Design and realization of ultra-wideband absorber from C to K band

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Here, a novel design of absorber loading dual-layer frequency selective surfaces (FSSs) in the Salisbury screen is proposed. The design of frequency selective surfaces is mainly composed of cross-dipole and dual-loop metal patch. Simulation results show that this absorbing structure can achieve ultra-wideband absorption from C band to K band and the fractional bandwidth reaches 117.1% below –10 dB. The thickness of the proposed absorbing structure is 0.078 \( \lambda_L \) and the unit cell size is 0.262 \( \lambda_L \), where \( \lambda_L \) is the wavelength of the lowest absorbing frequency. Moreover, it shows excellent polarization stability in TE and TM modes, and it has great angular stability. Finally, the prototype of this structure is fabricated, and the measured results are in good agreement with the simulation results.

### Introduction

As one of the main absorbing structures, Salisbury screen can achieve effective absorption of electromagnetic waves by placing a high resistance surface at \( \lambda/4 \) above the metal ground plate where \( \lambda \) is the resonant wavelength corresponding to the absorbing structure [1]. Frequency selective surface (FSS) is a periodically and infinitely one-dimensional or two-dimensional surface structure composed of different arrangements of the same element. It is selective for electromagnetic waves in space and is often called a spatial filter [2]. Due to the unique electromagnetic filtering characteristics of FSSs, it is also able to play an important role in engineering fields such as radar stealth, electromagnetic compatibility, and electromagnetic protection [3–5].

Some research has been done to improve the bandwidth and performance of absorption [6–10]. On the basis of existing research, in order to obtain thinner, more stable, larger bandwidth absorption structure, a novel design is proposed in this paper. By loading dual-layer FSSs in the intermediate medium layer of Salisbury screen, effective ultra-wideband absorption can be realized from 6.54 to 25.03 GHz at \(-10\) dB. In addition, the prototype of this absorbing structure is fabricated and the measured results are in good agreement with the simulation results.

### Description of absorbing structure

The thickness of the whole absorbing structure is only 3.59 mm equivalent to 0.078 \( \lambda_L \). The side view of this structure is shown in Figure 1a. It consists of four dielectric plates successively stacked from top to bottom and the unit size of each layer of dielectric plates is 12 mm \( \times \) 12 mm.

Specifically, for the first dielectric plate, its material is industrial foam with a dielectric constant of 1.1 and its thickness is 1.78 mm. Moreover, a high impedance surface with 377 \( \Omega \) square resistance is printed on the upper surface of the first dielectric plate. For the second dielectric plate, it is a RO4450B plate with a dielectric constant of 3.5, and its thickness is 0.55 mm. In addition, resistively loaded cross-dipole metal patch is printed on its upper surface as shown in Figure 1b. At each centre of the four branches of the cross-dipole metal patch, we load a chip fixed resistor with 150 \( \Omega \).

For the third dielectric plate, it is still a RO4450B plate, and its thickness is 0.6 mm. In addition, resistively loaded dual-loop metal patch is printed on its upper surface as shown in Figure 1c. At each centre of the four edges of the outer loop metal patch, we load a chip fixed resistor with 43 \( \Omega \). And similarly, for the inner loop metal patch, we load a chip fixed resistor with 200 \( \Omega \). For the lowest dielectric plate, its material is industrial foam with a thickness of 0.66 mm. Besides, the metal ground plate made of copper is printed on its lower surface.

### Simulation results

For demonstrating the performance of Salisbury screen absorber loading dual-layer FSSs, it is simulated by HFSS. When loading the dual-layer FSSs, the absorbing structure can generate two resonance points at 10.72 and 19.53 GHz, respectively. And, it can realize ultra-wideband absorbing ability from C band to K band (6.54–25.03 GHz) at \(-10\) dB. Figure 2 depicts the reflectivity curves of this structure in TE and TM modes. It can be seen from the figure that the two curves have a high degree of coincidence, and there is only a small difference in the absorption performance near 20 GHz, which does not affect the absorption bandwidth of this structure.

Figures 3a and 3b show the simulation of Salisbury screen absorber loading FSSs under oblique incidence with TE and TM modes. Compared with normal incidence, the deviation of the resonance frequency is no more than 6%, and the change of absorbing bandwidth is no more than 4% under oblique incidence. Although the absorption performance of this structure fluctuates when the incidence angle increases, it is still within the acceptable range and the whole structure still keeps the absorption capacity about 90% from C band to K band.
Table 1. Performance comparison among the wideband absorbing structures

| Ref. | –10 dB fractional bandwidth | Unit cell size | Thickness | Angular stability (90% absorption) |
|------|-----------------------------|----------------|-----------|-----------------------------------|
| [4]  | 71.5%                       | 0.240 \(\lambda_L\) | 0.079 \(\lambda_L\) | 0–30°                              |
| [6]  | 107.7%                      | 0.180 \(\lambda_L\) | 0.162 \(\lambda_L\) | 0–40°                              |
| [7]  | 108.7%                      | 0.328 \(\lambda_L\) | 0.074 \(\lambda_L\) | 0–22.5°                            |
| [8]  | 92.2%                       | 0.285 \(\lambda_L\) | 0.071 \(\lambda_L\) | 0–30°                              |
| [9]  | 114.4%                      | 0.215 \(\lambda_L\) | 0.076 \(\lambda_L\) | 0–30°                              |
| [10] | 126.8%                      | 0.168 \(\lambda_L\) | 0.088 \(\lambda_L\) | 0–30°                              |
| This paper | 117.1%                      | 0.262 \(\lambda_L\) | 0.078 \(\lambda_L\) | 0–45°                              |

Processing and measured results: In order to verify the simulation results, the prototype of this absorber is fabricated. The prototypes for dual-layer FSSs are shown in Figure 4. And the illustrations show the enlarged version of prototypes in Figure 4a,b. In addition, prototypes of FSSs are both 240 mm \(\times\) 240 mm in size and contain 20 \(\times\) 20 basic unit structures. Specifically, the package size of R1 and R3 is 0402 and R2 is 0805. The measured work is mainly completed in the microwave anechoic chamber by the test platform of NRL Bow method, and the experimental equipment mainly includes a network analyser (Anritsu MS46322A) and two high-frequency horn antennas. The measured environment is shown in Figure 4c,d. Measurement errors caused by external factors can be reduced by measuring standard metal plates before testing prototype of the proposed structure.

The comparison between measured and simulation results under normal and oblique incidence is shown in Figure 5a,b. The analysis from the Figure 5 shows that the deviation of resonance frequency between measured and simulation results is no more than 5% at the same angle and the change of reflectivity bandwidth is no more than 6% with TE and TM modes. These errors are mainly due to the fabrication error and edge error of FSSs prototype.

In particular, Table 1 compares designed absorbing structures with the advanced structures reported in the existing literature. It shows that this structure has larger –10 dB fractional bandwidth than [4] and [6–9], smaller cell size than [7] and [8], and thinner thickness than [4], [6] and [10]. In addition, it has the best angular stability compared to the references. It still maintains excellent absorbing performance when the incidence angle reaches 45°. So, we can conclude that the absorbing structure can achieve better angular stability while achieving large bandwidth, small size and thin thickness.

Conclusion: A novel ultra-wideband absorber is designed by loading dual-layer FSSs based on Salisbury screen in this paper. This absorbing structure can achieve ultra-wideband absorption with –10 dB fractional bandwidth of 117.1% from C band to K band. In addition, the thickness of the proposed absorbing structure is only 0.078 \(\lambda_L\) and the unit cell size is only 0.262 \(\lambda_L\), which can better meet the current demand for lighter, thinner and miniaturization. In addition, this structure has excellent polarization and angular stability. Finally, the prototype of this Salisbury screen absorber is fabricated and the measured results are in good agreement with the simulation results.

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References

1. Chambers, B., Tennant, A.: Characteristics of a Salisbury screen radar absorber covered by a dielectric skin. *Electron. Lett.* **30**(21), 1797–1799 (1994)
2. Munk, B.A.: *Frequency Selective Surfaces: Theory and Design*. Wiley-Interscience, New York (2000)
3. Sivasamy, R., et al.: A wideband frequency tunable FSS for electromagnetic shielding applications. *IEEE Trans. Electromagn. Compat.* **60**(1), 280–283 (2018)
4. Kundu, D., et al.: Single-layer wideband microwave absorber using array of crossed dipoles. *IEEE Antennas Wirel. Propag. Lett.* **15**, 1589–1592 (2016)
5. Yadav, S., et al.: Smartphone frequency shielding with penta-bandstop FSS for security and electromagnetic health applications. *IEEE Trans. Electromagn. Compat.* **61**(3), 887–892 (2019)
6. Seman, F.C., et al.: Design of a Salisbury screen absorber using frequency selective surfaces to improve bandwidth and angular stability performance. *IET Microw. Antennas Propag.* **5**(2), 149–156 (2011)
7. Zabri, S.N., et al.: Compact FSS absorber design using resistively loaded quadruple hexagonal loops for bandwidth enhancement. *Electron. Lett.* **51**(2), 162–164 (2015)
8. Li, M., et al.: An ultrathin and broadband radar absorber using resistive FSS. *IEEE Antennas Wirel. Propag. Lett.* **11**, 748–751 (2012)
9. Ghosh, S., et al.: Design, characterisation and fabrication of a broadband polarization-insensitive multi-layer circuit analogue absorber. *IET Microw. Antennas Propag.* **10**(8), 850–855 (2016)
10. Shang, Y., et al.: On the design of single-layer circuit analog absorber using double-square-loop array. *IEEE Trans. Antennas Propag.* **61**(12), 6022–6029 (2013)