RF Energy harvesting in urban environment using transparent rectenna arrays

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RF ENERGY HARVESTING IN URBAN ENVIRONMENTS USING TRANSPARENT RECTENNA ARRAYS

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1) Context / Study motivation

The energy harvesting becomes increasingly an attractive solution for contactless powering of low-consumption electronic devices, like sensors. It has been recently demonstrated in [1] that the ambient RF energy harvesting in urban and semi-urban environments can be competitive with other ambient sources, like thermal source and vibrations. Indeed, the ambient electromagnetic field increases and becomes more available due to the proliferation of base station and various transmitter antennas around the world.

The RF energy harvesting consists to capture and then convert the ambient electromagnetic waves into useful dc power. The important element of such a system is called rectenna [2]. Rectennas are often etched on opaque substrates. This study focuses on rectennas on transparent substrates. Transparent antennas [3], [4] constitute a great potential for energy harvesting applications, on either the availability of large glazed areas in the urban environment. They have interesting features making them almost invisible, non-intrusive and easily integrated in the urban environment. Transparent antennas are designed most commonly from meshed conductor [5] or transparent conductive films (AZO, ITO) [4].

This paper reports a new optically transparent dipole-rectenna and rectenna array in the ISM (Industrial Scientific Medical) band at 2.45 GHz. Both circuits have been achieved in a simple and low-cost manner and measured.

2) Description of approach and techniques

The proposed transparent rectenna is shown in Fig.1. It contains a half-wavelength dipole antenna and a coplanar stripline (CPS) RF-to-dc rectifier. The structure is printed on a 2-mm thickness transparent plexiglas substrate (ε_r = 3.4 and tanδ = 0.001). The rectifier is based on a SMS7630 Schottky diode (D). The output DC filter, located at a distance of 12 mm from the diode, contains three 100-pF surface mount capacitors spaced of about 2 mm one from each other. The output resistive load has been experimentally optimized and set to 2 kΩ. The structure has been designed and optimized under Ansys HFSS commercial software. The diode impedance, obtained by Agilent ADS simulation, is 26 – j295 Ω at -15 dBm input RF power level. The circuit was designed to achieve a complex conjugate impedance matching with the diode impedance at the frequency of interest.

The single-element rectenna dimensions are 10 cm x 10 cm. The transparency is higher than 95%, it is defined here as the ratio between the coppered area and the total area of the circuit. The proposed rectenna has been used to built a rectenna array (see Fig.2), constituted by 6 series-interconnected elements. The distance between two adjacent elements was set to 54 mm, resulting in a mutual coupling less than -15 dB. The array is printed on the plexiglas substrate with a 35 cm length and 20 cm width. Due to the series-interconnected topology of elements, the output load is 6 times higher than that of a single element.

The single-element rectenna and the rectenna array have been fabricated and measured inside an anechoic chamber. The measurement setup contains a 12-dB transmitting horn antenna and a 35-dB gain power amplifier. The rectenna (DUT: device under test) is set at a distance of 2 meters from the transmitter to ensure the far field conditions. A conventional voltmeter, connected in parallel over the output resistive load, measures the output dc voltage.

3) Results / Conclusions / Perspectives

Figure 3 shows the output dc voltages when the power density varies from 1 to ~10 µW/cm² (1.94 to 6.14 V/m), for the single rectenna and the 6-elements rectenna array. The single-element rectenna exhibits measured dc voltages of 75, 195 and 290 mV at 1, 5 and 10 µW/cm² power densities, respectively. The corresponding output dc powers are: 2.8, 19 and 42 µW. The 6-elements rectenna array shows measured output voltages of 0.55, 1.4 and 2.13 V at 1, 5 and 10 µW/cm² power densities, respectively. The corresponding output dc powers are: 25.3, 164.3 and 378 µW.

The single element shows efficiencies of 11, 19 and 26 % at 1, 5 and 42 µW/cm² power density, respectively. The rectenna array exhibits measured efficiencies of 16, 28 and 36 % at 1, 5 and 42 µW/cm² power density, respectively.

Figure 4 depicts the single-element rectenna and the 6-elements rectenna array output dc voltages against frequency from 2.4 to 2.5 GHz at 1 µW/cm². Results clearly show that the dc output voltage is nearly stable over the frequency band of interest.

This paper reports the design and experimental characterization of transparent rectenna and rectenna array in the ISM band at 2.45 GHz. These circuits were achieved in a simple and low-cost manner and experimentally tested. They present interesting dc output properties and are suitable for energy harvesting applications in urban environments. The proposed structures are single-layer coppered and exhibit more than 95% optical transparency.

The next purpose of this study consists to achieve single-band and multi-band transparent-rectenna-arrays prototypes at other frequencies like DTV, GSM and UMTS, offering more possibilities in terms of harvestable RF power. Transparent conductive films will also be discussed and addressed.

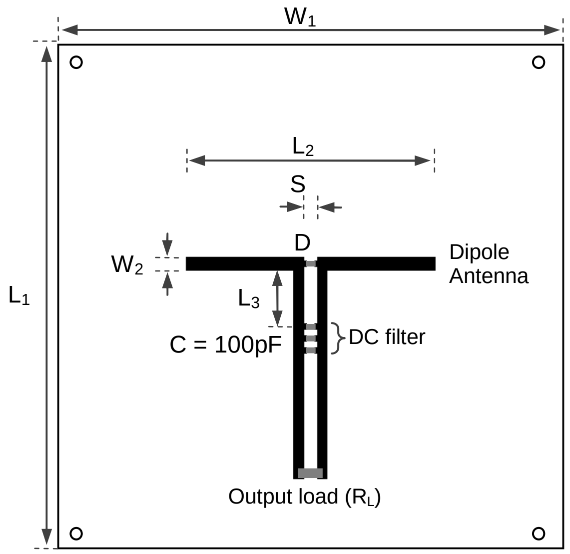

Figure 1. Layout of the single rectenna. L_1 = 100, L_2 = 45, L_3 = 12, W_1 = 100, W_2 = 4, S = 3 (all dimensions are in mm)

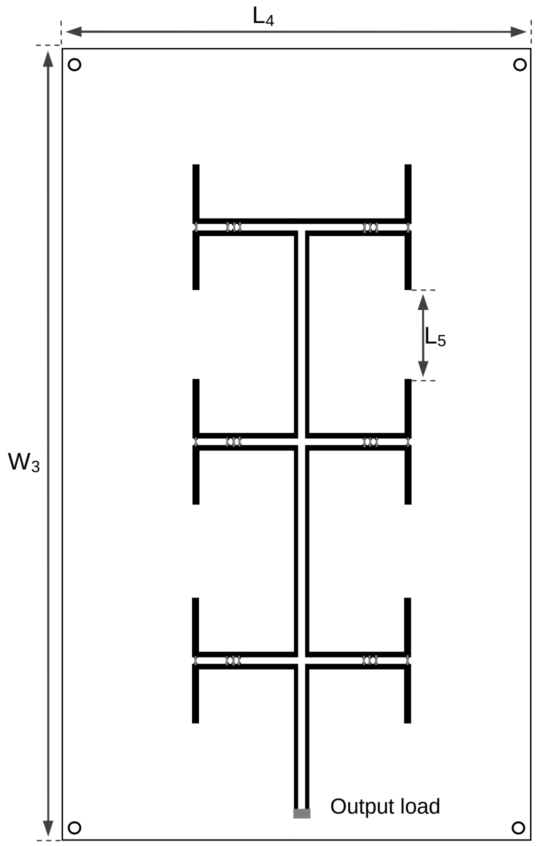

Figure 2. Layout of the rectenna array. L_4 = 200, L_5 = 54, W_3 = 350 (all dimensions are in mm)

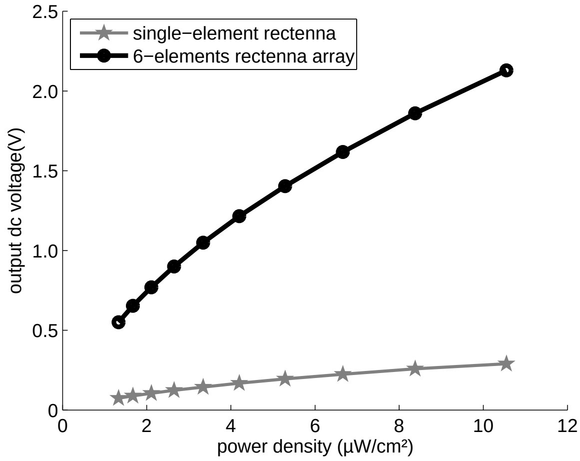

Figure 3. Measured output dc voltage versus power density

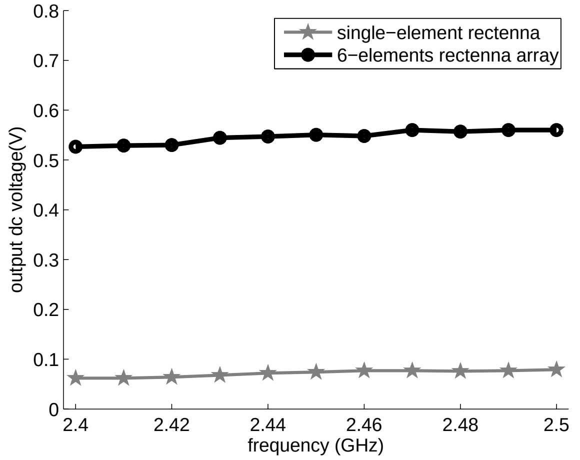

Figure 4. Measured output dc power versus power density

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