Miniaturization of a patch antenna by thin film materials

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Abstract— The miniaturization of printed antennas is made possible by changing the volume of the antenna with high permittivity materials, ferroelectric, ferromagnetic, magneto-dielectric, etc. More traditionally, the dielectric having a high permittivity were employed to decrease the physical dimensions of antenna patch. The problems often encountered with high permittivity substrates are, degradation of the gain and the bandwidth and therefore the efficiency of the antenna. The use of magnetic materials would be an interesting solution for the miniaturization of antennas without degrading performance due to the significant value of permeability.

Keywords- patch antenna, magneto-dielectric materials, HFSS, thin films.

I. INTRODUCTION

The patch antenna was introduced by John Q. Howell in 1972 [1]. Using a high-\(k\) dielectric material is the most common method to reduce the size of the antenna [2-3]. In this work, we will show firstly reducing antenna size for a planar antenna printed on a dielectric substrate and secondly on a substrate integrated magneto-dielectric material in a thin layer.

II. PATCH ANTENNA

The micro strip antenna is a transmission line consisting of a thin metallic conductor (typically from 17.5 to 35\(\mu\)m thick microwave) called radiating element, it is of arbitrary form, deposited on a thick substrate used to increase the power radiated and reduce the losses by the Joule effect and improve the bandwidth of the antenna, the lower side is entirely metalized to provide a ground plane, and is shown in Fig. 1. This transmission line cannot support the pure Electric- magnetic transverse (TM-TE) of the transmission, since the phase velocities are different in the air and the substrate, for this purpose the dominant mode of propagation is the quasi-TEM mode. The optimization of the dimensions is done using a program developed in MATLAB when the input data are: The frequency of operation, the substrate (thickness, electric permittivity and loss tangent), where the thickness of the substrate must be satisfy the equation (1)[5].

\[
h \leq \frac{c}{4f \sqrt{\varepsilon - 1}}.
\]  

(1)

Where:
\(\varepsilon\) = dielectric constant of the substrate
\(h\) = height of the substrate.
\(c\) = the air velocity
\(f\) = operating frequency

Thus, the effective dielectric constant \(\varepsilon_{\text{eff}}\) must be obtained to account for fringing and wave propagation in the line.

The \(\varepsilon_{\text{eff}}\) value is slightly lower \(\varepsilon_r\) because the fringing fields around the periphery of the label are not confined in the dielectric substrate, but are also distributed in the air. The effective dielectric constant has values in the range of \(1 < \varepsilon_{\text{eff}} < \varepsilon_r\), but when the dielectric constant of the substrate is much larger than unity (\(\varepsilon_r \gg 1\)), the \(\varepsilon_{\text{eff}}\) value will be closer to the value \(\varepsilon_r\) of the substrate [2].

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1 + \frac{\varepsilon_r - 1}{2 \sqrt{1 + 12 \frac{h}{w}}}}{2}
\]  

(2)

where:
\(w/h > 1\)
\(\varepsilon_{\text{eff}}\) = effective dielectric constant
\(\varepsilon_r\) = dielectric constant of the substrate
\(h\) = height of the dielectric substrate

The dimensions of the patch antenna along its length were extended at each end by \(\Delta L\) distance, which is based on the effective dielectric constant \(\varepsilon_{\text{eff}}\) and aspect ratio.
The effective length of the antenna is:

\[ L_{\text{eff}} = L + 2\Delta L \quad (4) \]

The actual length of the patch can then be determined by

\[ L = \frac{1}{2fr\sqrt{\mu\varepsilon_0\varepsilon}} - 2\Delta L \quad (6) \]

The conductance of the patch can be represented in the form [2]:

\[ G1 = \begin{cases} \frac{1}{90}\left(\frac{w}{\lambda_0}\right)^2 & w \ll \lambda_0 \\ \frac{1}{120}\left(\frac{w}{\lambda_0}\right)^2 & w \gg \lambda_0 \end{cases} \quad (7) \]

\[ Z_{\text{in}} = \frac{1}{Y_{\text{in}}} = R_{\text{in}} = \frac{1}{2G1} \quad (8) \]

III. MINIATURIZATION OF PATCH ANTENNA (HFSS SOFTWARE)

We consider the patch antenna shown with dimensions optimized for a 10 GHz resonance frequency and a substrate relative permittivity \( \varepsilon = 2.1 \).

The second multilayered microstrip line analyzed and simulated is the double-layered microstrip shown in Fig. 2. This antenna contains two different dielectric materials between the top conductor and the lower ground plane. A conformal mapping technique determines the characteristic impedance and effective dielectric constant of the double-layered microstrip[5]:

\[ q1 = \frac{h1}{2h} \left[ 1 + \frac{\pi}{4} - \frac{h}{w} \ln \left( \frac{\pi}{h} - \frac{\pi h1}{2h} \right) \right] + \cos \left( \frac{\pi h1}{2h} \right) \quad (9) \]

\[ q2 = 1 - q1 - \frac{1}{2} \ln \left( \frac{\pi}{h} - \frac{1}{w} \right) \quad (10) \]

\[ \varepsilon_{\text{eff}} = x - \frac{(q1 + q2)^2}{r1q2 + r2q1} \quad (11) \]

\[ x = 1 - q1 - q2 + \varepsilon r1\varepsilon 2 \quad (12) \]

To show the impact of a substrate, we consider four types of materials for the substrate with the same dimensions than antenna 10 GHz. The next table summarizes the case of antenna to simulate; after we use the software HFSS v13 for the simulation and see the behavior all antennas and compare with the first antenna for 10 GHz, here are all results:

<table>
<thead>
<tr>
<th>Material 1 ( \varepsilon = 2.1, \mu = 1 )</th>
<th>Fr of resonance</th>
<th>Bandwidth</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material 2 ( \varepsilon = 5.5, \mu = 1 )</td>
<td>9.5 GHz</td>
<td>20 MHz</td>
<td>5%</td>
</tr>
<tr>
<td>Material 1+1mil thin film ( \varepsilon = 2.1, \mu = 12 )</td>
<td>8.6 GHz</td>
<td>402 MHz</td>
<td>14%</td>
</tr>
<tr>
<td>Material 1+2mil thin film ( \varepsilon = 2.1, \mu = 12 )</td>
<td>9.15 GHz</td>
<td>502 MHz</td>
<td>8.5%</td>
</tr>
</tbody>
</table>

TABLE 1 Results obtained in the simulation by HFSS
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Figure 2. A multilayer antenna

Figure 3. Return loss of fundamental antenna

Figure 4. Return loss of all antennas

Figure 5. Gain of all antennas

Figure 6. Imaginary impedance of all antennas

Figure 7. Real impedance of all antennas
we find that the added film is given a good result for the miniaturization and the improvement of the performance of the antenna.

IV. CONCLUSION

The antenna printed on the substrate material 1 + 2mil thin layer is more efficient in terms of resonant frequency, as printed on the substrate material 2. This is explain by the fact that the effective permeability of the first substrate is larger compared to the other simulated materials, where magnetic and dielectric losses are lower or negligible.

References


