Impact of Substrate Thickness on Patch Antenna Performance

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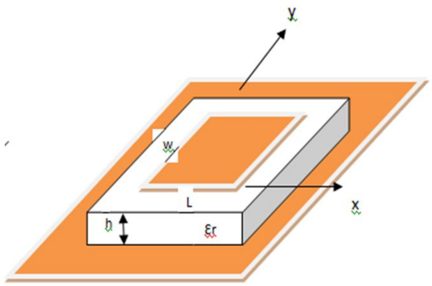
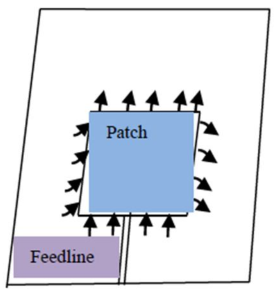
Abstract: Patch antennas are popular and widely used in wireless communication systems. Many articles have been published with regard to the design, fabrication of different types of patch antennas and arrays to suit the application requirements, however very few articles have appeared on the impact of geometry and structure of Patch antennas like dimensions and thickness on the electrical performance of the patch antenna. The most commonly used material for fabrication of patch antennas is glass epoxy (FR4) laminate of 1.2mm and 1.6mm thickness which is readily available. In this article, an analysis is made to find out the impact of FR4 laminate substrate thickness on the antenna performance parameters like gain, return loss, bandwidth. The analysis is carried out by simulating the parameters for patch antennas operating at 3GHz using FR4 material for different substrate thickness starting from 0.36mm to 3mm.

Keywords: Microstrip Patch antenna, RADAR, Defense wireless communication, Return loss, gain, Bandwidth etc.

Introduction

Currentlypatchantennashavebecomeverypopularduetotheirsimplicityindesign,easeoffabricationandlowcostandmultiplefrequencyoperations.Theyarelightweight,compact,cantakedifferentshapes,andcaneasilybemassproduced.Hence,patchantennasareextensivelyusedincommercial,professionalanddefensewirelesscommunicationequipments.Patchantennasareextensivelyusedindifferenttypesofwirelesscommunicationequipmentlikeshortrange(ZigBee,Bluetooth),longrange(WiFi)terrestrial(microwave),satellitecommunicationandRADAR.Microstrippatchantennas(MSAs)areknownfortheirlowcost,simplicityindesignandfabricationusingPCBtechnology.Fewdrawbacksofpatchantennaarelowpowerhandlingcapabilityandofferslowgainandnarrowbandwidth.Microstrippatchantennaconsistsofradiatingelementssuspendedoverinfinite(large) ground plane using different types of Dielectric materials as substrate.





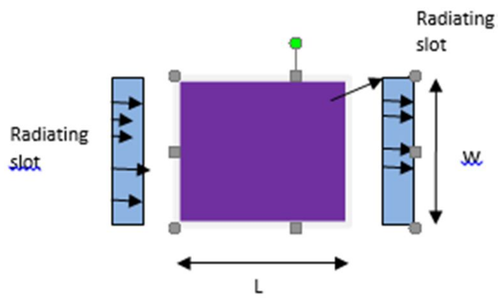


Fig .1. Geometry of rectangular patch antenna, Fig .2. Schematic of fringing effect, Fig .3.Variation of field lines

Fig.1.showsthetypicalrectangularpatchantennageometry.Theradiatingelementofpatchantennacanhavedifferentshapeslikesquare,circular,triangularsemicircular,sectoral,annularringandconformaltosuituserrequirement.Electriccurrentflowsfromtheradiatingelementandthegroundplaneacrosstheantennaandresultinginradiation.Radiationfromthepatchantennaoccursduetofringingeffectfromtheradiatingelementandgroundplane.Theelectricfieldlinesthatemergefromradiatingelementofpatchtothegroundplanearenotcompletelyconfinedtothesubstrate(dielectric),partialradiationoccursintoairasshownifFig.2.Hence,theseelectricfieldlinesarecalledasfringingfields.Duetothefringingeffect,thevalueofdielectricconstantofthesubstrate,Ɛrslightlyreduceswhichisrepresentedas Ɛeff,theeffectivedielectricconstantof substrate.

The analysis of the radiation from rectangular micro-strip antenna is carried out by considering it to be a planar structure by defining its length and width. The width of the patch is proportionate to the wavelength. The thickness of the substrate is smaller

compared to the wavelength. In TM10 mode, the fields along the length are 180° out of phase and hence they cancel out each other as shown in Fig. 3.On the other hand, it has no effect along the length of the patch. When the field along the width is resolved into components, all the components along the vertical plane cancel out and horizontal fields sum up. Therefore, the edges along the length are termed as non-radiating edges and edges along the width are called as radiating edges.
Thisarticlediscussesthedesign,simulation,andanalysisontheperformanceofpatchantennawithrespecttogainandbandwidthforvarious substratethicknesses.
Thisarticleisdividedinto5sections.SectionIistheintroduction,SectionIIdiscussesthepatchantennaperformanceparameters,SectionIII consistsofsimulationofPatchantenna,SectionIVconsistsofresultandanalysisofpatchantennausingFR4substrate,SectionVconsistsof conclusionandfuturescope.

Patch Antenna Performance Parameters

Performance of a patch antenna is evaluated based on parameters like directivity, gain, return loss, bandwidth, radiation pattern, polarization etc. In this paper, gain, return loss and bandwidth which are of importance for performance evaluation are considered for the analysis.

Return loss

Return loss is the loss of power in the signal returned or reflected by a discontinuity or mismatch between the antenna and the transmission line. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB);

$$RL(dB) = 10\, log_{10}\frac{P_i}{Pr} \quad (1)$$

Where RL is return loss in dB, Pi is the incident power and Pr is the reflected power.

Return loss can also be expressed as,

$$RL(dB) = 20 \log_{10}\frac{1}{\Gamma} \quad (2)$$

Where Γ is reflection co-efficient,

$$\Gamma = \frac{Zin - Z_0}{Zin + Z_0} \quad (3)$$

Which is also equivalent to,

$$\Gamma = \frac{SWR - Z_0}{SWR + Z_0} \quad (4)$$

Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss. Micro-strip Patch antenna impedance (edge impedance) varies from 200Ω to 500Ω. To achieve optimum radiating efficiency and gain, edge impedance has to be matched to characteristic impedance of the transmission line (50Ω). Fig .4. shows a simple matching technique to transform edge impedance to feeder line impedance using quarter wave transformer in between patch antenna and the transmission line.

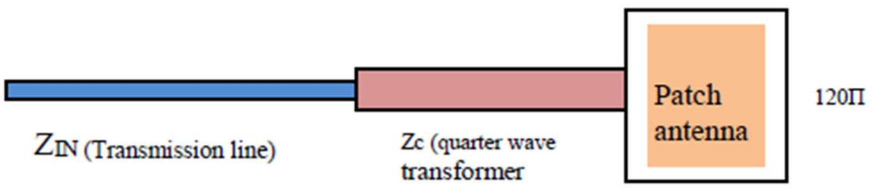


Fig .4. Typical impedance matching arrangement

The impedance of the quarter wave transformer is given by

$$ZC = \sqrt{Z_{IN}\, X\, Z_L} \quad (5)$$

Fig .5. shows typical return loss (S11) Vs. frequency graph of a patch antenna. The graph shows that the rectangular patch antenna is resonating at 20 GHz with a return loss of −21.5 dB.

Bandwidth

The bandwidth of an antenna defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.” The bandwidth can be considered to be the range of frequencies, on either side of a center frequency, where the antenna characteristics (such as input impedance, pattern, beam width, gain, Directivity) are within an acceptable value of those at the center frequency. Fig.5. shows that the rectangular patch antenna is resonating at 20 GHz with0.74 GHz and 0.25 GHz bandwidth at −3 dB and −10 dB respectively.

Bandwidth (BW)for a patch antenna can be defined as,

$$BW = \frac{VSWR - 1}{Q\sqrt{VSWR}} \qquad (6)$$

Bandwidth can be expressed as,

$$\%BW = \frac{Ah}{\lambda 0\sqrt{\varepsilon r}}\sqrt{\frac{W}{L}} \qquad (7)$$

Where λ0= free space wavelength, W= width of the patch antenna and L= length of the patch antenna, h= height is the substrate.

Where A=180 for $\frac{h}{\lambda 0\sqrt{\varepsilon r}} \leq 0.045$ (8)

Bandwidth can also be expressed as,

$$BW = 50hf^2 \qquad (9)$$

And εr= Effective permittivity.

It can be seen from equation (7) that bandwidth is directly proportional to width of the patch and height of the substrate. However,W has to be less than λ to avoid higher order modes of excitation. The present article focuses on impact of height h on the bandwidth.

Beam width of a pattern is defined as the angular separation between two identical points on opposite side of the pattern maximum.

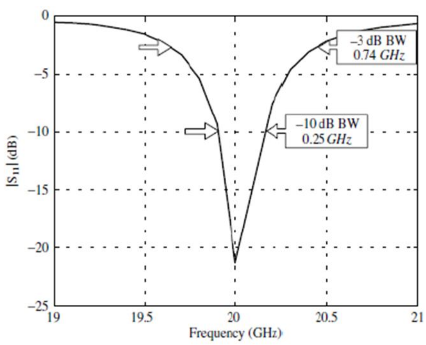


Fig .5. S11 for the 20 GHz rectangular patch antenna,

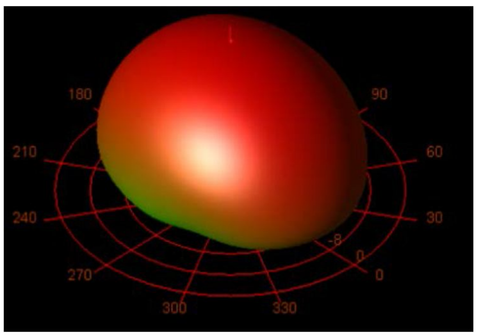


Fig .6.Typical3D radiation pattern of square patch antenna

Directivity

Directivity of an antenna defined as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions. It is an antenna parameter that measures how 'directional' an antenna's radiation pattern is. An omni directional antenna has effectively zero directionality, and the directivity of this type of antenna would be 1 (or 0 dB). The directivity of the aperture antenna whose area of aperture A is known can be calculated using the equation (10).

$$D(dBi) = 10\log\frac{4\pi}{\lambda^2}A \qquad (10)$$

Directivity of a rectangular patch antenna is given by,

$$D = 0.2W + 6.6 + 10log\left(\frac{1.6}{\sqrt{\varepsilon r}}\right)dB \qquad (11)$$

A typical 3D and 2D radiation pattern of a square patch antenna is as shown in Fig.6. and Fig.7.

respectively.

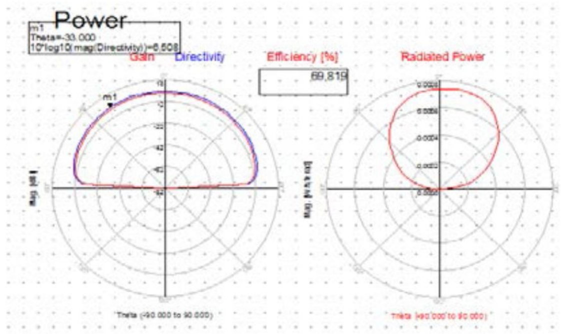


Fig .7. Typical2D radiation pattern of square patch antenna

Gain

Gain of the patch antenna describes the percentage of power transmitted in the direction of peak radiation (Bore sight) to that of an isotropic source. It is expressed in dBi. It is alsodefined as “the ratio of the radiation intensity, in a given direction, to the total input power”. It is given by the equation (12).

$G=k$D(12)

Where k is the efficiency factor, $0<k<1$

The W and L of a patch antenna are comparable to half wavelength. Hence rectangular patch antenna can be considered as a resonant dipole of length half wavelength of dipole which has approximately a gain of 2dB. The gain of patch antenna vary from 3dB to 7dBdepending upon the permittivity of the substrate.

Simulation of Microstrip Patch Antenna

This section presents the design of a square microstrip patch antenna using FR-4 laminate (εr=4.6) resonating at 3GHz using Keysight make ADS tool based on edge impedance (quarter wave transformer matching technique). The Performance (gain and bandwidth) were simulated for different thicknesses (0.36mm-3mm) commercially available FR-4 material. The schematic of the Patch antenna generated from ADS tool is presented in Fig.8. The layout generated from the schematic of the patch antenna is shown in Fig. 9. The simulated results obtained from ADS tool are presented in Fig.10, Fig.11 and Fig.12. Fig.10. shows S11 (return loss) parameter achieved. Fig.11. shows Antenna parameters like gain, directivity, power radiated, maximum intensity and effective angle.

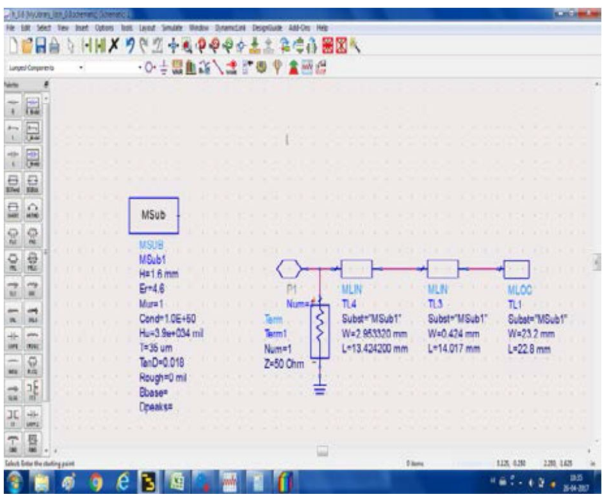


Fig .8.Schematic of patch antenna (1.6mm)

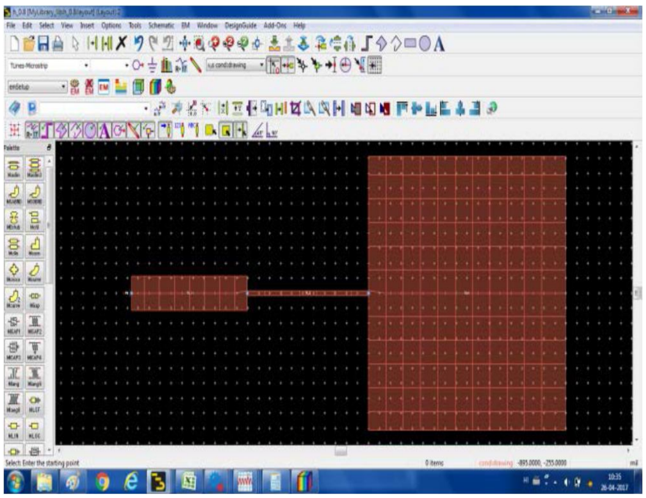


Fig. 9. Layout of patch antenna (1.6 mm)

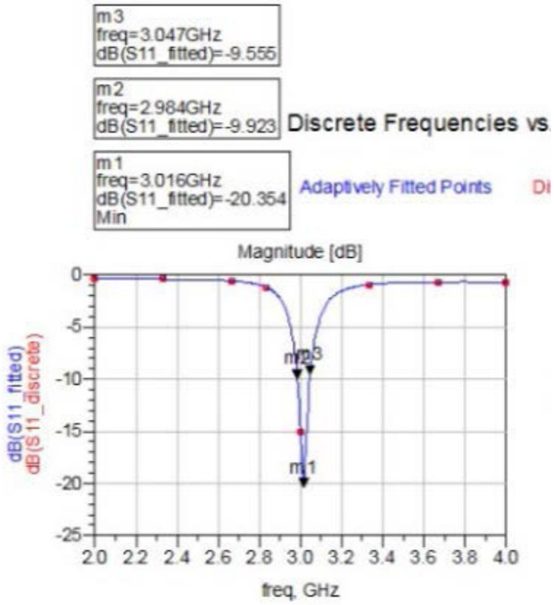


Fig .10. Return loss (S11) of patch antenna (1.6mm)

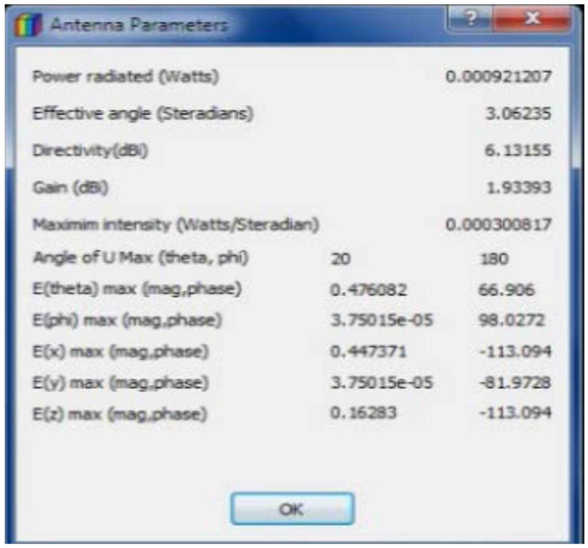


Fig .11.Antenna parameter of patch antenna (1.6mm)

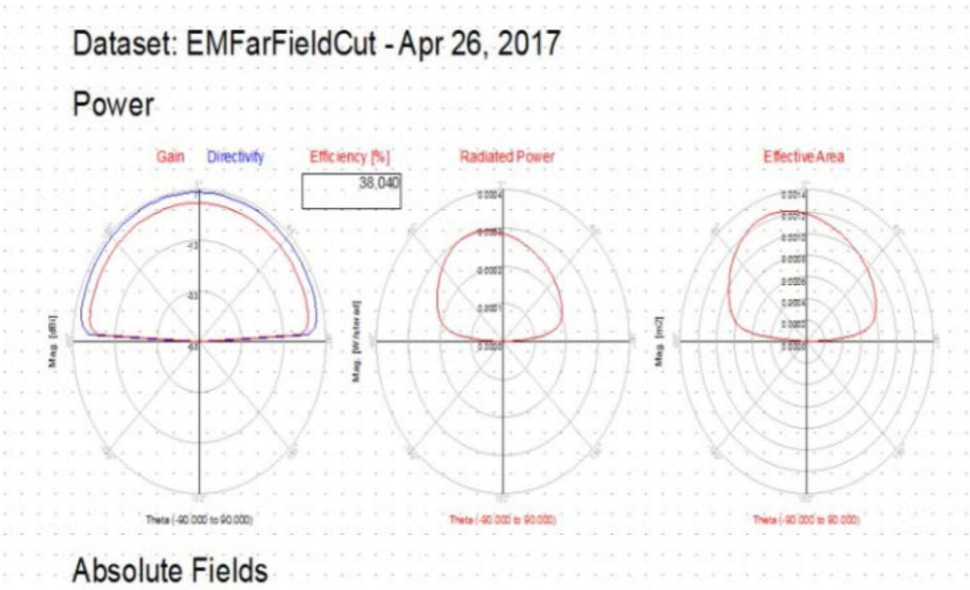


Fig .12. 2D Radiation pattern of patch antenna (1.6mm)

Result Analysis for Various Substrate Thicknesses

In this section, a detailed analysis of impact of substrate thickness on antenna parameters such as gain and bandwidth is presented. The gain and bandwidth parameters are simulated for different substrate thicknesses varying from 0.36mm to 3mm. Table I shows the values of gain in dBi corresponding to different substrate thicknesses in mm.Fig.13.shows graph of gain Vs. thicknesses of the substrate. It can be seen that the gain increases with the increase in substrate height.

Table II shows the bandwidth in MHz corresponding to different substrate thicknesses in mm.Fig.12.shows graph of bandwidth Vs. substrate thickness .It can be seen from Fig.14.that bandwidth increases with the increase in substrate height.

TABLE I : THICKNESS OF THE SUBSTRATE VS. GAIN

Thickness Of The Substrate (mm)	Gain (dBi)
0.36	-4.26202
0.6	-1.9877
0.8	-0.71986
1.2	1.07992
1.6	1.93393
1.8	2.85664
2.4	3.26667
3	3.24692

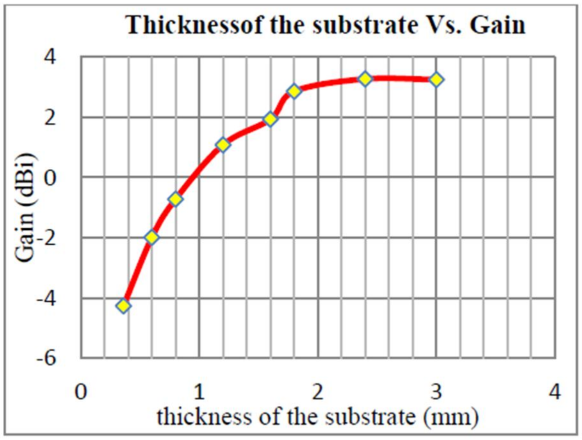


Fig.13. Plot of Thickness of the substrate Vs Gain

TABLE II: THICKNESS OF THE SUBSTRATE VS. BANDWIDTH(MHZ)

Substrate height (mm)	Bandwidth (MHz)
0.36	37
0.6	42
0.8	47
1.2	52
1.6	63
1.8	86
2.4	100
3	112

Conclusion and Future Scope

It is seen from section III that both gain and bandwidth of a patch antenna depends on the dimensions of the patch and height of the substrate. From the simulation results presented in section IV it can be concluded that substrate thickness of a patch antenna impacts the gain and bandwidth of a patch antenna. The simulated results further show that a linear relationship exists between thickness of the substrate and patch antenna performance parameters such as gain and bandwidth. Other methods like electromagnetic coupling, geometry variations (including dimensions) techniques and usage of different dielectric materials are also used to achieve higher gain and bandwidth.

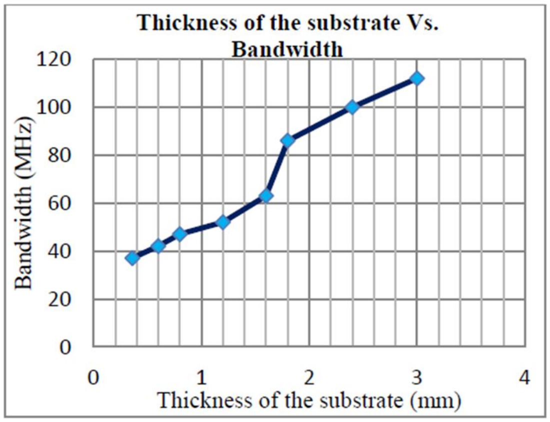


Fig.14. Plot of Thickness of the substrate Vs Bandwidth (MHz)

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