Electrical Model Simulation for a UHF RFID System in near and far fields

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Abstract: **Radio Frequency IDentification (RFID) deployment is needed for efficient item identification. A simulation environment in HP-ADS (Advanced Design System of Agilent Technologies) of Ultra High Frequency RFID systems is constructed in this paper. This paper simulates the system through an electrical model. The tag is represented by a simple empirical model representing the antenna and the chip. The chip is modeled by its impedance which varies with the code. The tag's model is suitable for near and far field applications. A wireless channel with path loss and variable distance factors establishes the reader-tag link. The reader has a mono-static architecture. Performance of the whole system can be evaluated by changing the operating distance. Modeling improvement can be obtained by modifying the parameters of the building blocks. Finally, some simulation results are also included in this paper where data recovery is achieved.**

Keyword: RFID, Tag, Reader, channel, code, simulation, electrical model, supply chain.

I. INTRODUCTION

Radio Frequency IDentification (RFID) is used in numerous applications. Examples on these applications are supply chain management, security control, sensor systems, and tracking of high priority objects [Wei05]. Although RFID is a promising technology however, its implementation is not free of technological challenges. Researchers and industry are responding to these challenges. Important advances have been made in antennas design, modulation and demodulation systems, digital signal processing, and analogue to digital converters, and in the power management of RFID systems.

Simulations are essential as a verification tool. These numerical simulations verify the proof of concept, reduce overall cost, and shorten deployment time. In essence, the impact of environmental variables and operational limitations on the design can be investigated ahead of the actual implementation of the system. RFID systems are designed to operate in either the HF, UHF or microwave frequency ranges. Models for HF-RFID can easily be found in the literature. This paper is concerned with the simulation of a UHF-RFID system using a simplified electrical model. Simulation results were obtained by using the HP-ADS (Advanced Design System of Agilent Technologies) platform. This approach takes into account electromagnetic effects [Han06], [Li06]. The purpose of this model is to simulate a real life RFID system using standard electrical models and simplified mathematical representation. System blocks are easily modified to accommodate different applications and situations. This approach can model an RFID system or any one of its components.

The characteristics of the UHF-RFID are discussed in section 2. Then the electrical model for a varying reader to tag distance is introduced in section 3. Simulation results are found in section 4. Finally, a brief conclusion is included at the end of this paper.

II. UHF-RFID

A. The System

This paper models a UHF RFID system that follows the EPC-Class 1- Generation2 protocol. A typical basic system is illustrated in Figure 1 which includes a reader, a mono-static antenna, a communication channel, and a tag.

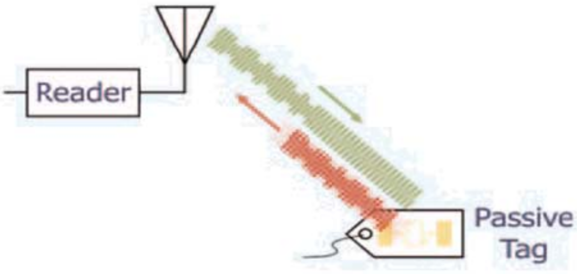

Figure 1: Overview of RFID systems

The reader interrogates a tag by transmitting a Continuous Wave (CW) in the 860-960 MHz frequency range. Typically, the tags consist of an antenna and a chip. Tags, which are physically placed upon each item, rectify the RF energy of the CW signal to create a small amount of power. This power is used by the tag to send the information stored on its chip (IC) back to the reader after modulating the RF signal with a load impedance modulation.

The chip impedance follows the digital variation of the stored code. The EPC-Class 1- Generation2 UHF-RFID standard defines an operational reader-tag distance between 0.5 and 9 meters in an industrial environment [EPC05]. This range implies that the reader should detect tags in the near and far fields of the reader's antenna. Path loss and fading statistics are two factors that need to be addressed.
A typical tag model is shown in Figure 2.

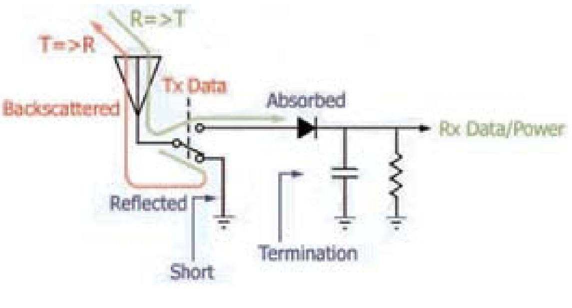

Figure 2: RFID tag

Readers can have a bi-static architecture with a transmitting and a receiving antenna [Bot08]. It can also have a mono-static architecture where the single antenna operates both in the transmitting and receiving modes. Handheld RFID readers are normally mono-static due to antenna size constraints. The detailed schematic of such system architecture is represented in Figure 3.

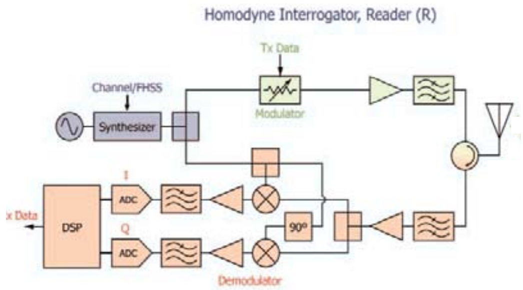

Figure 3: Mono-static RFID reader

A signal generator delivers a modulated signal to activate the tag then a CW signal is transmitted to the tag to interrogate it. The CW signal is split (before transmission) by a power divider into two parts: the first is amplified by a power amplifier, filtered and transmitted by the antenna to interrogate the tag. The second part (which is not transmitted) is used for the demodulation of the backscattered received signal after passing through a band-pass filter and a Low Noise Amplifier (LNA). The detection scheme is based on a direct IQ demodulator. After demodulation, the code undergoes low-pass filtering, analog to digital conversion, and digital signal processing. Thus, the data included in the tag code is recovered.

Isolators in the mono-static architecture are used to separate the transmission channel from the receiving one. The two most common choices of isolators are circulators [Rhe07] and directional couplers [Jun07]. The mono-static architecture suffers, as a result, from isolation leakage. A leakage power ratio of -25 dB may be achieved.
Thus, it is expected that the reader will process the backscattered signal in addition to a small portion of the transmitted signal.

The mono-static reader must simultaneously transmit the CW signal and receive the backscattered one, as it communicates with the tag. This fact need to be given a special attention during the design phase.

B. The Loading Effect

Load modulation and loading effect are based on the same physical phenomenon: the antenna current is modified by the load impedance. When the tag is located in the far field of the reader's antenna then, it is assumed that the load modulation is achieved by switching between two impedances which are code and frequency dependent. However, the far field model is not valid when the tag is in the near field. The far field model neglects the IC load and the impedance of the regulator. The voltage regulator has two functions namely, to control IC voltage and to attenuate the incident RF power. The resistance component limits the current in the tag, as the tag-reader distance is reduced, and thus prevents the failure of the communication system.
A discussion of this loading effect is found in [Mar09] and includes the impact of the impedance of the regulator and

the IC nominal power consumption as the separation distance is varied.

III. ELECTRICAL MODEL

Due to the importance of electromagnetic simulation and parameterization in the RFID design process as discussed in [Rut08]; this paper uses electric models to simulate all components of the system.

A. Near and Far Field Tag Model

Far field model: An easy way to model the electrical behavior of a tag is to use a Thevenin equivalent circuit for the tag antenna and connect this equivalent circuit in series with Z_{load}, the complex input impedance, of the chip. This equivalent model produced good results when used to study other aspects of the UHF RFID tag electrical behavior [Kar03], [Cur05], [Kho07].

The antenna impedance in Figure 4 is $Z_a = R_a + jX_a$. This impedance is placed in series with Z_{load} where Z_{load} is assumed to have two parallel components Z_1 and Z_2.

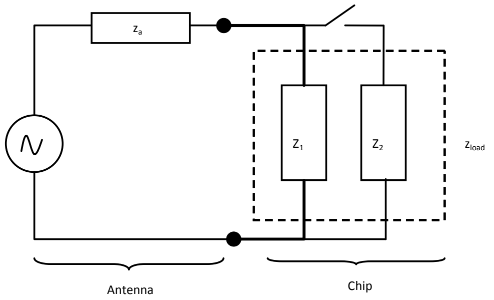

Figure 4: Equivalent Thevenin model of a passive tag when in the far field

The Z_{load} component Z_1 takes into account the input impedance of the major blocks of the RFID tag architecture [Der05] and has contributions from:

The tuning capacitors that match the chip to the antenna impedances.

The rectifier that generates the power voltage supply for the whole chip.

The demodulator that extracts the symbols embedded in the incident waveform.

The Power-on reset (*POR*) Circuit.

The logic and memory units for ISO/IEC answer compliance and cryptographic aspects.

The voltage regulator that maintains the power at a certain level and prevents the circuit from breaking down under large input RF power.

The Z_{load} other component $Z_2 = Z_{mod} = R_{mod} + jX_{mod}$ can be purely resistive ($X_{mod.} = 0$) or purely capacitive ($R_{mod.} = 0$) and that depends on which manufacturer model is used. The range of values of R_{mod} varies from few ohms to several hundreds of ohms. However if Z_{mod} was purely capacitive then its capacitance values may vary from tenths of fF to tens of pF.

Near field model: The equivalent load impedance when the tag is in the near field of the reader antenna is detailed in Figure 5. The components of this model are as follows:

R_w represents the dynamic behavior of the logic units and is supposed to be of high-impedance when no power is received.

R_{shunt} represents the behavior of the voltage regulator. Its value is a non linear function of the incident power. As the incident power varies with the separation distance between the tag and the reader, the value of the model R_{shunt} will also vary in a non linear fashion.

In other words, as the tag gets closer to the reader the received antenna power increases, and the antenna voltage increases as well. Therefore, R_{shunt} must decrease in order to limit the chip current but must not fall beneath the required chip minimum power level which for example is about 35μW for the UCODE HSL from NXP. The modeled R_{shunt} power law variation insures a constant power supply to the chip as the tag to reader operating distance varies.

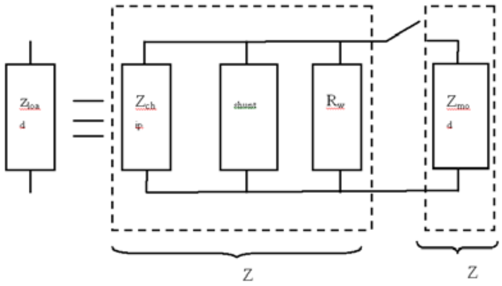

Figure 5: Detailed model of the impedance of the tag antenna when in the near field

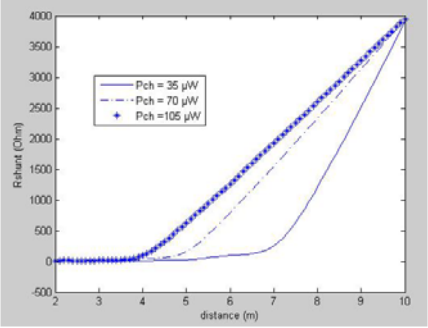

Figure 6: R_{shunt} variation versus the d for different chip power values

In [Col09], a relationship linking the chip power supplied to the values of R_{shunt} and the reader to tag distance "d" is presented. Using this expression and an interpolation function of MATLAB, a polynomial of order 15 models the variation of R_{shunt} with the reader to tag separation distance "d" as follows:

$$R_{\text{Shunt}} = \sum_{i=0}^{15} a_i d^{15-i} \qquad (1)$$

Figure 6 shows the R_{shunt} variation versus the distance d for different chip power values.

Tags model with HP-ADS: Figure 7 presents the electrical model of a tag functioning at 869 MHz. This scheme is simulated in the time-domain using the simulator "Envelope".

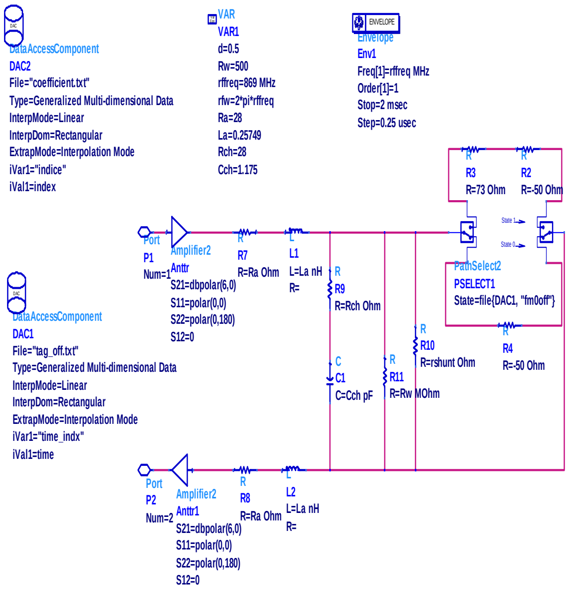

Figure 7: Electrical model of UHF- RFID tag

Based on [Par08] and on measurements made on tags in our laboratory, the measured data allowed us to model the tag antenna by an amplifier of gain 6 dB equal to the forward gain of the antenna, followed by a resistor of 73 Ω. In this model, the chip impedance was:

$$Z_{ch} = \left(28 - \frac{i}{1.175 * 10^{-12} w}\right)\Omega .$$

The logic unit impedance was $R_w=5*10^8\Omega$, the tag's antenna was characterized by an impedance $Z_a=(28+i*2.575*10^{-8}*w)\ \Omega$, a gain of 6 dB and a of length $\frac{\lambda}{2}$, where λ is the CW wavelength and w its angular frequency.

Based on measurements made on tags in our laboratory, the modulation impedance was found to be equivalent to a 73 Ω resistor for a bit "1" of the code, and to a short load for a bit "0".

A code following the form defined in the EPC - Class 1- Generation 2 is generated by a program written with MATLAB and loaded via the Data Access Component DAC1. This code commands the switch to select the suitable impedance, and modulate the received CW. HP-ADS normalizes all circuits by assuming a 50 Ω terminal resistance. Negative resistances are added to remove the effect of this terminal resistance. These negative resistances are simulated here by combining temporal and frequency simulations in the detection "Envelope" simulator.

The value of R_{shunt} is determined using (1). The coefficients a_i are calculated using a second MATLAB program and downloaded via the Data Access Component DAC2.

The tag model backscatters the RF modulated signal through its modeled antenna.

Reader to Tag Link's Model: in [Leo06], a wireless channel model for the reader-tag link includes a path loss and variable regional factor. It defines propagation effects as a function of the distance separating the reader from the tag. Although this model is highly ideal however, it is proved in [Leo05] that this model simulates fairly well a realistic channel for a large scale RFID deployment. This channel is modeled here as a switch. The switch selects one of the two parallel paths depending on the distance d between the reader and the tag. Each path has its own amplifier to model the specific attenuation as shown in Figure 8.

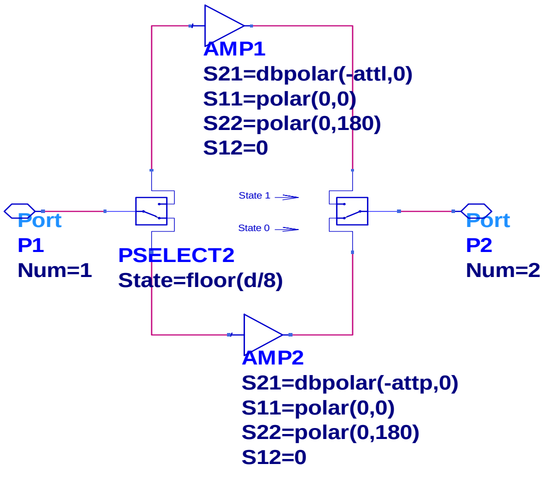

Figure 8: Propagation channel model

B. *Reader Model*

The reader antenna can be simply modeled by an amplifier having a gain equal to that of the antenna and a 50

Ω resistor, as presented in Figure 9.

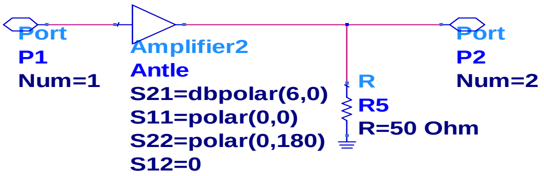

Figure 9: Reader antenna

Homodyne receiver (f_{LO}= f_{RF} = 869 MHz) is of simple architecture and widely used in RFID readers. Thus the RF received signal is directly detected by an IQ demodulator simulated by two mixers, connected to two local oscillators in quadrature of phase as shown in Figure 10.

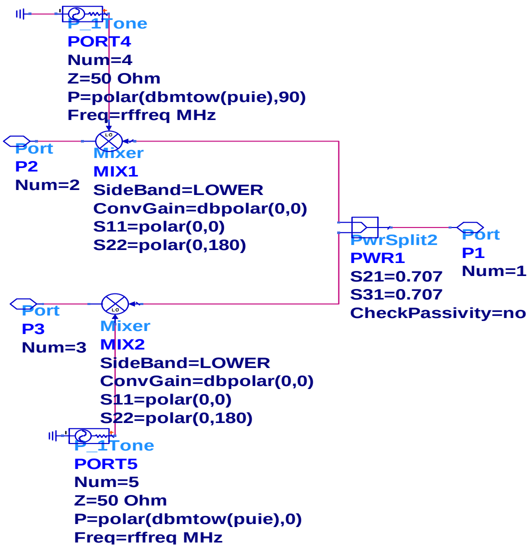

Figure 10: IQ demodulator

C. *UHF-RFID System Simulation*

Figure 11 presents the electrical model of an RFID system functioning at 869 MHz. This scheme is simulated in the time-domain using the simulator “Envelope”.

A generator delivers a CW signal at the RF frequency of 869MHz. A non ideal power divider characterized by no insertion loss and an isolation of 25 dB splits this signal into two parts: One signal will be transmitted by the reader antenna (Figure 9), via the propagation channel (Figure 8) and will be captured by the tag’s antenna (Figure 7). The second part is leaked back to the detection circuit.

The tag will modulate the received CW signal by its code and then backscatter the RF modulated signal to the reader, using the tag antenna.

The RF modulated signal is then received by the reader antenna after crossing the same propagation channel.

The tag model backscatters the RF modulated signal through its modeled antenna. After propagating through the channel model, the signal is then captured by the reader antenna.

The imperfect isolation of the power divider will impact the modeling of the mono-static reader. At reception, the leaked CW and the backscattered RF signal are added by the coupler with an insertion loss of 3 dB. The combined signal is detected by the IQ demodulator. The combiner’s insertion loss is compensated for by an amplifier of gain 3 dB.

The demodulator outputs I and Q represent the regenerated code that uniquely identifies the tag.

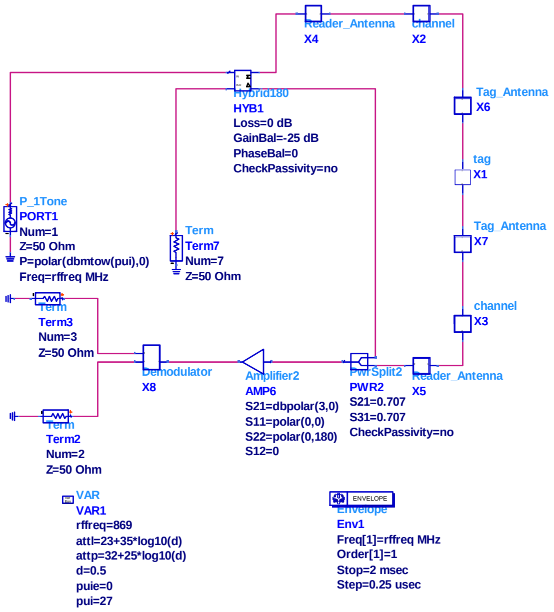

Figure 11: UHF-RFID simulated system

IV. SIMULATION RESULTS

A. Link Budget

The complete system was simulated with a transmitted CW power of 33dBm. The spectrum of the RF signal delivered by the tag is represented in Figure 12 with a carrier level of -10 dBm and a data power level of -33 dBm. The tag data has a bit rate of 40 KHz. It should be mentioned that HP-ADS normalizes the frequency axis to that of the carrier.

At reception, the spectrum is represented in Figure 13. The high power level of the carrier, due to the leaked signal, and the data attenuation due to the channel are both obvious.

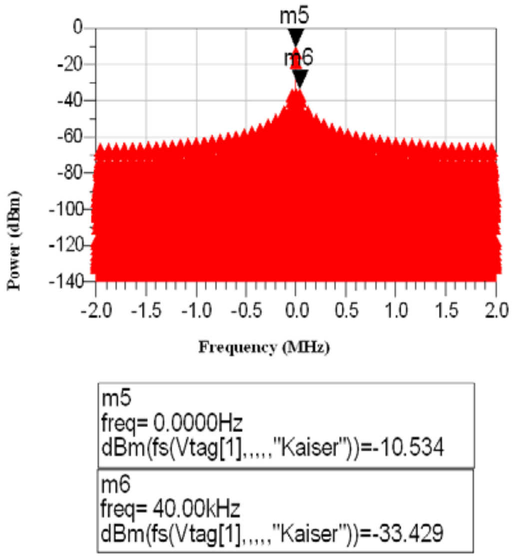

Figure 12: Spectrum delivered by the tag

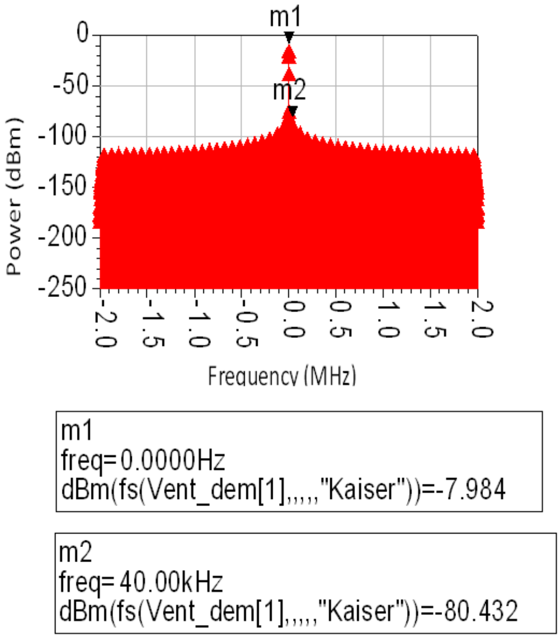

Figure 13: Spectrum at the receiver input

B. Code Recovery

By its nature, the load modulation produced by the tag is a Binary Phase Shift Keying modulation. Due to the propagation delay, the backscattered signal is phase shifted, which appears as an AM-PM modulation as presented by the constellation diagram in Figure 14.

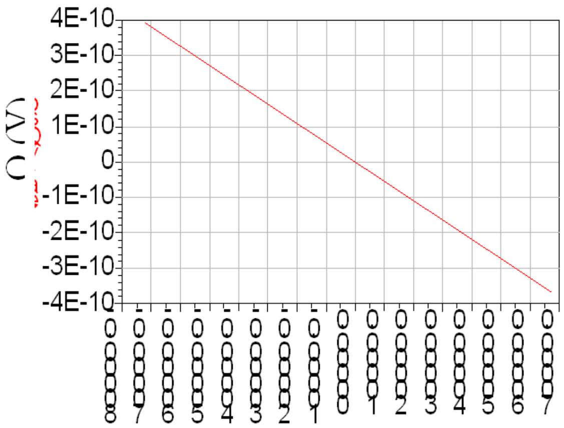

Figure 14: Data constellation diagram

In [EPC05], the tag's code has the form represented in Figure 15. For the purpose of this simulation, the tag code was assumed to contain the text shown in Figure 16. Table 1 show that the simulated RFID system recovered the tag's code for distances less than 10 m. For greater distances, the signal is highly attenuated and the code data is not recovered.

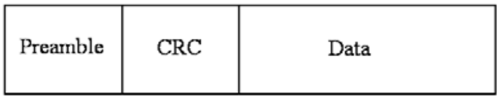

Figure 15: Tag data form

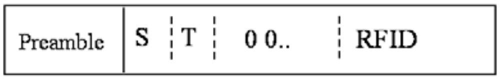

Figure 16: Simulated tag's code

Table 1: Code recovery as function of distance

Distance (in m)	Code
0.5	ST RFID
5	ST RFID
10	YY0 0 0 0 0 0 0 0 0 0 YYYY

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V. CONCLUSION

This paper presented an electrical modeling simulation of a UHF RFID system. Starting from published models for the system components, a design procedure was established which constitutes a basis for an electric and/or electromagnetic modeling of RFID systems. This procedure has the advantage of being modularly based which facilitates the improvement or modification of model blocks. In [Cha09], the tag's model was simplified. It is improved by taking care of the actual incident RF radiation on the tag by introducing variable simulation resistances whose values were empirically determined [Col09]. The tag data was successfully recovered for reader-tag separation distances between 0.5 and 9 meters.

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