The Impact of Different Ceramic Substrate Materials on the Performance of UWB Antennas

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Abstract. The use of various dielectric substrate materials for antenna shrinking has attracted a lot of scientific attention. A modified circular UWB band antenna design is presented and analyzed on different ceramic substrates such as Alumina 96%, Mg2SiO4, RO3003 and RT Duroid. Our original antenna design enriched a review of different methodologies for antenna design with ultra-wideband performance for various applications. CST Microwave Studio, a software tool based on the MOM method, is the primary design tool. The simulation results for the return loss ratio, gain, and efficiency for different substrate heights are discussed.

Keywords: antenna, UWB, ceramic substrate, defected ground.

1 Introduction

With the development of technology, antennas are becoming the most important component of wireless communication systems (WCS) in the modern era. There is an increasing need for broadband antennas with high gain meeting the constant advancements in WCS. In many wireless applications, the UWB antenna design is a crucial first step [1]. According to FCC regulations published on February 14, 2002, the frequency allotment for UWB is from 3.1GHz to 10.6GHz [2-3], which includes many narrow band frequencies used in WLAN, Bluetooth, Wi-Max, Wi-Fi, C-band, X-band and Ku-band applications [4-8]. In these applications, the design of UWB antennas is given much of the research efforts.

In the design of ultra-wideband antennas, numerous studies have used various antenna structures [9-13]. One of the most suitable design possibilities for planar layouts is the microstrip antenna [14-15]. The advantages of microstrip UWB antennas, such as their simple design, low profile, simple integration and straightforward production have drawn significant attention [16].

The main objective of this paper is to design a UWB antenna with different substrate materials. An elliptical disk monopole planar UWB antenna is presented and investigated. Gathering a trapezoidal ground plane and a flawed rectangular ground structure, this conventional construction, which is relatively geometrically simple fed by microstrip line provides a broad impedance of |S11|< 10 dB. The simulation results using the commercial microwave studio simulator CST are discussed.

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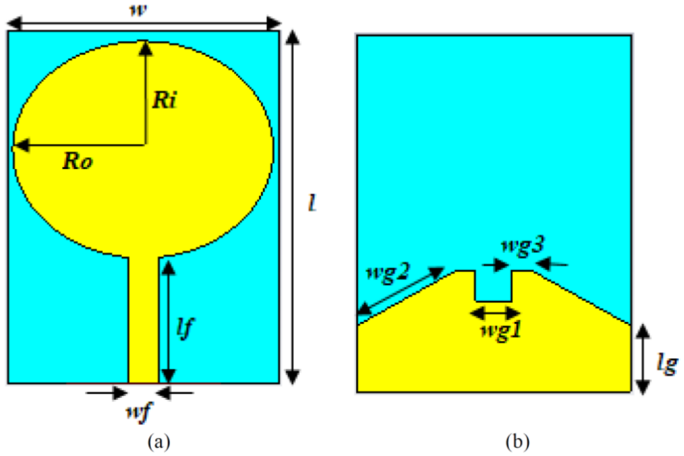
2 Antenna Design

The proposed antenna has dimensions of 25×32.5×1.5mm3. The model is made up of an elliptical patch that is fed by a microstrip line. To improve antenna performance, a trapezoidal ground plane structure and a defected rectangular ground are employed. The proposed planar microstrip patch antenna was designed and analyzed using CST Microwave Studio. The designed antenna was printed on different ceramic substrates. The geometrical parameters are shown in Figure 1.



(a) (b)

Fig. 1. Fig. 1. Geometry of the proposed antenna (a): perspective and (b): top view.

Table 1. Design parameters of the proposed antenna.

Param.	Value (mm)	Param.	Value (mm)
w	25	**wf**	2.84
l	32.5	**lg**	6
Ro	12	**wg1**	3.34
Ri	10	**wg2**	10.3
lf	11.57	**wg3**	1.83

The S11 parameter is analyzed on a regular basis for antenna synthesis to determine the required bandwidth performance. The antenna S11 coefficient results for various substrates are exported to CSV format for analysis and compiled for comparison purposes. The software tool used to prepare the data for Figure 2 is Origin Pro 8 for data analysis and graphing.

Table 2. Design parameters of the proposed antenna [17] [18].

Material	Dielectric Constant	loss tangent
Alumina (96%)	9.4	0.0004
Mg2SiO4	4.5	0.0012
Rogers RO3003	3	0.001
RT Duroid 5880	2.2	0.0009

3 Results Analysis

The choice of an appropriate substrate material is essential when developing a microstrip patch antenna [19][20]. The microstrip patch antenna's bandwidth, efficiency, and gain are all influenced by the permittivity and thickness of the substrate, by making the right choices, these performance parameters can be considerably enhanced.

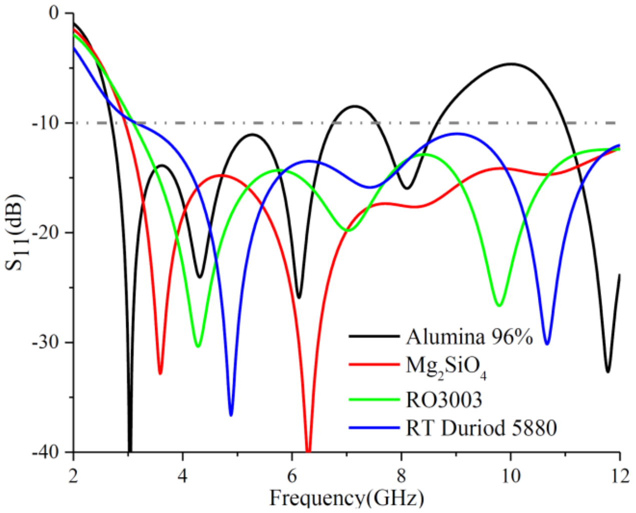


Fig. 2. S_{11} parameter for different substrate designs.

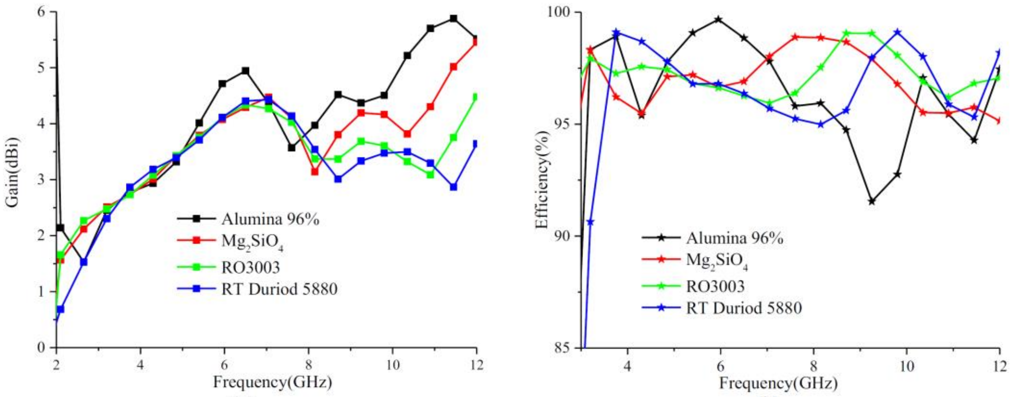
First, a fixed thickness is maintained for various substrate materials. Next, it is determined which of these types best fits the requirements for this application. Table 3 displays the corresponding bandwidth, resonant frequencies, and return losses for various substrate materials.

Table 3. Design parameters of the proposed antenna.

Material	**Band Width (GHZ)**	**Resonant Frequency (GHZ)**	**Return loss (dB)**
Alumina (96%)	5.96 (2.69-8.65)	3.04	-40
		4.3	-23.95
		6.15	-25.7
		8.1	-16
		11.8	-32.7
Mg2SiO4	9.05 (2.95-12)	3.5	-32.7
		6.3	-40
		8.28	-18
		10.6	-14.7
Rogers RO3003	8.9 (3.1-12)	4.3	-30.5
		7	-19.8
		9.8	-26.5

RT Duroid 5880	8.85 (3.15-12)	4.9	-36.55
		7.4	-15.5
		10.6	-29.9

For the whole UWB frequency spectrum, the target value of S11 should be lower than 10 dB. Simulated values of S11 at working frequencies of 3.04 GHz, 4.3 GHz, 6.15 GHz, 8.1 GHz and 11.8 GHz have been found to be -40 dB, --23.95 dB, -25.7 dB, -16 dB and -32.7 dB, respectively.

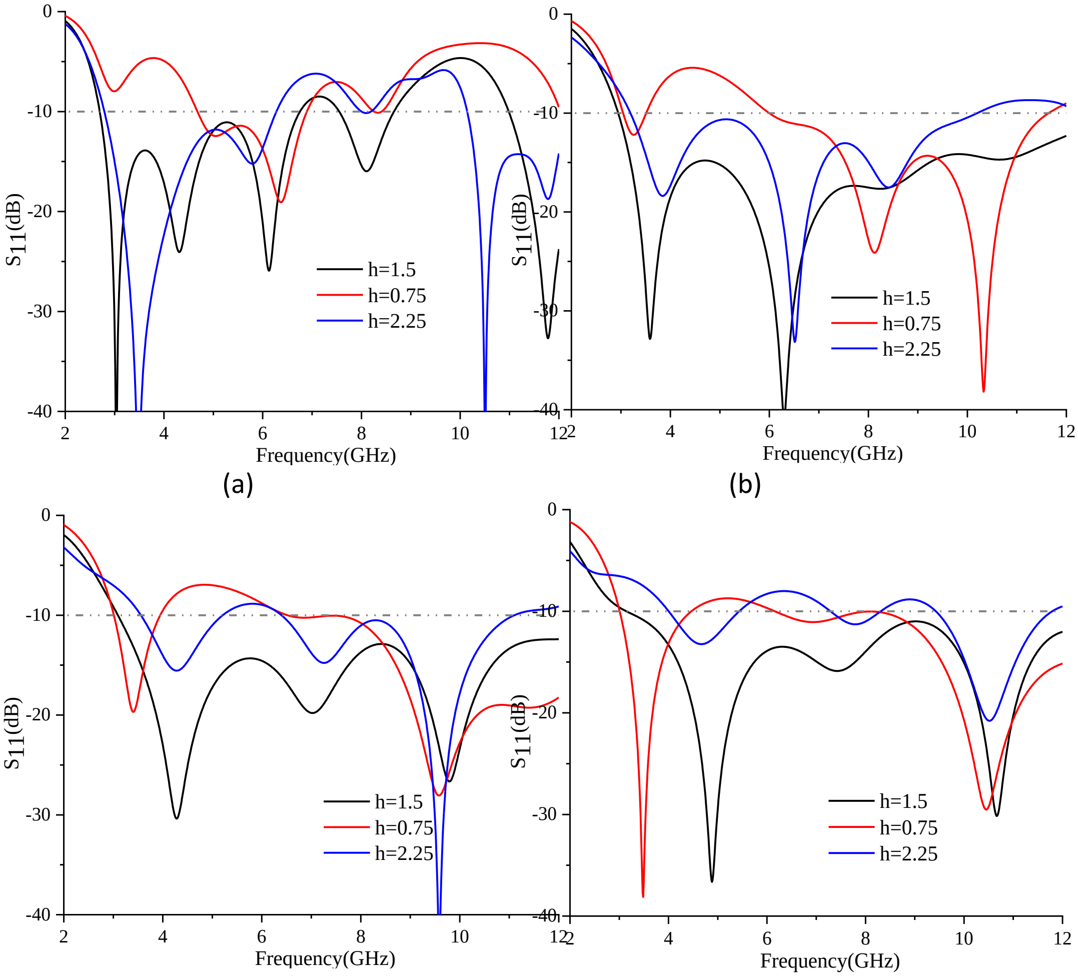


(a) (b)

Fig. 3. (a) Gain plot and (b) radiation efficiency plot with different substrates.

The developed antenna, which uses Alumina (96%) as its substrate material, offers a 6 GHz and width value of 10 dB spanning a range of 2.69 GHz to 8.65 GHz. The antenna geometry using Mg2SiO4 ceramic substrate material offers an absolute bandwidth of 9.05 GHz, which lies between 2.95 and 12 GHz. The proposed antenna using Rogers RO3003 substrate and RT Duroid 5880 substrate material shows an absolute bandwidth of 8.9 GHz and 8.85 GHz, respectively (Table 3). As a result, the resonance frequency decreases as the dielectric constant rises [21].

Figures 3. a and b show the gain and radiation efficiency obtained for the designed UWB antenna, respectively. Antenna gain is often related to the gain of an isotropic radiator, resulting in units of dBi. The maximum gain of 5.8 dBi is obtained with an alumina (96%) substrate that uses Mg2SiO4 as a substrate material; the gain ranges from 2 to 5.3 dBi, while the corresponding Rogers RO3003 and RT Duroid 5880 substrates exhibit lower values. The efficiency ranges from over 93% to 98% for the whole operating frequency range (Figure 3b).



(a) (b)

(c) (d)

Fig. 4. S_{11} parameters comparison for various substrate heights, (a) alumina (96%), (b) Mg2SiO4 substrate, (c) RO3003 and (d) RT Duroid 5880 substrates.

Figure 4 compares the S11 parameters of the various dielectric substrate materials used to build the antenna design for various substrate heights. This comparison is essential to show the impact of the type and thickness of the dielectric substrate material.

4. Conclusions

A microstrip antenna design for UWB applications is presented in this work. Alumina 96%, Mg2SiO4, RO3003, and RT/Duroid 5880 are different dielectric substrate materials on which a microstrip antenna has been designed and constructed. The CST Microwave Studio Suite software was used to design and simulate these radiating structures. Antenna designs that employ various dielectric substrate materials at both fixed substrate heights and variable heights have been compared and the outcomes of each design are presented and discussed.

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