A dual-band compact metamaterial absorber for RF energy harvesting at GSM bands

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Abstract

RF energy harvesting is a fascinating strategy for powering low-power sensors and devices, capturing electromagnetic (EM) energy everywhere present in modern day life. In this contribution, a very compact dual-band metamaterial cell is proposed for RF energy harvesting applications within the GSM bands. The simulated cell offers very high absorption peaks and quite good efficiencies in correspondence of 0.9 GHz and 1.8 GHz frequencies. Thanks to its appealing features, the proposed metamaterial configuration could be very attractive for the implementation of high efficiency and environmentally friendly harvesting systems.

1. Introduction

Currently, mobile devices and sensors are increasingly present in our daily life. Due to their ubiquity, there is an ever-growing interest in finding solutions to meet their energy needs. Until now, conventional batteries have been the primary power source for portable electronics and wireless sensors. However, this approach suffers from several intrinsic shortcomings, namely limited lifespan, high maintenance costs and pollution issues. A fascinating solution to overcome the above problems is represented by the implementation of energy harvesting systems [1]. Energy harvesting is a method of generating electrical energy from different unexploited energy sources available in the surrounding environment. It allows to reduce the pollution related to battery disposal, thus resulting more environmentally friendly. In last decades, numerous solutions have been pursued for the collection of energy from the environment that would otherwise be wasted, such as solar, thermal, wind, kinetic, and radio frequency (RF). In particular, the collection of RF energy [2] constitutes a very interesting solution for low power devices and consumer electronics. The fast increase in the number of RF emitters, due to the development of novel wireless technologies, offers the opportunity to exploit and collect RF energy, available in the surrounding environment. In this work, a dual-band metamaterial-based harvester, operating within the GSM frequency bands (i.e. 0.9 GHz and 1.8 GHz), is presented. The proposed unit cell consists of a miniaturized Minkowski fractal patch surrounded by a concentric square ring element, both printed on a thin-grounded dielectric substrate. The Minkowski geometry, already adopted by the authors for the design of reflectarray antennas [3, 4] and metamaterial absorbers [5, 6], allows to achieve very small resonators. Furthermore, it can be exploited to obtain multiband operations, thus allowing to simultaneously collect electrical energy from different RF-sources. At this purpose, infact, the Minkowski shape has already been adopted by the authors in [7] for designing a dual-band unit cell for RF harvesting, by incorporating two pairs of miniaturized Minkowski fractal resonators in the same cell. Anyway, the configuration proposed in this work offers a very high miniaturization level, with a unit cell 55% smaller than the one designed in [7]. A preliminary analysis of the proposed metamaterial-based harvester is presented and discussed. Very high absorption percentages and good unit cell efficiencies are demonstrated in correspondence of the GSM frequencies. Thanks to the above features, the proposed unit cell could be adopted for the implementation of very compact metamaterial absorbers for energy harvesting systems.

2. Metamaterial unit cell for RF energy harvesting

A conventional RF harvesting system consists of a receiving antenna and a rectifier circuit, usually called rectenna, which collects ambient high-frequency energy and convert it into DC power. Recently, metamaterial absorbers have been also proposed as a remarkable alternative to conventional antenna, offering a higher efficiencies in the first conversion stage from RF-to-AC power (Fig. 1) [8]-[10]. Metamaterial absorbers include an array of sub-half wavelength metallic resonators printed on a grounded dielectric slab (Fig. 1). Each patch efficiently couples with the incident electromagnetic (EM) wave, at the resonant frequency, thereby capturing EM power from the environment.

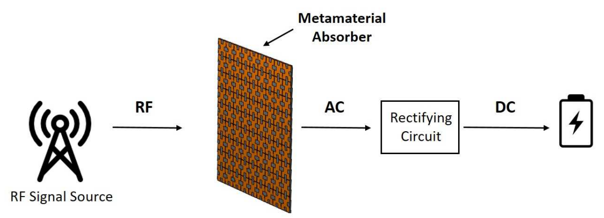

Figure 1. Block diagram of a metamaterial harvester.

The metallic pattern must be designed to fulfill the perfect absorption condition around one or more desired resonant frequencies. Then, the energy captured by the metamaterial elements is transformed into AC power, which is subsequently delivered to a rectifying circuit [11].

The unit cell proposed in this work is composed by a miniaturized Minkowski fractal patch surrounded by a concentric square ring resonator (Fig. 2(a)). Both elements are printed on a dielectric substrate and are properly connected to the ground plane through two resistive loads, representing the rectification circuit. The Minkowski patch is characterized by a side length L_2 and a scale factor S, regulating the 2[nd] resonance frequency [3], while the square ring width (W_1) and side-length (L_1) allow to fix the 1[st] resonance frequency [12]. Both the fractal geometry as well as the square ring patch, depicted in Fig. 2(a), allow to achieve very small cells with respect to other metamaterial geometries. The unit cell size, infact, is fixed to about $D\times D=0.1\lambda\times0.1\lambda$ at f_1, achieving a 55% size reduction with respect to the configuration proposed by the same authors in [7], for energy harvesting at the GSM bands. A Rogers TMM10 dielectric substrate is considered, having a loss tangent equal to 0.002, a dielectric constant equal to $\varepsilon_r= 9.8$ and a thickness h= 3.2 mm (see Fig. 2(b)). A ground plane covers the backside of the metamaterial structure, blocking the transmission through the absorbent panel. For this reason, the metamaterial absorption rate is given by $A(f) = 1 - |\Gamma(f)|^2$, where $\Gamma(f)$ is the unit cell reflection coefficient.

The unit cell is simulated and optimized through a full-wave software (Ansys Designer), by adopting the infinite array approach. The optimized cell sizes, reported in Table I, give a reflection coefficient equal to $|\Gamma|$=-24dB @0.9GHz and $|\Gamma|$=-25dB @1.8GHz, corresponding to very high absorption coefficient values, respectively equal to 99.6% and 99.7% (see Fig. 3).

TABLE I. DUAL BAND UNIT CELL DIMENSIONS

Frequencies	Unit Cell Parameters			
f_1/f_2	L_1 - W_1	L_2 – S	R_1	R_2
0.9/1.8 GHz	33.3mm - 6.15mm	19.7mm - 0.273	350Ω	78Ω

Finally, the RF-to-AC efficiency of the cell is evaluated by adopting the full-wave frequency domain solver CST Microwave Studio. The RF-to-AC efficiency of the unit cell is evaluated as the ratio between the total power delivered to the loads (P_{del_loads}) and the power incident onto the metamaterial surface (P_{inc}) [10]. Fig. 4 illustrates the amount of incident power which is delivered to the loads, corresponding to an efficiency respectively equal to 90% @0.9GHz and 88% @1.8GHz. As depicted in the same Fig. 4, only a smaller amount of power is dissipated within the copper and the dielectric substrate.

The above results make the proposed structure very appealing for energy harvesting application within the GSM frequency bands.

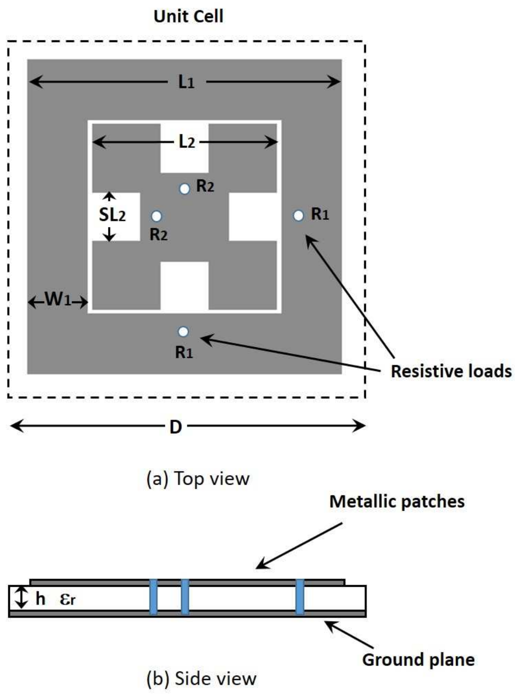

Figure 2. Metamaterial unit cell for ambient power harvesting: (a) Top view; (b) Side view.

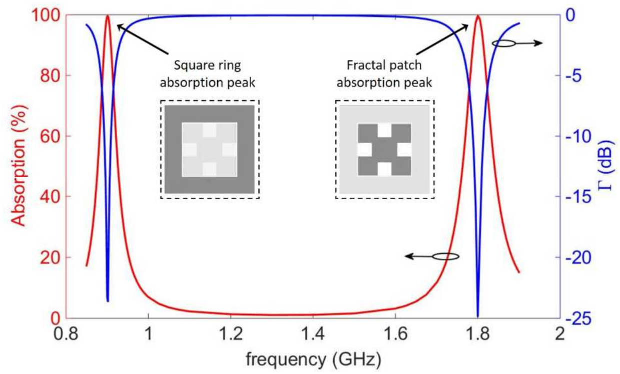

Figure 3. Simulated unit cell absorption and reflection coefficient.

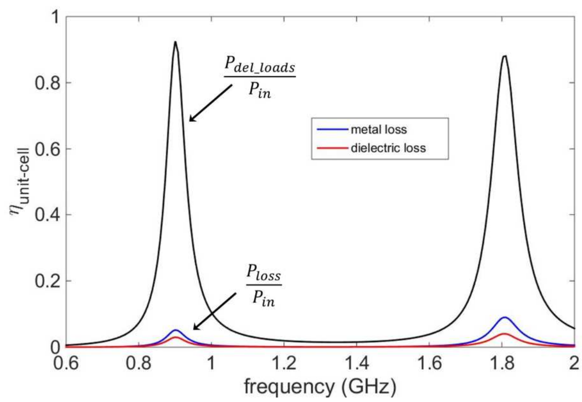

Figure 4. RF-to-AC efficiency of the unit cell.

3. Conclusion

The potentialities of a fractal-based metamaterial harvester have been illustrated for operations within the GSM band. A high versatility has been demonstrated in achieving perfect absorption and very good unit cell efficiencies, also showing the ability of the proposed metamaterial cell to offer a multi-band behavior. As future development, the proposed fractal structure will be further optimized to improve the RF-to-AC efficiency.

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