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REVIEW ARTICLE

Performance analysis of RF substrate materials in ISM band antenna applications

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Abstract

The tremendous growth in wireless communication needs compact, wideband, high gain, low-cost antennas for transmitting and receiving signals. This paper focused on the design of a rectangular microstrip antenna for ISM Band with a resonant frequency of 2.45GHz. It also examines how the dielectric constant and thickness of substrates affect antennas' performance. Four different substrates FR4, Alumina, PTFE, and RT Duroid 5880 with 1.6mm and 0.8 mm thickness, are considered in antenna performance comparison. The work is verified up to the simulation level in Advanced Design System (ADS) software. The S parameter simulation results are presented to compare the performance of antenna for various substrate materials.

Keywords: Microstrip Antenna, ISM Band, Bandwidth, Return loss, FR4, Alumina, Polytetrafluroethylin.

Introduction

Wireless communication involves transmitting information over a distance without the help of wires, cables or other electrical conductors. Application of wireless communication includes mobile communication, WI-FI, Bluetooth, TV communication, satellite communication, Radio communication, GPS units etc., In wireless communication, RF waves are transmitted and received using different types of antennas. Among the different types of antennas, Microstrip Patch Antenna is highly recommended for government and commercial applications. Some of the features of Microstrip antennas are lightweight, easy and inexpensive to fabricate, suitable for planar and non-planar surfaces, versatile in terms of resonant frequency, polarization, and radiation pattern and it can be mounted on spacecraft, satellites, mobile phones, aircraft, and missiles. Even though it has lot of advantages, it provides narrow band frequency and low gain. Microstrip antenna is a metallic path available in different shapes like rectangles, triangles, and circles, elliptical. Rectangular shape Microstrip antennae and elliptical shape antennas provide acceptable gain, return loss, VSWR (Neelima *et al.*, 2021). Rectangular Microstrip antenna with suitable dimensions can support multiband wireless communication systems (Sharma & Kumar, 2013; Krishnan *et al.*, 2019).

ISM bands are allotted for Industrial, Scientific and medical purposes all over the world. In this band 2.4GHz to 2.5 GHz is used for short-range communications like WI-FI, Bluetooth, RFID and ZigBee which Microstrip antennas can support. Microstrip antennas are constructed over a RF substrate. The electrical and mechanical properties of substrates like dielectric permittivity, loss tangent, surface roughness, thermal conductivity and dielectric strength decides the operating frequency and performance of the antenna. Some of the RF substrates used to construct the Microstrip patch antennas are FR4, Alumina, PTFE (polytetrafluoroethylene), RT Duroid, Bakelite, Rogers TMM10, and GaAs (Raj & Suganthi, 2017).

Review of Literature

Small size, wideband, high gain Microstrip Antennas are required for wireless communication. Bandwidth of Microstrip Patch Antenna is directly proportional to the thickness of substrate and inversely proportional to the relative dielectric constant of the substrate. Substrate with

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lower dielectric constant supports wide bandwidth and substrate with high dielectric constant gives high gain and directivity (Meena & Kannan, 2018). FR4 substrate material provides better gain and RT Duriod 5880 substrate assures better bandwidth for all shapes. An E-shaped microstrip antenna having Defective ground structure with I slots provides sufficient directivity and bandwidth (Aruna *et al.*, 2018; Thiyagarajan & Akhila, 2018). The techniques like defective ground structure, air gaps, slots on patch, shorting plates, stacked multi resonator structures, direct or gap-coupled structures improve the gain, bandwidth and directivity of antennas (Akinola *et al.*, 2019). Rectangular antenna with multiple slots can improve the bandwidth (Muvvala *et al.*, 2018; Thiyagarajan *et al.*, 2015). . An array of square patch antenna with multiple rectangular slots can further improve the bandwidth (Pratiwi & Munir, 2015). Equilateral Triangular Microstrip antenna with excitation of TM_{10},TM_{11} mode produced using two shorting posts can support wideband of operation (Wang *et al.*, 2016).

Proposed Work

Rectangular Microstrip antenna is designed using four different substrates FR4, Alumina, PTFE (polytetrafluoroethylene), RT Duroid 5880 for thickness 1.6mm, 0.8 mm at 2.45GHz. The antenna parameters bandwidth, return loss are obtained using ADS (Advanced System Design) simulation software and results are compared.

Antenna Design Equations

The width of the antenna is calculated using the following equation:

$$w = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r + 1}{2}}} \quad (1)$$

Effective dielectric constant is calculated using equation (2)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right) \quad (2)$$

Effective length is calculated using the equation (3)

$$L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

Equations (4) & (5) are used to calculate the physical length of the antenna.

$$\Delta L = h \times 0.412 \times \frac{(\varepsilon_{eff} + 0.3)\cdot\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \quad (4)$$

Length of the Patch is calculated using the below equation:

$$L = L_{eff} - 2\Delta L \quad (5)$$

In the above equations
C - Speed of light.
f_r – Resonant frequency
ε_r – permittivity of the dielectric
h – Thickness of the substrate
W - width of the patch

Substrate Specification

In this article Rectangular Microstrip patch antenna is designed for 2.45GHz on different types of substrates for different thickness values. RF substrates' electrical and mechanical properties decide their suitability for a particular application. These parameters include dielectric permittivity, loss tangent, surface roughness, thermal conductivity and dielectric strength. Among these dielectric constant and thickness of substrates highly control the bandwidth of antennas. Table .1 illustrates the thickness and loss tangent values of various substrates considered in this simulation. The parameter loss tangent describes the signal propagation loss encountered in the substrate. Signal propagation loss through the substrate is lower very less values of loss tangent.

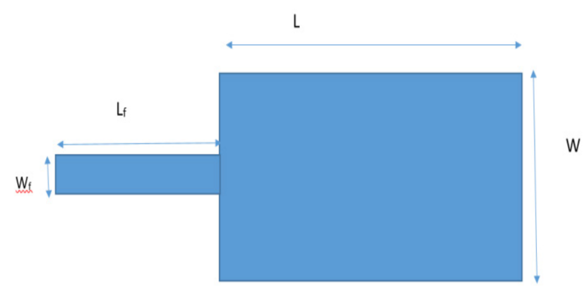

Figure 1: Microstrip antenna structure

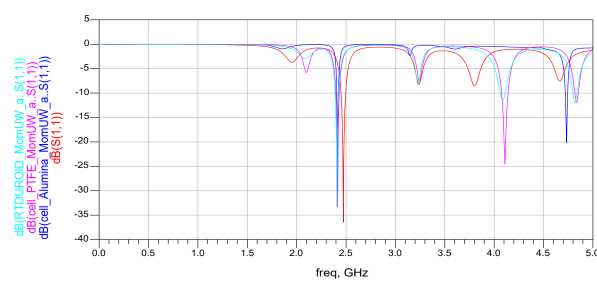

Figure 2: S parameter simulation results comparison of Microstrip antenna on different substrates in 1.6 mm thickness

Table 1: Substrate parameters

Substrate	*Dielectric constant* ε_r	*Loss tangent* $tan\delta$
FR4	4.6	0.02 - 0.03
Alumina	9.6	1 - 2
PTFE	2.06	0.004
RT Duroid 5880	2.20	0.009

Antenna geometry

Rectangular Microstrip Antenna is designed for ISM Band. It is etched on a dielectric substrate. The substrate is mounted on a ground plane which is made up of metal. The height of the substrate is h and the dielectric constant is ε_r. The width and length of the rectangular patch are mentioned as W and L. Feed line is connected along the length of the patch antenna.

The feed line length is L_f and feed line width is W_f. The dimensions W, L, h, ε_r control the performance of the patch antenna. The thickness of the substrate and the dielectric constant of substrate materials controls the width and length of the Microstrip patch antenna. The length L of the patch antenna decides the resonant frequency. The length is indirectly proportional to the resonant frequency. Width W. can change the input impedance and radiation pattern of the antenna If the width is large, the impedance will be low. The relative permittivity of the substrate decides the fringing field around the antenna, which controls the radiation. The bandwidth can be increased by decreasing the Dielectric constant and increasing the height of the substrate. The relation between bandwidth (BW) and W, L, h, ε_r is given below.

$$\text{Bw} \;\; \alpha \;\; \frac{(\varepsilon_r - 1)W * h}{\varepsilon_r^2 L}$$

The width and length of the antenna for 2.45GHz resonant frequency for various substrate is listed below:

Results and Discussion

The rectangular Microstrip antenna is constructed on FR4, Alumina, PTFE (polytetrafluoroethylene), RT Duroid 5880 for thickness 1.6, 0.8 mm for 2.45GHz. The design is simulated using ADS simulation software and the results are shown below.

In all the four substrates with thickness 1.6 mm, the simulation results are tabulated in table 4. Among the four substrates, FR4 gives better bandwidth for 2.45GHz. The Alumina substrate which has the highest dielectric constant gives lowest band of operation. Even though the area occupied by Alumina substrate is less, it provides narrow band of operation.

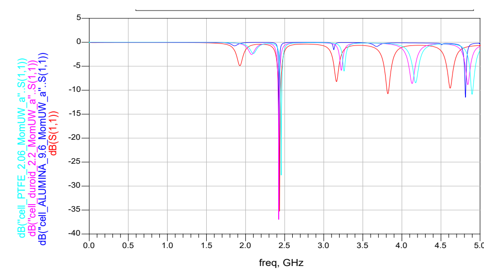

Figure 3: S parameter simulation results for Rectangular Microstrip antenna on different substrates for 0.8mm thickness

Table 2: Antenna Geometry Dimensions For 1.6 mm Thickness Substrates

Substrate	*Dielectric constant ε_r*	*Width W (mm)*	*Length L (mm)*	*Width of Feed Line W_f (mm)*	*length of Feed Line L_f (mm)*
FR4	4.6	36.5886	28.2038	2.958	16.4626
Alumina	9.6	26.5942	19.54	1.5914	12.0166
PTFE	2.06	49.49	41.79	5.1385	22.9866
RT Duroid 5880	2.20	48.4022	40.4859	4.929	22.378

Table 3: Antenna Geometry Dimensions For 0.8 Mm Thickness Substrates

Substrate	*Dielectric constant ε_r*	*Width W (mm)*	*Length L (mm)*	*Width of Feed Line W_f (mm)*	*length of Feed Line L_f (mm)*
FR4	4.6	36.5886	28.4416	1.4792	16.4626
Alumina	9.6	26.5942	19.7341	0.7957	12.0166
PTFE	2.06	49.4970	42.2693	2.5692	22.986
RT Duroid 5880	2.20	48.4022	40.9270	2.4649	22.3787

Table 4: Frequency response, bandwidth and return loss of microstrip antenna on different substrate material for 1.6 mm thickness

Substrate	*Resonant Frequency (GHz)*	*Bandwidth (MHz)*	*Return Loss (dB)*	*Antenna Dimension (L X W) mm^2*
FR4	2.474	54	-36.442	36.5886 X 44.6664
Alumina	2.415	20	-36.972	26.5942 X 31.5566
PTFE	2.415	38	-33.334	49.49 X 64.7766
Rogers RT Duroid	2.407	37	-33.232	48.4022 X 62.8639

Table 5: Frequency response, bandwidth and return loss of different substrate material for 0.8 mm thickness

Substrate	*Resonant frequency (GHz)*	*Bandwidth (MHz)*	*Return Loss(dB)*	*Antenna Dimensions (L X W) mm²*
FR4	2.434	31	-35.266	36.588 X 44.9042
Alumina	2.428	9	-34.215	26.5942 X 31.7507
PTFE	2.455	18	-27.737	49.4970 X 65.2553
Rogers RT Duroid	2.424	18	-36.996	48.4022 X 63.3057

From the simulation results, corresponding to substrates with height 0.8 mm, it is noted that the bandwidth provided by FR4 substrate is better than other substrates. Antenna designed using Alumina substrate gives the lowest bandwidth of operation. Table 4 and Table 5 shows the bandwidth of operation for substrate height value of 1.6 mm is better compared to the substrate height of 0.8 mm.

Conclusion

In this paper, a rectangular Microstrip patch antenna is designed for 2.45 GHz low power applications. A different variety of substrates such as FR4, Alumina, PTFE and RTDuroid 5880 for substrate thickness values of 1.6 and 0.8 mm. The antenna structure is simulated in a commercial advanced design system 2022 simulated software. The antenna parameters resonant frequency, bandwidth, return loss and area occupied by the antenna are listed in Table 4 and Table 5. The S parameter simulation result shows that the height of the substrate and dielectric constant significantly contribute to improving the antenna's performance. FR4 gives better bandwidth in the required frequency among the four substrates analyzed. The result also evidences that the height of the substrate and operation bandwidth have a direct relationship with each other. The substrates having a large dielectric constant provides the lowest band of operation.

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