Vol. 3 Issue No.2, April – June 2021 e-ISSN 2456-7701
Journal of Science and Technological Researches
A Peer Reviewed Journal
Origin of Innovation
Domain: www.jstr.org.in, Email: editor@jstr.org.in

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Date of Received	**21 May, 2021**
Date of Revised	**10 June, 2021**
Date of Acceptance	**26 June, 2021**
Date of Publication	**30 June, 2021**

DOI : https://doi.org/10.51514/JSTR.3.2.2021.48-51

To link to this article: http://jstr.org.in/downloads/pub/v3/i2/9.pdf

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ABSTRACT

The microstrip antenna with an air gap was introduced by Lee and Dahele and has been investigated for HPMA. The antenna consists of a hexagonal patch where an air gap also exists between the ground plane and the substrate below the hexagonal patch radiator. The recent years have seen a huge development in low cost compact antennas for communications purpose. This is where the microstrip antenna shines due to its light weight and compact size and capable of giving good radiation characteristics over a wide range of frequencies. We have investigated HPMA for various radiation characteristics at two operating frequencies in S and X band range.

Keywords: *Microstrip Antennas, Air Gap, Hexagonal Patch, Radiation Properties*

INTRODUCTION

The idea of microstrip emerged in 1953 and was patent in 1955. It began to gain interest in 1970s. Microstrip antennas consists of planar resonant radiating element parallel to, but separated from a ground plane by a thin dielectric substrate (t<<ʎ). The radiating elements together with the feed lines are easily photo etched on a thin dielectric sheet on a ground plane. The element may be a simple resonant dipole or a patch or a printed array of patches of any shape – here we have used a hexagonal shape. The HPMA offer performance similar to that of a rectangular geometry however, in some applications such as arrays, HPMA geometries offer certain advantages over other configurations [10-13]. It tends to be slightly smaller than the rectangular patches and thus could be a candidate when space is limited. HPMA also lackthe preferred axis (i.e. there is no length or width). The feed as can be seen in Fig 1. can be placed anywhere instead of just along the length.

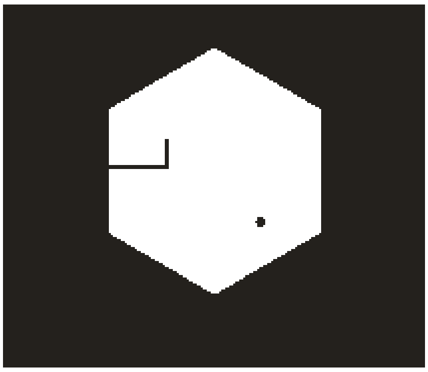

Fig 1. Top view of HPMA

Use of air gap between the substrate and the ground plane is that the effective permittivity is lowered resulting in the upward shift of resonance frequency [1,2,3]. Hence the band width increases due to this reduced effective permittivity and also due to the increased overall height of the dielectric. The air gap method has advantage as it has no additional cost and its application to any configuration and to arrays.

Formulation and computation of the problem

The configuration of air gap HPMAis shown in Fig 2. It is a two–layer cavity.The upper layer is the dielectric substrate of thickness h and relative permittivity of ε_r and the lower layer is an air gap of thickness Δ with permittivity equal to one. For the purpose of computation, we can consider it as an equivalent single layered structure of total height H = (h + Δ)

$\varepsilon_{re} = \frac{\varepsilon_r(\Delta+h)}{(\Delta+h\varepsilon_r)}$ (1) The HPMA with air gap is assumed to be a resonant cavity with perfect conducting side walls. As the circular disk is a limiting case of a polygon with large number of sides, the resonant frequency for the dominant as well as for the higher order may be calculated through Eqn. 2 by replacing 'a' by equivalent radius a_{eq}.

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

The equivalent radius a_{eq} is determined by comparing areas of hexagon and a circular disk of radius a_{eq}.

Thus, a_{eq} = 0.9094 S, where S is one side of the hexagonal patch radiator. Hence, the modified Eqn. for resonant frequency is as follows:

$$f_{nm} = \frac{1.1K_{nm}c}{2\pi S\sqrt{\varepsilon_{dyn}}} \quad \ldots(3)$$

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e-ISSN 2456-7701
Vol. 3 Issue No.2, April – June 2021

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} [5] is valid for h/a < 0.5 and ε_{re}< 10.

$$a_{eff} = a\left[1+\frac{2h}{\pi\varepsilon_{re}a}\left\{log\left(\frac{a}{2h}\right)+(1.41\varepsilon_{re}+1.77)+\frac{h}{a}(0.268\varepsilon_{re}+1.65)\right\}\right]^{1/2} \quad ...(4)$$

Dynamic permittivity ε_{dyn} [6] is given by

$$\varepsilon_{dyn} = \frac{C_{dyn}(\varepsilon)}{C_{dyn}(\varepsilon_0)} \quad ...(5)$$

$C_{dyn}(\varepsilon)$ is the total dynamic capacitance of the condenser formed by the conducting patch and the ground plane separated by a dielectric of permittivity ε. Fordominant mode TM_{11}

$$C_{dyn}(\varepsilon) = \frac{\varepsilon_0\varepsilon_{re}\pi}{h}\left[0.352a^2+\frac{a_{eff}^2}{2}\right] \quad ...(6)$$

and $C_{dyn}(\varepsilon_0)$ is obtained by replacing ε by $\varepsilon_0$in$C_{dyn}(\varepsilon)$.

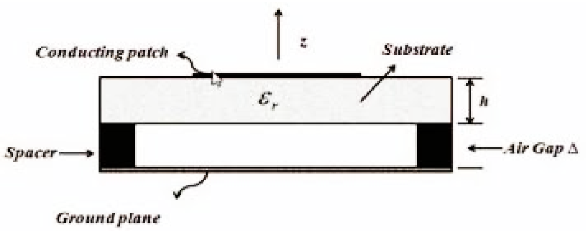

Fig 2. HPMA with an air gap

HPMA can be analysed by many methods. However, we have used cavity model with some modifications as under for predicting adequately the radiation and other characteristics.

1. 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.
2. 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.
3. Across the dielectric-air interface, the tangential electric field E and the normal electric flux density D are continuous.

Fields of two layeredcavities:

Based on above assumptions the fields of TM mode at a point (ρ,ϕ,z) satisfying the electric wall conditions at z=0 and z=H=(h+Δ) are as follows [4]

In the dielectric layer:

$$E_{z1} = C_1J_n(k_1\rho)cosn\varphi cos[\beta(H-z)] \quad ...(7)$$

$$E_{\rho1} = C_1\beta k_1^{-1}J_n'(k_1\rho)cosn\varphi sin[\beta(H-z)] \quad ...(8)$$

$$E_{\varphi1} = -C_1n\beta\rho^{-1}k_1^{-2}J_n(k_1\rho)sinn\varphi sin[\beta(H-z)] \quad ...(9)$$

$$H_{\rho1} = -C_1j\omega\varepsilon n\rho^{-1}k_1^{-2}J_n(k_1\rho)sinn\varphi cos[\beta(H-z)] \quad ...(10)$$

$$H_{\varphi1} = -C_1j\omega\varepsilon k_1^{-1}J_n'(k_1\rho)cosn\varphi cos[\beta(H-z)] \quad ...(11)$$

where $k_1^2 = \omega^2\mu_0\varepsilon-\beta^2$ ...(12)

in air gap

$$E_{z2} = C_2J_n(k_2\rho)cosn\varphi cos\beta_0z \quad ...(13)$$

$$E_{\rho2} = -C_2\beta_0k_2^{-1}J_n'(k_2\rho)cosn\varphi sin\beta_0z \quad ...(14)$$

$$E_{\varphi2} = C_2n\beta_0\rho^{-1}k_2^{-2}J_n(k_2\rho)sinn\varphi sin\beta_0z \quad ...(15)$$

$$H_{\rho2} = -C_2j\omega\varepsilon_0n\rho^{-1}k_2^{-2}J_n(k_2\rho)sinn\varphi cos\beta_0z \quad ...(16)$$

$$H_{\varphi2} = -C_2j\omega\varepsilon_0k_2^{-1}J_n'(k_2\rho)cosn\varphi cos\beta_0z \quad ...(17)$$

where $k_2^2 = \omega^2\mu_0\varepsilon_0-\beta_0^2$ ...(18)

Input impedance and radiation resistance:

Impedance is a prime determining factor in the amount of power transferred from the component to its associated circuitry and vice versa. However, in case of an antenna we must know how well the energy is coupled between the free space and the transmission line. Hence it becomes extremely important to study the impedance.

The HPMA is a resonant cavity, modelled by single resonant parallel L-C-R circuit. Taking f_r as resonant frequency, the input impedance is expressed as

$$Z(f) = \frac{R(\rho)}{1+Q_T^2\left[\frac{f}{f_r}-\frac{f_r}{f}\right]^2}+j\left[X_L-\frac{R(\rho)Q_T\left[\frac{f}{f_r}-\frac{f_r}{f}\right]}{1+Q_T^2\left[\frac{f}{f_r}-\frac{f_r}{f}\right]^2}\right] \quad ...(19)$$

R(ρ) is the input resistance at resonance and Q_T is the quality factor associated with dielectric (Q_d), conductor (Q_c) and radiation (Q_r) losses of the system.

$$\frac{1}{Q_T} = \frac{1}{Q_d}+\frac{1}{Q_c}+\frac{1}{Q_r} \quad ...(20)$$

$$Q_d = \omega = \frac{1}{(tan\delta)_{re}} \quad ...(21)$$

$$Q_c = H(\pi f\mu\sigma)^{\frac{1}{2}}(22)$$

Where σ=conductivity of the patch metal

$$Q_r = \frac{4a(K_{11}^2-1)\epsilon_{re}^{3/2}}{dK_{11}^3F(K_{11}/\sqrt{\epsilon_{re}}} \quad ...(23)$$

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

$-0.019411347X^6+0.001044121X^8-0.000049747X^{10}$ ...(24)

At resonance, the input impedance of HPMA is real. If the HPMA is fed at an arbitrary point (ρ_0,0,0) the resistance at romance is

$$R(\rho) = \frac{1}{G_T}\frac{J_1^2(k\rho_0)}{J_1^2(ka)} \quad ...(25)$$

Where J_1 is Besell's function of order one, k is propagation const. The fundamental mode corresponds to ka equal to K_{11} as 1.84118 and G_T total conductance that includes dielectric, omic and radiation losses.

$$G_T = G_d + G_c + G_r \quad ...(26)$$

$$G_d = \frac{2.39tan\delta}{4\mu_0 f_r H} \quad ...(27)$$

$$G_c = \frac{2.39(\pi f_r \mu_0 \sigma)^{-1/2}}{4\mu_0 f_r H^2} \quad ...(29)$$

$$G_r = \frac{2.39}{4\mu_0 f_r H Q_r} \quad ...(30)$$

The series inductive reactance due to coax-fed probe of diameter d_0 is expressed as

$$X_L = \frac{377\,fh}{c} log\left[\frac{c}{f\pi d_0\sqrt{\varepsilon_{re}}}\right] \quad ...(31)$$

HPMA efficiency is defined as

$$\eta\% = \frac{G_r}{G_T}\text{x}100 \quad ...(32)$$

Radiation resistance is calculated from $R_r = \frac{960}{(ak_0)^2 I_1}$ ...(33)

Where

$$I_1 = \int_0^{\pi}\{[J_{n+1}(k_0 asin\theta) - J_{n-1}(k_0 asin\theta)]^2 + cos^2\theta[J_{n+1}(k_0 asin\theta) + J_{n-1}(k_0 asin\theta)]^2\}\,sin\theta d\theta \quad (34)$$

Directivity[7,8]is the measure of the ability of an antenna to concentrate energy in a preferred direction and is expressed as

$$D = \frac{8}{I_1} \quad ...(35)$$

The gain G_g of the antenna is closely related to directivity.

$$G_g = \eta D \quad ...(36)$$

Important antenna parameters of air gap HPMA for two microwave frequencies 3 GHZ and 10 GHz at different air gap width have been calculated and tabled in Table 1 and 2 respectively.

Table 1: Antenna parameters of air gap HPMA at 3 GHz

Δ/λ	**S(cm)**	**R_r(ohms)**	**D(dB)**	**G_g(dB)**
0.00	2.112	439.241	7.267	7.006
0.02	2.672	374.522	8.618	8.524
0.04	2.855	363.909	9.068	9.013
0.06	2.947	359.388	9.289	9.249
0.08	3.002	356.796	9.418	9.388
0.10	3.038	355.088	9.503	9.478
0.12	3.065	353.87	9.563	9.543
0.14	3.084	352.955	9.608	9.59
0.16	3.009	352.239	9.642	9.627
0.18	3.112	351.665	9.669	9.656

Table 2: Antenna parameters of air gap HPMA at 10 GHz

Δ/λ	**S(cm)**	**R_r(ohms)**	**D(dB)**	**G_g(dB)**
0	0.634	547.277	8.222	8.146
0.01	0.678	414.916	7.612	7.563
0.02	0.712	400.579	7.883	7.842
0.03	0.739	391.281	8.099	8.064
0.04	0.760	384.82	8.276	8.245
0.05	0.778	380.092	8.422	8.395
0.06	0.793	376.485	8.546	8.521
0.07	0.806	373.643	8.651	8.628
0.08	0.817	371.393	8.742	8.721
0.09	0.826	369.439	8.820	8.801
0.10	0.835	367.836	8.889	8.872

CONCLUSION

Imprroved formulae for input impedance for air gap HPMA have been obtained. These exptesions are very much required for the efficient transfer of energy between the free space and the transmission line. Expressions have been derived using cavity mode along with model expension model and equivalent LCR circuit. Various important parimeters like radiation resistance, directivity and gain have been studied at various air gaps for HPMA at two frequencies 3GHZ and 10GHz and have been tabulated in Tables 1 and2. Air gap HPMA is designed on RT Duroid substrate with ε_r=2.33 and h=0.159cm and loss tangent, tanδ=0.00066. The radiation propertiessuch as radiation resistance, gain and directivity of the air gap HPMA have been studied. The proposed antenna has compact dimensions and suitable for wireless communication. Further using arreys geometries further improvement in gain and other parameters can be obtained [9].

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