CO-AXIAL FEED TO CIRCULAR PATCH : A PARAMETRIC STUDY

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ABSTRACT

Feeding mechanism plays an important role in the design of microstrip patch antennas. A microstrip patch antenna can be fed either by coaxial probe or by an inset microstrip line. Coaxial probe feeding is sometimes advantageous for applications like active antennas, while microstrip line feeding is suitable for developing high gain microstrip array antennas. In this paper, the effects of feeding at different location in the patch has been presented for analysis of impedance match by using Antenna Magus Electromagnetic Simulating Software.

Key Words: *Microstrip antenna, co-axial feed, input impedance of the patch*

1. INTRODUCTION

The microstrip patch antenna is one of the simplest radiating structures that can be built using printed circuits. Single patch antennas and patch antenna arrays are widely used in communication systems and airborne applications because of their light weight, precise reproduction through photolithographic techniques, conformal properties, suitability to integrate with active circuits, and low cost. Although the microstrip patch antenna is not the best in terms of electrical properties, it is the preferred structure used for radiation in the vast majority of low-cost applications because of its unique properties.

Modern communication systems demand for low cost and low profile antennas.Microstrip patch antenna is one of the candidate antennas meeting those requirements due to its conformal nature and capability to integrate with the rest of the printed circuitry.

Analysis

The input impedance behavior for coaxial probe fed patch antenna is well studied analytically using Transmission Line Model, Cavity model and Full wave analysis [2, 3,4].

For coaxial feeds, the location is usually selected to provide a good impedance match. We investigate the effect of its location on the excitation efficiency of various modes [1]. Also, different modes have different radiation patterns and affect the overall antenna pattern at different angular regions. The fig 1 shows the effect of the feed position S_f on the excitation of the first three modes, when the patch is resonant at the TM_{11} mode. The dominant mode has the strongest excitation efficiency of the other modes, i.e. TM_{01} and TM_{21} modes, increase progressively as the feed moves to the patch edge, but their peak radiation level is always below - 15 dB. The results also show that increasing the substrate height generally increases the excitation efficiency in other modes.

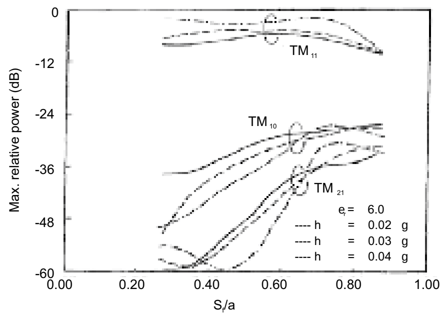


Fig.1 The effect of the feed position on the excitation efficiency of TM_{11} mode after the variation of height of the substrate.

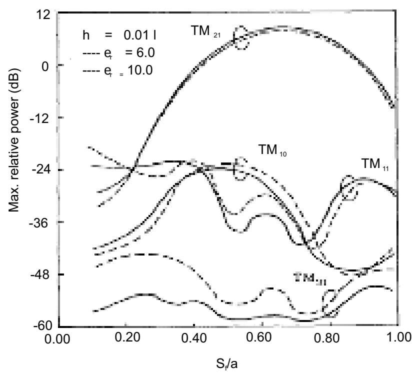


Fig.2 The effect of the feed position on the excitation efficiency of TM_{11} mode after the variation of di-electric constant.

The excitation efficiencies for a patch dominant at the TM_{21} mode are shown in Fig. 2. The results are plotted for two different substrate permittivities, and show similar excitations. Again the dominant mode has the strongest excitation and decreases thereafter but its peak radiation increases for $S_f > 0.68a$ (a is the radius of the circle) and decreases thereafter. The peak radiations of the other modes have more complex behavior and minimize $S_f = 0.75a$ and their contribution are below -25 dB range [1].

Fig.1 and 2 indicate that the resonance nature of a microstrip patch controls the excitation of the azimuthal modes, and the resonant modes can easily be excited significantly above the adjacent modes simply by selecting an appropriate location for the feed. With this type of excitation the contributions of the adjacent modes manifest themselves mainly in the cross-polarisation. They may be ignored if the antenna cross-polarization is not the main concern. Also, the substrate permittivity seems to have a small effect on the mode excitation.

The cavity model is a bidimensional model that can be applied to patches whose geometries are specified simply by curvilinear orthogonal coordinate systems (circular, rectangular, etc.). It is possible to consider either the dominant mode or the complete spectrum of modes. The circular microstrip patch antenna can be considered in the fundamental mode, modeled by a simple resonant parallel RLC circuit . To take the coax-feed probe into account, it is necessary to modify the input impedance by an inductive term[15] :

$$X_L = [(377.f.H)/c_o]\ \mathrm{Ln}\ [(c_o/(\pi.f.d_o\sqrt{\varepsilon_r})] \qquad \text{......................(1)}$$

Where c_o is the velocity of light in vacuum and d_o is the diameter of the probe. All expression presented hereafter are valid for the dominant mode. The input impedance is then obtained as [12] :

$$Z(f) = [R(\rho)/\{1+ Q_T^2(f/f_R - f_R/f)\}]$$

$$+J[X_L\{R(\rho).\ Q_T.\ (f/f_R - f_R/f)\}/ \{1+ Q_T^2(f/f_R - f_R/f)\}] \qquad \text{...................(2)}$$

Where (Q_T) is the quality factor associated with system losses and $R((\rho)$ is the input resistance at the resonance (the resistance R of the R-L-C circuit). Q_T includes radiation losses Q_R, dielectric losses Q_D and conductor losses Q_C [12] :

$$1/Q_T = [1/Q_R + 1/Q_C + 1/Q_D]^{-1} \qquad \text{..........................(3)}$$

1- QR has the following form of expression by Bahl

$$Q_R = [4.a.(\alpha_{11}^2 - 1).\ \varepsilon_r^{3/2}] / [H.a^3.F(\alpha_{11}/\sqrt{\varepsilon_r})] \qquad \text{..................(4)}$$

Where F(X) is given by the following

expression with the help of the development of Bessel function J_0 [17]

$$F(X) = (4/X^3)\{2.X.J_0(2X) + (X^2-1)\int J_0(t)dt\}$$

………………(5)

$$F(X) = [2.66667378-1.066662519X^2 +0.209534311X^4-0.019411347X^6+ 0.001044121X^8- 0.000049747X^{10}]$$

………………………..(6)

2 The dielectric losses have been obtained by [18] :

$$Q_D = 1/(\tan\delta)$$

……………(7)

Where (tan δ) is the dielectric loss tangent.

3 The losses in the conductor can be obtained by[18-19] :

$$Q_C = H/\delta_s,\ \delta_s = (\pi . f. \alpha_0.\sigma)^{-1/2}$$

…………….(8)

δ_s is the skin depth where σ is the conductivity of the conductor and μ_0 is the permeability of the dielectric. R(ρ) is the resonant resistance of the resonant parallel R-L-C circuit [12] which is given by :

$$R(\rho) = (1/G) . \{ J_1^2(K.\rho)/ J_1^2(K.a)\}$$

……………(9)

Where ρ is the feed position referred to the center of the disc of radius a. K is the propagation constant. The fundamental mode corresponds to K.a equal to α_{11} as 1.84118 and G_T includes the conductances due to ohmic, dielectric and radiation losses :

$$G_T = G_R+G_D+G_C$$

……………..(10)

1 The conductance due to radiation losses is given by [19] :

$$G_R = (2.39)/(4. \alpha_0. H. f_R.. Q_R)$$

……………………..(11)

2 The conductance due to dielectric losses is given by [20] :

$$G_D = \{(2.39). (\tan\delta)\}/(4. \alpha_0. H. f_R)$$

………………………(12)

3 The conductance due to ohmic losses is given by [20] :

$$G_C = \{2.39 . \pi. (\pi . f. \alpha_0)^{-3/2}\} / \{4.H. \sqrt{\sigma}\}$$

……………(13)

The Bessel function of order one, J_1, is expanded in terms of polynomial [9] , for 3 < t < 3 :

$$J_1(t) = t (0.5)- 0.56249985 (t/3)^2 + 0.21093575 (t/3)^4 - 0.03954289 (t/3)^6 + 0.00443319 (t/3)^8 - 0.0031761 (t/3)^{10}$$

……………(14)

An improved formulation is derived for the resonant frequency [13] of the TM modes in a circular microstrip antenna given by :

$$f_{r,nm} = (\alpha_{nm} . c_0)/ \{2\pi. a_{eff}. \sqrt{\varepsilon_{r,eff}}\}$$

……………(15)

Where α_{nm} is the m_{th} zero of the derivative of the Bessel function of order n , the dominant mode is the TM_{11} (n = m =1). For this mode, α_{11} =1.84118. c_0 is the velocity of light in vacuum, a_{eff} is the effective radius of circular patch defined through [16], and $\varepsilon_{r,eff}$ is defined as :

$$\varepsilon_{r.eff} = \frac{4\varepsilon_r \cdot \varepsilon_{r,dyn}}{\left(\sqrt{\varepsilon_r}+\sqrt{\varepsilon_{r,dyn}}\right)^{2}} \quad \ldots\ldots(16)$$

The term ε_{reff} is introduced to take into account the effect of ε_r in combination with the dynamic dielectric constant $\varepsilon_{r,dyn}$ [14] to improve the model. ε_{reff} is deduced as [16] to yield the resonant frequency as an average of the frequencies resulting from (15) by substituting ε_r and $\varepsilon_{r,dyn}$ separately in place of $\varepsilon_{r,eff}$. $\varepsilon_{r,dyn}$ is a function of the static main and static fringing capacitances and the mode of resonance as given by [22] :

$$\varepsilon_{r,dyn} = \frac{C_{dyn}(\varepsilon = \varepsilon_0\varepsilon_r)}{C_{dyn}(\varepsilon = \varepsilon_0)} \quad \ldots\ldots\ldots\ldots(17)$$

$C_{dyn\,(\varepsilon)}$ can be written [22] as

$$C_{dyn}(\varepsilon) = C_{0.dyn}(\varepsilon) + C_{e,dyn}(\varepsilon) \quad \ldots\ldots\ldots\ldots\ldots(18)$$

$C_{0,dyn}(\varepsilon)$ is the dynamic main capacitance of the dominant mode TM_{11} related to the static main capacitance $C_{0,stat}$ of the patch without considering the fringing field. It is given by [22]

$$C_{0.dyn}(\varepsilon) = 0.3525\, C_{0.stat}(\varepsilon) \quad \ldots\ldots\ldots\ldots\ldots(19)$$

$C_{e,dyn}(\varepsilon)$ represents the dynamic fringing capacitance of the dominant mode given by [22]

$$C_{e,dyn}(\varepsilon) = \frac{1}{2} C_{e.stat}(\varepsilon) \quad \ldots\ldots\ldots\ldots\ldots(20)$$

A comparatively recent formulation for the static capacitance of a circular microstrip disc obtained by Wheeler[15] is applied to calculate $C_{0,stat}$ and $C_{e,stat}$ since the result in [15] is much improved over the earlier ones [22], [24], [25], [26] and is widely applicable to the entire range of dielectric constants and to all H / a values of the antenna. The expression of the capacitance given by Wheeler [105] can be more explicitly written as:

$$\ldots\ldots\ldots(21)$$

Where: $$C_{e.dyn}(\varepsilon) = \frac{\varepsilon_0 \varepsilon \pi a^2}{H_T}(1+q)$$

$$\ldots\ldots\ldots\ldots\ldots\ldots(22)$$

$$q = u + \nu + u\nu$$

$$\ldots\ldots\ldots\ldots\ldots\ldots(23)$$

$$u = \frac{1+\varepsilon_r}{\varepsilon_r} \cdot \frac{4}{\pi a/h}$$

$$v = \frac{2}{3t} \cdot \frac{\ln(p)}{8+\pi a/h} + (1/t - g)/g \quad \ldots\ldots\ldots\ldots\ldots(24)$$

$$\ldots\ldots\ldots\ldots\ldots\ldots(25)$$

$$t = 0.37 + 0.63\varepsilon_r$$

$$\ldots\ldots\ldots\ldots\ldots\ldots(26)$$

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

$$\ldots\ldots\ldots\ldots\ldots\ldots(27)$$

$$g = 4 + 2.6a/H + 2.9H/a$$

In (21), the first term is equal to the static main capacitance $C_{0,stat}$ and the term q arises due to the fringing field at the edge of the disc capacitor. The fringing capacitance $C_{e,stat}$ thus is defined as:

(28)

Where

$$C_{e.stat} = C_{0.stat}(\varepsilon).q \quad (29)$$

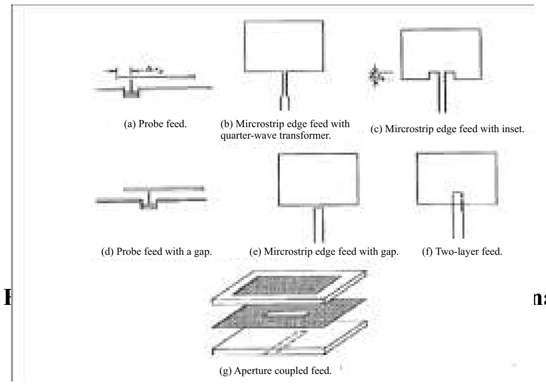
The following Equation also defines the effective radius of the microstrip disc

$$C_{0.stat}(\varepsilon) = \frac{\varepsilon_0 \varepsilon \pi a^2}{H}$$

(30)

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

Techniques [4] for feeding patches are summarized in Fig. 3. They can be classified into three groups: directly coupled, electromagnetically coupled, or aperture coupled. Direct coupling methods are the oldest and most popular, but only provide one degree of freedom to adjust impedance. The microstrip feed line exciting the patch edge and the coaxial probe are examples of direct feeds. The rectangular patch is normally fed along a patch centerline in the E-plane. This avoids excitation of a second resonant mode orthogonal to the desired mode, which would lead to excessive cross polarization.



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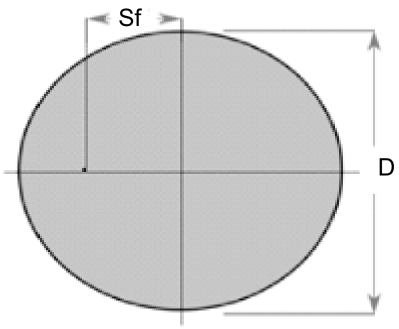
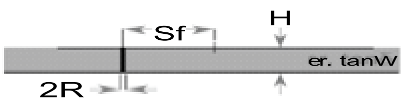


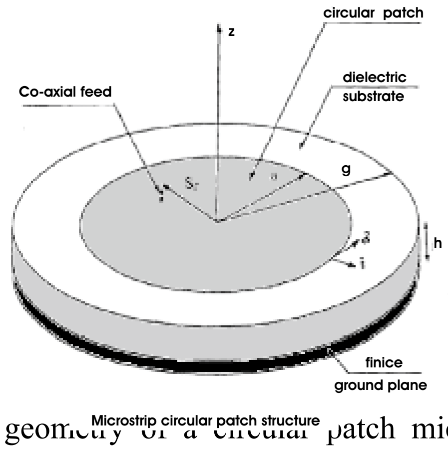


Fi… a with cc…

The direct coaxial probe feed illustrated in Fig 3 and Fig 4 is simple to implement by extending the center conductor of the connector attached to the ground plane up to the patch. Impedance can be adjusted by proper placement of the probe feed. For Rectangular patch antenna, as the probe distance from the patch edge, Sf in Fig.4, is increased, the input resistance is reduced by the factor $\cos^2(\pi S_f/L)$.

A disadvantage of coaxial probe feed is that it introduces an inductance that prevents the patch from being resonant if the substrate height is 0.1 λ or greater. Also, probe radiation can be a source of cross polarization.

Design



Fi…

The geometry of a circular patch microstrip antenna is shown in Fig.5, where the excitation is simulated by a co axial feed in the conducting patch. The radius is selected as [6]

$$a_r = a\left[1 + \frac{2h}{\pi a \varepsilon_r}\left(\ln\frac{\pi a}{2h} + 1.7726\right)\right]^{1/2} \quad (31)$$

Where a is the radius of the conducting patch, a_e is the effective radius due to the spread of the fringing field from the patch edge to the ground plane, h is the dielectric thickness and ε_r is the relative permittivity of the dielectric substrate. The effective radius is also calculated from

$$a_e = \frac{K_{nm}}{2\pi\sqrt{\varepsilon_r}} \quad ....(32)$$

where K_{nm} is the m th zero of the derivative of the Bessel function of order n. The effective patch radius is therefore a function of substrate height, the dielectric permittivity and the order of the excited mode.

The disk metallization radius 'a' can be determined by the resonance condition, that is, $J_n(k_o\sigma\sqrt{\varepsilon_r})=0$ For the lowest order mode n=1 and the 1st root of J_n occurs at 1.841 [8].

Using the above relations equation no. (9) feed point location S_f =7.245 mm have been obtained for optimum matching.

Now a parametric study on the effect on the change of feed position location S_f on a linearly polarized antenna has been presented by the help of antenna Magus EM simulation software [25].

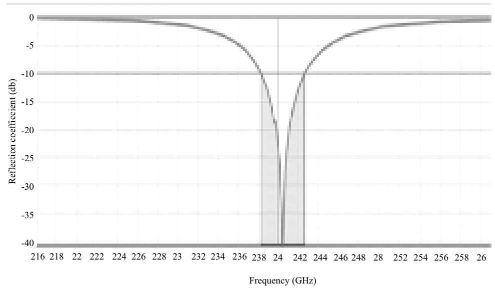
Design Objectives

Physical Parameters & Derived Quantities

Name	Value
Centre frequency	2.4 GHz
Input resistance	100 Ω
Substrate: The thickness of the substrate.	1.5 mm
Substrate: The relative permittivity of the substrate.	4.35
Substrate: The loss tangent of the substrate.	14e-3

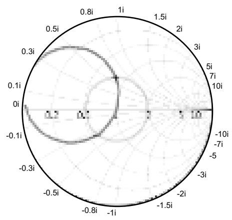
Name	Value
patch_diameter	34.33 mm
feed_offset	7.245 mm
feed_pin_radius	250 µm
substrate_height	1.5 mm
relative_permittivity	4.35
tan_delta	14e-3

Resu



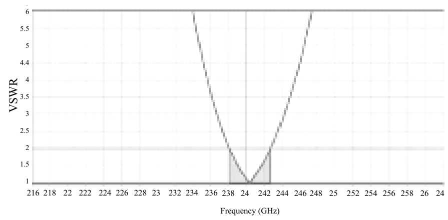
	Design 1
Reference impedance @port 1	100 W
Frequency at which S11=-10 db	2383 GHz 2.426 Ghz
Minimum S11 value	-43.42 @ 2404 GHz

Fig 6(a) Reflectio |) Feed position S_f =7.245 mm



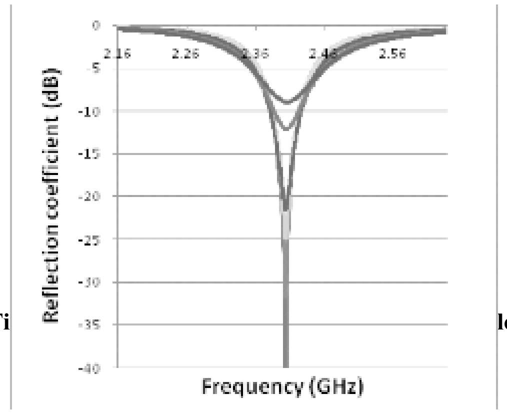
	Design 1
Reference impedance @port 1	100 W
Frequency at which VSWR=2	2.381 GHz 2.428 GHz
Minimum VSWR value	1.007

Fig 6(b) Smith ch 45 mm



	Design 1
Reference Impedance @ port 1	100W
Frequency at which VSWR=2	2.381 GHz 2.428 GHz
Minimum VSWR value	1.007 @ 2.404 GHz

Fig 6 (c) VSWR S_f =7.245 mm



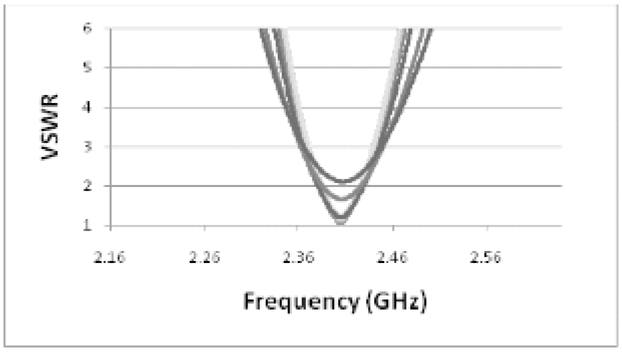
Fi … location

Location of feed	7.245 mm	7.00 mm	6.75mm	6.521 mm	6.5205 mm	8.00 mm	10.0 mm	12.0 mm
Minimum S11 value	-49.42 db@ 2.404 GHz	-31.76 db@ 2.404 GHz	-24.87 db@ 2.404 GHz	-21.03 db@ 2.405 GHz	-21.02 db@ 2.405 GHz	-21.42 db@ 2.404 GHz	-12.14 db@ 2.405 GHz	-8.947 db@ 2.406 GHz
Frequenc yat which S11=--10 db	2.383 db@ 2.426 GHz	2.383 db@ 2.426 GHz	2.384 db@ 2.425 GHz	2.386 db@ 2.424 GHz	2.386 db@ 2.424 GHz	2.382 db@ 2.428 GHz	2.388 GHz 2.423 GHz	
Reference impedance@ Port 1	100 W	100 W	100 W	100 W	100 W	100 W	100 W	100 W

Fig. 7 … s of feed l…

Location of feed	7.245 mm	7.00 mm	6.75mm	6.521 mm	6.5202 mm	8.00 mm	10.0 mm	12.0 mm
Minimum VSWR value	1.007@ 2.404 GHz	1.053@ 2.404 GHz	1.121@ 2.404 GHz	1.195@ 2.0405 Ghz	1.195@ 2.0405 Ghz	1.186 @ 2.404 GHz	1.657 @ 2.405 GHz	2.110 @ 2.406 GHz
Frequenc yat which VSWR=2	2.381 GHz 2.428 GHZ	2.382 GHz 2.427 GHZ	2.383 GHz 2.426 GHZ	2.384 GHz 2.425 GHZ	2.384 GHz 2.425 GHZ	2.380 GHz 2.429 GHZ	2.385 GHz 2.426 GHZ	
Reference impedance@ Port 1	100 W	100 W	100 W	100 W	100 W	100 W	100 W	100 W

Fig. 8 … feed locat…



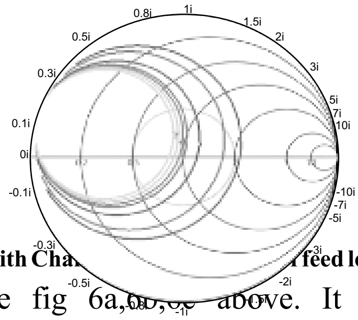


Fig. 9: Smith Cha… feed location

From the fig 6a,6b,6c above. It has been concluded that it is very much required to have impedance matching between antenna and co-axial feed to yield the best results. From the other result in the Fig 7,Fig 8 and Fig 9, it can be seen that how the same parameters deteriorates with the changes of its feed location.

The minimum return loss, VSWR have been obtained at the feed position S_f = 7.245 mm. Below 6.520 mm and above 12 mm, the above antenna will not work satisfactorily. As the co-axial feed-point moves from the edge toward the centre of the patch the resonant input impedance decreases monotonically and reaches zero at the centre and vice versa. To increase/decrease the input impedance, increase/decrease the feed offset is to be done.

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