Design of Neoteric Dense Dielectric Patch Antenna with Enhanced Performance

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Abstract- Microstrip patch antenna though widely used because of its smaller size and attractive features, its radiation efficiency is low particularly at higher frequencies due to the occurrence of metallic and conduction losses. The main objective of this work is to mitigate this major limitation occurring in metallic microstrip patch antennas. This can be accomplished by replacing the metallic patch of a microstrip antenna with a high permittivity thin dielectric slab. By doing so, a new type of patch antenna called the dense dielectric patch antenna (DD patch antenna) is formed. Due to the absence of the metallic layer, this antenna exhibits increased efficiency, better return loss values and high gain compared to the conventional microstrip antennas. The design of dense dielectric circular patch antenna and microstrip circular patch antenna are carried out using the same dimension and the performance of both have been analyzed using a suitable simulator tool.

Keywords: Dielectric Resonator Antennas (DRA), DD Patch, MSA (Microstrip Patch Antenna), millimeter wave, aperture coupling, return loss, radiation efficiency.

I. INTRODUCTION

At higher frequencies such as millimeter wave frequencies, metal surfaces become lossy, and so dielectric resonators are used at these frequencies. Dielectric resonators were initially used as high-Q elements in microwave circuits, such as filters and oscillators, in the late 1960s [11], [12]. In early 1980s, Long, McAllister, and Chen proposed using dielectric resonators as antennas (DRA) [13], [14]. Since then, DRAs were believed to be good, useful and efficient radiators [5], [15]–[21]. The basic configuration of a DRA is that the dielectric resonator (DR) is normally placed directly above the metallic ground plane.

Dielectric resonators are mainly used in millimeter-wave electronic oscillators to control the frequency of the radio waves generated. They are also used as band pass filters and antennas. A dielectric resonator antenna is mostly used at microwave frequencies and higher. It consists of a dielectric resonator mounted on a metal surface, and a ground plane. Radio waves are introduced into the resonator material from the transmitter circuit and bounce back and forth between the resonator walls, forming standing waves. The walls of the resonator which are partially transparent to radio waves, allows the radio power to radiate into space.

An important advantage of dielectric resonator antennas is that, since they lack metal parts, they become less lossy at high frequencies, dissipating minimum energy. So these antennas can have lower losses and be more efficient than metallic antennas at high frequencies. By replacing the metallic patch of a microstrip antenna with a high permittivity thin dielectric slab, better radiation efficiency can be obtained particularly at millimeter wave and terahertz frequencies in comparison with the conventional microstrip patch antenna. Dielectric waveguide antennas are used in some compact portable wireless devices, and military millimeter-wave radar equipment.

The major limitations occurring in the present systems are that they are less efficient at higher frequencies due to the presence of metallic layer. The selection of the feed and that of its location both play an important role in determining which modes are excited. This, in turn, will determine the input impedance and radiation characteristics of the DRAs. The problems such cross polarization, reduced polarization purity can be solved by the proper choice of the feeding technique for the dense dielectric patch antenna. In the existing designs there some limitations as stated above and the proposed structure overcomes these problems [2]–[7].

II. DD PATCH ANTENNA STRUCTURE

The proposed antenna model consists of three layers and the type of feeding technique used is aperture coupled feeding as shown in the figure 1. Basically, the DD patch acts as the top layer, a dielectric substrate as the middle layer and a double layer printed circuit board (PCB) as the bottom layer. The 3 layers include,

- Top layer - Dense Dielectric patch.
- Middle layer - Dielectric substrate 1.
• Bottom layer - Dielectric substrate 2.

There are many methods employed in order to excite the dielectric resonator antennas. Some of the techniques include aperture coupling, coaxial probe coupled feeding, microstrip line feeding, coplanar coupling and dielectric image guide coupling. The method of excitation varied in each technique and each have their own pros and cons. Among the various methods of coupling, aperture coupling is considered the right choice for dielectric patch antennas as they may beneficial features.

One common method of exciting a DRA is through an aperture in the ground plane upon which the DRA is placed. The small rectangular slot is probably the most widely used aperture. By keeping the slot dimension electrically small, the amount of radiation spilling beneath the ground plane can be minimized. Annular slots have also been used for exciting cylindrical DRAs, while cross-shaped and C-shaped slots are used to excite circular polarization. The aperture can itself be fed by a transmission line (either microstrip or coaxial) or a waveguide. Aperture coupling offers the advantage of having the feed network located below the ground plane, isolating the radiating aperture from any unwanted coupling or spurious radiation from the feed.

III. COUPLING TO DD PATCH ANTENNA

For most practical applications, power must be coupled into or out of the DRA through one or more ports. The port type and the location of the same with respect to the DRA will determine mode excited and amount of power coupled between the port and the antenna. The modes generated, the amount of coupling, and the frequency response of the impedance are the important performance metrics of DRA.

The slot length is chosen large enough so that sufficient coupling exists between the DRA and the feed line but small enough so that it does not resonate within the band of operation, which usually leads to a significant radiated back lobe [10].

In order to achieve strong coupling to the DRA, the aperture should be located in a region of strong magnetic fields. Centering the DRA over the slot will ensure strong coupling to the internal magnetic fields. Somedegree of impedance matching can be achieved by offsetting the DRA from the slot center. Feeding the aperture with a microstrip transmission line is the most common approach, since printed technology is easy to fabricate. Microstrip lines also offer a degree of impedance matching not available with coaxial lines or waveguides. The slot length and width will control the amount of coupling from the microstrip
line to the DRA. The area of the slot should be kept as small as possible to avoid excessive radiation beneath the ground plane. Also, if the aperture is too large, it will significantly load the DRA, and the resonant frequency will shift. The aperture introduces an air gap beneath the DRA, which will then no longer see a continuous ground plane. If the aperture is too large, then larger errors in the predicted resonant frequency and Q-factor occur [10].

IV. DESIGN OF DD PATCH, SLOT AND MICROSTRIP LINE FEED

The design of dense dielectric patch antenna and the slot for coupling is performed at the frequency of 3.9 GHz. The basic equations for the design of DD patch include the following.

\[ f_r = \frac{c}{2\pi \sqrt{\varepsilon_r}} \sqrt{\frac{2}{\frac{a}{\lambda_0^2}} + \left(\frac{\pi}{2b}\right)^2} \quad (1) \]

Based on the above equation, the radius of the DD patch is found. Also the slot which is present on the top surface of the bottom layer can be designed using the following equations.

The slot length is chosen large enough so that sufficient coupling exists between the DRA and the feed line but small enough so that it does not resonate within the band of operation, which usually leads to a significant radiated back lobe.

\[ l_s = \frac{0.4 \lambda_0}{\sqrt{\varepsilon_r}} \quad (2) \]

\[ \varepsilon_e = \frac{\varepsilon_r + \varepsilon_s}{2} \quad (3) \]

Here \( \varepsilon_r \) and \( \varepsilon_s \) are the dielectric constants of the DRA and substrate respectively.

A fairly narrow slot width is usually chosen to avoid a large back lobecompoment. At high frequencies, the equation (3) might result in a very narrow slot that may be difficult to fabricate due to etching limitations. At these frequencies, a wider slot width can be used.

\[ w_s = 0.2 l_s \quad (4) \]

The stub extension \( s \) is selected so that its reactance cancels out that of the slot aperture. It is generally initially chosen to be:

\[ s = \frac{\lambda_0}{4} \quad (5) \]

Here \( \lambda_0 \) is the guided wave in the substrate.

The amount of coupling actually achieved using the above guidelines is not always as high as desired. Oftentimes the coupling can be significantly improved simply by slightly offsetting the DRA with respect to the slot.

The design of the microstrip feed line located at the bottom surface of the substrate 2 is based on the general transmission line equations and in turn, this is based on the characteristic impedance value \( z_0 \) of the line. In this case, the characteristic impedance value is taken as 50\( \Omega \) [9].

V. ANTENNA GEOMETRY

Based on the above mentioned equations, the design parameters have been calculated for the desired frequency range and are tabulated in table 1:

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>PARAMETER</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microstrip circular patch</td>
<td>Diameter</td>
<td>12.5 mm</td>
</tr>
<tr>
<td>Dense dielectric patch</td>
<td>Diameter</td>
<td>12.5 mm</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>2 mm</td>
</tr>
<tr>
<td></td>
<td>Dielectric constant</td>
<td>82</td>
</tr>
<tr>
<td>Slot</td>
<td>Length</td>
<td>6 mm</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>1.2 mm</td>
</tr>
<tr>
<td>Microstrip line feed</td>
<td>Length</td>
<td>62.5 mm</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>3.31 mm</td>
</tr>
<tr>
<td>Substrate 1 and Substrate 2</td>
<td>Length</td>
<td>100 mm</td>
</tr>
<tr>
<td></td>
<td>Width</td>
<td>100 mm</td>
</tr>
<tr>
<td></td>
<td>Thickness</td>
<td>0.762 mm</td>
</tr>
<tr>
<td></td>
<td>Dielectric constant</td>
<td>2.94</td>
</tr>
</tbody>
</table>

With the help of the values tabulated, the design of the dielectric patch antenna and microstrip patch antenna are done as shown in figure 3.a and 3.b.
VI. RESULTS AND PARAMETER ANALYSIS

When the above designs are simulated it can be observed that the performance of the dielectric patch antenna is superior when compared to the microstrip patch antenna. The criteria taken for analysis include efficiency and gain of the antenna.

A. RETURN LOSS

Both antennas have been designed for the same dimensions and hence it will be observed that the frequency of operation varies. This shows that there is reduction in size observed in dielectric antennas compared to microstrip antennas at the same frequency. This adds to another advantage of dielectric resonator antennas. This can be clearly observed from figures 4.a and 4.b.

Figure 4.a. Return loss curve for MSA

It can be clearly observed from the figures that the DD patch antenna works at 3.9 GHz and the corresponding return loss value is -11 dB. Similarly for the same dimension, the circular microstrip antenna works at 3.8 GHz for a return loss of -13 dB.

Figure 4.b. Return loss curve for DD Patch

B. RADIATION EFFICIENCY

Also, it has been observed that the radiation efficiency of the dielectric patch antennas are better (around 96%) compared to MSA because of the occurrence of no metallic losses. This can be best shown with the help of figures 5.a and 5.b.

Figure 5.a. Radiation efficiency curve for MSA

C. GAIN

Figure 5.b. Radiation efficiency curve for DD patch
Also when analyzed with respect to the gain of the antenna, it can be observed that the gain of the dielectric patch antenna is higher when compared to MSA. A high gain of around 6.4 dBi can be attained for the mentioned design of dielectric patch antenna.

VII. CONCLUSION

A new type of patch antenna designated as dense dielectric patch antenna has been presented. It uses a dielectric material with very high permittivity to replace the metallic patch of a conventional microstrip antenna. The antenna has radiation characteristics similar to that of the metallic patch antenna. Due to the reduction of metallic loss, the antenna has potential applications at higher microwave frequencies. The proposed DD patch antenna has a gain of 6.4 dBi and radiation efficiency of around 96%.

REFERENCES

[8] “Antenna theory analysis and design” by A. Balanis.

AUTHOR’S PROFILE

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