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Gain Enhancement in Microstrip Patch Antennas by Replacing Conventional (FR-4 and Rogers) Substrate with Air Substrate

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Abstract: *The purpose of this paper is to presents the theoretical and simulation results of Rectangular, Circular and Triangular microstrip patch antennas geometry, the computed patch geometry dimensions and the achieved gain enhancement by replacing the conventional substrate with air substrate. The three patch geometries were investigated theoretically and reasonable values of resonant frequency return loss and gain are examined and compared.*

Keywords: *Microstrip antennas, air substrate antenna, improved gain microstrip antenna, antenna radiation patterns, antenna gain.*

1. INTRODUCTION

Microstrip patch antennas are of different shapes from popular rectangular, circular, and triangular, ring and any other arbitrary patch geometries are realizable though the basic geometries exhibit similar characteristic and widely used in RF applications. However they have major disadvantage of low gain and several methods has used to improve the gain of microstrip patch antenna. The resonance method [1] which involves the addition of a superstrate, increasing of gain by reduced parasitic element or a reduced surface wave [2-4]. Electromagnetic band-gap (EBG) structure has also been used [5] and introduction of air gap between the patch and ground to reduce the effective permittivity of the cavity under the patch [6-9]. This paper explored the method used by Guha et al. [9] for the estimation of gain enhancement in rectangular patch to circular and triangular patch geometry. We experimentally and comparatively investigate the three patch geometries by using FR-4 and Rogers substrates. The improvement in gain obtained in air substrate patch antennas for all the three patch geometries theoretically were experimentally verified by simulation results. Two identical patch antennas were modelled for each patch geometry with respect to each conventional substrate and their air substrate as a replaced model using CST Microwave software [10].

2. THEORETICAL CALCULATION

The gain of any antenna is directly related to its effective radiating area, A_{eff}. Therefore, in order to investigate the gain enhancement in the rectangular, circular and triangular microstrip patch antennas when the conventional dielectric substrate is replaced with air substrate, the change in the value of gain can be compared using the formula given by Guha et al. [9] as;

$$10\log\left[\frac{\left(A_{eff}/\lambda_o^2\right)_{air}}{\left(A_{eff}/\lambda_o^2\right)_{ref}}\right] \qquad (1)$$

Where A_{eff} is the effective radiating area of patch antenna and λ_o is the operating wavelength of the signal. Considering Figure 1, which comprise a rectangular patch and equivalent circular patch geometry.

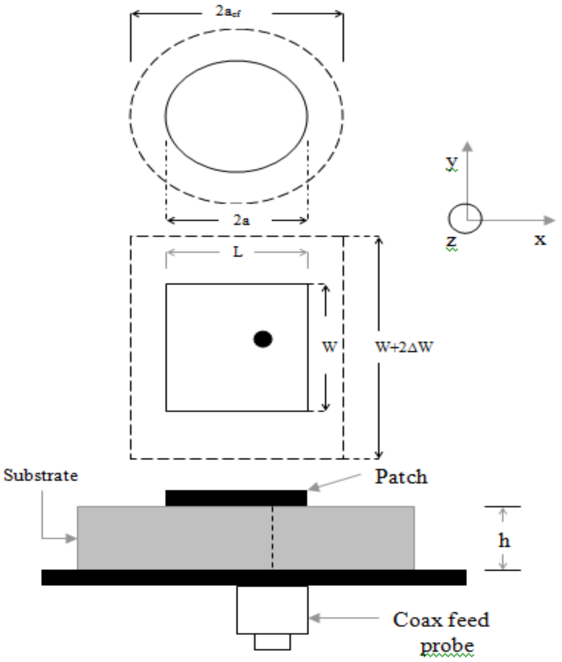

Figure1. *A schematic diagram of a rectangular patch with its equivalent circular dimension patch*

In order to compare the two geometry, its assumed that they have equal circumference.

Therefore, equating the effective circumference of the two patches in Figure 1, i.e.

$$(L + 2\Delta L) + (W + 2\Delta W) = \pi a_{eff} \tag{2}$$

Where $(L + 2\Delta L)$ and $(W + 2\Delta W)$ represents the effective length and width of the rectangular patch respectively and given by [9] as

$$\Delta L = \frac{\pi W\left(\sqrt{(1+q)}-1\right)}{2 * 1.44[2.5-0.5(W/L)]} \tag{3}$$

and

$$\Delta W = \Delta L\left(1.5 - {}^{W}/_{2L}\right) \tag{4}$$

Where q is the fringing factor given in [9] and λ_0 estimated as

$$\lambda_0 = 2(L + 2\Delta L)\sqrt{\varepsilon_{r,eff}} \tag{5}$$

The area of a circularly shaped Figure 1 is given as

$$A_{eff} = \pi {a_{eff}}^2 \tag{6}$$

Where a_{eff} is the effective radius of the circular patch given in [9] as

$$a_{eff} = a\sqrt{(1+q)} \tag{7}$$

and $\lambda_{0(c)}$, is the operating wavelength of the signal in the circular patch can be theoretically estimated as

$$\lambda_{0(c)} = {}^{1}/_{\alpha}\, 2\pi\left[a\sqrt{(1-q)}\right]\sqrt{\varepsilon_{r,eff}} \tag{8}$$

For triangular patch, assuming equilateral and equating it circumference to circular patch circumference, i.e.

$$2\pi a = 3S \tag{9}$$

where S is the side length of the equilateral triangle and from equation (9), we have

$$S = \frac{2\pi}{3} a \tag{10}$$

And effective side length is estimated as

$$S_{eff} = \frac{2\pi}{3} a\sqrt{(1+q)} \tag{11}$$

The area of an equilateral triangle is given as

$$A_{eff} = \frac{S_{eff}^2\sqrt{3}}{4} \tag{12}$$

and $\lambda_{0(t)}$ the operating wavelength of the signal is in the triangular patch can be theoretically estimated as

$$\lambda_{0(t)} = \frac{3}{2} S_{eff}\sqrt{\varepsilon_{r,eff}} \tag{13}$$

The patch antennas were modelled using FR-4 substrate ($\varepsilon_r \approx 4.4$, h ≈ 1.59 mm) and Rogers substrate ($\varepsilon_r \approx 3.48$, h ≈ 1.524 mm), these are regarded as reference antenna. When the conventional substrates (FR-4 and Rogers) were replaced with air, keeping the other parameters unaltered, and the electric fields near the edges of the patch becomes loosely bound, resulting in increased patch dimensions (effective length, width, radius and side length) in the three patch geometries, and hence increase gain.

3. RESULTS AND DISCUSSION

The numerical estimation of patch dimension for circular and triangular was based on rectangular dimension given in [9], (L = 12 mm, W = 17.73 mm) which gives circular patch radius (a) = 12.3 mm and side length (S) = 25.76 mm. A set of prototypes were modelled based on these dimension with CST Microwave studio software. For rectangular and circular patch antennas, the feed points are 2.9 mm and 3.15 mm from the patch's centre for FR-4/air and Rogers/air respectively in both geometry, and for triangular patch antennas, the feed points are 2.3 mm and 2.55 mm from the patch's centre. The enhancement of peak gain obtained computationally is compared are presented in Table 1 – 3, for rectangular, circular and triangular respectively. The simulation results obtained for resonant frequency and return loss (S_{11}) are presented in Table 4 – 6 for rectangular, while the simulation gain comparison for each patch geometry are presented in Figure 2, 3 and 4.

4. FIGURES AND TABLES

Table 1.*Rectangular patch calculated values of the effective patch dimensions and gain enhancement*.

Substrate	ΔL (mm)	ΔW (mm)	A_{eff} (mm^2)	$f_0 = c/\lambda_0$ (GHz)	A_{eff}/λ_0^2	ΔG (dB)
						Cal
Air	1.37	1.04	285.8	9.77	0.328	6.2
FR-4(4.44)	0.97	0.74	268.0	5.13	0.078	
Air	1.82	1.39	320.6	9.60	0.328	5.2
Rogers(3.48)	0.10	0.76	269.3	5.75	0.099	

Table 2. *Circular patch calculated values of the effective patch dimensions and gain enhancement*

Substrate	Δa (mm)	A_{eff} (mm^2)	$f_0 = c/\lambda_0$ (GHz)	A_{eff}/λ_0^2	ΔG (dB)
					Cal
Air	2.2	660.5	6.12	0.270	6.4
FR-4(4.44)	1.09	563.3	3.13	0.061	
Air	2.04	646.0	6.13	0.270	5.4
Rogers (3.48)	0.79	538.3	3.61	0.078	

Table3. *Triangular patch calculated values of the effective patch dimensions and gain enhancement*

Substrate	$\Delta s\ (mm)$	A_{eff} (mm^2)	$f_0 = c/\lambda_0$ (GHz)	$A_{eff}/\lambda_0^{\ 2}$	$\Delta G\ (dB)$
					Cal
Air	4.63	399.9	6.58	0.192	6.4
FR-4(4.44)	2.24	339.5	3.4	0.044	
Air	4.28	390.5	6.67	0.192	5.4
Rogers(3.48)	1.66	325.7	3.91	0.055	

Table 4. *Summary of result obtained for Rectangular patch antennas simulation*

PATCH DESIGN	SUBSTRATE	SIMULATION		
		FREQ	S_{11}	Gain (dB)
RECTANGLE	FR-4	5.39	-16.84	5.62
	AIR	10.09	-14.88	9.5
	ROGERS	6.04	-19.04	6.07
	AIR	10.26	-20.61	9.60

Table5. *Summary of result obtained from Circular patch antennas simulation*

PATCH DESIGN	SUBSTRATE	SIMULATION RESULT		
		FREQ	S_{11}	Gain (dB
CIRCULAR	FR-4	3.15	-14.44	5.59
	AIR	6.18	-13.63	9.18
	ROGERS	3.54	-18.15	5.97
	AIR	6.21	-15.13	9.37

Table 6. *Summary of result obtained from triangular patch antennas simulation*

PATCH DESIGN	SUBSTRATE	SIMULATION		
		FREQ	S_{11}	Gain (dB)
TRIANGLE	FR-4	3.39	-15.25	5.5
	AIR	6.45	-16.29	9.0
	ROGERS	3.84	-18.86	5.89
	AIR	6.47	-21.08	8.89

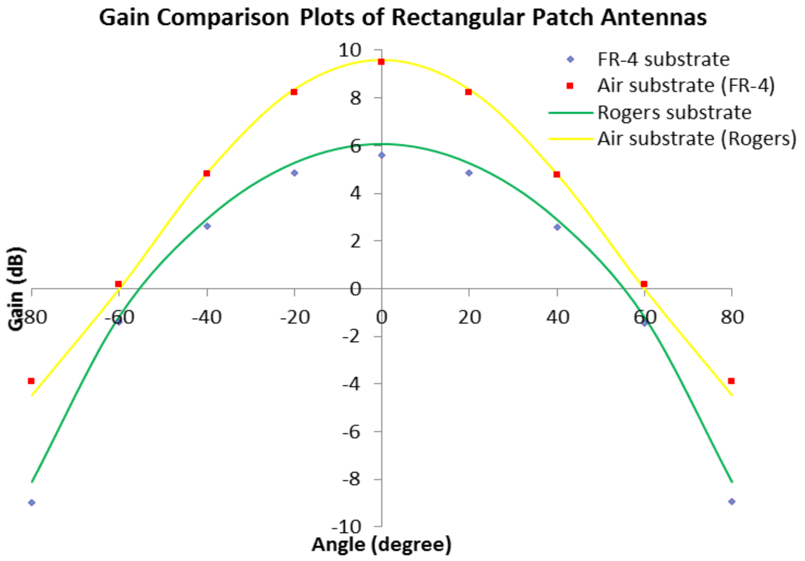

Figure 2. *Simulation Gain Comparison Plots of Rectangular Patch Antennas*

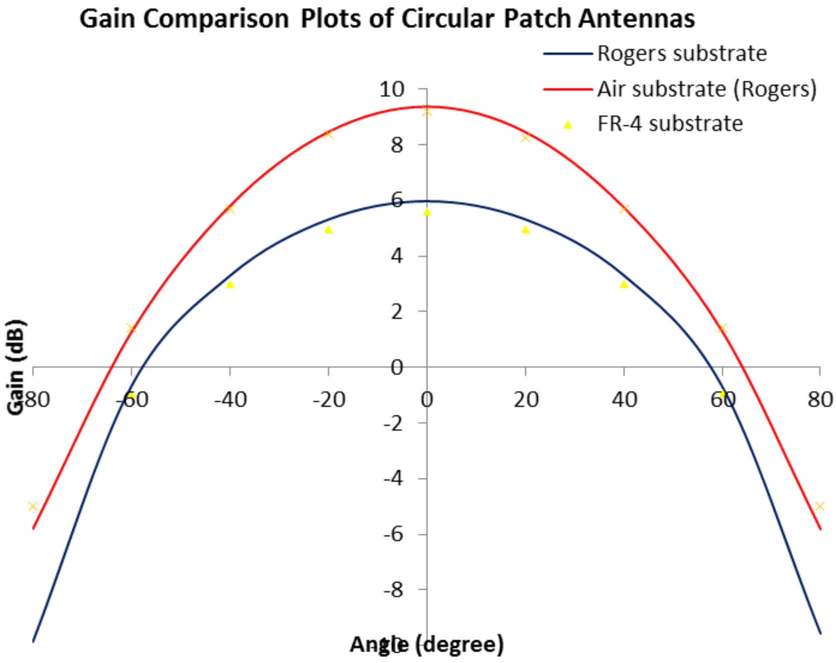

Figure 3. *Simulation Gain Comparison Plots of Circular Patch Antennas*

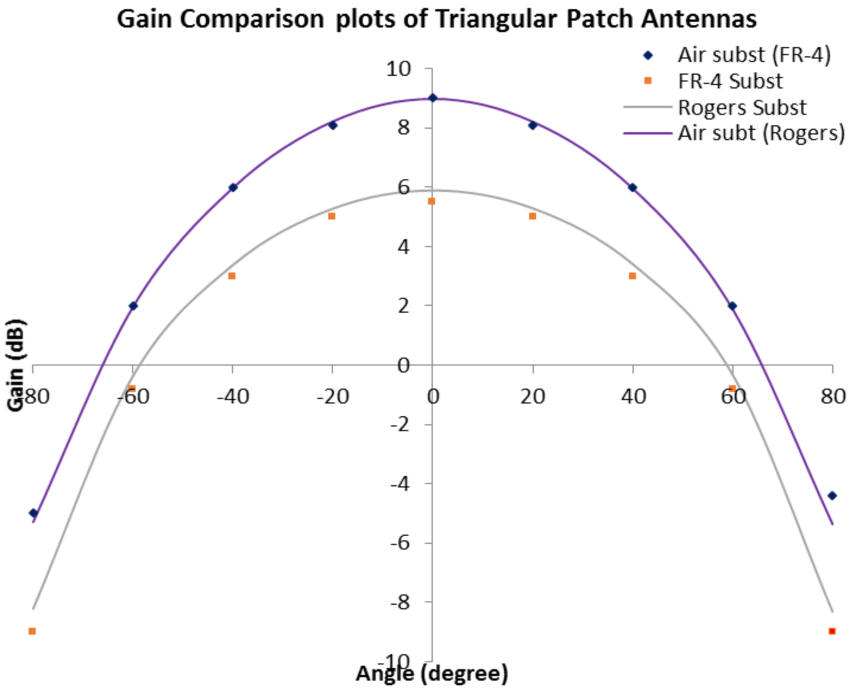

Figure 4. *Simulation Gain Comparison Plots of Triangular Patch Antennas.*

5. CONCLUSION

Numerical computation to predict the equivalent circular and triangular patch geometry from a reference rectangular patch geometry and the resultant increase in gain from this geometry when the conventional substrate is replaced with air substrate was theoretical analysed.

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