A Study of RFID Devices and Efficient Ways of Simulating RFID Systems with Maxwell Software

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Abstract: RFID area of applications is currently undergoing constant change in regard of standardization. As any other frequency allocation issue, RFID applications are generally governed by government legislation and as such it may differ in some countries. Standardization activities are seeking to create a more uniform environment in this respect. The most significant carrier frequencies for RFID applications that have been identified to cover low, medium and high ranges are 125 KHz, 13.56 MHz and 2.45 GHz. This paper deals with low and medium RFID applications which appear to enjoy a considerable degree of uniformity of standards and acceptance worldwide.

1. Introduction

The heart of an RFID system consists in an emitting antenna (reader) and a tag antenna. The data transmission between the two antennas is based on inductive coupling: the reader antenna generates a magnetic field which couples with the antenna on the tag. The vast majority of 125 KHz and 13.56 MHz RFID systems operate as passive devices. This means that the energy needed for the tag to respond to the reader is supplied by the reader energy. The response of the tag is done by changing the load of the field in terms of amplitude and/or phase of the signal.

Such inductive RFID operate in the "near field" of the reader antenna so that no electromagnetic wave propagation effects are part of the data transmission process. This is why we use the "antenna" term in a loose sense when it comes to inductively coupled circuits. The near field character of the coupling has as a direct effect on the effective distance between such circuits that still allows data flow with specified baud rates and accuracy. As such, as a rule, such effective distances are of the order of the characteristic dimension of the reader antenna. For coupling to longer distances one needs to remember that the field strength decreases with the third power of distance and, as a consequence, the power needed to make communication possible must therefore increase with the sixth power of distance. This sets limits to the "performance" of such devices. The performance is in fact defined for each particular application such that and RFID system must by fit for purpose.

Low and medium frequency device operate as a rule as passive devices, taking the energy needed to communicate from the emitting antenna. Active devices (mostly high frequency RFIDs) usually have a battery that can give an autonomy of around 10 years.

Passive devices have as a rule lower signal-to-noise characteristics (since they have to use incoming energy) but they have a long life and do not need maintenance. As a result they're also cheaper than active devices.

RFID systems antennas come in different shapes, however the vast majority are built using rectangular or circular shapes and have a relatively low number of turns, between 4 and 10. The RFID systems themselves can achieve high levels of complexity having incorporated memory, data processing capabilities that include communication encryption and protocols.

2. 13.56 MHz RFID simulation

13.56 MHz RFIDs are likely the most significant application in terms of number of such devices already manufactured and used in applications. Fig. 1 below shows a typical geometry for a 13.56 MHz RFID.

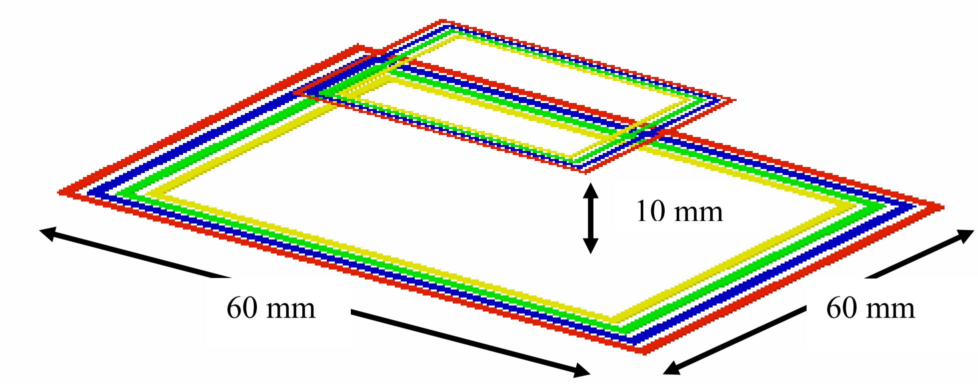


Fig. 1 RFID reader and tag geometry

The material considered for this example is copper but many RFID antennas also use aluminum.

The modeling approach we take here is to extract from the 3D field solution the electromagnetic essence which is the inductance and capacitance matrices as well as the resistance of the antenna loops. One aspect one has to bear in mind is the influence of the distributed nature of the respective parameters. As a consequence, each turn of the system is modeled individually and accounts in the global system for its own contribution. This makes it possible to take into account effects such as capacitive coupling between turns with benefic influence on the overall accuracy of the system level simulation. Indeed, modeling the capacitive coupling only between the two antennas as a whole may not be accurate enough for some applications.

The main modeling steps for the RFID application is to compute the distributed inductance matrix, capacitance matrix and the resistance of the loops. Additionally the stray capacitance of the reader antenna is also necessary for the calculation of another quantity, the self resonance of the antenna. For the reader antenna shown above (the larger coil in Fig. 1) Maxwell 3D Field Simulator computed a stray capacitance of 2.82 pF. This is simply obtained following an electrostatic simulation of the model that contains the reader antenna only. The inductance of the reader antenna simulation yielded a value of 1.85 µH. Thus, the self resonant frequency can be calculated with:

$$f = \frac{1}{2\pi\sqrt{L \cdot C}} = 69.9\ MHz$$

Maxwell 3D Field Simulator has the capability to export the distributed inductance matrix of the two antennas. There is a choice of the format of the exported matrix: the user can choose between Maxwell Spice format or Simplorer formats. Figure 2 shows the respective export panel. Since the antennas have 4 turns each, this results in a 8 by 8 inductance matrix. The diagonal terms of the inductance matrix represent the self inductance of each individual turn while the non-diagonal terms represent the respective mutual inductances.

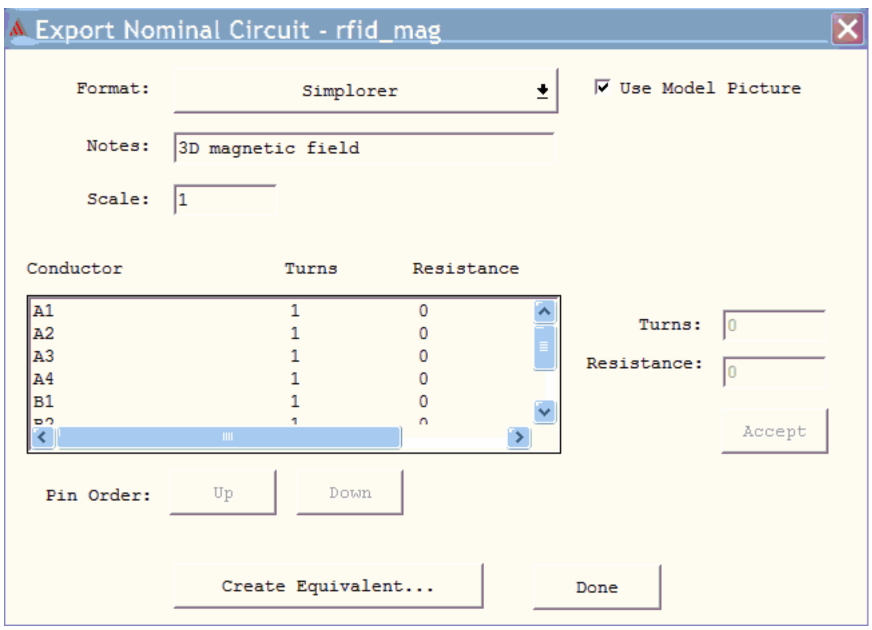


Fig. 2 Matrix export panel

A similar procedure is followed to export the capacitance matrix. This matrix brings a new dimension to the global model since the inter-turn capacitance is important for the accuracy of the system level simulation of the two inductively coupled antennas. It should be noted that another capacitor is built in and together with the antenna coil is tuned to provide the desired oscillating frequency of 13.56 MHz. The field simulation of that capacitor is a trivial aspect and will not be discussed here.

Another important factor in the simulation is the resistance of each antenna. One reason for this is the calculation of the quality factor of the antennas. Fig. 3 shows the distribution of the currents in the traces at 13.56 MHz. Strong skin and proximity effects can be clearly seen.

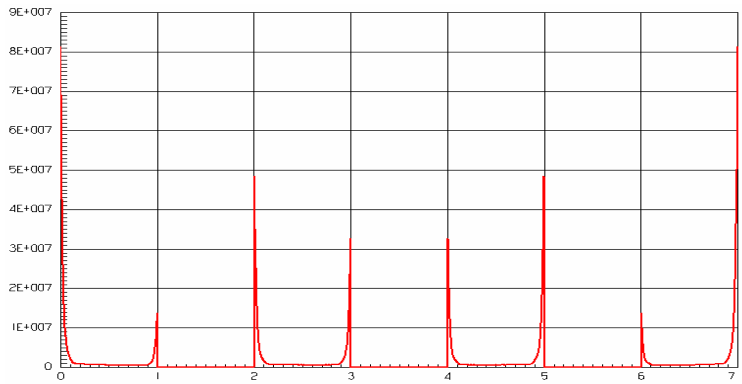


Fig. 3 Current distribution in the traces

The final step in the simulation of the system of the two antennas is bringing all the elements together in a circuit simulation. Fig. 4 shows a Simplorer model containing the exported matrices connected together with driving source.

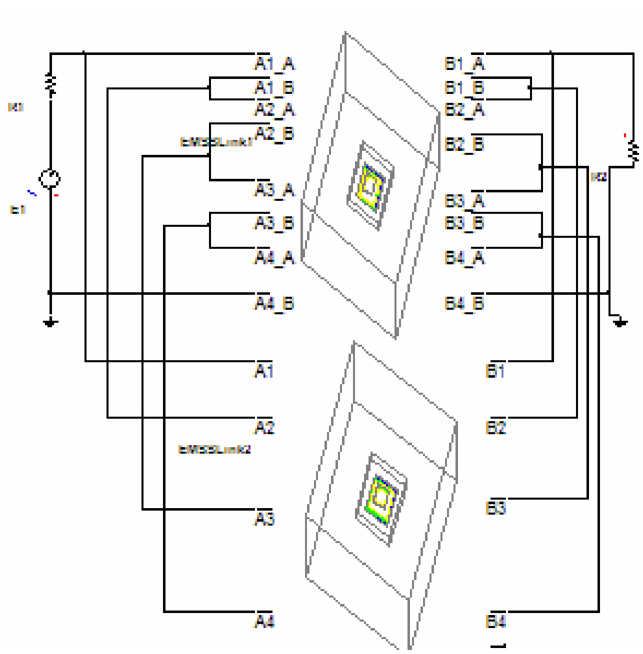
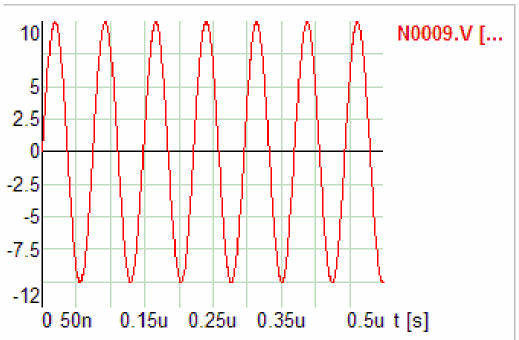


Fig. 4 Circuit model of the two antennas in Simplorer

The results of the simulation are shown in Fig. 5, the input signal is a 10 V 13.56 MHz voltage, the output signal has a magnitude of about 0.9 V for the tag placed at 10 mm above the reader.



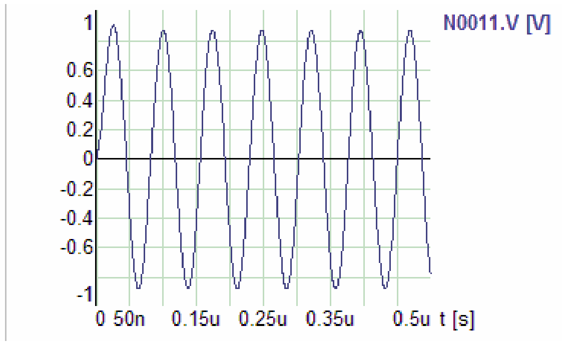


Fig. 5 Input and output signals after the circuit simulation

The above results reflect the simulation of the system for a given relative position between the reader and the tag antennas. Parametric simulations can also be performed, each with the possibility of exporting the respective matrices. Therefore a high degree of automation of all aspects of the simulation of this RFID application can be achieved. Fig. 6 shows for example the variation of different mutual inductances as a function of distance. It should be noted that automatic mesh adaptive process available in Maxwell is a key factor in achieving the desired accuracy of the simulation for various relative positions between the antennas.

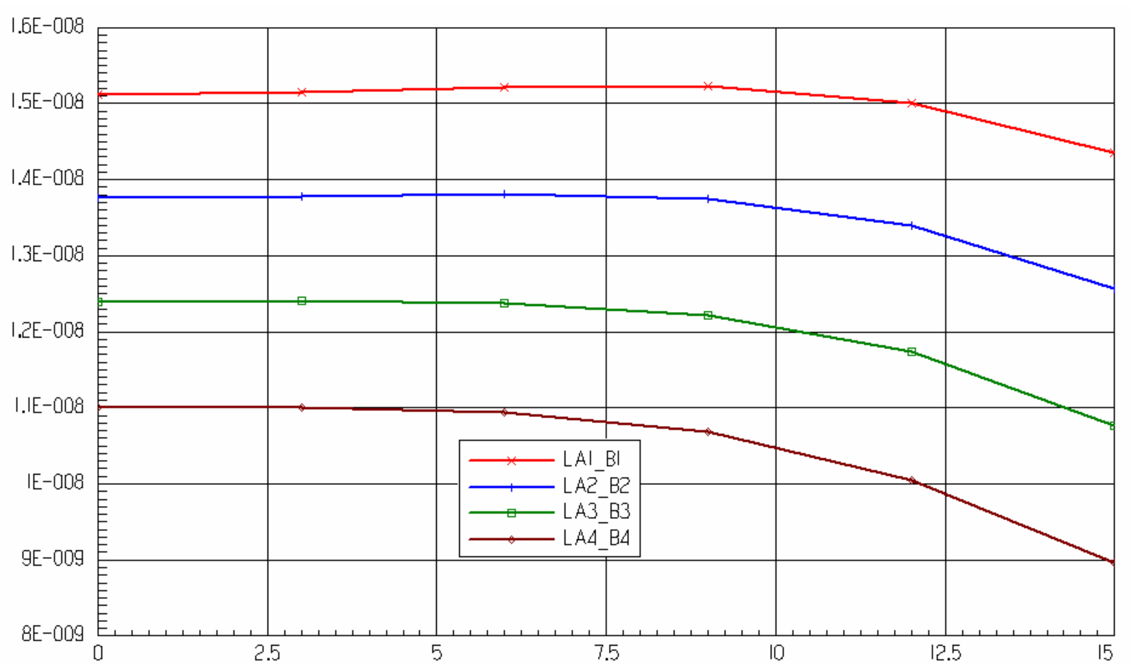


Fig. 6 Mutual inductance variation between various turns of the reader and tag coils for different relative positions between the two antennas

Fig 7 depicts the decrease of the magnetic field magnitude outside the reader loops along a line in the plane of the loops.

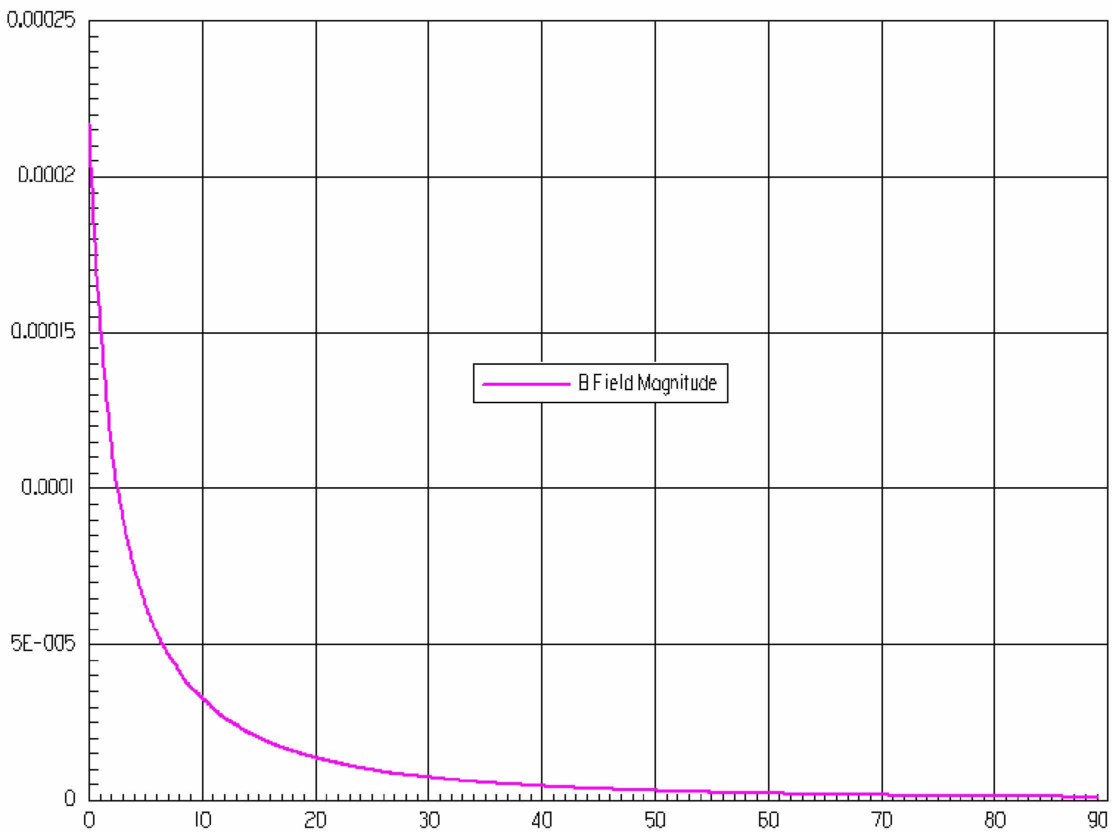


Fig. 7 Variation of the B field away from the reader antenna

3. Conclusion

This paper presents the essence of a very efficient and accurate procedure to simulate RFID low and medium RFID applications where the transmission of energy between antennas occurs through inductive magnetic field coupling. We note here excellent match between the simulation with Maxwell software and measurements performed by customers. The circuit simulation -once the equivalent circuits with field effects have been obtained- offers a number of advantages. Since these RFID antennas can be imbedded in complex systems, the system level simulation with high level of accuracy is possible at circuit level. The low and medium frequency RFID devices can be very efficiently modeled with Ansoft software tools and represent a good example of the usefulness of combined field and circuit level analysis.

It should be noted that at high frequencies where propagation effects cannot be ignored, a full field solution using a high frequency simulator becomes necessary.