Leaky wave-based HIS-inspired Antenna supported by negative permeability for millimeter-Wave Applications

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***Abstract*—High Impedance Surface (HIS) planar antenna governed by leaky wave properties is presented in this paper. Near the 'magnetic resonance', the slotted square shaped ring patches experience the peak current value. Thus, the slotted square shaped ring patch based metasurface antenna resonates at 29.7 GHz where the structure exhibits negative effective permittivity and effective permeability. Far-field performances are examined for a different number of elements distributed over the copper grounded substrate. Maximum gain of 9.142 dB near the resonance is obtained with good gain-bandwidth over a large frequency from this antenna composed of 6 elements.**

Keywords—High Impedance Surface (HIS), negative permittivity, negative permeability, leaky wave antenna, Artificial Magnetic Conductor (AMC)

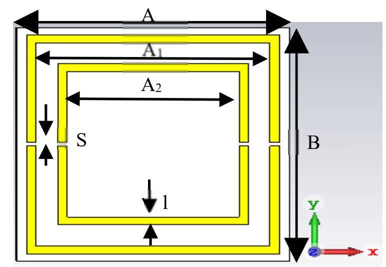
I. Introduction

In search of an efficient antenna ground plane which exhibits attractive reflection properties, researchers recognize High Impedance Surface (HIS) as an excellent choice [1]-[3]. HISs are also considered as the antenna radiation surface which have demonstrated improved antenna performance [4],[5]. In this paper, leaky wave properties of a slotted square ring patches are exploited to obtain an HIS-based metasurface antenna with high gain.

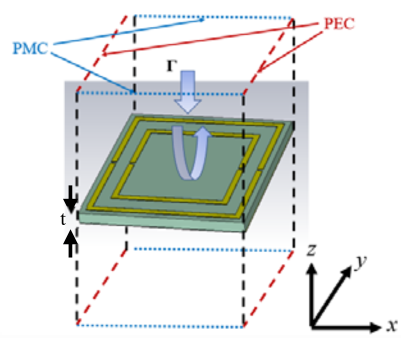
II. Unit cell design and analysis

First, the 'unit cell' of the antenna is simulated to obtain the operating frequency of the antenna and shown in Fig. 1(a). Its dimensions are: A =2.85, B = 3.05 mm, A_1 = 2.45 mm, A_2 = 1.8 mm, S = 0.05 mm, and l = 0.1 mm. The dielectric substrate used has a thickness of 0.1905 mm and relative permittivity, $\varepsilon_r = 2.2$. Periodic boundary conditions, depicted in Fig. 1(b), are considered to study the magnetic resonance of the cell. The copper clad of ground and patch conductors has a thickness of 9 μm and a conductivity of 5.8×10^7 S/m. Fig. 1(c) shows the reflection coefficient magnitude and phase angle plots with frequency. Minimum reflection coefficient occurs at 29.7 GHz, where the zero crossing of the phase occurs as well. These confirm the 'magnetic resonance frequency' or the operating frequency of the HIS-based structure.

This zero reflection phase is not found in common lossy medium. The surfaces which experience this phenomenon at a certain frequency are called 'Artificial Magnetic Conductor (AMC)', which are not readily available in nature. These are also recognized as metamaterials, the planar version of which are classified as metasurfaces. Several works [6], [7] reported that the metasurface properties are extracted in the frequency region where the antenna provides negative effective permittivity and effective permeability. The unit cell is analyzed in the full wave simulator 'CST Microwave Studio' to investigate the effective parameters at the magnetic resonance frequency. The effective permittivity and the effective permeability are calculated and shown in Fig. 2, which are -0.236 and -20.132, respectively. The negative permittivity and permeability values of the structure at the magnetic resonance further confirms it as a metasurface.



(a)



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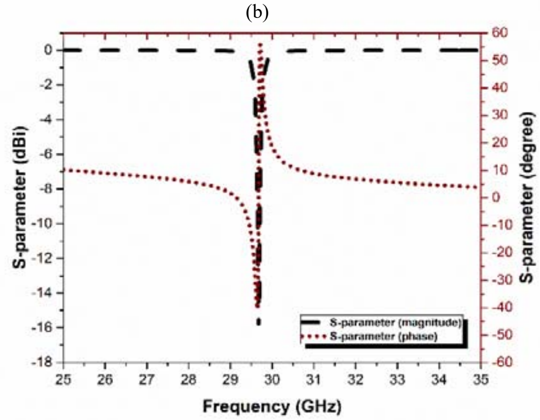


(c)

Fig. 1. (a) Unit cell dimensions, (b) the boundary conditions for unit cell analysis, and (c) the reflection coefficient magnitude and phase of the unit cell.

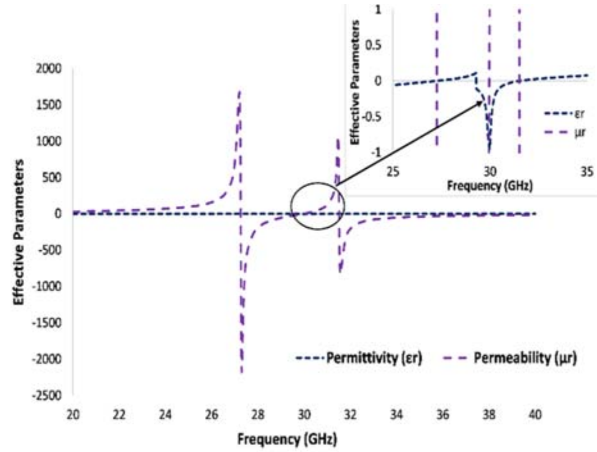
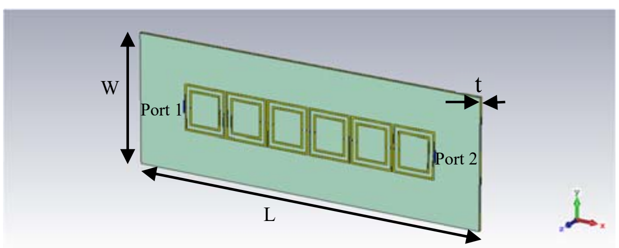


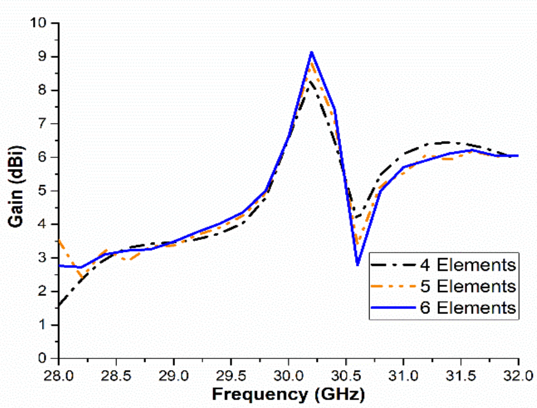
Fig. 2. Effective permittivity and effective permeability of the unit cell, at the resonance frequency 29.7 GHz. Negative values are found for both.

III. Linear antenna design and performance analysis

A linear antenna made of several unit cells is modeled as shown in Fig. 3(a) where differential feeding is implemented at two ends of the structure. Antenna dimensions are: L = 17 mm, W = 2.68 mm and t = 0.1905mm for 6-element array structure. Using commercial full wave simulation software CST, the antenna is simulated, and the total gain is plotted for 4, 5 and 6 elements.



(a)



(b)

Fig. 3. (a) 1D 4 element array antenna, (b) Comparison of broadside gain versus frequency for the 1D HIS antenna structure with differential feeding. Peak gain is concentrated near the resonance frequency 29.6GHz while the number of elements is increased peak gain is increased.

In the case of 4-element array antenna, the peak gain is 8.32 dBi at 30.2 GHz, which is close to the resonance frequency. The gain plots are shown in Fig. 3(b) for increased number of elements. With 6-unit cells, the antenna the peak gain is 9.142 dBi with a 3-dB gain bandwidth of 650MHz.

IV. Conclusion

A metasurface-based linear array antenna with negative effective permeability and effective permittivity at the resonance frequency is modeled and studied. Supported by leaky wave radiation, high gain is obtained from this structure. The antenna provides a reasonable gain bandwidth, the structure can provide higher gain with increased number of elements. This antenna is a potential candidate for mm-Wave 5G handheld devices because of its very thin thickness. Measured data from the fabricated prototype is planned to be presented at the symposium.

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