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Design and Simulation of Circular Patch Antenna for Different Substrates & Feeding Techniques

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Abstract: *An antenna is a device that is used to convert guided electromagnetic waves into EM waves. Significant developments have been done to design compact, minimal weight, low profile antennas. The technologist has focused into the design of microstrip patch antennas resulting in various microstrip antenna. Microstrip antennas may be made of any geometrical shape and dimension. In this project microstrip patch antenna has a radiating circular patch on one side of a dielectric substrate having very small thickness and has an infinite ground plane on the other side Dielectric materials may be considered as the backbone of microstrip antennas. Here we have designed the circular microstip patch antenna for three feeding techniques with different substrates for 7Ghz & 2.4 Ghz frequencies by using Ansoft HFSS Software. According to the simulation results circular microstrip antenna designed for 7GHz with Aperture coupling feed is more efficient with the substrate rogers RT/duroid 5870 (tm) having dielectric constant 2.33. In both the coaxial feed and microstrip line feed cases the results showing the good impedance matching between the feed line and the antenna. Coaxial feeding requires number of trial and error methods for getting impedance match at a particular feed position. For the microstrip line feeding impedance matching depends on the inset depth. Both shows the good agreement.*

Keywords: Circular Patch Antenna, Aperture coupling feed, Coaxial feed, microstrip line feed, substrates

Introduction

In this era of modern world with the blooming of modern wireless communication technologies where communication has become absolutely requisite, antennas are rightly to be said as electronic eyes of the world due to their undeniable role-playing place in the communication technology. With this fast growing development in antenna engineering Microstrip Patch Antennas are keeping a vital role in application of mobile radio, wireless communication, high-performance aircraft, satellite, missile and spacecraft because of their light weight, low profile, simplicity and low cost. Rectangular, circular, elliptical these are some common patch shapes that have a good demand and fame for their feed line flexibility and multiple frequency operation.

There are several methods available in literature to feed or transmit electromagnetic energy to a microstrip patch antenna. The most famous techniques are the microstrip transmission line, coaxial probe feed, aperture coupling and proximity coupling. The simplest feeding methods to realize are those of the microstrip transmission line and coaxial probe. Both the methods utilize direct contact with the patch to induce excitation. The point of excitation is adjustable, enabling the designer to control the impedance matching between feed and antenna, polarization, mode of operation and excitation frequency.

The antenna is one of the critical components in any wireless communication system. A microstrip patch antenna (MPA) consists of a conducting patch of any planar or non-planar geometry on one side of the dielectric substrate with a ground plane present on other side. Feeding can be done by using any one of the methods such as co-axial feed, line feed, inset feed, proximity coupling or aperture coupling. Some advantages of the microstrip antennas are its small size, low profile, and that it is lightweight. One of the most popular feeding techniques used for designing the UWB antennas is the microstrip feedline.

Literature Review

Nazia Tasnim, Rafeet Inum, Hasneara Khatun and Muhammad Abdul Goffar Khan (2019) Studied on a comparative performance study on circular and elliptical shape microstrip patch antennas and their arrays using different feeding techniques at an X band. The resonant frequency is chosen at 10 GHz which has a variety of application in wireless communication. CST Microwave Studio is used for design and simulation. A 3558.12 mm2 antenna having 2x4 array of circular patch with line feed that gives 16.2 dB gain,16.4 dB directivity with 94.42% efficiency and 1.54 of VSWR are results of the proposed model. It is found that microstrip line feeding shows better performance than coaxial probe feeding considering gain and directivity.

Muhammad Abdul Goffar Khan, Anil Kumar Gantala (2017) Studied on the performance characteristics of circular patch microstrip printed antenna at 3.5 GHz which is suitable for WiMAX applications. CMPA consists of circular shape radiating element on one side of the substrate having the ground plane on other side, CMPA has been fed by two methods, which are edge feeding and coaxial probe feeding. CMPA has been designed using substrates Rogers RT/duroid5880 (εr= 2.2, h=1.588 mm), Rogers RT/duroid5880 (εr= 2.2, h=2.87 mm) and FR4 epoxy (εr= 4.4, h=2.87 mm) separately for both feeding techniques. Return loss -27.072db, vswr-1.029, The maximum gain of 7.496 dB is obtained. In similar manner, the simulations have been carried out for Rogers RT/Duroid880 (εr= 2.2, h=2.87 mm) and FR4 epoxy (εr =4.4, h =2.87 mm). A CMPA with quarter wave transformer feed is achieved return loss of -18 dB after simulation and measured -24 dB at 10 GHz, CMPA with same dimensions have been simulated by HFSS and it has given a return loss of -29 dB at 10.02 GHz.

Navneet Saroha and Manjeet Goyat (2015) Studied on the design and simulation of rectangular & circular with EBG substrate using high frequency Structure Simulator (HFSS). The two different configurations of broadband microstrip patch antenna, multi stacked rectangular patch antenna & multi stacked circular patch antenna are analysed. Return loss & Gain are performance parameter. The substrate used in these two configurations is RT Duroid having dielectric constant 2.2. The result calculated is return loss of rectangular patch & circular patch with EBG substrates are -13.98 db & -43.4437 db and gain of rectangular patch & circular patch with EBG substrates are 5.7478 db & 10.4954 db respectively.

Sekhar M, S Nagakishore Bhavanam and Dr. P. Siddaiah (2014) Studied on an enhanced but simple triple band circular ring patch antenna with a new slotting technique, which is most suitable for X-band, Ku-band and K-band applications. This compact micro strip antenna is obtained by inserting small rectangular strip in a circular ring patch antenna. The antenna has been designed and simulated on an FR4 substrate with dielectric constant of 4.4 and thickness of 2mm. The design is analysed by Finite Element Method based HFSS Simulator Software (version 14.0), The simulated return losses obtained are -35.80dB, -42.39dB, and -44.98dB at 8.96 GHz, 14.44 GHz, 18.97 GHz respectively. The VSWR of the antenna at the centre frequencies 8.96 GHz, 14.44 GHz and 18.97 GHz is 0.2, 0.1 and 0.09 respectively. Therefore, this antenna can be applicable for X-band, Ku-band and K-band applications respectively.

M.Karmugil and K. Anusudha (2016) Studied on an efficient design of circular shaped microstrip patch antenna for Ultra-Wide Band (UWB) application is proposed with partial ground structure. UWB systems are popular because of their larger bandwidth and power management efficiencies but the design of UWB based applications requires low profile antennas. The proposed model of circular shaped microstrip patch antenna is designed for 6.3Ghz and 10.22Ghz resonant frequency which gives as a results of return loss -19.3391dB & -24.0508dB gain 4.0503dBi & 5.5311dBi and VSWR 1.2554 &1.1195 respectively. It has been found that circular antenna gives better return loss, good directivity and radiation pattern. The line feeding technique used in the proposed model provides good impedance matching, which further improves the characteristics of the antenna.

B. J. Kwaha, O. N Inyang and P. Amalu (2011) Studied on the design and implementation of circular microstrip patch antenna. A FORTRAN program was developed to simulate the basic parameters of a microwave circular patch antenna. These parameters are the actual radius of patch, effective radius of patch, conductance due to radiation, conductance due to conduction, conductance due to dielectric loss, directivity, input resistance and quality factors due to conduction, dielectric loss, and radiation. Patch radius decreases as the resonant frequency increases (0.2374cm at 10.0GHz and 0.05079 cm at 45.0GHz for GaAs). The results obtained in the proposed paper were compared favorably with results obtained from manual computation of the same parameters and these agree with other designs such as the rectangular patch. It was also deduced that directivity increases with increase in substrate height, but at the expense of loading effect. A lower radiation conductance loss was observed at higher substrate height, but at the expense of increasing losses due to surface wave.

R. Devi, Dipak and kr. Neog (2015) Studied on determination of radius of circular Microstrip patch antenna using clonal selection algorithm. A method based on clonal selection algorithm (CSA) for computing the radius of circular microstrip antennas (MSAs) is presented. The CSA is a stochastic method which has the capability of optimizing multimodal problems. The method gives the radius as output for given values of resonant frequency (fr), height (h), dielectric constant (εr) of the circular microstrip antenna. Therefore, the proposed method is less time consuming and would be more helpful to design circular MSAs. Furthermore, it is not computationally tedious. Thus, CSA approach presented here can be used by a MSA designer practically without any background in sophisticated mathematical techniques.

Motivation

In the rapid increasing technology of wireless communication, there is a great demand for compact, low profile, low cost and light weight microstrip antenna. However, the main disadvantage of microstrip antenna is narrow bandwidth that limits its applications. In order to check the efficiency and reduce the size of antenna, hence the Circular microstrip patch antenna for different substrate and feeding techniques was used.

Methodology

1) Study on architecture & design equations for circular microstrip patch antenna.
2) Dimensions of Circular microstrip patch antenna to be calculated for different substrate and feeding techniques.
3) Simulation of Circular antenna for different substrates and feeding techniques.
4) Analysis and tabulation of results obtained and comparing VSWR, S11, radiation pattern with each other.

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Design and Implementation

The patch is in the form of circle, where the radius of the radiating elements can be obtained through the equation (1.1)

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}} \quad \text{………. (1.1)}$$

Where,
a = circular radius dimension (cm)
h = Thick of substrate (m)
$\mathcal{E}$r = Relative dielectric permittivity of substrate (F/m)
F = logarithmic function (F) of radiating element

While the logarithmic function (F) of the radiating element is determined by the equation (1.2)

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \quad \text{…………… (1.2)}$$

Where,
fr = Resonating Frequency (MHz)
$\mathcal{E}$r = Relative dielectric permittivity of substrate (F/m)

As for the width and length of the slot is obtained by using the equation (1.3) & (1.4)

$$W = \frac{c}{2 f_0} \quad \text{………………… (1.3)}$$

$$L = \frac{c}{2 f_0 \cdot \sqrt{\varepsilon_r}} - 2\Delta l \quad \text{………………... (1.4)}$$

Where,
L = Length of slot
W = Width of slot

The patch length is selected from the resonant condition and the fringing field consideration and fringing field length is given by equation (1.5)

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{eff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{W}{h} + 0.8)} \quad \text{…………… (1.5)}$$

The effective dielectric constant of the propagation medium (air + solid dielectric substrate) is calculated by equation (1.6)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}} \quad \text{……………. (1.6)}$$

1) Design of 2.4 GHz Circular patch for Coaxial Feed

Specifications of Substrate and Conductor Materials used in the design of circular patch antenna for microstrip line feed are as follows:

Dielectric material: Rogers TTM 4 (tm)
- Dielectric Constant ($\mathcal{E}$r) = 4.5
- Dielectric Thick (h) = 1.6mm
- Loss tangent (tan δ) = 0.002
- Frequency = 2.4GHz

Substrate coating material (conductor) copper:
- The thickness of the conductor material (t) = 0.0001 m
- Copper conductivity (σ) = 5.80 x 107 mho m^{-1}
- The characteristic impedance of line = 50 Ω

The operating frequency of the antenna (fr) is 2.4GHz, and then we calculated the amount of radius (a) of the radiating elements of microstrip antenna with Eqs. (1.1) and (1.2) with

the specification microstrip of the material was obtained; for fr = 2.4GHz; logarithmic function value F = 1.7267 and patch radius = 17.256mm. The impedance of the microstrip transmission line is 50 Ω, λ_0 values for 2.4GHz is 0.1249m. To improve the performance of the antennas, a slot was added to this design. The effective dielectric constant of the propagation medium and fringing field length is obtained by Eqn (1.5) & (1.6) $\mathcal{E}$eff = 4.751 ΔL= 0.731mm, slot size on the radiating element is obtained by using Eqs. (1.3) and (1.4), W = 62.45mm and L = 27.7mm.

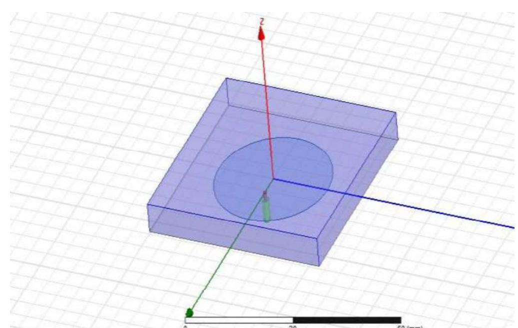

Fig 1.1 Geometry of Circular Microstrip patch antenna for Coaxial feed

The Fig 1.1 shows the geometrical analysis and the dimensions of the antenna is analyzed using electromagnetic simulation software (HFSS) from ANSYS. The radiating patch is printed on the commercially available substrate of FR4 having dielectric constant (εr) = 4.4 with the thickness of (h) = 1.6 mm by using Coaxial feeding technique.

2) Design of 2.4 GHz Circular patch for Microstrip line Feed

Specifications of Substrate and Conductor Materials used in the design of circular patch antenna for microstrip line feed are as follows:

International Journal of Advances in Engineering and Management (IJAEM)
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Dielectric material: Rogers TTM 4 (tm)

- Dielectric Constant ($\mathscr{E}$r) = 4.5
- Dielectric Thick (h) = 1.6mm
- Loss tangent (tan ẟ) = 0.002
- Frequency = 2.4GHz

Substrate coating material (conductor) copper:

- The thickness of the conductor material (t) = 0.0001 m
- Copper conductivity (σ) = 5.80 x 107 mho m^{-1}
- The characteristic impedance of line = 50 Ω

The operating frequency of the antenna (fr) is 2.4GHz, and then we calculated the amount of radius (a) of the radiating elements of microstrip antenna with Eqs. (1.1) and (1.2) with the specification microstrip of the material was obtained; for fr = 2.4GHz; logarithmic function value F = 1.7267 and patch radius = 17.256mm. The impedance of the microstrip transmission line is 50 Ω, λ_0 values for 2.4GHz is 0.1249m. To improve the performance of the antennas, a slot was added to this design. The effective dielectric constant of the propagation medium and fringing field length is obtained by Eqn (1.5) & (1.6) $\mathscr{E}$eff = 4.751 ∆L= 0.731mm, slot size on the radiating

element is obtained by using Eqs. (1.3) and (1.4), nW = 62.45mm and L = 27.7mm.

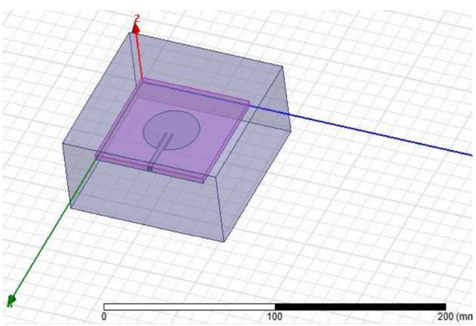

Fig 1.2 Geometry of Circular Microstrip patch antenna for Microstripline feed

The Fig 1.2 shows the geometrical analysis and the dimensions of the antenna is analyzed using electromagnetic simulation software (HFSS) from ANSYS. The radiating patch is printed on the commercially available substrate of Rogers TMM 4 having dielectric constant (ε**r**) = 4.5 with the thickness of (h) = 1.6 mm by using Microstrip line technique.

3) Design of 7 GHz Circular patch for Aperture Coupling Feed

Specifications of Substrate and Conductor Materials used in the design of circular patch antenna for Aperture Coupling feed are as follows:

Dielectric Material: Rogers RT/Droid 5870 (tm)

- dielectric Constant ($\mathscr{E}$r) = 2.33
- dielectric Thick (h) = 1.6 mm
- Loss tangent (tan ẟ) = 0.0012
- Frequency = 7GHz

Substrate coating material (conductor) copper:

- The thickness of the conductor material (t) = 0.0001 m
- Copper conductivity (σ) = 5.80 x 107 mho m^{-1}
- The characteristic impedance of line = 50 Ω

The operating frequency of the antenna (fr) is 7GHz, and then we calculated the amount of radius (a) of the radiating elements of microstrip antenna with Eqs. (3.1) and (3.2) with the specification microstrip of the material was obtained; for fr = 7GHz; logarithmic function value F = 0.823 and patch radius = 82.12mm. The impedance of microstrip transmission line is 50 Ω, λ_0 values for 7GHz is 42.8mm. To improve the performance of the antennas, a slot was added to this design. The effective dielectric constant of the propagation medium and fringing field length is obtained by Eqn (3.5) & (3.6) ∆L=0.789mm $\mathscr{E}$e=2.544, slot size on the radiating element is obtained by using Eqs. (3.3) and (3.4), W = 21.4mm and L = 12.44mm.

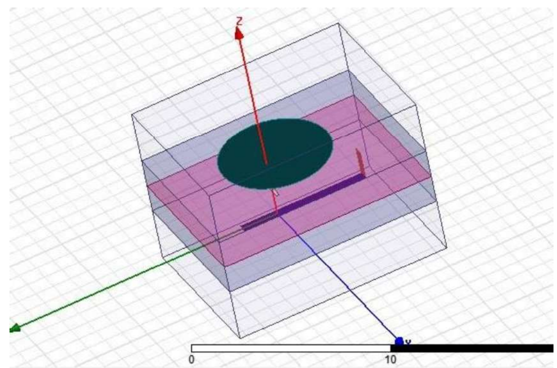

Fig 1.3 Circular Microstrip patch antenna for Aperture Coupling feed

The Fig 1.3 shows the geometrical analysis and the dimensions of the antenna is analyzed using electromagnetic simulation software (HFSS) from ANSYS. The radiating patch is printed on the commercially available substrate of Rogers RT/Duroid 5870 (tm) having dielectric constant (ε**r**) = 2.33 with the thickness of (h) = 1.6 mm by using Aperture Coupling feed technique.

Results and Discussion

1) Circular patch antenna for Coaxial Feed

Results obtained for circular microstrip patch antenna for coaxial feed and the substrate FR4 a are as follows:

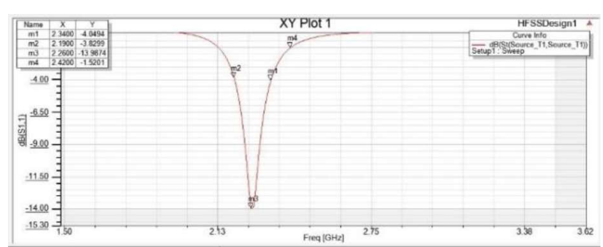

Fig 2.1 S_{11} for Circular Patch Antenna for Coaxial feed

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 3, pp: 67-75 www.ijaem.net ISSN: 2395-5252

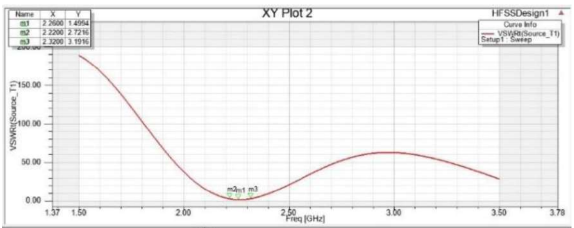

Fig 2.2 VSWR of Circular Patch Antenna for Coaxial feed

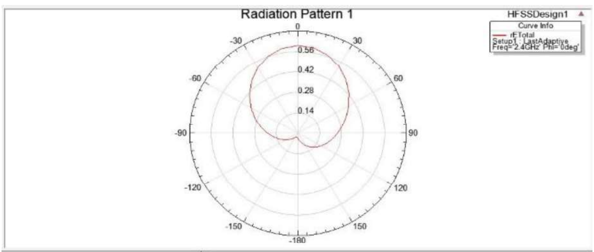

Fig 2.3 Radiation pattern of Circular Patch Antenna for Coaxial feed

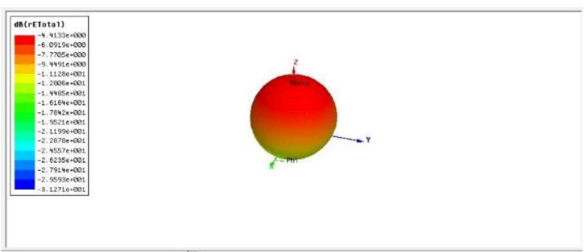

Fig 2.4 3D Radiation pattern of Circular Patch Antenna for Coaxial feed

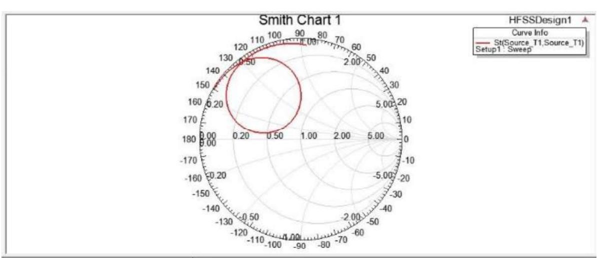

Fig 2.5 Smith Chart of Circular Patch Antenna for Coaxial feed

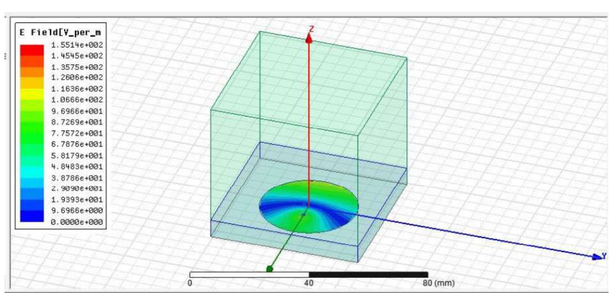

Fig 2.6 Surface current distribution of Circular Patch Antenna for Coaxial feed

Fig. 2.1 shows the simulated Return loss (S_{11}) for the coaxial feed circular patch antenna. The designed antenna covers 1.5 GHz to 3.5 GHz bandwidth with S11 < -10 dB. The Fig 2.2 shows the VSWR, it is the ratio of peak amplitude to the minimum amplitude of a standing wave. If the VSWR = 1.0, power is not reflected back and thus the magnitude is constant along the transmission line. The proposed antenna shows the VSWR ≤ 2 and the power is excited through the antenna and thus shows good impedance matching as shown in the Fig 2.2. The Fig 2.3 and Fig 2.4 shows the radiation pattern, Fig 2.5 shows the Smith chart and Fig 2.6 shows the surface current distribution of the proposed antenna.

2) Circular patch antenna for microstrip line feed

Results obtained for circular patch antenna for microstrip line feed and the substrate Rogers TMM 4 are as follows:

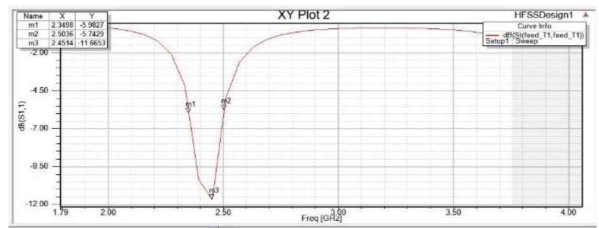

Fig 2.7 S_{11} for circular Patch Antenna for Microstrip line feed

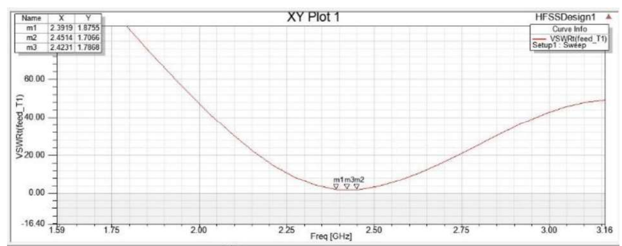

Fig 2.8 VSWR of Circular Patch Antenna for Microstrip line feed

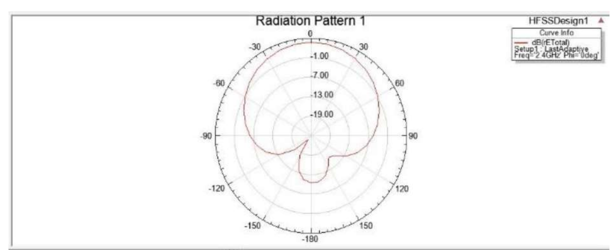

Fig 2.9 Radiation Pattern of Circular Patch Antenna for Microstrip line feed

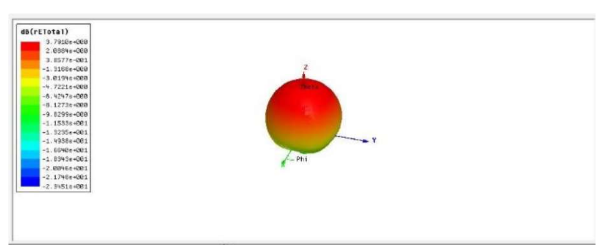

Fig 2.10 3D Radiation Pattern of Circular Patch Antenna for Microstrip line feed

International Journal of Advances in Engineering and Management (IJAEM)
Volume 2, Issue 3, pp: 67-75 www.ijaem.net ISSN: 2395-5252

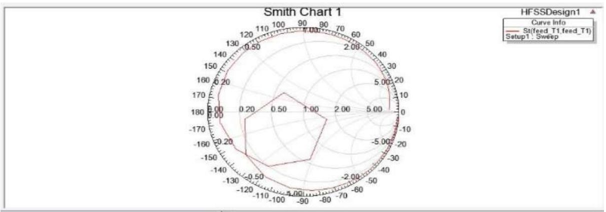

Fig 2.11 Smith Chart of Circular Patch Antenna for Microstrip line feed

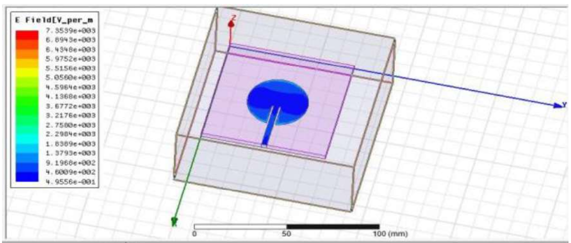

Fig 2.12 Surface current distribution of Circular Patch Antenna for Microstrip line feed

Fig. 2.7 shows the simulated Return loss (S_{11}) for the Microstrip line feed circular patch antenna. The designed antenna covers 1.5 GHz to 3.5 GHz bandwidth with S11 < -10 dB. The proposed antenna shows the VSWR ≤ 2 and the power is excited through the antenna and thus shows good impedance matching as shown in the Fig 2.8. The Fig 2.9 and Fig 2.10 shows the radiation pattern, Fig 2.11 shows the Smith chart and Fig 2.12 shows the surface current distribution of the proposed antenna.

3) Circular patch antenna for Aperture Coupling Feed

Results obtained for circular patch antenna for Aperture coupling feed and the substrate Rogers RT/Droid 5870 (tm) are as follows:

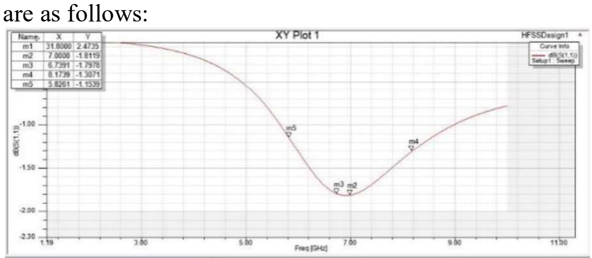

Fig 2.13 Return loss of Circular patch antenna for Aperture Coupling feed

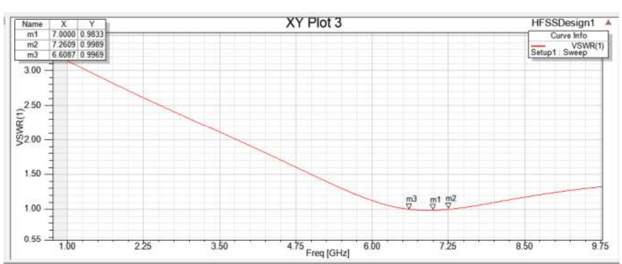

Fig 2.14 VSWR of Circular patch antenna for Aperture Coupling feed

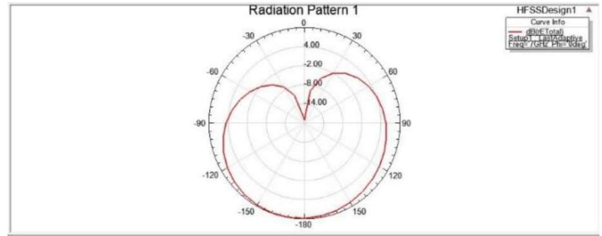

Fig 2.15 Radiation Pattern of Circular patch antenna for Aperture Coupling feed

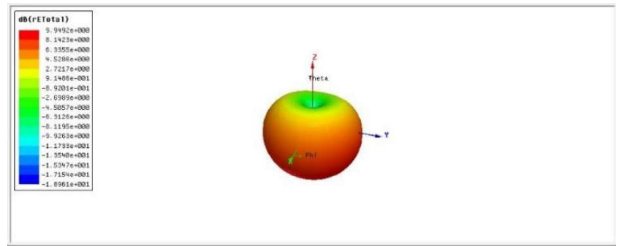

Fig 2.16 3D Radiation Pattern of Circular patch antenna for Aperture Coupling feed

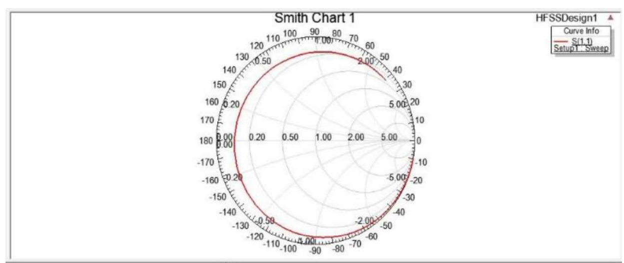

Fig 2.17 Smith Chart of Circular patch antenna for Aperture Coupling feed

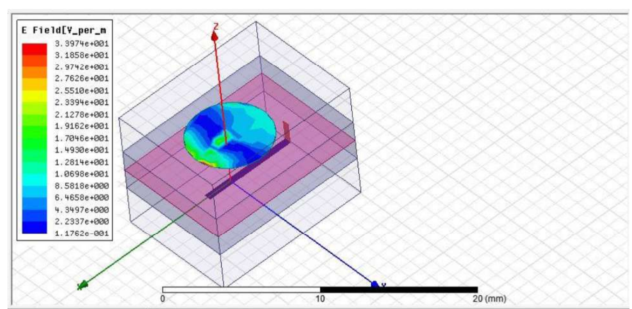

Fig 2.18 Surface current distribution of Circular patch antenna for Aperture Coupling feed

Fig. 2.13 shows the simulated Return loss (S parameter) for the Aperture coupling feed circular patch antenna. The designed antenna covers 1.5 GHz to 10 GHz bandwidth with S11 < -10 dB. The proposed antenna shows the VSWR 0.99 and the power is excited through the antenna and thus shows good impedance matching as shown in the Fig 2.14. The Fig 2.15 and Fig 2.16 shows the radiation pattern, Fig 2.17 shows the Smith chart and Fig 2.18 shows the surface current distribution of the proposed antenna.

Tabulation

Results obtained for circular patch antenna for different substrates and feeding techniques are compared and verified with each other, it was shown in table1.

Feeding techniques	Coaxial (Probe) Feed	Microstrip line Feed	Aperture Coupling Feed
Substrates	FR 4	Rogers TMM 4 (tm)	Rogers RT/Duroid 5870 (tm)
Dielectric Constant	4.4	4.5	2.33
Frequency	2.4GHz	2.4GHz	7GHz
Return loss (S11)	-1.5dB	-5.98dB	-1.8119dB
VSWR	1.4	1.6	0.99
Gain dB	1.27	4.273	0.481
Radiated power	0.0027979W	0.0086961W	0.33321W
Accepted power	0.0048465W	0.0093365W	0.34215W
Incident power	0.012075W	0.01W	1W
Radiation Efficiency	0.5773	0.9314	0.9738

Table 1 Tabulation of Results obtained for different feeding techniques

Conclusion

A series of studies on the investigations of different characteristics of the circular microstrip patch antennas of different substrates and feeding techniques have been described. A Circular microstrip patch antenna with coaxial feed, microstrip line feed and aperture coupling feeding techniques for wideband impedance is presented for 2.4 GHz and 7GHz applications. To achieve all aspects, different structures with modified radiating & ground planes have been described and investigated. Antennas are designed for the substrates FR4, Rogers TMM 4 (tm) and Rogers RT/Duroid 5870 (tm) respectively. The proposed antennas are designed, simulated and the results are verified and compared with each other. The simulated results for return loss (S11) are -1.5dB, -5.98dB and -1.8dB respectively. VSWR value for the antennas are 1.4, 1.6 and 0.99 respectively. The measured results show that the proposed antennas have good impedance matching and radiation patterns characteristics.

According to the simulation results circular microstrip antenna designed for 7GHz with Aperture coupling feed is more efficient with the substrate rogers RT/duroid 5870 (tm) having dielectric constant 2.33. In both the coaxial feed and microstrip line feed cases the results showing the good impedance matching between the feed line and the antenna. Coaxial feeding requires number of trial and error methods for getting impedance match at a particular feed position. For the microstrip line feeding impedance matching depends on the inset depth. Both shows the good agreement. The investigations are done by both simulation and measurement. Simulated investigation is done by using commercially available software ANSOFT- HFSS.

Future Scope

The Circular Microstrip patch antenna have a tremendous application potential. Even as of now, these antennas are designed and used in Personal Communication System, Mobile Satellite Communication, Direct Broadcast Satellite, Global Positioning System, Wireless Local Area Network, Intelligent Vehicle Highway System, and also it is receiving attention for Microwave Therapy. Simulators are invaluable tools for Circular microstrip patch antenna. Suitability of these tools depends upon the sophistication of the models used in them. The present models can be extended for array of circular microstrip patch antenna for different substrates and feeding techniques. For this development some additional models will have to be developed. Many applications in communications and radar required dual frequency. The present work can be extended also for designing of dual frequency patch antenna.

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