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Research paper

Inverted dual U slot loaded truncated microstrip patch antenna for wireless applications

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Abstract

Dual U Slot Loaded Truncated Microstrip Patch Antenna is designed for wireless applications. The proposed geometry comprised of two inverted U slots in truncated circular patch antenna operation covering 2.24 to 2.72 GHZ frequency bands are obtained. It is found that the slot and truncated is used to improve the bandwidth and return loss respectively. The resonant frequency is found to be 2.5GHZ. The bandwidth of the proposed antenna for lower and upper resonant frequency is found to be 19.2%. The proposed antenna is fed by 50Ω co-axial probe feed and simulated on Rogers RT/duroid5880 substrate. Rogers RT/duroid 5880 substrate has dielectric constant and loss tangent of 2.2 and 0.0009 respectively. An air gap is used in this proposed design for tuning the desired frequencies and increasing the bandwidth. The antenna shows an acceptable gain of 2.1dB to 5.7dB with unidirectional pattern over the obtained frequency band.

Keywords: *Microstrip, Line feed, Return loss, VSWR, Gain, Axial ratio, Radiation efficiency*

1. Introduction

In communication systems antenna is a very important component. By definition, an antenna is a device used to convert an RF signal, travelling on a conductor, into an electromagnetic wave in free space. An antenna will maintain the same characteristics regardless if it is transmitting or receiving, this property is known as reciprocity. Many antennas are resonant devices, which operates well over a relatively narrow frequency band. An antenna must be tuned to the same frequency band of radio system to which it is connected; otherwise the receiving and the transmitting will be impaired. When the signal is feed into an antenna, the antenna will emit radiation distributed in space in a certain way. In the antenna design field, the term radiation pattern (or antenna pattern or far-field pattern) refers to variation of power radiated by an antenna as a function of the direction away from the antenna. Antennas have wide range of applications and a few of them are as follows Bluetooth, networking, wireless networking, satellite, Wi-Fi & Wireless LAN applications, GSM, GPS,PCS etc.

2. Literature survey

J.A. Ansari [2011] et.al designed dual frequency resonance antenna by introducing half U-shaped slot in semicircular disk. It is analysed by using circuit theory concept. From the analysis they concluded that compact Half U-slot loaded semicircular disk patch antenna can operate at two resonance frequencies 1.50/2.32 GHz and useful for various applications. The resonance frequency is highly dependent on the slot dimensions as well as probe radius and feed locations.[1]

Ka Yan Lam et.al [2011] they designed a single-feed circularly polarized (CP) patch antenna at L-band and built using the recently developed U-slot loaded patch technique. The antenna is fabricated on a high-dielectric-constant ($\varepsilon_r = 10.02$) substrate with the presence of the U-slot and it achieves a reasonable axial-ratio bandwidth. Their operating frequency is 1.575 GHz, the size of the patch is $0.13\lambda_o \times 0.13\lambda_o$, while the ground size is $0.315\lambda_o \times 0.315\lambda_o$ and the thickness of the substrate is $0.05\lambda_o$. They achieved a measured gain of 4.5 dBi, and axial-ratio bandwidth of 3.2%.[2]

Sanjeev Kumar Mishra et.al. [2011] they proposed a simple, low-cost, and compact printed dual-band fork-shaped monopole antenna for Bluetooth and Ultra Wide Band (UWB) applications Dual-band operation covering 2.4-2.484 GHz (Bluetooth) and 3.1-10.6 GHz (UWB) frequency bands are obtained by using a fork-shaped radiating patch and a rectangular ground patch. The proposed antenna was fed by a 50-Ω microstrip line and fabricated on a low-cost FR4 substrate having dimensions 42 (L_{sub}) × 24 (W_{sub}) × 1.6 (H) mm^3. The antenna structure wass fabricated and tested. Measured S_{11} is $\leq$ -10 dB over 2.3-2.5 and 3.1-12 GHz. The antenna shows acceptable gain flatness with nearly omnidirectional radiation patterns over both Bluetooth and UWB bands [3].

K.F.Lee et.al. [2011] they described dual- and triple-band patch antennas using U-slots [4]. In this approach, one starts with a broadband patch antenna, another U-slot is cut in the same patch or in another patch. It is found that the patterns and gains of the dual-and triple-band antennas are similar to those of the original broadband antenna. Because the band notches introduced by the U-slots occur within the bandwidth of the antenna without slots, this method is suitable when the frequency ratios of the adjacent bands are small, usually less than 1.5.

3. Microstrip antenna

Due to less weight, conformability and low cost, microstrip antennas are attractive. These antennas can be integrated with printed strip-line feed networks and active devices. This is a comparatively new area for antenna engineering. Since the mid 1950's. The radiation properties of microstrip structures have been known. The application of this type of antennas started in early 1970's when conformal antennas were required for missiles. Rectangular and circular micro strip resonant patches have been used widely in a variety of array configurations. A major contributing factor for current advances of microstrip antennas is the recent revolution in electronic circuit miniaturization brought about by developments in large scale integration. As conventional antennas are often bulky and costly part of an electronic system, micro strip antennas based on photolithographic technology are seen as an engineering break through.

Several types of microstrip antennas are available in telecommunications (also known as printed antennas) the most common of which is the microstrip patch antenna or patch antenna. It is wide-beam narrowband fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane.

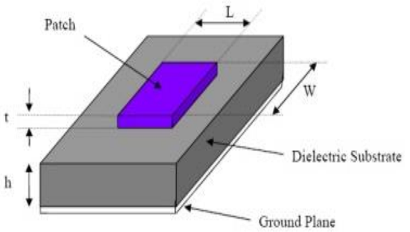

Figure.1: Structure of a microstrip patch antenna

Rectangular microstrip antenna

Patch antennas can be printed directly onto a circuit board therefore it is increasingly used [5]. These antennas are attractive very widespread within the mobile phone market, and also having low cost, low profile and are easily fabricated[6]-[9].

Consider the microstrip antenna shown in figure 1, fed by a microstrip transmission line. The patch antenna, microstrip transmission line and ground plane are made of high conductivity metal (typically copper). The patch is of length L, width W, and sitting on top of a substrate (some dielectric circuit board) of thickness h with permittivity.

The thickness of the ground plane or of the microstrip is not significantly important. Normally the height h is much smaller than the wavelength of operation, but not much smaller than 0.05 of a wavelength.

The frequency of operation of the patch antenna of figure 2 is determined by the length L. The center frequency will be approximately given by,

$$fc = \frac{C}{2L\sqrt{\mathcal{E}r}} = \frac{1}{2L\sqrt{\mathcal{E}r\mathcal{E}o\mu o}} \qquad (1)$$

The above equation says that the microstrip antenna should have a length equal to one half of a wavelength within the dielectric (substrate) medium.

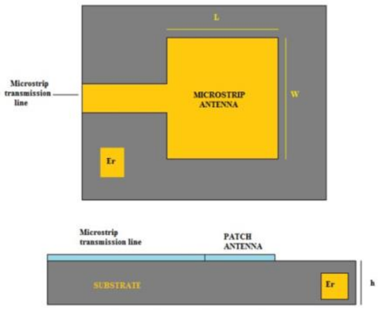

Figure.2: Geometry microstrip patch antenna

Microstrip antenna parameters

The performance of the antenna is determined by several factors includes radiation pattern, VSWR, return loss, directivity, gain, bandwidth, polarization, and impedance. All parameters are perfectly symmetric they apply equally to transmitted and received signals. Antenna radiation patterns can be divided into three main categories: isotropic, directional and Omni-directional [10]-[15].

4. Methods of analysis

The favored models for the analysis of microstrip patch antennas are the transmission line model, cavity model, and full wave model (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but the accuracy is very less. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, adaptable and can take care of single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature.

Transmission line model

This model represents the microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The microstrip is essentially a no homogeneous line of two dielectrics, typically the substrate and air.

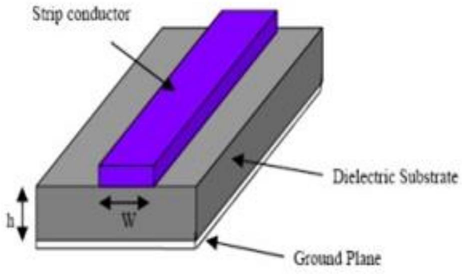

Figure.3: Microstrip line

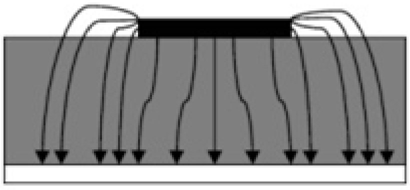

Figure.4: Electric field line

The majority of the electric field lines reside in the substrate and parts of some lines in air as seen from Figure 4. As a result, this transmission line cannot support pure transverse-electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ε_{reff} is slightly less thenε_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 3. The expression for ε_{reff} is given by Balanis as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{\frac{1}{1+\frac{12h}{W}}} \tag{2}$$

Where,
ε_{reff} = Effective dielectric constant
ε_r = Dielectric constant of substrate
h = Height of dielectric substrate
W = Width of the patch

Consider Figure 5 below, which shows a rectangular microstrip patch antenna of length L, width W resting on a substrate of height h. The co-ordinate axis is chosen such that the length is along the x direction, width is along the y direction and the height is along the z direction.

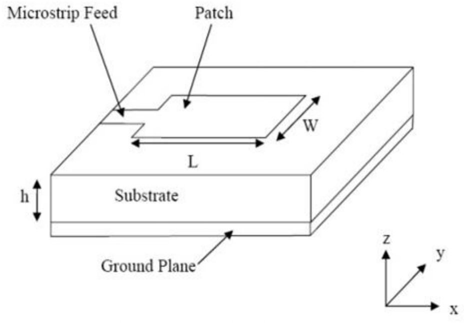

Figure.5: Microstrip patch antenna

In order to operate in the fundamental TM_{10} mode, the length of the patch must be somewhat less than λ/2 where λ is the wavelength in the dielectric medium and is equal to $\lambda_o/\sqrt{\varepsilon_{reff}}$ where λ_o is the free space wavelength. The TM_{10} mode implies that the field varies one λ/2 cycle along the length, and there is no variation along the width of the patch. In the Figure 6 shown below, the microstrip patch antenna is represent by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be determined into normal and tangential components with respect to the ground plane.

It is seen from Figure 7 that the regular components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is λ/2 long and hence they cancel each other in the broadside direction. The tangential components, which are in phase, i.e., the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are λ/2 apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions.

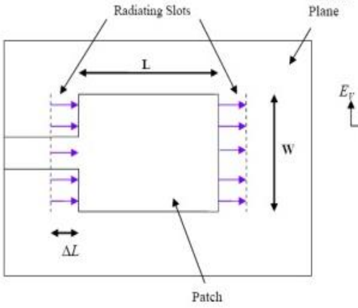

Figure.6: Top view of antenna

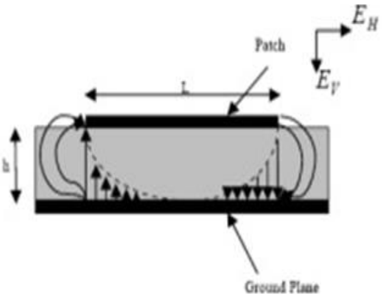

Figure.7: Side view of antenna

The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by Hammerstad as: [1.4]

$$\Delta \mathrm{L}(0.412 * \mathrm{h})\frac{(\varepsilon_{\mathrm{reff}}+0.3)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.264\right)}{(\varepsilon_{\mathrm{reff}}-0.258)\left(\frac{\mathrm{W}}{\mathrm{h}}+0.813\right)} \tag{3}$$

The effective length of the patch L_{eff} now becomes:

$$L_{eff} = L + 2\Delta \mathrm{L} \tag{4}$$

For the given resonance frequency f_0, the effective length given by,

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{5}$$

For a rectangular microstrip patch antenna, the resonant frequency for any TM_{mn} mode is given by James and Hall as:

$$f_0 = \frac{c}{2\sqrt{\varepsilon_{reff}}}[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2]^{\frac{1}{2}} \tag{6}$$

Where m and n are modes along L and W respectively.

For efficient radiation, the width W is given by Bahl and Bhartia as:

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} \tag{7}$$

5. Simulation software

HFSS is a high-performance full-wave electromagnetic (EM) field simulator for arbitrary 3D volumetric passive device modeling that takes advantage of the familiar Microsoft Windows graphical user interface. It integrates simulation, visualization, solid modeling, and automation in an easy-to-learn environment where solutions to your 3D EM problems are quickly and accurately obtained. Ansoft HFSS employs the Finite Element Method (FEM), adaptive meshing, and brilliant graphics to give you unparalleled performance and insight to all of your 3D EM problems.

HFSS is an interactive simulation system whose basic mesh element is a tetrahedron. This allows you to solve any arbitrary 3D geometry, especially those with complex curves and shapes, in a fraction of the time it would take using other techniques.

The name HFSS stands for High Frequency Structure Simulator. Ansoft pioneered the use of the Finite Element Method (FEM) for EM simulation by developing/implementing technologies such as tangential vector finite elements, adaptive meshing, and Adaptive Lanczos-Pade Sweep (ALPS). Today, HFSS continues to lead the industry with innovations such as Modes-to-Nodes and Full-Wave Spice. The simulation results for the parameters such as return loss, VSWR, gain, axial ratio and radiation efficiency as a function of frequency are discussed.

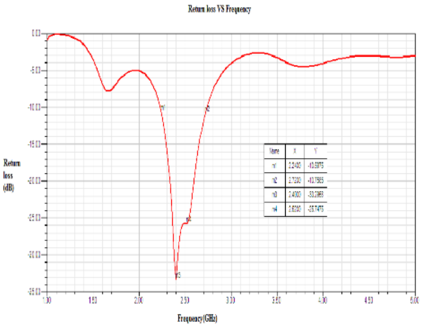

Figure.8: Simulated return loss Vs frequency

Figure 8 shows the return loss variation with respect to frequency of the antenna. Return loss may be defined as the difference in dB between the power sent towards the antenna-under-test (AUT) and power reflected. The requirement for reflection coefficient for wireless devices specifies 10 dB return loss BW. The proposed antenna shows operating frequency at 2.4-2.7 GHz. The center frequency is 2.5 GHZ.

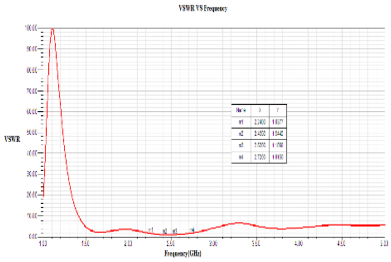

Figure.9: Simulated VSWR Vs frequency

Figure 9 shows the simulated VSWR vs. frequency plot. In the desired operating frequencies, the VSWR is less than two. Hence, the impedance matching is good at the frequency range of 2.4-2.7 GHZ. The VSWR in both the frequency range is less than 2. (VSWR < 2).

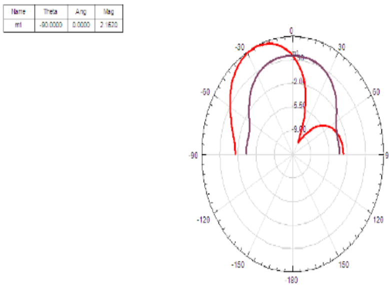

Figure.10: Simulated radiation pattern in the principal plane (φ=0)

Figure 10 shows the radiation pattern of proposed antenna at 2.4 GHz. The radiation pattern show a hemispherical radiation pattern in the principal plane= 0. The Gain value is 2.1 dB in the bore-sight axis of the antenna. The proposed antenna is unidirectional antenna which radiating above half of the radiation pattern (above 90 degree).

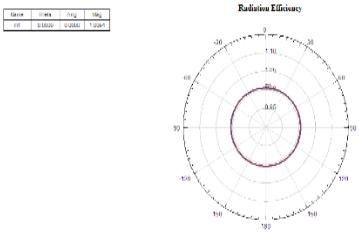

Figure.11: Simulated radiation efficiency of the proposed antenna at 2.4 GHz

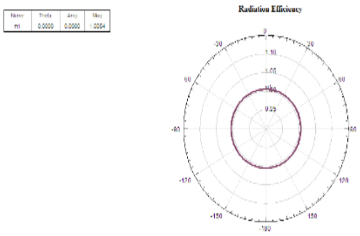

Figure.12: Simulated radiation efficiency of the proposed antenna at 2.5 GHz

Figure 11 and Fig.12 shows the radiation efficiency of the designed antenna, computed using HFSS. The radiation efficiency is obtained as more than 0.95 or 95 %. Also, the air between the substrate and ground plane influences the radiation pattern.

6. Conclusion

Thus a simple, low cost dual frequency microstrip patch antenna for WIMAX/WLAN/ISM/WIFI applications proposed is designed, simulated and measured. This co-axial fed antenna can be easily integrated within the printed circuit boards (PCBs) of various systems. Dimensions of the inverted U shaped slot govern the required band, while truncation of the circular patch govern low return loss to operate in a resonating bands. From observing the return loss, VSWR, radiation pattern graphs is very clear that this antenna covers all the desired operating frequencies between 2.4 - 2.7GHz, where the VSWR of 1.8377 @ 2.24 GHZ and 1.0442 @ 2.4 GHz, 1.1088@ 2.52GHz, 1.8160 @2.72GHz. Hence, the proposed antenna provides effective control over the operating band. The antenna provides more than 95 % efficiency, and it gain varies from 2.1 - 5.7 dB over desired frequency. The antenna has nearly unidirectional radiation pattern, which indicates that the proposed antenna is suitable and good candidate for WIMAX/WIFI/WLAN/ISM application bands.

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