

## RESEARCH

# Frequency-selective surfaces (FSS), absorbers and rasorbers: Theory and approach

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joohigrg@gmail.com**Received:** 01 November 2023; **Accepted:** 10 November 2023; **Published:** 11 April 2024

The field of electromagnetic wave manipulation and control is based on the essential elements of frequency-selective surfaces (FSS), absorbers, and rasorbers. When designing radomes, frequency-selective surfaces (FSSs) are often utilized as spatial filters for incoming electromagnetic (EM) waves to protect the antennas and lower the radar cross-section (RCS) of the antenna system. The frequency-selective rasorber (FSR) was designed in this study. We employed strategies like Frequency-Selective Surface (FSS), Lossy layer, and ANSYS HFSS Resonator to develop FSR. The power loss, far-field directivity, and electric field in the antenna at frequencies of 2 and 14 GHz are all shown in the experimental result. It was demonstrated that at frequency 2 GHz, the greatest power loss is 76087.1 W/m<sup>3</sup> and the smallest loss is 0 W/m<sup>3</sup>. The greatest loss at frequency 14 GHz is 539233 W/m<sup>3</sup> and the smallest loss is 0 W/m<sup>3</sup>. We could expect further advancements in the way we harness and regulate electromagnetic waves for the benefit of society as researchers continue to improve and invent these technologies.

**Keywords:** frequency-selective surfaces, electromagnetic, radar cross-section, FSS, polarization, sensitive, angular stability

## 1. Introduction

The increasing reliance on electronic devices has increased the prevalence of electromagnetic pollution. 2D and 3D structures can be designed externally to filter and absorb electromagnetic waves in the appropriate bandwidth (1). As electromagnetic metamaterials have advanced, so have Frequency-Selective Surfaces (FSSs). The frequency-selective construction is widely used in modern antenna systems, shielding from electromagnetic radiation systems, including RCS reduction devices to minimize the Radar Cross Section (RCS) (2).

In 1995, the first Frequency-Selective Rasorber (FSR) was developed, ushering in a new era of scientific inquiry (3). The FSRs' primary distinguishing feature is a transparent and absorbance window (s). In terms of their functional properties, the FSR structure can be broken down into

transmission bands: at two different times: (1) before (T-A) and (2) after (A-T) (4). However, the passband in such systems is typically located far from the bandwidth of the absorption band. Therefore, FSR designs incorporating their transmission band within the absorbed band have been proposed (A-T-A) to increase communication security (5).

In addition, certain three-dimensional FSRs are shown as a different way to create double-sided absorbers (6). The parallel arrangement of absorbers and transmitters in the 3-D structure allows for a wide range of absorptions without increasing insertion loss (7). Radar-absorbent substances (RAM), as well as Radar-absorbent structure (RAS), have grown into crucial stealth technologies for aircraft, missiles, as well as warships in contemporary conflicts due to their ability to render an object partially invisible to radar or other detection systems of tracking and thereby significantly increase the survivability of a plane. These cutting-edge technologies' capacity to modify the

transmission, reflections, and absorption of electromagnetic radiation across a wide frequency range has garnered a lot of attention and praise.

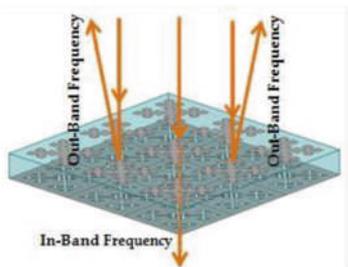
### 1.1. Frequency-selective surfaces (FSSs)

Frequency-selective surfaces (FSS) were first established by Marconi and Franklin in 1919 to enhance wireless telegraphy and telephony using periodic patterns within an antenna (8). The FSS is a surface-created periodic structure that filters electromagnetic waves (wireless signals) at a certain frequency (9). Such surfaces are made up of regular arrays of conductivity or dielectric material elements arranged in a predetermined geometry, and they respond to incident electromagnetic fields in a way that varies with their frequency (10). **Figure 1** shows the functionality of FSS achieved by a complementary self-resonating network.

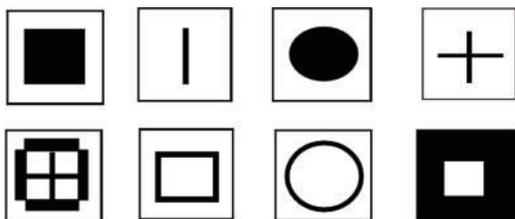
By transmitting or reflecting electromagnetic energy only in some frequency bands while attenuating and blocking others, FSS act as frequency-sensitive filters. To obtain the appropriate transmission and reflection qualities at frequencies or frequency bands, the unit cells' size and forms in an FSS must be carefully designed (12). Depending on their construction, operational principle, and frequency response characteristics, various types of FSS can be identified (13).

Square patches, dipoles, circular patches, cross-dipoles, Jerusalem crosses, square loops, rings, and square apertures are only some of the FSS element shapes. **Figure 2** displays the FSS shapes that occur most frequently. Freestanding dipole arrays suffer the most instability in their resonance frequency because of changes in incidence angle.

Some frequent FSSs are as follows:



**FIGURE 1** | The functionality of an FSS (11).



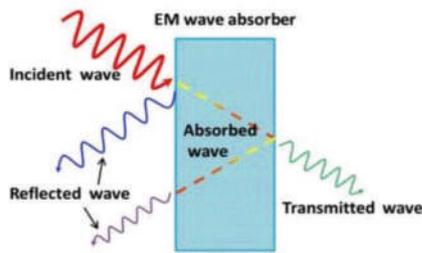
**FIGURE 2** | Typical forms for FSS elements.

- **Periodic FSS:** It comprises identically shaped unit cells that recur at regular intervals. For resonance effects to be induced at desired frequencies, periodicity is crucial. These FSS varieties are commonly utilized in situations calling for selective frequency response because of their straightforward architecture.
- **Bandpass FSS:** It lets through a selected frequency band while reflecting or attenuating all other frequencies. Communications, radar, and microwave filters rely on them to send and receive signals at the appropriate frequencies.
- **Band-reject (Notch) FSS:** Notch FSS, often known as FSS, is an alternative to bandpass FSS. They block one range of frequencies while letting others through. These configurations aid in decreasing interference and filtering out undesirable frequencies.
- **Dual-band FSS:** It is optimized to provide separate frequency-selective responses over two unique frequency ranges. These architectures are used in multi-band communication networks and other scenarios that require selective control over various frequencies.
- **Wideband FSS:** Compared to standard narrowband FSS, wideband FSS is designed to operate over a wider range of frequencies. Broadband uses are a good fit for these structures because of their wide frequency range of effectiveness.
- **Polarization-dependent FSS:** In FSS with a polarization dependence, the frequency response varies with the polarization state of that incident electromagnetic field. Varying polarizations can have varying transmission or reflection qualities depending on their design.
- Frequency-selective surfaces are increasingly useful in areas such as communication, radar systems, technology for stealth, and electromagnetic shielding because of ongoing research and improvements in materials and design methodologies.

### 1.2. Absorbers

In contrast to reflectors, absorbers take in electromagnetic waves and transform them into thermal energy. Their ability to absorb electromagnetic waves makes them perfect for enhancing signal quality and decreasing noise in electrical equipment. In situations where stray reflections could degrade a signal or otherwise endanger the operation of delicate machinery, absorbers prove invaluable. As shown in **Figure 3**, there are three stages that an incident electromagnetic wave goes through when passing through an EM-absorbing material: reflection, absorption, and penetration.

Different types of absorbers, including resistive, magnetic in nature, and dielectric absorbers, are optimized for different



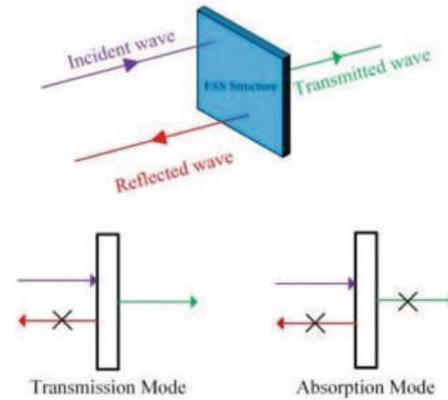
**FIGURE 3** | Electromagnetic wave absorption procedures (14).

frequencies and uses. To transform EM energy into thermal energy, resistive absorbers use carbon-loaded foams and conductive sheets, among other resistive materials. Magneto-lossy materials are used in magnetic absorbers because they dissipate energy as heat when subjected to magnetic fields. In contrast, dielectric absorbers use high-dielectric-loss materials to convert electromagnetic energy into thermal energy (15–17). Different types of absorbers are better or worse suited for different applications due to factors like frequency range of interest, absorbing efficiency, along with physical limits. Improved performance and new uses for absorbers have resulted from ongoing studies in material science and absorber design.

### 1.3. Rasorbers

Rasorbers, an acronym for "Radome and Absorbers," are a relatively new development in electromagnetic wave controls. In recent years, reports of rasorbers being used for stealth applications with either a single narrow passband or many narrow passbands have surfaced. These FSR have recently surpassed FSS absorbers in favor due to their transmission properties and absorption (18). **Figure 4** shows a bandpass FSS integrated with the absorbers to produce the FSS-based rasorbers. When the ground layers of the FSS-based absorber are swapped out for a bandpass FSS, it gets the absorption band and a transmission band (19). Due to its potential use in multi-band wireless communication and radar systems, bandpass FSS has recently been the subject of substantial research as an independent application.

Broadband absorption and a lowpass band in an FSR with a double resistive layer architecture have been observed. Two absorption and two transmission layers are used to create a transmission band between the two absorption bands, as reported in another FSR based on a four-layer architecture (20). The FSR includes the bandpass FSS layer and the resistive sheet layer. The insertion loss of the transmission band is determined only by the impedance of the resistive sheet layer when the lossless bandpass FSS is used at the bottom layer. The high-transmittance performance is due to the infinite impedance of the resistivity layer (21). Therefore, many studies have focused on the layout of resonance frameworks in recent years, and the analogous



**FIGURE 4** | Schematic of an FSS-based rasorber.

parallel LC resonance pattern in a resistive sheet layer is typically employed to accomplish infinite impedance. These FSRs operate in various transmission bands with high-transmittance achievement and their broadband absorption properties are excellent outside the transmission band due to their varied resonance structures.

Section 2 (Problem formulation and research objective), presents a detailed explanation of the problem formulation and outlines the objectives of the study. Section 3 (Research gap) delves into the research gap identified in previous studies, highlighting the need for further investigation. Finally, Section 4 discusses the research methodology, elaborating on the planned approach to conduct the study.

## 2. Problem formulation and research objective

This study aimed to use the ANSYS HFSS program to study the electromagnetic characteristics of FSS that have been combined with a Lossy Layer. The key focus was analyzing and optimizing the FSS design to achieve the desired frequency-selective qualities while including a Lossy Layer to boost electromagnetic wave absorption. Specific frequency bands can be investigated to characterize the FSS's reflection and transmission characteristics and the impact of the Lossy Layers on the system's performance can be analyzed. Major Research Objectives were as follows:

- (a) To better understand how FSS can be designed and optimized to obtain enhanced frequency-selective features and enhanced reflection and transmission characteristics for specific frequency bands.
- (b) To investigate the design and characterization of innovative absorbers with frequency- and wavelength-specific electromagnetic absorption capabilities, emphasizing utilizing cutting-edge materials and architectures to maximize absorption efficiency.

- (c) To investigate the theoretical foundations and practical verification of Rasorbers, a novel idea that combines the functions of FSS and Absorbers, to better comprehend their special qualities and prospective applications in cutting-edge electromagnetic wave control and manipulation.
- (d) To determine the most appropriate technology for a given application by comparing and analyzing the performance of conventional absorbers, FSS, and rasorbers in real-world scenarios like those involving wireless communications, radar technology, and electromagnetic interference mitigation.

### 3. Research gap

Even though FSS and Absorbers have been the subject of substantial research, their integration into real-world systems and machinery has not yet been thoroughly investigated. A combination of these methods may enhance solutions for manipulating electromagnetic waves. FSS and Absorbers are Rasorbers. More experimental and theoretical research is required to fully comprehend their electromagnetic properties and maximize the potential of this new technology. There are measures for evaluating FSS, Absorbers, and Rasorbers, but no criteria exist for evaluating their effectiveness across frequency ranges and applications. Thorough and widely recognized evaluation measures could promote field development and fair comparisons. Absorbers along with Rasorbers scalability and manufacturing: Advanced Absorber and Rasorber designs cannot be suitable for large-scale applications due to their precision and materials. Addressing these issues and discovering scalable production technologies can bring laboratory studies to life.

### 4. Research methodology

Ansys HFSS is a finite element method electromagnetic field solver that operates in the frequency domain and can solve Maxwell's equations in three dimensions. The solver's output is in three dimensions. It provides accuracy on a par with industry standards, adaptive meshing of arbitrary shapes, fully parametric modeling, various optimization engines, high-performance computation capabilities, and multi-physics integration through an environment called Ansys Workbench. Antennas, filters, waveguides, connections, transitions, as well as electronic packages are just some of the things that are designed with the help of HFSS, which has been commercially accessible for close to thirty years now (22).

Using the HFSS's built-in calculator, users can perform various mathematical operations on field data. The calculator can use geometrical, complex, vector, or scalar data

to provide numerical, graphical, or exportable results. Additionally, frequently used words can be created and imported into any project. The field calculators are used to determine the axion couplings to a cavity phase in haloscope detectors as a number that ranges from 0 to 1. This value can be obtained by entering the relevant information into the field's calculator (23).

#### 4.1. Proposed methodology

The proposed layout's operation steps are depicted in **Figure 5** as follows:

##### (a) Field Directivity for $\phi = 0$

The area that is the furthest from the antenna and has the highest concentration of electromagnetic fields is referred to as the far-field region. This region is also referred to as the Fraunhofer region. This location is situated in close proximity to the radiative near-field region. An antenna's radiation pattern in this area is mostly unaffected, regardless of how close or far it is from the source. **Figure 6** displays the far field directivity radiation pattern in 2D. From this, we can observe that the major lobe magnitude for  $\phi = 0$  at frequency 14 GHz is 7.17 dBi, and the main lobe direction is 180.0 deg.

The far-field directivity radiation pattern is shown in graph form in **Figure 7**. From this, we can observe that at the same frequency for  $\phi = 90$ , the major lobe magnitude is 3.55 dBi, and the main lobe direction is 107.0 deg.

##### (b) Field Directivity for $\Theta = 90$

The far-field directive for  $\theta = 90$  is shown in **Figure 8** at a frequency of 2 GHz. From this vantage point, we can observe that the magnitude of the major lobe is 147 dBi, and the orientation of the main lobe is 0.0 deg.

The 3D plot of the far field cross-polar type component at a frequency of 14 GHz is shown in **Figure 9**. It is clear from this position that the efficiency of the rod is 0.3687 dB, whereas the overall efficiency is 1.955 dB. It is possible to demonstrate energy radiation via the use of radiation patterns. By expanding the size of the patch and also using structures made of dielectric-coated layers, we may achieve higher levels of directivity.

The far-field directivity cross-polar at frequency 14 GHz for  $\theta = 90$  is shown in **Figure 10**. From this vantage point, we can observe that the magnitude of the major lobe is -4.53 dBi, and the orientation of the main lobe is 158.0 deg.

##### (c) Electric Field

The graph of the electric field (in V/m) vs time (in ns) is shown in **Figure 11**. We can see from the graph that the magnitude of the electric field decreases as the passage of time increases. At the longest time scale, 5 ns, it displays a value

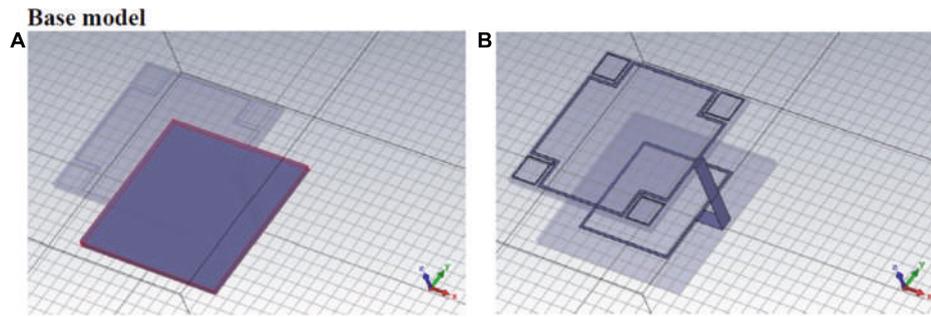


FIGURE 5 | Schematic of an FSS-based raserber. (A) Bottom View; (B) Top View.

of 45 volts per meter (V/m) in the electric field, while at the shortest time scale, 0.1 ns, it displays the maximum value of the electric field, which is 345 V/m.

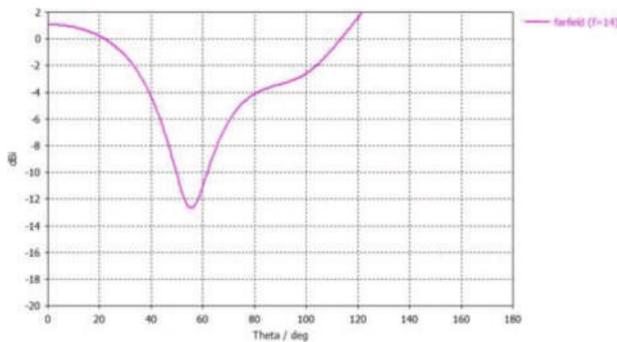


FIGURE 6 | Far-field Directivity Abs (Phi-0).

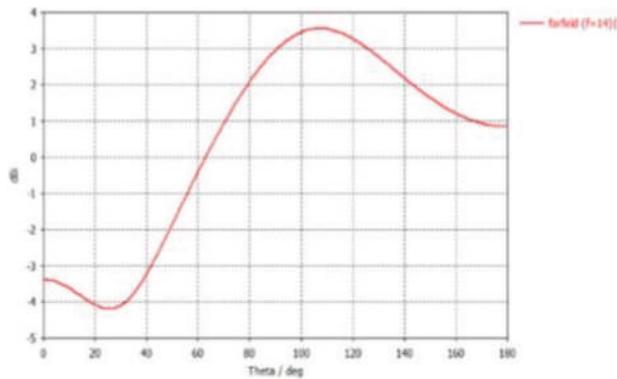


FIGURE 7 | Far-field Directivity Abs (Phi-90).

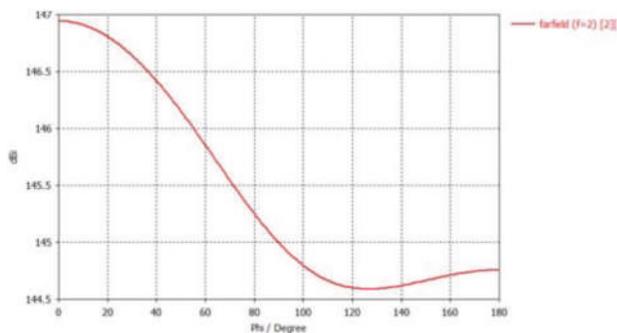


FIGURE 8 | Far-field Directivity Cross Polar (Theta-90).

(d) Three-Dimensional Plot of Power Flow

The power loss density of electromagnetic waves in unimolecular processes can often be clearly determined from an analogous time-varying resistance, which is connected to the number of substances in reactions. In this part, we will define the 3D plot of power flow at frequencies of 14 and 2 GHz, as well as the 3D plot of far-field cross-polar at frequency 14 GHz, and the 3D plot of magnetic field (H-field) at frequency 14 GHz. The three-dimensional plot of the power flow is shown in Figure 12 (a, b). The plot reveals that the highest power flow at frequency 14 GHz is  $2.71721 \times 10^6$  V.A/m<sup>2</sup>. In a similar vein, the maximum flow at a frequency of 2 GHz is  $9.52904 \times 10^6$  V.A/m<sup>2</sup>.

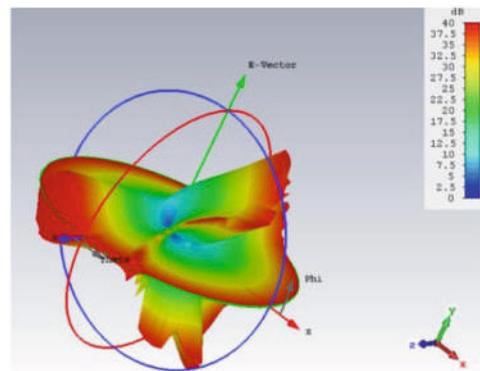


FIGURE 9 | 3D Plot of Far Field.

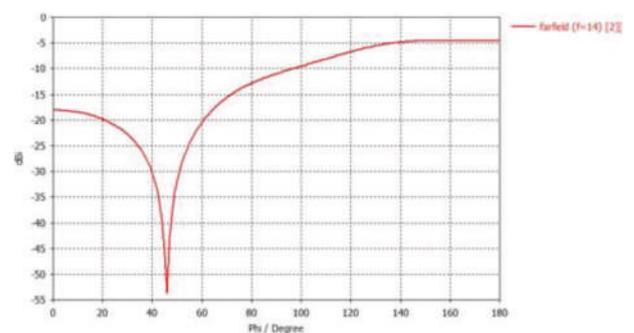


FIGURE 10 | Far-field directivity cross-polar (Theta = 90).

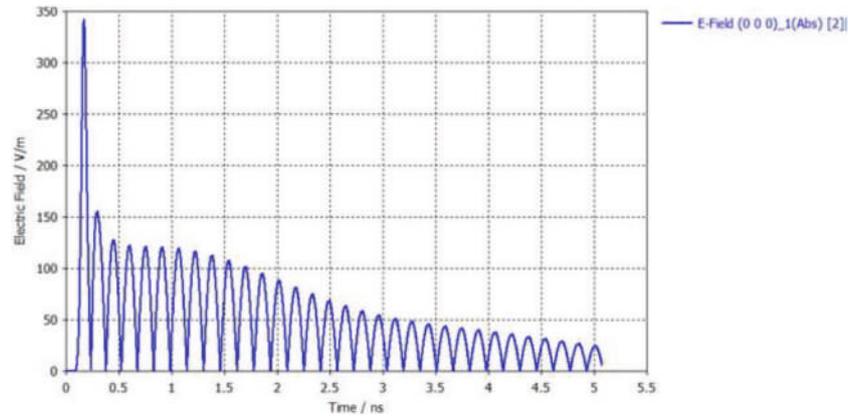


FIGURE 11 | Graph of Electric Field.

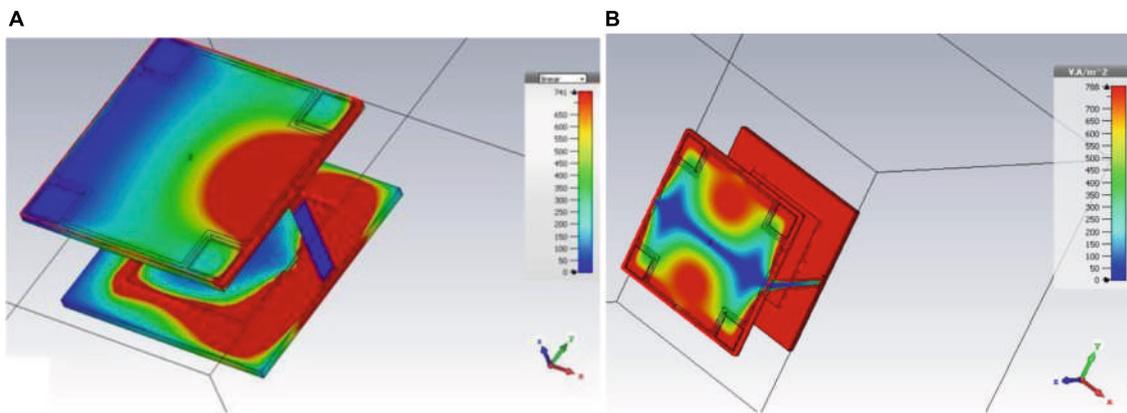


FIGURE 12 | 3D plot of power flow at frequencies of (a) 14 GHz and (b) 2 GHz.

## 5. Conclusion

Frequency-Selective Surfaces (FSS), Absorbers, and Rasorbers are essential components in the field of electromagnetic wave control and manipulation. Each of these technologies serves specific purposes and has a wide range of applications in various industries. FSS structures have proved to be valuable in controlling the transmission and Plot of Far Field reflection properties of electromagnetic waves at specific frequencies. Future research will likely focus on developing new materials and metamaterials with tailored electromagnetic properties, enabling the improved performance of FSS, absorbers, and absorbers. There will be a continued effort to miniaturize these components, making them suitable for smaller, portable devices and integrated circuits. Tunable and reconfigurable FSS, absorbers, and rasorbers will become more prevalent, allowing for dynamic control of electromagnetic waves in real time. Researchers will explore the potential of multifunctional FSS, absorbers, and rasorbers that can serve multiple purposes simultaneously, reducing the complexity of electromagnetic systems.

With the rollout of 5G and future wireless communication technologies, designing broadband absorbers and FSS

will remain a significant research area to address the demand for devices that can operate across a wide range of frequencies. As environmental concerns become more prominent, the development of eco-friendly materials and manufacturing processes for these components will gain importance. The space industry will continue to rely on FSS, absorbers, and rasorbers for satellite communication, thermal management, and protection from space debris and radiation.

## Author contributions

All the authors have accepted responsibility for the entire content of this submitted manuscript and approved the submission.

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## References

1. Fahad AK, Ruan C, Nazir R, Haq TU, He W. Dual-band ultrathin meta-array for polarization conversion in Ku/Ka-band with broadband transmission. *IEEE Antennas Wireless Propag Lett.* (2020) 19:856–60. doi: 10.1109/LAWP.2020.2982281
2. Wan W, Li Y, Wang H, Zhu Z, Cheng Y, Jiang L, et al. Chiral absorber-based frequency selective rasorber with identical filtering characteristics for distinct polarizations. *IEEE Trans Antennas Propag.* (2022) 70:3506–14.
3. Huang H, Shen Z. Absorptive frequency-selective transmission structure with a square-loop hybrid resonator. *IEEE Antennas Wireless Propag Lett.* (2017) 16:3212–5.
4. Zhang K, Jiang W, Gong S. Design bandpass frequency selective surface absorber using LC resonators. *IEEE Antennas Wireless Propag Lett.* (2017) 16:2586–9.
5. Dutta R, Ghosh J, Sarkhel A. Planar frequency selective surface-based switchable Rasorber/Absorber for airborne application. *IEEE Antennas Wireless Propag Lett.* (2022) 21:1842–6.
6. Shen Z, Wang J, Li B. 3-D frequency selective rasorber: Concept, analysis, and design. *IEEE Trans Microwave Theory Techn.* (2016) 64:3087–96.
7. Omar AA, Shen Z, Huang H. Absorptive frequency-selective reflection and transmission structures. *IEEE Trans Antennas Propag.* (2017) 65:6173–8.
8. Zhu H, Huang J, Yuan N, Yi B. Tunable frequency selective radome with broadband absorbing properties. *Progress Electro Res Symp.* (2017) 2017:2478–82.
9. Xing Z, Yang F. A novel high-performance fuss-AMC radome unit *IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting.* (2020).
10. Gao B, Huang S, Ren Z, Chen Y, Wang X. Design and verification of an integrated free-standing thick-screen FSS radome. *IEEE Antennas Wireless Propag Lett.* (2018) 17:1630–4.
11. Anwar RS, Mao L, Ning H. Frequency selective surfaces: A review. *Appl Sci.* (2018) 8:1689.
12. Chatterjee A, Parui SK. Frequency-dependent directive radiation of monopole-dielectric resonator antenna using a conformal frequency selective surface. *IEEE Trans Antennas Propag.* (2017) 65:2233–9.
13. Panwar R, Lee JR. Progress in frequency selective surface-based smart electromagnetic structures: A critical review. *Aerospace Sci Technol.* (2017) 66:216–34.
14. Xie S, Ji Z, Zhu L, Zhang J, Cao Y, Chen J, et al. Recent progress in electromagnetic wave absorption building materials. *J Build Eng.* (2020) 27:7102. doi: 10.1016/j.jobbe.2019.100963
15. Karakas B. A newly-designed nano-fluid Batio3 ethanol system for modern electromagnetic absorption applications. *Gazi Univ J Sci Part Eng Innov.* (2018) 5:125–40.
16. Shen Y, Zhang J, Pang Y, Wang J, Ma H, Qu S. Transparent broadband metamaterial absorber enhanced by water-substrate incorporation. *Optics Express.* (2018) 26:15665–74.
17. Duan Y, Guan H. *Microwave absorbing materials.* London: CRC Press (2016).
18. Subedi S, Zhang YD, Amin MG, Himed B. Group sparsity-based multi-target tracking in passive multi-static radar systems using Doppler-only measurements. *IEEE Trans Signal Process.* (2016) 64:3619–34. doi: 10.1109/TSP.2016.2552498
19. Cui T. Absorption-transmission-type multifunctional coding metasurface. *J Phys Part D.* (2022) 55:6.
20. Wang Z, Zeng Q, Fu J, Chen W, Lv B, Song M, et al. A high-transmittance frequency-selective rasorber based on dipole arrays. *IEEE Access.* (2018) 6:31367–74.
21. O'Reilly. *Future-proof your career.* (2023). Available online at: <https://www.oreilly.com/library/view/radome-electromagnetic-theory/9781119410799/c03.XHTML>
22. Jones M. Microwave cavity simulation using Ansys HFSS. In *Microwave cavities and detectors for axion research. Proceedings of the 3rd International Workshop.* (2020). p. 1–7. doi: 10.1007/978-3-030-43761-9\_1
23. Kulkarni S, Joshi MS. Design and analysis of shielded vertically stacked ring resonator as complex permittivity sensor for petroleum oils. *IEEE Trans Microw Theory Techniques.* (2015) 63:2411–7.