Improving gain of ultra-wideband planar antennas: a grounded frequency-selective surface reflector

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Article Info

Article history:

Received May 12, 2023
Revised Jul 11, 2023
Accepted Jul 30, 2023

Keywords:

Frequency-selective surface
Gain
Grounded reflector
Planar antenna
Ultra-wideband

ABSTRACT

This paper introduces a method to enhance the gain of ultra-wideband (UWB) planar antennas by employing a grounded frequency-selective surface (FSS) as a reflector. The grounded FSS reflector comprises square patch structures (SPSs) of unit cells with a complete ground plane. The designed FSS utilizes miniaturized unit cells that are printed on both sides of an FR4 substrate, making it highly suitable for a wide range of applications, particularly as a reflector to optimize the gain of UWB omnidirectional radiators. This concept is demonstrated by employing a circular monopole UWB antenna as the radiator. The measured outcomes of the suggested antenna with the grounded FSS maintain a broad frequency range of bandwidth of 9.162 GHz, spanning from 2.638 GHz to 11.8 GHz. The antenna, in combination with the FSS, achieves a significant measured gain of 7.6 dBi and a high efficiency of 93% at 9.6 GHz. The attributes of the suggested UWB FSS make it an ideal solution for seamless combining with small-sized broadband circuits, thereby maximizing its effectiveness.

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1. INTRODUCTION

Frequency selective surfaces (FSS) are structured configurations of metallic components or apertures that exhibit specific frequency-dependent transmission or blocking characteristics in response to incoming waves. The properties of FSSs are affected by various factors, including the frequency, angle of incidence, and polarization of the electromagnetic waves [1], [2]. As a result, FSSs possess a wide range of characteristics and find extensive application as filters, polarizers, absorbers, and in the field of antenna engineering [3]-[5]. They are employed in various areas such as wireless communication systems, satellite communications, and for reducing radar cross section (RCS). Due to their versatility and usefulness, FSSs have emerged as a prominent area of research, attracting the interest of scholars and industry professionals alike. Consequently, numerous books have been dedicated to FSSs, and extensive research has been conducted to develop and analyze these valuable structures [6].

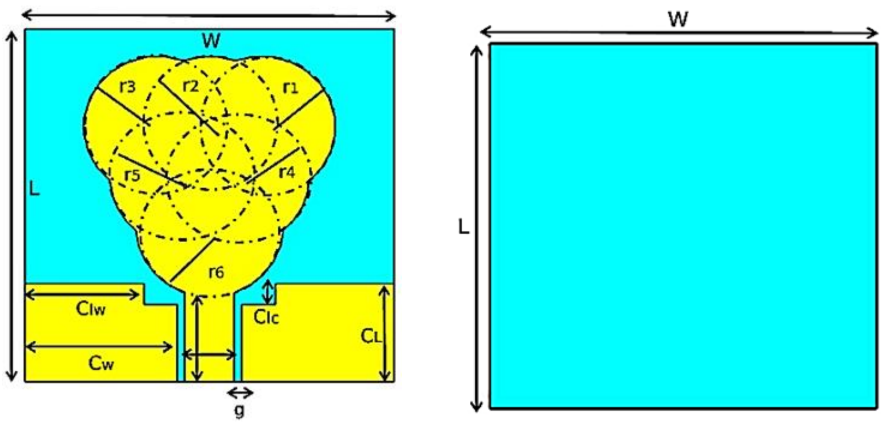
In recent decades, there has been a significant increase in interest and recognition of ultra-wideband (UWB) technology. It has emerged as a highly promising technology capable of surpassing several limitations faced by traditional technologies, such as restricted bandwidth, slow data transfer rates, signal deterioration due to multiple paths, and interference [7]-[9]. This advancement is achieved by utilizing the license-free UWB frequency band, which was approved by the Federal Communications Commission (FCC) in 2002 [10]. As a result, numerous UWB microwave components have been suggested. Building on a similar idea, there has been a growing effort to develop broadband FSSs in order to expand the range of applications for FSSs. This includes integrating them into UWB systems such as UWB communication systems and UWB radars, as well as enhancing the performance of UWB microwave components like antennas. UWB FSSs offer the potential to increase gain and reduce back-radiation, which holds significant value for UWB technology [11]-[15].

While many UWB antennas proposed thus far have focused on providing omnidirectional radiation, which is necessary for conventional wireless systems, there is a need for directional radiation to meet the low power requirements mandated by UWB regulations, specifically the maximum effective isotropic radiation power (EIRP) of -41.3 dBm/MHz [16], [17]. Planar monopole antennas demonstrate favorable qualities such as a streamlined design, small dimensions, and straightforward production, which render them a prospective choice for directional purposes provided that their radiation properties can be improved. To address this, previous studies (references [18]-[24]) have employed multilayer FSSs with stop-band responses to achieve this objective. Consequently, the utilization of UWB FSSs with stop-band response has led to an increase in the gain of various omnidirectional UWB antennas throughout the UWB frequency range. This demonstrates the effectiveness of using UWB FSSs as reflectors for UWB monopole antennas, particularly when they can offer a linear phase response across the UWB band. However, these reflectors typically consist of multilayer FSSs, necessitating multiple spaced FSS layers. This requirement results in the need for a significant amount of space and introduces the possibility of errors due to the complexity involved in their fabrication.

This paper introduces a novel approach where a single-layer FSS is presented to achieve broadband coverage while enhancing antenna gain through the whole UWB frequency range, while also maintaining a linearly varying phase. The modeled FSS cells are positioned on both sides of an FR4 substrate and have a miniaturized cell size of 6×6×1.6 mm mm (width×length×thickness). The FSS design and analysis were performed using CST-MWS software as part of the methodology. The subsequent section provides a comprehensive explanation of the design process through parametric studies, offering essential design insights. Following that, the main outcomes illustrating the performance of the suggested FSS are introduced and analysed.

2. ANTENNA DESIGN STRATEGY

Figure 1 demonstrates the arrangement of the UWB planar antenna with an empty ground plane. The planar antenna has overall dimensions of 26×26×1.6 mm (width × length × thickness). The artistic radiated patch, resembling a strawberry as suggested in [25], is constructed using six cylinders, coplanar waveguide feed (CPW). In this section, the CPW feed, referred to as C_{lc}, was removed from the inner side, as shown in Figure 1(a), and the ground plane is only dielectric as shown in Figure 1(b). Introducing free space between the feed line and the coplanar structure contributes to a broader bandwidth, allowing the generation of licensed ultra-wideband signals ranging from 2 to 11 GHz. Additionally, this modification enhances the impedance matching between the feed and the radiated patch.

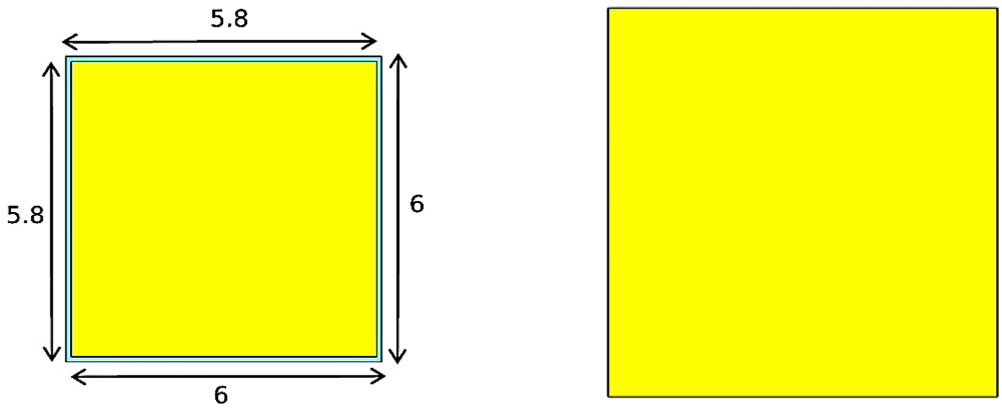


(a) (b)

Figure 1. The design configuration of the UWB planar antenna; (a) frontal perspective and (b) rear perspective, where the dimensions are; W=26, L=26, r_1,r_2,r_3,r_4,r_5,r_6= 5.4, S=3.8, W_f=3.65, L_f=6.8, C_w=11.15, C_l=7.5, C_{wc}=8.7, g=0.525, C_{lc}=1.6, T_c=0.02, T_s=1.6. All dimensions are in mm

2.1. Grounded FSS reflector

A FSS composed of conductor elements operates at a high resonance frequency and behaves predominantly as a transparent medium, although its ability to reflect waves increases with frequency. By incorporating a metallic ground plane (MGP), the transmitted waves can be completely reflected. This grounded FSS significantly enhances the gain of the antenna through the whole UWB spectrum, leading to consistent and sustained amplification. The grounded FSS can be likened to a grounded dielectric slab incorporates with periodic patches, resembling a high impedance surface but without vertical vias. Although eliminating the vertical vias from the mushroom-like structures of this high impedance surface causes the electromagnetic bandgap (EBG) to disappear, surface waves can still propagate across the entire frequency range, with minimal impact on the desired characteristics of in-phase reflection or active metamaterial control (AMC) when the incident wave is normal. The configuration of the FSS cell element consists of the front single-patch structure (SPS), as presented in Figure 2(a), with a full ground copper, as shown in Figure 2(b).



(a) (b)

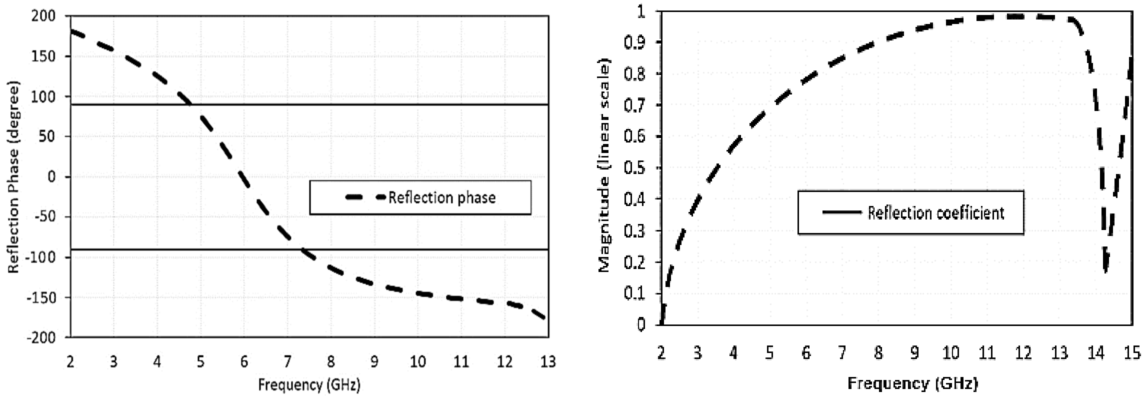
Figure 2. The modeled SPS unit cell in (a) front view and (b) back view

The size of the unit cell determines the range of frequencies in which the reflection phase changes from -90° to +90°, known as the in-phase band [26]. The selection of the substrate material also plays a significant role in expanding the in-phase band. In this case, an FR4 substrate with specific properties was utilized to achieve a broader in-phase band. The chosen FR4 substrate had a dielectric constant of 4.3, a dielectric loss tangent of 0.02, and a thickness of 1.6, all of which contributed to widening the in-phase band.

The phase of reflection and the reflection magnitude of the grounded FSS cell element, computed using CST-MWS with the chosen parameters, are depicted in Figure 3. The calculation was performed by applying "unit cell" boundary conditions and utilizing the Floquet port configuration. The graph demonstrates the attainment of a wide in-phase band spanning from 4.8 GHz to 7.3 GHz, fulfilling the desired objective. Additionally, an AMC feature is observed at 6 GHz, further confirming the successful achievement of the required specifications as shown in Figure 3(a).

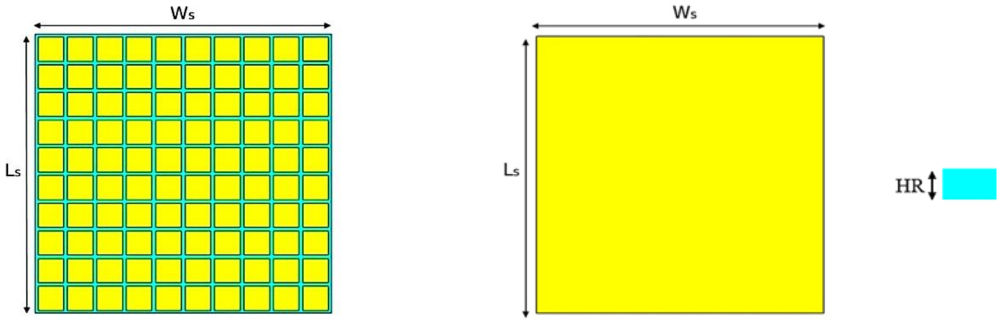
The reflection magnitude of the unit cell, in the absence of a ground plane, exhibits variation across the UWB spectrum. It ranges from 0.3 at lower frequencies to 0.8 at higher frequencies. Figure 3(b) illustrates that the unit cell becomes entirely reflective at approximately 14.2 GHz. Consequently, when a ground plane is introduced, the amount of reflection becomes uneven and decreases proportionally with frequency as suggested in [26].

Subsequently, the SPS unit cells are printed on a dielectric substrate made of FR4 material, as shown in Figure 4(a), serving as a reflector. The front side of the substrate layer comprises a 10x10 array of square patch unit cells, with a grounded metallic copper layer on the ground plane of the substrate, as presented in Figure 4(b). As a result, the backside of the reflector is entirely covered in copper, as depicted in Figure 4. The complete dimensions of the grounded SPS reflector are 61×61×1.6 mm, representing the width, length, and thickness (WS×LS×HR), respectively.



(a) (b)

Figure 3. Displays the reflection properties of the FSS SPS structure: (a) phase of reflection of the grounded FSS with optimized dimensions and (b) reflection magnitude of the FSS in the absence of a ground plane



(a) (b)

Figure 4. Proposed SP reflector in which; (a) front look and (b) back look

2.2. UWB radiator combined with grounded FSS reflector

To further assess the modeled design concept, the UWB monopole planar antenna is utilized as the radiator. It is a CPW-fed planar monopole antenna printed on an FR4 substrate, as illustrated in Figure 5. In this study, the grounded FSS reflector, along with the UWB radiator, is tested, simulated, and extensively discussed in terms of their performance. The grounded FSS will be integrated with the planar antenna and separated by an airgap (S=10 mm). The grounded FSS is designed using an FR4 substrate with a dielectric constant of 4.3 and a dielectric tangent loss of 0.02, which is employed for the experiment. The substrate has a thickness of 1.6 mm.

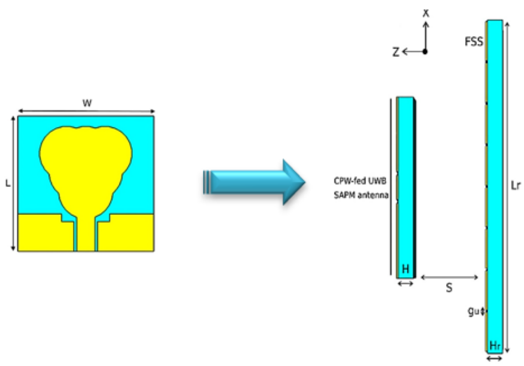
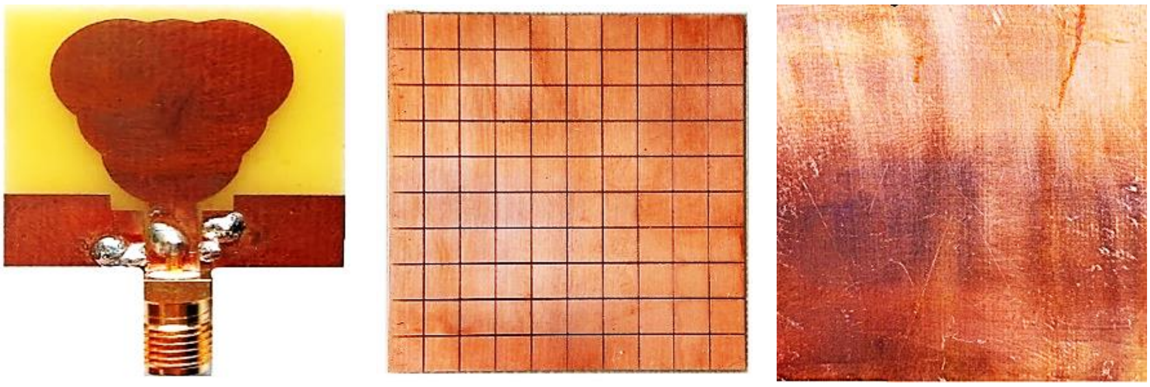


Figure 5. illustrates the configurations of both the utilized UWB antenna and the proposed configuration, where L_r=L_w=61 mm, L=W=26 mm, S=10 mm, H_r=H=1.6 mm, g_u=0.25 mm

3. RESULTS AND DISCUSSION

The grounded FSS reflector proposed with optimized dimensions, along with the utilized radiator, was fabricated and photographed, as depicted in Figure 6. The UWB planar antenna is shown in Figure 6(a), while the front and ground planes of the FSS SPSs reflector are presented in Figure 6(b) and Figure 6(c), respectively. In all four scenarios, the reflection coefficient, peak gain, radiation patterns, and efficiency of the UWB antenna were computed through numerical analysis and measured experimentally. The antenna with UWB FSS reflectors obtains a bandwidth from 2.65 GHz to 13.55 GHz. It is important to note that the selection of the four cases was done to evaluate the performance across the entire UWB frequency range, rather than focusing on specific directions. This methodology evaluates the capability of the proposed reflectors to significantly improve antenna performance across the entire UWB frequency range. The simulation and measurement outcomes exhibit a satisfactory level of agreement, validating the effectiveness of the approach.



(a) (b) (c)

Figure 6. The fabricated prototypes include: (a) the planar antenna, (b) the first side of the FSS SPSs reflector, and (c) the second side of the complete grounded reflector

Figure 7 displays the magnitude of the reflection coefficient |S11| for the UWB planar antenna when installed above the grounded FSS reflector. It indicates that a reflection magnitude below -10 dB is attained across various UWB band variations. The measured |S11| of the antenna with the reflector exhibits an expanded bandwidth of 9.162 GHz, spanning from 2.638 to 11.8 GHz, compared to the antenna alone which has a bandwidth of 8.2 GHz, ranging from 2.2 GHz up to 10.4 GHz. The UWB frequencies extend from 2.65 GHz to 13.55 GHz, providing a 10.9 GHz bandwidth.

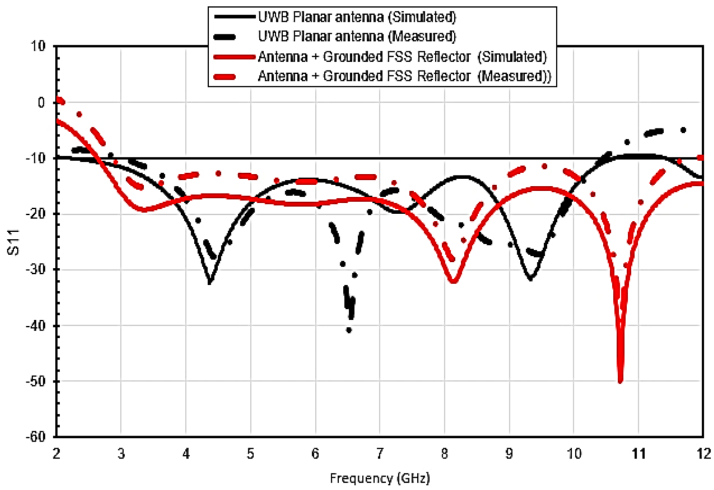
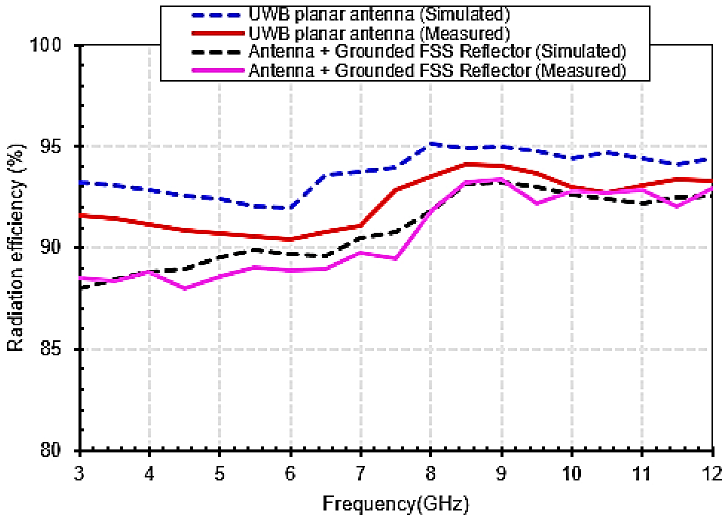


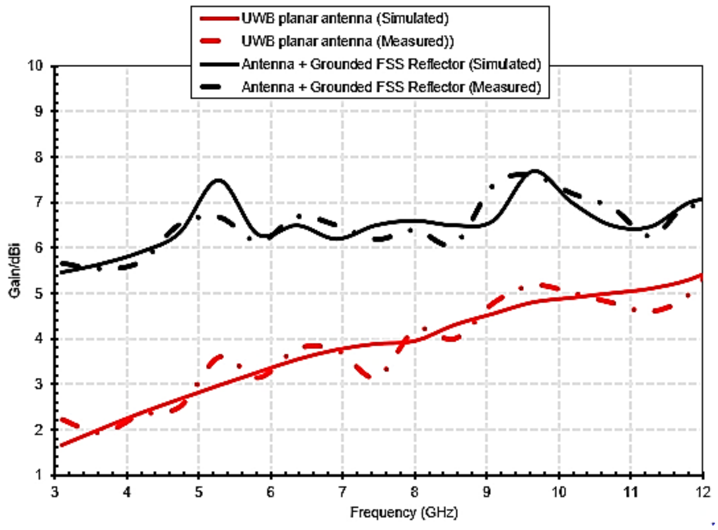
Figure 7. The simulated and measured magnitude of the reflection coefficient |S11| for the suggested antenna in conjunction with the grounded reflector

Figure 8 illustrates the gain and efficiency across various frequencies, as acquired from both simulated and measured 3D radiation patterns for each frequency. The 2D radiation patterns offer a clearer depiction of the primary radiation direction. The antenna, after being loaded with the grounded reflector, achieves a high measured gain of 7.6 dBi at 9.6 GHz, compared to 5.2 dBi without the reflector as presented in Figure 8(a). The antenna radiation efficiency reaches 94.1%, and after loading the grounded reflector, the efficiency becomes 93.1% as depicted in Figure 8(b). This minor decrease in efficiency after mounting the reflector is due to the copper loss induced during antenna propagation.

Figure 9 presents the radiation characteristics of the proposed antenna, demonstrating enhancements in both directivity and gain throughout the UWB frequency range. It is evident that the antenna's directivity and gain experience an increase at higher frequencies within the UWB band, while they decrease at lower frequencies. This behavior can be attributed to the utilization of a smaller FSS size in the latter scenario. The E-field and H-field measurements are presented in Figure 9(a) and Figure 9(b) for the frequencies 3 GHz and 9 GHz, respectively. Nonetheless, the antenna achieves a quasi-constant gain across the entire UWB band, with a maximum variation of 2.4 dBi, which is a noteworthy accomplishment. The remarkable achievement of maintaining a quasi-constant gain in the antenna is attributed to several factors, including the linearly decreasing reflection phase of the suggested FSS and the close proximity between the FSS and the radiator. Such benefits are unattainable using a flat metal reflector. Consequently, the result is a compact, low-profile UWB antenna that presents an enhanced, nearly consistent gain.

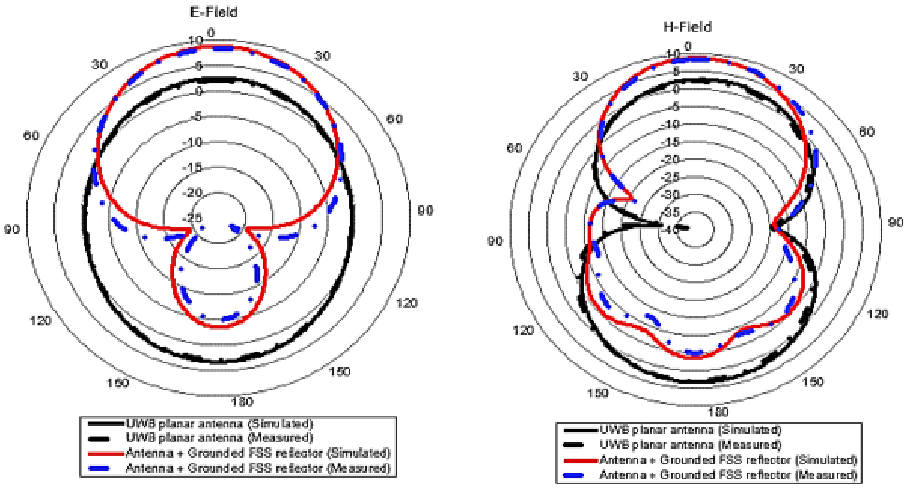


(a)



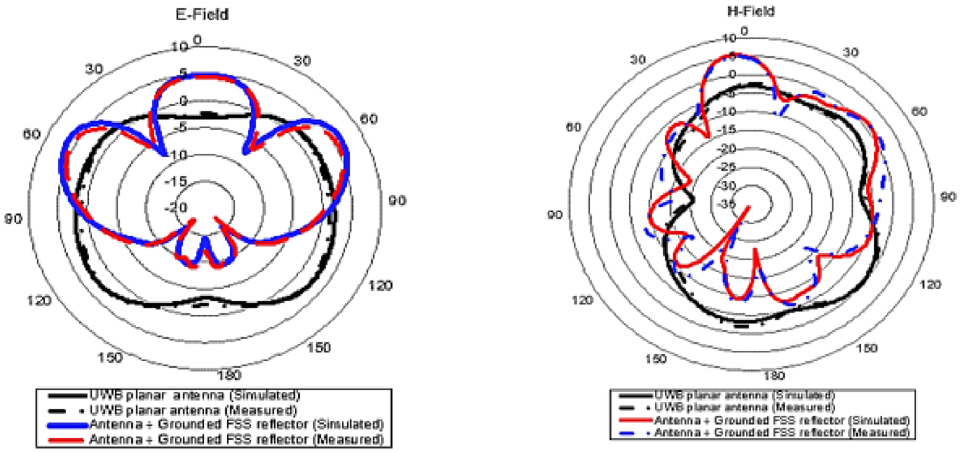
(b)

Figure 8. Predicted and measured outcomes (a) radiation efficeiny (%) and (b) gain



(3 GHz)

(a)



(9 GHz)

(b)

Figure 9. E and H field measurements of the proposed planar antenna with FSS grounded reflector at (a) 3 GHz and (b) 9 GHz

4. CONCLUSION

The primary goal of this paper is to create a single layer broadband FSS that can enhance the gain of UWB planar antennas. To achieve this objective, a novel FSS concept called "grounded with filtering response" is introduced, which covers the entire UWB band. The paper presents and discusses the design process of this proposed FSS to provide a better understanding of its operation mechanism. Additionally, experimental results are presented to validate the design concept. The proposed UWB FSS possesses several desirable features, including a compact size, lightweight profile, and proven performance. These qualities render it appropriate for UWB applications and a highly promising option for combining with compact printed circuits designed for broad frequency range. Furthermore, the FSS demonstrates its ability to function as a UWB reflector, as demonstrated by its successful utilization with a UWB compact antenna as a radiator. One crucial aspect of the proposed FSS is its reflection phase, which exhibits a linear decrease with frequency across the entire UWB band. This characteristic is essential for UWB reflectors and pulsed systems.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) and the Ministry of Higher Education (MOHE) in Malaysia for their support in this research.

REFERENCES

[1] B. A. Munk, "Frequency Selective Surfaces: Theory and Design," *John Wiley & Sons Inc*, New York, 2000, [Online] Available: https://www.wiley.com/en-us/Frequency+Selective+Surfaces:+Theory+and+Design-p-9780471370475.

[2] E. Kim, B. Kim and S. Nam, "Analysis of electromagnetic wave transmission through a choke using FE-BIM with arbitrary incident angle/polarization," *in IEEE Transactions on Electromagnetic Compatibility*, vol. 39, no. 1, pp. 11-16, Feb. 1997, doi: 10.1109/15.554690.

[3] S. Jiang, X. Kong, L. Kong, X. Jin and J. Yuan, "Switchable Polarization-Insensitive Frequency-Selective Surface Reflector/Absorber With Low Profile by Using Magnetic Material," in *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 10, pp. 2078-2082, Oct. 2021, doi: 10.1109/LAWP.2021.3104228.

[4] N. Jawad and L. Markley, "A Single-Layer Frequency Selective Surface With Dual Wideband Band-Stop Response," in *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 6, pp. 916-920, Jun. 2020, doi: 10.1109/LAWP.2020.2982132.

[5] A. J. A. Al-Gburi, I. B. M. Ibrahim, M. Y. Zeain and Z. Zakaria, "Compact Size and High Gain of CPW-Fed UWB Strawberry Artistic Shaped Printed Monopole Antennas Using FSS Single Layer Reflector," in *IEEE Access*, vol. 8, pp. 92697-92707, 2020, doi: 10.1109/ACCESS.2020.2995069.

[6] F. Capolino, "Theory and Phenomena of Metamaterials," *CRC press*, Taylor and Francis Group, 1st ed, 2009, [Online] Available: https://www.routledge.com/Theory-and-Phenomena-of-Metamaterials/Capolino/p/book/9781420054255.

[7] N. Qasem and H. M. Marhoon, "Simulation and optimization of a tuneable rectangular microstrip patch antenna based on hybrid metal-graphene and FSS superstrate for fifth-generation applications," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 18, no. 4, pp. 1719-1730, Aug. 2020, doi: 10.12928/telkomnika.v18i4.14988.

[8] R. A. Fayadh, M. F. A. Malek, H. A. Fadhil, and F. H. Wee, "Planar finger-shaped antenna used in ultra-wideband wireless systems," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 12, no. 2, p. 419, 2014. doi: 10.12928/telkomnika.v12i2.71.

[9] A. J. A. Al-Gburi, I. M. Ibrahim, and Z. Zakaria, "An ultra-miniaturized MCPM antenna for ultra- wideband applications," *Journal of Nano- and Electronic Physics*, vol. 13, no. 5, pp. 1–4, 2021, doi: 10.21272/jnep.13(5).05012.

[10] Md. S. Islam, I. Md. Rafiqul, M. H. Habaebi, and N. Sakib, "Design of UWB microstrip patch antenna with variable band notched characteristics," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 19, no. 2, p. 357, 2021. doi: 10.12928/telkomnika.v19i2.18147.

[11] Y. Zou and J. Pan, "Broadband and High-gain Antenna based on Novel Frequency Selective Surfaces for 5G Application," 2019 *IEEE 4th Advanced Information Technology, Electronic and Automation Control Conference (IAEAC)*, Chengdu, China, 2019, pp. 2488-2491, doi: 10.1109/IAEAC47372.2019.8997989.

[12] K. Yao, S. Lan, and L. Xu, "A high gain Fabry-Perot cavity antenna with a double-layered partially reflecting frequency selective surface structure," 2017 *International Symposium on Antennas and Propagation (ISAP)*, Phuket, Thailand, 2017, pp. 1-2, doi: 10.1109/ISANP.2017.8228834.

[13] S. A. Santoso, S. Hamid, S. Chalermwisutkul and D. Heberling, "High Gain Resonant Cavity Antenna Integrated with Frequency Selective Surface Radome Absorber," 2019 *Thirteenth International Congress on Artificial Materials for Novel Wave Phenomena (Metamaterials)*, Rome, Italy, 2019, pp. X-366-X-368, doi: 10.1109/MetaMaterials.2019.8900919.

[14] A. J. A. Al-Gburi, I. M. Ibrahim, Z. Zakaria, M. K. Abdulhameed, and T. Saeidi, "Enhancing Gain for UWB Antennas Using FSS: A Systematic Review," *Mathematics*, vol. 9, no. 24, p. 3301, Dec. 2021, doi: 10.3390/math9243301.

[15] A. Chatterjee and S. K. Parui, "Performance Enhancement of a Dual-Band Monopole Antenna by Using a Frequency-Selective Surface-Based Corner Reflector," in *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 6, pp. 2165-2171, Jun. 2016, doi: 10.1109/TAP.2016.2552543.

[16] D. M. Pozar, "Microwave and RF Design of Wireless Systems" New York, USA, *John Wiley & Sons Inc*, 2000, [Online] Available: https://pce-fet.com/common/library/books/33/9509_[David_M._Pozar]_Microwave_and_Rf_Design_of_Wirele(b-ok.org).pdf

[17] A. J. A. Al-Gburi, I. B. M. Ibrahim, Z. Zakaria, B. H. Ahmad, N. A. B. Shairi, M. Y. Zeain., "High gain of uwb planar antenna utilising fss reflector for uwb applications," *Computers, Materials & Continua*, vol. 70, no.1, pp. 1419–1436, 2022, doi: 10.32604/cmc.2022.019741.

[18] Y. Ranga, K. P. Esselle, L. Matekovits and S. G. Hay, "Increasing the gain of a semicircular slot UWB antenna using an FSS reflector," 2012 *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC)*, Cape Town, South Africa, 2012, pp. 478-481, doi: 10.1109/APWC.2012.6324954.

[19] Y. Ranga, L. Matekovits, K. P. Esselle and A. R. Weily, "Design and analysis of frequency-selective surfaces for ultrawideband applications," 2011 *IEEE EUROCON - International Conference on Computer as a Tool, Lisbon*, Portugal, 2011, pp. 1-4, doi: 10.1109/EUROCON.2011.5929186.

[20] Y. Ranga, L. Matekovits, A. R. Weily, and K. P. Esselle, "A constan gain Ultra-wideband antenna with a multi-layer frequency selective surface", *Progress In Electromagnetics Research Letters*, vol. 38, pp. 119-125, 2013, doi: 10.2528/PIERL13021007.

[21] N. H. M. Radi, M. M. Ismail, Z. Zakaria, J. A. Razak, and S. N. I. Abdullah, "Development and design of wearable textile antennaon various fabric substrate for unlicensed ultra-wideband applications," *TELKOMNIKA (Telecommunication Computing Electronics and Control)*, vol. 20, no. 6, pp. 1181–1188, Dec. 2022, doi: 10.12928/telkomnika.v20i6.23356.

[22] X. -C. Zhu, P. -P. Zhang, Y. -X. Zhang, J. -X. Ge and Z. -H. Gao, "A High-Gain Filtering Antenna Based on Folded Reflectarray Antenna and Polarization-Sensitive Frequency Selective Surface," in *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 8, pp. 1462-1465, Aug. 2020, doi: 10.1109/LAWP.2020.3007540.

[23] J. Liang, L. Guo, C.C. Chiau, X. Chen and C.G. Parini, "Study of CPW-fed circular disc monopole antenna for ultra wideband applications" *IEE Proceedings - Microwaves, Antennas and Propagation,* vol. 152, no. 6, December 2005, doi: 10.1049/ip-map:20045179.

[24] M. A. Kenari, "Printed planar patch antennas based on metamaterial," *International Journal of Electronics Letters*, vol. 2, no. 1, pp. 37-42, 2014, doi: 10.1080/21681724.2013.874042.

[25] A. J. A. Al-Gburi, Z. Zakaria, I. M. Ibrahim, M. F. Akbar, A. D. K. Al-Obaidi, and A. Khabba, "A parametric study on strawberry radiated shaped monopole antenna for ultrawideband applications." *Bulletin of Electrical Engineering and Informatics,* vol. 12, no. 1, pp. 232-239, 2023, doi: 10.11591/eei.v12i1.4547.

[26] R. W. Ziolkowski and N. Engheta, "Metamaterials: Physics and Engineering Explorations. Hoboken," NJ, USA, *John Wiley & Sons Inc*, Jul. 2006, [Online] Available: https://media.wiley.com/product_data/excerpt/28/04717610/0471761028.pdf

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