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STEERABLE ARRAY ANTENNA USING A 2 × 2 BUTLER MATRIX FOR 5G APPLICATIONS

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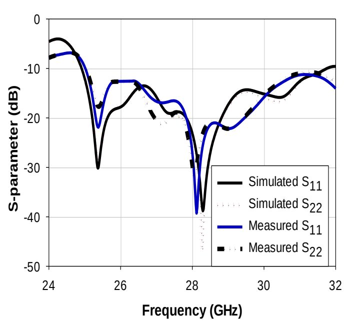
Graphical abstract



Abstract

This paper presents the design of a beam steerable array antenna based on branch line coupler (BLC) at 28 GHz frequency band for fifth generation (5G) wireless applications. The array is designed using Rogers RT/duroid 5880 substrate material of 0.254 mm thickness and dielectric constant of 2.2. The designed antenna has six elements array and is fed by a BLC which serves as a beamformer to obtain the beam scanning ranging from -16 to +16 degrees. The maximum gain of 14.5 dBi and a wideband that cover from 25.2 GHz to 32 GHz was obtained by measurement. The proposed antenna is applicable to 28 GHz frequency band proposed for 5G wireless communications. All simulated and measured results are clearly presented.

Keywords: Array antenna, branch line coupler, millimeter wave, steerable antenna.

Abstrak

Kertaskerja ini membentangkan rekaan antena tatasusunan alur mampu kendali berasaskan pengganding talian cabang yang beroperasi pada jalur frekuensi 28GHz bagi pengunaan wayarles generasi kelima (5G). Tatasusunan ini direkabentuk menggunakan substrat Rogers RT/duroid 5880 yang ketebalan 0,254 mm dan pemalar dielektrik 2.2. Rekabentuk Antena ini mempunyai enam elemen tatasunan dan disuapkan oleh pengganding talian cabang yang berfungsi sebagai pengimbas alur bagi mendapatkan julat imbasan antara -16 hingga 16 darjah. Gandaan maksimum 14.4dBi dan jalurlebar yang meliputi 25.2 GHz hingga 32 GHz dicapai melalui pengukuran. Antena yang direkabentuk dapat diaplikasikan pada jalur frekuensi 28 GHz yang dicadangkan untuk komunikasi wayarles 5G. Semua keputusan simulasi dan pengukuran dibentangkan dengan jelas.

Kata kunci: Antena tatasusunan, pengganding talian cabang , gelombang milimeter , antena mampu kendali

1.0 INTRODUCTION

The fifth generation (5G) wireless communication, otherwise known as IMT 2020 denotes the next major phase of mobile telecommunications standards beyond the current LTE-Advanced. The Next Generation Mobile Networks Alliance (NGMA) define 5G network requirements as the network that promises faster speed such that there would be 1-10 Gbps connections to end points in the field, 1 millisecond end-to-end round trip delay, 1000 times bandwidth per unit area, 10-100 times number of connected devices, 99.9 % availability, 100 % coverage, 90 % reduction in network energy usage, up to ten year battery life for low power machine-type devices and more. In order to meet these demands, millimetre wave frequency band has been recommended for 5G wireless communication. [1, 2]. But according to Friis equation, free space path loss increases with increase in frequency and distance. Therefore, it is expected that at millimetre wave, the propagation loss can be quite high; even for short distances, and the communication link might not be maintained in a non-line-of-sight (NLOS) environment where there is an obstacle blocking the receiver from the transmitter [3][4]. According to [3], it may be difficult for an omnidirectional or fixed beam antenna to cope with millimetre wave frequency due to high propagation loss.

To solve these problems, many researchers have proposed smart antenna [5], which is an array of antennas that can generate high directive beam in the desired direction and form nulls towards the undesired interferer. Smart antenna system can be either adaptive array or switched beam array antenna. In an adaptive array system, digital signal processing and algorithms are used to steer the antenna beam towards the desired user to optimize the performance and capacity by minimizing the undesired co-channel interference and then increase the channel capacity of the system. While switched beam array antenna deploy the use of switches to select one of the many multiple fixed beam to steer the beam in the direction of the desired use [6]. In both methods, there is enhancement of the signal-to-interference ratio (SIR) because the received desired signal strength is maximized and the undesired signal interference is minimized.

One major way of achieving switched beam antenna at low frequency is with radio frequency micro-electro-mechanical system (RF MEMS) switches or positive-intrinsic-negative (PIN) diode switches. In most cases, these switches are loaded on the antenna element for the antenna to generate a null to the undesired user and maximize its radiation pattern to the desired user. However at higher frequencies, it has a major drawback due to the small dimension of antenna at high frequency. The length and width of an antenna is a function of its wavelength which at very high frequency is a millimetre size. However, beam switching or pattern reconfigurable at millimetre wave frequency have been presented in [7, 8]. In [7], capacitive MEMS SPDT switches was monolithically integrated in a quasi-Yagi antenna at 20 GHz. A careful study on the paper shows a drop of the antenna gain from 5.2 dBi to 4.6 dBi after integration of the switch. Moreover, the process of integration is a complex one. Also, the measured return loss exhibited multiband characteristics which could be caused by the switch. While in [8] slot array antenna was reported to steer antenna beam at millimetre wave using MEMS switch but admitted that the use of switch is a major drawback to slot array design. Other antenna designs at millimetre wave frequency such as [9-11], did not consider beam steering.

Butler matrix (BM) is a beamforming network, functioning as a feeding network to antenna to produce multiple beams of progressive phase difference. By selecting any of the input ports, the fixed multibeam can be steered towards the desired user. In this article, a 2 × 2 BM is used to feed a linear array antenna at 28 GHz of frequency. The 2 × 2 BM was chosen to steer antenna beam due to its simplicity and low cost of implementation. It also eliminates the use of switches.

2.0 ANTENNA CONFIGURATION AND DESIGN

Figure1depicts the geometry of a conventional 2 × 2 BM otherwise known as branch line coupler (BLC) or 3 dB coupler. The BLC is a four port device. An input signal to P1 splits equally between the two outputs ports (P2 and P3). P2 is the through port while P3 is the coupled port. P4 is the isolation port; input signal at P1 is not expected to pass through P4 by theory. P2 and P3 are 90 degrees out of phase due to the additional distance travelled by P3. The design consists of two series arm quarter-wave length transmission line sections of characteristics impedance Zr each, connected to two shunt branches. The shunt arms are quarter-wave length transmission line too, with characteristics impedance Zp each.

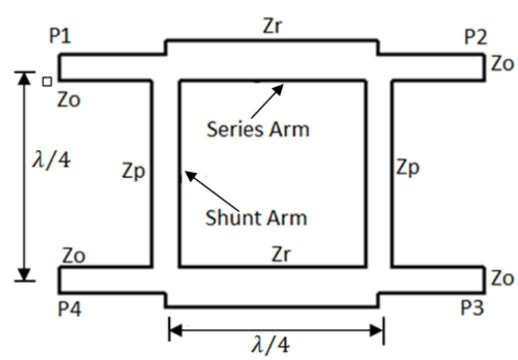


Figure 1 Geometry of a conventional branch line coupler

The impedances, of the shunt branch lines $Z_p = Z_o$ (where Z_o is 50 Ω input impedance) and the impedances of the series branch $Z_r = Zo\,/\,\sqrt{2}$. By appropriate selection of Z_p and Z_r, the circuit can be made to operate like a directional coupler.

Figure 2 shows the diagram of the proposed beam steerable antenna. The basic structure comprises of the BLC and 2 × 3 linear array patch antenna. The design started with the design of the BLC to achieve the required amplitude and phase. The extension of the ports was adopted to give room for the connection of the connectors since the quarter-wavelength distance between the ports are too small. A transmission-line calculator was used to obtain initial dimensions of the proposed BLC. Interpolated quasi Newton optimizer in the time domain solver of CST-MWS 2015 is used to obtain the final dimensions of the width (W_t) and length (L_t) of the transmission lines as 0.85 mm and 7 mm respectively. All the metallic layers are 0.0175 mm thick and the substrate of the Rogers RT/duroid 5880 substrate with dielectric constant 2.2 and thickness 0.254 mm are used for both the feed and the array antenna design. The proposed antenna has dimension of 28 mm × 20 mm × 0.254 mm. The radiating array consists of six patch element antenna linearly arranged at the output of the BLC. The linear array antenna is based on the optimized patch size of $L_a \times W_a$. Where $L_a = W_a = 3.84\ mm$ with a separation of $6\ mm\ (0.56\lambda_o)$ in the y-axis and $5.7mm\ (0.53\lambda_o)$ in the x-axis respectively. The size of the patch is made square for uniform current distribution on the patch elements.

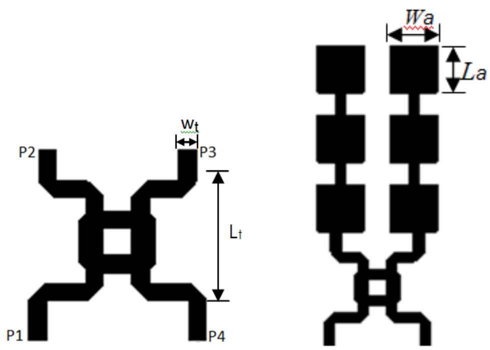


Figure 2 Layout of the proposed array antenna (a) the feed structure (b) the antenna structure.

3.0 RESULTS AND DISCUSSIONS

The simulated and measured results are shown in Figures 3 and 4. From Figure 3, the simulated and measured return loss of the proposed 3 dB coupler is 37.8 dB and 26.64 dB respectively while the simulated and measured coupling factors S_{21} and S_{31} are 3.53 dB and 3.72dB, 3.53 dB and 3.7 dB respectively. The simulated phase difference between coupled and through port is 89.8°. However due to imperfection in fabrication a value of 87.5° was obtained in measurement.

Figure 4 shows the simulated and measured return loss of the proposed antenna. The simulation and measurement performances are in good correlation. The measured impedance bandwidth of about 6.8 GHz and of the designed frequency for a -10 dB return loss criterion is achieved, with the peak array gain of 14.5 dBi. Figure 5 represent the fabricated prototype of the proposed antenna.

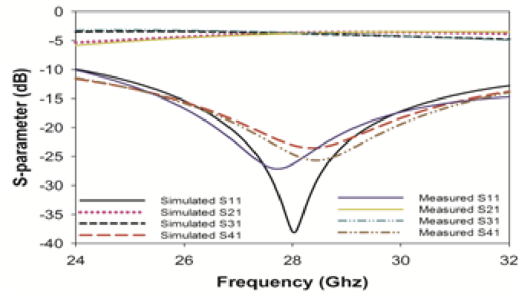


Figure 3 The simulated and measured S-parameter of the proposed Branch line coupler.

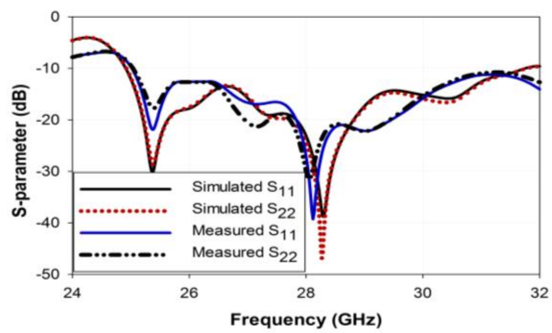


Figure 4 The simulated and measured S-parameter of the proposed antenna.

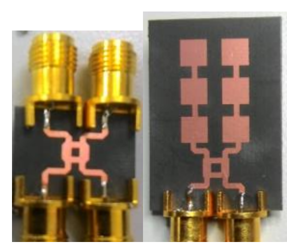
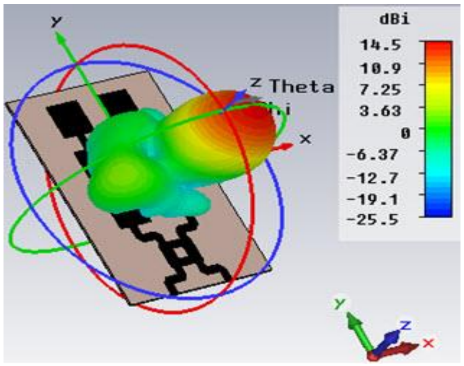
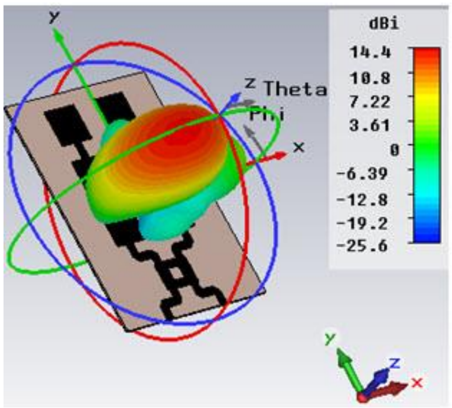


Figure 5 The fabricated prototype of the proposed antenna.

The 3D diagram of the realized beam is shown in Figure 6. It clearly depicts the scanned beam when any of the input port is selected. The electronic beam scanning is achieved by the use of a BLC. BLC does not need any DC biasing current to operate and this makes the proposed beam steering antenna simpler compared to the use a switches. With the BLC as the feed, two fixed beams are formed at angles –16° and +16°. By selecting any of the input ports a beam scanning of -16° to +16° is achieved.



(a)



(b)

Figure 6 The 3D representation of the scanned beam, (a) Radiation pattern due to port 1(b) Radiation pattern produced by port 2.

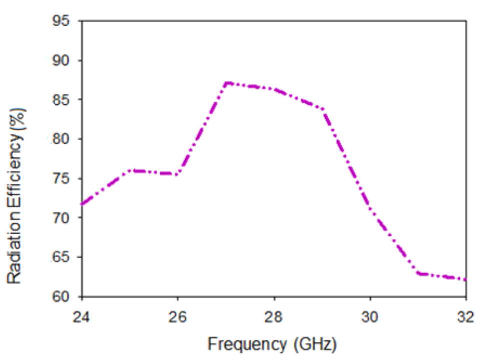


Figure 7 Radiation efficiency of the designed array antenna in percentage.

Figure 7 shows the graph of the radiation efficiency in percentage. From Figure 7, the radiation efficiency of the designed array antenna is well above 70 % within the frequency of operation with the maximum value of 87% at 27 GHz and minimum value of 62.66% at 32GHz.

4.0 CONCLUSION

A beam steerable antenna has been designed, modeled and the results presented. The designed antenna has a 2 × 2 BM as its feed and as a result does not need any switch to achieve a steerable beam. Both the feed and the array antenna are designed in a single layer thereby making fabrication more cost-effective. The required amplitude and phase shift of the BLC was first achieved before integration of the array antenna ensuring the accuracy of the operating range. The proposed antenna eliminates the need of switches while significantly enhance the bandwidth and gain. The peak IEEE gain of 13.8 dB and directivity of 14.5 dBi at the designed frequency is much better than the directivity of 12.66 dBi reported in [10] for grid antenna of almost the same size. The designed antenna would support the future 5G mobile communication proposed to operate at 28 GHz of frequency.

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