Reflecting/Absorbing Dual-Mode Textile Metasurface with AI-Driven Parametric Studies

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Reflecting/Absorbing Dual-mode Textile Metasurface with AI-Driven Parametric Studies

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***Abstract*—This paper presents a textile-based reflecting/absorbing dual-mode metasurface, and emphasizes the role of AI-driven parametric studies in the designing process. The proposed textile metasurface can achieve a reflecting mode with the zero-degree refection phase centre at 2.4 GHz, and an absorbing mode at the same resonance frequency. The absorption and reflection band of the design are centered at the same frequency by applying a state-of-the-art AI-driven antenna design technique, self-adaptive Bayesian neural network surrogate model-assisted differential evolution for antenna optimization (SB-SADEA) method. The proposed design can also achieve polarization insensitivity and a certain level of incident angle insensitivity. The fabricated prototype of the design achieves a maximal absorption rate of 99.8% and maintains an absorption over 90% in the frequency range of 2.39 to 2.43 GHz. Moreover, a textile linear polarized monopole antenna was fabricated and tested along with the reflection metasurface. A 5 dB realized gain enhancement can be achieved with the metasurface applied. Both simulations and measurements verify the effectiveness of the proposed dual-mode textile metasurface design.**

***Index Terms*—reconfigurable metasurface, textile, reflection, absorption.**

I. Introduction

Due to their superior electromagnetic properties, metamaterials have been applied in scenarios including low-profile high-performance antennas [1], planar electromagnetic absorbers [2] and electromagnetic radiation shielding [3] over the past decade. For applications which require conformal or wearable compatibility, planar, flexible metasurfaces are the desirable solution. Metamaterial absorbers have been developed on flexible substrates such as paper [4], cotton [5] and PDMS [6]. Moreover, the reconfigurability of the metasurfaces is widely studied to incorporate multiple functionalities (reflection/absorption/transmission, etc.) into a single metasurface to expand its range of applications. Most of the reported state-of-the-art reconfigurable metasurfaces were realized by incorporating electronically controlled components, such as PIN diodes [7, 8], MEMS [9] and liquid metal [10].

This paper presents a dual-mode textile metasurface, with switchable reflective and absorptive mode controlled by a flexible carbon coated resistive net. This two-layer textile metasurface structure does not require any surface-mount electronic component, and is fully flexible and ultra-thin. The self-adaptive Bayesian neural network surrogate model-assisted differential evolution for antenna optimization (SB-SADEA) method is applied to determine the optimal matching point to align the two modes of the metasurface[11]. SB-SADEA is the latest method in the SADEA series, which are machine learning-assisted global optimization methods for contemporary antennas. SADEA-I[12] realizes efficient global optimization of antenna structures without any initial design, and its improvements from SADEA-II to V are reviewed in [16]. Although there are only two design variables, the specifications are very stringent. Standard global and local optimization techniques embedded in commercial EM simulators cannot meet the specifications; SB-SADEA is therefore employed. Full-wave simulations and experimental results are reported to support the feasibility of the proposed metamaterial.

II. Design of the Metasurface Unit Cell

A. The unit cell structure of the design

In this work, common commercial felt with dielectric permittivity of 1.2 and a loss tangent of 0.005 is selected as the substrate. These properties are measured with the waveguide transmission line method. The resistive net is made with carbon-coated polyurethane with conductivity of 1000 S/m (sheet resistance measured to be 20 ohm/square) and thickness of 50 μm. The resistive net is loaded on the conductive textile patch to convert a reflecting mode to an absorbing mode. The structure of one unit cell is shown in the following Fig. 1. The values of the parameters listed are shown as following **L**=58 mm, **w**=55 mm, **h**=0.5 mm, **a**=17 mm, **d**=3 mm. Due to the limitation of fabrication accuracy, approximations of the optimized results are used here.

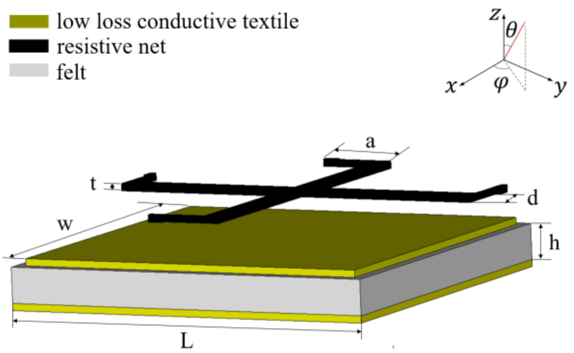

Fig. 1. The schematic view of a unit cell from the proposed structure.

B. *The Application of SB-SADEA Method*

The design of the EBG unit cell follows an impedance matching logic. To efficiently link the structural design to the equivalent impedance and obtain the optimal design parameters, the SB-SADEA method was applied. The proposed unit cell is modelled and discretized in CST microwave studio with over 6000 Tetrahedral mesh cells. Each EM simulation costs about one minute on average on a workstation with an Intel 8-core i9-990K 3.6 GHz CPU and 64 GB RAM. Table I shows the search ranges of the design parameters and the geometric constraints that must be satisfied to ensure the congruity of the structure in all possible cases. The specifications are shown in Table II. After 334 EM simulations (about 6 hours), SB-SADEA obtained a design satisfying both specifications. The optimal design and its performance are reported in Table I and Table II, respectively.

TABLE I

SEARCH RANGES OF THE DESIGN VARIABLES AND THE OPTIMAL DESIGN BY SB-SADEA (ALL SIZES IN MM)

Parameters	Lower bound	Upper bound	SB-SADEA Optimum
a	0.5	41.25	30.5
d	0.5	27.5	7.2
a ≥ d a ≤ d/2+27.5			

TABLE II

DESIGN SPECIFICATIONS AND PERFORMANCE OF PROPOSED DESIGN OBTAINED BY SB-SADEA

Item	Specification	SB-SADEA Optimum
Maximum reflection coefficient (S_{11}) (2.39 to 2.42 GHz)	≤ -10 dB	-10.3 dB
Maximum reflection coefficient (S_{11}) at 2.4 GHz	≤ -20 dB	-27.2 dB

Full wave simulations of the AEBG and REBG with different mesh setups are also performed to validate the performance of the optimized parameters. A simulated absorption rate of 99.8% can be achieved for incident electromagnetic waves parallel to the metasurface.

III. FABRICATION AND VALIDATION OF THE DESIGN

The fabricated metasurface is shown in the following Fig. 2. Ultra-thin (0.02 mm) polyethylene terephthalate (PET) electronic tape is used to attach the resistivity net onto the conductive surface.

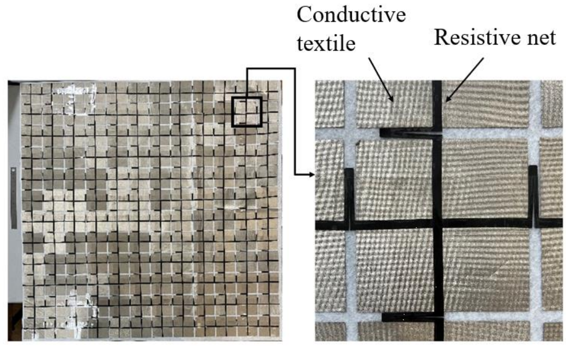

Fig. 2. The fabricated structure of the proposed AEBG.

The effect of polarization and incident angle on the absorption rate is also investigated. With varying incident angle theta from 0° to 30°, and different polarization angle of phi from 0° to 60°, the absorption rate maintains relatively stable, as shown in Fig. 3 (a) and (b) here.

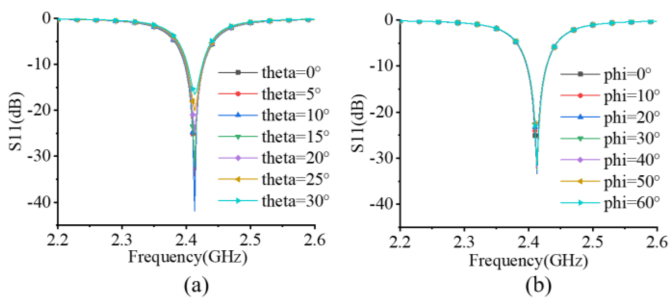

Fig. 3. (a) Absorption for various theta angle when phi = 0°. (b) Absorption for various phi angle when theta = 0°.

The simulated and measured absorption rates are compared with the following Fig. 4. The measurement matches the simulation well with a slight frequency shift.

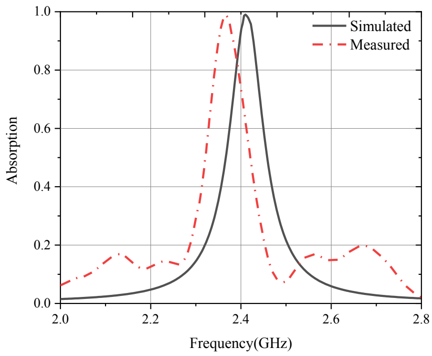

Fig. 4. Comparison of the measured and simulated absorption for the normal incidence wave.

IV. CONCLUSION

In this paper, a textile-based reflecting/absorbing dual-mode planar metasurface is proposed. The metasurface can either function as a reflector for a linear polarized antenna, or a thin absorber, when operating at the same frequency band. Thanks to the SB-SADEA method, the geometry parameters for the structure can be obtained efficiently without excessive parament sweeping. The design has been fabricated to demonstrate the practicality of the metasurface unit.

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