Design of Tri-Band Microstrip Patch Antenna

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Abstract: ***Compared with conventional microwave antennas, microstrip antennas are with small size, light weight, simple to manufacture, low cost, and ease of integration, etc. therefore, microstrip antenna has a wide range of applications in communication and radar fields. The antenna have been analyzed and designed by using the 'High Frequency Structure Simulator' (HFSS) software. The designed antenna in this paper can achieve triple band performance to simultaneously cover the 1.90GHz, 2.45GHz and 3.20GHz frequency with return loss of -26.0dB, -24.0dB and -18.0dB respectively. The designed antenna application systems include global system for mobile communication (GSM), the wireless area network (WLAN) in the 2.4-GHz (2.4-2.485 GHz) band, global positioning system (GPS), Worldwide Interoperability for Microwave Access (Wi-MAX) as well as global navigation satellite systems (GNSS). Other important areas of applications include biomedical, missiles and much more.***

Keywords: Coaxial Probe Feed, HFSS-Software, Low profile, Microstrip Patch antenna, Triple Frequency Bands.

1. Introduction

Antennas for portable cellular phones are required to be small in size and light in weight. Microstrip antennas have the attractive features of low profile, small size, low cost, and conformability to mounting hosts which makes them excellent candidates for satisfying this design consideration. Recently, many novel planar antenna designs to satisfy the requirements of mobile cellular communication systems have been developed. In modern wireless communication systems and increasing of other wireless applications, wider bandwidth, multiband and low profile antennas are in great demand for both commercial and military applications. This has initiated antenna research in various directions. Traditionally, each antenna operates at a single or dual frequency bands, where different antenna is needed for different applications. This will cause a limited space and place problem. In order to overcome this problem, multiband antenna can be used where a single antenna can operate at many frequency bands. This paper describes a method of design of the rectangular shaped microstrip antenna with it's distinguish resonant frequencies. The simulation is done using ANSOFT HFSS software; High Frequency Structure Simulator (HFSS) is high-frequency simulation software which is based on a finite element method and its accuracy and powerful features makes it a common tool for antenna designers, the proposed rectangular shaped antenna in this paper was no exception [1]. The printed antenna in this paper is very suitable for integration with wireless local area network (WLAN) applications, widely used in the areas of mobile radio and wireless communication applications, also found very useful in the field of global navigation satellite systems(GNSS), global positioning system (GPS). Other important areas of applications include biomedical, missiles and much more. Currently, the wireless area network (WLAN) in the 2.4-GHz (2.4-2.485 GHz) and 5-GHz (5.l5-5.875 GHz) bands is the most renowned networks for accessing the internet and also these type of antennas not only requires dual band operation but also needs to have an appropriate [2] radiation profile in both bands, namely equal gain, wide beam width, and high front-to-back ratio.

The rectangular patch antenna is approximately a one-half wavelength long section of rectangular microstrip transmission line. As the antenna is loaded with a dielectric as its substrate, the length of the antenna decreases as the relative dielectric constant of the substrate increases [2]. The simple model of a typical Microstrip Rectangular Patch can be seen in figure 1 below.

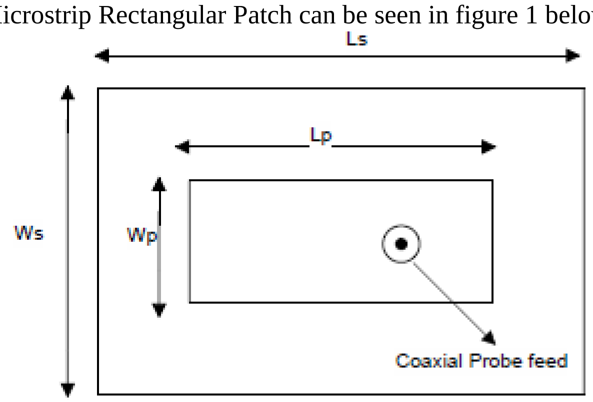


Figure 1: Geometry of the proposed antenna

From the above figure, the Ls stand for the length of the substrate, Ws stand for the width of the substrate, Lp stand for the length of the patch while Wp is the width of the patch. However, it is important to point out that the geometry was not drawn to a scale of the actual design, the model is just a copy made similar to the original version of the proposed design but a little bit enlarged for the purpose of clarification.

2. Antenna Design

This project presents a rectangular shape patch antenna where the antenna behaviors are investigated methodically. In addition to the theoretical design procedure, numerical simulation was performed using software (HFSS) to obtain design parameters such as size of patch and feeding location. In this approach, the metal film was printed on a dielectric substrate, which is sitting on and perpendicular to a perfectly conducting ground plane. The Microstrip patch antenna is designed to operate at a triple frequency band, the patch was designed as rectangular shaped resonating on FR4_epoxy substrate with the substrate thickness of 1.6 mm and relative permittivity dielectric constant of 4.4. The length 'Lp' of the patch is 37.20mm and width 'Wp' is 27.99mm. The area of the ground plane sets 74.4×55.98 mm^2. Although there are many configurations that can be used to feed microstrip antennas, the designed antenna in this paper employ the Coaxial-Probe feed method, where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane. The coaxial probe feed was located on the positive coordinate of both X-axis and Y-axis because it was easy to fabricate and match [1]-[3] at the frequency bands of interest. The simulation environment of this design patch antenna was shown in figure 2 below.

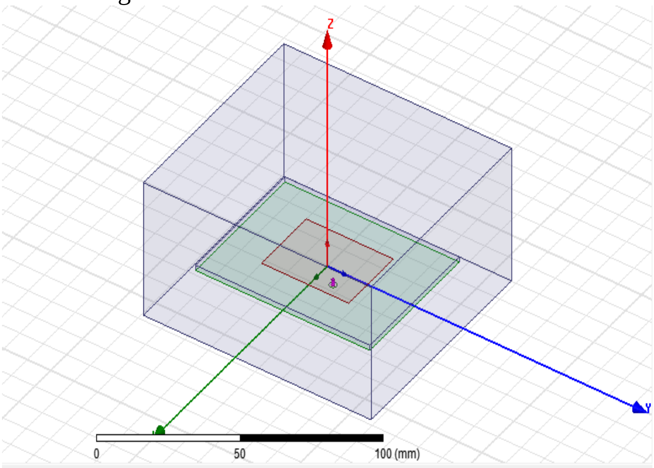


Figure 2: Simulation of the patch antenna

A 50 Ω coax probe feed is directly attached via the circular cut out (Lumped port) on the patch structure with a radius of 1.5mm circular port. The cylindrical coax pin is made up of pec (Perfect electric conductor) material with a radius of 0.6mm and height of 1.6mm. The coaxial-line feed defines; where the inner conductor of the coax is attached to the radiation patch while the outer conductor is connected to the ground plane [3] as shown in figure 2. For the radio frequency system, application of these antennas must be matched to the traditional 50Ω impedance of the front-end circuitry. Therefore, the impedance network has to be plugged between the source and antenna.

Moreover, the length of the patch is also obtained from the equation (1) below

$$L = L_{eff} - 2\Delta L \qquad (1)$$

The width of the proposed antenna was obtained with the help of equation (2) below

$$W = \frac{c}{2 f_r} \sqrt{\frac{2}{(\varepsilon_r + 1)}} \qquad (2)$$

3. Analysis and Configuration

Although there are many methods for the analysis of microstrip antennas. The most popular models are the transmission-line, cavity and full wave (which include primarily integral equations/Moment Method). The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling. Compared to the transmission-line model, the cavity model is more accurate but at the same time more complex. However, it also gives good physical insight and is rather difficult to model coupling, although it has been used successfully. In general when applied properly, the full-wave models are very accurate, very versatile, and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements, and coupling. However they are the most complex models and usually give less physical insight. Since the rectangular patch is by far the most widely used configuration and it is very easy to analyze using both the transmission-line and cavity models, which are most accurate for thin substrates [3]. In this paper however, the transmission-line model was employed because it is easier to illustrate and it gives good physical insight. Basically the transmission-line model represents the microstrip antenna by two slots, separated by [3] a low-impedance Zc transmission line of length L as can be seen in figure 3.

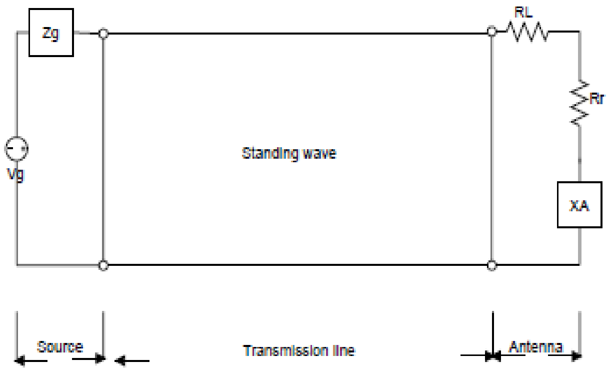


Figure 3: Transmission-line Thevenin model

A transmission-line Thevenin equivalent of the antenna system in the transmitting mode was shown in Figure 3 where the source is represented by an ideal generator, the transmission line is represented by a line with a characteristic impedance Zc, and the antenna is represented by a load ZA, where ZA = (RL+Rr) + jXA] connected to the transmission line. The load resistance R_L is used to represent the conduction and dielectric losses associated with the antenna structure while R_r referred to as the radiation resistance, is used to represent radiation by the antenna. The reactance X_A is used to represent the imaginary part of the impedance associated with radiation by the antenna. Under ideal conditions, energy generated by the source should be totally transferred to the radiation resistance R_r which is used to represent radiation by the antenna. However, in a practical system there are conduction-dielectric losses due to the lossy nature of the transmission line and the antenna, as well as those due to reflections (mismatch) losses at the interface between the line and the antenna [3].When a transmission line is used in between the antenna and the transmitter (or receiver) one generally would like an antenna system whose impedance is resistive and near the characteristic impedance of that transmission line in order to minimize the standing wave ratio (SWR) and the increase in transmission line losses it entails, in addition to supplying a good match at the transmitter or receiver itself [3].

Therefore, the analysis and design of the stepped impedances resonators was achieved using transmission line theory and their equivalent lumped element circuits.

4. Radiation Box and Boundary Conditions

Although the object is assigned a dielectric material, its outer surfaces need to be perfect conductors so as to simulate the coaxial feed cable accurately. It is for this purpose that 'boundary conditions' are used in HFSS. Therefore, the Perfect-E boundary condition was assigned using Object Name, by so doing, its entire outer surface was modeled to be perfect electric conductor. The boundary condition in a zoomed view of the coax cable was shown below in Figure 4.

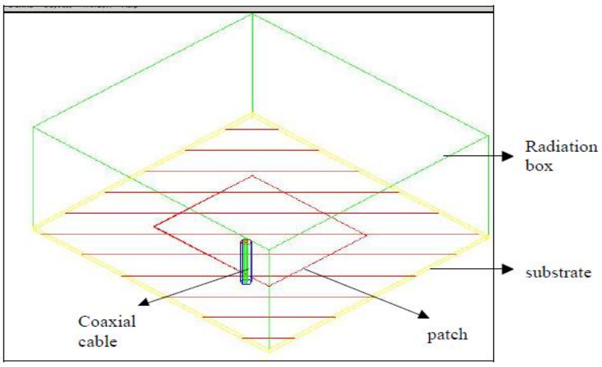


Figure 4: Rectangular Patch with radiation box.

It should be noted that the inner conductor, which extends all the way up to the patch has already been chosen to be made up of pec material as well. The next step was to open up a hole in the ground plane for the inner conductor of the coaxial cable to pass through and extend up to the patch. In order to accomplish this, the circular cut out (Lumped port) with a radius of 1.5mm circular port was created. As mentioned earlier, the object Radiation box was specifically created so that it can be assigned the Radiation boundary. However, the patch lies on its bottom surface and hence the boundary condition should not be applied to that surface of the patch. That is why each of the remaining surfaces needed to be individually selected and declared as Radiation boundaries as opposed to selecting the whole object. These surfaces are highlighted with slant lines in Figure 4. It should be pointed out that each side surface of the substrate lies right below and touches the corresponding side surface of the box. While assigning boundaries, both the touching faces are treated as one surface and the radiation boundary is assigned accordingly [4]. The final step was to devise the means to inject energy into the structure. This was done by setting up a port. The logical location of the port was at the bottom surface of the coaxial cable. This is shown using slant lines. The location shown in the figure 4 was applied by appropriately choosing the correct point on the patch where triple band performance can be achieved. The feed point must be located at that point on the patch where the input impedance is 50 ohms for resonant frequency. This ended the process of defining ports and boundary conditions. With this, the design and corresponding analysis of the antenna simulation was successfully completed [4], [7].

5. Simulation Results and Discussion

The simulated results were obtained by using the Ansoft HFSS; high frequency structure simulator (HFSS) software. In this paper the rectangular patch antenna was designed and the experimental (simulation) results regarding the antenna characteristics were presented and summarized as can seen in the table-1 below.

Table 1: Simulation results of the antenna

S/N	*Frequency (GHz)*	*Return loss (dB)*	*VSWR*	*Bandwidth (MHz)*
1	1.90	-26.0	1.35	600
2	2.45	-24.0	1.45	500
3	3.20	-18.0	1.50	500

Good return losses, VSWR as well as the radiation pattern characteristics were all obtained in the frequency band of interest.

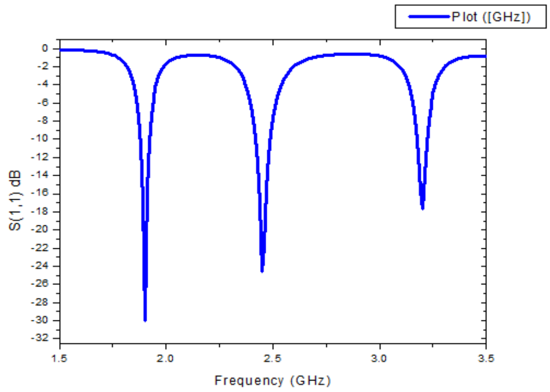


Figure 5: Return Loss

The return loss 'RL' is a parameter which indicates the amount of power that is lost to the load and does not return as a reflection. Electromagnetic waves are reflected leading to the formation of standing waves when the transmitter and antenna impedance do not match. Hence the return loss is a parameter similar to voltage standing wave ratio to indicate how well the matching between the transmitter and the antenna has taken place [3]. The return loss is given as:

$$RL = -20\log_{10}|\Gamma| \text{ (dB)} \quad (3)$$

For perfect matching between the transmitter and the antenna $\Gamma = 0$, while for RL = ∞ it means no power would be reflected back. Where as if $\Gamma = 1$ has a RL = 0dB which implies that all incident power is reflected. The total antenna efficiency is used to take into account losses at the input terminals and within the structure of the antenna. Such losses may be due to reflections because of the mismatch between the transmission line and the antenna [3].

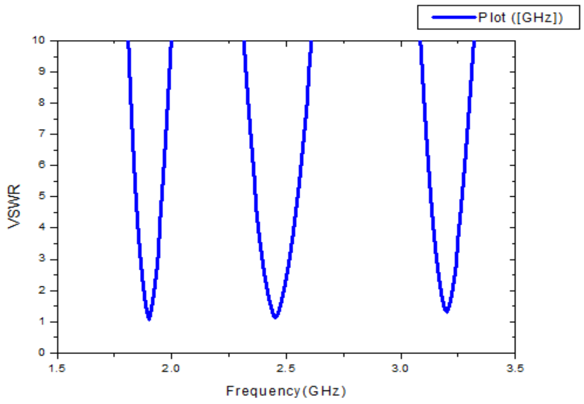
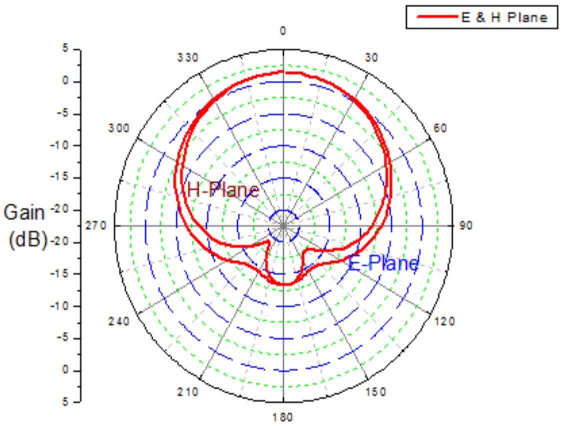


Figure 6: Voltage Standing Wave Ratio (VSWR)

The voltage standing wave ratio is basically a measure of the impedance mismatch between the transmitter and the antenna. For a good antenna, the VSWR must be greater than one but less than two. The higher the VSWR, the greater is the mismatch. The minimum VSWR which corresponds to a perfect match is unity. The VSWR for the designed antenna frequency bands of 1.90GHz, 2.45GHz and 3.20GHz were 1.35, 1.45 and 1.50 respectively.

Moreover, the radiation characteristics of the triple band patch antenna were also presented below. The radiation patterns as well as the corresponding 3D polar plot for the three resonance frequency for 1.90GHz, 2.45GHz and 3.20GHz bands were presented below in the figure (a/7), figure (b/8) and figure (c/9) respectively in terms of the E and H planes.



(a) Radiation Pattern at 1.90GHz

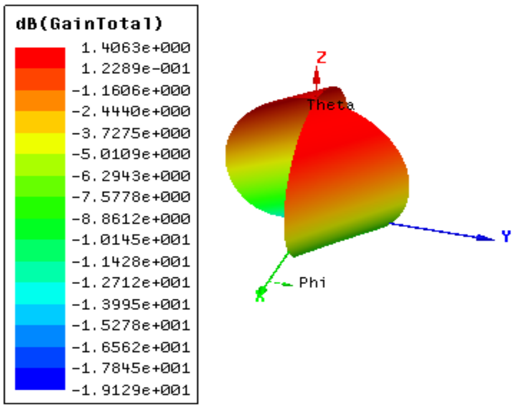
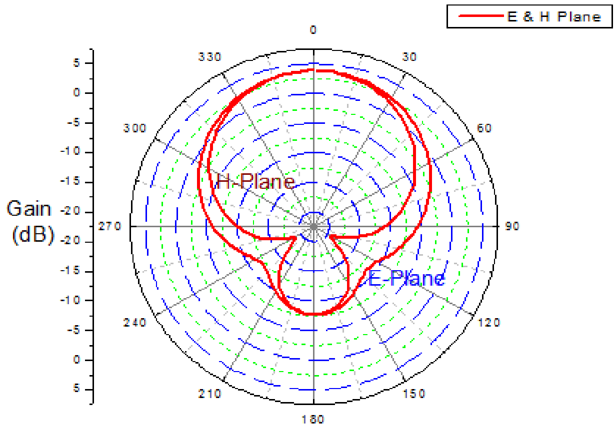


Figure 7: The 3D Polar Plot at 1.90GHz



(b) Radiation Pattern at 2.45GHz

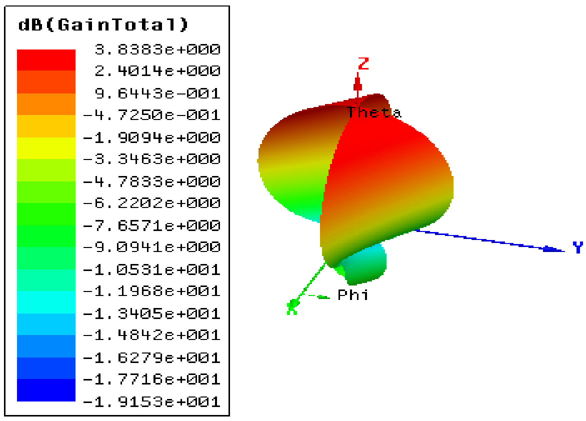
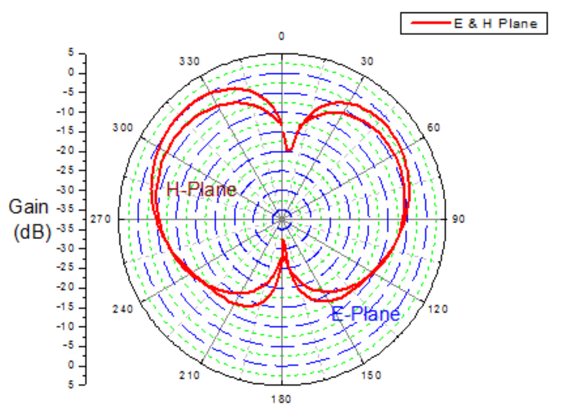


Figure 8: The 3D Polar Plot at 2.45GHz



(c) Radiation Pattern at 3.20GHz

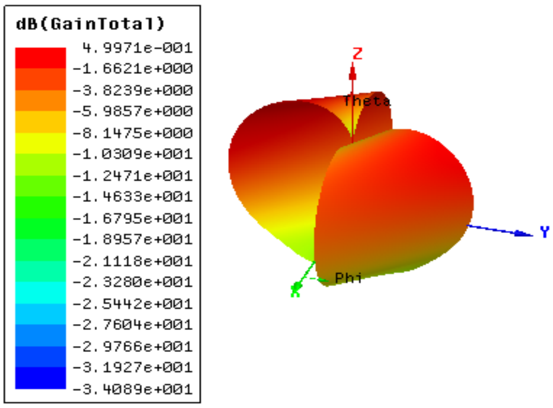


Figure 9: The 3D Polar Plot at 3.20GHz

Microstrip antennas appeared as a by-product of microstrip circuits, which by now have become a matured technology. Their design and realization took advantage of the techniques developed for microstrip circuits and used microstrip circuit substrate. The increasing demand of multi-band personal communications handsets fosters development of small size and integrated multi-bands antennas. The preferred solutions are usually metallic patches with multiple resonances. These patches allow a great flexibility in the antenna design, as they are cost effective and straight forward to produce, as well as easy to adapt to the shape of the handset. The demand for high performance multi-standard communication handsets has led to the research and studies of this interesting topic. Therefore, it is important to study the basic concepts of multi-band antenna systems, a system that brings the world of wireless communication to a new era [1]-[6].

6. Conclusion

A very low profile microstrip rectangular patch antenna has been presented. Empirical equations were obtained to design the patch antenna operating at the 1.90GHz, 2.45GHz and 3.20GHz frequency bands with return loss of -26.0dB, -24.0dB and -18.0dB respectively. The simulated results were obtained by using the Ansoft HFSS software. The measured and simulated characteristics of the antenna for the far field report of the rectangular plot, the 3D polar plot and radiation characteristics. Moreover, the VSWR for the designed antenna frequency bands of 1.90GHz, 2.45GHz and 3.20GHz were 1.35, 1.45 and 1.50 respectively. Thus; the designed antenna is suitable for wireless communication systems operating at very lower frequency. Fabricated sample has verified the proposed antenna with very good properties.

7. Acknowledgment

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Author Profile

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