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Study of Bandwidth of Airgap Circular Patch Microstrip Antenna (CPMA) in S and X Band

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Microstrip antennas have received a lot of attention in the recent years because of their potential applications in many portable communication systems. There has been significant advancement in improving the inherent narrow operating bandwidth of microstrip antennas. Use of air gap between the substrate and the ground plane is an effective and convenient approach for improving the band width. Hence, in this paper an attempt has been made to study and develop a broad band microstrip antenna by creating an air gap between the ground plane and the dielectric substrate. The analysis has been done on a circular patch in microwave frequencies range of S and X band. Effect of air gap on band width has been studied and plotted. This can conveniently be applied to the array configuration of any geometry for much larger band gap achievement.

Keywords: Microstrip antennas, Bandwidth, Airgap circular patch.

1. INTRODUCTION

Narrow bandwidth is a major disadvantage for microstrip antenna. Hence, much effort has gone into broadening the bandwidth and search for new microstrip configuration with wider bandwidth [1,2,3,4,5]. Broad bandwidth has been a dominant feature of research and much effort continues to be extended. One way to increase the bandwidth is by using multi dielectric layer. Another simple way is to introduce an airgap of adjustable width between the substrate and the ground plane. This work was started by Lee and Dhale and has been investigated for circular patch geometry. This idea of leaving an adjustable air gap width between the substrate and the ground plane has been tried to search for a solution to the existing problem. A slight increase in the resonant frequency of the air gap in the design causes a slight reduction in the effective permittivity. The resonant frequency can be tuned by adjusting the air gap width. The bandwidth will thus increase, partly due to the increase in the height of the dielectric medium and partly due to the reduced effective permittivity. Air gap method has many advantages like no addition of costly components, applicability to any configuration of patch radiator and its attraction for array applications. However, the only disadvantage is the need to change the air gap mechanically since no electronic tuning is possible. The analysis has been performed for circular patch geometry for the purpose of band width enhancement at two different operating frequencies in S and X band.

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2. FORMULATION AND COMPUTATION OF THE PROBLEM

The bandwidth of an antenna in a particular system depends upon how sever an effect the variation of an antenna characteristics with frequency has upon the overall system performance. Although in a particular situation any of the antenna parameters may prove to be critically limiting on the antenna bandwidth, in most cases it is the antenna SWR, which limits the performance. Thus, the bandwidth of an antenna for a feed line SWR≤S (S is some assumed value) from frequency f_1 to f_2 (where $f_1 < f_2$), is defined as

$$\mathrm{BW} = \frac{f_2 - f_1}{f_r} \qquad \text{... (1)}$$

Here, f_r is the resonant frequency.

At resonance, the patch input impedance is real. Let its value be R_0. When it is connected to a transmission line with characteristics impedance, Z_0, the bandwidth can be expressed as

$$\mathrm{BW} = {}^{1}/_{Q}\sqrt{{}^{(TS-1)(S-T)}/_{S}} \qquad \text{... (2)}$$

Where $T = \frac{R_0}{Z_0}$

For the antenna fed with microstrip line and uses a quarter wave transformer connected to the patch edge and for the probe fed patches, the above expression in equation (2) reduces to

$$\mathrm{BW} = \frac{1}{Q}\frac{S-1}{\sqrt{S}} \qquad \text{... (3)}$$

Both of the above matching approaches, equations (1) and (2), involve essentially a single element matching network. It turns out that neither produces the maximum bandwidth for the elementary matching. The maximum band width occurs when [6]

$$\mathrm{T} = \frac{1}{2}\left(S - \frac{1}{S}\right) \qquad \text{... (4)}$$

To realize this value of T, the patch is matched to the impedance, R_0/T. This introduces a mismatch to the feed line whose impedance is Z_0. The patch is thus, perfectly matched at one frequency, i.e. its resonant frequency. The SWR is very good in and around the resonant frequency but rapidly degrades as the frequency moves away from resonance. The mismatch introduced by equation (4) means the match is not as good at resonance but is better for frequencies remote from resonance. The previous techniques place all of it at the resonant frequency to create a perfect match; equation (4) “spreads” a poorer but still acceptable match over a band of frequencies. The bandwidth obtained when equation (4) is satisfied is given by

$$\mathrm{BW} = \frac{1}{\mathrm{Q}}\frac{\sqrt{\mathrm{S}^4-1}}{\mathrm{S}} \quad \text{... (5)}$$

When maximum SWR is 2:1, the bandwidth becomes = 1/Q. Wide bandwidth could be obtained using more sophisticated matching approaches. The maximum attainable bandwidth for a given SWR is [6].

$$\mathrm{BW_M} = \frac{1}{\mathrm{Q}}\frac{\pi}{\ln[(\mathrm{S}+1)(\mathrm{S}-1)]} \quad \text{... (6)}$$

Whereas optimum matching network is a filter that “absorbs” the reactive part of the patch impedance into the structure.

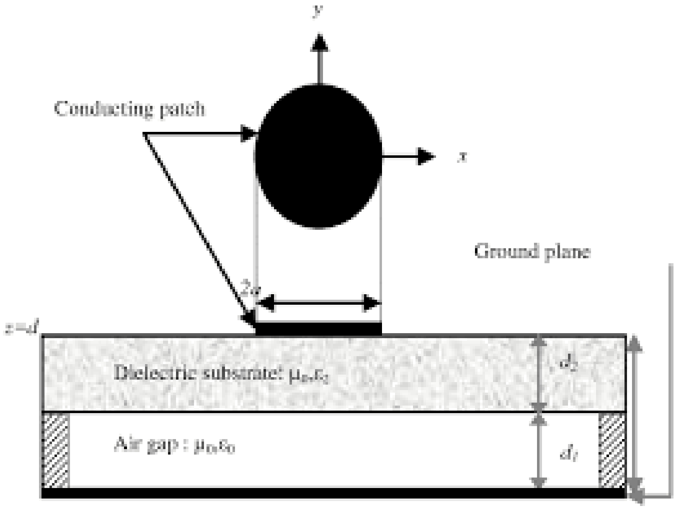

Fig. 1: Circular patch micro-strip antenna (CPMA) with an air gap.

The geometry and coordinate system of circular patch micro strip antenna (CPMA) with an air gap between the substrate and the ground plane is shown in Figure 1. For one patch micro strip antenna with an air gap the cavity under 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 ‘d_2’ with relative permittivity ε_r and the bottom layer being the air gap of thickness ‘ d_1’ with permittivity ε_0.

On application of the magnetic wall condition at ‘a’ (the physical radius of the circular patch) and the condition that the tangent electric field E and the normal electric flux density D must be continuous across $z=d_1$. Like all resonators, electric and magnetic energy is stored in the cavity. Power is dissipated in the walls because of finite conductivity of the metal and in any dielectric because of loss mechanism in them. Thus antenna quality factor Q_T is associated with the system losses, including radiation losses

Q_r, dielectric losses Q_d and conductor losses Q_c. The expression for the quality factor may be written as follows

$$\frac{1}{\mathrm{Q_T}} = \frac{1}{\mathrm{Q_d}} + \frac{1}{\mathrm{Q_c}} + \frac{1}{\mathrm{Q_r}} \quad \text{... (7)}$$

$$\mathrm{Q_d} = \varpi \frac{energy\ stored}{average\ power\ dissipated} = \frac{1}{(tan\delta)_{re}} \quad \text{... (8)}$$

$$Q_c = \varpi \frac{energy\ stored}{power\ loss\ due\ to\ conductor\ losses} = d(\pi f \mu \boldsymbol{\sigma})^{\frac{1}{2}} \quad \text{... (9)}$$

Where $d=d_1+d_2$ and σ=conductivity of the patch metal

$$\mathrm{Q_r} = \frac{4a(K_{11}^2 - 1)\epsilon_{re}^{3/2}}{dK_{11}^3 F(K_{11/\sqrt{\epsilon_{re}}}} \quad \text{... (10)}$$

Where K_{nm} = ka is the mth zero of derivative of Bessel's function of order n. For dominant mode TM_{11} (n=m=1), K_{11}= 1.84118

$$F(X) = 2.666667378 - 1.066662519X^2 + 0.209534311X^4$$
$$-0.019411347X^6 + 0.001044121X^8 - 0.000049747X^{10} \quad \text{... (11)}$$

Thus after the careful determination of Q_d, Q_c and Q_r the improved bandwidth is obtained through equation (2) to (7). The antenna geometry is designed on RT Duroid substrate with height d_2 = 0.159 cm and dielectric constant ε_r = 2.33. The bandwidth of CPMA with air gap 'd_1' has been computed at two frequencies 3 GHz and 10 GHz and tabulated in Table 1 and in Table 2 respectively. The variation of the bandwidth with the air gap has been studied and plotted in Figure 2.

Table 1 : Study of bandwidth of a CPMA with the variation on air gap at 3 GHz.

d_1/λ	**a (cm)**	**Q_T**	**BW (%)**
0.0	1.904	40.879	0.998
0.02	2.178	17.987	2.269
0.04	2.231	11.638	3.508
0.06	2.213	8.458	4.827
0.08	2.173	6.462	6.317
0.12	2.071	4.393	9.293
0.13	2.044	4.035	10.112

Table 2 : Study of bandwidth of a CPMA with the variation of air gap at 10 GHz.

d_1/λ	a (cm)	Q_T	BW (%)
0.00	0.479	10.788	3.784
0.01	0.504	8.933	4.57
0.02	0.519	7.645	5.339
0.03	0.529	6.684	6.108
0.04	0.536	5.931	6.883
0.05	0.539	5.322	7.671
0.06	0.539	4.818	8.473

In Tables above, d_1/λ is the air gap height relative to the wavelength used, a (cm) is the physical radius of the patch, Q_T is the antenna total quality factor determined using equation (7) and BW (%) is the percentage bandwidth calculated using equation (5).

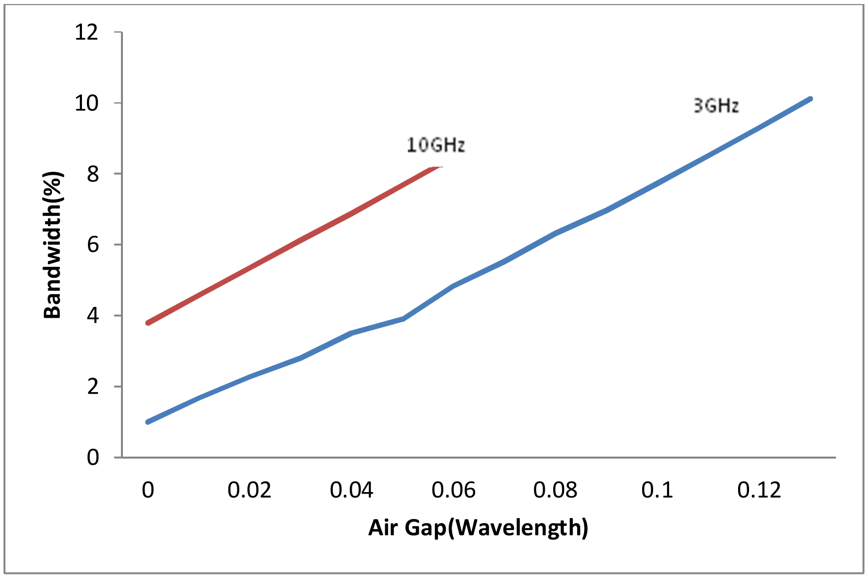

Fig. 2 : Variation of bandwidth of CPMA with air gap.

3. CONCLUSION

In this paper we have analysed CPMA for bandwidth enhancement using the air gap configuration in S and X band of microwave range. On analysing the results we have noticed a considerable enhancement of bandwidth on varying air gap height. The bandwidth obtained is 8.473% for f = 10 GHz, d_1 = 0.06 Å and 10.112% for f = 3 GHz, d_1 = 0.13 Å. From Table 1 and Table 2 and Figure 2, we observe that the bandwidth increases linearly with air gap width. The antenna geometry is designed on RT Duroid substrate with height d_2 = 0.159 cm and dielectric constant ε_r = 2.33. Thus we conclude that the air gap CPMA can be utilized for bandwidth enhancement while retaining most of the desired electrical characteristics.

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