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Research Article

A Compact Crossover Design for Butler Matrix Feeding Network in 5G Sub 6 GHz Wireless Applications

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Abstract

The butler matrix is one of the passive feeding networks used with array antennas to form beams. There are several advantages to using this beamforming network. One of them is that it is easy to manufacture, and the other is that it is low in cost. Butler matrix structure consists of three passive microwave components. These are directional hybrid couplers, phase shifters, and crossovers. A crossover is a passive microwave component used to cross between two lines with high isolation between them. This article presents microstrip crossover for use in Butler matrix feeding networks designed for 5G applications. The crossover has been presented in the article was designed and simulated. The proposed crossover operates at 4.5 GHz and it is designed for use in mostly butler matrix applications. The crossover has been proposed in the article has been designed using the FR-4 substrate. The dielectric constant of the used substrate is 4.3 and the thickness is 1.57 mm. The size of the designed crossover is 62.8 x 27.8 mm^2. The reflection coefficient and isolation level are in the permissible level in order for the proposed crossover to be utilized in the Butler matrix beamforming network for 5G the application. The return loss value of the designed crossover is 26.09 dB at 4.5 GHz. Same time the isolation value is 22.78 dB.

Keywords: Crossover, Butler Matrix, 5G Application, FR-4 Substrate, Wireless Communication

6 GHz Altı 5G Kablosuz Haberleşme Uygulamalarında Butler Matris Besleme Hattı İçin Küçük Boyutlu Atlama Tasarımı

Özet

Butler matrisi, hüzme oluşturmak için dizi antenlerde kullanılan besleme ağlarından bir tanesidir. Bu besleme ağını kullanmanın birkaç avantajı vardır. Bunlardan biri imalatının kolay olması, diğeri ise maliyetinin düşük olmasıdır. Butler matris yapısı üç pasif mikrodalga bileşeninden oluşur. Bunlar yönlü hibrit kuplörler, faz kaydırıcılar ve atlamalardır. Atlama, aralarında yüksek izolasyon bulunan iki hat arasında geçiş yapmak için kullanılan pasif bir mikrodalga bileşenidir. Bu makale, 5G uygulamaları için tasarlanmış Butler matris besleme ağlarında kullanımı için mikroşerit atlama sunar. Makalede sunulan atlama tasarlanmış ve simüle edilmiştir. Önerilen atlamanın çalışma frekansı 4.5 GHz'dir ve çoğunlukla butler matris uygulamalarında kullanılmak üzere tasarlanmıştır. Makalede önerilen çaprazlama, FR-4 malzeme kullanılarak tasarlanmıştır. Kullanılan malzemenin dielektrik sabiti 4.3, kalınlığı 1.57 mm'dir. Tasarlanan geçidin boyutu 62.8 x 27.8 mm^2'dir. 5G uygulaması için butler matris besleme ağında önerilen atlamanın kullanılabilmesi için yansıma katsayısı ve izolasyon seviyesi izin verilen seviyededir. Tasarlanan atlamanın 4.5 GHz'de geri dönüş kaybı 26.09 dB'dir. Aynı zamanda izolasyon değeri ise 22.78 dB'dir.

Anahtar Kelimeler: Atlama, Kablosuz Haberleşme Uygulamaları, Butler Matris, FR-4 Malzeme, 5G Uygulamaları.

1. Introduction

In recent years with the development of 5G technology in wireless communication, we will have download rates, reliable internet everywhere, and more services [1]. However, to obtain these services, we need high-gain antennas that serve higher frequencies and advanced phase progression technology. Therefore, there is a need for antenna systems that will direct the antenna array beams in the desired direction and solve the coverage problems. Phased array antennas are a good choice to meet this requirement [2].

Beam-forming feeding networks are commonly used to design phased array antennas. Examples of these are The Butler matrix, Rotman Lens, Blass, and Nolan matrix. The most widely used of these is the Butler matrix structure.

Butler matrix is a low-cost, simple, passive beam-forming feeding network, which is frequently used to direct the beam of the antenna to desired directions [3-7]. Butler matrix structure consists of quarter wavelength couplers, crossovers, and phase shifters [8].

Crossovers are important microwave components that are permitted two signal lines to crossover each other with perfect isolation [9-11]. Considering the Butler matrix application for the feed of array antennas available in 5G wireless technologies, the crossovers have become a very important component. The conventional crossover structure is achieved by adding two directional couplers back-to-back. On the contrary, in our design, a new type of crossover design has been realized without using the BLC structure. Thus the area of the designed structure has been reduced. The conventional crossover is shown Fig 1.

In this study, a novel miniaturized microstrip crossover is designed and investigated. Also, the designed crossover with a new configuration using the meander microstrip lines technique is proposed to reduce the size of its operating frequency. In this article microstrip crossover has been presented for use in Butler matrix feeding networks designed for 5G wireless communication applications.

2. Material and Method

In this section, the design of the crossover is introduced. The crossover has been designed to operate at 4.5 GHz and implemented on an FR-4 substrate. The dielectric constant of the used substrate is 4.3 and the thickness is 1.57 mm. The size of the crossover is 62.8 x 27.8 mm^2. Crossover design consists of several stages. Firstly, the crossover has been structured then, the thickness of the meander transmission line in the middle of the structure, which is connecting the bottom side and the upside has been increased and S-Parameters values have been numerically computed.

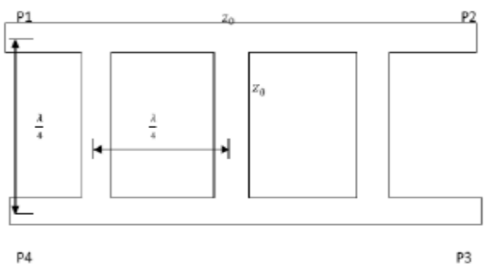

Fig. 1 Conventional Crossover

2.1. Design of Crossover

First of all, the crossover has been structured and S-Parameters values have been investigated. The proposed crossover is shown in Figure 2. The S-parameter results are shown in Figure 3. According to the results, it has been observed that the S_{11} value is -22 dB, the S_{21} value is -10 dB, and the S_{41} value is -14 dB at the operating frequency of 4.5 GHz. The measured S_{31} value is -1.77 dB at 4.5 GHz.

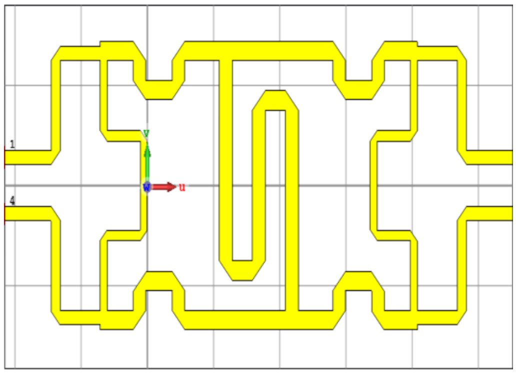

Fig. 2 Initial Designing of Crossover

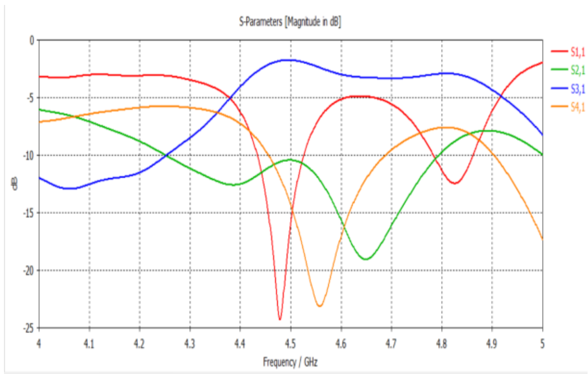

Fig. 3 S-Parameters of Initial Design

In the second stage of the design, the thickness of the meander transmission line in the middle of the structure, which is connecting the bottom side and the upside has been increased by 0.5 mm and S-Parameters values have been investigated. According to the results, it has been observed that the measured S_{11} value is -21.46 dB, the S_{21} value is –14.39 dB, the S_{41} value is -18.18 at the operating frequency of 4.5 GHz. The measured S_{31} value is -1.29 at 4.5 GHz. The designed crossover is shown in Figure 4. The S-parameter results are shown in Figure 5.

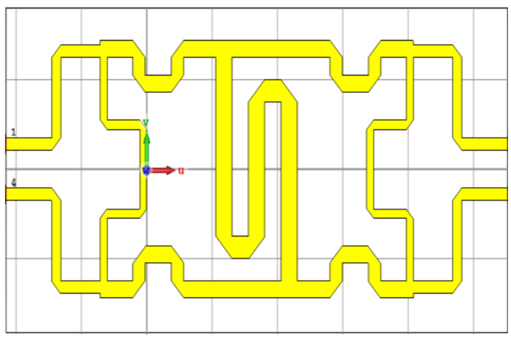

Fig. 4 Designing of Crossover (after thickness has been increased 0.5 mm)

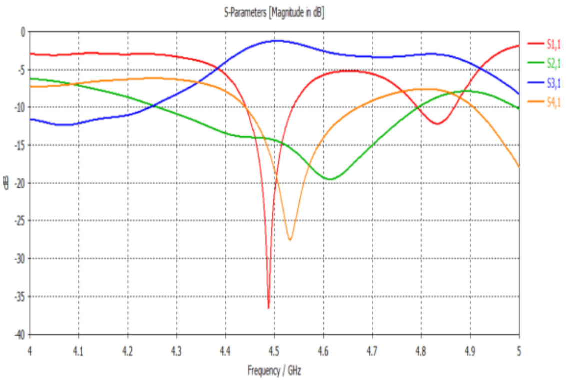

Fig. 5 S-Parameter of Design (after thickness has been increased 0.5 mm)

2.2. The Final Design of Crossover

At the final stage of design, the thickness of the meander transmission line in the middle of the structure, which is connecting the bottom side and the upside has been increased between 0 and 2 mm and the most optimal results have been found at 1.3 mm. According to the results, it has been observed that the measured S_{11} value is –26.09 dB, the S_{21} value is -27.71 dB, and the S_{41} value is -22.78 dB at the operating frequency of 4.5 GHz. The designed crossover is shown in Figure 6. The S-parameter results are shown in Figure 7.

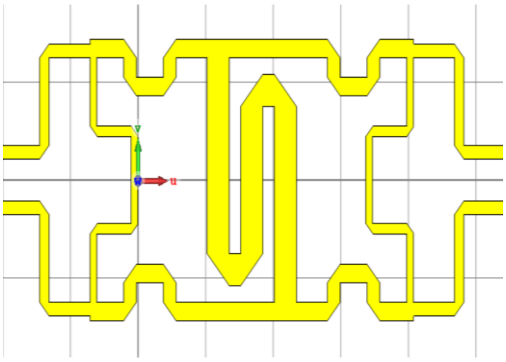

Fig. 6 The Final Designing of Crossover

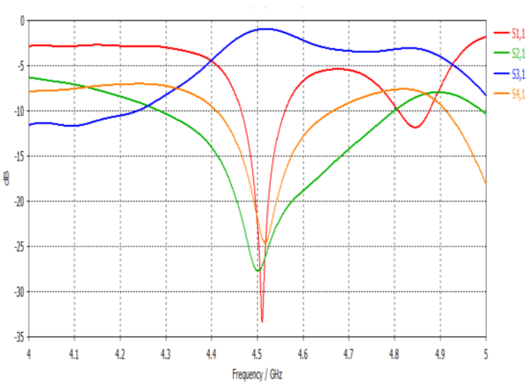

Fig. 7 S-Parameters of The Final Design

2.3. Dimensions of The Designed Crossover

The dimensions of the designed Crossover are shown in Figure 8 and Figure 9.

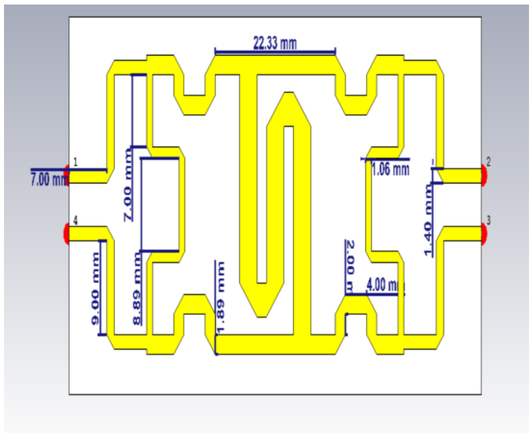

Fig. 8 Dimensions of The Designed Crossover

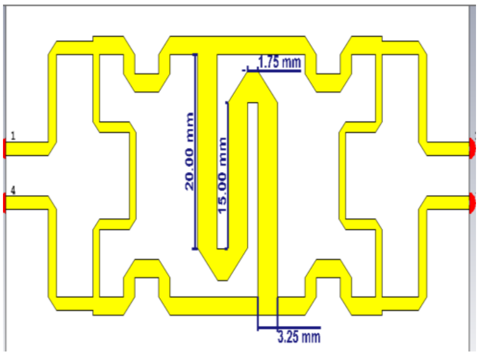

Fig. 9 Dimensions of The Designed Crossover

3. Results and Discussion

As a result in this paper, we design a novel miniaturized crossover for use in the butler matrix feeding network. The designed crossover operates at 4.5 GHz. The reflection coefficient and isolation level are in the permissible level in order for the proposed crossover to be utilized in the butler matrix beamforming network for 5G application. The designed crossover is implemented on a FR-4 substrate with a 4.3 dielectric constant and 1.57 mm thickness. The overall size of the crossover is 62.8 x 27.8 mm^2. The simulated results satisfy the requirements of 5G wireless communication.

4. Conclusions and Recommendations

In this article microstrip crossover has been presented for use in Butler matrix feeding networks designed for 5G wireless communication applications. The size of the designed crossover is more compact than the conventional crossover. The measured return loss is -26.09 dB, the S_{21} value is -27.71 dB, and the S_{41} value is -22.78 dB at the operating frequency of 4.5 GHz. A novel crossover design has been proposed for use in the butler matrix for 5G Wireless applications.

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