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# Gain Enhancement Evaluation in Circular Microstrip Patch with Air Substrate

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***Abstract* — An analytical method is proposed for estimating the gain enhancement and change in resonant frequency of the circular microstrip patch antenna. When dielectric substrate is replaced with air, gain enhancement is achieved in circular microstrip patch antenna. The validity of the proposed analytical model is verified over different physical dimensions of the antenna. A close agreement between the results of analytical model and that obtained using a commercial 3D electromagnetic solver is observed.**

***Index Terms* — Dielectric substrate, Gain, Circular microstrip patch, Microstrip patch.**

## I. INTRODUCTION

A microstrip patch antenna has a conducting patch on a grounded dielectric substrate. This microstrip patch antenna is used in wireless communication and in high performance application such as aircraft, spacecraft, satellite and missile. Microstrip patch antennas exhibit different characteristics based on patch shapes, resonant frequency and dielectric substrate. Normally, the gain of the microstrip patch antenna ranges from 5-7 dB. Larger gain is often desirable. It is well known that when a dielectric substrate is replaced by air, gain enhancement results. In [1], a method is presented for estimating the gain enhancement in rectangular microstrip patch antenna when PTFE substrate is replaced with air. The gain improvement was due to change in substrate properties. Chattopadhyay et al [2] examined the characteristics of rectangular microstrip patch with variable air gap theoretically and experimentally. Improved formulas were derived for rectangular microstrip patch by comparing it to an equivalent circular microstrip patch antenna. Dubey et al [3] present the radiation performance of two patch stacked microstrip antenna comprising of hexagonal and a square patches. The stacked microstrip patch is compared with a planar hexagonal patch antenna. Irregular hexagonal patch gives better performance compared to a regular hexagonal patch. A linear hexagonal array antenna integrated with MEMS switches was proposed by N. K. Saxena in [4] which operates at dual frequencies. MEMS switch are used to control or change frequency value. Hexagonal patch linear array antenna gives high directivity. A simple method to tune resonant frequency of single or stacked patch antenna is by introducing air gap. Impedance bandwidth increases due to air gap. Dehele et al has compared the theoretical and experimental results for circular-discs, annular-rings and dual-frequency stacked disc when air gaps are introduced [6]. Resonant frequency of circular microstrip patch antennas with and without air gaps was presented in [7]. Improved formulation for resonant frequency of equilateral triangle microstrip patch antenna with an air gap between ground and substrate was proposed in [8]. The results were verified theoretically and experimentally.

Only limited literature seems to be available related to microstrip patch antenna on air substrate. The case of a circular patch with dielectric and/or air substrate does not seem to have been considered till now. In this paper, estimation of gain enhancement in circular microstrip patch antenna on air substrate is obtained from analytical

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formulation and 3D simulation. The calculation is based on the determination of the effective radiating area and resonant frequency of the antenna. The gain enhancement obtained by both theoretical analysis and FEM based 3D simulator are closely agreeable.

The rest of this paper is organized as follows: Section 2 presents the analytical formulation of circular microstrip patch. Results obtained by analytical formulation and 3D simulation are indicated in section 3. Finally in section 4 conclusions are made.

## II. THEORY

The gain of the antenna is directly related to its effective radiating area $A_{eff}$. Without going into rigorous calculation for absolute gain values, the change in gain can be obtained by comparing to a ideal reference antenna using the formula [1] given by Guha et al.

$$\Delta G = 10\log_{10}\left[\frac{\left(A_{eff}/\lambda_0^2\right)_{air}}{\left(A_{eff}/\lambda_0^2\right)_{ref}}\right] \quad (1)$$

Where, $A_{eff}$ is the effective radiating area of the patch antenna and $\lambda_0$ is the operating wavelength of the signal. A coaxially fed circular microstrip patch antenna with radius a printed on a dielectric substrate ($\varepsilon_r$) is shown in Figure 1.

The derived formula to calculate effective radiating area and the wavelength are given below as

$$A_{eff} = \pi a_{eff}^{\ 2} \quad (2)$$

Where $a_{eff}$ is the effective radius of a circular microstrip patch because of fringe fields given in [2] as

$$a_{eff} = a\sqrt{(1+q)} \quad (3)$$

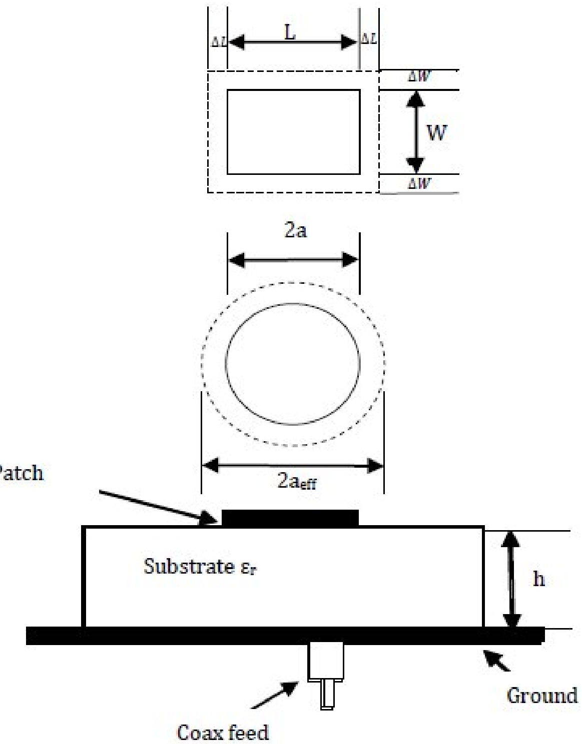


Figure 1. A coax-fed circular microstrip patch with its equivalent rectangular patch

Where $a$ is the natural radius of the circular micro strip patch and $q$ is the fringing factor calculated from [5].

$$q = u + v + uv \quad (4)$$

Where,

$$u = \frac{(1+\varepsilon_r)}{\varepsilon_r}\frac{4}{\pi a/h} \quad (5)$$

$$v = \frac{2}{3t}\frac{\ln(p)}{8+\pi a/h} + \frac{\left(\frac{1}{t}-1\right)}{g} \quad (6)$$

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$$t = 0.37 + 0.63\varepsilon_r \qquad (7)$$

| Substrate | $A_{eff}$ $(mm^2)$ | $f = c/\lambda_0$ $(GHz)$ | $A_{eff}/\lambda_0^2$ | $\Delta G\,(dB)$ | |
|---|---|---|---|---|---|
| | | | | Theoretical | Simulated |
| FR4(4.4) | 564.14 | 3.3 | 0.0613 | | |
| Air | 662.14 | 6.2 | 0.02697 | 5.8 | 5.84 |

$$p = \frac{1 + 0.8(a/h)^2 + (0.31a/h)^4}{1 + 0.9a/h} \qquad (8)$$

TABLE I. The calculated values of the effective patch dimensions and gain enhancement compared to simulated results.

$$g = 4 + 2.6a/h + 2.9h/a \qquad (9)$$

Where, $h$ is the height of the dielectric substrate and $\varepsilon_r$ is its relative permittivity.

A Patch etched on a standard FR4 ($\varepsilon_r = 4.4$, $h = 1.56\ mm$) substrate is kept as a reference antenna. Without altering any of the parameter in the antenna only FR4 substrate is replaced with substrate. Larger gain is Observed due to change in dielectric which has its impact on antenna losses.

## III. Results

The circular microstrip patch was designed with radius $a$ as 12.3 mm. The frequency of the antenna is calculated theoretically from the given value of the radius. The antenna was modeled using ANSOFT HFSS software with coaxial feeding technique to obtain the antenna's gain. The impedance matching of the antenna can be obtained by changing the position of the coax feed. The gain enhancement could be found by comparing with an antenna on air substrate for the above mentioned dimension. The gain enhancement is achieved both by theoretical calculation and simulation. The dielectric substrate used is FR4 which has the dielectric constant as 4.4 and height of the dielectric material is 1.59 mm. The theoretically computed values for effective radiating area, frequency are tabulated below. Simulated and theoretical results for gain enhancement ($\Delta G$) shows a close approximation.

The gain plot obtained for circular patch antenna with FR4 dielectric substrate and air substrate is shown in Figure 2 & 3 respectively.

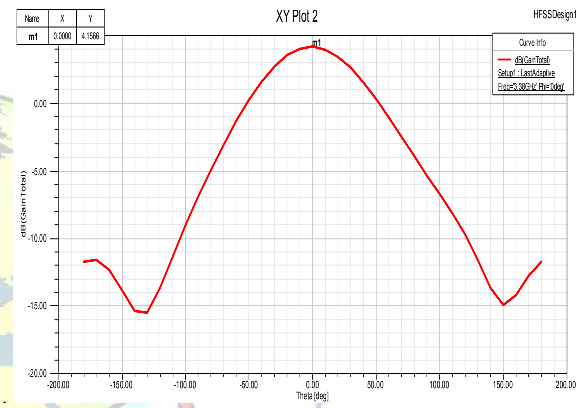


Figure 1. Gain plot for dielectric substrate circular microstrip patch antenna

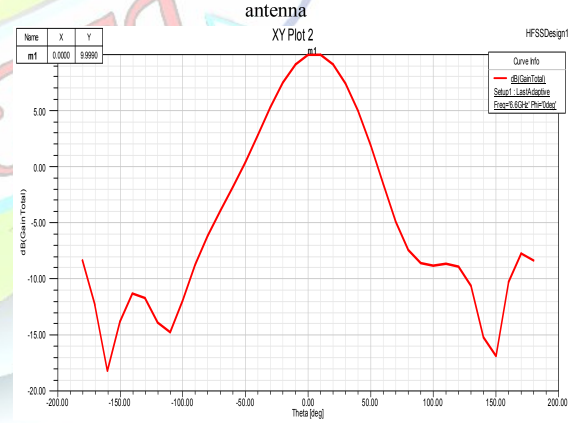


Figure 2. Gain plot for dielectric substrate circular microstrip patch antenna.

The gain enhancement of 5.8 dB is obtained.The circular microstrip patch antenna with FR4 substrate resonates at 3.3 GHz with a gain of 4.15dB. When circular microstrip patch antenna is on air substrate it resonates at a higher frequency of 6.2 GHz with 9.99 dB gain. Figure 3. Represents a plot between Dielectric constant $(\varepsilon_r)$ and gain enhancement ($\Delta G$) for a circular microstrip patch antenna. Gain

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enhancement increases as the substrate's dielectric constant increases. Gain enhancement of microstrip patch antenna is directly related to its dielectric constant.

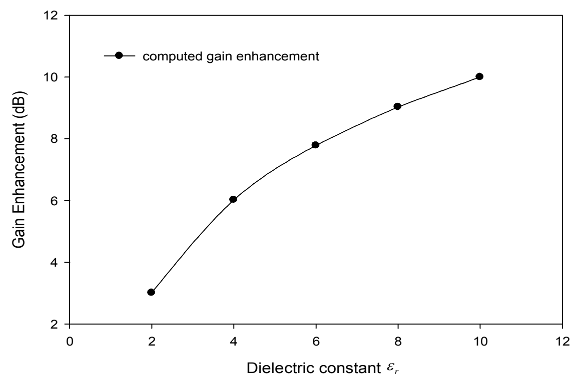


Figure 3. A plot between dielectric constant and its Gain enhancement for circular microstrip patch.

## IV. Conclusion

In this paper, gain enhancement of a conventional circular microstrip patch antenna when a dielectric substrate is replaced with air is computed and compared with 3D simulations. This gain enhancement is achieved due to reduction in dielectric loss in air substrate. This approach can be extended to any regular patch geometry.

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