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Analysis of Transverse Magnetic Modes in Microstrip Patch Antenna

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ABSTRACT

Transverse magnetic modes in microstrip patch antenna are analyzed. Two radiation beams off broadsides are obtained by operating the patch antenna at the higher order mode TM02 instead of the fundamental mode TM01 which radiates a broadside beam. Antenna bandwidth is broadened by using a U-slot technique. Rogers RT Duroid with the relative permittivity 2.2 is used as a dielectric substrate material with the thickness of 3.175mm. The proposed patch antenna is designed and simulated by using HFSS. The antenna frequency range is 5.18-5.8GHz with VSWR less than 2, with the impedance bandwidth of 11.8%. The antenna resonates at 5.2 GHz, which exhibits two radiation beam

Keywords: Transverse Magnetic Modes, Microstrip Patch Antenna, Radiation beam.

1. INTRODUCTION

Microstrip antennas offer the advantages of thin profile, light weight, low cost, and conformability to a shaped surface and compatibility with integrated circuitry. In addition to military applications, they have become attractive candidates in a variety of commercial applications such as mobile satellite communications, the direct broadcast (DBS) system, the global positioning system (GPS), remote sensing and hyperthermia. This was led to extensive research aimed at improving the impedance bandwidth of microstrip antennas in the last several years.

The basic form of the microstrip antenna, consisting of a conducting patch printed on a grounded substrate, has an impedance bandwidth of 1-2%. One way of improving the bandwidth to 10-20% is to use parasitic patches, either in another layer (stacked geometry) or in the same layer (coplanar geometry). However, the stacked geometry has the disadvantage of increasing the thickness of the antenna while the coplanar geometry has the disadvantage of increasing the lateral size of the antenna. It would therefore be of considerable interest if a single-layer single-patch wideband microstrip antenna could be developed. Such an antenna would better preserve the thin profile characteristics and would not introduce grating lobe problems when used in an array.

Indoor wireless links have intrinsic characteristics that affect the system performance, such as the multipath effect that causes signal fading, and interference effect from adjacent cells that degrades the bit error rate. From the physical layer perspective, one solution to combat these impairments is the use of directional antennas rather than the traditional omnidirectional ones [1]. They have the ability to confine the power in certain directions instead of scattering the power everywhere. As a result of less power loss toward unwanted directions, the multipath and interference effects are reduced. Directional antennas can be single or dual/multi-beam. Dual/multi-beam antennas are antennas that have more than one directive beam from a single aperture. These antennas are useful for indoor wireless systems which require coverage of multiple areas [2], as they reduce the required number of antennas and are found to improve the link quality [3], resulting in easier network deployment.

Microstrip antennas have been widely used in many modern communication systems, because of its robustness, planar profile, and low cost. Most of these antennas operate at their fundamental mode $TM01$, which gives a broadside beam [4]. Microstrip antenna operating at the higher order $TM02$ mode has dual symmetric radiation beams, with each beam directed at respectively [5][6]. It is well known that the major drawback of a microstrip antenna is its narrow bandwidth. One of the popular techniques for broadening the patch antenna bandwidth is to incorporate a U-slot on its surface as proposed in [7][8]. U-slot microstrip antenna operating at the TM_{02} mode to attain dual radiation beams with wideband performance is proposed. The U-slot inclusion on the patch's surface introduces asymmetry, which affects the radiation, such as pattern symmetry, pattern stability, cross-polarisation level, and the direction of the beams [9].

In this paper, radiation characteristics of the microstrip patch antenna are analyzed for different transverse magnetic modes and incorporating U-slot on the patch to attain wideband performance is proposed.

2. ANTENNA GEOMETRY

The proposed antenna geometry is shown in Fig. 1, where a coaxial-fed rectangular patch is printed over a Rogers RT Duroid substrate of thickness 3.175mm and permittivity 4.4. A U-slot is cut on the patch's surface, which is mounted over the substrate of size Lg×Wg=67×74mm. The other side of the substrate is coated with metal, which is the ground plane of the antenna. All the design parameters were calculated by equations that are explained in the following sections and the calculations results of all dimensions are shown in Table I.

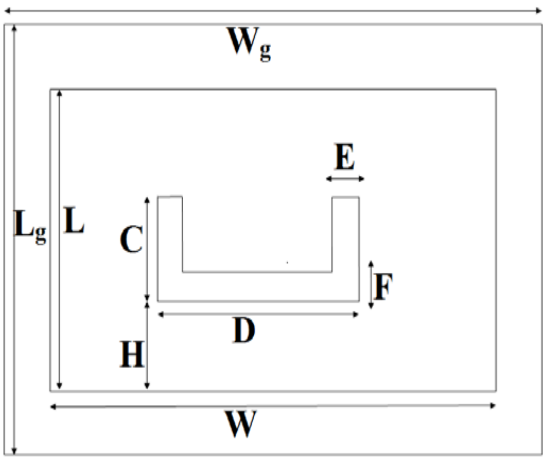

Fig. 1. Geometry of proposed U-Slot microstrip antenna

2.1. Calculation of patch dimension

Width of the patch can be calculated using the below formula [12]:

$$W = \frac{C_0}{2f_0}\sqrt{\frac{2}{1+\epsilon_r}} \qquad (1)$$

Where C_0 is the free-space velocity of light i.e 3×10^8 m/s and ε_r is the dielectric constant of the material here 2.2.

The value of the effective dielectric constant is given by:

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

Where h and W are the height and width of the substrate material for an antenna respectively.

Length of the patch can be calculated as follows:

$$L_{eff} = \frac{C_0}{2f_0\sqrt{\epsilon_{reff}}} - 2dL \qquad (3)$$

The dL is the length extension due to the fringing field and can be calculated using the equation:

$$dL = 0.412h\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (4)$$

In general, the resonant frequency of rectangular patch antennas is calculated by using resonant length transmission line or cavity models, together with equations for the effective dielectric constant and edge extension. The resonant frequency f_{mn} of a rectangular patch of width W and length L is given by

$$f_{mn} = \frac{C_0}{2\sqrt{\epsilon_{reff}}}\sqrt{\left(\left[\frac{m}{L_{eff}}\right]^2 + \left[\frac{n}{W}\right]^2\right)} \qquad (5)$$

2.2 Calculation of ground dimension

The ground dimension of an antenna can be calculated as follows:

Width of the ground is given as:

$$W_g = W+6h \qquad (6)$$

Length of the ground is given as:

$$L_g = L+6h \qquad (7)$$

2.3 Calculation of U-Slot parameters

Slot thickness E and F is given by:

$$E = F = \frac{Wavelength\ of\ light}{60} \qquad (8)$$

Slot width D is given by:

$$D = \frac{C_0}{f_{low}(\epsilon_{reff})^{\frac{1}{2}}} - 2(L + dL - E) \qquad (9)$$

Slot height C is given by

$$C = D \times 0.75 \qquad (10)$$

Other parameters are calculated as:

$$\epsilon_{eff}\,(pp) = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{D-2F}\right]^{-\frac{1}{2}} \qquad (11)$$

Where h is the thickness of the dielectric substrate.

$$2d_{L-E-H} = 0.824h\frac{\left(\epsilon_{reff(pp)} + 0.3\right)\left(\frac{D-2F}{h} + 0.262\right)}{\left(\epsilon_{reff(pp)} - 0.258\right)\left(\frac{D-2F}{h} + 0.813\right)} \qquad (12)$$

Height of slot from base H is given as:

$$H = L - E + 2d_{L-E-H} - \frac{1}{\sqrt{\epsilon_{reff(pp)}}}\left[\frac{C_0}{f_{high}} - (2C + D)\right] \qquad (13)$$

2.4. Feeding technique & location

The common feeding technique used in microstrip patch antennas is coaxial feeding. The inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane. The main advantage of this technique is that feed can be placed at any desired location inside the patch in order to match with its input impedance. The impedance matching will depend on feed point location on the patch. Feed point location in order to match 50ohm impedance is calculated using the following equation:

Along the width of the patch:

$$X_f = \frac{W}{2} \qquad (14)$$

Along the length of the patch:

$$Y_f = Y_0 - dL \qquad (15)$$

Where $Y_0 = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{50}{Z_0}}$ (16)

$$Z_0 = \sqrt{50 \times Z_{IN}} \qquad (17)$$

$$Z_{IN} = 90 \times \frac{{\epsilon_r}^2}{\epsilon_r - 1}\left(\frac{L}{W}\right)^2 \qquad (18)$$

This equation provides only an approximation. Impedance matching was achieved after a lot of iterations and the calculated values are listed in the table:

Table I: Design parameters of U-Slot

SPECIFICATION	VALUES(mm)
Slot Width (D)	12
Slot Length (C)	28.25
Height of Slot from Base (H)	2
Slot Thickness (E=F)	2

3. PARAMETRIC STUDY

The proposed antenna is shown in fig.2. The overall size of the antenna is 67×74×3.175mm.The feeding method used here is coaxial feeding. Due to substrate thickness, the increased probe length makes the input impedance more inductive, leading to matching problems. The parameters that have the critical influence on the antenna performance are chosen for parametric study. These parameters are L, W, C and H. To study their effects on the antenna performance, the parametric study is carried out on the parameters mentioned above.

3.1. Patch with U-Slot

The proposed antenna consists of U-Slot incorporated on the patch is shown in fig. 2 which attains wide bandwidth without adding the parasitic patch in another layer or in the same layer.

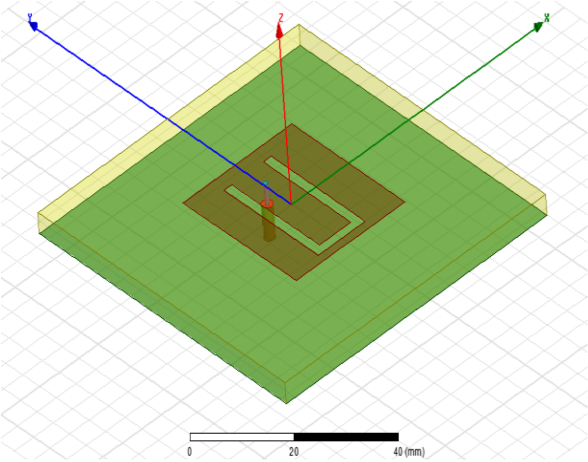

Fig. 2. U-slot Microstrip Patch Antenna

The wideband behavior is due to the fact that current along the edges of slot introduces an additional resonance which in conjunction with the resonance of patch produces broadband frequency response characteristics. It is important to note that, although, this is an electrically thick probe fed patch, there is no inductive component associated with the input impedance is shown in fig.3.This is due to introduction of the slot in the patch which results in capacitive reactance which counteracts with the inductive reactance of the probe. Return loss, VSWR and gain of the proposed antenna are shown in fig.

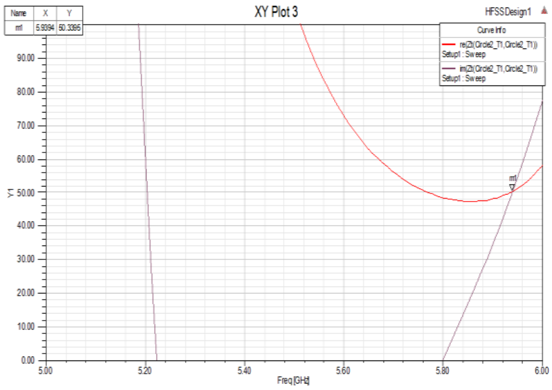

Fig. 3. Impedance Characteristics of the proposed antenna

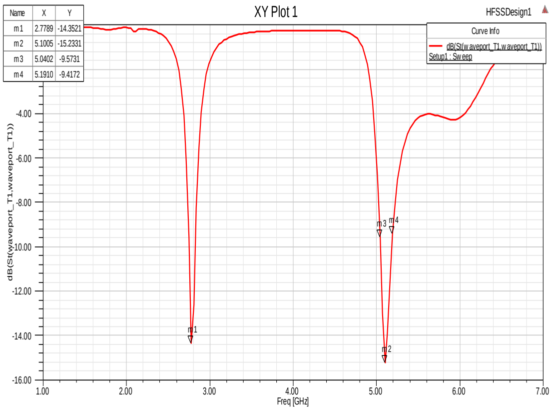

Fig. 4. Return loss of proposed antenna

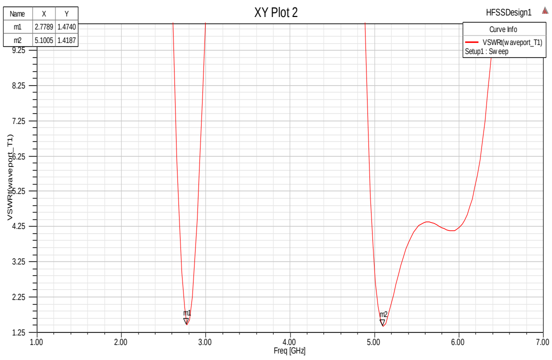

Fig. 5. VSWR of the proposed antenna

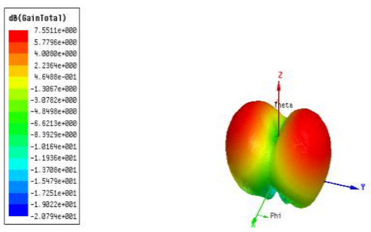

Fig. 6. Gain of the antenna

3.2. Mode of operation

Fig.7 shows the current distribution on the surface of a U-slot patch antenna. From the figure, it is observed that dual mode is obtained by having a patch length L to be λ_d, where λ_d is the wavelength in the dielectric substrate. According to the cavity model of the patch antenna [10], the current on the patch's surface, has two maxima at TM_{02}. Therefore, for a U-slot to work effectively, it should intercept both current maxima. It is obvious that the presence of two maxima on the patch indicates a λ_d resonator at the TM_{02} mode.

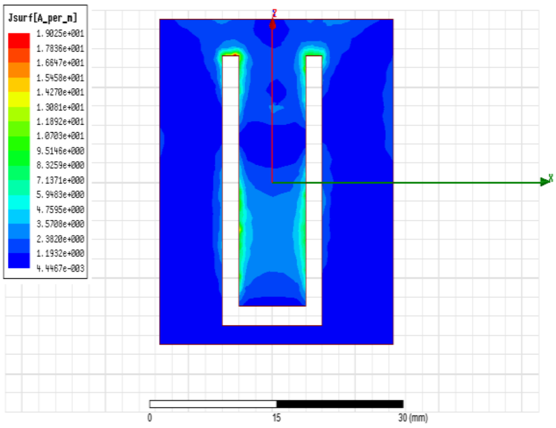

Fig. 7. Current distribution of the antenna at TM_{02} mode

4. CONCLUSION

A U-slot microstrip antenna operating at a higher order mode TM_{02} has been proposed and investigated. The antenna has 11.3% bandwidth (5.17-5.81 GHz) with better impedance matching and exhibits dual radiation beams. The proposed design is a desirable candidate for stationary terminals of various indoor wireless communication networks.

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