Substrate Permittivity Effects on the Performance of the Microstrip Elliptical Patch Antenna

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ABSTRACT

In this paper, the performance of a microstrip elliptical patch antenna is investigated using different substrate materials. The Microstrip antenna is studied with different substrates for a radiating elliptical patch of fixed dimensions. The effects of the dielectric constant of the perfect and lossy substrates on the resonant frequency, bandwidth and gain are investigated. A gain drop of 1.3 dB per decade is observed. Return loss, input impedance, radiation patterns and current distributions are investigated and presented with the help of Ansoft-HFSS.

Keywords: *Substrate permittivity, elliptical patch.*

1. INTRODUCTION

Substrate permittivity is one of the basic parameter on which the antenna performance depends mostly. The substrate permittivity (ε_r) combined with the thickness h of a microstrip antenna affect the resonant frequency, gain, matching bandwidth and polarization. Microstrip antenna theory [1]-[5] indicates a degradation in performance when ε_r increases. High permittivity substrates reduce antenna size at the cost of the gain and matching bandwidth [6]-[9]. This study evaluates these parameters when antenna dimensions and resonant frequency of an elliptical patch (Fig. 1) are fixed. The evaluation is performed using the Finite Element Method from the commercial software Ansoft HFSS v.11. Air and other dielectric materials provided by HFSS, such as RT-duroid, FR4_Epoxy, Benzocylobuten, and Roger Ultrom200 are used to quantify the performance variations of the microstrip elliptical patch. A special nematic room temperature liquid crystal polymer material dielectric constant and dielectric loss tangent at microwave frequency is investigated and used in this present work along with the other materials.

The physical dimensions of the radiating element of the antenna are fixed. Using different substrate materials [10], the resonant frequency and the corresponding gain are evaluated. In HFSS some of the materials used are ideal, i.e., the loss tangent δ is zero, while others are lossy ($\delta > 0$). This parameter is accounted for by evaluating the lossy materials with default δ not equal to zero, and as perfect dielectrics, with $\delta = 0$. The effects of δ are also reported. Figure (1) shows the Ansoft generated model for the microstrip elliptical patch antenna.

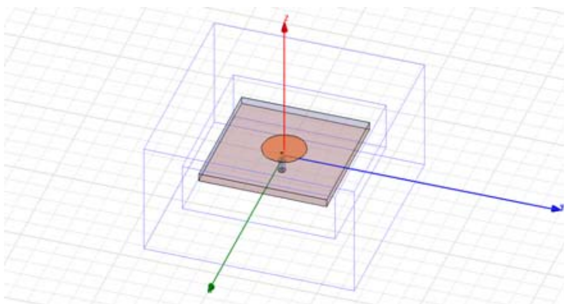

Figure (1) Elliptical patch antenna

Table (1) Data table of the Antenna

Material	ε_r	Loss tangent	Return loss (dB)	Gain (dBi)
Air	1.0006	0	-7.8	5.30
RT-duroid	2.2	0.0009	-15.9	8.15
Roger ultrom 200	2.5	0.0019	-18.0	7.71
Benzocylob uten	2.6	0.0001	-19.5	7.828
Liquid crystal polymer	2.85	0.02	-17.5	6.6096
FR4	4.4	0.02	-29.2	3.2086

At the resonant frequency of 2.4GHz the proposed antenna is designed with patch dimension along x-axis and y-axis of 43.8mm. substrate thickness of 1.59mm, substrate dimensions along x-axis and y-axis are 130mm. feed location along x-axis is 7.2mm and coaxial inner radius, outer radius and feed length of 1.04mm, 3.54mm and 10.4mm respectively.

2. RESULTS AND DISCUSSION

The return loss curves for elliptical patch antenna with different substrate materials are shown in figure (2). Among all the substrate materials FR4 is giving minimum -29.8dB return loss and the Air substrate is giving maximum of -7.8dB. RT-duroid is giving -15.69dB, Roger-ultrom200 is giving -17.9dB, liquid crystal polymer is giving -17.12dB and benzocylobuten is giving the return loss of -19.23.

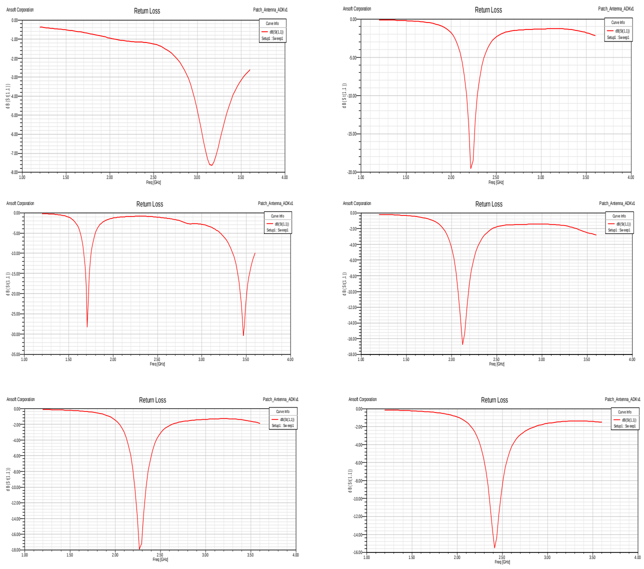

Figure (2) Return loss curves, (2a) Air, (2b) RT-duroid5880, (2c) Roger-ultrom200 , (2d) Benzocylobuten, (2e) LCP (2f) FR4

The driving point or feed point of an antenna is the location on an antenna where a transmission line is attached to provide the antenna with a source of microwave power. The impedance measured at the point where the antenna is connected to the transmission line is called the driving point impedance or input impedance. Figure (3) shows the input impedance smith chart curves for the elliptical patch antenna for different substrate materials. From the input impedance smith chart curve we obtained the rms and bandwidth for all the antennas of different substrate materials.

The rms obtained from all the substrates and their bandwidth ratios are listed in the below table (1)

Table (2) rms and bandwidth parameters

Substrate Material	rms	Bandwidth %
Air	0.8122	83.54%
RT-duroid	0.8226	88.56%
Roger-ultrom200	0.8266	83.88%
Benzocylobuten	0.8295	82%
LCP	0.8095	78%
FR4	0.7437	63%

From the table (2) it is clear that the RT-duroid is giving the maximum bandwidth and FR4 substrate is giving lesser value. Form this point it is clear that the dielectric constant of lesser value is giving better bandwidth ratio in compared with the dielectric constant of higher value substrate material. Next to RT-duroid the Roger-ultrom200 is giving better bandwidth ratio and air substrate is very close to it.

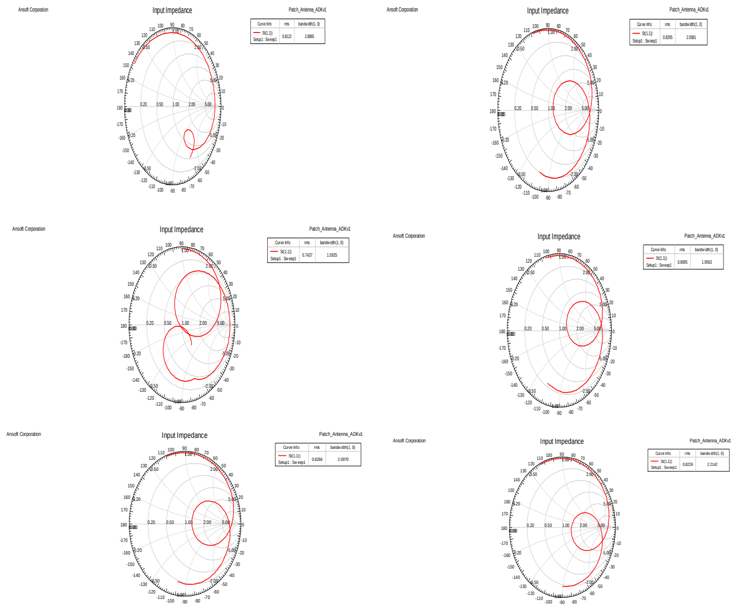

Figure (3) Input impedance smith chart, (3a) Air, (3b) RT-duroid5880, (3c) Roger-ultrom200 (3d) Benzocylobuten, (3e) LCP (3f) FR4

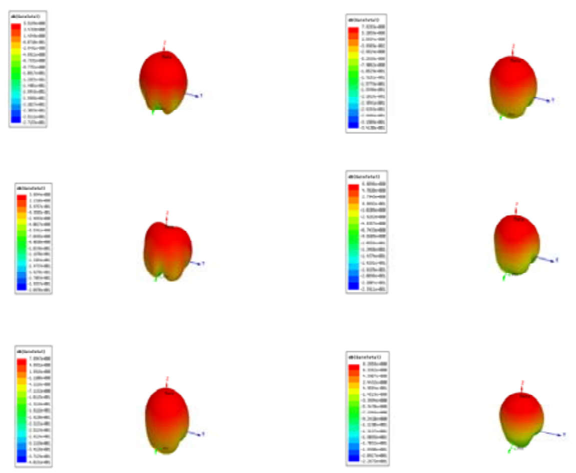

Figure (4) 3D-gain total, (4a) Air, (4b) RT-duroid5880, (4c) Roger-ultrom200 (4d) Benzocylobuten, (4e) LCP (4f) FR4

A maximum gain of 8.15dB is obtained by using the RT-Duroid substrate and among all the substrate materials FR4 substrate material based antenna is giving less gain of 3.2dB. The gain in 3D and 2D representation is given in the figure (4) and figure (5) for the elliptical antenna with different substrate materials.

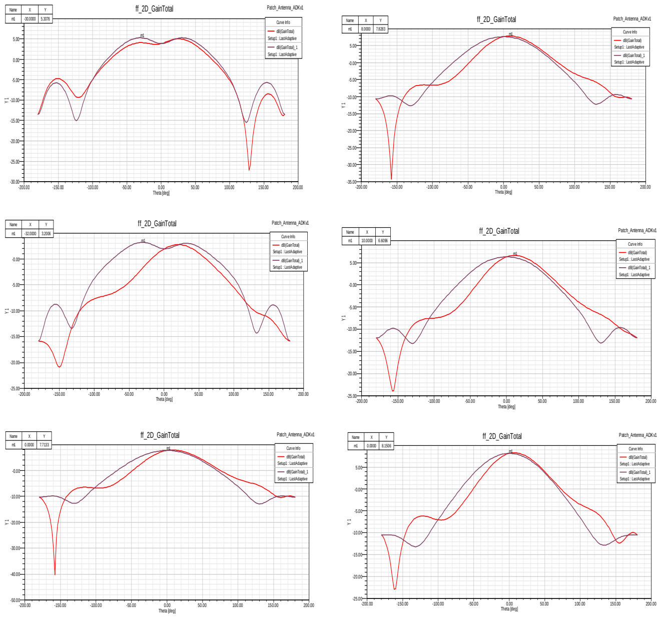

Figure (5) 2D-gain total, (5a) Air, (5b) RT-duroid5880, (5c) Roger-ultrom200 (5d) Benzocylobuten, (5e) LCP (2f) FR4

The radiation pattern of the antenna at phi=0^0 and 90^0 is given in the figure (6) and radiation pattern of antenna at theta=0^0 and 90^0 are shown in the figure (7). The liquid crystal substrate material used antenna is giving omni directional pattern in compared with the other materials and second to liquid crystal substrate the RT-duroid is giving appropriate radiation pattern among all the other materials. It is obvious from these results that the radiation pattern is acceptable for the all the substrate materials that we have chosen and the Liquid crystal polymer and the RT-duroid is giving better radiation pattern compared to other substrate materials.

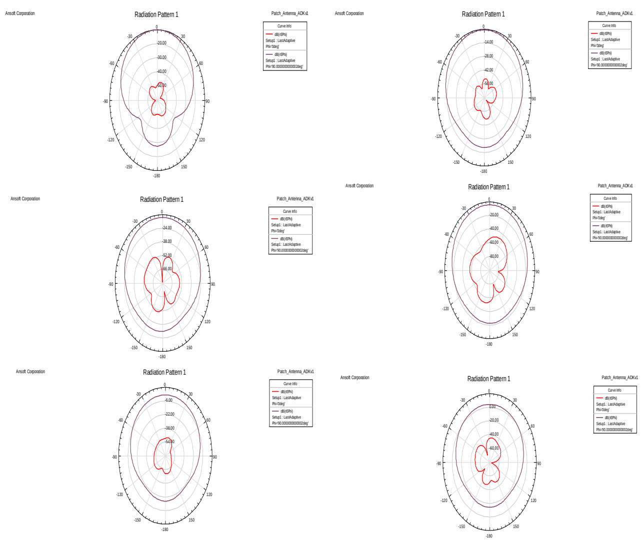

Figure (6) gain phi at 0^0 and 90^0, (6a) Air, (6b) RT-duroid5880, (6c) Roger-ultrom200 (6d) Benzocylobuten, (6e) LCP (6f) FR4

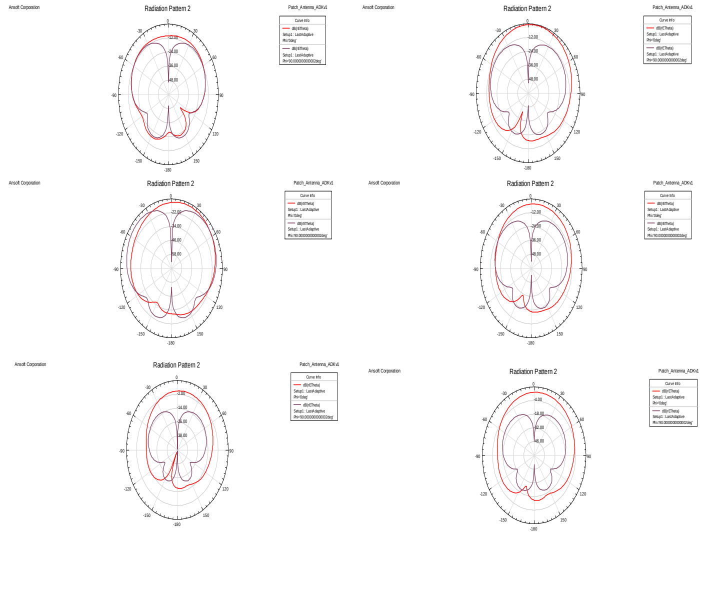

Figure (7) gain theta at 0^0 and 90^0, (7a) Air, (7b) RT duroid5880, (7c) Roger-ultrom200 (7d) Benzocylobuten, (7e) LCP (7f) FR4

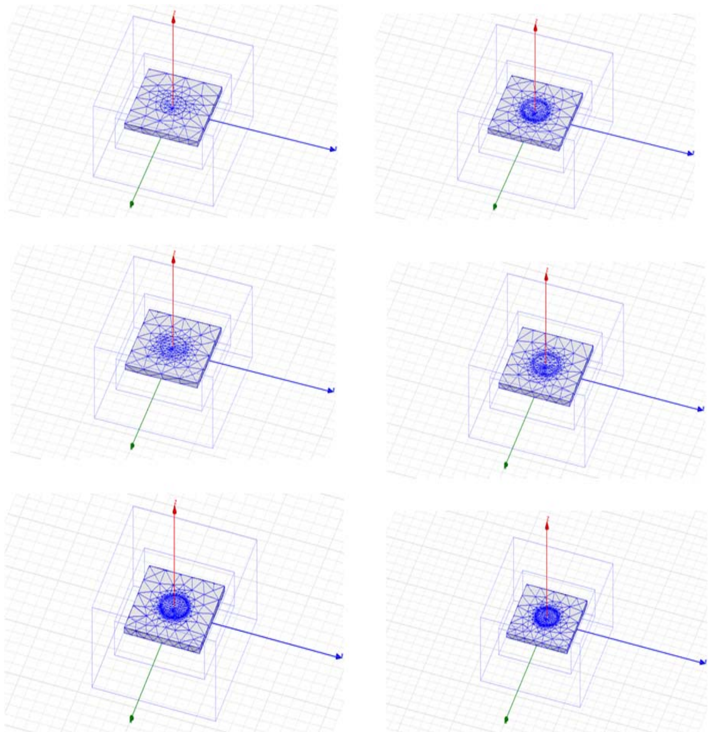

Figure (8) Current distribution, (8a) Air, (8b) RT-duroid5880, (8c) Roger-ultrom200 (8d) Benzocylobuten, (8e) LCP (8f) FR4

The current distribution of the proposed antenna model on all the six substrate materials are given in the figure (8). It is observed that the RT-duroid, LCP and FR4 substrate materials based antenna is giving the mesh generation of more concentration around the patch. Which indicating the current distribution concentration at the radiating patch for these materials based antennas are giving better results compared with the other substrate materials.

CONCLUSION

Performance evaluation of the microstrip elliptical patch antenna on different substrate materials with permittivity varying from 1.006 to 4.4 is simulated. A maximum gain of 8.15dB is obtained for the RT-duroid substrate used antenna in the present work. FR4 substrate based antenna is giving the least gain value 3.20dB for the proposed dimensional model. Similarly bandwidth of 88% achievement obtained in the case of RT-duroid, whereas by using FR4 only 63% is achieved. A gain drop of 1.3dB per decade is observed when going from dielectric constant of 1 to 4.4 for the substrate materials chosen. The loss tangent of substrate is also considered along with permittivity while simulating the present model.

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