# Rectenna Design For Electromagnetic Energy Harvesting

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**Abstract— The energy harvesting is the process by which energy from different sources of radiation is captured and stored. The harvesting of this energy would be an alternative energy capable of replacing, totally or partially, the battery of certain micro systems that require a low amount of energy. This paper firstly presents the quantification of the radiated power available in the ambient environment with respect to frequency through various measurements. This quantification of the RF power according to the considered environment is necessary since, it allows to choose frequency bands with the highest power density, and then to estimate the recoverable maximal DC power.**

**Secondly, we present various simulation results under HFSS software to analyze the performance of antenna candidates for this study and which are the first elements constituting the rectennas.**

**Index Terms—*harvesting, rectenna, printed antennas, broadband antenna, rectifier*.**

## I. Introduction

Over the last few years, wireless applications such as FM, TV, GSM, WIFI, WIMAX, etc., of weak to great powers, have invaded our environment and led to the multiplication of broadcasting stations in the townscape [1]. Most of these broadcasts are omnidirectional and permanent in time. The availability of this radiant energy is becoming interesting for certain applications of low consumption.

The Energy Harvesting also called energy scavenging or power harvesting is defined as the process by which energy from different sources of radiation is captured and stored. The harvesting of this energy would be an alternative energy capable of replacing, totally or partially, the battery of certain micro systems that require a low amount of energy to function [2].

Electromagnetic energy harvesting is a challenging problem and it is receiving increasing research and application interests. It aims at collecting a part of the radiated electromagnetic energy in the surrounding environment and converting it into useful energy.

This presentation focuses on the design and simulation of antenna for rectenna (rectifying antenna circuit) for electromagnetic energy harvesting. The electromagnetic energy to harvest is radiated by public communication systems. A rectenna is device capable of transforming microwave energy into continuous electrical energy. The first development of rectenna dates back to the 1960s. Since then, the development of new rectennas has kept growing with the constant issue of efficiency optimization [3].

## II. Block Diagram of a Rectanna

As shown in Figure 1, a rectenna consists of a receiving antenna allowing the capture of radio-frequency (RF) waves, followed by a circuit of rectification and filtering, which converts the microwave energy into electrical energy (DC: Direct Current) and maintaining the integrity of the specifications.

A high frequency (HF) filter is placed downstream to the antenna. The role of this filter is to eliminate harmonious disturbances and to adapt the impedance of “rectifier load circuit” group to the radiation impedance of the antenna.

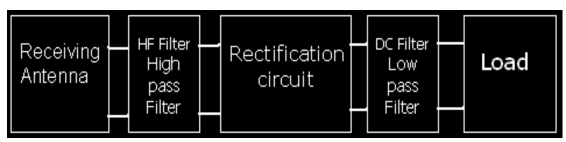



**Figure 1:** Block diagram of a conventional rectenna.

This approach allows maximizing the power transfer between the antenna and the rectifier circuit. The DC filter also has a double function: first to participate in the adaptation of the impedance group, second to filter the output tension to make it usable by the load. Harmonics created by the non-linearity of the rectifier circuit must be confined between the HF filter and the DC filter [2]. For the antenna, dipoles and patch with linear or circular polarization and high gain are mostly used. Circular polarization is a very important feature in the design of rectennas. It keeps a DC voltage virtually unchanged with the rotation of the receiver (rectenna) or the transmitter (horn antenna typically used to measure the performance of rectenna) [4] [5].

## III. Quantification of The Radiated Power in The Surrounding Area

The objective of the process of quantification of electromagnetic power in the surrounding environment is to measure the higher levels of recoverable power in terms of frequency ranges. To this end, a CORNET ED85EX portable field meter (Figure 3) that allows measuring electromagnetic fields is used. The field meter ED-85 is a compact device of high technology that allows making fast measurements of electromagnetic field and RF power density in the ambient environment in the bandwidth 1 MHz to 8 GHz with a sensitivity ranging from -55 dBm to 0 dBm. It is equipped with a SMA connector, to connect the source to measure or an antenna, as well as filters and attenuators. It is specifically designed for the measurement and verification of wireless, WLAN, Bluetooth, DECT, CDMA, AM/FM radio systems, mobile networks, as well as leakage of microwave ovens, wireless systems, wireless video surveillance, RF transmitters, spy microphones, etc. It also checks the security level of the ambient electric field [6].

**Figure 2:** CORNET ED85EX - Field meter 8 GHz.

A first set of measures of the power density of electromagnetic waves in the environment were made in different places in Paris in November 2012, for several distances from different base stations. These measurements were performed by the portable electromagnetic fields meter CORNET ED85EX, and registered according to time, to get an idea of the evolution of RF signals. These measures are presented as a histogram displayed in Figure 3 which shows the variation of the power density of the RF signals, in dBm, in terms of the frequency and time in the frequency range 1 MHz-8 GHz.

To ensure the connection between the wireless terminals, low noise amplifiers are typically used to amplify some RF signals including mobile telephony (GSM, UMTS, ...) [7] [8]. These signals in the 1.8GHz-1.9GHz band, are almost constant in time, according ANFR [1], this frequency band is reserved for mobile GSM/1800 and DECT1880MHz-1900MHz.

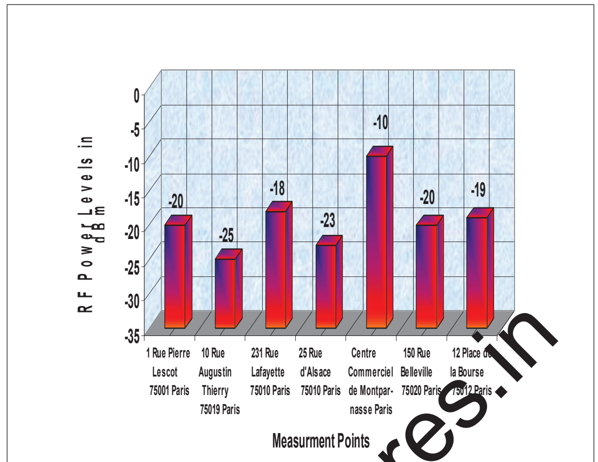



**Figure 3:** Measures of power density at different points in Paris.

Our measurements have been compared to those performed by the ANFR on the same places. ANFR measurments are accessible via its website [9]. As an example (sheet of measure N° 24481: 1 Rue Pierre Lescot 75001 Paris), the most intense signals measured by ANFR are located in the GSM900, GSM1800, and UMTS band, where the intensity of the measured electromagnetic field was 8.7316V/m for GSM900, and 4.3684V/m for UMTS 2100, and the average value is 10.5839 V/m. The average levels of electromagnetic field strength available to our measurement point are equal to 1.242 V/m.

The difference between our results and the results of the ANFR can be explained mainly by the choice of the measure points, that is to say, the coordinates of ANFR. In its measurement reports, ANFR does not specify the coordinates of the measure points. The only data that can be found are the distance between the measure point of the nearest base station antenna, and the nature of the extent, that is to say, inside or outside. These only available data make it difficult to localize the measure points of ANFR. Also, from the frequency point of view, our measures are not pointed at frequencies, GSM900, GSM1800, Wifi and UMTS, etc. Our field meter gives the mean density of the field measured over the frequency range of 1MHz-8GHz. It does not give us the opportunity to know the density levels of the electromagnetic field at each frequency of transmission, GSM 900, GSM 1800, DUCT, UMTS, Wifi, etc.

A second set of measurements were performed later in the same way in Algeria, specifically in the city of Jijel and its surroundings. However, no measurements are available on the ANF (Algerian agency of frequencies) website. Consequently, it was not possible to locate the antennas relay. The measurements were therefore carried out randomly. These measures are presented in figure 4.

[1] Agence Nationale des Fréquences

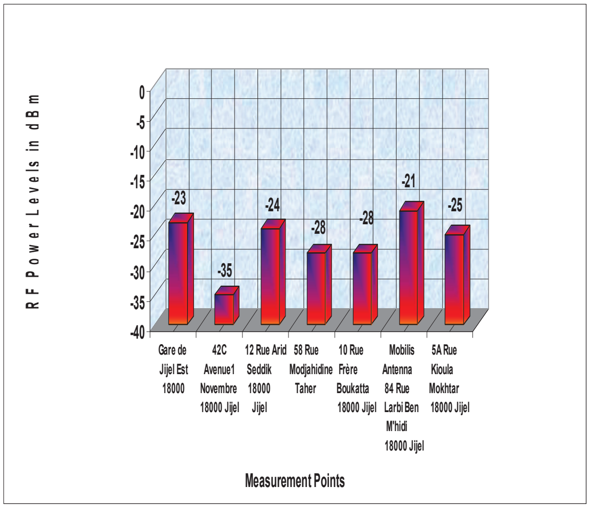


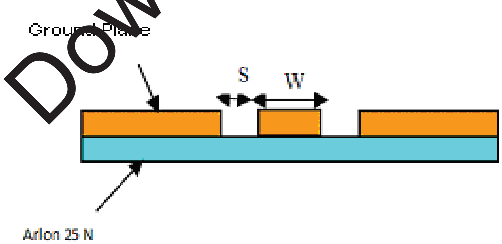

**Figure 4:** Measurements of power density at different points in Jijel.

## IV. ANTENNA DESIGN

The first wideband antenna studied is based on a classic structure of antenna with double slot [3] as shown in Figure 5. It was optimized to work in the [1GHz-3GHz] band. The first innovation that we brought was the addition of a frame engraved around the double slot antenna, with the aim of widening its frequency band of functioning, in particular towards low frequencies.

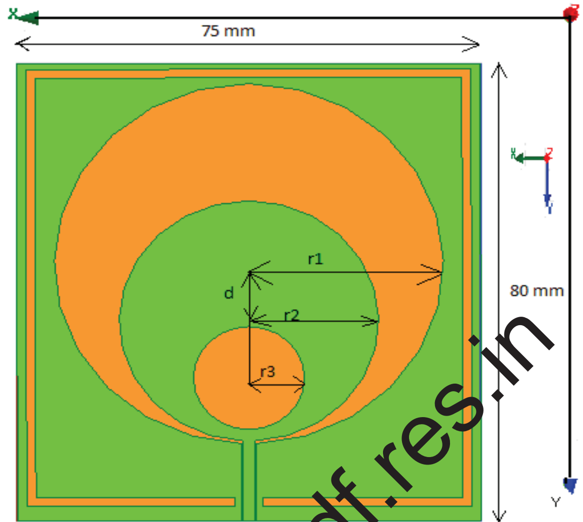
The antenna was simulated and optimized under HFSS software, on a Arlon 25N substrate, of dimension 75 mm X 80 mm, of thickness 1.524 mm, and of relative permittivity $\varepsilon_r = 3.38$. The variables of the design are indicated in the plan of figure 5. The radiant structure is established by two imbricated slots using circular forms of radius $r_1$ and $r_2$, etched on the ground plane of the Arlon 25N substrate of a simple face. The food of both slots is ensured by a coplanar line CPW, of width W=1.88 mm spaced out by the mass plan of a distance s=0.21mm, ending by a buckle of variable width.

The choice of simple-face substratum allows the antenna to shine in an omnidirectionale way. The measured input return loss of the antenna is presented in Figure 6.




(a)

**Figure 5 :** Designed antenna. a) Coplanar line. b) Topology of double slot antenna.




(b)

**Figure 5** (continued)

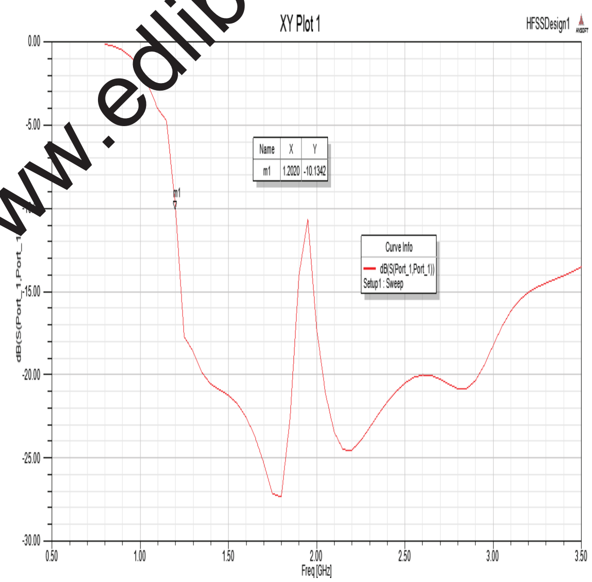



**Figure 6:** Measured input return loss ($S_{11}$) of the antenna.

As can be seen from Figure 6, the antenna appears as adapted for frequencies between 1.2 GHz and 3.5 GHz. To mitigate this problem, we tried to modify the dimensions of the antenna and the frame to widen its bandwidth towards low frequencies (<1GHz), since as indicated in Section III, the frequency band where the intensity of RF power is the most important is the [1 GHz-3 GHz] band.

Figure 7 displays the pattern at 1.8 GHz according to the angle theta (measured off the z-axis), and phi (the azimuthal angle measured counterclockwise off the x-axis). The radiation pattern is maximum at 0 and 180 degrees, equal 3.5dB.

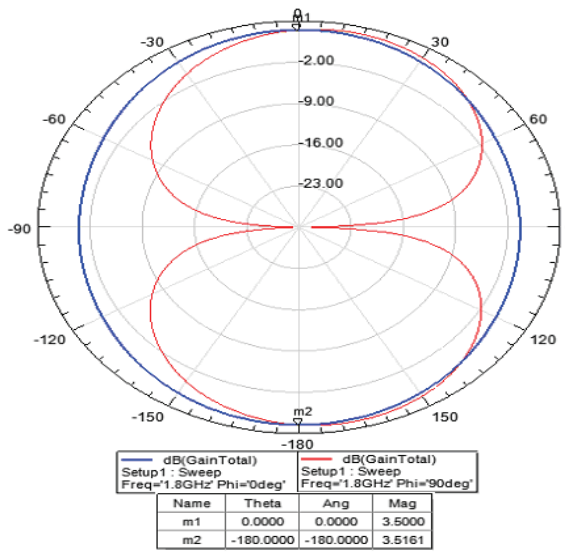



**Figure 7:** Radiation pattern at 1.8 GHz.

Figure 8 shows the radiation pattern at 1.9 GHz according to the angle theta (measured off the z-axis), and phi (the azimuthal angle measured counterclockwise off the x-axis).

The radiation pattern is maximum at 0 and 180 degrees, upper to 2.7dB, with Phi = 90 and 0 degrees, and becomes minimum at 90 degree.

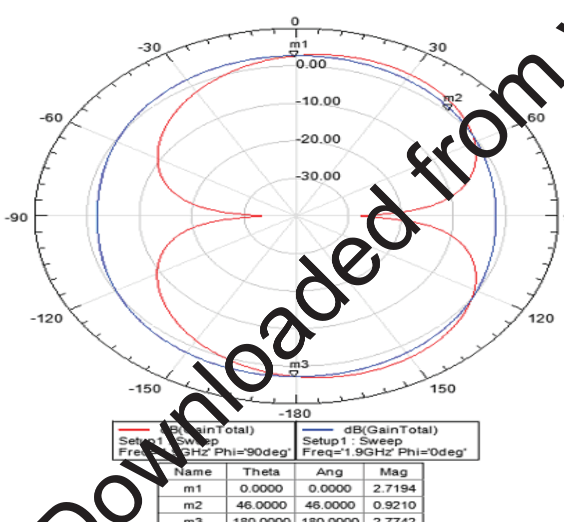



**Figure 8:** Radiation pattern at 1.9 GHz.

Figure 9 displays the radiation pattern at 2.1 GHz according to the angle theta (measured off the z-axis), and phi (the azimuthal angle measured counterclockwise off the x-axis). As can be seen, the radiation pattern is maximum at 0 and 180 degrees, equal 4 dB, with Phi = 90 and 0 degrees, and becomes minimum at 90 degree.

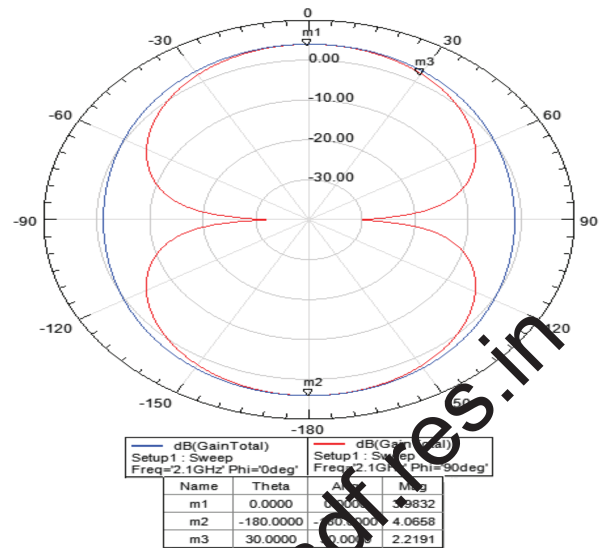



**Figure 9:** Radiation pattern at 2.1 GHz.

Figure 10 shows the radiation pattern at 2.4 GHz according to the angle theta (measured off the z-axis), and phi (the azimuthal angle measured counterclockwise off the x-axis).

The radiation pattern is maximum at 0 and 180 degrees, upper to 4dB, with Phi = 90 and 0 degrees, and becomes minimum at 90 degree.

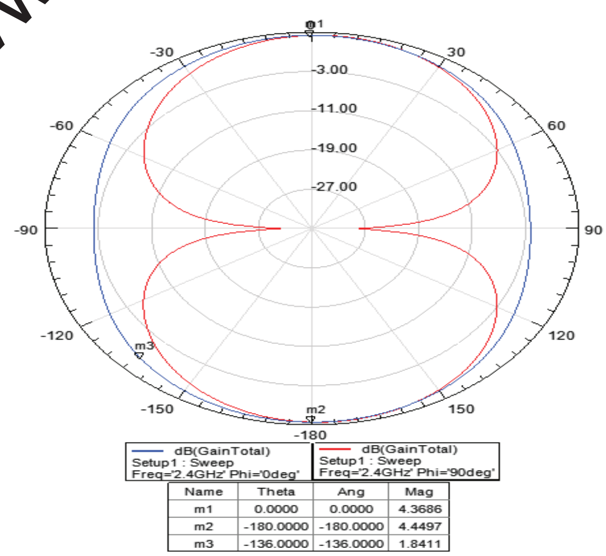



**Figure 10:** Radiation pattern at 2.4 GHz.

## V. CONCLUSION

In this article we presented the quantification of the available radiated power in the surrounding environment. It has been found that the measured power density in the urban environment of the city of Paris varies from one point to another. It depends on the distance between the transmitter and the measured point as well as on obstacles in the presence of the physical characteristics of the propagation environment and the frequency of the signal. Among the measures made by the ANFR, the bands of GSM900, GSM1800 and UMTS remain the most interesting power sources, and the most spread.

This RF energy continuously available in urban areas can be an alternative energy to feed partially or totally electronic devices of low consumption in order to make them autonomous devices.

In Algeria the power levels varies from one point to another with a power density measured between 0.05 mw /m² and 3.5 mw /m² – between -20 dBm and -45 dBm–, a little less than in France.

The analysis of the electromagnetic radiations in urban areas shows clearly that the RF energy is available permanently but the quantity is very low. The exploitation of these low levels of radiated energy will have to overcome some specific difficulties, not yet solved, in terms of integration of antennas, and harvesting efficiency. Finally the optimization of the energy efficiency often requires the association of a harvesting system with an energy storage system.

The first element of the energy harvesting system with which the RF power will be captured is the antenna. The study, the choice and the optimization of various characteristics of this element are necessary for increasing the reception of RF power. The use of a network of antennas can increase the RF power level received and thus increase the DC power output of the harvesting circuit.

The second part described a wide band antenna for applications of wireless power transmission and energy harvesting. This antenna with double slot is very interesting for the continuation of our study for a harvesting system of electromagnetic energy by maximizing the received RF energy.

The bandwidth presented by this antenna covers a band close to the band of our study (1GHz-3GHz and beyond), with a reflection coefficient (S11) below -10dB on all the bandwidth, minimizing the losses by reflection. The simulated gain exceeds 3 dBm in the band of interest with an omnidirectional radiation and a polarization of E field capable to receive several polarizations (horizontal and vertical).

The potential improvements would be to widen even more the bandwidth towards low frequencies around 800 MHz also studied, and will owe the being still, to widen the bandwidth. (Change of technology, other topology).

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