Design Analysis of Microstrip Patch Antenna in X-band

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Abstract

In this paper we design and analyze rectangular microstrip patch antenna operating in microwave X band frequency. The frequency range is specified by the IEEE at 8.0 to 12.0 GHz at which the patch antenna is analyzed. Goal is to design microstrip patch antenna which can operate at microwave frequency of larger bandwidth so that it can fulfill the demand of modern wireless communication system.

Key words:- Patch Antenna, X-band, Radiation pattern, VSWR, MGRID, return loss etc.

Introduction

Microstrip antennas are attractive due to their light weight, conformability and low cost. These antennas can be integrated with printed strip-line feed networks and active devices. Rectangular and circular micro strip resonant patches have been used extensively in a variety of array configurations. It is very easy to analyze a rectangular microstrip antenna using transmission and cavity model.

The X band is a segment of the microwave radio region of the electromagnetic spectrum. In communication engineering, the frequency range of X band is rather indefinitely set at approximately 7.0 to 11.2 GHz. In radar engineering, the frequency range is specified by the IEEE at 8.0 to 12.0 GHz. For military communications satellites, ITU has assigned the X band uplink frequency band as from 7.9 to 8.4 GHz. The ITU-assigned downlink frequency band is from 7.25 to 7.75 GHz. The US military uses all frequencies in this spectrum; however, they use select signals on the frequencies throughout this spectrum. The typical local oscillator frequency of an X band low-noise block converter is 6300 MHz. Both of these frequency bands are 500 MHz wide. In engineering, this pair of frequency bands may be referred to as the 8 / 7 GHz X band satellite communications system. X band is used in radar applications including continuous-wave, pulsed, single-polarization, dual-polarization, synthetic aperture radar, and phased arrays. X band radar frequency sub-bands are used in civil, military, and government institutions for weather monitoring, air traffic control, maritime vessel traffic control, defense tracking, and vehicle speed detection for law enforcement.

I. Microstrip Patch Antenna

We use rectangular patch antenna as they are most extensively used and for analysis we use transmission line model. A Microstrip Patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Fig1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

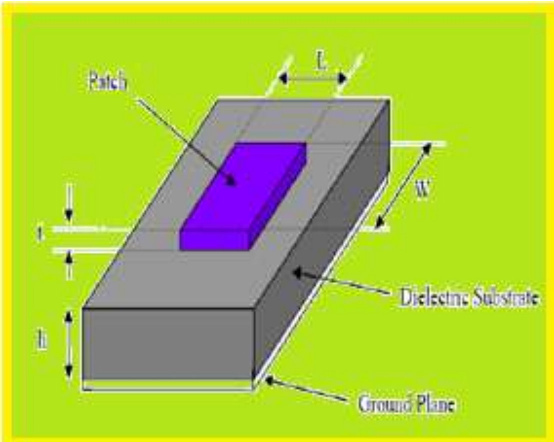


Fig 1 (a) Microstrip Patch antenna

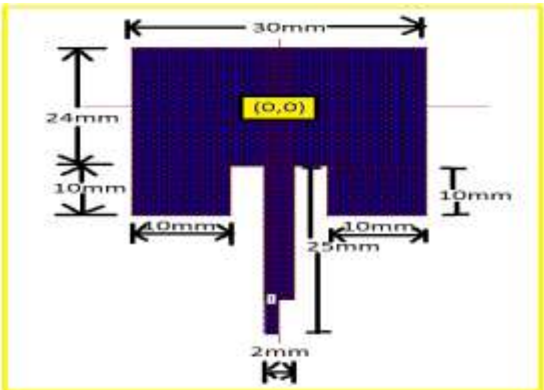


Fig 1 (b) MGRID Structure

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, substrates with higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a trade-off must be realized between the antenna dimensions and antenna performance.

II. Transmission Line Model

Transmission line model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a non homogeneous line of two dielectrics, typically the substrate and air.

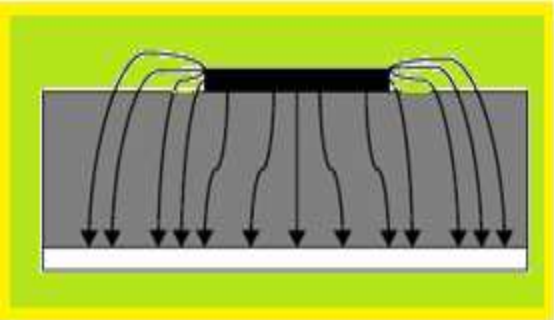


Fig 2 Electric field lines

Hence, as seen from Figure 2, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less then ε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 2 above. The expression for ε_{reff} is given by Balanis as :

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

For a rectangular patch, the length L of the patch is usually $0.3333\lambda o < L < 0.5\ \lambda o$, where λo is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda o$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\ \lambda o \le h \le 0.05\lambda o$. The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \le \varepsilon_r \le 12$.

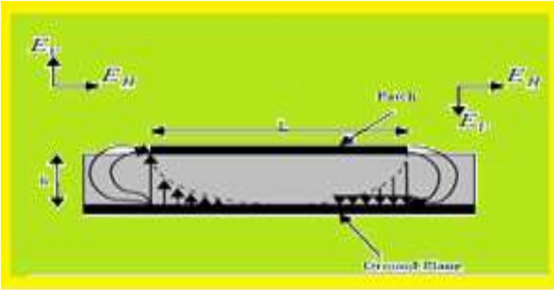


Fig 3 Side View of Antenna

The normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is λ/2 long and hence they cancel each other in the broadside direction. The tangential components which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ/2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically as:

$$\Delta L = 0.412\, h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)}$$

The effective length of the patch L_{eff} now becomes

$$L_{eff} = L + 2\Delta L$$

For a given resonance frequency f_o, the effective length is given as

$$L_{eff} = c / (2 f_o \sqrt{\varepsilon_{reff}})$$

Considering the rectangular patch Microstrip antenna the resonating frequency for the mode TM_{mn} is given by

$$f_o = c\,[\,(m/L)^2 + (n/W)^2]/ (2\sqrt{\varepsilon_{reff}})$$

m, n are the operating modes of the Microstrip patch antenna, along with L as length W as width.

For the effective radiation the design of the structure is the utmost important aspect and for this the width is calculated as

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{\lambda_o}{2}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

These equations are used for further calculation.

III. Calculation

From the above formula given by Balanis the length and width of patch antenna can be calculated at 8. 3 GHz microwave frequency.

- Resonating frequency = 8.3 GHz
- Dielectric constant = 2.2
- Height =1.588 mm
- Tangent loss = 0.0002

Calculated dimension are:

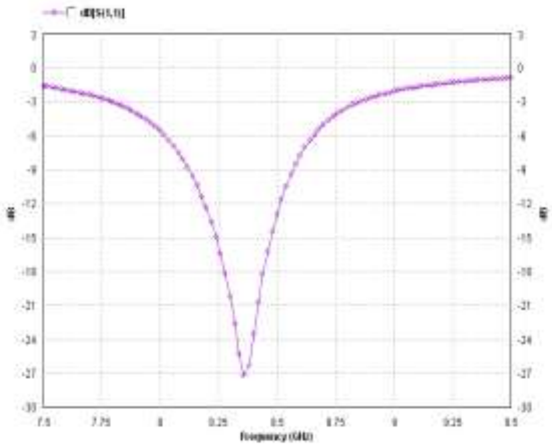
- Length = 30 mm
- Width = 24 mm
- For better bandwidth 10mm*10mm two square conducting plates also attached with the rectangular patch antenna.
- Microstrip feed line dimension = 25 mm*2mm

On the basis of above parameter and obtained parameter patch antenna is designed on IE3D electromagnetic simulator.

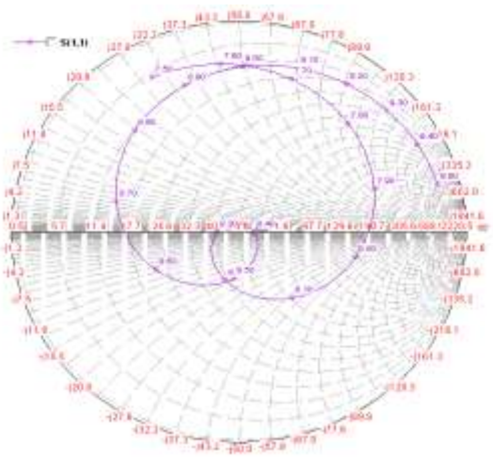
Result

Simulating rectangular patch antenna on electromagnetic simulator IE3D we get following results.

(a) Return loss

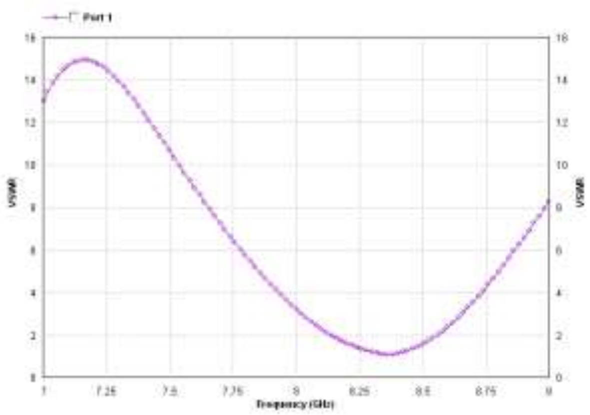


(b) Smith Chart

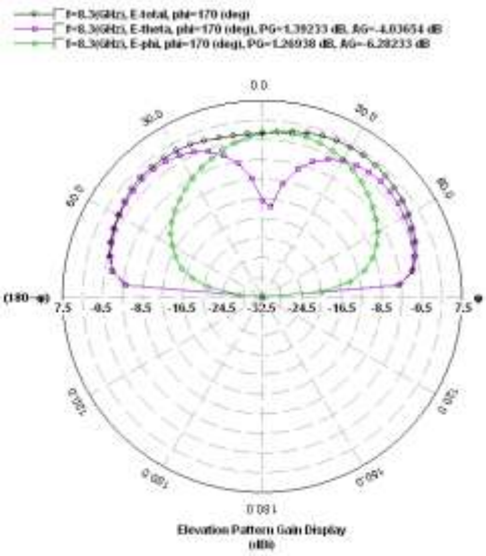


(c) VSWR

Voltage standing wave ratio is nearly 1 at centre frequency.

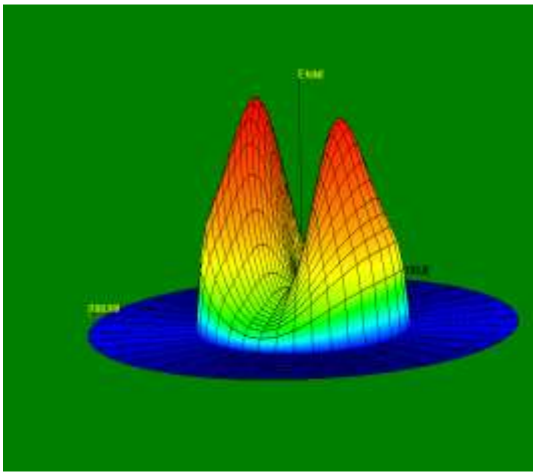


(d) Radiation pattern



(e) Radiation Pattern 3 D view of E theta

The radiation pattern of a rectangular microstrip patch antenna can be seen below, which consist of right field and left field.



Conclusion

From the above simulation results of microstrip patch antenna we can say that microstrip antenna reflection coefficient is -27 dB at resonating frequency. The performance is more than meeting the demanding bandwidth specification to cover the 8.00 GHz – 8.70 GHz frequency bands of 700 MHz. At the same time, the antenna is thin and compact with the use of low dielectric constant substrate material. These features are very useful for worldwide portability of wireless communication equipment. The parametric study provides a good insight on the effects of various dimensional parameters. It provides guidance on the design and optimization of microstrip patch antenna.

References

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