Absorptive frequency selective surface using parallel *LC* resonance

Qiang Chen, Liguo Liu, Liang Chen, Jiajun Bai and Yunqi Fu✉

A frequency selective surface with absorptive/ transmissive property is represented. It allows waves at high frequency around 10 GHz to transmit with very low insertion loss by using the resonance between a parallel microstrip LC structure. It also possesses a wide absorption over lower band by inserting lumped resistors into elements. The absorption band is over 3–9 GHz. A prototype is fabricated and its absorptive/ transmissive performance is measured.

Introduction: Frequency selective surface (FSS) usually refers to a kind of 2D periodical structure composed of array of patches or apertures, with bandstop/ bandpass property [1]. Absorptive FSS (AFSS) is defined as a kind of multilayer periodical structure, which is not only bandpass at some frequencies but can also absorb waves over another band in this Letter. It is composed of a bandpass FSS layer at the bottom and a resistive layer on the top. Over the stopband of bandpass FSS, the AFSS performs as an absorber, while at the passband of FSS, it should transmit operation signals, which also requires the resistive layer to be nearly transparent at this frequency. Recently, several AFSS designs and their applications as stealthy radome to reduce bistatic radar cross-section of antenna were reported [2–7]. However, most of these works were about AFSS structures whose absorbing band locates below the transmission band. Although a metamaterial absorber with transmission band at 21 GHz and a −7 dB absorption band over 5–13 GHz was reported in [8], its insertion loss is higher than 1.2 dB. It is more difficult to design an AFSS structure with transmission band higher than absorption band. The resistive layer should resonant at low frequency to absorb the waves and meanwhile must be nearly transparent at high frequency to pass the high frequency. This requires the resistive element to have a paradoxical dimension. On the basis of the concept of 'rasorber' mentioned in [9], an AFSS structure with good transmissive performance at X band by virtue of a shorted 'choke' structure of length $\lambda_h/4$ (λ_h is the wavelength at high transmissive frequency) has been designed in [10].

In this Letter, another approach to design AFSS with transmissive property at high band using parallel inductor (L) and capacitor (C) resonance is proposed. This AFSS structure possess a wide absorption over lower band and a good transmissive property at f_h of 10 GHz.

AFSS design: A unit cell of the AFSS is depicted in Fig. 1. In the resistive layer, a tiny parallel microstrip LC which resonates at high frequency f_h and two lumped resistors are put into the centre of each dipole element with length of about $\lambda_l/2$. The impendence of the parallel LC is $Z = 1/(\mathrm{j}wC + 1/\mathrm{j}wL)$. At the resonance frequency $f_h = 1/2\pi\sqrt{LC}$, the impendence Z would be infinite. In the view of induced current, the dipole is choked into two short sections. If both the two sections were shorter than $\lambda_h/3$, slight current would be induced upon them. The resistive would be nearly transparent at f_h. With a bandpass FSS at the bottom resonating at the same frequency, the waves at f_h could pass through the AFSS structure. The parallel LC structure is optimised to resonate at 10 GHz.

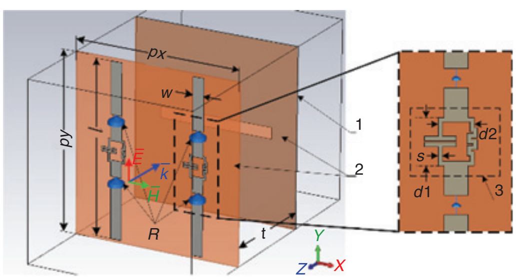

Fig. 1 *Unit cell of AFSS structure*

1. Bandpass FSS layer; 2. F4BM substrates with permittivity of 2.65 and thickness of 0.25 mm; 3. parallel LC resonance structure.
$px = 18$ mm, $py = 19$ mm, $t = 12$ mm, $l = 18.4$ mm, $w = 1.2$ mm, $s = 0.2$ mm, $d1 = 2.4$ mm, $d2 = 1.8$ mm, $R = 150\ \Omega$

Over the lower band below 10 GHz, the impedance of the parallel LC exhibits finitely inductive with the dimension of about $\lambda_l/2$, the dipole still resonates at low frequency around 6 GHz and strong current can be induced. By loading lumped resistors and with the bandpass FSS as ground plane, effective absorption can be obtained. The dimensions of the AFSS structure and lumped parameters were optimised to obtain good transmissive property at 10 GHz and wideband absorptive property.

The absorptive/ transmissive performances of the AFSS were simulated by CST Microwave Studio. Owing to the dipole element of the AFSS, both the performances were researched under the vertical polarisation. Considering the AFSS was illuminated by a y-polarised plane wave, the reflection and transmission coefficients are shown in Fig. 2. The insertion losses at the transmission frequency of 10.2 GHz are lower than 0.15 dB. Over the wide lower band 3–9 GHz, the reflection coefficients are below −10 dB.

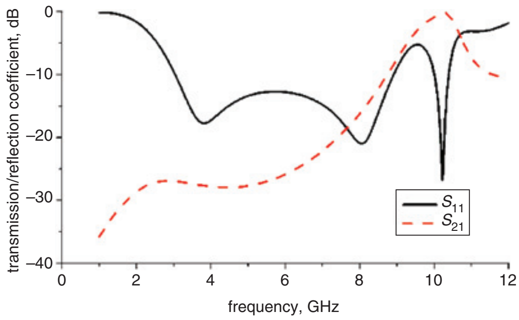

Fig. 2 *Simulated reflection and transmission coefficients of AFSS*

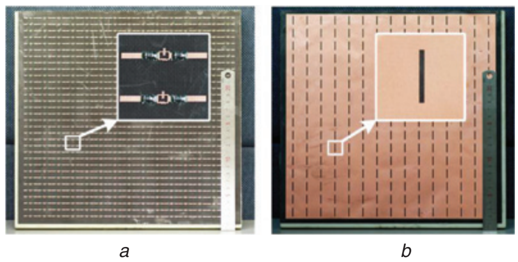

Fig. 3 *Photograph of fabricated AFSS*

a Resistive layer
b Bandpass FSS

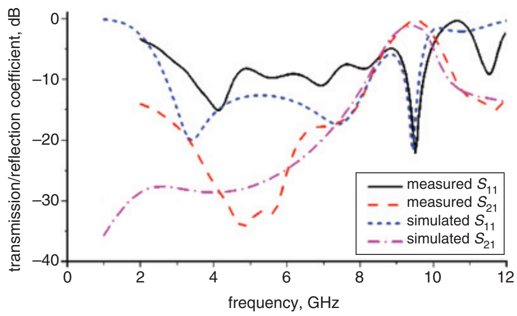

Fig. 4 *Re-simulated and measured reflection and transmission coefficients of AFSS*

Experiment results: A prototype of the AFSS was fabricated, with the overall size of $300 \times 300\ \mathrm{mm}^2$, as depicted in Fig. 3. The resistive layer and bandpass FSS were printed on F_4BM substrates. They were pasted at different sides of a polymethacrylimide (PMI) foam spacer ($\varepsilon_r \approx 1$) with thickness of 11.5 mm by epoxy resin adhesive ($\varepsilon_r \approx 3.8$). Actually, the effect of the thin layer of epoxy on the performance of AFSS cannot be ignored. Considering two layers of the epoxy with thickness of about 0.3 mm in each layer between the substrate and the PMI foam, we re-simulated S parameters of the AFSS and measured the transmissive/ absorptive performance of the prototype. Results are shown in Fig. 4. It can be seen that the measured results agree well with the simulated around the transmission frequency, which is shifted to 9.45 GHz due to the epoxy. The insertion loss is lower than 1 dB. Over the lower band, the simulated absorption band is from 2.7 to 8.3 GHz. the measured absorption band is a little worse than the simulated, but anyway it is verified.

Conclusion: We have proposed a new approach to design AFSS structure with wideband absorptive property over lower band and good transmissive property at high frequency. The resistive layer is realised by inserting a parallel *LC* resonance structure and lumped resistors into dipole element. We have designed an AFSS structure which is transmissive at 10.2 GHz with insertion loss lower than 0.15 dB. It absorbs waves over wide lower band 3–9 GHz. Its transmissive/ absorptive property is experimentally verified.

Acknowledgments: This work was supported by the National Natural Science Foundation of China (grant no. 61571448) and program for New Century Excellent Talents in University (grant no. NCET-10-0894) and Naval University of Engineering (grant no. HGDQNEQJJ 15 010).

Submitted: *4 November 2015* E-first: *19 February 2016*

doi: 10.1049/el.2015.3885

One or more of the Figures in this Letter are available in colour online.

Qiang Chen, Liang Chen, Jiajun Bai and Yunqi Fu (*College of Electronic Science and Engineering, National University of Defense Technology, Changsha 410073, People's Republic of China*)

✉ E-mail: yunqifu@nudt.edu.cn

Liguo Liu (*College of Electronic Engineering, Naval University of Engineering, Wuhan 430033, People's Republic of China*)

References

1 Munk, B.A.: 'Frequency selective surfaces: theory and design' (Wiley, New York, USA, 2000)

2 Arceneaux, W.S., Akins, R.D., and May, W.B.: 'Absorptive/ transmissive radome'. US Patent 5,400,043, 1995

3 Costa, F., and Monorchio, A.: 'A frequency selective radome with wideband absorbing properties', *IEEE Trans. Antennas Propag.*, 2012, **60**, (6), pp. 2740–2747, doi: 10.1109/TAP.2012.2194640

4 Motevasselian, A., and Jonsson, B.L.G.: 'Design of a wideband rasorber with a polarization-sensitive transparent window', *IET Microw. Antennas Propag.*, 2012, **6**, (7), pp. 747–755, doi: 10.1049/iet-map.2011.0444

5 Liu, L.G., Li, Y.Q., Meng, Q.Z., Wu, W.W., Mo, J.J., Fu, Y.Q., and Yuan, N.C.: 'Design of an invisible radome by frequency selective surfaces loaded with lumped resistors', *Chin. Phys. Lett.*, 2013, **30**, (6), pp. 064104, doi: 10.1088/0256-307X/30/6/064104

6 Chen, Q., and Fu, Y.Q.: 'A planar stealthy antenna radome using absorptive frequency selective surface', *Microw. Opt. Technol. Lett.*, 2014, **56**, (8), pp. 1788–1792, doi: 10.1002/mop.28442

7 Chen, Q., Chen, L., Bai, J.J., and Fu, Y.Q.: 'A miniaturized absorptive frequency selective surface', *IEEE Antennas Wirel. Propag. Lett.*, 2015, **14**, pp. 80–83, doi: 10.1109/LAWP. 2014.2355252

8 Chen, X., Li, Y.Q., Fu, Y.Q., and Yuan, N.C.: 'Design and analysis of lumped resistor loaded metamaterial absorber with transmission band', *Opt. Express*, 2012, **20**, (27), pp. 28347–28352, doi: 10.1364/OE.20.028347

9 Munk, B.A.: 'Metamaterials: critique and alternatives' (Wiley, New York, USA, 2009)

10 Chen, Q., Chen, L., Bai, J.J., and Fu, Y.Q.: 'Design of absorptive frequency selective surface with good transmission at high frequency', *Electron. Lett.*, 2015, **51**, (12), pp. 885–886, doi: 10.1049/el.2015.0228