Application of FSS for Microstrip Antenna for Gain Enhancement

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Abstract. In this present paper, a dual-band microstrip patch antenna (MPA) using frequency selective surface (FSS) is proposed. The dual-band MPA is designed using the rectangular shaped patch with an elliptical slot at the center of the patch and full ground plane. The FSS in this paper act as a reflection plane which is loaded onto the dual-band MPA in order to improve the gain of the antenna at higher band. The FSS is obtained by the periodic array of 3 x 5-unit cell in the x-y direction, which based on the amalgamation of a square and circular loop elements. After merging the FSS, the gain and return loss at 5 GHz increased to 0.915 dB and -25.08 dB respectively. The dual-band MPA is simulated using the FR-4 substrate with a thickness of 1.6 mm and a relative permittivity of 4.4. The overall size of the MPA and FSS is relatively compact and easy to fabricate. The proposed antenna can be used in WiMAX and WLAN applications.

1. Introduction
In a wireless communication system, the antenna is one of the most important components as both of the transmission and reception of radio frequency signals are using it. There are varieties types of antennas but microstrip patch antenna is the favored type of printed antenna among people. The substrate that mainly used for this type of antenna is FR-4 because it is universal and cheap as well as for education purpose. Microstrip patch antenna plays a very significant role in the maintenance of wireless communication systems which are very simple in construction that using a conventional microstrip fabrication technique. Latest applications nowadays such as mobile communications, WLAN, Global Positioning System (GPS), WiMAX, Bluetooth, and radars are using microstrip antenna.

A basic patch antenna only capable to operate in one frequency. Nevertheless, nowadays demands require an antenna to operate in multiple or different frequency band in one single antenna. Due to limited space of the device, at least the antenna is demanded to operate in dual frequency band such as WiMAX and WLAN. Dual band operation is activated by simultaneously stimulating the first and second resonant modes. The designed antenna can generate sufficient impedance bandwidth to cover the Worldwide Interoperability for Microwave Access (WiMAX) system at 3.5 GHz as well as the Wireless Local Area Networking (WLAN) system at 5.0 GHz by selecting slot dimensions appropriately. The structure of dual-band antenna is not a new idea especially dual-band microstrip patch
antenna. Many manufacturers have merged multiple elements for years to establish antennas that operate in two different bands.

An alteration of the basic patch antenna makes it capable to operate in dual band, such as creating a slot on the design. By creating a slot on the design, a new current path is created hence producing another frequency band. However, by producing another current path, the antenna will suffer the frequency gain. Where now the gain already been divided into two pathways. During the 1960s, the technology of frequency selective surface (FSS) were only owned by military to be used in applications such as radar absorber materials, stealth aid and filter design [1]. FSS is a planar periodic structure organized on a dielectric substrate with homogenous two-dimensional array of elements. Determine by the characteristic of the array elements, any plane waves that approaching the FSS will either be transmitted, reflects entirely or partly. The phenomenon when the wave is transmitted is passband while the other one is called stopband. These happened when the frequency and resonant frequency of EM wave and FSS elements were matched. As stated by the circuit theory, spatial filters or referred to as FSS structures are equivalent to the microwave filters. FSS is the repetitive surface that is designed to improve antenna’s performance and parameters, for instance, gain, bandwidth, radiation pattern, reflection coefficient, transmission coefficient, and VSWR by merging the FSS with an antenna.

In this present work, a proposed dual-band microstrip patch antenna (MPA) with elliptical slots at the center is introduced in the rectangular patch and the full ground plane at resonant frequency 3.5 GHz and 5 GHz. Then, the designed FSS is combined with this MPA to improve the gain of the antenna. The simulations and measured results of the return loss and gain of the designed antenna over the frequency band of interest are presented.

2. Microstrip Patch Antenna (MPA) design and development
The designed antenna is printed on both sides, one side is the patch and another side is ground plane. The feeding technique that is used in this project is a microstrip line feeding technique. This technique is when a conducting strip is connected to the edge of the patch. The feed also etched on the substrate. One of the advantages of microstrip line feed is that it is easier to fabricate compared to another method. Microstrip line feed can be consider as extension of patch as it is just conducting strip connecting to the patch.
Table 1. Design Parameters of Proposed dual-band Antenna.

| Parameters | Description | Dimension (mm) |
|------------|-------------|----------------|
| Ws         | Width of Substrate | 86             |
| Ls         | Length of Substrate | 62             |
| Wp         | Width of Patch     | 40             |
| Lp         | Length of Patch    | 30             |
| Wrec       | Width of Rectangular Slots | 10           |
| Lrec       | Length of Rectangular Slots | 8          |
| Wf         | Width of Feed      | 6              |

The performance of the microstrip antenna eventually relies on upon its dimension. As the antenna is simulated with the selected substrate which is FR-4 with a 1.6 mm thickness and relative permittivity of 4.4, the value of width and length of the patch can be found using the following formula that had been provided.

Patch width ($W$)

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

Patch length ($L$)

$$L = \frac{c}{2f_r \varepsilon_{eff}} - (2\Delta l)$$

Effective dielectric constant ($\varepsilon_{eff}$)

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( 1 + \frac{12h}{W} \right)^{-\frac{1}{2}}$$

Length of extension ($\Delta l$)

$$\Delta l = 0.412h \left[ \frac{\varepsilon_{eff} + 0.3}{\frac{\varepsilon_{eff} + 0.3}{\varepsilon_r + 0.264} + 0.264} \right] \left[ \frac{\varepsilon_{eff} - 0.268}{\frac{\varepsilon_{eff} - 0.268}{\varepsilon_r - 0.8} - 0.8} \right]$$

[Where, $f_r$ is resonant frequency, $\varepsilon_r$ is relative dielectric constant, $h$ is substrate height. Using above expressions width of patch ($W$) = 26 mm and length of patch ($L$) = 20 mm are calculated.]

Figure 1 shows proposed dual-band MPA having rectangular shaped patch. The proposed antenna is altered in order to achieve the resonant frequencies which are 3.5 GHz and 5 GHz. It is fabricated on FR-4 substrate of dimension 86 mm × 62 mm, with the relative permittivity of 4.4. Here the proposed antenna is designed using two rectangular slots in each bottom edge of the patch and an elliptical slot which is located in the center of the rectangular patch. The geometrical dimensions of proposed dual-band microstrip patch antenna design used in the simulation are given in Table 1. In figure 2 a dual-band MPA is designed using CST studio Suite 2017 software tool, where the return loss without FSS is observed are -23.447 dB and -22.142 dB at a resonant frequency of 3.5 GHz and 5 GHz respectively which is shown in the figure 3. The gain of the dual-band antenna without FSS at 5 GHz is shown in figure 4. The designed dual-band MPA then going through the fabrication process. The fabricated antenna then soldered with a 50Ω SMA connector and measured with network analyzer as shown in figure 5.
Figure 2. 3D view of dual-band MPA

Figure 3. Return loss result of MPA without FSS.

Figure 4. Gain at 5GHz without FSS
3. Frequency Selective Surface (FSS) design and development

The TE / TM excitation of frequency selective surface (FSS) generates resonance attitudes for specific frequencies. Throughout this project, the FSS is designed based on the combination of rectangular patch and ring layout. This FSS is designed with the aim to enhance the gain and return loss of the dual-band MPA at 5 GHz only. So, this FSS is band-pass type. This is because the gain at 3.5 GHz is already high. The width and length of the full FSS design is same as the dimension of the MPA which is 86 mm x 62 mm. The geometrical dimensions and parameters of FSS unit cell is shown in figure 6 and Table 2. The FSS is obtained by the periodic array of 3 x 5-unit cell in the x-y direction. The return loss, S11 of the FSS is shown in figure 7. The designed FSS then going through the fabrication process. The fabricated FSS is shown in figure 8.

Figure 9 shows the designed dual-band MPA merged together with FSS. The air gap between the dual-band MPA and FSS is 42mm. Lately the use of FSS as an antenna gain enhancer is being extensively researched. After implanting the new FSS with the rectangular patch antenna, it is found that the gain has been improved from 0.772 dB to 0.915 dB at 5 GHz as the designed FSS is only focused on the higher frequency. This is because the gain at lower frequency band is already high which 1.59 dB. In figure 10, the return loss of the dual-band MPA with FSS is observed, which the results are −17.042 dB and −25.08 dB at a resonant frequency of 3.5 GHz and 5 GHz respectively. The gain of the dual-band antenna with FSS at 5 GHz is shown in figure 11. The fabricated dual-band MPA and FSS are merged together and measured using Network Analyzer as shown in figure 12.
Table 1. Design Parameters of Proposed FSS

| Parameter                          | Dimension (mm) |
|------------------------------------|----------------|
| Side Length, $L$                   | 16.67          |
| Outer Square Loop Length, $A_1$    | 13.50          |
| Outer Ring Radius, $R_1$           | 5.5            |
| Inner Square Loop Length, $A_2$    | 6.83           |
| Inner Ring Radius, $R_2$           | 2.165          |

Figure 6. FSS Unit Cell

Figure 7. Return Loss ($S_{11}$) of FSS
Figure 8. Fabricated FSS

Figure 9. Designed Dual-Band MPA with FSS

Figure 10. Return Loss of Dual-Band Antenna with FSS
4. Simulation and measurement result

Simulation result and measured result of dual-band MPA with and without FSS are shown in figure 13 and figure 14 respectively. Meanwhile Table 3 shows the comparison value of the results mentioned above.
5. Conclusion

In this paper, a new FSS is designed to improve the gain of the dual-band microstrip patch antenna. The centre frequency of this FSS is at 5.0 GHz. The proposed FSS structure acted as the reflection plane which improved the performance which are gain and return loss of the dual-band at WLAN (5 GHz) frequency successfully. The 5 GHz return loss after loading FSS is better which is from -22.142 dB to -25.08 dB. Although there are a slightly different value due to some error in fabrication, the measured return loss after loading FSS also increasing which is from -16.418 dB to -17.001 dB. The gain after merging the MPA with FSS also higher which is from 0.772 dB to 0.915 dB. So, the proposed FSS is proved to improve the gain of dual-band MPA at 5 GHz frequency.

References

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