Efficient Design of Rectenna in L&S-Band using Defected Ground Structure

Amit kumar¹, Laxmi Shrivastava²

¹,²Department of Electronics, Madhav Institute of Technology and Science Gwalior, India

Abstract—The Rectenna consisting of RF-DC conversion circuits and receiving antennas needs to be designed for high conversion efficiency to realize efficient power transmission. In this paper, the main area of investigation is to design Rectenna circuit by using low pass filter, diode, with patch antenna with the desired frequency lying in that range can be added to get the complete Rectenna circuitry. The parameters of the antenna are calculated by using Matlab in this paper. Later for efficient designing we added defected structure to the ground

Keywords— Low Pass Filter (LPF), Rectenna, Microstrip line, Defected Ground Structure-DGS, CST-MW, Matlab, MSP (microstrip patch)

I. INTRODUCTION

Microwave and millimetre-wave are used for not only the radio-communication but also the wireless power transmission. For example, Space Solar Power System (SSPS), Radio Frequency Identification (RF-ID), and electric vehicle, etc [1].

A rectenna is a rectifying antenna, a special type of antenna that is used to convert microwave energy into direct current electricity. They are used in wireless power transmission systems that transmit power by radio waves. A simple rectenna element consists of a dipole antenna with low pass filter and RF diode connected across the dipole elements. The diode rectifies the AC current induced in the antenna by the microwaves, to produce DC power, which powers a load connected across the diode. Schottky diodes are usually used because they have the lowest voltage drop and highest speed and therefore have the lowest power losses due to conduction and switching. Large rectenna consist of an array of many such dipole elements.

The passive filters work moderately well at frequencies up to a few hundred megahertz [2]. Away from this range, components move away significantly from anything close to ideal. The microwave filters are footed on distributed parameters rather than lumped inductors and capacitors. For low-power applications, Stripline and Microstrip filters are widely used for the reason that of their low expenditure and repeatability. For high-power supplies, waveguide structures are employed.

Microstrip line is bimetallic which contain two metallic surface separated with a small distance, having a dielectric material between them.

There are one metallic surface having the filter geometry and other plane having the ground plane at which the reflection of wave happens. In this the short and open curved transmission line stubs are use having the length of the order of λ/4 or λ/8. Kuroda’s identities are also use in realization of filter, it allow the transformation of series stubs into shunt stubs and vice versa. [3]

DGS is an imprinted periodic or non-periodic cascaded configuration imperfection in ground of a planar transmission line (e.g., microstrip, coplanar and conductor backed coplanar waveguide) which perturbs the shield current distribution in the ground flat surface cause of the defect in the round. This disturbance will change distinctiveness of a transmission line for example line capacitance and inductance. In a word, any flaw etched in the ground plane of the microstrip can give augment to increasing effective capacitance and inductance.

II. DESIGNING OF ANTENNA

In this paper transmission line method are used to analysis the rectangular MSP antenna. The design resonant frequency of rectangular MSP antenna is 2.5GHz with 50Ωmicrostrip line feed. MSP antenna is characterized by using thickness (h), dialectic constant (εr), and length (L), width (W) of patch. The performances of design MSP antenna such as radiation pattern, return loss, directivity, VSWR and gain are simulated by using CST Microwave Studio software.[4-5]

Mathematical Rules To Calculate Dimensions Of Antenna (Microstrip Patch)

The mathematical formula is used to calculate the dimensions of antenna’s patch in the form of length and width. [6]

A- Width formula of Rectangular MSP is taken as

$$W = \left( \frac{c}{2f_r} \right) \left( \frac{\varepsilon_r - 1}{\varepsilon_r} \right)^{-2}$$

Where c = 3\times10^8\text{ m s}^{-1}, \varepsilon_r = 4 \cdot 2, f_r = 2\cdot 5\text{GHz}
B. Formula of effective dielectric constant is taken as

$$
\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{12W}{h}\right)^{-\frac{1}{2}}
$$

At h (substrate height) = 1.6 mm

C. Formula of length extension is taken as

$$
\Delta l = 0.412h \left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)^{\left(\frac{W}{h} + 0.264}{W}{\frac{W}{h} + 0.8}\right)
$$

D. Length formula of Rectangular MSP is taken as

$$
L = \left(\frac{C}{2F\sqrt{\varepsilon_{eff}}}\right) - 2\Delta l
$$

<table>
<thead>
<tr>
<th>S.No</th>
<th>Antenna Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Frequency of resonance</td>
<td>2.5 GHz</td>
</tr>
<tr>
<td>2</td>
<td>Dielectric (relative) constant</td>
<td>4.3</td>
</tr>
<tr>
<td>3</td>
<td>Substrate’s thickness</td>
<td>1.6</td>
</tr>
<tr>
<td>4</td>
<td>Loss tangent</td>
<td>0.02</td>
</tr>
</tbody>
</table>

### Table 1
Design Specifications Parameter Of Antenna

<table>
<thead>
<tr>
<th>S.No</th>
<th>Antenna Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Patch Width</td>
<td>36.855</td>
</tr>
<tr>
<td>2</td>
<td>Patch Length</td>
<td>28.564</td>
</tr>
<tr>
<td>3</td>
<td>Length of Tx line</td>
<td>17.9</td>
</tr>
<tr>
<td>4</td>
<td>Width of Tx line</td>
<td>0.182</td>
</tr>
</tbody>
</table>

### Table 2
Calculated Antenna Dimensions

#### III. FILTER DESIGNING

The design of Microstrip low pass filters involves two main moves. The first one is to select a suitable low pass model. The selection of the type of response, together with passband ripple and the number of reactive essentials, will depend on the necessary specifications.

The element values of the low pass prototype filter, which are regularly normalized to make a source impedance $g_0 = 1$ and a cut-off frequency $\Omega c = 1.0$, are then altered to the L-C elements for the desired cut-off frequency and the required source impedance, which is in general 50 ohms for Microstrip filters. The next main step in the design of Microstrip lowpass filters is to come transversely an appropriate Microstrip realization that approximates the lumped element filter [3][7].

#### Fig. 1: Ladder circuit for low-pass filter prototype beginning with a series element

In order to exemplify the design process for this category of filter, the design of a three-order LPF is described in follows.

The filter design steps are as follows:

- **Order of filter $N = 3$**
- **Relative Dielectric Constant $\varepsilon_r = 4.3$**
- **Height of substrate, $h = 1.6$ mm**
- **The loss tangent $\delta = 0.02$**
- **The highest line impedance $Z_H = Z_{OL} = 93\Omega$**
- **The lowest line impedance $Z_L = Z_{OC} = 24\Omega$**
- **Cutoff frequency $f_c = 2.5$ GHz**
- **The filter Source/load impedance $Z0 = 50$ ohms**

A low pass prototype with Chebyshev response is chosen, whose element values are given as below taken from the Table 3 [1] with passband ripple $L_{At} = 0.5$dB for $N=3$ [2-3][8].

$$
\begin{align*}
g_0 &= g_4 = 1 \\
g_1 &= g_3 = 1 \cdot 0.316 \\
g_2 &= 1 \cdot 1474
\end{align*}
$$

$$
\begin{align*}
L_1 &= \frac{Z_0 \Omega_c}{g_0 2\pi f_c} = 3 \cdot 04045 \times 10^{-9} \ H \\
C_2 &= \frac{g_0 \Omega_c}{Z_0 2\pi f_c} = 1 \cdot 3527 \times 10^{-12} \ F
\end{align*}
$$
For the cutoff $f_r = 2 \cdot 5$. Using the element transformations we have after calculating the value parameter with the help of formulae values the results are tabulated below.

### Table 3
Filter Design Parameters At 2.5 Ghz

<table>
<thead>
<tr>
<th>No</th>
<th>Parameter</th>
<th>Inductor section</th>
<th>Capacitor section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Characteristic Impedance</td>
<td>$Z_{ol}=93\Omega$</td>
<td>$Z_{oc}=24\Omega$</td>
</tr>
<tr>
<td>2</td>
<td>Effective Dielectric Constant</td>
<td>$\epsilon_{ref f_e}=2.94$</td>
<td>$\epsilon_{ref f_e}=3.53$</td>
</tr>
<tr>
<td>3</td>
<td>Width of Microstrip Line</td>
<td>$W_L=0.884mm$</td>
<td>$W_c=8.948mm$</td>
</tr>
<tr>
<td>4</td>
<td>Length of Microstrip Line</td>
<td>$l_L=8.438mm$</td>
<td>$l_c=7.245 mm$</td>
</tr>
</tbody>
</table>

### IV. RECTENNA

The main components of Wireless Power Transmission are Microwave Generator, Transmitting antenna and Receiving antenna (Rectenna) [8].

The Rectenna is a passive component consists of antenna, rectifying circuitry with a low pass filter between the antennas and rectifying diode. Schottky barrier diodes (GaAs-W, Si, and GaAs) are typically used in the rectifying circuit because of the quicker reverse recovery time and much lesser forward voltage drop and good RF characteristics. The Rectenna efficiency for various diodes is different for different frequency [9].

![Figure 1: Rectenna having Antenna, Filter and Rectifier](image1)

The above figure shows the Rectenna system having the antenna, filter and rectifier; it is use for receiving the wireless power. The wireless signal received by antenna is filtered in LPF the higher order harmonics are remove after filtering. After the LPF a rectifier is connected following by the load. The output voltage is measured across this load element. The proposed filter is used in this Rectenna system.

![Figure 2: CST view of Rectenna](image2)

The figure 2 shows the design of Rectenna system with rectangular patch antenna followed by microstrip filter followed by rectifying system and load.

The simulated result obtained by the CST microwave studio is shown the figure 3.

![Figure 3: Return loss graph of Rectenna](image3)

Generally in RF design, a diode can be modeled as combination of resistance and capacitance. This is shown in Figure 1. [10]

### V. SIMULATION AND RESULTS

CST MICROWAVE STUDIO is a fully featured software package for electromagnetic analysis and design in the high frequency range. It simplifies the process of creating the structure by providing a powerful graphical solid modelling front end which is based on the ACIS modelling kernel. After the model has been constructed, a fully automatic meshing procedure is applied before a simulation engine is started.

Since no one method works equally well for all applications, the software contains several different simulation techniques (transient solver, frequency domain solver, integral equation solver, multilayer solver, asymptotic solver, and eigen mode solver) to best suit various applications. The frequency domain solver also contains specialized methods for analyzing highly resonant structures such as filters.
Since we get a design in which we are getting dual band Rectenna system having -35 db return loss at 2.5 GHz.

Now to obtain some additional advantage over the design we added defect to the ground plane of the design which can seen in the figure presented over here.

Here the defect given is not regular type defect, in actual it is obtained after several times simulation or can say that by hit and trial rule. Figure 4 represents the back side view of the patch of Rectenna.

So on again simulating the design of Rectenna with the defected ground structure added to it we got another result with 4 actual working bands and peak of the return loss is obtained at 2.12 GHz with the value of -42 db.

So the great optimization is obtained here in this result as shown in figure 5, but as it was designed for 2.5 GHz but not working on that is because of the defected structure.

We get some mismatch in the simulated result of Defected Ground Structure design whose return loss is least at 2.12 GHz because of discontinuity in the structure but since we get getting a better result therefore it shows a great working design. Introduction of defected ground increases the sharpness of the peak and reduces the bandwidth which is the great advantage to make it work on the selected frequencies.

The working efficiency of the first design is around 97.7 % calculated via radiation pattern of the design and for second one it is around 88.3%.

Figure 6 represents the radiation pattern of the design first and second respectively.

VI. CONCLUSION

The above result is obtained by adding a patch antenna of frequency 2.5 GHz, whose parameter is calculated by general formula of rectangular patch antenna [3] and the filter on the same frequency simulated via CST studio.

REFERENCES


