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Design & Simulation of Microstrip Patch Antenna for C-Band Communication Services

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Abstract- When a fewer number of microstrip antennas are to be used for the transmission and reception of electromagnetic signals in a system, the size of the antenna array becomes a critical issue to deal with. Instead of using a number of antennas, we can use the desired number of patch antennas over a single substrate only. Main motive is to maintain the coupling suppressing sectional structure in simple manner, whilst providing a higher amount of efficiency in coupling of microstrip patch elements/antennas. At microwave frequency, the microstrip is often used as a transmission line because of its very good efficiency in transferring energy/microwave signals. In this work, an antenna design is simulated at 4.8 GHZ for its working in the C-Band communication services. The size of the array structure is kept to the minimum value.

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Design & Simulation of Microstrip Patch Antenna for C-Band Communication Services

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Abstract- When a fewer number of microstrip antennas are to be used for the transmission and reception of electromagnetic signals in a system, the size of the antenna array becomes a critical issue to deal with. Instead of using a number of antennas, we can use the desired number of patch antennas over a single substrate only. Main motive is to maintain the coupling suppressing sectional structure in simple manner, whilst providing a higher amount of efficiency in coupling of microstrip patch elements/antennas. At microwave frequency, the microstrip is often used as a transmission line because of its very good efficiency in transferring energy/microwave signals. In this work, an antenna design is simulated at 4.8 GHZ for its working in the C-Band communication services. The size of the array structure is kept to the minimum value. It does not affect the other characteristics of the antenna array. Once an antenna design is finalized, their operational characteristics remain unchanged during the use.

Keywords: antenna array, mutual coupling, microstrip patch antenna, performance optimization.

I. Introduction

Microstrip Patch antenna is currently, the most famous and hot topic in antenna field technology. It is highly useful in aircrafts with high performances, space-crafts, satellite and other applications as these are the areas where weight, size, cost, performance, ease of installation, and aerodynamic profile are the big constraints & a cheap patch microstrip antenna is needed [1-3].

At the microwave range of frequency value, the microstrip line is used as x-mission line as it has excellent performance in the transfer of energy & microwave signals. The most significant merit of microstrip line is, it does not produce large parasitic capacitances/inductances. While comparing it with other transmission-lines, it is found that the stripline and microstrip are very easy to use, feasible and less expensive to manufacture/fabricate and are feasible to attach to surface-mounted components & structures[4-5].

The operating frequency of microstrip antennas usually ranges from 1 to 50 GHz [6-7]. The following figure shows the block diagram of basic microstrip patch antenna system.

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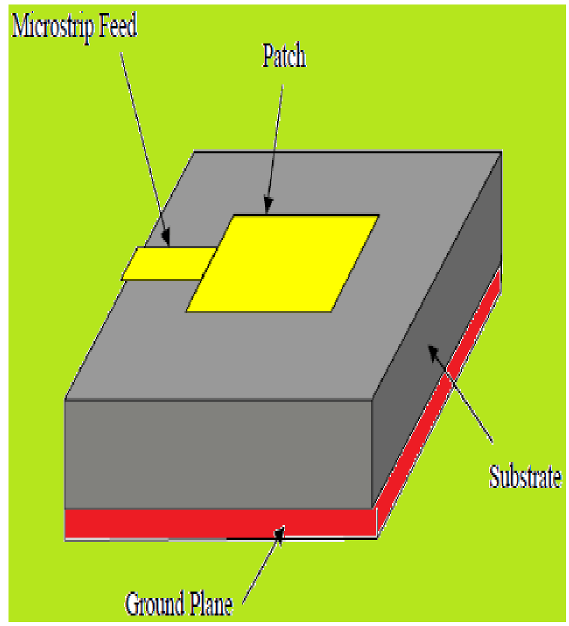


Fig. 1: Microstrip Patch Antenna

II. Quarter wave Transformer

It is quarter wavelength section of a transmission line. It is used to match the impedance between antenna and main transmission feed-line. It is not hard to construct the quarter wave line sections at low values of impedances [8-10]. It has an impedance of 70 ohms, which provides exact match to the impedances b/w strip line and the patch antenna elements.

III. Design Parameters for C-Band Systems

We start with the microstrip patch antenna by calculating the length and width of a rectangular microstrip antenna for resonance at 4.8 GHz.

- Frequency (Resonance) of Operation (f_r):

Resonant frequency of the microstrip antenna should be selected wisely. Hence, the antenna design must be able to operate in the specific frequency range. The resonant frequency selected for my design is 4.8 GHz.

- Permittivity of FR-4 (ε_r):

The dielectric material selected for the design is FR-4, which has a dielectric constant of 4.4.

- Height of Dielectric Substrate (h):

For the microstrip patch antenna, the height of the dielectric substrate is selected as 1.60 mm. Hence, the essential parameters for the design are:

Resonating frequency, f_r = 4.8 GHz..

Permittivity of substrate, ε_r = 4.4.

Height h of substrate, h = 1.60 mm.

Substrate used, FR-4.

IV. Design Equations

Due to fringing effects, electrically patch of antenna looks larger than physical specifications. Enlargement on 'L' is given by [11-12]:

$$\Delta L = 0.412(\varepsilon_{reff} + 0.3)(Wh^{-1} + 0.264) / \left[(\varepsilon_{reff} - 0.258)(Wh^{-1} + 0.8)\right] \quad - (1)$$

Here, effective relative permittivity is as follows:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2\sqrt{1 + 12hW^{-1}}} \quad - (2)$$

This is related to the ratio of h/W. The larger the h/W, the smaller is the effective permittivity. The effective length of the patch is given by:

$$L_{eff} = L + 2\Delta L \quad - (3)$$

The resonance frequency or the TM10 mode is given by:

$$f_r = \frac{1}{2L_{eff}\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} = \frac{1}{2(L + 2\Delta L)\sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} \quad - (4)$$

Optimized width for efficient radiator is as follows:

$$W = \frac{1}{2 f_r \sqrt{\varepsilon_o}} \sqrt{\frac{2}{\varepsilon_r + 1}} \quad - (5)$$

The reflection coefficient and VSWR can be related through the following formula as:

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|} \quad - (6)$$

The value of reflection coefficient is given by:

$$\Gamma = (Z_L - Z_0)/(Z_L + Z_0) \quad - (7)$$

The return loss should be a large negative number as possible. It is defined empirically through following:-

$$LRT = -20\log_{10}(|\Gamma|) = -20\log_{10}\left|\frac{Z_a - Z_o}{Z_a + Z_o}\right| \quad - (8)$$

The impedance bandwidth is inversely proportional to quality factor of an antenna and is given by:-

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}} \quad - (9)$$

The bandwidth of an antenna is given by:-

$$BW = \left\{\frac{2(f_u - f_l)}{f_u + f_l} \times 100\%\right.$$

(Bandwidth < 100 %) or,

$$BW = \left\{\frac{f_u}{f_l} : 1\right. \quad - (10)$$

(Bandwidth > 100 %)

Mathematically, directivity (dimensionless) can be written as:

$$D_n = \frac{U(\theta,\phi)}{U(\theta,\phi)} = \frac{4\pi U(\theta,\phi)}{P_t} = \frac{4\pi U(\theta,\phi)}{\oiint U d\Omega} \quad - (11)$$

V. Design Procedure

If the substrate parameters (ε_r & h) & operational frequency (f_r) are known, then we can easily find out patch array dimensions, using above simplified equations and by following the below design procedure:

Step 1: Width Calculation:

Use the above equation to find the patch width W. by substituting the value of f = 4.8 GHz and permittivity as 4.4, the width of the antenna patch comes out to be as 19 mm.

Step 2: Calculation of the effective permittivity:

By using the above mentioned equations & putting the value of permittivity as 4.4, width as 19 and height as 1.6 mm, the effective value of dielectric constant is obtained as 3.8985.

Step 3: Computation of the extension of length:

The value of extended length comes out to be as 0.7277 mm by using the aforesaid equations [13-14].

Step 4: Determine the actual length 'L':

Solving the following equation for 'L' which is given by:

$$L = \frac{1}{2 f_r \sqrt{\varepsilon_{reff}}\sqrt{\varepsilon_o \mu_o}} - 2\Delta L \quad (12)$$

Here, difference in length comes out to be 0.7277 mm. The actual length of the patch is obtained as 14.37 mm, while its width comes out to be 19 mm (W/L < 2). The effective value of permittivity of FR-4 is obtained as 3.8985.

VI. Design of 50 ohms Feeding-Line

To design a feed line, the ratio of width of feed line to height of substrate must be less than 2. Their ratio is given by the

following relation:

$$W/d = \{8.e^{A}/(e^{2A}-2)\} < 2 \quad - \quad (13)$$

$$\text{So, } A = \{(Z_0)/60\}[(1+ \varepsilon_r)/2]^{1/2} + [(-1+ \varepsilon_r)(.23+.11/ \varepsilon_r)/(1+ \varepsilon_r)]$$

Here, the thickness (d) of the substrate is 1.60 mm, εr is 4.4, length (l) of the feed line is assumed as 07 mm and input impedance of feed line is 50 ohms. The value of constant 'A' is calculated as 1.5297 and that of εeff (effective) is obtained as 3.8985. Also, w/d is less than 2. So, the width of both the feeding lines comes out to be 3.05 mm. Therefore, W = 3.05 mm and L = 7 mm.

VII. Design of Quarter-Wave Transformer

The input resistance to patch is denoted by R_{in} & is given by:

$$R_{in} = (120/2* \text{width of patch})*(c/f)*(\varepsilon_{eff})^{-1/2} \quad - (14)$$

From the above equation, the input resistance is obtained as 100 ohms, by putting effective permittivity as 3.8985, frequency as 4.8 GHz and patch width as 19 mm. Therefore, the equivalent resistance is given by [15-16]:

$$Z_q = (50*R_{in})^{1/2} \quad - (15)$$

So, the equivalent resistance comes out to be 70 ohms. The value of 'A' is obtained as 2.07, by putting permittivity as 4.4 and Z_q as 70 ohms. Also, the transformer's width is obtained as 1.656 mm. The length of the transformer is given by the following relation:

$$L = (1/4)*(\varepsilon_{eff})^{-1/2}*(\text{wavelength of EM wave}) \quad - (16)$$

For a height of 1.6 mm and transformer width of 1.656 mm, the value of effective permittivity comes out to be as 3.18. The parametric values of transformer are obtained as: L = 8.76 mm, W = 1.66 mm, R_{in} = 100 ohms & Z_q (equivalent) = 70 ohms.

VIII. Mathematical Model Ling

The expression for the effective permittivity is given by the following relation:

$$\varepsilon_{eff} = \frac{1+\varepsilon_r}{2} + \frac{\varepsilon_r - 1}{2}\left(1+\frac{12h}{W}\right)^{-0.5} \quad - (17)$$

Where, h = Height of dielectric substrate, &

W = Width of the patch.

The fringing fields along the width are modelled as radiating slots and electrically, patch of the microstrip antenna looks larger as compared to the physical dimensions. The dimensions of patch along with its length are extended on each end by the distance **Δl,** which is given empirically by the following relation:

$$\Delta l = 0.412h\left(\frac{0.262+W/h}{0.814+W/h}\right)\left(\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right) \qquad (18)$$

The effective length of the patch L now becomes:

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\Delta l \qquad (19)$$

For efficient radiation, the width W is given by:

$$W = \frac{c}{2 f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{-0.5} \qquad (20)$$

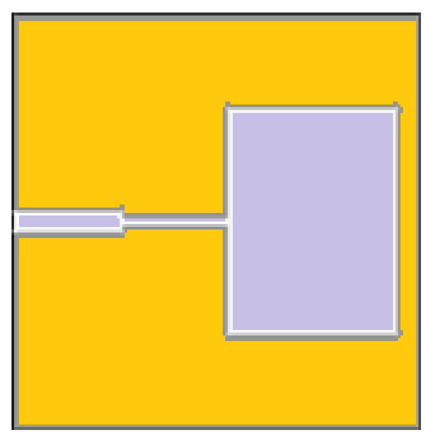


Fig. 2: Microstrip Patch Antenna with Feed, Patch & Impedance-Matching Transformer

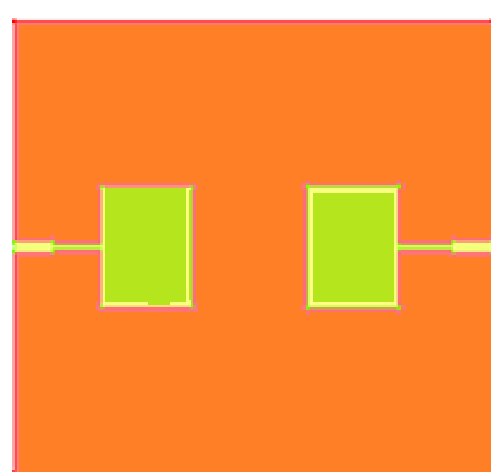


Fig. 3: Microstrip Patch Antenna Array

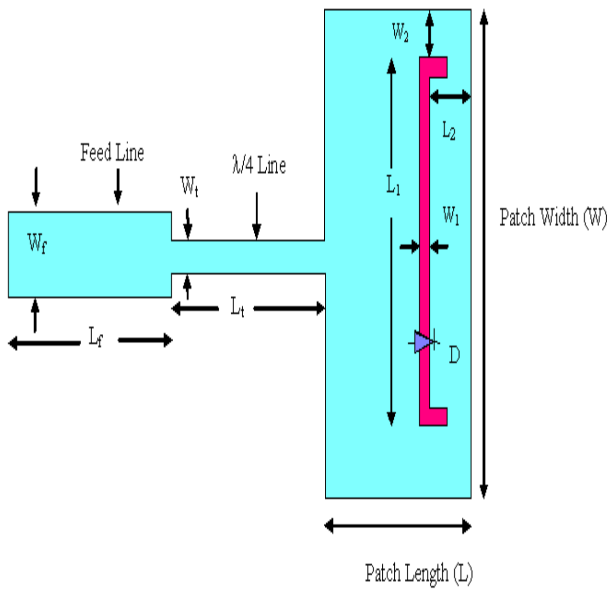


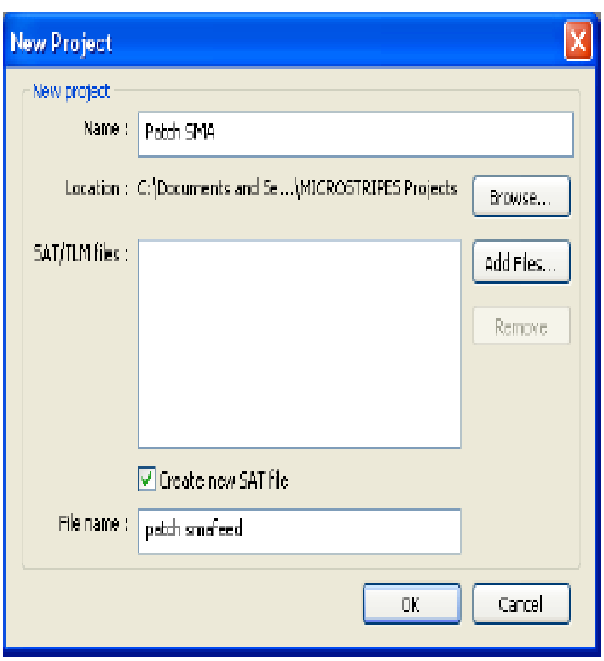
Fig. 4: Antenna Design Specifications

IX. Simulation Steps

Antenna simulation is performed by CST Micro-stripes Software, which is based on Transmission Line Model.

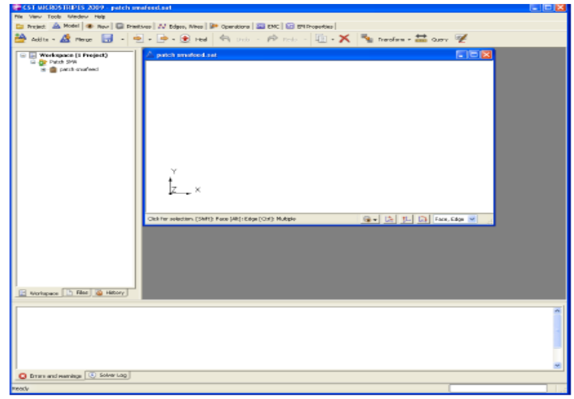
Step 1: To open the window:

Launch CST MISCROSTRIPES from the Start menu, and click on the Create a new project button.



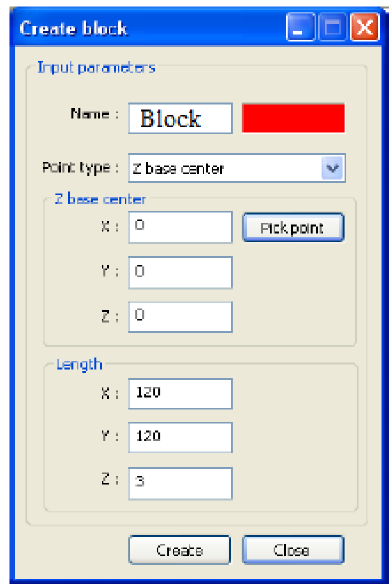
Step 2: To create a new project:

Create a new project with an empty model, a Build window will open within the CST MICROSTRIPES window.



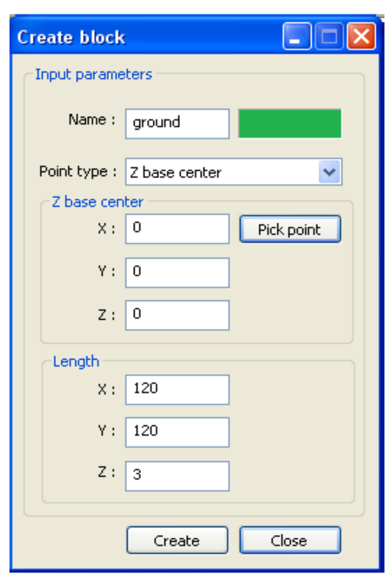
Step 3: To create substrate Block:

Create block of substrate plane using the solid block primitive by clicking its tab.



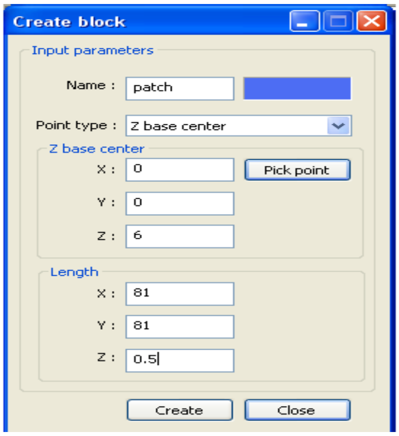
Step 4: To create ground plane

Create the ground on dielectric substrate; the ground will be of the same dimensions as the substrate plane.



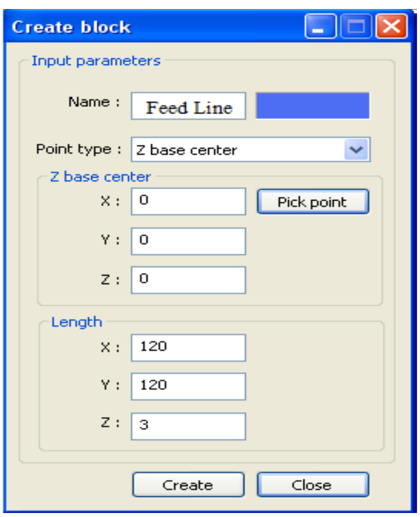
Step 5: To create Patch:

Create a rectangular patch on top of the dielectric substrate.



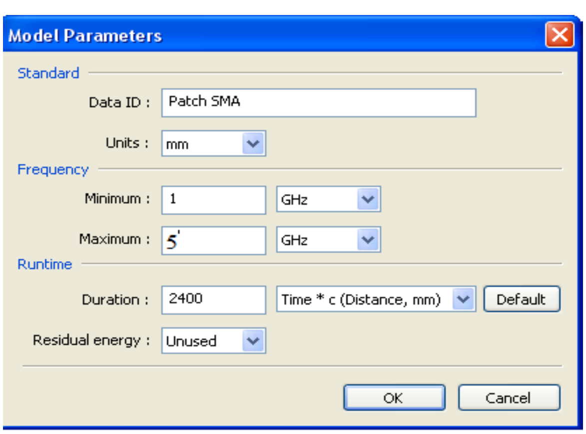
Step 6: To create Feed-Line:

Create a 50 ohms feed-line for the patch antenna.



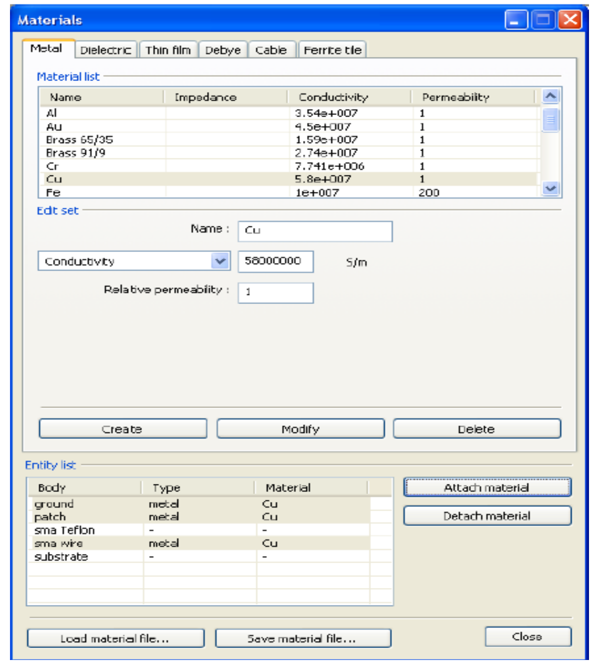
Step 7: To set electromagnetic parameters:

Construct the geometry of the patch antenna. The next step is to describe the electromagnetic parameters of the model.



Step 8: To define material parameters:

Define the materials used in the design and attach them to the geometrical bodies created in the previous section.



Step 9: Result Analysis:

- Analyze the model and display the results in the CST MICROSTRIPES window.
- The results for the "return loss v/s frequency" will automatically be displayed.

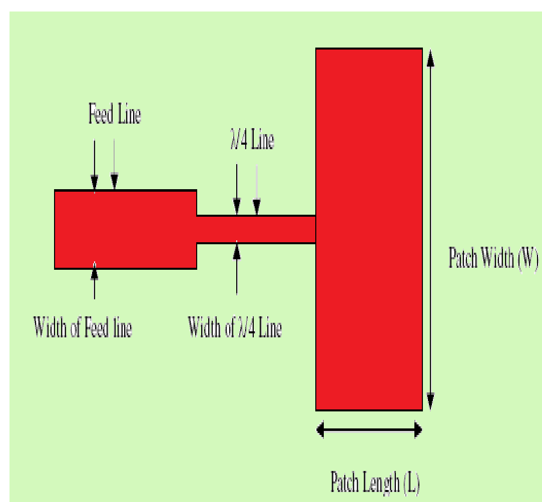


Fig. 5: Antenna Design with Feed-line, Patch & Transformer

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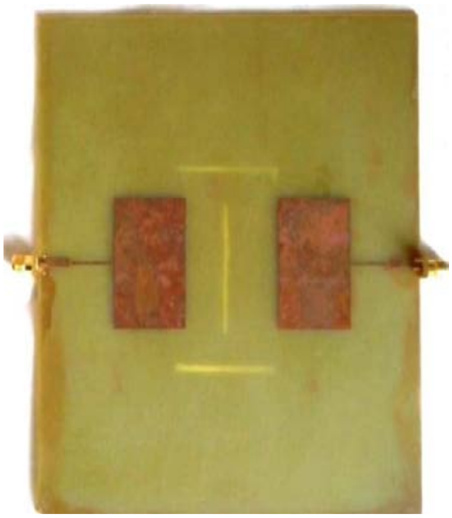

Fig. 6: Designed Antenna Array Structure

X. Conclusion

- The Microstrip Patch Antenna Array has been analyzed at the resonance frequency of 4.8 GHz for C-Band Wireless Communication Application and Services.
- Compactness, easy fabrication and cost effectiveness of the proposed antenna is useful for commercial wireless communication applications.
- The antenna array design consists of a feed-line (50 ohms), an impedance matching quarter-wave transformer and patch antenna elements for transmission and reception of the EM signals in the system.
- The length and width of the patch antenna elements are respectively 14.37 mm and 19 mm.
- The length and width of the feed-line is respectively 07 mm and 3.05 mm.
- The length and width of the quarter-wave transformer is respectively 8.76 mm and 1.66 mm.
- The FR-4 Substrate had the dimensions of 75 mm* 75 mm, with a height of 1.6 mm and a permittivity of 4.4.
- The antenna array has been designed & simulated over CST-Microstripes electromagnetic Simulator Software.
- The antenna and radiation efficiencies of over 90% have been obtained in the given wireless communication antenna array system.
- The antenna array design works successfully at 4.8 GHz for the C-Band Communication Service/System.

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