

DESIGN OF A MICROSTRIP PATCH ANTENNA ARRAY USING IE3D SOFTWARE

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ABSTRACT

In this paper detailed investigations have been performed on the design of a microstrip patch antenna array of given specifications using IE3D, an electromagnetic simulation package by Zeland Software Inc. Here a new idea of trapezoidal patch has been used to increase the bandwidth of the antenna array.

1. INTRODUCTION

The purpose of this work is to design a microstrip patch antenna array using commercial simulation software like IE3D [1]. The IE3D by Zeland Software Inc. has been recently considered as the benchmark for electromagnetic simulation packages. It is a full wave, method of moment (MOM) simulator solving the distribution on 3D and multilayered structures of general shape. The primary formulation of the IE3D is an integral equation obtained through the use of Green's functions. In the IE3D, it is possible to model both the electric current on a metallic structure and a magnetic current representing the field distribution on a metallic aperture. The specifications for the design purpose of the structure are as follows

- Number of elements : 4
- Input impedance : 50Ω
- Resonance frequency : 2.5 - 2.7 GHz
- VSWR : 1 - 1.4

These specifications were chosen to design a lightweight and compact microstrip array

antenna at S-band for Manpack Satellite Communication terminals.

The design of the whole structure is performed in the following steps

- i) To design a single microstrip patch antenna
- ii) To design the power divider to feed the antenna
- iii) To design the complete array

2. THEORY

2.1. To design a microstrip patch antenna

The rectangular microstrip antenna is a basic antenna element being a rectangular strip conductor on a thin dielectric substrate backed by a ground plane (Figure 1). Considering the patch as a perfect conductor, the electric field on the surface of the conductor is considered as zero. Though the patch is actually open circuited at the edges, due to the small thickness of the substrate compared to the wavelength at the operating frequency, the fringing fields will appear at the edges.

Here, the "Transmission Line Model" [2] has been used to predict the radiation characteristics of the patch. In this model, the patch antenna is treated as two parallel radiating slots and a transmission line interconnecting them (Figure 2). The electric and magnetic fields are calculated separately for each slot and the resultant field pattern is a combination of the two slots. The E-plane radiation pattern of the patch given by this model is expressed as follows [2]:

$$E_\phi = \frac{-j2V_0Wk_0e^{-jk_0r}}{4\pi r} F(\theta, \phi) \quad (1)$$

$$E_\theta = 0 \quad (2)$$

$$\text{Here } F(\phi) = \frac{\sin\left(\frac{k_0 h \cos\phi}{2}\right)}{\left(\frac{k_0 h \cos\phi}{2}\right)} * \cos\left(\frac{k_0 h \cos\phi}{2}\right) \quad (3)$$

The radiated power is expressed as follows

$$P_r = \frac{V_0^2 I_1}{240\pi^2} \quad (4)$$

where,

$$I_1 = \int_0^\pi \sin^2\left(\frac{k_0 W \cos\theta}{2}\right) \tan^2\theta \sin\theta d\theta$$

The radiation resistance is defined as follows

$$R_r = \frac{V_0^2}{2P_r} = \frac{120\pi^2}{I_1} \quad (5)$$

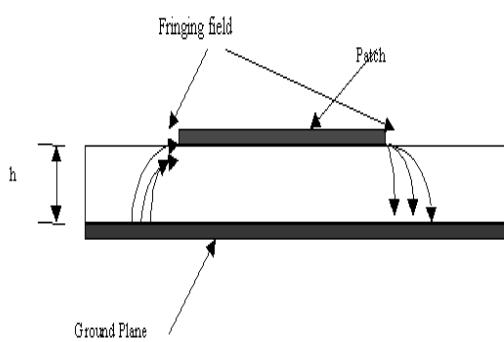


Figure 1. Microstrip patch antenna.

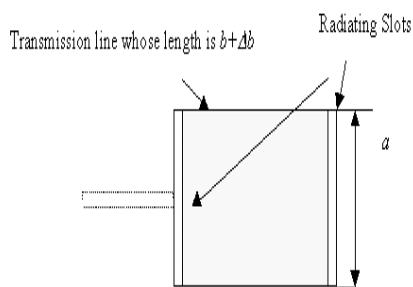


Figure 2. Transmission line model of a microstrip patch antenna.

The micro-strip transmission line consists of three layers: -

4. The ground layer
5. The dielectric substrate
6. The metal strip

Due to this structure the field lines are partly in the substrate and partly in air. Thus the fields of the strip do not constitute a pure TEM wave but a hybrid TM-TE wave. For this geometry the effective wavelength in the dielectric is given by [3]

$$\lambda_g = \lambda_0 / \sqrt{\epsilon_r} \quad (6)$$

For a given characteristic impedance Z_0 and dielectric constant ϵ_r , the relation between W (width) of the strip and the thickness of the dielectric layer (d) is given by [3]

$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A}-2} & \text{for } W/d \leq 2 \\ \frac{2}{\pi} \left[B - 1 - \ln(2B-1) + \frac{\epsilon_r - 1}{2\epsilon_r} \left\{ \ln(B-1) + 0.39 - \frac{0.61}{\epsilon_r} \right\} \right] & \text{for } W/d > 2 \end{cases} \quad (7)$$

$$A = \frac{Z_0}{60} \sqrt{\frac{\epsilon_r + 1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1} \left(0.23 + \frac{0.11}{\epsilon_r} \right); \quad B = \frac{377\pi}{2Z_0\sqrt{\epsilon_r}}$$

2.2 Feed Line

The edge feed is used to feed the microstrip patch antenna, connected to one edge of the patch (Figure 3). The characteristic impedance of the feed line is dependent on the width of the microstrip feed line.

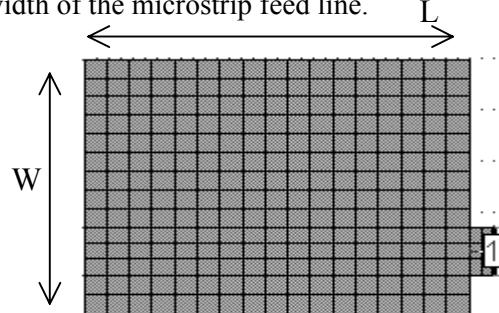


Figure 3. An edge fed rectangular patch antenna.

The patch antennas are to be fed by a single feed line, the power from which has to be divided equally to each patch antenna. The phase of the power delivered should be the same at each patch.

For the present design, the T-junction power divider [3] is used. Figure 4 shows a symmetric T-junction power divider, realized in microstrip. The tops of the line are shown, with the dielectric layer and ground plane underneath. The structure is symmetric. It can

be shown, with the two lines having a characteristic resistance $\sqrt{2}Z_0$ and length $l = \lambda_g/4$ at the center frequency f_0 and with $Z = 2Z_0$, the divider is matched, $S_{11} = S_{22} = S_{33} = 0$ at f_0 . Symmetry then guarantees that a signal incident on port 1 will split equally and at the center frequency.

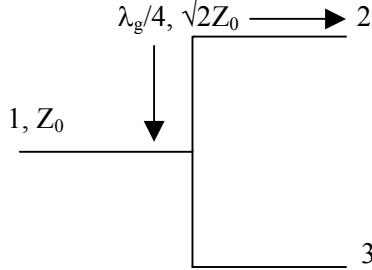


Figure 4. Symmetric T-junction power divider.

The elements of the scattering matrix at the center frequency are:

$$S_{11} = S_{22} = S_{33} = S_{23} = S_{32} = 0 \quad (8)$$

$$S_{12} = S_{21} = S_{13} = S_{31} = -1/\sqrt{2} \quad (9)$$

At any other frequency the two lines of length $l = \lambda_g/4$ are not a quarter-wavelength long.

The three ports are not perfectly matched, the power coupled from port 1 to port 2 and 3 is not exactly one-half and ports 2 and 3 are not perfectly isolated.

3. RESULTS

3.1. Design of an edge fed patch antenna

The dielectric value of the substrate used for the design is 2.5. For a rectangular patch with resonant frequency of f_r the dimensions of the resonant patch are given as follows [4]

$$W = \frac{c}{2f_r} * \left(\frac{\epsilon_r + 1}{2} \right)^{-1/2} \quad (10)$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(1 + 12h/W \right)^{-1/2} \quad (11)$$

$$\Delta l / h = 0.412 \left(\frac{(\epsilon_e + 0.3)(W/h + 0.264)}{(\epsilon_e - 0.258)(W/h + 0.8)} \right) \quad (12)$$

$$L = \frac{c}{2f_r \sqrt{\epsilon_e}} - 2\Delta l \quad (13)$$

Using the above formulae (equation (10)-(13)), the length and width of a patch are

evaluated and designed accordingly. The feed line has 50-ohm characteristic impedance.

Next, the thickness of the substrate is increased. This brings down the VSWR below 2 over a portion of the desired band (Figure 6). It is found that decreasing the width of the edge close to feed brings down the VSWR over the remaining band (Figure 6) and resonance close to 2.6 GHz. This changes the rectangular patch into trapezoidal patch (Figure 5).

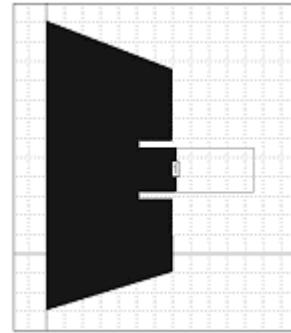


Figure 5. Trapezoidal microstrip patch antenna.

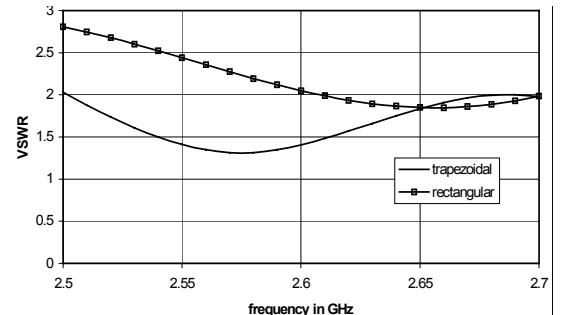


Figure 6. Comparison of Frequency vs. VSWR of Port 1 of a trapezoidal and rectangular patch antenna.

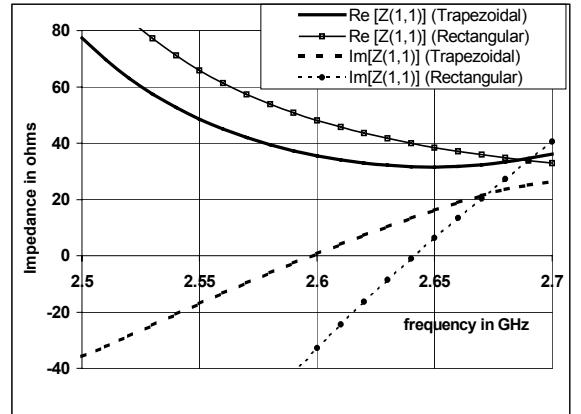


Figure 7. Comparison of Frequency vs. impedance of a trapezoidal and a rectangular patch antenna.

3.2 Design of a Symmetric Power Divider

3.2.1 Design parameters

$$Z_0(\text{Port 1}): 50 \Omega$$

$$\epsilon_r = 2.5, d = 4\text{mm}, f_r = 2.6 \text{ GHz}$$

Using the equations (6)-(7), the width for the 50Ω line is evaluated as 11.4mm; corresponding W for 70Ω line is 6.5mm. The effective wavelength was calculated to be 75mm. So the length of each strip is evaluated as 18.5mm.

An external resistance of 100 ohms ($2Z_0$) is added across the two output ports for better isolation of the two output ports. Figures 8 and 9 show the symmetric power divider and its S-parameters.

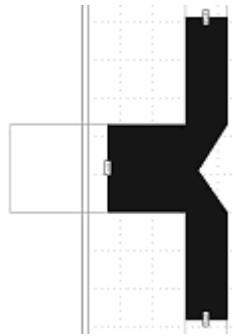


Figure 8. Symmetric Power divider.

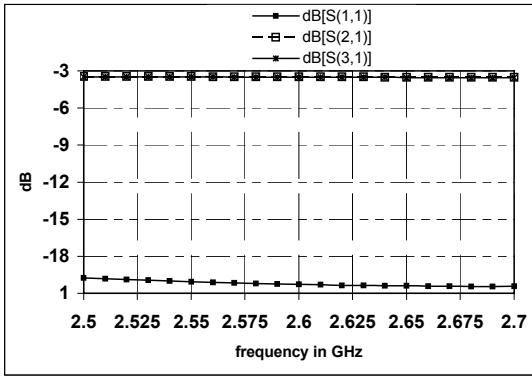


Figure 9. S-parameter graphs of the Symmetric Power divider.

3.3 Design of patch array

3.3.1 Design of a 2 by 1 array

The 50Ω line was extended with bends incorporated so as to fit the structure. The

1:1 Wilkinson divider designed was used to connect the two patches. The input port of the patch and the output port of the divider are matched by putting a 50Ω line of length $\lambda_g / 4$. Z_{in} of patch = 35Ω , Z_0 of divider strip = 70Ω , hence Z of matching line = $\sqrt{Z_{in}Z_0} = 50\Omega$. Figures 10, 11 and 12 show the 2:1 array, the VSWR and the impedance plot respectively.

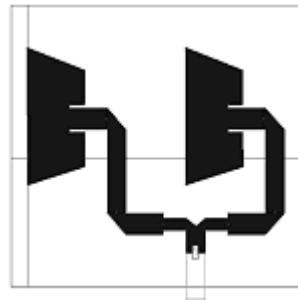


Figure 10. Design of a 2 by 1 array.

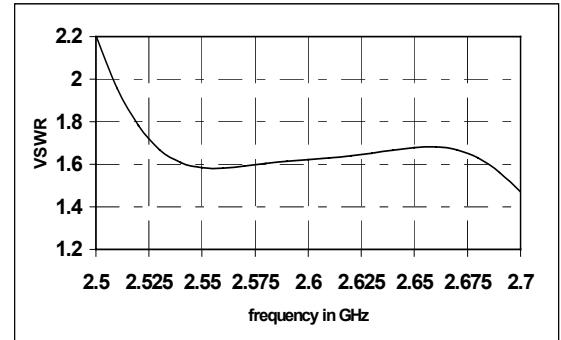


Figure 11. Frequency vs. VSWR of Port 1 of a 2 by 1 array antenna.

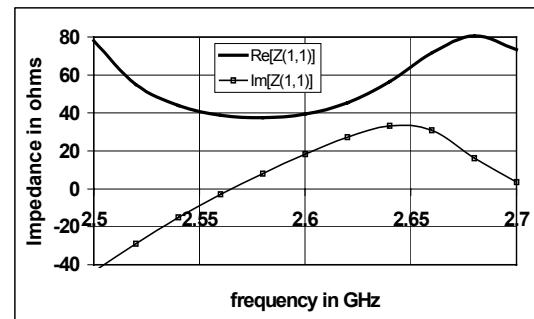


Figure 12. Frequency vs. Impedance of a 2 by 1 array antenna.

3.3.2 Design of a 4 by 1 array

Two sets of 2 by 1 arrays were joined together with another Wilkinson power divider (1:1) to form a linear 4 by 1 array (Figure 13). Figures 14 and 15 show the impedance and VSWR plot of 4 by 1 array respectively.

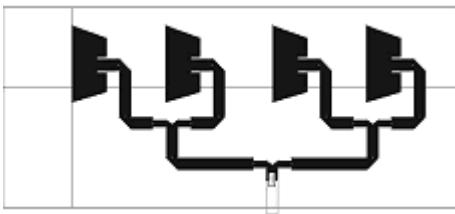


Figure 13. Design of a 4 by 1 array.

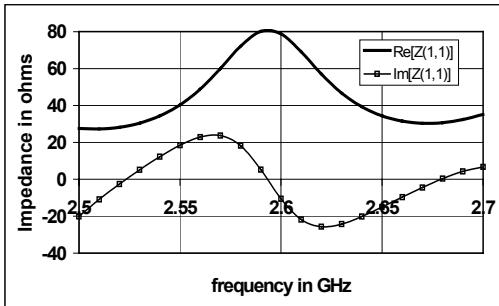


Figure 14. Frequency vs. Impedance of a 4 by 1 array antenna.

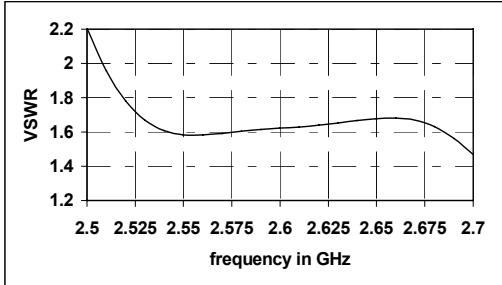


Figure 15. Frequency vs. VSWR of a 4 by 1 array.

4. CONCLUSIONS

From the studies of the results it is noticed that the increase in the substrate thickness had increased the impedance bandwidth of the antenna. Also the change in the geometry of the rectangular to a trapezoidal one has increased the impedance bandwidth of the antenna (Figure 7) and also decreased the VSWR value (Figure 6) at the cost of more computational time and complexity. Trapezoids with different

aspect ratio are simulated. The VSWR and impedance data are collected for the simulated trapezoids. These data are used to choose the aspect ratio. From the studies of the results achieved using IE3D, it can be concluded that the results are as per requirements, though the VSWR is slightly higher (1.5-2.2) (Figure 15) than the required value (1-1.4) for the desired frequency range.

The impedance bandwidth can also be increased by i) attaching a separate lossless matching network, without altering the antenna element itself, ii) adding parasitic strips parallel to the non-radiating edges of the square patch to improve the match to 50-ohm line and hence to improve the bandwidth and needs further investigations.

5. REFERENCES

- [1] *IE3D User's Manual*, Release 9, Zeland Software, Inc.
- [2] I.J.Bahl and P.Bhartia, *Microstrip Antennas*, pp. 31-83.
- [3] David M. Pozar, *Microwave Engineering*, John Wiley & Sons, 1998.
- [4] David M. Pozar and Daniel H. Schaubert, *Microstrip Antennas*, pp. 4-10, IEEE Press, 1995.