Recycling RF energy in the GSM-1800 band

D. BOUCHOUICHA[1], Mohamed LATRACH[2], Hedi SAKLI[1]

[1]SYSCOM, Ecole Nationale d'Ingénieurs de Tunis, BP. 37, Le Belvédère, Tunis 1002, Tunisia

[2]Groupe RF& Hyperfréquence-école supérieure d'électronique de l'ouest(ESEO)
4 Rue Merlet de la Boulaye, BP 30926, 49009 Angers, France

Abstract
In this paper, we present a study about the recuperation and the wireless transfer of the RF micro-energy in the waveband 1800 MHz -1900MHz.
Actually, a series of measurements of the power RF available in the ambient surrounding using a spectrum-analyzer has enabled to us to determine the level of this power which is nearly constant in time and of order -14.5dBm/m² (33.4µW/m²). Meanwhile, two types of antenna were studied to recover the power RF. The first is a spiral antenna which represents a quasi-unidirectional radiation with a circular polarization and a measured gain equal to 2.24dBi, the second is a array of circular patch antenna with a rectilinear polarization and a measured gain equal to 5.24dBi.
Additionally, a rectifier RF/DC with low power of input based on Schottky diodes (voltage double) was characterized. Two systems (rectenna) were also tested in the ambient surrounding where the maximum measured power is about 0.33µW.
What is more, some energy transfer tests were carried out inside the anechoic room whose the efficiency of conversion RF/DC could reach 20%. The maximum transferred power DC is equal to 5.6µW, with an 18KΩ of load.
Keywords: *antenna, rectifier RF/DC, wireless power transmission, rectenna, harvesting RF energy.*

1. Introduction

The extension of the telecommunication systems increasingly generates the electromagnetic waves in our environment at various frequencies and powers. This existing energy RF can be regarded as a source of energy for lower-consumption-electronic devices like sensors. Moreover, since 1950 [1], the supply of the systems by the electromagnetic wave has drawn the attention of several research-teams and, thus, several projects have been developed; for instance, helicopter powering [2], solar power satellite (SPS) [3], the SHARP System [4], and recently for RFID applications [5].
The work presented in this article is about the harvesting of RF energy in the 1800MHz-1900MHz band.
This is accomplished by the use of one or more antennas to recover the RF energy. This energy will be converted on DC power by us the rectifier (RF/DC). The recovered power, therefore, will either supply an electronic device or it will be stored in an accumulator.
The recovered power DC depends on the efficiency of the conversion RF/DC and on the RF power emitted by the transmitter

$$P_{dc} = \eta_{RF/DC} . P_{RF}$$

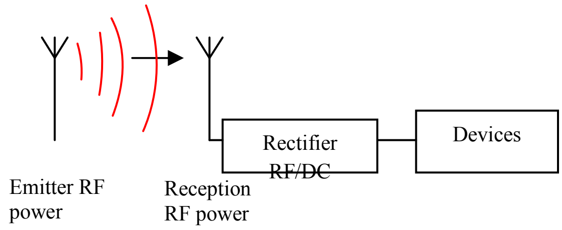

Fig.1. Conceptual view of the harvesting RF energy system

In the first section, we present the results of measurements of the density of the surrounding RF power which were carried out to determine the levels of power available. In this same part, a rectifier RF/DC with low level of power is presented.

The second section is devoted to the study of the radiant element (antenna) which will be able to collect the maximum of radiated power with a reasonable dimension to be used on electronic devices. A comparison of the characteristics of two types of antennas, spiral and a array of circular patch antennas, is also carried out.

The last part of this work deals with the development of a system of recycling electromagnetic energy (RF) called "rectenna". Two systems were realized: the first is at the base of the spiral antenna, and the other is by using the array of patch antennas. The two circuits were tested in the ambient surrounding to recover the energy RF emitted by the base station, then tested in the anechoic room by using an emitter RF.

2. Measurement of the ambient power RF and development of a rectifier.

A measurement campaign was conducted in urban areas, and for a day, and a frequency band ranging from 680 MHz to 3.5GHz. These measurements, as a matter of fact, showed that the density of the measured power is quasi constant in time and ranges from -60dBm/m² with -15dBm/m² according to the frequency. That more than half of the total density of the measured density of power (-14.5dBm/m²) is localized in the frequencies wave-band 1.8GHz-1.9GHz (Fig.2).The results of these measurements are, accordingly, comparable with the ones obtained by Joseph A. [6]

The levels of energy carried by the ambient air are very low, requiring the design of a converter RF/DC with high sensitivity and a conversion efficiency of the rather very high.

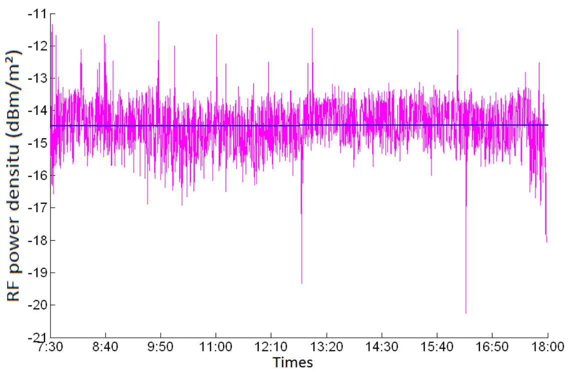

Fig.2: Variation of the total density of the power RF in the wave-band 1800MHz-1900MHz

The voltage doubler topology based on a Schottky diode of the type HSMS2850 [7] is used on the converter RF/DC.

The levels of power RF available in the ambient environment are low, which requires a matching circuit to minimize the losses by reflection and to maximize the transmission of power towards the electronic device. This adaptation is ensured by a capacity of a value equal to 47pF placed in parallel with a distance "d" at the entry of circuit (Fig.3). To take account of the disturbances which can be brought about by the presence of the connector SMA, a model of this last was added to the circuit (Fig.3). To have a better matching in the frequency band (1.8GHz-1.9GHZ), the optimizations of the distance "d" were made with ADS [8]. The optimal distance "d" is, equal to 6.5mm where the return loss is low than -10dB (Fig.4). A prototype was realized and validated by measurement. The Fig.5 shows a comparison of the simulated and measured results of the return loss (S11). It is noticed, however, that there is a good correlation between the results with a return loss about -18dB at the central frequency of the wave-band 1.8GHz-1.9Hz.

In view of that, the impedance presented by the rectifier is variable according to the power because the characteristics of the diodes constituting the rectifier depend on the power. By fixing the distance d at 6.5mm, we simulated the circuit on several levels of power. Fig. 6 presents the variation of the return loss according to the frequency at different value of the power RF (0dBm, -10dBm, -20dBm....). It is noticed that there is an adaptation of this circuit to an impedance of 50Ω; in other words, the return loss is inferior to -10dB is ensured for powers RF lower than -20dBm.

Optimizations of the value of load RL were carried out to maximize the power DC. The value of 18KΩ was given in (Fig.7).

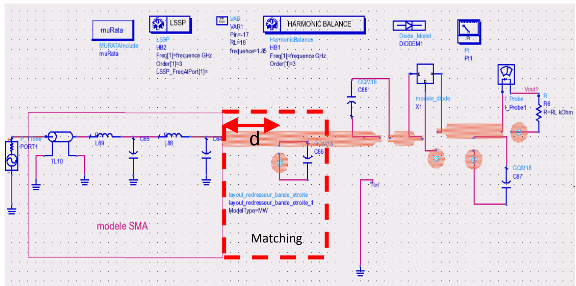

Fig.3: Circuit of the converter RF/DC

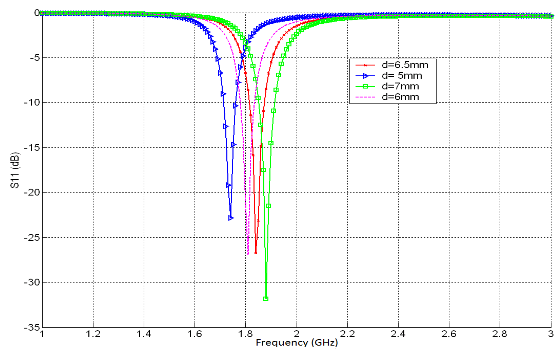

Fig.4: Variation of the return loss simulated according to the distance d.

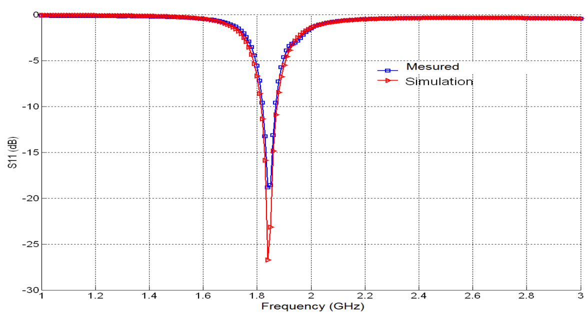

Fig.5: Variation of the return loss measured and simulated according to the frequency with P_{RF}=-40dBm.

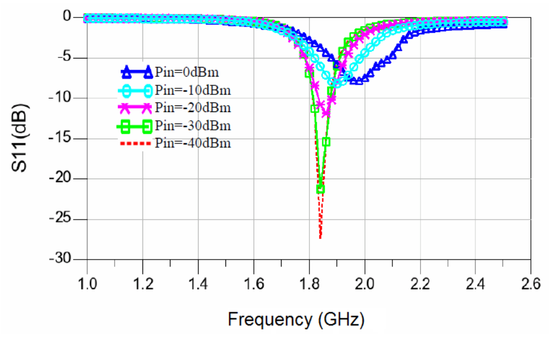

Fig.6: Variation of the return loss simulated according to the power RF.

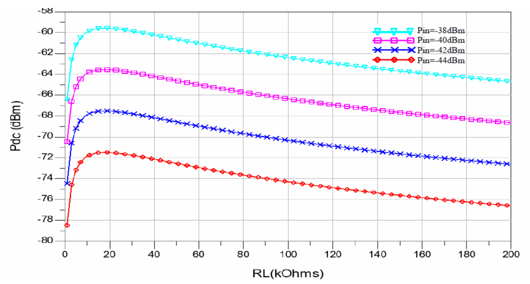

Fig.7: Variation of the DC power according to the load R_L.

3. Antennas

This part of the article is dedicated to the presentation of the results of the study of the radiant element. The antennas studied in this section we present two types with a better size/gain: a spiral antenna with circular polarization and a array of circular patch antenna with a rectilinear polarization.

3.1 Spiral antenna

The geometry and dimensions of the spiral antenna are presented by Fig.8.It is an antenna printed on a substrate of the single-sided type FR4, its thickness is equal to 0.8mm and its permittivity is ε = 4.4 (δ=0.02).The antenna dimension is 54 mm over 43 mm; it is surrounded by a metal framework of 1 mm of width. This metal track, actually, makes it possible to increase the gain in the normal direction of the antenna and to widen the band-width towards low frequencies. The metal track generates a capacity-effect with the arms of the antenna what makes it possible to go down in frequency. The variation of the simulated and measured return loss (S11) is presented by Fig.9. It is inferior to -16dB in the frequencies band 1.8GHz-1.9GHz, which ensures a minimum of loss by reflection.

The radiation pattern of the antenna at the frequency 1.85GHz is presented on Fig.10, it is quasi unidirectional in XOZ plan, with a maximum gain simulated about 3dBi. The measured gain is equal to 2.24dBi.The polarization of this antenna can be regarded as circular as shown in Fig.11, the difference between the direct polarization (Eco) and the crossed polarization (E_cross) is inferior to 5dB.

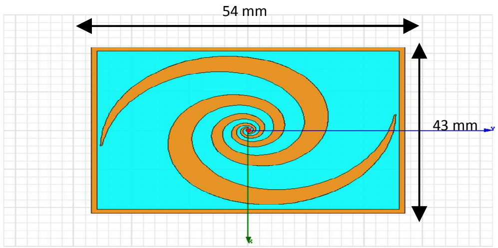

Fig.8: Design of the spiral antenna

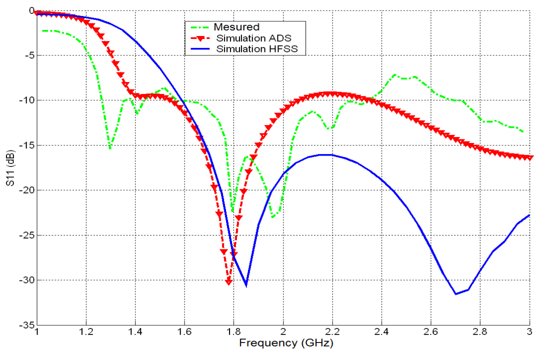

Fig.9: variation of the return loss according to the frequency.

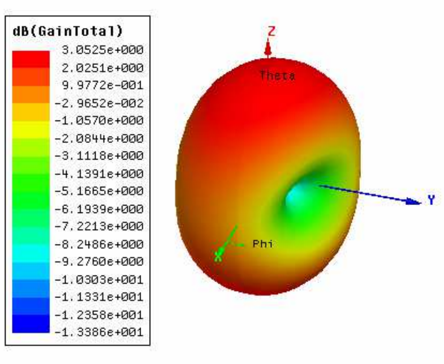

Fig.10: Radiation pattern at 1.85GHz

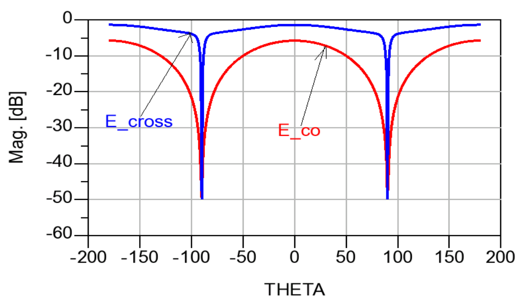

Fig.11: Polarization of the field E

3.2 Array of Circular patch antennas

By using the circular patch antenna as an elementary antenna of a two- element array (Fig.12), we could have a gain of about 5dBi.This array of antenna is printed on a substrate of the type FR4 of a permittivity equal to 4.4 and a thickness equal to 0.8mm.The excitement of this array is ensured by a micro-strip line. Fig.13 shows that the return loss of this array is lower than -15dB in the wave-band 1.8GHz-1.9GHz, which minimizes the losses by return loss and ensures a good transmission of the received RF power.

Furthermore, the radiation pattern at the central frequency of the frequencies band of study (1.85GHz) is presented on Fig.14; it is unidirectional with a maximum measured gain equal to 5.24dBi, which maximizes the received RF power. The polarization of the field E is presented on Fig.15. It is a rectilinear polarization since the difference between the direct polarization (E_co) and the crossed polarization (E_cross) is higher than 20dB.

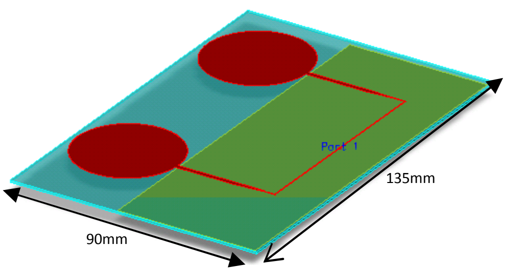

Fig.12: Array of circular patch antenna

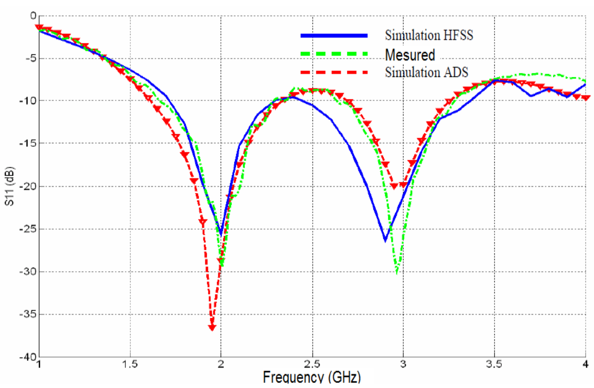

Fig.13: Variation of the return-loss according to the frequency

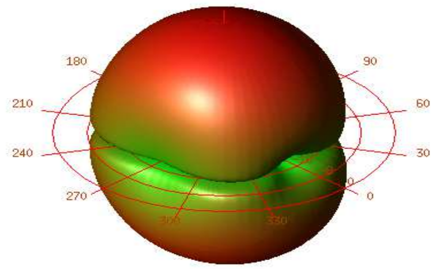

Fig.14: Radiation pattern at 1.85GHz

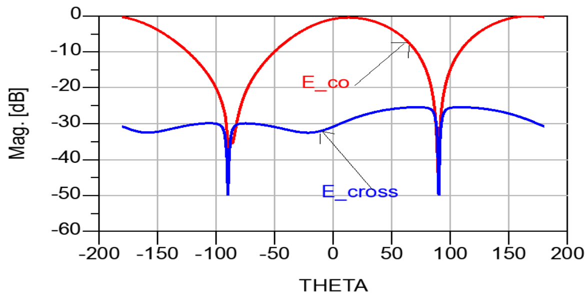

Fig.15: Polarization of the field E at the frequency at 1.85GHz

4. Rectenna

By fitting the developed rectifier together with the two types of antenna (spiral, array of antenna), we obtained two prototypes of harvesting RF energy system (Fig.16). In fact, we tested these systems by placing them near a base station located on the roof of a high building at an altitude of 27 m. The rectennas are placed at 1.3m on the ground in direct visibility with the base station. Then, we gradually moved it away at a distance of 100m while measuring the terminal voltage of the load RL = 18kΩ. These measurements are shows on Fig.17. It is noticed that, at first, the tension measured by the rectenna based on a spiral antenna grows gradually up to the value of 42mV at 25 meters away from the first point of measurement, and then it collapses beyond 30 meters to oscillate, in a random way, between 0 and 15mV. All along the first 25 meters, the gradual increase of the tension can be explained by the fact that when the rectenna of the principal lobe gets nearer to the radiation of the base station. For medical reasons, however, the principal lobe radiated by this type of antennas is directed, with a light slope, towards the ground.

The variations beyond 30 meters are explained by the multiple reflections of the electromagnetic field (fading) on the surrounding buildings. The peak of tension DC (42mV) corresponds to a power of 0.1µW, whereas the average tension along the 100 meters is about 8mV for an average power equal to 3.55nW.

At the same point of measurement, we tested the rectenna based on the array of patch antenna. One may notice that the measured tension follows the same evolution as the tension measured for the rectenna with the spiral antenna with a peak of tension equal to 77mV (0.33µW) that corresponds to a distance equal to 25m.The average tension is equal to 16.16mV (14.5nW).This rectenna is better than that of the spiral antenna because the gain of the array (5.24dBi) is higher than that of the spiral antenna (2.24dBi).

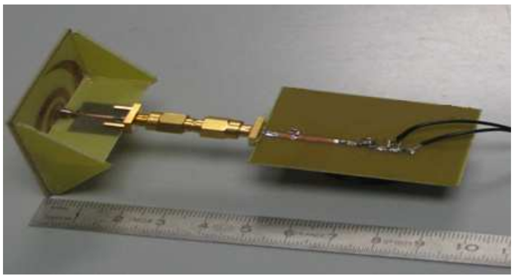

Fig.16: Prototype Of the rectenna based on a spiral antenna

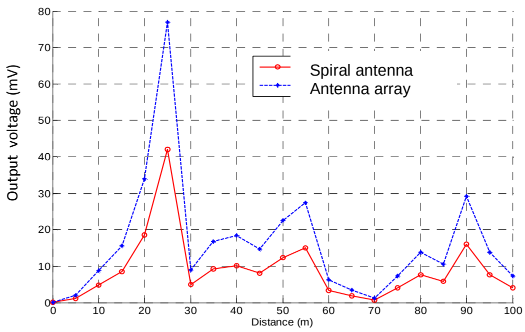

Fig.17: Tensions measured according to the distance

The levels of the measured powers are very low and cannot allow us to feed directly electronic devices. On the other hand, it is possible to accumulate this energy by storing it in an accumulator like a super capacity or micro-battery, so as to feed an electronic device in a shorter time than accumulation time. Nevertheless, if we use an emitter microwave to transfer wireless RF energy, we can increase the energy recovered by the rectenna by having an effect on the microwave power which supplies the transmitter and thus to increase the continuous power at the output side of the rectifier.

Hence, we positioned the rectennas under tests, in an anechoic room, at a distance d=2.51m of a microwave source composed of a generator and a cornet antenna adapted to the study of wireless RF power transmission (Fig.18).The transmitting antenna used was a cornet antenna model 3115, marketed by ETS-Lindgren. The gain of this antenna is worth 8.75dBi at the frequency 1.85GHz [9], and the free space path-loss of the wave reached 45.8dB on 2.51m.

A RF power (15dBm) was applied to the input of the cornet antenna. The highest output voltages correspond to those measured at output of the rectenna using an array of circular antennas. For a RF power equal to 15dBm (32mW), the maximum voltage measured at the boundaries of the load reached 317mV (Fig. 19); that is to say, a continuous power is equal to 5.6µW for 20% of efficiency of rectifier RF/DC.

The global efficiency of transfer of energy which is expressed by the report of DC power recovered by the power RF injected into the cornet antenna ($\eta = \frac{P_{dc}}{P_{RF}}$) is equal to 0.0175%. This total poor efficiency is due primarily to the attenuation of the microwave power between the cornet antenna and the rectenna (~46dB) as well as the efficiency of conversion RF/DC of the used rectifier.

For the rectenna based on a spiral antenna, the maximum DC power measured at the frequency of 1.85GHz reaches 2.22 µW; that is to say, the equivalent of a continuous tension at the boundaries of the load R_L=18KΩ is equal to 200mV.

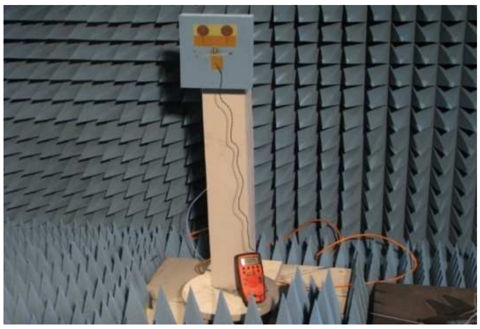

Fig.18: slotted measuring section

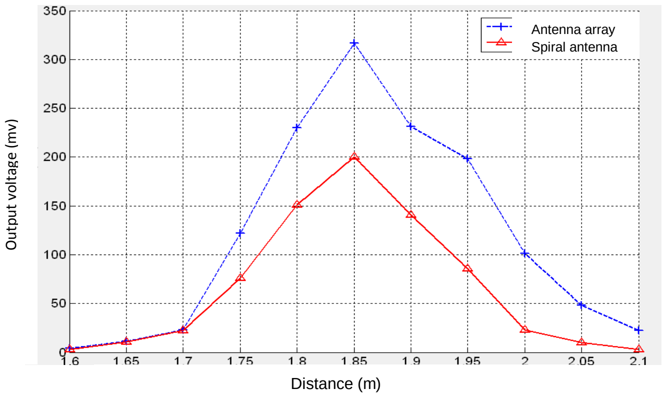

Fig.19: Output DC voltage at the boundaries of load RL according to the frequency (P_{RF} = 15dBm).

4. Conclusion

The focal point of this work is the study of the recycling RF energy systems and the wireless power transmission of electromagnetic energy.

Indeed, two recycling RF energy systems (rectennas) were realized. The maximum power recovered near a base station was obtained by the rectenna based on an array of patch circular antenna where it reaches 0.33µW. Some tests under a strong field were carried out inside the anechoic room in order to transfer more energy. Accordingly, the best performances were obtained by the system with an array of two-patch antenna. Indeed, the use of antenna array increase the level of the received RF power by increasing the surface of reception, and thus the gain therefore more congestion. The global efficiency, for the RF power equal to 15dBm in the input cornet antenna, reached 0.018%, with an efficiency of conversion RF/DC of rectifier is about 20%. The maximum measured power, debited in the load R_L=18KΩ, is lower than 5.6µW.

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[7] Datasheet, HSMS-285x Series, Surface Mount Zero Bias Schottky Detector Diodes, AVAGO.

[8] ADS: Advanced Design System software

[9] Datasheet, Double-Ridged Waveguide Horn Model 3115, ETS-lindgren

Authors' information

D. BOUCHOUICHA was born in Medenine, Tunisia, in 1978. He received the M.A. degree in electronics (high frequency systems of communication) from the university of Marne-la-Vallée, Paris –France, in 2006. In 2010 he received the Ph.D. degree in electronics from the University of François Rabelais, Tours, France. He is currently a Professor of electronics engineering with the Institut Suprieur d'Informatique, Medenine, Tunisia. Where his research involves RF and microwaves. His field of interest is the design of hybrid, and passive microwave circuits, antennas and their applications in wireless communications, and wireless power transmission.

Adresse: SYSCOM, Ecole Nationale d'Ingénieurs de Tunis, BP. 37, Le Belvédère, Tunis 1002, Tunisia.

Mohamed LATRACH (M'03) was born in Douar Ksiba, Sless, Morocco, in 1958. He received the Ph.D. degree in electronics from the University of Limoges, Limoges, France, in 1990.

He is currently a Professor of microwave engineering with the Ecole Suprieure d'Electronique de l'Ouest (ESEO), Angers, France, where his research involves RF and microwaves. His f eld of interest is the design of hybrid, monolithic active, and passive microwave circuits, metamaterials, LH materials, antennas and their applications in wireless communications, and wireless power transmission.

Adress :Groupe Radio& Hyperfréquence-Ecole Supérieure d'Electronique de l'Ouest (ESEO)
4 Rue Merlet de la Boulaye, BP 30926, 49009 Angers, France

Hedi SAKLI, is born in Tunisia in 1966, holds a PhD in telecommunications from the National Engineering School of Tunis, Tunisia. It is since 2004 assistant prof. at the University of Gabes. His research interests propagation in anisotropic media and metamaterials, numerical methods in electromagnetics, modeling of transistors and antennas.

Address: SYSCOM, Ecole Nationale d'Ingénieurs de Tunis, BP. 37, Le Belvédère, Tunis 1002, Tunisia