattering parameter performances for the proposed designed coupler

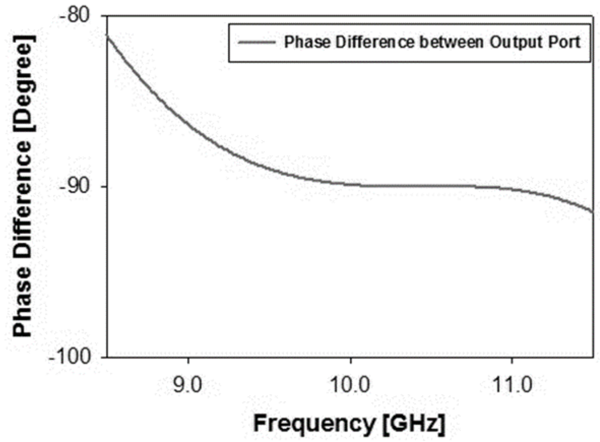


Figure 6: Phase difference between output port for the proposed coupler

III. Result and Discussion

Figure 5 and Figure 6 illustrate the performance of the proposed 5G coupler in terms of scattering parameters and phase differences between output ports, respectively. Based from the results shown in Figure 5, the optimal S_{11} and S_{41} are better than 37 dB and 32 dB, respectively, ranging from 8.6 GHz to 11.6 GHz. Meanwhile, the performance for the throughput and coupling, S_{21} and S_{31} are at are -3.6 dB and -2.9 dB, respectively, also ranging in the same frequency range.

As for the phase difference as depicted in Figure 6, the best phase difference performance along the operating frequency is at -90.4˚ The phase difference for Port 2 and Port 3 shows expected result of near -90° (between -85° and -95°) in between 8.6 GHz to 11.6 GHz.

Thus, best performance for S_{21} and S_{31} are expected where output signal from Port 1 evenly distribute at its output ports, Port 2 and Port 3. Based on overall results, the bandwidth of the coupler is 3 GHz which is at most 60% larger compare to coupler in [13].

Table 2 depicts the summary of the optimal results plotted in Figure 5 and Figure 6 and the performance comparing with the previous works. Comparing the results obtained to the 5G couplers proposed in [12], [13], the scattering parameter, phase differences and bandwidth coverage of the proposed coupler in this paper perform better as shown in Table 2.

Table 2
Summary of the Optimal Results (at 10 GHz) for the Proposed 5G and Coupler Comparison with Previous Works in [12], [13]

Parameter	Multilayer coupler [12]	5G Coupler [13]	Proposed Coupler
Return loss, S_{11}	-12.7 dB	-21.6 dB	-37 dB
Throughput, S_{21}	-3 dB ±1.3 dB	-4.3 dB	-3.6 dB
Coupling, S_{31}	-3 dB ±1.6 dB	-3.4 dB	-2.9 dB
Isolation Loss, S_{41}	-12.2 dB	-25 dB	-32 dB
Phase Difference between Output Ports	approximately to -90º	-90.7º	-90.4 º
Bandwidth (GHz)	1.5 GHz	0.9 GHz	3 GHz

IV. Conclusion

A design of 5G 3-dB branch-line coupler is introduced in this paper. A tight coupling coupler operated at 10 GHz is achieved by implementing four stubs and two slots into a basic branch-line coupler circuitry. The bandwidth of the proposed coupler has enhanced by up to 60% compared to the one proposed in the literature earlier. Besides bandwidth, the simulation results also show improvement in terms of scattering parameter and phase difference of the proposed coupler. The scattering parameter and phase differences of the proposed designed coupler show good performance from 8.6 GHz to 11.6 GHz. Thus, due to the good performances, the coupler is suitable to be used to construct a Butler Matrix later and be used in Intelligent Transportation System (ITS) applications.

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