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, Polytetrafluoroethylin.

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
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\textsubscript{10}, TM\textsubscript{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:

\[
w = \frac{c}{2f_r\sqrt{\varepsilon_f + \frac{1}{2}}} \quad (1)
\]

Effective dielectric constant is calculated using equation (2)

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + \frac{1}{2} \left(\frac{1}{1 + \frac{12h}{w}}\right)}{2}
\]

Effective length is calculated using the equation (3)

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

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

\[
\Delta L = h \times 0.412 \times \frac{(\varepsilon_{\text{eff}} + 0.3) \cdot \left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{\text{eff}} - 0.250) \left(\frac{w}{h} + 0.8\right)} \quad (4)
\]

Length of the Patch is calculated using the below equation:

\[
L = L_{\text{eff}} - 2\Delta L \quad (5)
\]

In the above equations:

- \(C\) - Speed of light.
- \(f_r\) - Resonant frequency
- \(\varepsilon_r\) - 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](image1)

![Figure 2: S parameter simulation results comparison of Microstrip antenna on different substrates in 1.6 mm thickness](image2)

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Dielectric constant (\varepsilon_r)</th>
<th>Loss tangent (\tan \delta)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4</td>
<td>4.6</td>
<td>0.02 - 0.03</td>
</tr>
<tr>
<td>Alumina</td>
<td>9.6</td>
<td>1 - 2</td>
</tr>
<tr>
<td>PTFE</td>
<td>2.06</td>
<td>0.004</td>
</tr>
<tr>
<td>RT Duroid 5880</td>
<td>2.20</td>
<td>0.009</td>
</tr>
</tbody>
</table>
**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 \( \varepsilon_r \). 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 \( W, L, h, \varepsilon_r \) 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 \( W, L, h, \varepsilon \) is given below.

\[
BW \propto \frac{(\varepsilon_r - 1)W + h}{\varepsilon_r L}
\]

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.

Table 2: Antenna Geometry Dimensions For 1.6 mm Thickness Substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Dielectric constant ( \varepsilon_r )</th>
<th>Width ( W ) (mm)</th>
<th>Length ( L ) (mm)</th>
<th>Width of Feed Line ( W_f ) (mm)</th>
<th>Length of Feed Line ( L_f ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4</td>
<td>4.6</td>
<td>36.5886</td>
<td>28.2038</td>
<td>2.958</td>
<td>16.4626</td>
</tr>
<tr>
<td>Alumina</td>
<td>9.6</td>
<td>26.5942</td>
<td>19.54</td>
<td>1.5914</td>
<td>12.0166</td>
</tr>
<tr>
<td>PTFE</td>
<td>2.06</td>
<td>49.49</td>
<td>41.79</td>
<td>5.1385</td>
<td>22.9866</td>
</tr>
<tr>
<td>RT Duroid 5880</td>
<td>2.20</td>
<td>48.4022</td>
<td>40.4859</td>
<td>4.929</td>
<td>22.3787</td>
</tr>
</tbody>
</table>

Table 3: Antenna Geometry Dimensions For 0.8 Mm Thickness Substrates

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Dielectric constant ( \varepsilon_r )</th>
<th>Width ( W ) (mm)</th>
<th>Length ( L ) (mm)</th>
<th>Width of Feed Line ( W_f ) (mm)</th>
<th>Length of Feed Line ( L_f ) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR4</td>
<td>4.6</td>
<td>36.5886</td>
<td>28.4416</td>
<td>1.4792</td>
<td>16.4626</td>
</tr>
<tr>
<td>Alumina</td>
<td>9.6</td>
<td>26.5942</td>
<td>19.7341</td>
<td>0.7957</td>
<td>12.0166</td>
</tr>
<tr>
<td>PTFE</td>
<td>2.06</td>
<td>49.4970</td>
<td>42.2693</td>
<td>2.5692</td>
<td>22.9866</td>
</tr>
<tr>
<td>RT Duroid 5880</td>
<td>2.20</td>
<td>48.4022</td>
<td>40.9270</td>
<td>2.4649</td>
<td>22.3787</td>
</tr>
</tbody>
</table>

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

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

References


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

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