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PARAMETRIC ANALYSIS OF DIFFERENTIALLY FED INVERTED RECTANGULAR PATCH ANTENNA

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ABSTRACT

This article throws lights on the advantages offered by inverted patch over conventional patch antenna. The antenna is designed in inverted mode along with variable air gap in order to overcome the drawbacks of the conventional model and achieve tune-ability of the antenna with respect to the air gap height. This inverted design offers enhancement of bandwidth approximately 10%, relatively high gain, and perfect impedance match. Tunability of the patch as a function of air gap height is also revealed and validated with theory.

Keywords: Differentially Fed, Inverted Patch, Microstrip, Superstrate, Tunability.

I. INTRODUCTION

Conventional microstrip antenna also known as patch antenna is attractive due its low weight, low cost, and ease of installation. But despite of this it has certain operational drawbacks like low power, low efficiency, narrow bandwidth, etc... In order to alleviate these shortcomings inverted model of microstrip antenna is designed as shown in Fig.1. The structure offers several advantages over conventional microstrip configuration [2]. Air being the medium below the patch offers easy integration of active devices with the patch as well as wide bandwidth without any enhancement in weight, volume or cost. The probe does not require any penetration through the substrate, or any soldering with the patch to accommodate active devices. These features, unlike conventional microstrip, offer a great advantage to achieve perfect impedance matching without any degradation of substrate and the patch. Moreover, the air medium between the patch and ground plane is also free from surface wave excitation. Differentially fed patch antennas (DFPA) [2], [4] in microwave systems have received considerable attention in recent years. DFPA is proposed to simultaneously obtain wide bandwidth and good radiation patterns. The differential signal can feed to the antenna through using current conducting probes that are located at a precise position on the patch to excite the desired mode and obtain a 180 degree phase shift between them. The currents on the two probes flow in opposite directions and their leakage radiation is cancelled. Moreover, the currents on the patch are symmetrically distributed. These two factors result in low cross-polarization and symmetrical co-polarization. The introduction of air gap between patch and ground plane indicates the possibility of tuning the microstrip antenna. By changing the height of the air gap desired frequency of operation can be obtained. The inverted patch also offers tunability [3][5] of the antenna, which means antenna can be tuned to desired frequency of operation by changing the air gap height i.e. patch is the function of air gap height.

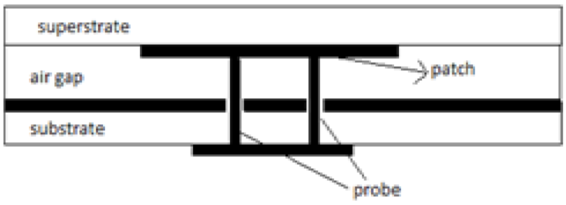
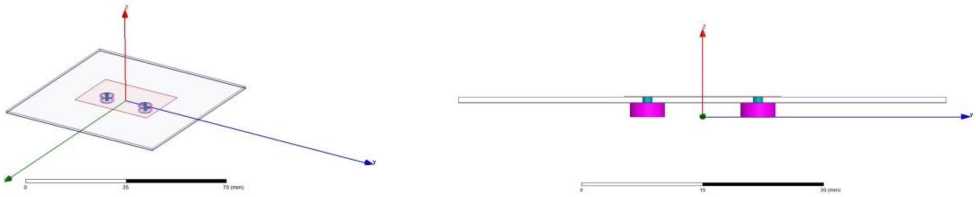


Figure 1. Inverted Model of Microstrip Antenna

II. PROPOSED DESIGN

2.1 Antenna Configuration

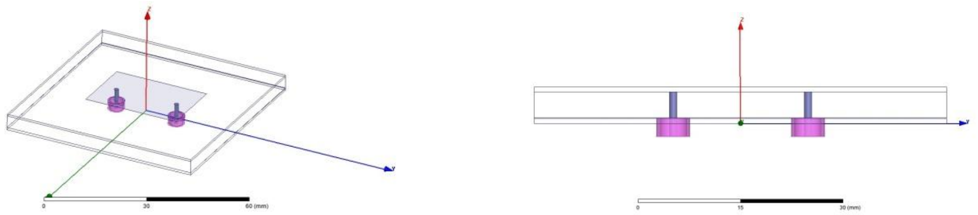
To establish the features for the inverted patch we have designed both conventional and inverted patch using HFSS solver one of the several commercial tools used for antenna design. Rectangular patch is selected because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. Dimension of the patch is taken in such a way that W/L ratio is always 1.5. Here in this design in Fig. 2 (a) & (b) there is a ground plane (material used: copper; relative permittivity=1) over to which is a substrate layer (material used: Rogers RT/duroid 5880 tm; relative permittivity=2.2), then a rectangular patch (dimension: length (L) =5mm width (W) =7.5mm) is situated over the patch. Here coaxial cable or probe feed is used which is fed differentially. The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is extended up to the patch antenna. The position of the feed can be altered to control the input impedance. In the design of inverted patch in Fig. 3 (a) & (b) same materials are used but there is a substrate layer (material used: Rogers RT/duroid 5880 tm; relative permittivity=2.2) at the bottom, a ground layer (material used: copper; relative permittivity=1) over it. Here an air gap (material used: air; relative permittivity=1.006) is introduced between the ground plane (material used: air; relative permittivity=1.006) is introduced between the ground plane and conducting patch (dimension: length (L) =5mm width (W) =7.5mm) along with another substrate layer which is called superstrate (material used: Rogers RT/duroid 5880 tm; relative permittivity=2.2) is placed over the patch.



(a) **(b)**

Figure 2. Conventional Patch Antenna (a) 3D View (b) Side View

For tuning, a constant air gap for a particular patch dimension is taken and probe center is varied to get a good reflection coefficient (s_{11}) value for a particular frequency. Again changing the air gap height and reflection coefficient (s_{11}) is measured for all possible frequencies by changing the probe center, calculating the bandwidth. After completion patch dimension are changed and same calculation is repeated. Various parameters such as the length and width of the patch, substrate thickness (h2), height of the air gap (h1) and the feed location were adjusted for optimized bandwidth performance.



(a) **(b)**

Figure 3. Inverted Patch Antenna (a) 3D View (b) Side View

2.2 Equation

The resonant frequency for the rectangular patch antenna is stated as, [1]:

$$f_{r,nm} = \frac{c}{2\sqrt{\varepsilon_{reff}}}\sqrt{\left(\frac{n}{L+2\Delta W}\right)^2+\left(\frac{m}{W+2\Delta L}\right)^2} \quad (1)$$

An effective dielectric constant (ε_{reff}) must be obtained to account for wave propagation in the line and fringing.

$1 < \varepsilon_{reff} < \varepsilon_r$.

$$\Delta L = \frac{(\varepsilon_{reff}+0.03)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \times (0.412h) \quad (2)$$

Effective relative dielectric constant is given as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \quad (3)$$

considering an inverted circular patch with both the patches is resonating at the same frequency, having identical circumference and a=1.7L, where a is the radius of circular patch:

$$\Delta L = \left[\frac{\pi a\left(\sqrt{1+q}-1\right)}{2\left(2.25-0.5 W/L\right)}\right] \quad (4)$$

The expression for effective line width taking into account the presence of superstrate is written as, [5]:

$$w_{ef} = \sqrt{\frac{\varepsilon_r}{\varepsilon_{reff}}}\left[w+0.882h+0.164\frac{h(\varepsilon_r-1)}{\varepsilon_r^{\ 2}}\right]+\sqrt{\frac{\varepsilon_r}{\varepsilon_{reff}}}$$
$$\frac{h(\varepsilon_r+1)}{\pi\varepsilon_r}\left[\ln\left(\frac{W}{2h}+0.94\right)+1.451\right] \quad (5)$$

As an approximation, the iteration for w_{ef} assumes that $\varepsilon_r \approx \varepsilon_{r1}$ and $\varepsilon_{reff} \approx \varepsilon_r$. Once ε_{reff} and ε_r are determined using the first value of w_{ef}, (5) is used to determine effective line width a second time. This new value of w_{ef} is used in the calculation of open line length extension ΔL. Additional iterations of this calculation loop results in insignificant changes in effective permittivity and resonant frequency is predicted.

$\therefore$ Improved formula for ε_{reff} for an inverted microstrip antenna can be more explicitly written as, [6]:

$$\varepsilon_{reff} = p_1 + (1 - p_2)^2 \times \left[\varepsilon_r^2 p_2 p_3 + \varepsilon_r \left\{p_2 p_4 + (p_3 + p_4)^2\right\}\right] \times$$
$$\left[\varepsilon_r^2 p_2 p_3 p_4 + (\varepsilon_r p_3 + p_4)(1 - p_1 - p_4)^2 + \varepsilon_r p_4 \left(p_2 p_4 + (p_3 + p_4)^2\right)\right]^{-1} \quad (6)$$

Where,

$$p_1 = 1 - \frac{h_1}{2w_{ef}} \ln\left(\frac{\pi}{h_1} w_{ef} - 1\right) - p_4 \quad (7)$$

$$p_2 = 1 - p_1 - p_3 - 2p_4 \quad (8)$$

$$p_3 = \frac{h_1 - g}{2w_{ef}} \ln\left[\frac{\pi w_{ef}}{h_1} \frac{\cos(0.5\pi g/h_1)}{\pi(0.5 + h_2/h_1) + 0.5\pi g/h_1} + \sin(0.5\pi g/h_1)\right] \quad (9)$$

$$p_4 = \frac{h_1}{2w_{ef}} . \ln\left(\frac{\pi}{2} - \frac{h_1}{2w_{ef}}\right) \quad (10)$$

$$g = \frac{2h_1}{\pi} . \arctan\left[\frac{\pi h_2/h_1}{(\pi/2)(w_{ef}/h_1) - 2}\right] \quad (11)$$

The relative permittivity is given as:

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

Where, $A = \left(1 + \frac{10h}{w_{ef}}\right)^{-1/2}$ (13)

The above equation (13) is accurate within $\pm 2\%$ for all values of ε_r, Therefore the improved resonant frequency is given as:

$$f_{r,nm} = \frac{c}{2\sqrt{\varepsilon_{rq}}} \sqrt{\left(\frac{n}{L + 2\Delta L}\right)^2 + \left(\frac{m}{W + 2\Delta W}\right)^2} \quad (14)$$

$$\varepsilon_{rq} = ita * \varepsilon_{reff} \quad (15)$$

Where *ita* is the correction parameter, and ε_{rq} is the modified effective relative permittivity.

III. RESULT AND OBSERVATION

3.1 Comparison

On comparing the results we see that the bandwidth is enhanced (given in TABLE I) using inverted patch, the radiation pattern obtained provides better gain and narrow beam width, even from the impedance vs. frequency plot it is shown that for the inverted patch resistive and reactive impedance is approximately equal to 50ohm and 0ohm respectively, thereby perfect impedance match.

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TABLE I. Representing Calculated and Simulated Frequency for Conventional and Inverted Patch

Patch	Calculated frequency (GHz)	Simulated frequency (GHz)	Percentage bandwidth
Conventional Patch	4.97	4.85	4.75%
Inverted Patch	13.6	14.26	43.54%

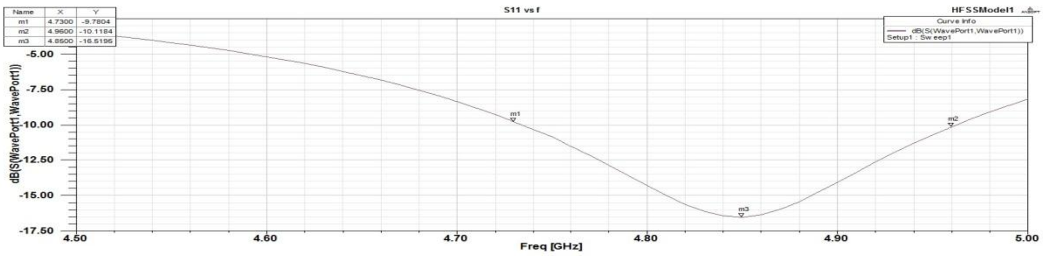

Figure 4. Plot of reflection coefficient (s_{11}) vs. frequency for conventional rectangular patch microstrip antenna, s_{11} (dB) on y-axis, frequency (GHz) on x axis at frequency 4.85GHz

Figure 5. Plot of reflection coefficient (s_{11}) vs. frequency for inverted rectangular patch antenna, s_{11} (dB) on y-axis, frequency (GHz) on x axis at frequency 14.26GHz

(a) **(b)**

Figure 6. Plot of radiation pattern of (a) simple patch antenna at frequency 4.85GHz, showing wide beam width, and unidirectional pattern (b) inverted patch antenna at frequency 14.26GHz, showing narrow beam width, multidirectional pattern

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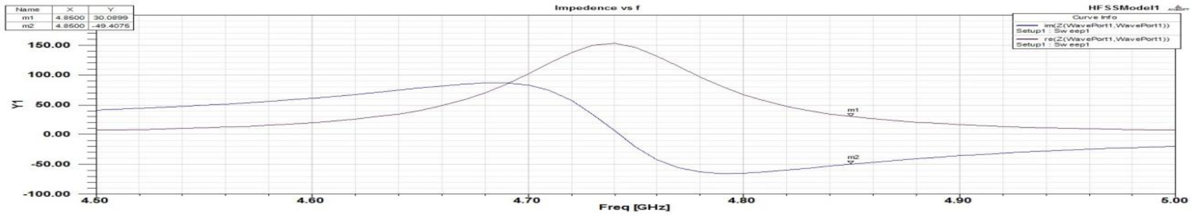

Figure 7. Impedance vs. frequency plot for conventional patch, here resistive and reactive impedance is not approximately equal to 50ohm and 0ohm respectively, thereby mismatch.

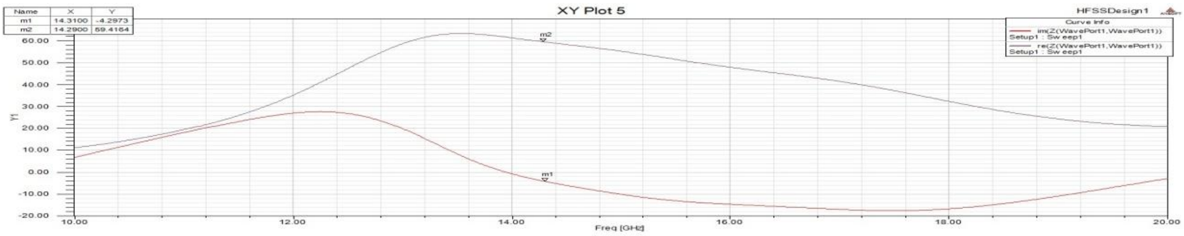

Figure 8. Impedance vs. frequency plot for inverted patch, here resistive and reactive impedance is approximately equal to 50ohm and 0ohm respectively, which matches with the port impedance that we have taken as 50ohms in the simulator.

3.2 Tunability

Since for each patch dimension and air gap height we have got the calculated resonant frequency from the calculation given in (1 and 14) and from the simulation results we have got the simulated resonant frequency value, now by plotting the resonant frequencies (both calculated and simulated) on y axes, and air gap height on x axis we see that, with increase of air gap height the frequencies (both calculated and simulated) are decreasing. Therefore simulated result validates the theoretical or calculated results. Results for different patches are given in a tabular as well as on graphical form in the following section.

TABLE II. Representation of Different patch Dimension and their Respective Resonant Frequency Both Calculated and Simulated

L	W	W/L	Mode	Probe center	Air gap	fcal	fsim	fcal-fsim
mm	mm		n,m	mm	mm	GHz	GHz	GHz
20	30	1.5	1,0	9	1	5.53	5.4487	0.081
20	30	1.5	1,0	10	1.25	5.44	5.4481	-0.008
20	30	1.5	1,0	10	1.5	5.36	5.4474	-0.087
20	30	1.5	1,0	10	2	5.21	5.4458	-0.235
15	22.5	1.5	1,0	3	1	7.2	7.7008	-0.501
15	22.5	1.5	1,0	4	1.25	7.04	7.6993	-0.659
15	22.5	1.5	1,0	4	1.5	6.91	7.6968	-0.786
15	22.5	1.5	1,0	5	2	6.66	7.6924	-1.032
10	15	1.5	1,0	5	1	10.3	9.9639	0.296
10	15	1.5	1,0	5	1.25	9.97	9.9612	0.008
10	15	1.5	1,0	4	1.5	9.71	9.9573	-0.247
10	15	1.5	1,0	6	2	9.24	9.9535	-0.713

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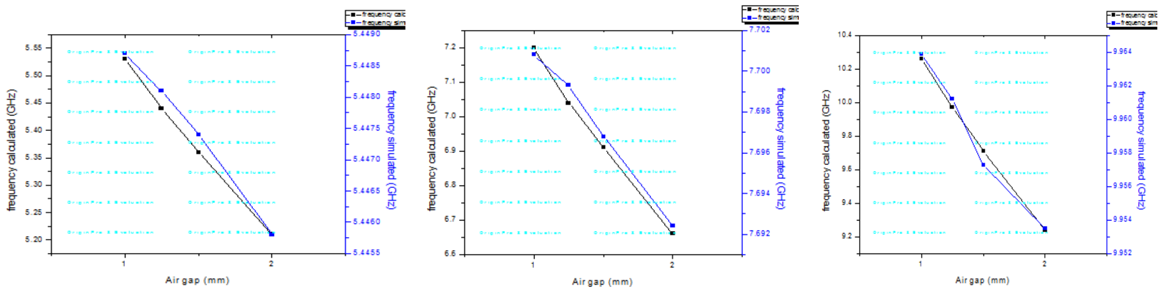

(a) (b) (c)

Figure 9. Plot of Frequency (Calculated and Simulated) vs. air gap for (a) L=20mm W=30mm (b) L=15mm W=22.5mm (c) L=10mm W=15

IV. CONCLUSION

The idea of rectangular patch microstrip antenna both with simple and inverted patch is successfully implemented and also validated with the theory**.** In TABLE I we have predicted the resonant frequency for inverted and conventional patch, drawn a comparison and verified the enhancement of bandwidth. In TABLE II, the predicted resonant frequencies for different air gap heights are compared with our measurements. Tunability of a patch as a function of air gap height is also revealed with increase in air gap height there is fall in resonant frequency we get a clear graph indicating this, and thus tunability is achieved and validated as per theory. With the help of differential feed we observed good radiation patterns, graphs for different patch dimension and air gap height. Therefore we overcame the shortcomings of the simple rectangular patch by using an inverted patch model.

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