Resonant Frequency of a Circular Patch Antenna (CPA) with an air gap in S and X Band

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An important analytical model is presented for the calculation of resonant frequency of a CPA with an air gap at two operating frequencies 3 and 10 GHz in S and X band range. This approach has a great degree of freedom in a sense that it is applicable to all dimensions, small to large and all shapes. The CPA with an air gap was introduced by Lee and Dahele and has been investigated for circular patch geometry.

Keywords: Microstrip antennas, Resonance frequency, Air gap.

1. INTRODUCTION

In last couple of years the application of microstrip antennas has considerably increased due to its many advantages like small size, low cost compatibility with planar and non planar surfaces, usage of print circuit technology etc. Microstrip antennas are being used in GSM and satellite communication, in aircraft, missiles and military communications. Since microstrip antennas have inherent narrow bandwidth, it becomes very important to compute the resonant frequencies accurately.

The resonant frequency of a particular mode in a microstrip antenna can be determined by shape and the size of the conducting patch on the substrate, the relative permittivity of this substrate and the height of the substrate. Lee and Dahele had shown that the resonant frequencies could be varied by the introduction of an air gap between the substrate and the ground plate [1,2,3]. Further this air gap can be varied. The effect of this introduced air gap is to reduce the effective permittivity of the cavity under the patch resulting in an upward shift in the resonant frequency. Thus, the resonant frequency can be tuned by adjusting the air gap width.

The analysis has been performed for CPA for the purpose of study of resonant frequency.

2. FORMULATION OF THE PROBLEM

Consider the CPA with an air gap of adjustable width h_1 as shown in Figure 1. One of the simplest techniques to improve the bandwidth of microstrip antenna is to introduce an air gap of adjustable width between the substrate and the ground plane [4]. The air gap has the effect of lowering the effective permittivity of the cavity under the patch, resulting in an upward shift in the resonant frequency [5]. The resonant frequency can be tuned by adjusting the air gap width and hence the bandwidth. The air gap method has several advantages along with the cost component as it has the freedom to be applied to any configuration of patch radiator and their arrays. However, the only disadvantage is the need to change the air gap mechanically since no electronic tuning is possible.

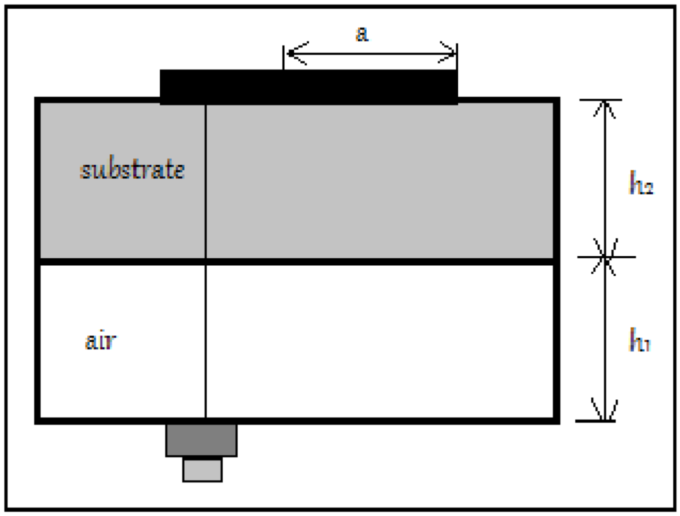

Fig. 1 : CPA with air gap.

3. COMPUTATION OF PROBLEM

Many theoretical models have been proposed for analysing microstrip antennas. The numerical models are time consuming, while analytical methods, though less accurate, enable the computation to be done with ease. For engineering applications, less accurate results are often sufficient. These results can be obtained rapidly with simple methods such as the cavity model. For the one patch microstrip antenna with an air gap the cavity under the consideration is the space between the conducting patch and the ground plane. It is therefore a two layered cavity. The top layer being the substrate of thickness 'h_2' with relative permittivity of ε_r and the bottom layer being the air gap of thickness 'h_1' with permittivity ε_o. As a result the usual assumptions of the cavity model, layers have to be modified. The modified assumptions are as follows [4].

(i) Due to close proximity between the conducting patch and the ground plane, only transverse magnetic- TM modes are assumed to exist. The z- component of the electric field is a function of z since the cavity is two layered.

(ii) The cavity is assumed to be bounded by perfect electric walls on the top and the bottom and by perfect magnetic wall along the edge.

Across the dielectric-air interface, the tangential electric field E and the normal electric flux density D are continuous.

On application of magnetic wall condition (at the physical radius “a” of the circular patch) and the conditions that the tangential E and normal D must be continuous across $z=h_1$, an expression for resonance frequency f_{nm} can be obtained which after modification by [6,7,8] has the following form:

$$f_{nm} = \frac{K_{nm} c}{2\pi a_{eff}\sqrt{\varepsilon_{dyn}}} \quad ...(1)$$

Where K_{nm} =(ka) is the mth zero of derivative of Bessels function of order n. For dominant mode TM_{11} (n=m=1), K_{11} = 1.84118, and c is the velocity of light in free space. An effective radius a_{eff} [8] in equation (1) is valid for h/a < 0.5 and ε_{re} < 10. It also accounts for the fringing fields at the edge of the CPA and is defined as

$$a_{eff} = a\left[1 + \frac{2h}{\pi\varepsilon_{re}a}\left\{log\left(\frac{a}{2h}\right) + (1.41\varepsilon_{re} + 1.77) + \frac{h}{a}(0.268\varepsilon_{re} + 1.65)\right\}\right]^{1/2} \quad ...(2)$$

Here, ε_{re} is equivalent permittivity of the structure considered and defined as

$$\varepsilon_{re} = \frac{\varepsilon_r(h_1+h_2)}{(h_2+h_1\varepsilon_r)} \quad ...(3)$$

Dynamic permittivity ε_{dyn} introduced [9] in equation (1) depends on the dimensions, the equivalent permittivity ε_{re}, and the field distribution of the mode under study and dynamic permittivity is given by

$$\varepsilon_{dyn} = \frac{C_{dyn}(\varepsilon)}{C_{dyn}(\varepsilon_0)} \quad ...(4)$$

Where $C_{dyn}(\varepsilon)$ is the total dynamic capacitance of the condenser formed by the conducting patch and the ground plane separated by a dielectric of permittivity ε. It takes into account the influence of the fringing field at the edge of the circular patch antenna (CPA) and is expressed as following for dominant mode TM_{11}.

$$C_{dyn}(\varepsilon) = \frac{\varepsilon_0\varepsilon_{re}\pi}{h}\left[0.352a^2 + \frac{a_{eff}^2}{2}\right] \quad ...(5)$$

And $C_{dyn}(\varepsilon_0)$ is the total dynamic capacitance when $\varepsilon=\varepsilon_0$ and can be obtained similarly as $C_{dyn}(\varepsilon)$ by replacing ε by ε_0.

Having selected RT/Duroid substrate with height h_2 = 0.159 cm and dielectric constant ε_r = 2.33 and operating frequency f = 3 GHz and 10 GHz, the radius of the micro strip disk element is calculated [10]. Resonant frequency is calculated from equation (1). The variation of resonant frequencies with different air gap width and antenna dimensions have been studied and tabulated in Tables 1 and 2 and carefully plotted in Figure 2. It is evident that resonant frequency indeed decreases as antenna becomes electrically thicker.

Table 1 : Resonant frequency of air gap CPA at 3 GHz.

h_1/λ	A (cm)	a_{eff} (cm)	ε_{re}	f_r (GHz)
0.0	1.904	2.03	2.33	4.099
0.005	1.973	2.138	1.899	4.104
0.01	2.074	2.278	1.679	3.853
0.02	2.178	2.456	1.455	3.575
0.03	2.219	2.569	1.343	3.419
0.038	2.229	2.631	1.286	3.338
0.04	2.231	2.65	1.245	3.314
0.05	2.227	2.714	1.229	3.236
0.06	2.213	2.768	1.197	3.174
0.07	2.194	2.815	1.172	3.122
0.08	2.173	2.859	1.153	3.074
0.09	2.149	2.899	1.138	3.031
0.10	2.123	2.938	1.125	2.991
0.11	2.097	2.976	1.115	2.953
0.12	2.071	3.014	1.106	2.916

Table 2 : Resonant frequency of air gap CPA at 10 GHz.

h_1/λ	a (cm)	a_{eff} (cm)	ε_{re}	f_r (GHz)
0	0.479	0.595	2.33	14.757
0.005	0.493	0.619	2.163	14.174
0.01	0.504	0.641	2.033	13.699
0.02	0.519	0.677	1.849	12.966
0.03	0.529	0.708	1.714	12.409
0.04	0.536	0.734	1.618	12.019
0.05	0.539	0.757	1.545	11.596
0.06	0.539	0.778	1.488	11.282

In Tables 1 and 2 h_1/λ is the height of the air gap relative to the wavelength, a (cm) is the physical radius of the patch, a_{eff} (cm) is the effective radius of the patch in cm calculated by equation (2), ε_{re} is the effective permittivity calculated by equation (3) and f_r (GHz) is the calculated resonant frequency using equation (1).

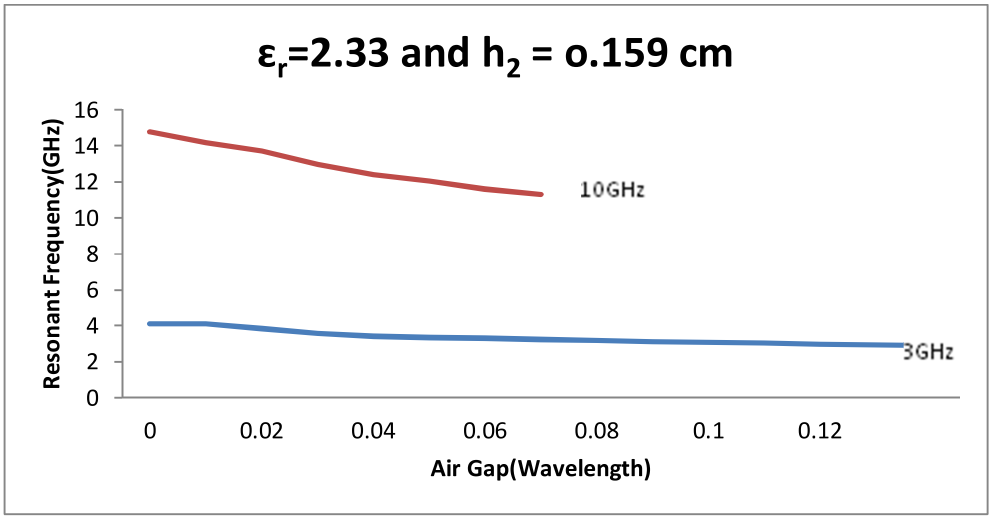

Fig. 2 : Variation of resonant frequency of CPA with air gap**.**

3. CONCLUSION

In this paper we have analyses the resonant frequency of CPA geometry with an air gap configuration in X band (3 GHz) range and X band (10 GHz) range. The antenna geometry is designed on RT Duroid substrate with height h_2 = 0.159 cm and dielectric constant ε_r = 2.33. The variation of resonance frequency with air gap width is plotted in Figure 2 for two operating frequencies. From this plot it is evident that the resonant frequency decreases with the air gap width. Hence it can be concluded that the CPA with an air gap is a good choice to be used for bandwidth enhancement.

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