

Analysis of Efficiency in Dual-Band Antenna for 5G Using FR4 Substrate and Compare with RT Duroid Substrate

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Abstract

Aim: This study involves developing a compact dual-band antenna for FR4 and comparing its efficiency to a dual-band antenna for RT duroid.

Materials and Methods: The antenna was made using an efficiency that was built on a commercially available FR4 substrate with a thickness of 2.6 mm. The performance was analyzed with the aid of Ansoft HFSS version 13.0 software. The sample size is estimated to be 32 using the G Power statistical tool with a probability of 80%.

Results: In this study, a return loss of -33.15dB and -21.06 dB at 12.7GHz followed by 15.4GHz, and efficiency is 0.3 is obtained. The significance of RT duroid substrate value is 0.001 which is less than ($p < 0.05$).

Conclusion: The Efficiency is high at 2.8 GHz frequency in novel RT duroid substrate (-0.14105 dB) compared to FR4 substrate (-10.445 dB).

Keywords: Dual-band antenna, FR4 substrate, Novel RT duroid, Frequency, Return loss, Efficiency, Communication.

DOI: 10.47750/pnr.2022.13.S04.093

INTRODUCTION

Advances in the field of mobile communication have had an important impact on economic and social development in the past few years. As a result, 5G technology has emerged as a pedestal of the future 2022 generation. More devices are interconnected in this new generation of wireless communication age, which necessitates high data rates for a variety of applications. In both operating bands, the radiation patterns are nearly omnidirectional with moderate gain (Mercy and Joseph Wilson). Multiple-input multiple-output of dual-band antenna array with wide bandwidth and low profile for synthetic aperture radar imagery applications and wireless communication application (Kong and Xu 2018). The traditional FR4 substrate is replaced with a novel RT duroid substrate structured into a thin dielectric laminate, allowing two modes to propagate simultaneously together with the transmission line structure in distinct frequency bands, namely the quasi-TEM mode and the TE₁₀-like mode (Li and Wang 2018). The Wireless communication applications of the research include satellite and broadcasting (Abbas et al. 2020).

Over the past three years, many articles have been published on dual-band antennas. 1240 research articles were published in IEEE explore and 864 research articles were published in science direct. Because of the excessive growth of communication technology, the electromagnetic spectrum has become a scarce resource in danger of running out and has gotten worse day by day (Li and Wang 2018), particularly in useful bands such as VHF, UHF, and lower SHF frequencies, where the signal wavelength is in the order of centimeters and decimeters (Mahmoud and Montaser 2020). The return loss of dual-band antenna for 5G applications is being analyzed through simulation at 13.6 GHz, 16.0 GHz (Kong and Xu 2018). Finding an antenna at 12.7 GHz, 15.4 GHz frequency with high Return loss performance has become extremely difficult (Ez-Zaki, Ghammaz, and Belahrach 2018) dual-band antennas provide better 5G applications. The designed antennas have low return loss and we tried to reduce the return loss in dual-band antennas in satellite wave applications (Rama and Vakula 2014). Our team has extensive knowledge and research experience that has translate into high quality publications (Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar et al. 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al.

2021; Arun Prakash *et al.* 2020; Kamath *et al.* 2020; Shanmugam *et al.* 2021; Rajasekaran *et al.* 2020; Adhinarayanan *et al.* 2020; Rajesh *et al.* 2020; Aurtherson *et al.* 2021)

The existing antennas have less return loss and efficiency. To overcome this, a dual-band antenna for Novel RT substrate for 5G application and comparing the return loss with the existing dual-band antenna for FR4 substrate has been designed.

MATERIALS AND METHODS

The study setting of the proposed work was conducted in the Semiconductors Laboratory, Department of Nanotechnology, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai. There are two groups in this research work. One group refers to the efficiency of dual-band antenna for FR4 substrate and the other group refers to the efficiency of dual-band antenna for novel RT duroid substrate. For each group, the sample size is 16. The total sample size of the research work is 32. The pre-test analysis is found to be 80% for the total sample size of dual-band antenna for novel RT duroid substrate (Kane, Phar, and BCPS 2021). HFSS software tool was used for antenna designing, it consists of several predefined simulation tools for antenna designing. The size of the dual-band antenna is 35mm * 25mm * 1.6 mm.

In group 1, the return loss was compared to a previous study by (Awan *et al.* 2019). The authors reported a return loss of -13 dB and -27 dB at the frequency of 13.6 GHz and 16.0 GHz with an efficiency of 1.3 and 1.6 using a Rogers RT/Duroid substrate. In our study, group II constitutes a dual-band antenna with FR4 substrate, and the efficiency was obtained using HFSS 13.0 version software. The testing procedure measures return loss dual-band antenna for novel RT duroid substrate and dual-band antenna for FR4 substrate. The results (Return Loss and Efficiency) were extracted into CSV files. The mean, standard deviation, and significant difference of the simulation results were calculated using SPSS. In this research, frequency and dielectric constant are independent variables since they are both inputs and cannot be changed. Efficiency (Return loss, Efficiency) is a dependent variable because it is determined by its inputs. The statistical analysis of the research work is carried out using One-way Anova, which is used to compare return loss (S11), efficiency, return loss of dual-band antenna, and 5G applications, and its graphical comparison is shown in Fig. 3.

The dual-band antenna design and the sweep frequency range from 1GHz to 3GHz will be analyzed to determine the resonating frequency at 2.45GHz and then the efficiency of -33.15 dB will be evaluated. For both FR4 substrates and Novel RT duroid substrates, the frequency is the dependent variable, and the efficiency is the independent variable (Yang *et al.* 2021).

Ansoft HFSS is a simulation tool for designing high-frequency antennas. HFSS tool is used for design, simulation, and verification of FR4 substrate and RT duroid substrate. Origin pro v8 was used for comparative analysis of the efficiency of FR4 substrate and dual-band antenna.

STATISTICAL ANALYSIS

Statistical comparisons of parameters like efficiency and return loss were conducted using SPSS Version 21 (Stehlik-Barry and Babinec 2017). The independent variables are the width and height of the substrate, the length and width of the patch, and the operating frequency of the antenna. Gain, Return loss, and antenna efficiency are dependent variables. An independent sample t-test was used.

RESULTS

The return loss and efficiency of dual-band antenna for novel RT duroid substrates are analyzed at 12.7 GHz and 15.4 GHz. Table 1. Shows the design parameter of the dual-band antenna for both FR4 substrate and Novel RT Duroid substrate to calculate the efficiency The return loss and efficiency results have been simulated for the antenna. A comparison of the return loss and efficiency of dual-band antenna for RT duroid substrate was shown in Table 2.

Statistical analysis of return loss and efficiency for dual-band antenna for novel RT duroid substrate was performed using SPSS software. The efficiency of dual-band antenna for novel RT duroid substrate has the highest mean (7.42) over dual-band antenna for FR4 substrate (5.57). The descriptive statistical analysis is illustrated in Table 3. The mean, standard deviation, and significance difference for novel RT duroid substrate and FR4 substrate.

Return Loss, Efficiency of dual-band antenna for FR4 substrate shown in Fig. 1. Efficiency of dual-band antenna for novel RT duroid substrate shown in Fig. 2. As $p < 0.05$, the difference between the two groups is inconsequential. Fig. 3 shows the results that the efficiency is lower than the dual-band antenna for FR4 substrate presented. In Fig. 4 the mean (± 1 SD) Efficiency of a dual-band antenna for the Novel RT duroid substrate and a dual-band antenna for the FR4 substrate. Because the significance value is 0.001 which is less than ($p < 0.05$), there is a statistically insignificant difference between the Return Loss, efficiency of dual-band antenna for novel RT duroid substrate, and dual-band antenna for FR4 substrate, as shown in Table 4. The voltage standing wave ratios at 12.7 GHz and 15.4 GHz are 0.3 and 1.

DISCUSSION

The efficiency of dual-band antenna for FR4 substrate and novel RT duroid substrate are analyzed for 2.8 GHz by varying the sweep frequency ranging from 1 GHz to 3 GHz. Efficiency and frequency characteristics of dual-band antennas for FR4 and RT duroid substrates are analyzed by varying the length of the dual-band antenna. After analyzing the simulation waves, it has been observed that the efficiency is greater for novel RT duroid substrate.

From the simulation curves, it has been observed that the dual-band antenna for novel RT duroid substrate is better than the dual-band antenna for FR4 substrate. Based on the performance of our antenna, it can be actively considered for satellite communication systems because of its thin profile and lightweight. The results show that there is improvement in return loss i.e -33.15 dB and -21.06 dB at the frequency of 12.7 GHz and 15.4 GHz with an efficiency of 0.3. The proposed innovative dual-band antenna for novel RT duroid substrate has good bandwidth and less return loss which is exactly suitable for wideband and wireless communication applications. The main advantage of this antenna was its compact size with the length of 35mm and with the width of 25mm.

It was observed that by varying the Length / Width of the patch, the return loss of the antenna changed. Wireless communication systems demand antennas with attractive characteristics such as lightweight, low profile, and high gain have increased significantly for higher efficiency (Kong and Xu 2018). Waveguide-based components are favored in novel RT duroid due to various advantages over their dual-band counterparts (Manimegalai et al 2019). In contrast to dual-band or planar components, waveguide-based components have a higher power handling capability, a higher efficiency factor, lower losses, and better isolation (Kumar et al. 2020). It was also reported that if the length of the patch decreases, the resonant frequency (f_r) increases which results in poor FR4 performance (Patchala, Raja Rao, and Prasad 2020). In this article, increasing the length of the patch resulted in higher performance. However, the efficiency of the dual-band antenna for FR4 substrate used in our study was low when compared to embedding a novel RT duroid substrate on top of the patch (Tangthong, Nuangpirom, and Akatimagool 2015).

In this comparative study of FR4 substrate and a novel RT duroid substrate with the same resonating frequency of 2.5 GHz, the efficiency of the novel RT duroid substrate is 87.0212 % better than the FR4 substrate. Also, it has a thin dimension with a low loss tangent and dielectric constant. Novel RT duroid substrate gain is much higher than FR4 gain.

CONCLUSION

The efficiency is high at the frequency of 2.8 GHz for RT duroid substrate (-30.25 dB) compared with FR4 substrate (-19 dB). The efficiency is very less at 2.8 GHz frequency in the FR4 substrate. The dual-band antenna with novel RT duroid substrate has good efficiency.

DECLARATIONS

Conflict of Interest

No conflict of interest in this manuscript.

Authors Contributions

Author GK was involved in antenna design, antenna parameters analysis, manuscript writing. Author AD was involved in antenna validation, the study of simulated results, and a critical review of the manuscript.

Acknowledgment

The authors would like to express their gratitude towards Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (Formerly known as Saveetha University) for providing the necessary infrastructure to carry out this work successfully.

Funding

We thank the following organizations for providing financial support that enabled us to complete the study.

1. DLK Technologies Pvt. Ltd., Chennai.
2. Saveetha University.
3. Saveetha Institute of Medical and Technical Sciences.
4. Saveetha School of Engineering.

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TABLES AND FIGURES

Table 1. Design parameter of the dual-band antenna for both FR4 substrate and Novel RT Duroid substrate to calculate the efficiency at sweep frequency 1 GHz to 3 GHz.

Parameter	Specification
Length of the substrate	35 mm
Width of the substrate	25mm
Height of the substrate	1.6 mm
Length of the patch	21 mm
Width of the patch	0.035 mm
Height of the patch	4 mm
Length of the feed line	2.5mm
Sweep	11 to 17 GHz

Table 2. Comparison of the Return loss of dual-band antenna for FR4 Substrate with dual-band antenna for Novel RT Duroid substrate. Dual-band antenna for Novel RT duroid substrate has better return loss compared to the dual-band antenna for FR4 substrate RL=-33.15 dB and efficiency is 0.3.

Type of antenna	Frequency (GHz)	Return loss (dB)	Frequency (GHz)	Return loss (dB)	Efficiency

Dual-band antenna for FR4 Substrate	12.7	-33.15	15.4	-21.06	0.3
Dual-band antenna for Novel RT Duroid Substrate	13.6	-13.0	16.0	-27.0	1.1

Table 3. Statistical analysis of return loss and efficiency for dual-band antenna. There is a statistically insignificant difference between the groups. Dual-band antenna for novel RT Duroid has a higher mean(7.42) than the dual-band antenna for FR4 Substrate mean (5.57).

Group	N	Mean	Std.Deviation	Std.Error Mean
Return loss				
Dual-band antenna for FR4 Substrate	16	15.3200	1.55048	0.49031
Dual-band antenna for RT duroid Substrate	16	14.3100	1.50440	0.47573
Efficiency				
Dual-band antenna for FR4 Substrate	16	5.5710	5.39475	1.70597
Dual-band antenna for RT Duroid Substrate	16	7.4260	10.81909	3.42130

Table 4. Independent sample T-test which shows the significance in which the return loss of dual-band antenna for Novel RT duroid substrate is found with statistical insignificant ($p>0.05$) when comparing dual-band antenna for FR4 substrate.

	Levene's Test for Equality of Variances		T-test for equality of means						
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std.Error Difference	95% confidence interval of the difference	
								Lower	Upper

Frequency	2.186	0.001	-40.620	1	.000	-11.0000	.049031	14.2109	16.421
			Equal variances assumed						
Equal variances not assumed			-40.620	18	.000	-11.0000	0.47573	13.2338	15.382
Efficiency	.235	.633	-1.977	1	.064	-6.61900	1.70597	-9.4302	9.4302
			Equal variances assumed						
Equal variances not assumed			-1.977	18	.064	-6.61900	3.4130	-.3135	15.165

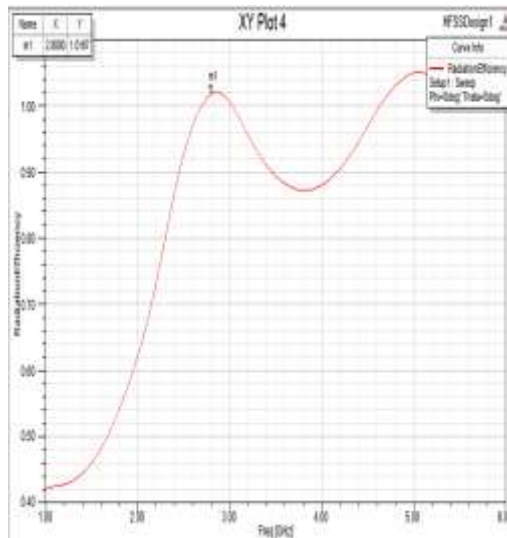


Fig. 1. The Efficiency of dual-band antenna for FR4 substrate at 2.8 GHz and 5GHz is 1.0167 dB and 1.0058 dB

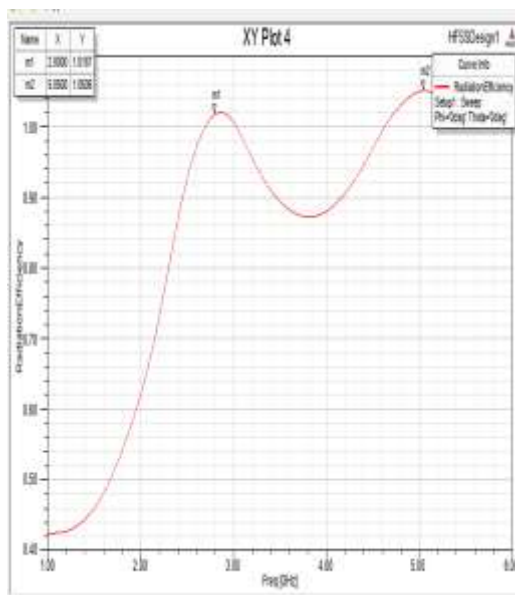


Fig. 2. The Efficiency of dual-band antenna for RT duroid substrate at 2.800 GHz and 5.050GHz are 1.0167 dB and 1.0508 dB.

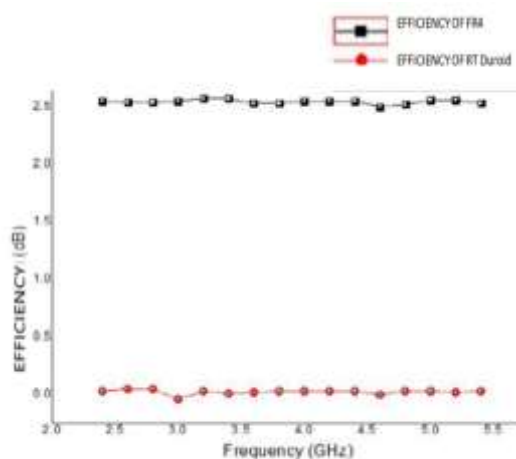


Fig. 3. Comparison of the Efficiency for both RT duroid substrate and FR4 substrate. The **Black** line represents the FR4 substrate and The **Red** line represents the RT Duroid substrate.

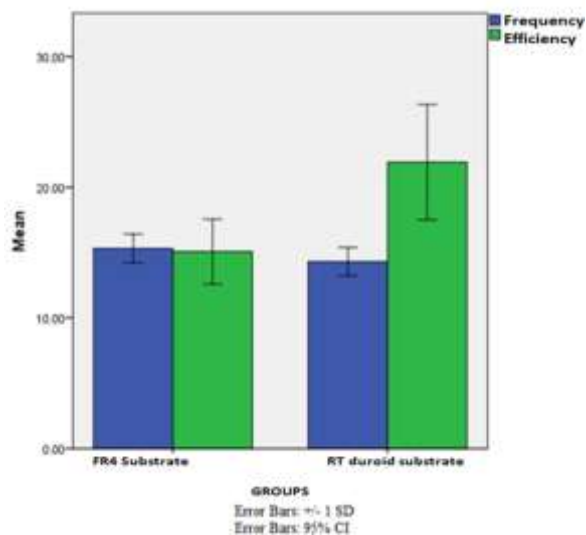


Fig. 4. Bar chart comparing the mean efficiency of dual-band antenna for Novel RT duroid Substrate and dual-band antenna for FR4 substrate. The dual-band antenna for Novel RT duroid substrate has the highest Frequency and efficiency. The dual-band antenna for Novel RT duroid substrate appears to have better efficiency than the dual-band antenna for FR4 Substrate. X-axis: FR4 substrate, RT duroid substrate, and Y-axis: efficiency Mean with +/- 1SD.