Design and Analysis of Frequency Selective Surface for ISM and Lower Ultra-Wideband Antenna

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Abstract. A Compact, dual-layer Frequency Selective Surface (FSS) is presented for electromagnetic shielding applications. The square loop FSS is modified to provide band rejection characteristics for ISM band and lower Ultra-Wide Band (UWB) covering from 2.2 GHz to 7.1 GHz with the bandwidth of $(S21 < -20\text{dB})$ 4.9 GHz. The novel design exhibits symmetric property due to which it achieves polarization-insensitive stable band rejection of the desired frequency band for various angles of incidences up to $60^\circ$. The proposed FSS structure has compact dimensions of $0.170\lambda \times 0.170\lambda \times 0.0117\lambda$. The design was fabricated on either side of the substrate made of FR-4 with a dielectric constant of 4.4 and loss tangent of 0.02. The measured results are well per the simulation results. The proposed FSS in this paper has various applications, including the aerospace industry, hospitals, random, and in the scope of electromagnetic filters, etc.

Keywords: BANDSTOP; FSS; ISM; UWB; Wideband; Antenna.

1. Introduction
Frequency Selective Surfaces (FSS) are a two-dimensional periodic array of metallic patches of regular or arbitrary geometries on a dielectric slab made up of FR4 substrate generally. These structures exhibit the property to reflect or transmit electromagnetic waves, which generally act as a band-stop or band-pass filter. FSS is an acronym for frequency selective surface, which is mainly designed to operate as a filter. The proposed design shows the band stop characteristics with a simulated bandwidth of 4.9 GHz from (2.2 to 7.1 GHz). The FSS, which is acting as a filter, is shown in Figure 1.

The design's performance depends upon the length of the conducting path, the substrate's material. The substrate's width, the presence of conventional loops, etc. In this project, the compact-sized FSS with dimensions 23.72mm x 23.72 mm is proposed, which exhibits diagonal symmetry and it is symmetric about the X and Y axes. As it is not symmetric concerning 90° rotations, it is not showing the same bandwidth for incident TE and TM modes. Frequency selective surfaces can be considered as wave filters. There are two critical challenges in designing frequency selective surfaces that are often exploited in constructing these surfaces. One is the interference of waves reflected from partially conducting or transmitting boundaries and the other is the interaction of waves with the conducting surfaces. The cascaded boundaries, spacing, and dielectric constant factors affect the transmitting or rejecting of the surfaces' waves.
The ISM band, which is reserved for industry, scientific and medical industries, is generally unlicensed frequency bands that vary according to the different regions and permits. The 2.45GHz band is generally accepted for applications in industries like Bluetooth, cordless phones, etc. Lower Ultra-wide bands ranging from (3.1 to 5.6) GHz are used for wireless transmissions of the digital data with less power consumption. It can carry signals through obstacles also. Devices that operate within the lower ultra-wideband frequency can be disrupted due to interference. The taxonomy of the FSS is shown in Figure 2.

![Figure 1: Frequency Selective Surface](image)

**Figure 2: A taxonomy of Frequency Selective Surface**

2. Literature Survey

D. Sood has proposed the FSS for a wide stop-band filter [1] to design the unit cell. The simulated value of bandwidth varies from 4.71 to 12.41 GHz for transmission coefficient < -20dB. For C and X band, it exhibits excellent band-stop characteristics. The unit cell which he proposed has a thickness of 1.6 mm. An array of unit cells is fabricated on the dielectric substrate FR-4 on either side of it.

Tuhina Oli has proposed a compact ultra-wideband frequency FSS[2]. The designed unit cell in this paper is similar to the "H" structure. The is simulated value of the bandwidth ranging from 2.87 to 10.87 GHz for transmission.

The coefficient value of which is less than (-20dB). The proposed FSS unit cell design has a higher bandstop response and also exhibits good angular stability. The unit cell thickness is around 1.8 mm. The array of structures is fabricated on either side of the substrate (FR-4). This paper’s main advantage is the
simulated value, and the measured value shows a very good correlation.

Ramprabhu Sivaswamy has developed the ultra-wideband FSS [3]; the compactness is achieved by varying the horizontal spacing, and also it has a square loop design with two square roots on the right side and two other square roots on the left side, such that it exhibits similar TE and TM modes. By modifying the square root sizes, there will be an increase or decrease in the electrical wavelength.

Ramprabhu Sivaswamy introduced the ultra-wideband FSS [4] with bandstop characteristics. The proposed design consists of a single-layer substrate, and it is polarization independent. This design provides wide bandstop characteristics from 4 GHz to 12 GHz.

Dual-band performances depend upon isomorphic FSS like concentric squares and circle rings. Tian-Yao-Du presented a novel angular independent [5] dual-band FSS increase the bandwidth, and the proposed design exhibits dual stop-band characteristics at 2.5 GHz and 3.5 GHz.

David Ferreira, Telmo R. Fernandes presented frequency selective surface [6], which acts as a band stop filter resonating at two frequencies 2.4 GHz and 5.2 GHz, the proposed design is acting as a dual-band FSS. The unit cell dimensions are 39.5 mm x 39.5 mm, with a copper thickness of 0.035 mm, and the substrate width is 2.5 mm, and the substrate's permittivity is 4.4 mm. The FSS has a more extensive profile.

Zuo Shen Zheng, Shaobo, Qu described above the ISM band frequencies [7] using organic magnetic substrate antenna with frequency selective surface. To get better bandwidth and performance, FSS is adopted. Bandwidth is ranging from 5.56 to 6.3 GHz. The simulated bandwidth is 0.74 GHz.

Mingbao Yan introduced the novel BPF [8] with significantly smaller-sized periodic elements repeated over the substrate's surface. It is a single-sided design printed on the substrate, which is having the permittivity of 2.65. The design exhibits excellent stability under different angles of incidence of EM waves.

Bora Doken proposed a frequency surface design [9] for 2.4 GHz and 5.8 GHz, a hybrid design, which acts as a band stop filter. The design is printed on either side of the thickness of 1 mm, providing a stable response for all polarizations, a small circular loop is printed on the substrate's bottom layer to provide a high attenuation degree, and the circular loop is printed on the substrate's lower side to achieve the angle of incidence independence for 5.8 GHz.

Munk [10] provides a basic understanding for the design of frequency selective surface, which can act as either a band-pass or band-stop filter, which helps us choose the required elements for our design to act as a band stop filter, and also helps in achieving the desired frequency range of bandwidth, and also in achieving compactness of the design. The FSS designs reported in the literature have a complex design and larger profile. So FSS with compact-sized FSS along wide bandwidth is the need of the hour considering the grown interest in short-range communication.

This work in this paper is organized as follows: The FSS design is discussed in section In section IV, transmission characteristic results are discussed and concluded with section V.

3. FSS Design
The proposed FSS exhibits the BSF characteristics in ISM and lower ultra-wideband (at two frequency ranges around 2.4 GHz for ISM band and 3.1 to 5.6 GHz (lower ultra-wideband). The frequency selective surface has a huge role in communication, which helps filter out the undesired frequency bands most frequently used in aircraft, isolation chambers, etc.

The surface's design was performed on the ANSYS HFSS simulation software, and the resultant graphs were studied. The literature found that the design should be symmetrical to provide a similar result for 90° rotations [11].

The loop type structures were used from the past designs and base papers to obtain the frequency ranges for large bandwidths. We initialize our design with the square loop with small slots inserted in the inner side to move along [12]. The slots are inserted in order to provide a large conducting path. The bandwidth of the
design can be increased by introducing the dielectric substrate on both sides of the periodic array of patches or one side of the patch or employing the loops elements [13]. The lower resonant frequency can also be obtained using the dielectric or increasing the conductivity length or inserting the elements in between the gaps.

The resonance frequency is inversely proportional to the inductance (L) and capacitance (C). The slots inserted will provide. The capacitive nature and the path will provide the inductive nature. FR4 epoxy is used as a substrate with a dielectric constant (4.4), the loss tangent of (0.02), which provides a reasonable result, and the patch we have used is copper. We observed the frequency selective surfaces are designed separately for ISM band and ultra-wideband from the past papers. The proposed design has the significance of covering dual-frequency ranges and compact-sized FSS. The characteristic graphs were observed at each stage of the revolutionary process, and considerable measures were taken to improve the result [14]. Large conducting path lengths and higher capacitance were provided to move the graph towards the lower frequency range. As reported in the literature, to obtain the larger bandwidth, the design was printed on both sides of the substrate [15].

Finally, the design has a 23.5 mm x 23.5 mm size, which exhibits compactness, polarization-independent, and independent on the angle of incidence, which acts as a band stop filter at two frequency ranges, from 3.1 to 5.6 GHz and around 2.45 GHz.

4. Proposed Design

The proposed design exhibits symmetricity, compactness, and independence on the incidence angles for a particular extent of up to 60°. The novelty of the design held in designing the unit cell for ISM and lower ultra-wideband frequency range. Figure 3 discusses about design of the unit cell for ISM and Figure 4 displayed the proposed design dimensions in details

![Figure A](image1.png)  
**Figure A:** Design of the unit cell for ISM
Table 1: Proposed Design Dimension’s

| REPRESENTATIONS | DIMENSION VALUES |
|-----------------|------------------|
| W1              | 23.14285708      |
| W2              | 4.821428559      |
| W3              | 1.928571424      |
| W4              | 2.410714279      |
| W5              | 0.964285712      |
| W6              | 2.892857136      |
| W7              | 0.642857141      |
| W8              | 0.803571427      |
| W9              | 2.892857136      |
| W10             | 2.603571422      |
| W11             | 0.289285714      |
| W12             | 1.928571424      |
| W13             | 2.121320344      |
| C1(RADIUS)      | 3.860567528      |
| D1              | 6.238930735      |

Figure 4: Proposed Design Dimension
5. Results And Discussion

Where, Figure 5 discusses about Design Evolution graphs initially (stage1), the design's development started with the basic square loop with the small square-shaped patches on all sides, which increases the conductivity path and the capacitance between the periodic elements. Hence, the lower cutoff frequency decreases.

In stage 2, the “T” shaped wedges' width increased, which results in a shift of the resonant frequency to the lower side.

![Figure 5: Design Evolution graphs initially](image)

5.1 Transmission Coefficients (Db) At Different Stages

In stage 3, the “+” shaped slots are drawn on all sides of the geometry, increasing the inductance or current distribution length and the adjacent cells' capacitance.

In stage 4, the two circular slots are employed at the center position, and the patch is placed on either side of the substrate. The evolution plots for the unit cell were shown in Figure 3. Placing the patch on either side will increase the bandwidth. Placing the patch on either side of the substrate will increase the bandwidth. In the proposed unit cell on stage 5, three small circle slots are employed, and the patch was placed on either side of the substrate[16]. It produces the two resonant peaks at 2.3 GHz and 6.5 GHz, and the bandwidth also increased. The resonant peaks obtained at the required frequencies of the proposed design are of size 23.72 mm x 23.72 mm, and the bandwidth obtained is 4.9 GHz. In all the stages, the conducting patch is placed on either side of the substrate[17].

Note: In all the stages, the conducting patch is placed on either side of the substrate.

5.2 Angular Stability

The design exhibits the stable response for different angles of incidence of the electromagnetic waves. It shows the stable response up to the extent of 60°. The design also exhibits the symmetric property. It also shows the same response for 90° rotation of the design, and the angular response is also stable for 90° rotation[18]. Where, Figure 6 explains about Angular stability.
6. **Simulated Graphs Forte and Tm Modes At Various Angle Of Incidence Of Em Waves**

**Figure 6:** Angular stability

**Figure 7:** Simulated Transmission Characteristics (dB) TE Mode

**Figure 8:** Simulated Transmission Characteristics (dB) TM Mode
7. Measured graphs for TE and TM modes at various angle of incidence of EM waves

Figure 9: Measured Transmission Characteristics (dB) TE Mode

Figure 10: Measured Transmission Characteristics (dB) TM Mode

8. Measured vs. Simulated transmission coefficients (dB)

Figure 11: Measured vs. Simulated transmission Coefficients (dB)
Figure 12: Anechoic chamber

The transmission characteristics (dB) for the design exhibit angular stability up to 60°, as shown in Figures 7, 8, 9, and 10. The final design was examined in the Anechoic chamber, as shown in Figure 12. An anechoic chamber is used to absorb reflections of all the electromagnetic waves during the testing of the model; the proposed design is excited by using the horn antenna. The simulated and measured transmission coefficients (dB) are in good correlation, showing a very low variance in the corresponding frequency bands shown in Figure 11. The fabricated model of the proposed design was shown in Figure 13, and the analysis setup is shown in Figure 14. The measurements were taken by exciting the horn antenna. The results are very close to each other, as shown in Figure 11, resulting in that the design is most suitable for applications in the ISM and lower ultra-wideband frequencies. Table 2 shows comparison of the proposed FSS with the previous designs.

Figure 13: Fabricated design
Figure 14: Frequency Selective Surface Measurement set up

Table 2: Comparison of the proposed FSS with the previous designs

| FSS       | Thickness(mm) | Dielectric constant | Dimensions in terms of (λ/3) | Bandwidth(GHz) | Fractional Bandwidth | Type of metallic layer used |
|-----------|---------------|---------------------|------------------------------|----------------|----------------------|----------------------------|
| [1]       | 1.6           | 4.4                 | 0.180x0.180x0.125            | 7.7            | 89.95                | Dual                       |
| [2]       | 1.8           | 4.4                 | 0.150x0.150x0.017            | 8              | 11.6                 | Dual                       |
| [3]       | 1.6           | 4.4                 | 0.175x0.175x0.018            | 4.7            | 80.34                | Single                     |
| [4]       | 1.6           | 4.4                 | 0.201x0.201x0.007            | 0.3            | 12.24                | Dual                       |
| [5]       | 1.6           | 4.3                 | 0.133x0.133x0.013            | 0.290/0.290    | 11.9                 | Dual                       |
| Proposed  | 1.6           | 4.4                 | 0.170x0.170x0.170x          | 4.9            | 105.37               | Dual                       |

9. Conclusion
The unit cell presented in this paper is compact in size and symmetrical. Figure 9 represents the simulation vs. measured results for FSS on ISM and Lower ultra-wideband. Designed FSS shows the band-stop-filter characteristics for ISM (2.45 GHz) frequency and lower ultra-wideband (3.1 to 5.6 GHz) frequency. The simulated (-20 dB transmission) bandwidth is 4.9 GHz by fabricating design on either side of the dielectric substrate (thickness of 1.6 mm and the dielectric constant of 4.4, loss tangent of 0.02) between the two arrays of metallic layers. An array of a metallic layer on both sides is used because it shows larger bandwidth. The proposed design shows the angular stability for both TE and TM modes up to 60 degrees, and it has the same angular response for 90 degrees also. The proposed design has a fractional BW of 105.37.

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