A Dual-Band Millimeter-Wave Microstrip Antenna Array for 5G Applications

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ABSTRACT
In this paper, microstrip antenna array is discussed. The proposed antenna array is designed for millimeter-wave applications targeting the 24.25 GHz to 27.5 GHz and 26.5 GHz to 29.5 GHz range of the frequency spectrum. The dielectric substrate considered is the Rogers RT Duroid 6002. Initially, a conventional antenna is designed and simulated. The basic design is studied first and then is subjected to the next stage in the design. A 2X1 microstrip antenna array is later evolved from the initial conventional design whose radiation characteristics are studied. Later stage, another 2X1 antenna array is connected, which makes the end structure a combination of two 2X1 microstrip antenna array connected back to back. The end result is a 4 element antenna array with dual-band characteristics with S11 parameter -32.88 dB at 24.67 GHz with a gain of 8.67 dB and -35.07 dB at 29.35 GHz with a gain of 10.30 dB. The end structure is compared with the initial and intermediate stage designs in terms of S11, gain and VSWR and important findings are tabulated.

Keywords
Millimeter-wave communications, dual-band antenna, 5G applications, mm-Wave.

1. INTRODUCTION
Vast changes and the increased use of mobile data are seen in the last decade. This tremendous increase in the usage of cellular communications and wireless applications led to the shortage of the available bandwidth which proved to be a serious issue for the service providers [1]. These cellular service providers have a limited range of carrier frequency spectrum to deliver multimedia and other applications for wireless systems [2]. The broadband cellular network providers need to cope with the truth that they need to understand the increasing demands for consumer data and traffic volumes. An improved and efficient wireless technology and wideband range of the spectrum is necessary to meet the needs of wireless carriers [3]. There is an overcrowded situation present in the sub-3 GHz spectrum and on the other side, the 3 – 300 GHz frequency range is said to be under-utilized. The Super High Frequency (SHF) is the 3-30 GHz range and the 30-300 GHz is the Extremely High Frequency (EHF) range. The EHF is the millimeter-wave band. On the account of showing similar characteristics in terms of propagation in both the SHF and EHF band, the radio waves here are termed as millimeter-waves referring to 3 - 300 GHz as its band with wavelengths 1 to 100 mm [4]. The 5G systems will likely utilize in or near this underutilized spectrum ranging from 30-300 GHz. Because of the extremely small wavelengths, it is necessary to deploy highly directional antennas. On the other hand, these antennas should be able to steerable. Collectively these antennas should be used using novel methodologies [5]. One important point to mention is the lossy characteristics of mm-wave bands compared to the lower microwave frequencies. More reliable mm-wave channel modeling is necessary to mitigate or reduce the lossy conditions [6]. Because of the range of working is shifted to higher frequencies (24 to 86 GHz), the antennas designed should also have proper radiation characteristics. Multiband and ultra-wideband antennas with high directivity and efficiency are proved to very useful for 5G wireless communication systems [7]. In particular, the regions between 24 to 29.5 GHz are mainly focused on 5G as this region offers lower attenuation and lower atmospheric absorptions compared to the higher range of frequencies [8].

2. ANTENNA DESIGN STRUCTURE
A Conventional antenna is designed in the first stage of the design process. The antenna is designed to resonate at 24 to 26 GHz frequency range. The patch dimensions considered are 4.11 X 3.23 (in mm) in terms of the width and length which are calculated using the patch antenna design calculations as mentioned in [9]. The substrate used is Rogers RT / Duroid 6002 with a dielectric constant of 2.94 and loss tangent 0.0012. The antenna is fed using strip-line feeding mechanism as shown in Figure 1.

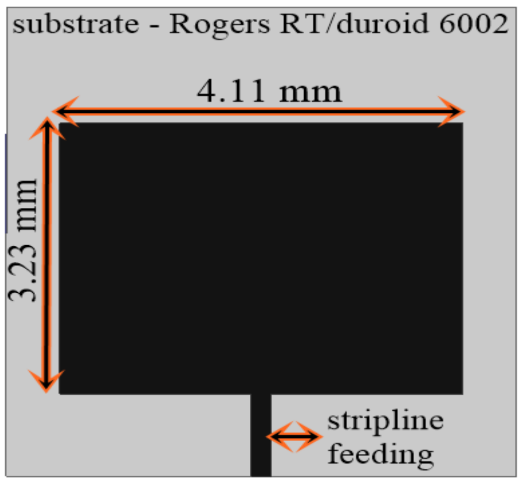

Figure 1. Conventional Antenna Design

The simulated results are discussed, with the S11 parameter being -38.52 dB for a center frequency of 25.50 GHz with VSWR calculated to be 1.024. The gain for the conventional antenna is found to be 6.935 dB at 25.50 GHz. The S11, VSWR and gain plots of the conventional antenna are given in Figures 2, 3 and 4.

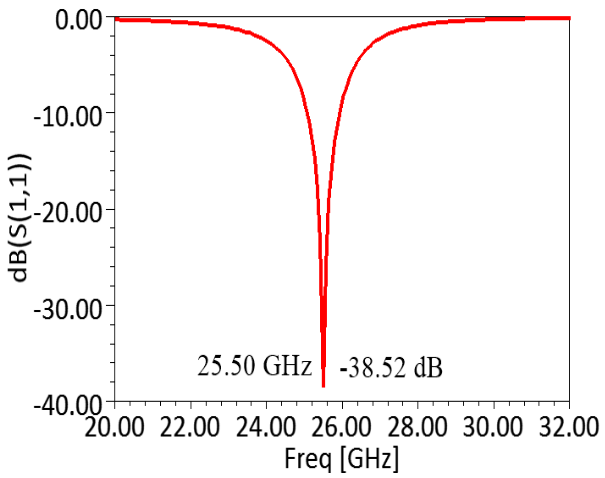

Figure 2. S11 plot for the conventional antenna

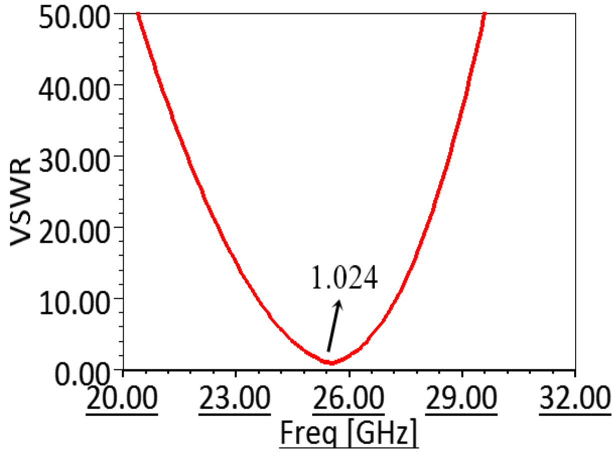

Figure 3. VSWR plot for the conventional antenna

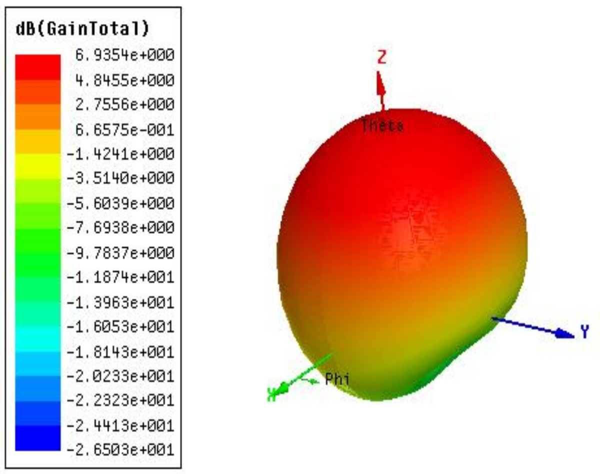

Figure 4. 3-dimensional gain plot for conventional antenna

3. 2X1 MICROSTRIP MILLIMETER-WAVE ANTENNA ARRAY

The design is extended to array configuration post the simulation of the conventional antenna. A 2X1 millimeter-wave antenna array is realized with the same patch dimensions discussed for conventional antenna and be able to work in the 24 to 26 GHz frequency range. The distance between the individual antenna is optimized to be ‘7 mm’ from the center of feed of each antenna element. The array configuration is shown in Figure 5

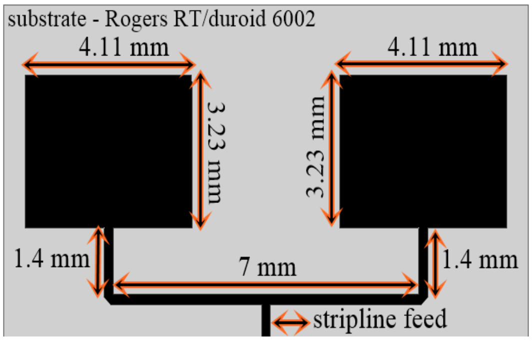

Figure 5. 2X1 microstrip millimeter-wave antenna array

The designed antenna array is simulated for computing the antenna parameters. The S11 plot for the 2X1 antenna array is found to be -22.67 dB with a VSWR of 1.095 at a center frequency of 25.73 GHz. The gain for this array is found to be 9.60 dB with a more directional pattern. The results for S11, VSWR and gain plots are shown in Figures 6, 7 and 8.

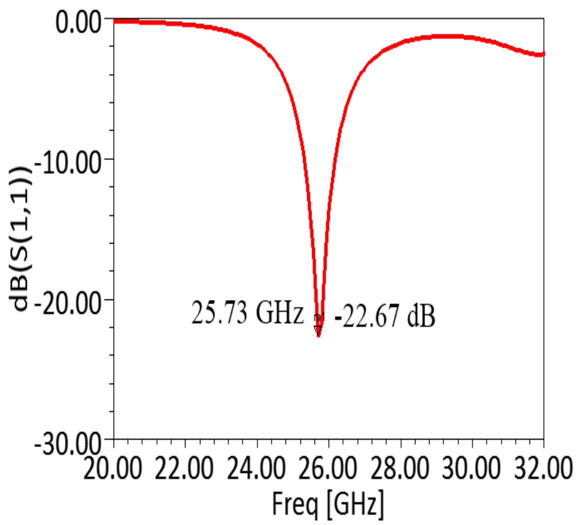

Figure 6. S11 plot for the 2X1 antenna array

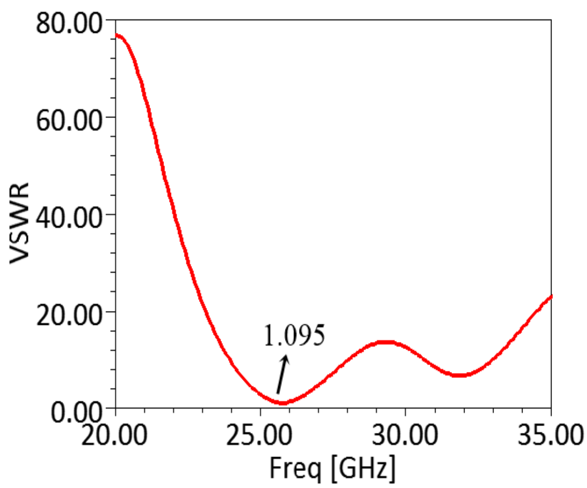

Figure 7. VSWR plot for the 2X1 antenna array

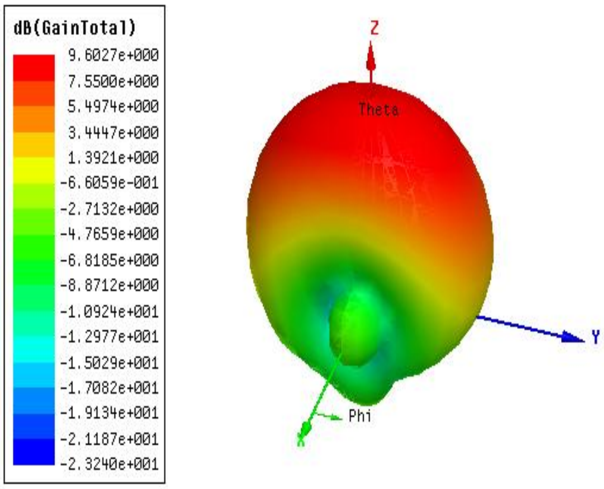

Figure 8. 3-dimensional gain plot the 2X1 antenna array

4. 4-ELEMENT DUAL BAND MILLIMETER-WAVE ANTENNA ARRAY

As a final stage in the design process, a 4 element millimeter-wave antenna array is designed. The array is designed to realize dual-band characteristics in the frequency range of 24 to 29.5 GHz. For this, to the initial 2X1 antenna array, another 2X1 antenna array in a flipped configuration is attached and a common feed point is given making the configuration look like two 2X1 antenna array connected back to back. The proposed array configuration is shown in Figure 9.

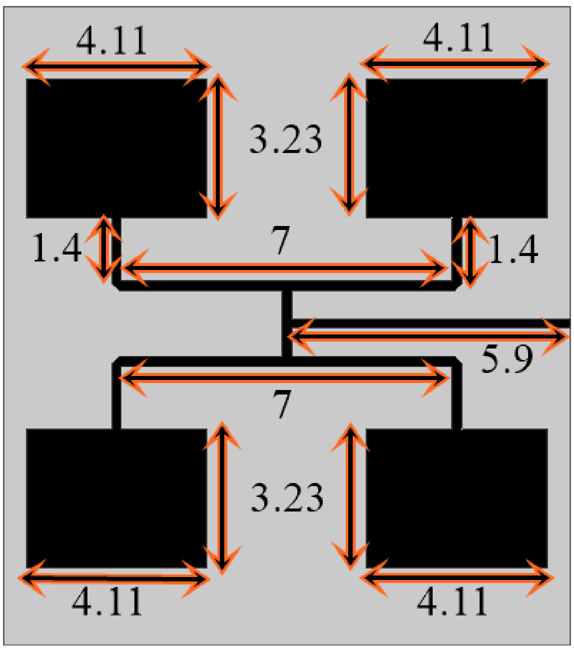

Figure 9. 4-Element Dual-band millimeter-wave antenna array

The designed antenna array configuration excited two frequency bands with improved radiation properties being more directional. The S11 parameter is found to be -32.88 dB at a frequency of 24.67 GHz and -35.07 dB at a frequency of 29.35 GHz with corresponding VSWR values of 1.046 and 1.035. The gain is also computed from the 3-dimensional gain plot. The gain at 24.67 GHz is found to be 8.67 dB and at 29.35 GHz it is 10.30 dB. The S11, VSWR and gain plots are shown in Figures 10, 11, 12 and 13.

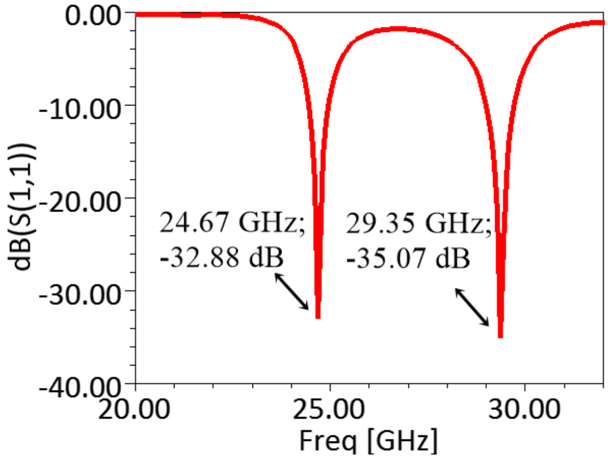

Figure 10. S11 plot for the 4-element antenna array

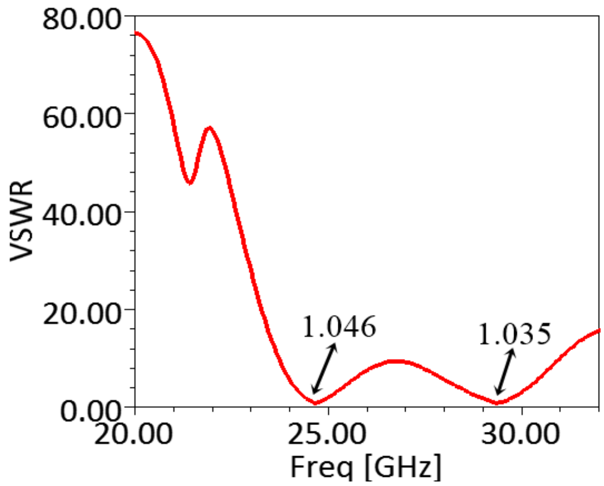

Figure 11. VSWR plot for the 4-element antenna array

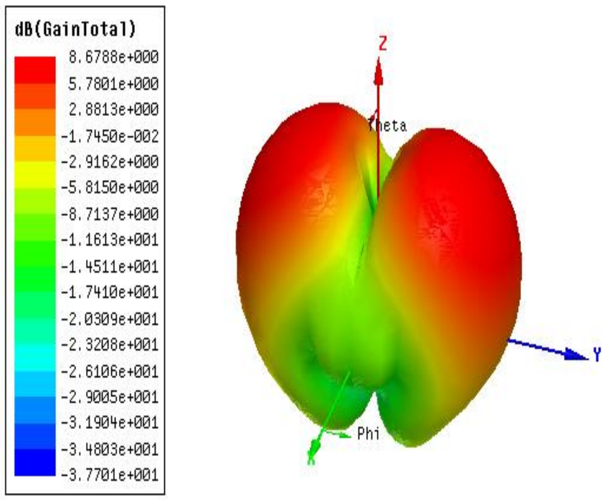

Figure 12. 3-dimensional gain plot at 24.67 GHz frequency

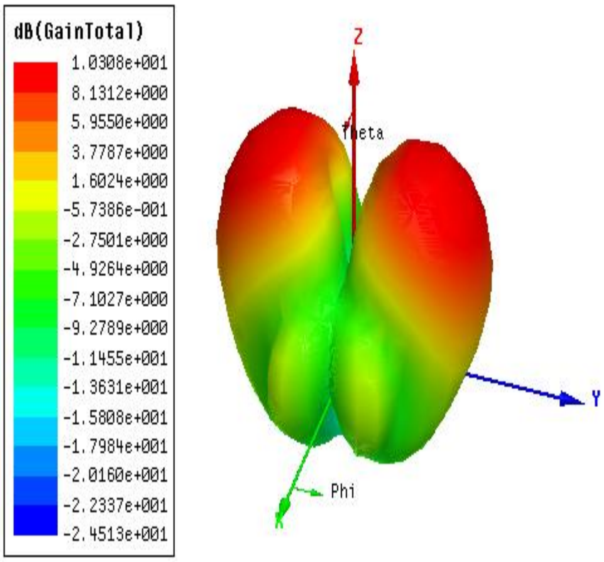

Figure 13. 3-dimensional gain plot at 29.34 GHz frequency

Table 1. Different characteristic parameters for the antenna structures considered

Antenna Configuration	Operating Frequency (GHz)	S11 (in dB)	VSWR	Gain (in dB)
Conventional Antenna	25.50 GHz	-38.52	1.024	6.93
2 X 1 Antenna Array	25.73 GHz	-22.67	1.095	9.60
Proposed 4 - element Antenna Array	24.67 GHz and 29.35 GHz	-32.88 and -35.07	1.046 and 1.035	8.67 and 10.30

6. CONCLUSION

A 4 – element dual-band millimeter-wave microstrip antenna array is designed and simulated covering the 5G frequency bands 24 to 29.5 GHz. The designed antenna array, as expected, exhibited dual-band characteristics with an S11 value of -32.88 dB at 24.67 GHz and -35.07 dB at a frequency of 29.35 GHz with 1.046 and 1.035 VSWR values. The gain, when computed, is found to be 8.67 dB at -24.67 GHz and 10.30 dB at 29.35 GHz. The pre-final versions of the proposed structure also showed good agreement with the taken frequency considerations. The conventional antenna showed up an S11 of -38.52 dB at 25.50 GHz with VSWR of 1.024 and gain value of 6.93 dB, whereas for the 2X1 antenna array the S11 is -22.67 dB at 25.73 GHz with a VSWR of 1.095 and gain value of 9.60 dB. Therefore, the proposed antenna array with dual-band characteristics resonating at 24.67 GHz and 29.35 GHz with a good directional gain of 8.97 dB and 10.30 dB can be extensively used as mm-Wave antenna array for 5G applications.

7. REFERENCES

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