AN INDIRECT NON-INVASIVE METHOD FOR MEASURING INPUT IMPEDANCE AND CONNECTION EFFECTS OF AN RFID TAG ANTENNA

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Abstract

This paper presents a non-destructive, non-invasive method for measuring the input impedance of a Radio Frequency Identification (RFID) transponder (tag) antenna at the operating frequency. The derivation of the theoretical basis for determining the antenna impedance is presented along with the experimental measurement method using a Vector Network Analyzer (VNA) in conjunction with a Giga-Hertz Transverse Electromagnetic (GTEM) cell where the tag is located. By providing three different terminations to the antenna, the frequency dependent parameters can be measured in order to define a two-port network and determine the input impedance of the antenna. All measurements were performed using the actual RFID tag that operates in UHF (915 MHz) band. The resulting input impedance of the antenna was validated with the electromagnetic simulation software by constructing a model of the testing system and applying the proposed measurement method. The simulated results were found to be in agreement with the experimental measurements accounting for any discrepancies.

I. Introduction

The area of application for the radio frequency identification (RFID) has grown tremendously over the past few years. The RFID systems are used in various fields of identifying and tracking objects and mainly in supply chain management [1], which in turn has become the main driver for the passive RFID technology.

A typical passive RFID tag derives its power from the radio frequency (RF) energy generated by the interrogator (reader). Any power loss between the tag antenna and the integrated circuit (IC) chip limits the maximum distance from which the transponder (tag) can be read [2]. Maximizing collected energy is essential to increasing the range and robustness of a passive system.

The characteristics of an antenna are fundamental to an understanding of how it is used in a passive device for both radio communication and energy harvesting. These most important characteristics include gain, radiation pattern, and polarization. The input impedance is one of the characteristics, which is of fundamental importance. It is necessary to match the impedance of an antenna to a load in order to efficiently couple the RF power [3]. This can be achieved by using the maximum power transfer theorem.

The input impedance of the chip can be measured and is typically available in publications [1, 4]. However, the tag antenna characteristics lack accurate information about the input impedance. This is due to the manufacturing flow, where the production of the RFID tags requires multiple steps and different assembly methodologies with the objective of lowering the final cost of the RFID label [5]. The low cost packaged can significantly degrade the input impedance of the tag's antenna. The final cost and fabrication requirements for the RFID tag impose a set of criteria on the assembly of the tag, where the typical methods for measuring the real impedance of the tag's antenna are not feasible.

II. Theory

The proposed indirect (non-invasive) measurement technique is adopted from the method of connecting three known loads to the feed point of the antenna for determining its parameters [6, 7]. Also, the same methodology is used for convention two-port calibration procedure of the VNA. This method eliminates the necessity of any direct probe connection to the terminals of the antenna. Because there is no physical connection of the probe to the antenna, it becomes critical for the measurement of the input impedance of the antenna which is integrated within the package.

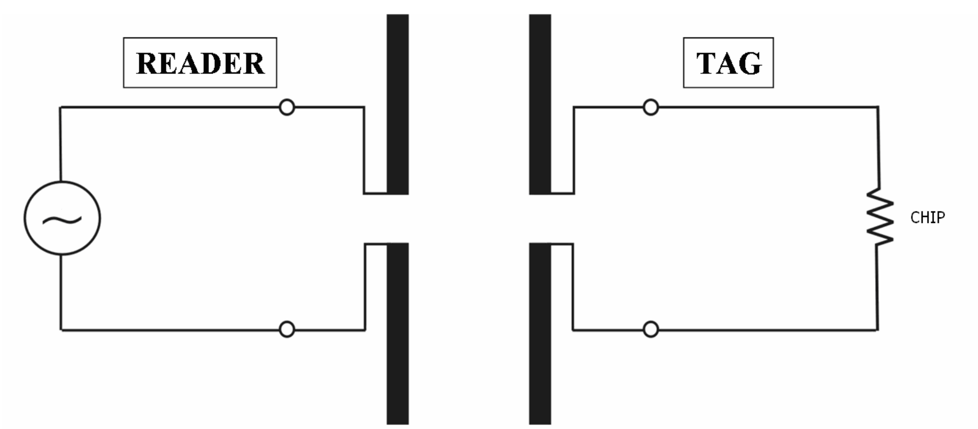

Figure 1: The simplified model of the RFID system

The transfer function between the reader and the tag can be expressed in terms of the parameters that define an equivalent two-port network [8, 9]. An equivalent two-port network is illustrated in Figure 2.

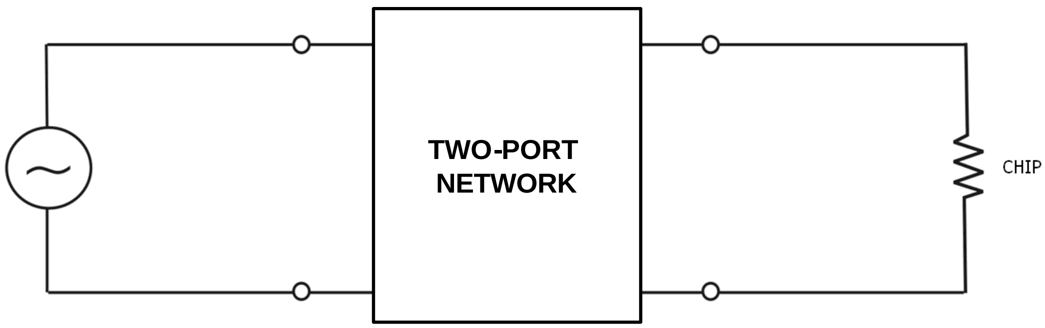

Figure 2: An equivalent two-port network representation

The two-port matrix captures the relationship between the reader's antenna and the tag's antenna in the free space. Given the two-port reciprocal network, its behavior can be uniquely determined by the T-network in Figure 3.

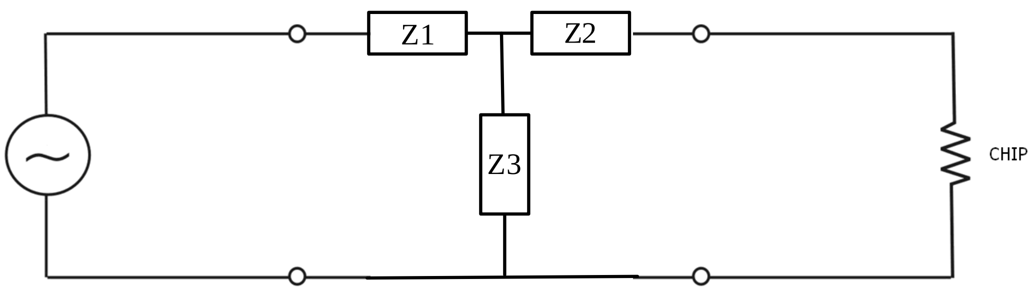

Figure 3: T-network representation

Applying circuit theory, an impedance matrix that describes the two-port network can be constructed as following:

$$Z = \begin{bmatrix} Z_{11} = Z_1 + Z_3 & Z_{12} = Z_3 \\ Z_{21} = Z_3 & Z_{22} = Z_2 + Z_3 \end{bmatrix}$$

By providing three different terminations, the frequency dependent Z-parameters can be determined. Based on the collected data, all elements of the two-port matrix can be calculated from one-port measurements only. After reconstructing the two-port information, the input impedance of the antenna can be calculated as following:

$$Z_{IN} = (Z_{11} - Z_{12}) + \frac{Z_{12} \cdot [(Z_{22} - Z_{21}) + Z_{OUT}]}{Z_{21} + [(Z_{22} - Z_{21}) + Z_{OUT}]}$$

III. Simulation

The measurement method and the equations have been conceptually validated in the Ansoft Designer/HFSS [10] by modeling a close-to-reality test system with an RF generator (RFID reader) and the tag's antenna. A production quality tag was selected for the evaluation. Due to availability, the AD-220 manufactured by the Avery Denison Corporation was modeled in the HFSS. This is a general purpose RFID tag that was designed to be used on cartons. The antenna was printed on a substrate using silver ink. The tag's nominal operating frequency range was 902MHz to 928MHz. Figure 4 illustrates the AD-220 tag.

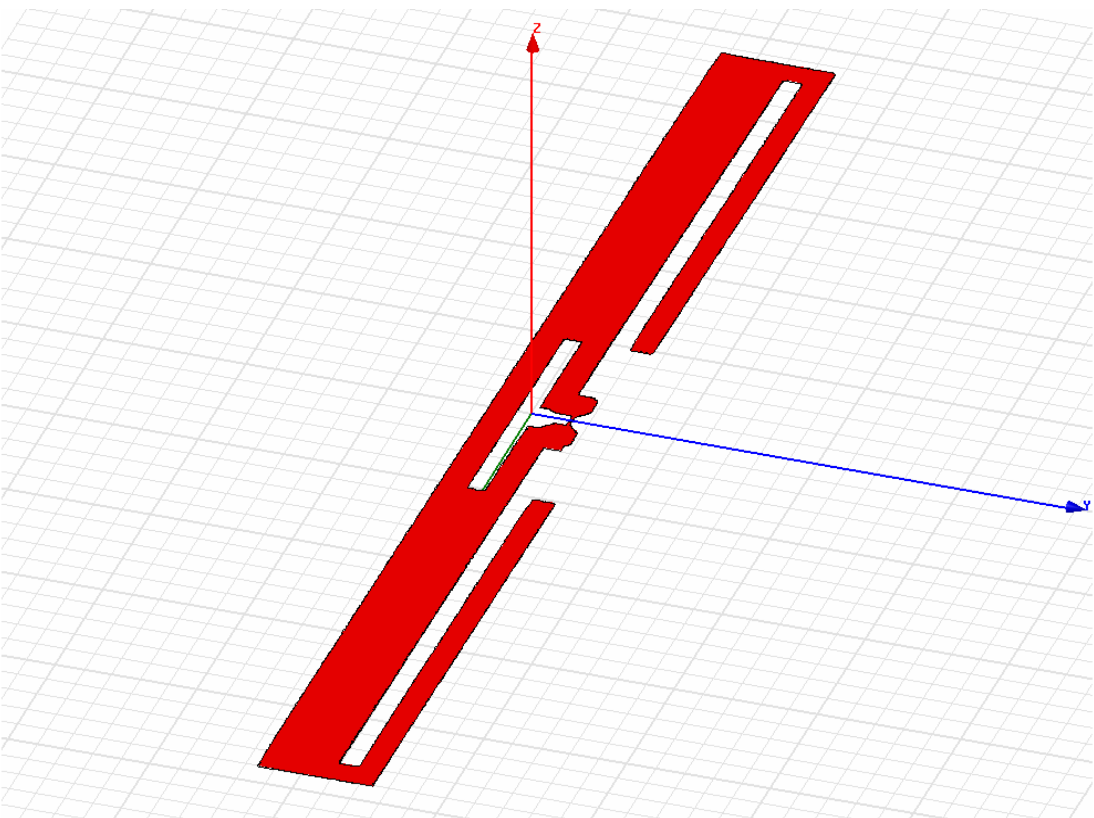

Figure 4: Avery Dennison AD-220

The three-dimensional simulation of the environment between the reader antenna and the transponder was simulated in HFSS and saved into the two-port block. With Designer/HFSS dynamic link, the system was simulated with three different loads: open, short and matched. The simulation model is shown in Figure 2. The model consists of the patch antenna (RF source) and the transponder antenna (tag). For the selected tag, a three-dimensional model of the antenna was designed in HFSS. The simulation was performed for the three different lumped elements (loads), which were inserted between the two input terminals of the tag's antenna. By applying the proposed method, the input impedance of the antenna was extracted from the simulation results.

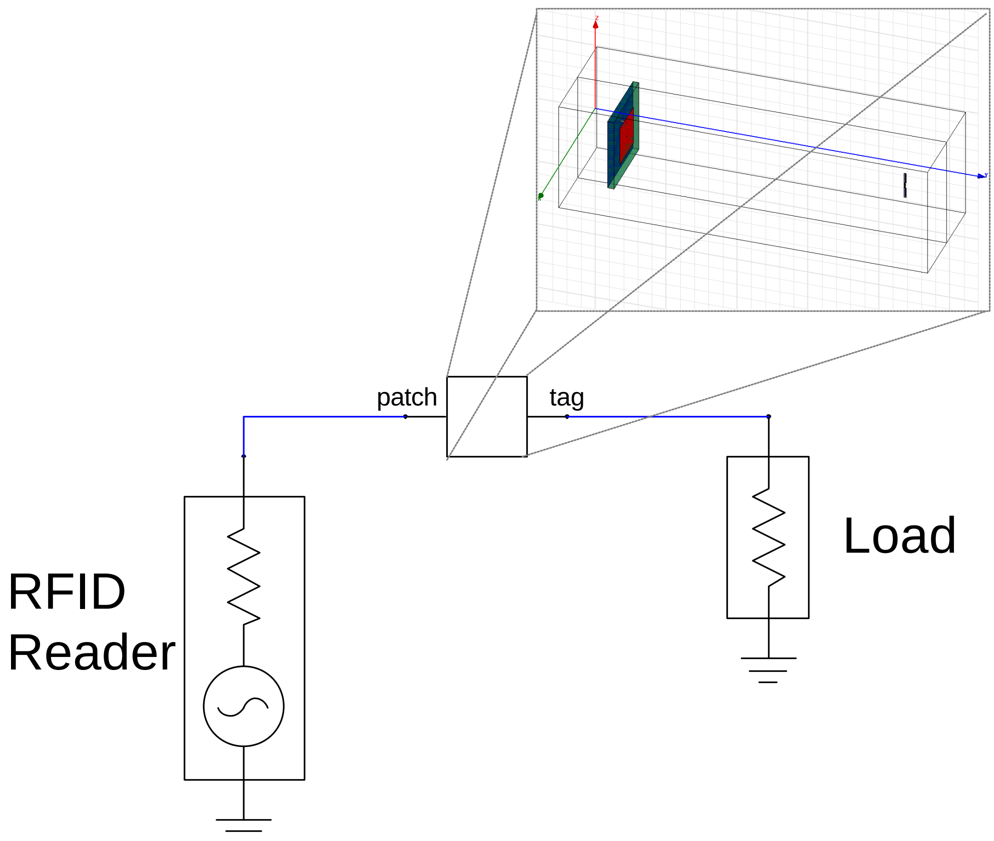

Figure 2: The model of the RFID system in Ansoft HFSS

IV. Measurement Methodology

The experimental testing of the same RFID tag as in simulations was carried out to confirm the validity of the measuring method. The measurement system consists of the computer controlled Vector Network Analyzer (VNA) connected to the Giga-Hertz Transverse Electromagnetic (GTEM) cell. The GTEM cell provided the controlled environment for accurate measurements. The GTEM cell has been successfully used in measuring the maximum read range of the RFID tags [2], where the results were in good agreement with the testing in the anechoic chamber.

The semi-automated system used a PC to control the VNA, which allowed data acquisition for a large number of tags as well as the required calculation in the real time. Based on the mathematical derivations, the software performed the data extraction and the calculations. All computations were performed on the collected data to extract the statistical data, which were interpolated to quantitatively measure the quality of the assembly and contact methods. Figure 3 illustrates the proposed model of the measurement system.

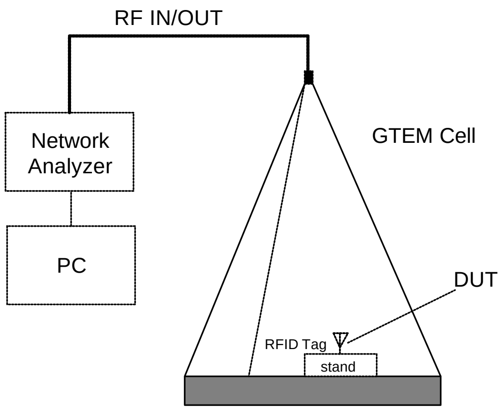

Figure 3: The simplified model of the measurement system

V. Results

The experimental measurements have been performed using 30, AD-220, tags that were randomly selected. Two additional, AD-220, tags were modified to provide open and short circuit results. The power level was maintained constant in order to eliminate any variation in input impedance of the IC chip due to the nonlinear behavior of the front-end circuitry. Table 1 contains the simulation and experimentally measured results for the input impedance of the tag antenna at 915MHz. The differences between the results can be attributed to the packaging of the tag, which are not included in the electromagnetic modeling of the tag antenna.

Table 1: The simulation and experimentally measured results

	Ansoft HFSS	**Averaged Measured**
$\mathbf{Z_{in}}$	3.05+j96.24 $(96.29\angle 88.18)$	3.87+j128.29 $(128.4\angle 88.25)$

VI. Summary

In this paper, an indirect technique for measuring the input impedance of the tag antenna on the basis of a two-port network is proposed. The validation of the measuring method is presented by providing the results from the simulation of the test system in the electromagnetic solver where any differences can be attributed to the packaging of the tags. Current research is being conducted to validate the influence of the antenna/chip packaging/mounting for both the inlay and the tag. This effort requires careful characterization of the tag materials and their incorporation into the HFSS simulation model.

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