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DESIGN AND ANALYSIS OF DOUBLE U SLOT LOADED DUAL FREQUENCY MICROSTRIP ANTENNA

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Abstract—The objective of the work is to design a dual frequency microstrip antenna for small frequency ratio applications. The proposed geometry comprised of suspended truncated circular microstrip antenna, with double U slot etched on the radiating element. The design parameters are radius of circular patch, width and length of slot, height of air gap. The proposed design of the antenna has enough freedom to control the dual design frequencies/frequency ratio by varying the above design parameters. FR4 substrate with dielectric constant 4.4 is chosen for design and fabrication. The dual design frequencies are 1.93 GHz and 2.17 GHz, covering the applications such as WCDMA, 3G mobile data terminals, and 4G LTE applications. The antenna is fed by a 50 Ω coaxial probe. The simulation of the antenna is performed using ANSOFT HFSS and analyzed for return loss, VSWR and radiation pattern. The antenna is fabricated and tested for impedance matching and radiation characteristics. The simulation and experimental results show that the antenna worked well at desired dual frequencies. The impedance matching is well at both frequencies (VSWR < 2). Though, the measured radiation pattern is unidirectional in co-polarisation, nearly omnidirectional (butterfly) pattern is obtained in cross-polarisation and gain is about 5.54 dB at 1.93 GHz and 8.23 dB at 2.17 GHz. Also, the design is well suited for small frequency ratio dual frequency applications.

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1. INTRODUCTION

In wireless communication applications, microstrip antennas play a vital role due to numerous advantages such as light weight, easy fabrication, dual/multi-band operation, dual or circular polarisation and low cost. Several compact dual band microstrip antennas have been reported over the years. A simple technique for achieving dual band operation has been to load the radiating patch with a slot, when properly designed [1]. Dual frequency microstrip antennas found in the literature can be divided into three categories, (a) Orthogonal mode dual frequency patch antenna, (b) multi-patch dual frequency patch antenna, (c) reactively loaded dual frequency patch antennas. In all the above techniques, the general concept is that the fundamental resonant mode is perturbed in order to get the dual frequency operation. The popular method for getting the dual frequency operation is to connect a stub or etching a slot on the patch, known as reactive loading of the MSA [2]. In recent years, some papers were reported for dual/triple band operation by using single/double U slot in the microstrip antenna. It is seen that the applications which require dual frequency operation with small frequency ratio were designed by using the U slot in a wideband microstrip antenna [3]. Dual frequency operation is achieved by introducing half U slot in a semicircular disk patch antenna [4]. A few designs by using U slot in getting the dual frequency and circular polarization were widely discussed in [5–11].

In this work, a double U slot loaded Microstrip antenna is designed, simulated, fabricated and tested for dual band operation. The paper is organized as follows: Section 2 explains the antenna structure, Section 3 describes about the simulation results, Section 4 details about the experimental results and Section 5 concludes the paper.

2. ANTENNA STRUCTURE

The proposed antenna structure is shown in Figure 1 (top view) and Figure 2 (side view). The truncated circular patch of radius 'a' is printed on the FR4 substrate ($\varepsilon_r = 4.4$). A double U slot with width 5 mm is cut in the truncated circular disk patch antenna. Also, it is a suspended type microstrip antenna. The air gap between the substrate and ground plane is used for increasing the bandwidth. The design requires dual frequency operations at 1.93 GHz and 2.17 GHz. It is desired to obtain the radiation pattern unidirectional and moderate gain of more than 5 dB at both frequencies.

The general formulae for designing circular disk patch antenna is

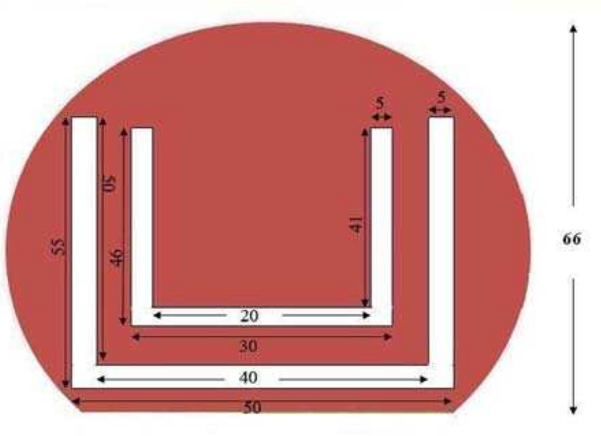

Figure 1. Top view of MSA (All dimensions are in mm).

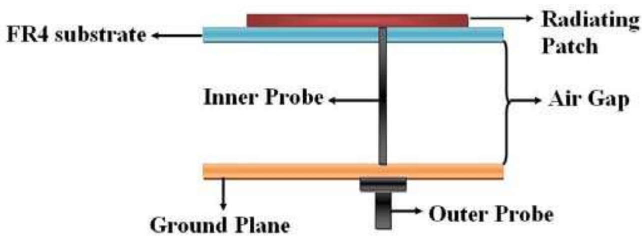

Figure 2. Side view of MSA.

listed below by Equations (1)–(6), mentioned in [12, 13].

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

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

$$a_e = a\left\{1 + \frac{2h}{\pi\varepsilon_r a}\left[\ln\left(\frac{\pi a}{2h} + 1.7726\right)\right]\right\}^{1/2} \tag{3}$$

The equivalent dielectric constant for air-substrate geometry is given in the Equation (4) in [14]

$$\varepsilon_{eq} = \frac{\varepsilon_r\,(h+g)}{(\varepsilon_r g + h)} \tag{4}$$

The radius of the circular patch is found by replacing ε_r by ε_{eq}.

The value of initial air gap for approximately obtaining maximum bandwidth is given in the Equation (5) in [13],

$$g \approx 0.14\lambda_0 - h\sqrt{\varepsilon_r} \tag{5}$$

where a = radius of circular disk patch; a_e = effective radius of circular disk patch

ε_r = dielectric constant of the substrate,

ε_{eq} = equivalent dielectric constant for air-substrate geometry,

g = height of air gap; h = thickness of the substrate,

f_r = resonant frequency; λ_0 = center wavelength.

The initial value of air gap is found from Equation (5). The equation holds good for maximum attainable bandwidth. The centre frequency is assumed as 2 GHz. FR4 substrate is chosen as substrate ($\varepsilon_r = 4.4$). Using the above Equations (1)–(5), the initial dimensions of antenna were found. Then, the design and simulation of the antenna is carried out using ANSOFT HFSS software by using the initial values. The dimensions are optimized to get the desired frequencies and also, the design is concentrated on the compactness of the antenna, especially reducing the air gap height, hence to reduce the overall thickness of substrate. The increase in thickness of the air-substrate geometry leads to increase in surface waves, reducing the radiation efficiency and gain of the antenna. The final design parameters are given in Table 1.

Table 1. Design specifications of the proposed patch antenna.

Design parameters	Final value
Air gap height 'g'	8 mm
Radius of the circular patch 'a'	40 mm
Substrate thickness 'h'	1.6 mm
Dielectric constant 'ε_r'	4.4
Equivalent dielectric constant (air-substrate) 'ε_{eq}'	1.14

The above final values are used for simulating the characteristics of the antenna. The U slot actually perturbs the resonant frequency of circular disk patch. The order of few modes of circular disk patch antenna is TM_{11}, TM_{21}, TM_{02}, TM_{31} and TM_{12} based on values of roots of Bessel's function

$$f_r = \frac{\chi_{\mathrm{nm}} \times c}{2\pi a_e\sqrt{\varepsilon_r}} \tag{6}$$

The fundamental mode in the circular disk patch is TM_{11}, χ_{nm} value = 1.841.

$$C = \text{velocity of light} = 3 * 10^8\,\text{m/s}.$$

The resonant frequency of circular patch with air gap is modified as

$$f_r = \frac{\chi_{\mathrm{nm}} \times c}{2\pi a_e \sqrt{\varepsilon_{eq}}} \tag{7}$$

For TM_{11} mode, the theoretical value of f_r for circular patch of radius 40 mm is found to be 1.685 GHz. This value is for a circular patch without truncation and before etching the double U slot in the radiating patch. The desired frequencies of resonances can be obtained by properly designing the double U slot and also, the circular patch is truncated in order to reduce the actual area of radiating patch. The U slot length, width and the height of air gap, dielectric substrate thickness and dielectric constant of the substrate are the key design parameters in designing the antenna.

3. SIMULATION RESULTS

The simulation of the above designed antenna was performed using ANSOFT HFSS software. Figure 3 shows the Return loss (dB) vs Frequency (GHz) plot.

The FR4 substrate size of 100 mm * 100 mm * 1.6 mm is chosen as a dielectric material. Coaxial probe is used for exciting the patch. The feed position of the patch is optimised for getting the dual frequencies.

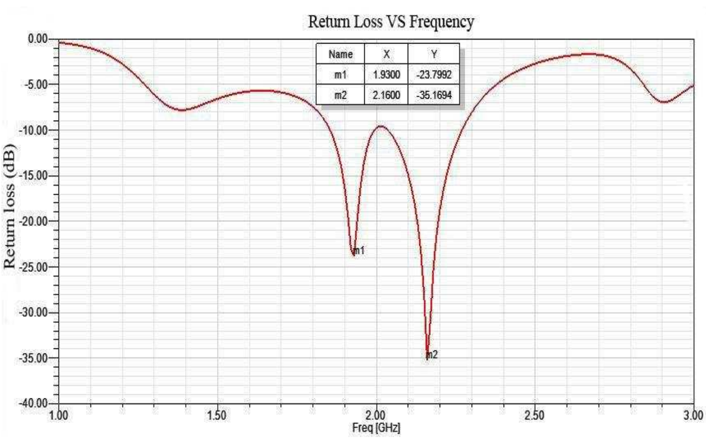

Figure 3. Return loss (dB) vs frequency (GHz).

Return loss (dB) is defined as that the difference in dB between power sent towards antenna under test (AUT) and power reflected [14]. The requirement for reflection coefficient for wireless devices specifies 10 dB return loss bandwidth.

Figure 3 shows the Return loss (dB) vs Frequency (GHz) graph. It is inferred from the return loss graph that the antenna exhibits return loss value −23 dB at 1.93 GHz and −35 dB at 2.17 GHz. Hence, the impedance matching is well at both frequencies with reference to a 50 Ω characteristic impedance coaxial cable assumed in the simulation.

Figures 4 and 5 show the radiation pattern, computed for dual

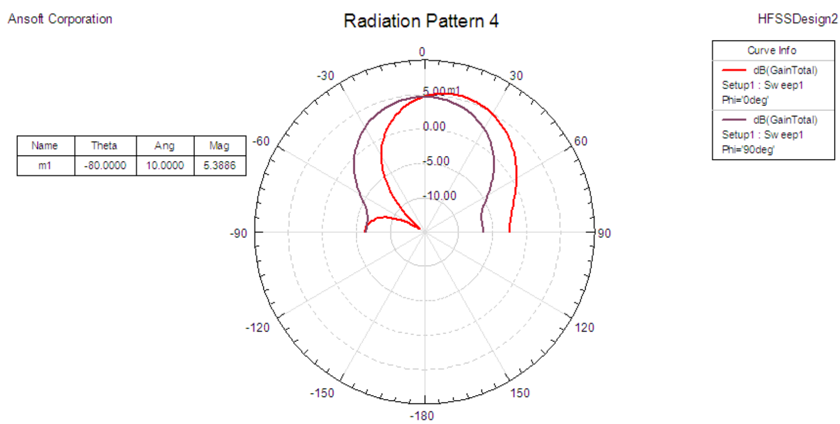

Figure 4. Radiation pattern at 1.93 GHz.

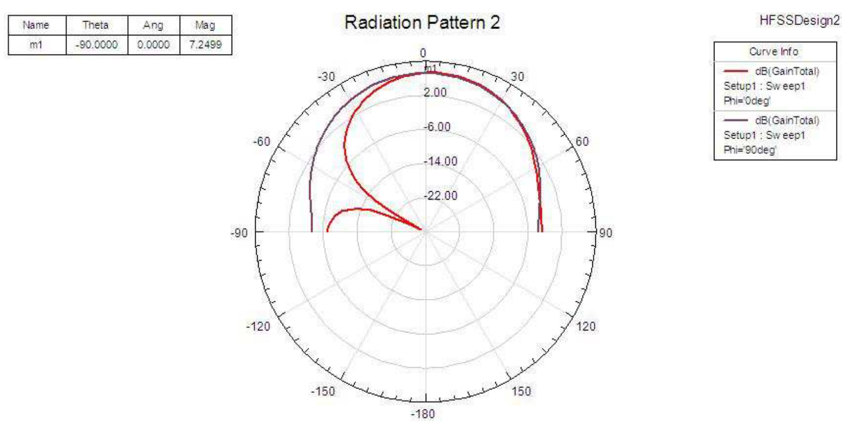

Figure 5. Radiation pattern at 2.17 GHz.

frequencies in both principal planes namely, $\varphi = 0°$ and $\varphi = 90°$. The radiation pattern at 1.93 GHz shows maximum radiation in the upper half and gain is about 5.3 dB in the $\varphi = 0°$. The maximum gain is obtained at $\theta = 10°$. Since, infinite ground plane is assumed, the simulated patterns do not show much side lobes/back lobes. The radiation pattern at $\varphi = 90°$ plane has broadside pattern covering more area. The gain value is about 5.3 dB.

The radiation pattern at 2.17 GHz shows maximum radiation in the upper half and gain is about 7.2 dB in the $\varphi = 0°$. The maximum gain is obtained at bore-sight axis $\theta = 0°$. The radiation pattern at $\varphi = 90°$ plane has unidirectional pattern, covering wide area. The gain value is about 7.3 dB. Compared to the lower frequency of operation, this antenna has very high gain value at 2.17 GHz, i.e., due to well impedance matching at this frequency (VSWR attains approximately unity).

The radiation efficiency of the antenna is also computed at both frequencies separately. The value of radiation efficiency at 1.93 GHz and 2.17 GHz are 87.78% and 94.84% respectively.

4. EXPERIMENTAL RESULTS

Figure 6 shows the photograph of the fabricated antenna. The experimental results of impedance matching (return loss plot) is measured using Agilent make vector network analyzer. Initially, the calibration is done to make the cable loss to zero at the desired frequency range. Figure 7 shows the measured Return loss (dB) vs frequency (GHz) plot.

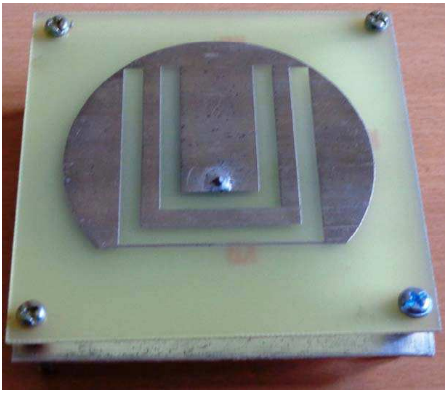

Figure 6. Photograph of the fabricated antenna.

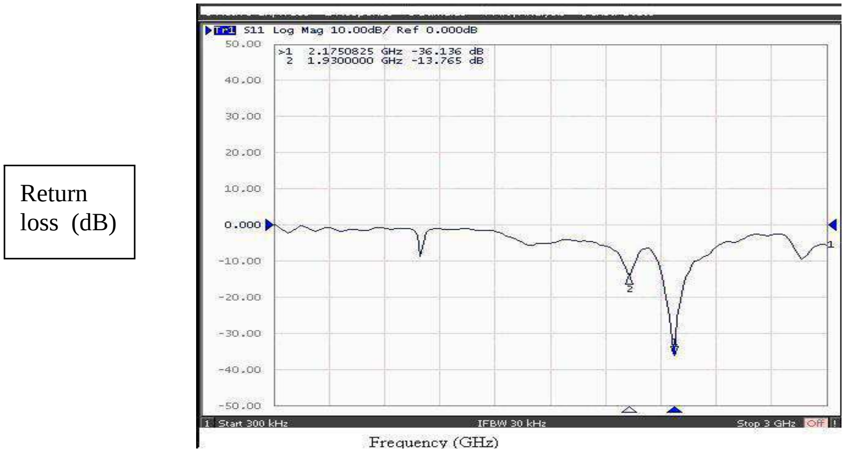

Figure 7. Measured return loss vs frequency (GHz).

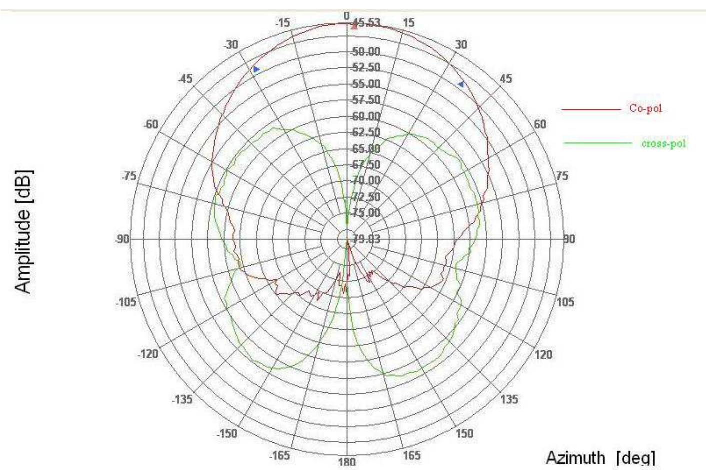

Figure 8. Measured radiation pattern at Co-pol and at cross-pol at1.93 GHz.

The measured return loss shows that the fabricated antenna resonates exactly at same desired frequencies. The impedance matching is well at both desire frequencies at 1.93 GHz and 2.17 GHz. The measured return loss is −13.765 dB at 1.93 GHz and −36.136 dB at 2.17 GHz. The impedance bandwidth obtained at 1.93 GHz is about 100 MHz (5.1% at centre frequency 1.93 GHz) and 150 MHz at 2.17 GHz (6.91% at centre frequency 2.17 GHz).

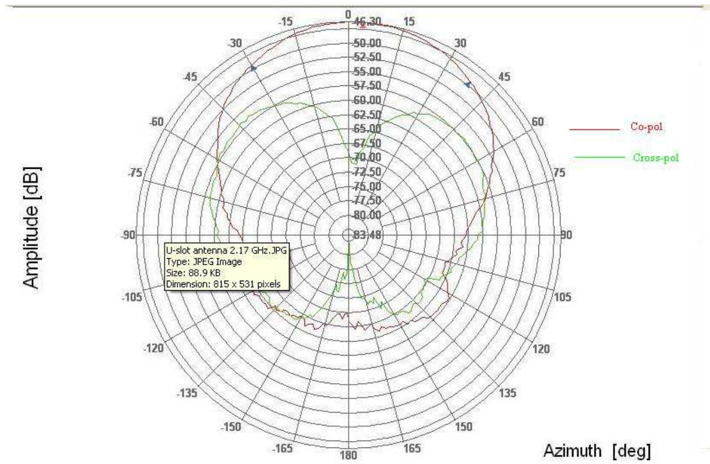

Figure 9. Measured radiation pattern at Co-pol and at cross-pol at 2.17 GHz.

The radiation pattern and Gain measurement is taken in an anechoic chamber. Figure 8 shows the radiation pattern at 1.93 GHz in both principal planes.

The measured pattern at co-polarization radiates mostly in the upper hemisphere. The main beam peak is obtained as -45 dB at $\theta = 2^\circ$. The 3 dB beam width, HPBW is about 64° in the co-polarization. The front to back ratio is 35 dB which ensures unidirectional pattern, required for mobile application receivers. The cross polarization pattern shows an approximate omni-directional butterfly pattern, a null present in the boresight axis at $\theta = 0^\circ$ and $\theta = 180^\circ$. The main beam peak is obtained as -55 dB at $\theta = -142^\circ$. The 3 dB HPBW is about 45°. The gain of the antenna is measured at 1.93 GHz using standard gain antenna procedure. The standard gain horn antenna is used as reference antenna. The gain value at co-polarisation is measured as 5.54 dB.

Figure 9 shows the radiation pattern at 2.17 GHz for co and cross polarizations. The measured pattern at co-polarization radiates mostly in the upper hemisphere. The main beam peak is obtained as -46 dB at $\theta = 4^\circ$. The 3 dB beam width, HPBW is about 68° in the co-polarization. The front to back ratio in the co-pol is 35 dB which ensures unidirectional pattern, required for mobile application receivers. The cross polarization pattern shows a butterfly pattern, a null present in the boresight axis at $\theta = 0^\circ$ and $\theta = 180^\circ$. The main beam peak is obtained as -56.35 dB at $\theta = -44^\circ$. The 3 dB HPBW is about 62°. The gain of the antenna is measured at 2.17 GHz using standard gain antenna procedure. The standard gain horn antenna is used as reference antenna. The gain value at co-polarization is measured as 8.23 dB.

From Table 2, it is very clear that the antenna is well working at desired dual frequency band and the gain of the antenna is high at both frequencies.

Table 2. Table 2 shows the comparison of simulated and measured results at both desired frequencies.

Parameters	Lower resonant frequency 1.93 GHz		upper resonant frequency 2.17 GHz	
	simulated	measured	simulated	measured
Resonant frequency f_r	1.93 GHz	1.93 GHz	2.17 GHz	2.17 GHz
Return loss (dB)	−23.7792	−13.765 dB	−35.1694	−36.136 dB
Gain (dB)	5.3	5.54	7.3	8.23
3 dB Beamwidth	65°	64.48°	62°	68.35°
Impedance bandwidth	1.77–1.99 (200 MHz)	100 MHz	195 MHz approximately	150 MHz approximately

5. CONCLUSION

Hence, the suspended dual frequency MSA with double U slot is designed, simulated, fabricated using FR4 substrate. The desired working frequencies for this antenna are 1.93 GHz and 2.17 GHz. The antenna exhibits good impedance matching bandwidth 5.1% and 6.9% at lower and upper resonant frequencies respectively. The radiation characteristics reveal that the antenna has moderate gain value 5.54 dB and 8.3 dB at lower and upper resonances respectively and shows unidirectional pattern, showing FBR of more than 25 dB at both resonances 1.93 GHz and 2.17 GHz. It is clearly demonstrated from the simulation and measured results. Also, the design offers freedom to the antenna engineer for changing the operating frequencies by varying the slot length and width, air gap, circular patch radius etc. The frequency ratio between upper and lower resonance is 1.21. The design is most adaptable to low frequency ratio dual frequency MSA applications. The desired center frequencies of this antenna cover 3G WCDMA and 4G Long term equipment (LTE) applications.

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