AMC loaded folded dipole with heart-shaped radiation pattern

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This Letter presents a novel pseudo-omnidirectional antenna that is appropriate for wide beam applications, e.g. handheld devices, along with a reduced back radiation that suits wearable applications as well. The design consists of a horizontal omnidirectional antenna placed on a proposed artificial magnetic conductor (AMC) surface that enhances the gain in the broadside direction, reduces the back radiation, and enables good radiation in the side directions. A 5 GHz folded dipole on a 2 × 2 AMC array surface is designed and characterised. Simulations and measurements, which are in a very good agreement, show that the radiation has a heart-shaped pattern, with a front to back ratio of >13 dB, a front to side ratio of <2.5 dB, and a half-power beam width of >230°.

Introduction: In the last few years, artificial magnetic conductors (AMCs) [1] have found their ways in several applications. Among them are: low profile planar antennas with improved radiation characteristics [2] and wearable devices that require a large front–to-back ratio (FBR) [3].

AMC is a two-dimensional periodic structure that fully reflects the incident waves with 0° phase, contrary to the perfect electric conductor (PEC), which fully reflects the incident waves with 180° phase. This feature improves the radiation characteristics of antennas, e.g. the radiated fields from a dipole antenna placed horizontally above the AMC add constructively instead of destructively as in the common PEC [1].

This Letter shows that engineering the AMC constituent unit cells adds an extra degree of freedom to shape the radiation pattern. The unit cell considered in the implementation of the AMC was initially proposed by the authors to realise an optically transparent AMC surface [4]. The advantage of this unit cell in this context is that it consists of two wire resonators (cross and cross-loaded loop) separated by a dielectric substrate. Engineering its geometry enables the generation of a heart-shaped radiation pattern for the folded dipole, i.e. a pseudo-omnidirectional radiation above the AMC surface and a very low radiation below it. This radiation pattern has many advantages in applications that require wide angle coverage and involve human body interaction. It can also be deployed in radio direction finding for military applications [5].

Unit cell design: Conventional AMC consists of a layer of conducting periodic patches above a conductor-backed substrate. Its equivalent circuit model consists of a capacitor connected in shunt to a short-circuited transmission line. At the operating frequency, the whole surface behaves as a parallel resonant circuit that reflects the incident wave with 0° phase. The proposed unit cell, which is shown in Fig. 1, replaces both the capacitive patches and conductor ground with series resonant elements. The elements (L_{bot}, C_{bot}) on one side (the bottom surface) resonate at f_{bot}, and (L_{top}, C_{top}) on the other side (the top surface) resonate at f_{top}. The resonators are designed such that f_{bot} is less than f_{top} and there is an overlap between their reflection magnitude frequency responses. Hence, between f_{bot} and f_{top} there is a frequency (f_0) where the equivalent impedance of the top resonator (L_{top}, C_{top}) is capacitive (C_{eff}) and the transferred impedance of the bottom resonator (L_{bot}, C_{bot}) at the plane of the top surface is inductive (L_{eff}). At this frequency (f_0), the unit cell constitutes a parallel resonator and an AMC behaviour is achieved. To operate properly, the top resonator should have a low capacitance (C_{top}), which imposes a constraint on L_{top} to be relatively high, while the bottom resonator should have a very large bandwidth, which implies a high capacitance (C_{bot}) and a relatively low inductance (L_{bot}).

To achieve these specifications, the bottom resonator is designed to have the shape of a square loop with two perpendicular wires across it (cross-loaded loops), and the top resonator is designed to have the shape of a simple cross as shown in Figs. 1*a* and *b*, respectively. This design is preferred over simple horizontal or vertical wires as it is polarisation independent. In this design, the dielectric substrate also plays a critical role as there is a trade-off between: reducing its electrical thickness, which leads to a large overlap between the top and bottom resonators frequency responses, a narrow bandwidth due to the reduction of L_{eff}, an increase in the coupling between the top and bottom resonators, and consequently more power loss and high absorption at (f_0), and increasing its electrical thickness, which results in an increase in the size, a reduction of the frequency responses overlap, a decrease in the coupling between the resonators and, hence, a reduction in the power loss.

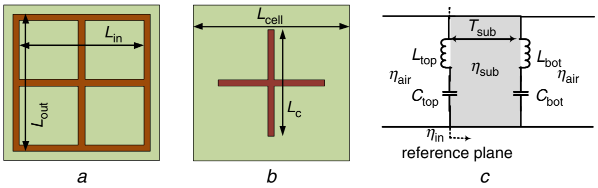


Fig. 1 *Proposed AMC unit cell*

a Bottom layer
b Top layer
c Equivalent circuit model

Fig. 2 shows the simulated reflection and transmission coefficients of the proposed unit cell. The operating frequency is 5 GHz. The substrate is Rogers 5880 that has a thickness of 6.36 mm, a relative permittivity $\varepsilon_r = 2.2$ and a loss tangent $\tan\delta = 0.001$. The bottom and top layers are copper with a trace width of 1 mm. The side length of the unit cell, L_{cell}, is 25 mm. The bottom resonator has $L_{\text{out}} = 22$ mm and $L_{\text{in}} = 20$ mm, while the top resonator has $L_c = 17$ mm. The simulations with periodic boundary conditions conducted on the commercial EM simulator ANSYS HFSS v15 show that the 0° phase occurs at 4.94 GHz and the ±90° bandwidth (the shaded area in Fig. 3) extends from 4.17 to 5.61 GHz with a reflection magnitude better than −0.77 dB.

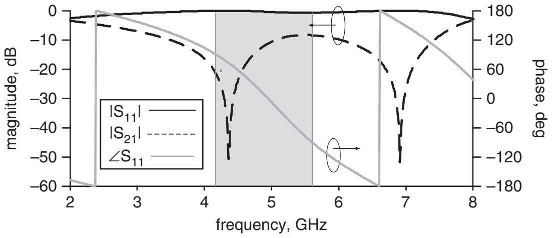


Fig. 2 *Simulated magnitude of reflection coefficient (solid black) and magnitude of transmission coefficient (dashed black) along with phase of reflection coefficient (solid grey)*

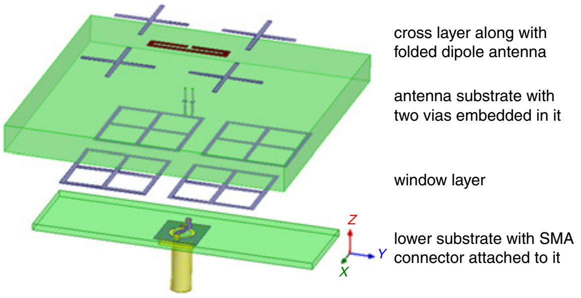
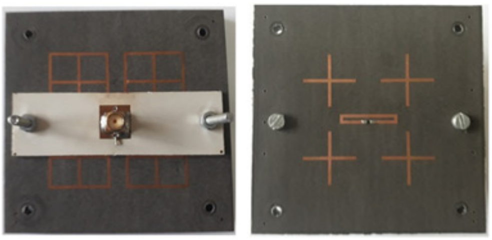


Fig. 3 *Detailed layers of SMA-fed folded dipole on 2 × 2 AMC array*

Antenna on AMC surface: While several designs of the unit cell can achieve the ultimate performance of the AMC surface, 0 dB reflection magnitude, only optimised ones can provide a heart-shaped radiation pattern for dipole antennas. Fig. 3 shows a 5 GHz folded dipole patterned on the top metal layer of the AMC surface. The width of the arm is 1 mm, the separation is 1 mm, and the length is 18.5 mm. Two vias that have a quite long length feed the antenna. They form a two-conductor transmission line that transforms the impedance to a smaller one. The input impedance of the folded dipole, which is approximately four times larger than that of the ordinary dipole, compensates the effects of the vias and enables a good matching. The AMC consists of 2 × 2 unit cells. The substrate is a stack of two 3.18 mm Rogers 5880 layers. The area is 65 mm × 65 mm. A layer of Rogers 3003, that has a thickness of 1.524 mm, a size of 65 × 20 mm, a relative permittivity $\varepsilon_r = 2.2$, and a loss tangent $\tan\delta = 0.001$, is inserted between the SMA connector and the AMC bottom surface to prevent shortening the unit cells. Varying the dimensions of the unit cell, while keeping the ultimate performance of the AMC, changes the radiation pattern of the folded dipole. The dimensions of the unit cell, shown in Fig. 1, with the separation between the cross-loaded loops is 5 mm instead of 3 mm to compensate the effect of the Rogers 3003 substrate, result in a heart-shaped radiation pattern.



a *b*

Fig. 4 *Fabricated antenna structure*

a AMC bottom layer with lower substrate and SMA connector
b AMC top layer with folded dipole antenna

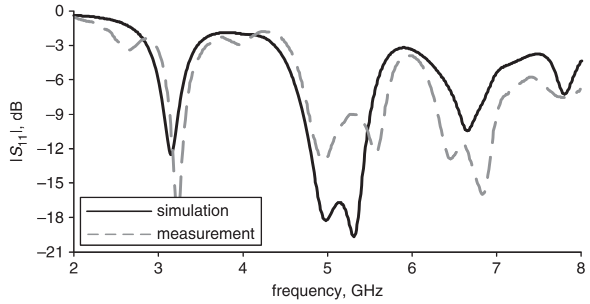
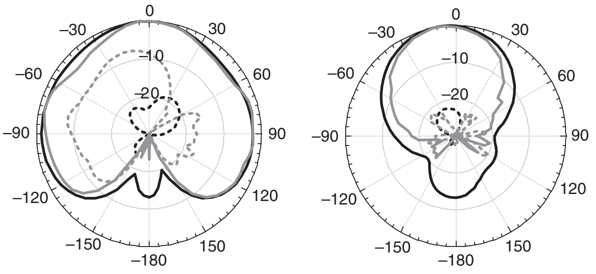


Fig. 5 *Simulated (solid black) versus measured (dashed grey) return loss of folded dipole on AMC surface*



a *b*

Fig. 6 *Simulated radiation pattern at 5 GHz (black) versus measured one at 4.94 GHz (grey) of folded dipole on AMC surface for both co-polarisation (solid) and cross-polarisation (dotted). Axis is shown in Fig. 3*

a H-plane (*XZ*)
b E-plane (*YZ*)

Fig. 4 shows a photo of the fabricated structure. The total height of the substrate layers is nearly 8 mm, which is less than one-seventh the free space wavelength (λ_0) at 5 GHz, i.e. the antenna has a relatively low profile. The measured return loss compared to the simulated one is shown in Fig. 5. The resonance frequency is shifted to 4.94 GHz due to parasitic effects that can be attributed to soldering. Fig. 6 shows the measured radiation pattern at 4.94 GHz and the simulated one at 5 GHz. They are in a very good agreement. Fig. 6*a* shows that the FBR in the *H*-plane (*XZ*) is >13 dB in simulations, whereas it is >20 dB in measurements, the ratio between the front and side directions is <2.5 dB, and the half-power beam width is >230° in both simulations and measurements. The tilting of the maximum radiation angle from the 0°, shown in Fig. 6*b*, is due to the asymmetric feeding of the folded dipole. The directivity and efficiency of the simulated antenna at 5 GHz are 6.362 dB and 98%, respectively, while the measured ones at 4.94 GHz are 7.241 dB and 86.89%, respectively. The back radiation is greatly reduced due to the measurement setup, which explains why the measured directivity is greater than the simulated one.

Conclusion: A novel approach was proposed to design a near-perfect AMC. The constituent unit cell had two resonators on the top and bottom layers of the substrate. Placing a folded dipole above the proposed surface resulted in a heart-shaped (pseudo-omnidirectional) radiation pattern, which is a good approximation to the ideal perfect magnetic conductor. Measurements of a folded dipole on a 2 × 2 AMC array operating at 5 GHz confirmed the theoretical predictions. The FBR was >13 dB and the front to side ratio was <2.5 dB. The antenna with the AMC had a relatively low profile as the height is smaller than $\lambda_0/7$.

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

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