Materials Applied to Rectangular Dielectric Resonator Antenna (RDRA) Targeting 5G Applications

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1. Abstract

This study conducts a dual assessment, employing two commercial software applications, of a model of RDRA operating at a central frequency of 28 GHz, targeting 5G applications. The simulated materials consist of Ceramic Alumina (Al_2O_3) and a Low-Temperature Co-Fired Ceramic (LTCC) LMP-CTO-KMO. The antennas with LMP-CTO-KMO resonators showed the most promising results, achieving an (S_{11}) value of -43.67 dB at 28.6 GHz, a bandwidth of 2670 MHz, and a gain of 6.5 dB.

2. Introduction

Currently, with the proliferation of interconnected devices in the Internet of Things (IoT) context, the number of connections has exponentially increased, imposing a growing demand for quick and instantaneous responses. [1] Dielectric Resonator Antennas (DRA) have stood out as one of the most promising options for 5G applications in mobile devices. They offer compactness, wide bandwidth, and miniaturization proportional to $\lambda_0/\sqrt{\varepsilon_r}$. The use of dielectric materials as resonators dates back to 1938, with Richtmeyer's contributions [2]. Materials with high permittivity $(\varepsilon_r > 20)$ are particularly advantageous for these applications [3]. In recent decades, there has been significant research focus on this type of material, that has high permittivity (ε_r) for use as component of antenna.

This work proposes the simulation and design of rectangular geometry Dielectric Resonator Antennas (DRA). These simulations aim to investigate the behavior of materials with ε_r in the range of 9 to 30. The feeding technique employed is the slot method, resulting in resonance frequency range of 28 GHz, aligned with 5G applications.

3. Simulation Model

Rectangular Dielectric Resonator Antennas consist of a rectangular dielectric resonator positioned on a square substrate and a metallic ground plane. Figure 1 illustrates the design of the proposed project. The antennas were designed to operate with Rogers Duroid 5880 substrate. Rectangular resonator antennas are calculated through the transcendental equation (1), which has equation (2) as its solution [3]:

$$tan(k_z d) = \frac{k_z}{\sqrt{(\varepsilon_r - 1){k_0}^2 - {k_z}^2}} \qquad (1)$$

$$\varepsilon_r {k_0}^2 = {k_x}^2 + {k_y}^2 + {k_z}^2 \qquad (2)$$

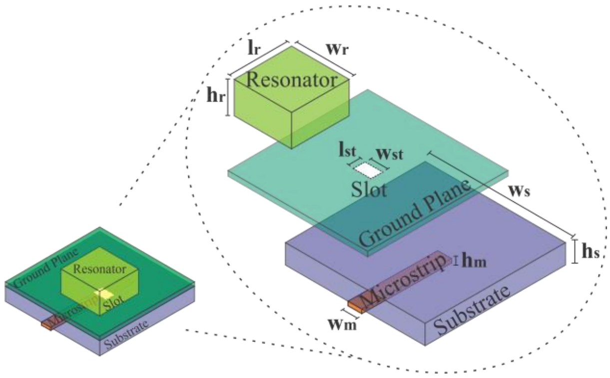

Fig.1. *Antenna Design*

Table 1 presents the parameters used for the DRA model, where w is width, l is length and h is height, followed by the initial of each component.

Table I. *Antenna Parameters (mm)*

Sim's	$l_r \times w_r \times h_r$	$w_s \times h_s$	w_m	l_{st}	w_{st}
01	3.4 × 2.102 × 1.0171	9.9 × 0.254	0.73	1.72	0.67
02	3.4 × 1.3 × 1.5	9.9 × 0.254	0.73	1.82	0.23

4. Materials

The materials employed were alumina (Al_2O_3) ε_r of 9.8 with a purity of at least 99%, readily available in the software library (Simulation 01) and LTCC (Low-Temperature Co-Fired Ceramic) phosphate LMP-CTO-KMO doped with molybdenum, ε_r of 9.1 [4], referred to as LMP (Simulation 02).

5. Results and Discussion

Comparing the results, in the HFSS software, simulation 01 exhibits a higher (S_{11}) coefficient. However, in both software, simulation 02 showed a wider bandwidth, approximately 42% larger compared to simulation 01. Both simulations resonate near the central frequency of 28 GHz.

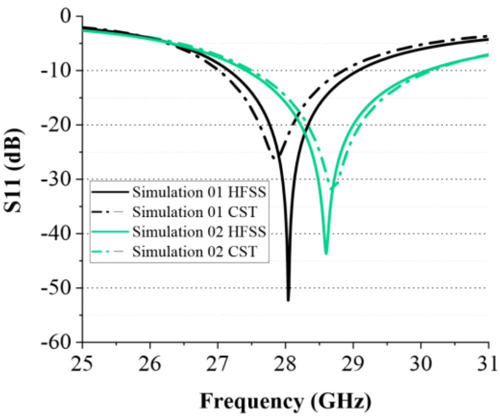

Fig.2. *S_{11} parameter's simulations.*

When observing the variation in results due to the use of HFSS and CST software, where no significant discrepancy is noted, one can overlook such relatively small variations and attribute them to the different approaches of the methods as well as variations in modeling.

Table II. *Simulation's Results*

Simulation	Freq. (GHz)	BW (MHz)	Gain (dB)	VSWR
01 HFSS	28.06	1880	6.1	1.04
02 HFSS	28.6	2670	6.5	1,38
01 CST	27.85	1856	5.78	1.10
02 CST	28.7	2650	6.16	1.04

Figure 3 shows the 2D radiation pattern with a gain of 6.5 dB in the maximum direction and 3D radiation pattern, both for the LMP antenna simulation in HFSS, in CST the lobules have the same display.

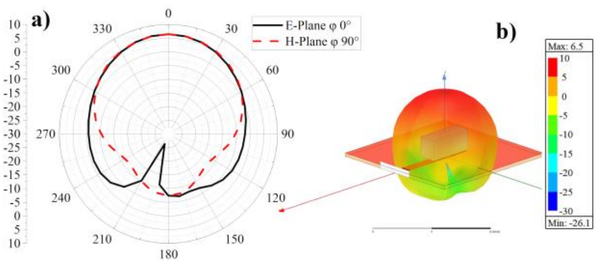

Fig.3. *a) 2D gain radiation pattern of LMP. b) 3D radiation pattern of LMP.*

The simulations proposed in this work investigate the effectiveness of ceramic materials as resonators for DRA antennas.

Barman and Dasgupta [5] designed a DRA with a resonator material ($\varepsilon_r = 10$) for 5G. This study simulations shows that gain values of simulation 02's are preferable. Additionally, the total volume is reduced, and the geometries are simplified.

Table III. *Comparison with the literature*

Material	Freq. (GHz)	ε_r	BW (MHz)	Gain (dB)	Ref.
Rogers RT	28	10.2	2800	6.17	[5]
-	28.08	3.0	3776	7.12	[6]
Al_2O_3	28.06	9.8	1880	6.1	This study
LMP	28.6	9.1	2670	6.5	This study

6. Conclusions

Simulation 02 demonstrating superior characteristics, including a 42% wider bandwidth, higher gain, and reduced size. The simulated models showed maximum energy transfer, reduced reflection and noise. The material LMP-CTO-KMO, used as the resonator in simulation 02, consistently exhibited superior properties. Consequently, LMP-CTO-KMO emerges as a highly viable material for a wide range of applications, including 5G technology, microwave technology, and MIMO antennas. Alumina presents itself as a good candidate when considering the ease and feasibility of its application, being a ceramic material with excellent thermal and dielectric properties.

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