DESIGN OF SQUARE MICROSTRIP ANTENNAS WITH DEFECTED GROUND STRUCTURE

4.1. Introduction

This chapter gives the design perspective and fabrication of square microstrip antennas (SQMA) with strip-line feeding technique and defected ground structures embedded on ground plane. SQMSA is designed and then distinctive defected ground structures are embedded on ground plane of microstrip antenna. The equations used for the design of these antennas are obtained from Bahl. I J and Bhartia. P [8].

The design equations are exercised to discovery the dimension of path antenna for which we need some basic information like, selection of material of substrate with proper selection of permittivity of material with low loss tangent value, which plays a very important role in the parameter changes of antenna designed. Next most significant design consideration is thickness of the material used.

4.2. Design specification of strip-line patch antenna

Most important step in design consideration is the selection of initial parameters such as design frequency selection of substrate with required material and proper loss tangent, electrical properties such as relative dielectric constant (ε_r) and loss tangent ($\tan\delta$) of material used as substrate. Is taken in consideration to provide a proper efficiency and required bandwidth above properties of material, which effect the parameter of the antenna. The high significance of dielectric constant results in minor patch, which reduces bandwidth as well as in tougher fabrication acceptances. A high loss tangent degrades antenna efficiency with increase losses. The substrate thickness (h) is chosen large possible to maximum bandwidth and efficiency of antenna designed but should avoid the surface wave excitation. The value of these are chosen as per the equation [8],

$$h \leq \left(\frac{0.3c}{2\pi f_0 \sqrt{\varepsilon_r}}\right) \tag{4.1}$$

where,

c = is velocity of light in cm.

f_0 =is the operation frequency in GHz.

ε_r=is the relative dielectric constant.

Modified Glass epoxy substrate material of permittivity ε_r = 4.2 and loss tangent $\tan\delta$ = 0.002 and height of substrate selected is 1.6 mm which is commonly used in the printed circuit board (PCB). It is low cost and most universally manufactures substrate.

4.2.1. Patch design

For the known values of (ε_0, h), resonant frequency (f_r) and free space wavelength (λ_0), the design of SQMA is made as under.

(a) Patch width (W)

The elemental width of SQMSA is given by [2],

$$W = \frac{c}{2f_r}\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}^{-1/2} \tag{4.2}$$

(b) Extension length (Δl)

The extension length Δl is considered by using the length of SQMSA in order to retain the actual length of the patch constant. The extension length is considered due to fringing fields that appear on the edges of patch antenna and is given by [8].

$$\Delta l = 0.412h\left[\frac{(\varepsilon_e+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_e+0.258)\left(\frac{W}{h}+0.8\right)}\right] \quad (4.3)$$

where,

ε_e is effective dielectric constant. Given by

$$\varepsilon_e = \left(\frac{\varepsilon_r+1}{1}\right) + \left(\frac{\varepsilon_r-1}{1}\right)\sqrt{1+\frac{12h}{W}}^{-1/2} \quad (4.4)$$

(c) Patch length (L)

Once the extension length (Δl) and effective dielectric constant (ε_e) are determined utilizing the equations (4.3) and (4.4), then the patch length of SQMSA is establish by using the equation [8],

$$L = \frac{c}{2f_r\sqrt{\varepsilon_e}} - 2\Delta l \quad (4.5)$$

The calculation of the length and width formulation is for rectangular patch antenna [6] which provides an option for selecting any of one parameter length of width for the design of square patch design in our work we select length of patch design and consider width of patch to be same as of length, by doing this we obtain a first stage of optimization that is reduction of size of patch.

4.2.2. Microstrip feed design

The microstrip feed is designed by calculating the values of $\frac{W}{h}$ ratio for the known values of characteristic impedance Z_o and ε_r. The W/h equations are [8],

$$\frac{W}{d} = \left(\frac{8e^{A}}{e^{2A}-2}\right) for\ \frac{W}{d} < 2 \tag{4.6}$$

$$\frac{W}{d} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\right]\left\{\ln(B-1) = 0.39 - \left(\frac{0.61}{\varepsilon_r}\right)\right\} for\ \frac{W}{d} > 2 \tag{4.7}$$

where, $$A = \frac{Z_0}{60}\sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \tag{4.8}$$

and $$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \tag{4.9}$$

By using equations (4.6) to (4.9) the width of microstrip-line feed W_f can be acquired by multiplying the values of h to the values obtained from equation (4.6) or (4.7) as per their $\frac{W}{h}$ condition. The length of microstrip-line L_f is obtained from effective guide wavelength λ_g . It is given by [8],

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}} \tag{4.10}$$

where, $$\varepsilon_{eff} = \varepsilon_r - \frac{\varepsilon_r - \varepsilon_e}{1 + G\left(\frac{f_r}{f_p}\right)^2} \tag{4.11}$$

$$G = \left(\frac{Z_0 - 5}{60}\right)^{\frac{1}{2}} + (0.004 \times Z_0) \tag{4.12}$$

$$f_P = \frac{Z_0}{2\mu_0 h} \tag{4.13}$$

$$\mu_0 = 4\pi \times 10^{-9} \tag{4.14}$$

and $$\lambda_0 = \frac{c}{f_r} \tag{4.15}$$

The length of L_f is commonly taken as $\frac{\lambda}{4}$ for single element square microstrip antenna in order to keep minimum loss in microstrip-line feed. However, L_f can be extended to any value as it acts as connecting link between patch and source.

The microstrip-line feed designed as per the above procedure is of 50Ω since copper is used as the radiating material. This can be connected at the midpoint (M_p) along the width W of square patch. But the impedance obtainable by the patch at M_p might not be equivalent to 50Ω. Hence, microstrip-line feed need not be connected at this point as impedance mismatch occurs. In such case a matching transformer must be used between M_p and 50Ω microstrip-line for improved impedance matching. The succeeding equations are used to regulate the impedance R_{in} at M_p along the width of SQMSA,

$$R_{in} \cong \frac{(120\lambda_0)^2+\left(\frac{377h}{\sqrt{\varepsilon_r L}}\right)^2 tan^2\beta l}{240\times L\times\lambda_0(1+tan^2\beta l)} \quad (4.16)$$

where,
$$\beta = \frac{2\pi\sqrt{\varepsilon_r}}{\lambda_0} \quad (4.17)$$

$$l = \frac{\theta\pi}{180\beta} \quad (4.18)$$

Impedance of quarter wave transformer Z_t is given by $Z_t = \sqrt{R_{in} \times Z_0}$. The length is determined by using equations (4.10) to (4.15). The width of quarter wave transformer is determined by using equations (4.6) to (4.9) after making the condition $\frac{W}{d} < 2\ or\ \frac{W}{d} > 2$.

4.2.3. Ground plane design

The length (L_g) and width (W_g) of the ground reflector plane of antenna is calculated using [2] equation,

$$L_g = 6h + L \; and \; W_g = 6h + W \qquad (4.19)$$

where, h is the height of modified glass epoxy substrate.

The designed geometry of the SQMSA is as shown in Figure. 4.1, Using above design formulae, first a conventional SQMSA with center-fed 50Ω microstrip line feed ($\varepsilon_r = 4.2, h = 1.6mm$) is designed for TM_{10} mode for 2.4 GHz and 5 GHz

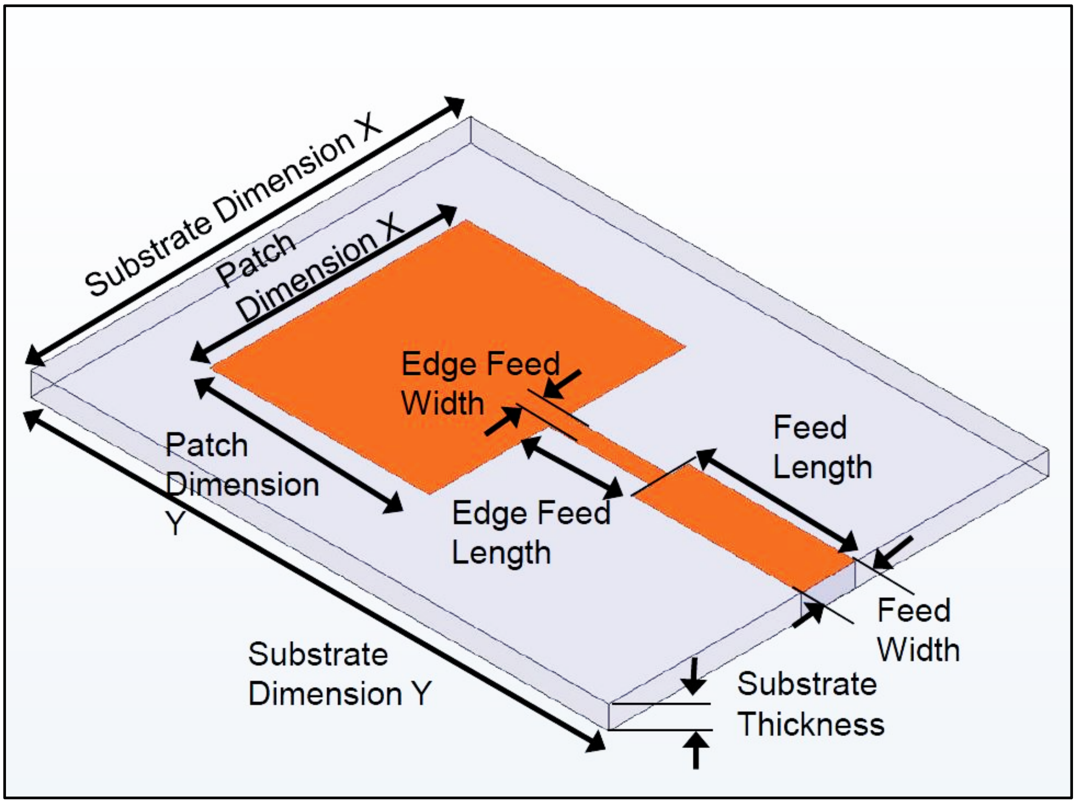


Figure. 4.1: Geometry of SQMSA

4.3. Results and discussions

The simulated, experimental results with discussions of the proposed square microstrip antenna without defect on ground plane are presented. The following antenna characteristics are simulated using High Frequency Structural Simulator, simulation tool and verified by vector network analyzer for practical readings are reported.

1. Return loss (RL)
2. Bandwidth
3. Radiation pattern
4. Gain
5. Reduction in the antenna size (%)

4.3.1. Return loss (RL)

In this parameter which is used to indicates the quantity of signal power that is received at load and will not reoccurre as a reflection. From above discussion in the previous section, waves are echoed leading to the creation of standing waves under condition that transmitter and antenna designed impedance do not match. Henceforth the RL is considered which is similar to the VSWR used to indicate the matching between the transmitter and antenna designed has taken place. The RL is represented as

$$RL = -20 log_{10} \Gamma dB \quad (4.20)$$

To have faultless matching between transmitter and antenna, $\Gamma = 0$ and $RL = \infty$, which implies no power would be echoed back. Although, when $\Gamma = 1$ and $RL = 0\ dB$, which implies that all instance power is reflected. Generally, for practical applications $VSWR < 2$ is acceptable. Since this resembles to a return loss of -10dB.

4.3.2. Bandwidth (BW)

The bandwidth of an antenna is designated as “the range of frequencies at which designed antenna resonates”. The valuable bandwidth of antenna could be limited by numerous factors, such as impedance and gain. The input impedance is commonly the main feature is limiting the functional bandwidth of small antennas. The input impedance antenna varies fast with frequency. This restriction the frequency range above which antenna can be coordinated to its feed line. Impedance bandwidth is typically specified in RL or VSWR. Typical matching requirements are VSWR< 2 or $RL < -10\,dB$. Bandwidth (BW) is calculated from the formula as follows:

$$BW(\%) = \left(\frac{f_H - f_L}{f_r}\right) \times 100 \quad (4.21)$$

where, f_H - The higher cut-off frequency

f_L - The lower cur-off frequency

f_r - The resonant frequency

4.3.3. Radiation pattern

The antenna radiation pattern is a 2D or 3D plot of far-field radiation measurement of desined antenna as a parameter of the three-dimensional co-ordinates which is indicated by the elevation angle θ and the azimuth angle $\emptyset$. More precisely it is plot of the power emitted from an antenna per unit solid angle which is the radiation strength of antenna.

4.3.4. Antenna Gain

Antenna Gain term explains when considerable power is transmitted in the direction of highest radiation when compared with isotropic source. Antenna gain is further commonly quoted in a real antenna's requirement sheet since it considers the authentic losses that happen. An antenna having a gain of 3 dB means that power established at far distance from antenna will be 3 dB greater (twice as much) than it would be accepted from a lossless isotropic antenna through the similar input power given. Usually gain of a practical antenna can range between 40-50 dB for very large dish structure antennas. On the other side, the peak gain of antenna can be subjectively low because of depleted efficiency related to the antenna. Electrically small antennas can be very inefficient with antenna gain lesser than -10 dB.

In our work presented the designing, simulation process and optimization of proposed antennas are carried out by using commercially available well-known ANSYS-HFSS electromagnetic high frequency simulation software tool version 13.0.

The experimental work of various antennas with different defected structures loaded on ground plane is carried out by using German make Rhode and Schwarz (R&S) Vector Network Analyzer (VNA) of ZVK model (10 MHz - 40 GHz) in Microwave Electronics Research Laboratory (MERL), Department of Post Graduate Studies and Research in Applied Electronics, Gulbarga University, Kalaburagi-585106 which was sponsored by Department of Science and Technology (DST), Government of India, New Delhi under FIST program.

4.3.5. Reduction in the antenna size (%)

The reduction in the antenna size (%) is calculated using the following formula:

Reduction in the antenna size (%) = $\frac{(f_c - f_{RA})}{f_c} \times 100$ % Where f_{RA} is the resonating frequency of the conventionally designed antenna, f_C frequency where antenna designed is resonating.

The detailed study of performance characteristics of rectangular patch verses square patch antenna is investigated and published in the International Journal based on the results for our thesis work the square patch antenna is selected. [1]

4.4. Design of conventional 2.4GHz Square Microstrip antenna (SQMSA)

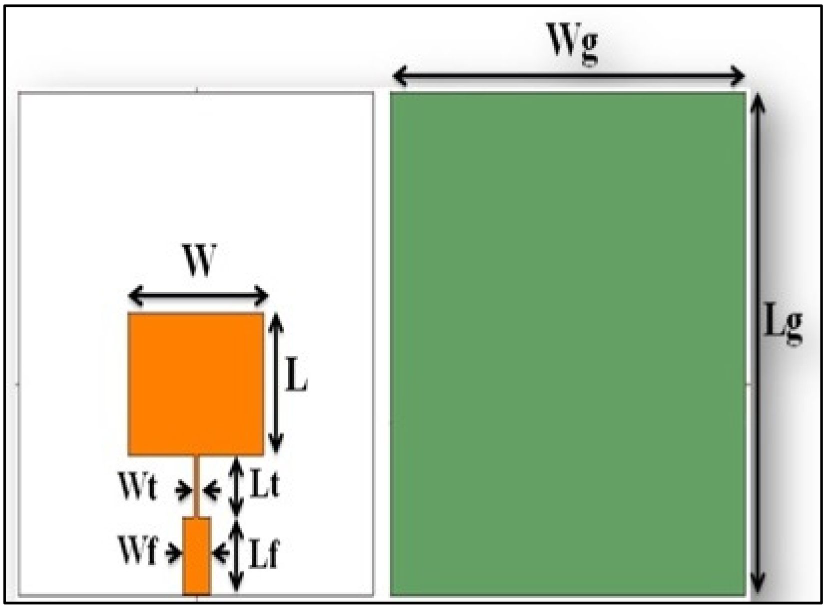
The conventional SQMSA has been designed by using formulas discussed in Section 4.2 and optimized by using method of movement HFSS electromagnetic simulation tool. Figure. 4.2(a) shows the geometry and photographic interpretation of the conventional SQMSA, where a low cost modified glass epoxy dielectric material with relative permittivity (ε_r) of 4.2 with thickness (h) is of 1.6 mm is chosen. The conventional proposed antenna of 2.4 GHz is designed with dimensions length of patch L= 3.010 cm and the width of the radiating patch W= 3.010 cm respectively, which is provoked by simple 50Ω microstrip-line feed be affected by dimensions length $L_f = 1.580\ cm$ and width $W_f = 0.317\ cm$ using quarter wave transformer of length L_t= 1.580 cm and W_t = 0.0580 cm for their impedance matching. The ground plane has length of L_g= 7.193 cm and W_g= 4.200 cm is chosen.

4.4.1. Results and discussions

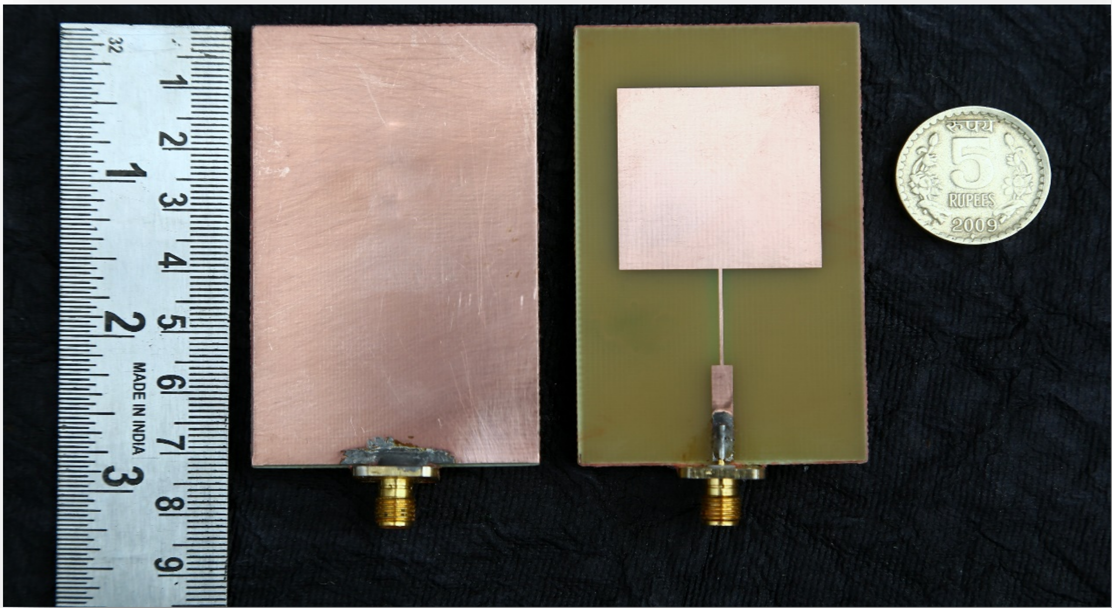
The proposed conventional SQMSA has been realized and optimized by means of HFSS simulation tool, after the simulations the antenna is fabricated by using lithographic process for practical measurement using VNA. The simulated antenna found resonating at 2.38 GHz with lowest return loss of -15.4 dB with bandwidth of

[1] International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE) **"Performance Analysis and Comparison of Square and Rectangular Antenna Embedded with Same DGS"** Vol-3 Issue-2, Feb-2015, pp. 1126-1131 ISSN: 2320-9798, Impact factor 6.577. (peer reviewed)

120 MHz, whereas the measured antenna is resonating at 2.35 GHz with lowest return loss of -14.22 dB giving bandwidth of 128 MHz



(a) Design Geometry



(b) **Photographic view of the conventional 2.4 GHz SQMSA**

Figure 4.2: Geometry of 2.4GHz SQMSA

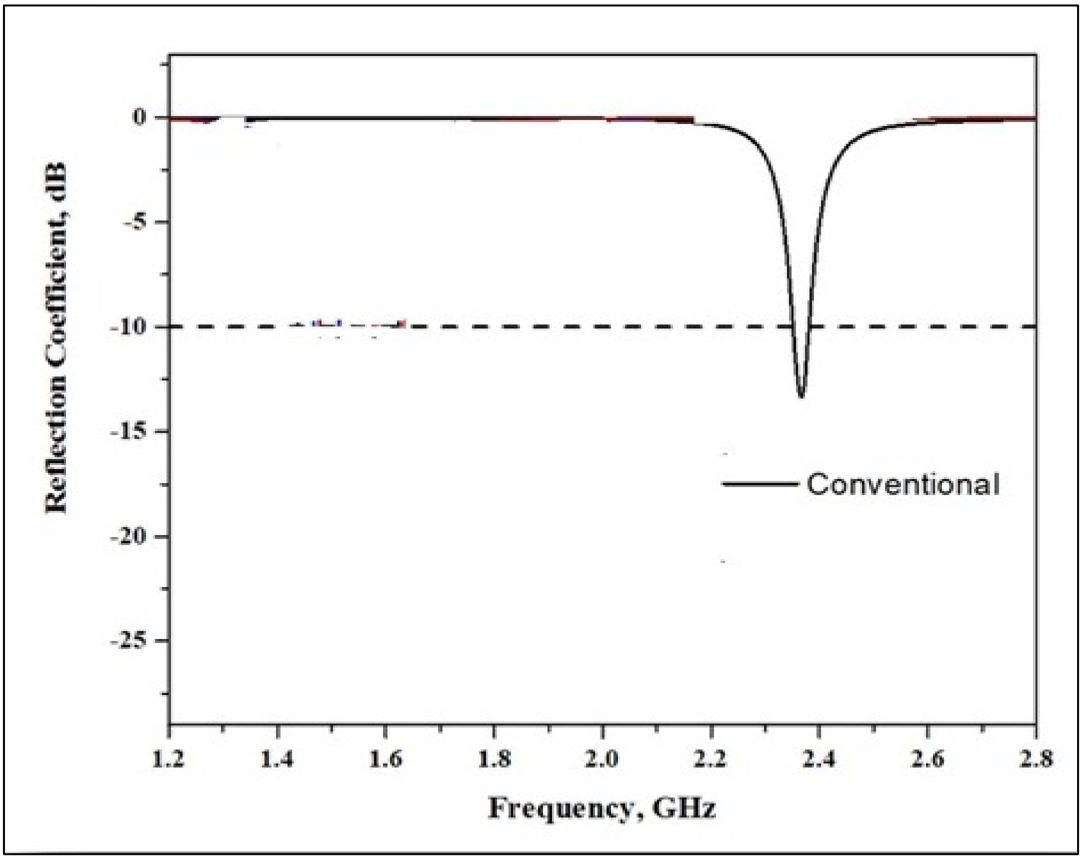


Figure. 4.3: Measured return loss characteristics of 2.4GHz SQMSA

In the Figure. 4.3 shows simulated and measured value of return loss features of conventional 2.4GHz SQMSA for comparison. From the figure a reasonable agreement involving both simulation results and measured data is seen. The comparison results are tabularized in Table 4.1.

Table 4.1: Comparison of simulated and measured parameters of 2.4GHz SQMSA

Antenna	Resonating Frequency (GHz)		Return loss (dB)		Bandwidth (MHz)		Bandwidth (%)	
	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
SQMSA	2.38	2.35	-15.4	-14.22	120	128	2.65	2.814

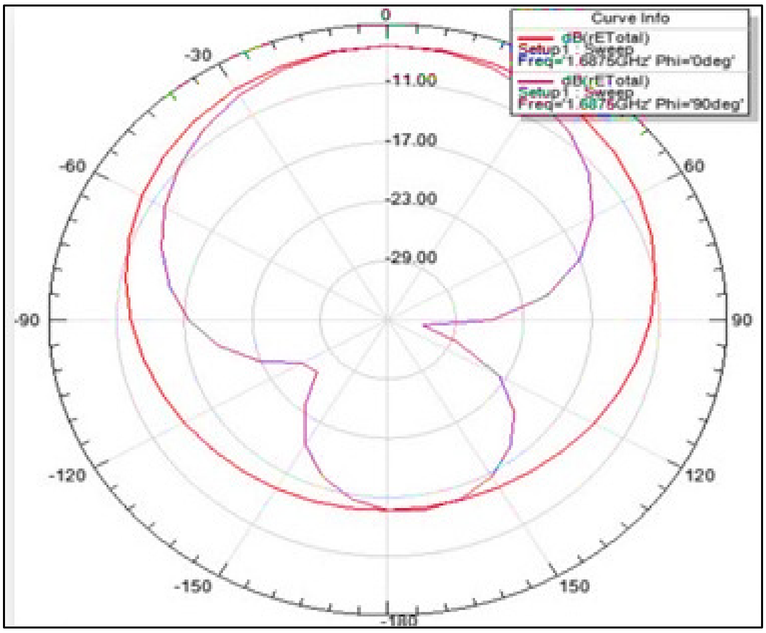
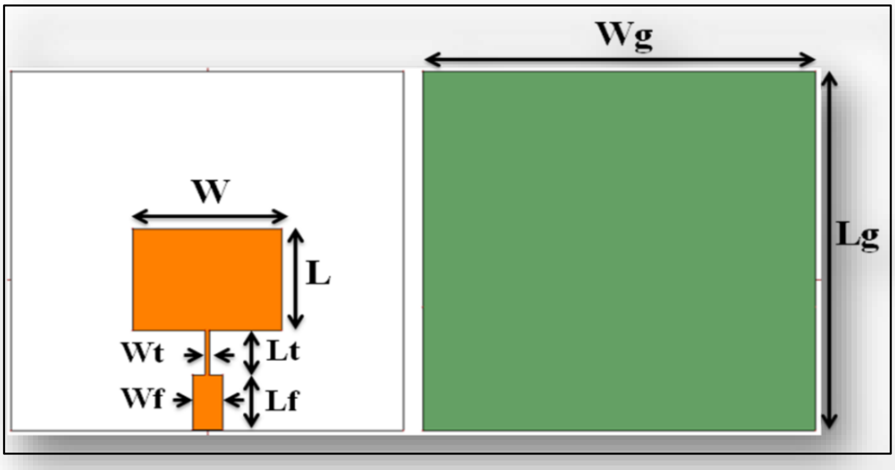


Figure. 4.4: Radiation pattern of SQMSA at 2.38 GHz

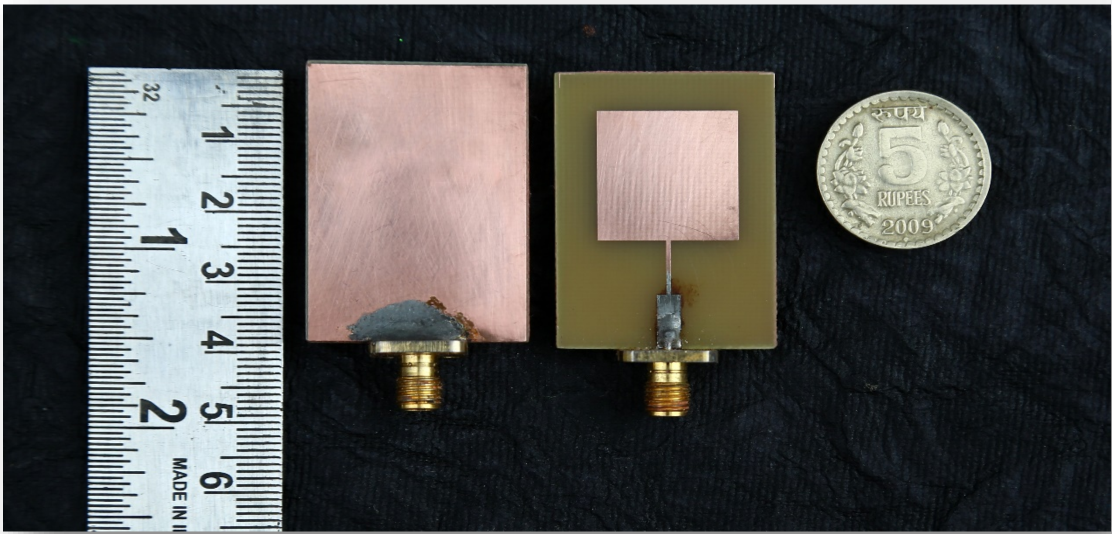
The radiation pattern has been studied. Figure. 4.4 shows the typical elevation radiation pattern of conventional SQMSA taken at resonant frequency from figure the pattern shows broadside radiation. The gain is found 3.6 dBi for designed antenna.

4.5. Design of conventional 5 GHz Square Microstrip antenna (SQMSA)

The conventional SQMSA has been designed by using formulas discussed in Section 4.2 and optimized by using method of movement HFSS electromagnetic simulation tool. Figure. 4.5(a) shows the geometry and photographic interpretation of the conventional SQMSA, where a low cost modified glass epoxy dielectric material with relative permittivity (ε_r) of 4.2 with thickness (h) is of 1.6 mm is chosen. The conventional antenna is designed for 5 GHz with length of radiating patch L= 1.8605 mm and the width of the radiating patch W= 1.8605 mm respectively, which is provoked by simple 50 Ω microstrip-line feed be affected by dimensions length $L_f = 0.7702\ mm$ and width $W_f = 0.3161\ mm$ using quarter wave transformer of length Lt= 0.7746 mm and Wt=0.0609 mm for their impedance matching. The ground plane has length of Lg= 3.9323 mm and Wg=2.8205 mm is chosen.



(a)



(b)

Figure. 4.5: (a) Geometry and (b) photographic view of the conventional 5GHz SQMSA

4.5.1. Results and discussions

The proposed conventional SQMSA has designed and optimized by HFSS simulation tool, after the simulations the antenna is fabricated by using lithographic process for practical measurement using VNA. The simulated antenna is found resonating at 4.837 GHz with lowest return loss of -22.36 dB with bandwidth of 150 MHz, whereas the measured antenna is found resonating at 4.97 GHz with lowest return loss of -32.42 dB giving bandwidth of 187 MHz

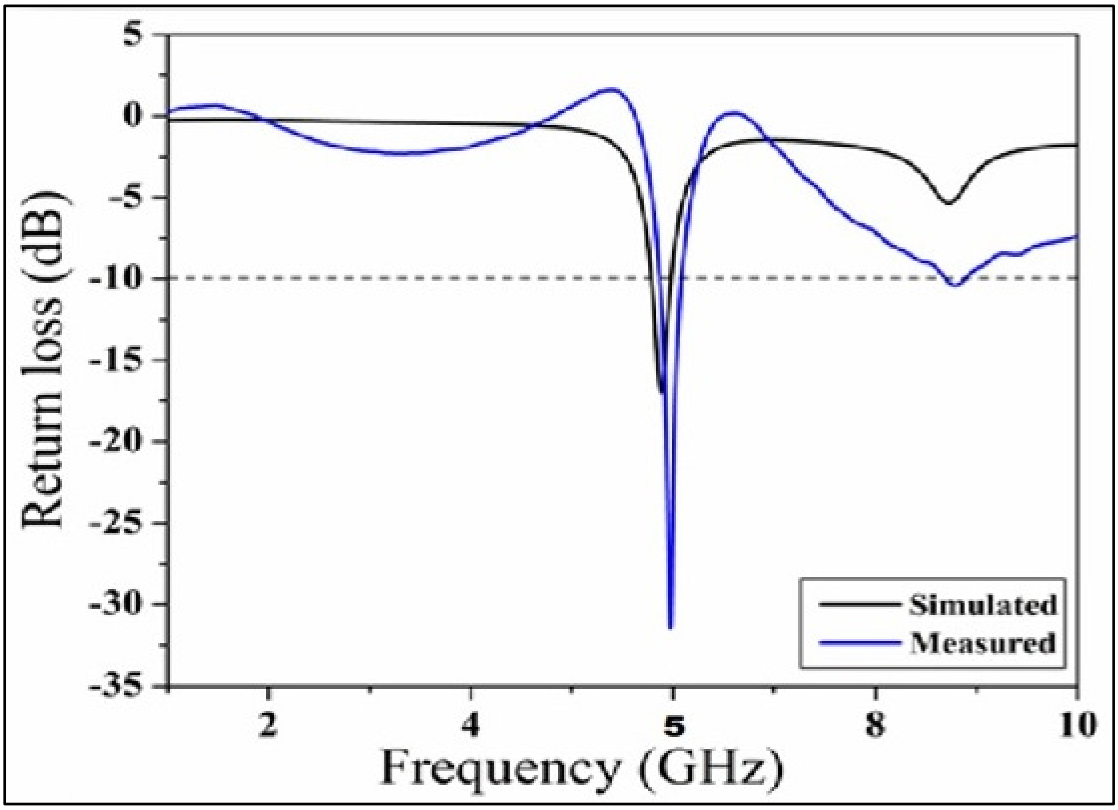


Figure. 4.6: Simulated and measured return loss characteristics of SQMSA

In the Figure. 4.6 shows return loss characteristics of conventional SQMSA for comparison. From the figure a reasonable understanding between the simulation results and measured data is seen. The comparison results have been tabulated in Table 4.2.

Table 4.2: Comparison of simulated and measured parameters of 5 GHz SQMSA

Antenna	Resonating Frequency (GHz)		Return loss (dB)		Bandwidth (MHz)		Bandwidth (%)	
	Sim	Meas	Sim	Meas	Sim	Meas	Sim	Meas
SQMSA	4.837	4.97	-22.36	-32.42	150	187	2.98	4.18

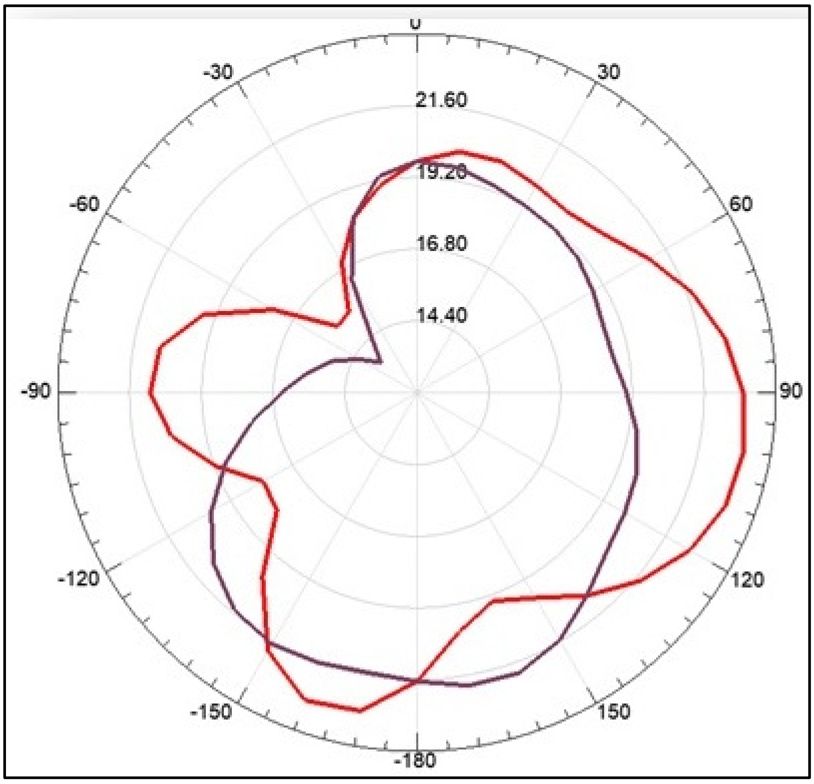


Figure. 4.7: Radiation pattern of SQMSA at 4.83 GHz

The radiation pattern is studied. Figure. 4.7 shows the typical elevation radiation pattern of conventional SQMSA taken at which antenna is found to resonant at 4.83 GHz. From figure the pattern shows broadside radiation. The gain of antenna designed is 4.18 dBi.

4.6. Design of Defected Ground Structure

Design and investigation are two challenges for DGS. The commercially accessible EM solvers is utilized to design and investigate DGS structures. To relate the proposed designed antenna embedded with DGS section to a practical circuit design example, it is essential to extract the corresponding circuit parameters. In process to obtain the equivalent circuit parameters of unit cell DGS at the reference plane, the *S*-parameters vs. frequency would be computed by full wave electromagnetic (EM) simulation to describe the cut off features of DGS section. [37]

The flow chart in Figure. 4.8 shows conventional design and investigation methods of DGS's. The full wave solver is utilized to obtain the *S*-parameters performance of the DGS. The disadvantage of this method that is having no direct correspondence between the physical dimensions of DGS and the equivalent LC parameters. A microstrip patch antenna is actually an open resonator restricted by two electric walls at top and bottom. The ground plane serves as the bottom boundary and as such a defect on ground plane under the patch should perturb the excited EM fields [37]. This in turn should cause several changes in field profile or their orientation under the patch. This basic conception has been implemented to develop or modify the properties of microstrip patch antennas.

Flow chart provides a flow of how DGS is embedded on ground plane of designed antenna and is studied, in this work the defect is embedded exactly below the patch dimensions only to increase the antenna performance, since below the patch antenna provides some better results. Detailed explanation of effect of and limitation of defect is explained in further chapters which gives an improved understanding of which is the best optimal position of placing the defect on ground plane.

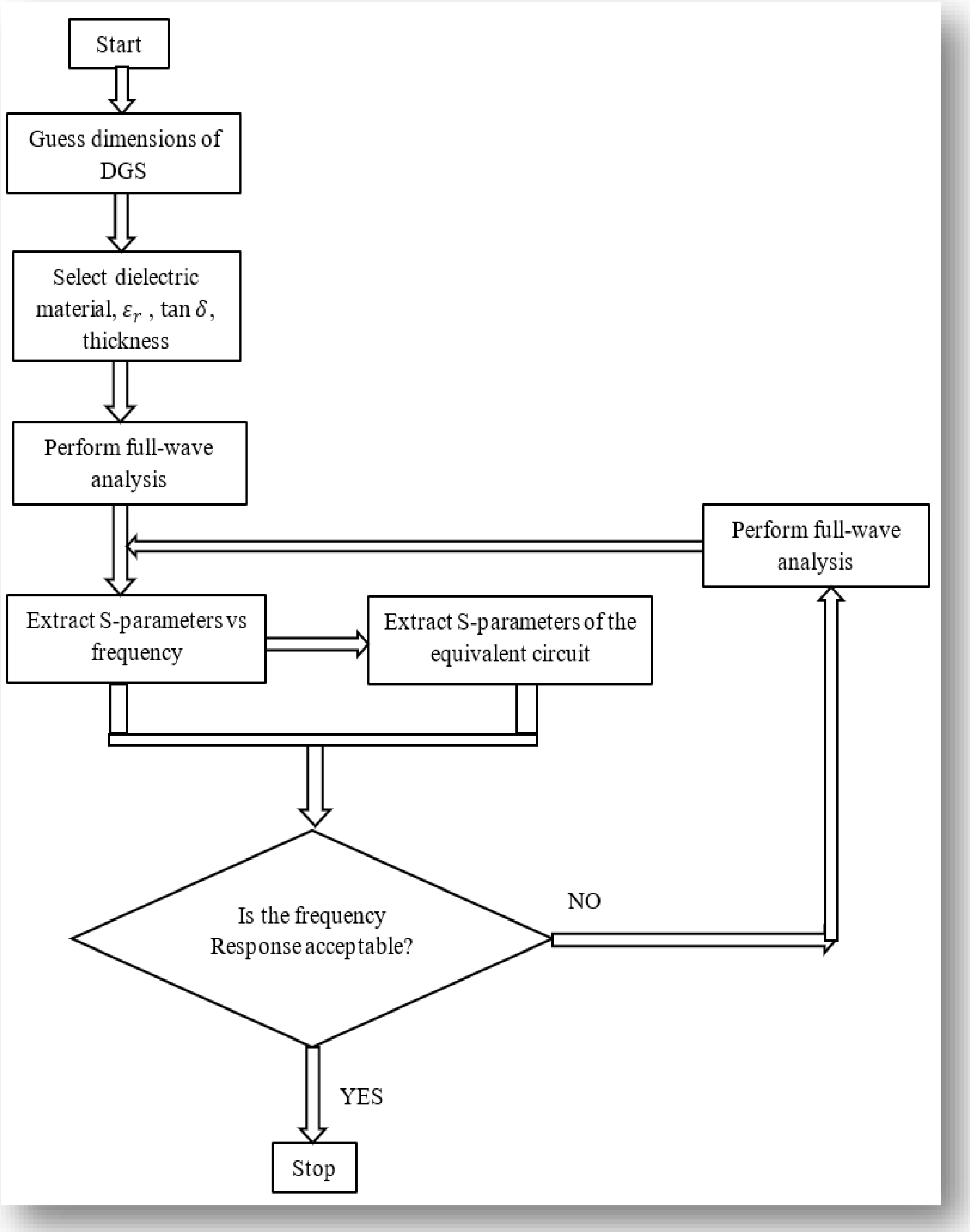


Figure 4.8: Conventional design and analysis method of dumbbell DGS.

Using the above conventional design, various shapes of defects has inserted on ground plane of conventional antenna. In the succeeding chapter, a detailed result analysis on the DGS embedded antennas and novel design structures are studied, where the chapter is divided into two sections to provide a separate study for 2.4 GHz conventional design embedded with DGS after observing the parametric changes. Further study is continued on 5 GHz conventional design embedding with novel design structures on ground plane.