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An Efficient, Wide-Band and Wide-Angle Metamaterial Electromagnetic Energy Harvester

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Abstract. This work presents the design and subsequent numerical analysis of a new metamaterial based, electromagnetic energy harvester. The structure exploits the geometry of the well-known electric split ring resonator (eSRR) and presents high efficiency (i.e., greater than 90%), it is wide-band (i.e., full width at half maximum of 47%) and wide-angle (i.e., 92 deg.).

1 Introduction

Metamaterials have been the subject of increasing research focus over the last number of decades. This is due to the attractive characteristic of their properties relating to geometric unit cell designs, as opposed to the inherent properties of their materials. Metamaterial absorbers exhibit near perfect absorption of radio frequency (RF) power and this function can be exploited to harvest this energy and supply small electrical devices. A measure of an absorber's performance is its absorptivity defined as,

$$A = 1 - R - T, \tag{1}$$

where R is the reflectance (i.e., $|S_{11}|^2$) and T is the transmittance (i.e., $|S_{21}|^2$) of the structure [1]. In a typical absorber, the captured energy is mainly dissipated in its dielectric and metallic parts. By inserting a properly placed resistor into the absorber's geometry, it is possible to channel the captured energy into this load. This type of structure is called a *metamaterial harvester* (MH) [2],[3]. The inserted load in such a geometry represents the input impedance of the rectifying circuit. The ratio of the power delivered to the load, P_l, over the total incident power, P_i, represents the MH's efficiency given as [4],

$$\eta_l = \frac{P_l}{P_i} \tag{2}$$

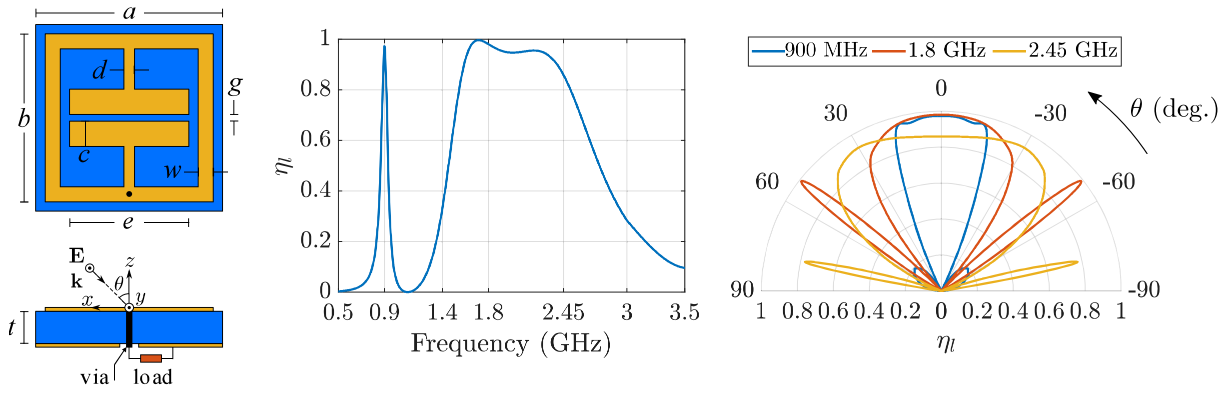
The contribution of this work is the design and analysis (in terms of efficiency) of a new MH, which is highly efficient, wide-band and wide-angle compared to existing designs available in the literature [5]. It consists of an electric resonator, which is created by a load connected through a via, this represents the input impedance of a rectification system. The MH can deliver more than 90% of the incident power to the rectifier at 5G frequency bands n1 (2.1GHz), n2 (1.9GHz), n3 (1.8 GHz), n8 (900 MHz) and n25 (2.6 GHz) as defined in 5G NR FR1 as well as Wi-Fi (2.45GHz).

2 Metamaterial Harvester Design

The unit-cell structure of the proposed MH is depicted in Fig. 1(a). It is realized via an electric–split ring resonator (eSRR) [1], which is imprinted on the front face of a $t = 12.5$ mm thick, lossy but low-cost dielectric foam, with relative permittivity $\epsilon_r = 1.04$ and a loss tangent $\tan\delta = 0.001$. The opposite side of the dielectric is covered by a full metallic plane.

The chosen metal is copper with a thickness of 35 μm and the electric conductivity of $5.8 \cdot 10^7$ S/m. As a result, the structure can effectively be characterized as electrically thin as it has thickness of approximately $\lambda/26$ at its lower operating frequency (i.e., 900MHz). The dimensions of the eSRRs are $a = 35.69$ mm $b = 33.4$ mm, $c = d = w = 2.07$ mm, $e = 28.22$ mm and $g = 0.48$ mm, and are the result of a full electromagnetic analysis by using the CST Microwave Studio$^{\text{TM}}$. They were obtained through a maximization of η_l at 900MHz, 1.8 GHz and 2.45 GHz bands for the proposed MH. A load of 50 Ω was adjusted between the vias and the ground plane (via has a radius of 0.5 mm). The incident plane wave propagating along the z-direction with its electric-field component is polarized along the y-axis, as depicted in Fig. 1(a).

The simulated results are presented using the MH's efficiency η_l, and depicted in Fig. 1(b). For normal incidence, two distinct highly absorbing regions appear: a narrow frequency band 880-920MHz and another wideband $1.55 - 2.5$ GHz. In these regions high MH efficiency (i.e., $\eta_l > 80\%$) is achieved, resulting in a full width at half maximum (FWHM) of 4.5% and 47%, respectively. The values of the absorption at 900MHz, 1.8 GHz and 2.45 GHz is 98%, 98% and 90%, respectively. For oblique incidence, and TE–polarization (i.e., electric component along y-axis, as depicted in Fig. 1(a) the simulated MH efficiency η_l versus the angle of incidence θ is depicted in Fig. 1(c). Efficiency remains higher than 80% for $\theta \leq 18$ deg. at 900MHz while at 1.8 GHz and 2.45 GHz $\eta_l \geq 80$ % for $\theta \leq 30$ deg. and $\theta \leq 46$ deg., respectively; especially for the latter case it is evident that the MH operation is wide-angle.



(a) (b) (c)

Figure 1: (a) The MH's geometry; (b) simulated efficiency (i.e., η_l) versus frequency; (c) angle of incidence.

3 Conclusion

A new MH was designed and numerically tested through full electromagnetic analysis in this work. The structure presents high efficiency, it is wide-band and wide-angle. These features indicates that the proposed MH is an attractive solution for the design of high efficiency and low-complexity wide-band (or triple-band) RF energy harvesting applications.

References

[1] N. I. Landy, *et al.*, Perfect Metamaterial Absorber, *Phys. Rev. Lett.* **100** (2008) 207402.

[2] T. S. Almoneef and O. M. Ramahi, Metamaterial electromagnetic energy harvester with near unity efficiency, *Appl. Phys. Lett.* **106** (2015) 153902.

[3] H. Zhong, *et al.*, Wideband metamaterial array with polarization-independent and wide incident angle for harvesting ambient electromagnetic energy and wireless power transfer, *Appl. Phys. Lett.* **111** (2017) 213902.

[4] S. D. Assimonis, *et al.*, High efficiency and triple-band metamaterial electromagnetic energy harvester, *2015 9th International Conference on Electrical and Electronics Engineering (ELECO)* (2015) 320-323

[5] L. Li, *et al.*, Progress, challenges, and perspective on metasurfaces for ambient radio frequency energy harvesting, *Appl. Phys. Lett.* **116** (2020) 060501.