UHF Near-Field Wireless RFID Power Transfer Through Two Distant Rectangular Waveguides

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***Abstract* — Feasibility of a wireless power transfer (WPT) system for supplying power to a metallically closed volume is demonstrated. The solution proposed is based on a metallic rectangular waveguide. After optimization, simulated transmission coefficient is -1dB, corresponding to power transmission efficiency of 80%. This near-field WPT system is a good candidate for several specific RFID UHF applications where the measuring volume is mobile with respect to the base station.**

***Keywords* — near-field, relay antenna, RFID, rectangular waveguide, wireless power transfer**

I. INTRODUCTION

Passive radiofrequency identification (RFID) is a well know technique nowadays. It has become progressively popular in automatic identification data collection systems. It allows wireless transfer and the collect of information about goods and products, animals, people [1]. Usually, an RFID system is composed of RFID readers and RFID tags. The latter are attached to every object to be identified, and transmits a unique identification code, and the RFID reader reads and writes the identification codes stored by the RFID tag [2]. The operating frequency ranges cover from Low Frequency (LF) to Ultra High Frequency (UHF) bands, depending on the purpose of the system, and the communication ranges, and according standards of legislation the maximum effective isotropic radiated power (EIRP) is limited to 35 dBm [3] for the European region.

Naturally, for such cases of use to work, a complete RFID system has to be located inside the closed volume [4] . Or at least antennas must be located inside the closed volume and be connected with coaxial cables to an external RFID reader located outside of it [5]. In both cases, the system can be made mobile with the use of batteries, but it will require to be connected to an external power source from time to time. And an RFID reader is required per closed volume.

In some situations, it would be interesting to have mobile and at the same time completely passive mobile closed volumes, eliminating all environmental problems created by batteries [6][7] . To do this, a system includes a local RFID reader with several antennas installed inside the enclosure. The system establishes communication between a local RFID reader and a central station with protocols such as Bluetooth or Zigbee there are several patents related to that idea. Three of them present the details of a system for tracking and monitoring an inventory within one or several confined metallic enclosure [5], [8]–[10]. However, in this system, only information is transmitted through the confined metallic enclosure, the power required by the RFID reader is contained inside the enclosure.

In addition to the previous requirement, sharing the same RFID reader for several mobile closed volumes would be a great economical advantage. An example of a scenario could be several work shop trolleys containing tools used in an aeronautic industry, aero spatial industry or a nuclear plant. A single RFID reader could be placed on a fixed station and to realize the inventory of the tools inside a trolley, an operator would simply have to punch the trolley next to the fixed station. This requires the need of a wireless power transmission of the interrogating RFID signal and the retro diffused responses of the tags inside the trolley.

In this work, we propose and study such a wireless power transfer (WPT) system. It is composed of two separate rectangular waveguides. The WPT system is equivalent to a waveguide discontinuity, namely, an open one which is describe in [11]–[14]. These study analyze the behavior of an open-ended discontinuity of a rectangular waveguide as a radiating element from a computational point of view, without taking into account possible applications.

In Section II, the whole structure and the optimization of the design of the WPT system is presented with numerical simulations. In Section III, experimental results are presented to validate the concept

II. SYSTEM DESIGN

A. *Waveguide antenna design*

The whole system consists in a mobile metallic cabinet and a fixed station. The later contains the RFID reader connected to the WPT system. The former contains all tag items and at least one inner antenna connected to the WPT system, as it is shown in Fig.1. The WPT system is two rectangular waveguides connected to a coaxial cable on one side and open in air on the other side. The separation between the two openings and proper alignment can easily be assured by an appropriate mechanical system.

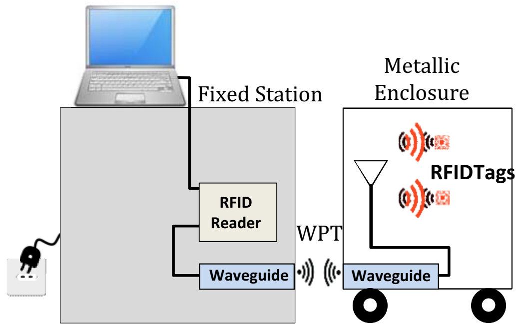


Fig. 1. Reading RFID tag with WPT system

B. Waveguide Design

Waveguide are commonly used in a variety of application in the microwave frequency band, especially in the range of centimeter and millimeter waves, mostly because they are relatively low loss and have a large power-handling capability. The solution uses such waveguides, as depicted in Fig. 2. The WPT system is equivalent to a waveguide discontinuity, namely, an open one. Therefore, when the electromagnetic field impinges on the termination of the transmitting waveguide, part of the associated power is coupled to the second waveguide, while a second part is reflected, and a third part is radiated in free space.

There is a standard rectangular waveguide which covers the concerned frequency band: the European Telecommunication Institute (ETSI) frequency band, 866 to 868 MHz. It is the WR1150 waveguide, with a broad wall width, *W*, of 291.1 mm, a height, *H*, of 146.05 mm, and a cutoff frequency at 513 MHz. These dimensions are still very large, especially when it is necessary to use more than one WPT system, depending on the number of inner antennas. It is necessary to resize the waveguides, not only to get less bulky solution, but also a lighter solution. So, according to [15], it is possible to estimate the dimensions of the waveguide especially the broad wall width:

$$W = \frac{c}{2f_c} \quad (1)$$

where c is the speed of light, and f_c is the cutoff frequency.

With the *W* obtain as a starting point for one waveguide. Numerical optimization is done to minimize the reflected and radiated power losses by considering the two waveguides with Ansys HFSS.

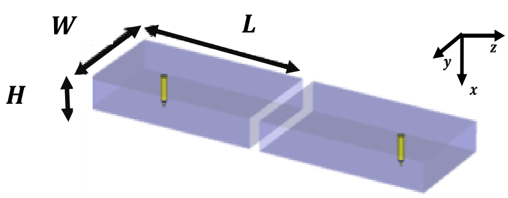


Fig. 2 Design of the straight waveguide WPT system

A cutoff frequency less than 860 MHz was found. *W* equal to 174.8 mm, *H* equal to 40 mm, and a length, *L*, of 305 mm, as presented in Fig. 2, gave the best results. Both transmitting and receiving waveguides are well impedance-matched with the feeding circuit and the load impedance, respectively. A reflection loss of -19 dB, and a minimal insertion loss of -1.02 dB are achieved at 868MHz, when they are face-to-face and separated by an air gap of 2 cm. Results show that the system operates from 864 MHz to 870 MHz, as shown in Fig. 3, which is compatible with the ETSI UHF RFID band.

From the *S*-parameters, the power transfer efficiency, η, can be computed the following way[16]:

$$\eta = \frac{P_{Rx}}{P_{av}} = \frac{|S_{21}|^2(1-|\Gamma_{Rx}|^2)}{|1-S_{22}\Gamma_{Rx}|^2(1-|\Gamma_{Tx}|^2)} \quad (2)$$

where P_{Rx} is the power delivered to the receiving port and P_{av} is the available power from the excitation port, Γ_{Rx} and Γ_{Tx} are the reflection coefficients at the receiving and excitation ports respectively. They are expressed as [15]:

$$\Gamma_{Tx} = S_{11} + \frac{S_{12}S_{21}\Gamma_{Rx}}{1-S_{22}\Gamma_{Rx}} \qquad \Gamma_{Rx} = S_{22} + \frac{S_{12}S_{21}\Gamma_{Tx}}{1-S_{11}\Gamma_{Tx}}$$

The power transfer efficiency is higher than 80% over all the band, the maximum value is 85%.

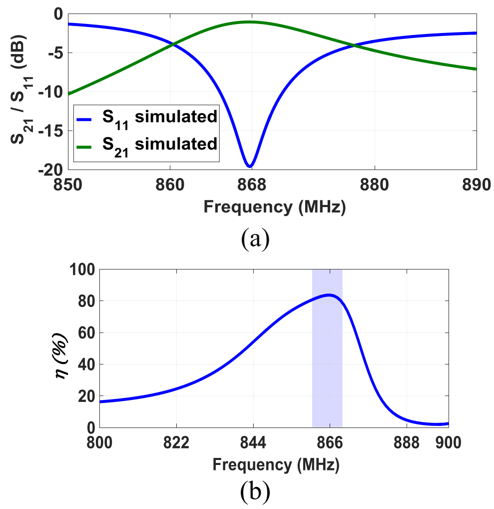


Fig. 3 Performances of waveguide system: (a) S-parameters, (b) PTE

C. Tolerance estimation

The tolerances of the system were evaluated in order to validate the feasibility of a real implementation. For that, the frequency was fixed to 868MHz, and the parameter S_{21} was simulated while one side of the WPT system was displaced. along *z*, *y*, and *x* axis.

The threshold limit was fixed to -3dB where half of injected power should be received by the second waveguide. As depicted in Fig. 4 a tolerance of 2.8 cm is obtained along the *x*-axis while more than 5 cm is obtained for *y* and *z* axes.

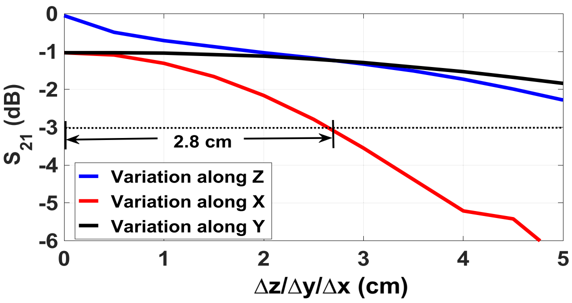
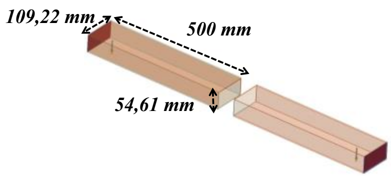


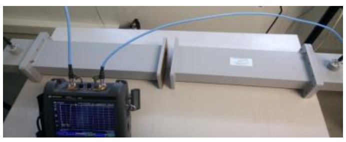
Fig. 4 S_{21} variation at 868 MHz. Along the x, y and z-axis

III. Experimental Validation

In order to validate the efficiency of the proposed solution, measurements were made. But because of available components in our laboratory, a standard rectangular waveguide, WR430, was used instead of the optimized one. It worth mentioning here that the waveguide band is out of the target one in UHF RFID but measurements of the *S*-parameters can still be done, as well as the calculation of the power transfer efficiency. The response of the WR430 waveguide was simulated so it can be compared to the measurements. The dimensions and the photography of the WR430-based-system are shown in Fig. 5.



(a)



(b)

Fig. 5 Design of the standard straight waveguide WPT (WR430) for WPT system

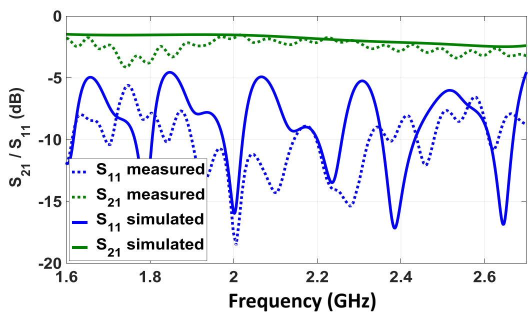


Fig. 6 Measured and simulated S-parameters and efficiency with the standard straight waveguide, W430 Top) S-parameters. Bottom) P*ower transfer efficiency.*

Measured and simulated S-parameters of the WPT system are presented in Fig. 6. The agreement between simulation and measurements is fair, and validates the feasibility of this solution. The power transfer efficiency is also presented in Fig. 7. Best results of 85% are obtained at 2.45 GHz.

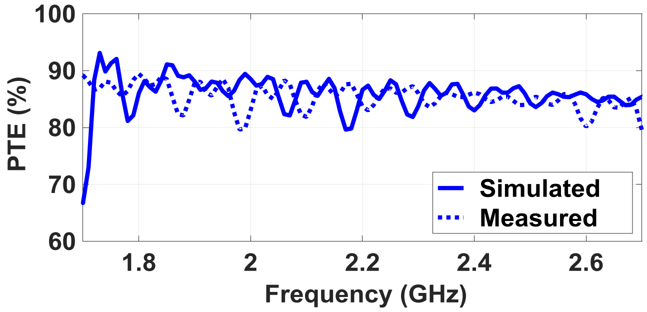


Fig. 7 PTE of the rectangular waveguide WR 430

A tolerance study was also done, but since this structure does not operate at the desired frequency, we arbitrarily evaluated the tolerance at 2.45 GHz as depicted in Fig. 8

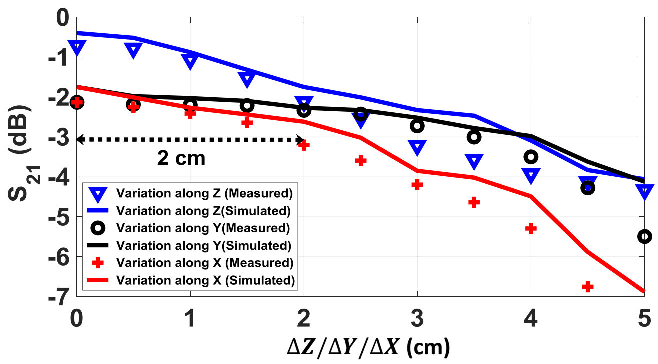


Fig. 8 S_{21} variation at 2.45 GHz. Along the x, y and z-axis

The results can be observed in Fig. 8. Regarding the longitudinal distance between the receiving and transmitting parts of the WPT system, a stable an optimal distance is found between 0 cm to 1 cm air gap. For smaller gaps or bigger ones, insertion loss increases. This is caused by mismatch of the whole structure. For an arbitrary value of -3 dB of the S_{21}, a tolerance of 2.5 cm is obtained along the *z*-axis. Concerning height (along the *x*-axis) or lateral (along the *y*-axis) misalignments, at -3 dB, tolerances of 2 cm and 2.5 cm were respectively obtained.

IV. Conclusion

This paper demonstrated the feasibility of WPT system for UHF applications for RFID applications. The solution is based on metallic waveguides placed face to face. A power tranfert efficiency of 80% and acceptable tolerances to misalignement were obtained. The proposed solution has very satisfactory performance in terms of efficiency, it is robust and well adapted for transmitting power between two seperated elements of an RFID system.

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