

# Analysis of a Square Parasitic Antenna by Using Lumped Elements

Abdelhak Ferchichi, Med Karim Azizi, and Gharsallah Ali

**Abstract**—In This paper, a novel approach to design a parasitic antenna for an RFID application. This approach is based on using a parasite square patch near to a square patch. The square antenna is simulated by using HFSS and ADS and the proposed parasitic antenna is developed by using Lumped elements. This antenna can be integrated in an RFID TAG by using the electrical model of both antenna and IC. The size of antenna is 31mm\*31mm\*8.5mm.

**Keywords**—RFID TAG, parasitic antenna, Lumped element.

## I. INTRODUCTION

RECENTLY the Radio Frequency identifications (RFID) systems is used in many applications such us Industry, Education, Transport, and Medicine, [1]–[4]. Besides of the use of RFID systems, many other systems can be used in the same time or space with those systems. For this reason, it will be very important to integrate many systems in the same terminal. One of the essential components in RFID systems is the antenna, that's why, antenna design become very critical and very important in the performance of all the systems. Many solutions were used in order to satisfy some details like proposing a miniaturized antenna for the TAG by applying some techniques like fractal antenna, replied dipole, minder lines, [2], [5] besides many others works proposed antennas for the Reader with high Gain or directivity by applying techniques likes array antenna, metamaterial antennas, [6], [7], CPW antenna [8]. Later, thinking about multi frequency, wide band and ultra wide band antenna becomes very useful for both TAG and Reader. One way to obtain the desired antenna is the introducing of a parasitic element near the original patch, [9].

One major problem is the absence of analytic equation to control the resonant frequency and to determine the geometric dimensions to the parasitic antenna. For this reason, the electrical model can be considered as a solution to this problem. This tool consists of replacing the antenna by an electrical model composed by Lumped element. After building the electrical model we can control all antenna parameters very easily and the simulation time will be reduced to seconds.

We develop in this work, a design of a parasitic antenna for an RFID system. In the first section, we described the building of an electrical model to a square patch which resonates on an RFID frequency which is 2.45 GHz; we have also compared the simulation results obtained by ADS, HFSS and the electrical model. In the second Section, we developed our

parasitic square antenna by adding a parasite element near the active square element. In the third section, we present the different simulations results and we conclude with a parametric discussion of the proposed solution. In the last section we conclude our work and we propose some perspectives.

## II. THE ELECTRICAL MODEL OF A SQUARE ANTENNA

### A. Utility of the Electrical Model

In order to design antenna structures, many techniques are developed. Those techniques use numerical methods based on resolving electromagnetic equations in different form. For this reason, much software was used like ADS simulator, HFSS simulator, and IE3D simulator. Those entire Simulators give their results by resolving electromagnetic equations in their integral or differential forms. But those techniques have some limitation. First, we cannot take the calculation of all kinds of losses. Besides after simulating the structures, we have not the possibility to control antenna parameters like return loss, input impedance when modifying geometry of antenna, nature of substrate. That is why, replacing an antenna by an equivalent circuit will be very important in parametric analyzing of the proposed structure. In this way, the model techniques have a great interest. One of those solutions is modeling an antenna by an electrical model. Besides, to develop an effective simulation tool for RFID antennas, we have considered using an appropriate method. Indeed, what we seek is a simple, effective, fast and can integrate our antenna with other components. In our work methodology, we set a goal of proposing new structures that meet the needs of RFID systems: miniaturized antennas for TAG and high gain antennas for readers.

It is by means of amendments made to the geometry of the patch, the nature and position of the source, and the integration of other elements that goal has been reached. The important parameters that we control every time are the resonant frequency and impedance. We seek that the chip can be identified by the reader at the resonant frequency (operating frequency) and are adapted with the antenna in the tag itself. The requested tool should allow us to control the resonant frequency of a quick and simple based on changes in the structure itself. This modeling tool can replace the patch studied by a new model. This is controlled by certain parameters such as: the geometry of the patch (patch size, shape), the characteristics of the materials used (permittivity, height, thickness of the substrate and the characteristics of the metal thickness and losses), the nature and the position of the excitation and the set of all losses.

To achieve this goal, several existing tools can be used which include, modeling neural networks, modeling using

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genetic algorithms, modeling using the model of transmission lines (known by the term: Transmission Line Model TLM) and electrical modeling.

Each tool has advantages and disadvantages. The first three tools are useful in the case of the patch of definite form. But the disadvantage of these techniques is that once the model is constructed it will be very difficult to control it with any change in the shape of the antenna and the type of excitation. The electrical modeling provides a simple analysis of the antenna to be useful later when making modifications to the patch level, [10]. This technique uses the model of cavity antenna. It is to characterize the impedance of the antenna electrical parameters through: R, L and C. These parameters will be determined based on the geometric parameters of antennas and antenna environment: substrate, losses, radiation, [11]. The antenna is replaced by a block RCL resonant. These parameters are called respectively: resonance resistance R, capacity C total and total inductance L.

### B. The Electrical Model of the Square Patch Antenna

The proposed square patch is a single layer resonant element which is characterized by its geometric shape, dimensions and the nature of the dielectric substrate. The structure is presented in the Fig. 1 which consists of a planar antenna deposited on a dielectric height h and permittivity. The substrate we used is FR4 epoxy with a permittivity  $\epsilon_r = 4.4$  and height  $h = 1.6\text{mm}$ . The structure is shown in Fig. 1.

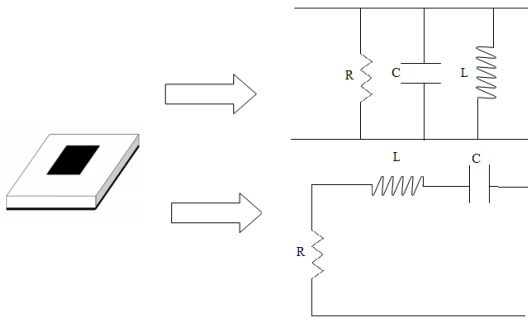


Fig. 1. Electrical model of a square patch antenna.

This antenna can be modeled as an RLC resonant at the same frequency of the antenna studied. RLC parameters are calculated based on the geometric parameters of the antenna and the characteristics of the dielectric, [12]. There are two possible configurations: series and parallel (Fig. 1).

We have chosen the parallel configuration; the parameters of the proposed model are calculated from the formula of input impedance:

$$Z_{in} = R + jX$$

$$Z_{in} = \frac{R}{1 + Q_T^2 \left[ \frac{f}{f_r} - \frac{f_r}{f} \right]^2} + j \left[ X_L - \frac{RQ_T \left[ \frac{f}{f_r} - \frac{f_r}{f} \right]}{1 + Q_T^2 \left[ \frac{f}{f_r} - \frac{f_r}{f} \right]^2} \right],$$

where  $Q_T$  is the factor quality of the antenna,  $f_r$  is the resonant frequency,  $X_L$  is the reactance of the coaxial cable, R is

the resonant resistance, all the parameters are developed in previous works, [13]. We can calculate those parameters using the equation below:

- The resonant resistance: it can be calculated using the equation below:

$$R = \frac{Q_T H}{\pi f_r \epsilon_{dyn} \epsilon_0 A} \cos^2 \left( \frac{\pi x_0}{a} \right),$$

where:

$Q_T$  is the Quality factor

$f_r$  is the resonant frequency

$\epsilon_{dyn}$  is the dynamic permittivity

$A$  is the air of the square patch

$a$  is the length of the edge

$x_0$  is the distance between the feed point and the edge of the patch

- The capacitance: it is calculated using the equation below:

$$C_{dyn}(\epsilon) = \frac{\epsilon_0 \epsilon_r A}{H \gamma_n \gamma_m} + \frac{1}{2 \gamma_n} \left( \frac{\epsilon_{reff}(\epsilon_r, H, a)}{c_0 Z(\epsilon_r = 1, H, a)} - \frac{\epsilon_0 \epsilon_r A}{H} \right)$$

- The inductance L: it is calculated in order to verify the equation below:

$$L = \frac{1}{(2\pi f_r)^2 C_{dyn}}$$

### C. Simulation Results

The simulation of the patch using HFSS, ADS and the proposed model gave us the results in Fig. 2. First, we notice that there's a good agreement between the results with a slight difference in terms of bandwidth. On the other hand, in terms of time of simulation, the electric instant response while the same model takes a few minutes by using the HFSS or ADS, which is a very important advantage.

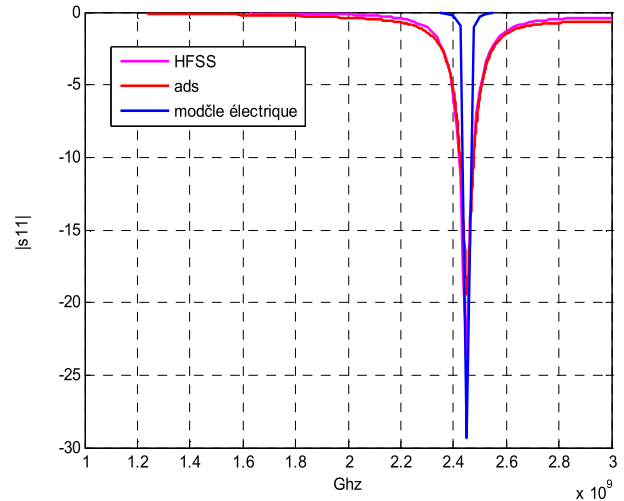


Fig. 2. Model validation for electrical square patch.

As we can see in the table below, we can compare easily the results obtained by the three tools: HFSS, ADS and Electric model (Table 1).

TABLE I  
COMPARISON OF SIMULATION RESULTS

	HFSS	ADS	Electrical model
Resonant frequency (GHz)	2.45	2.45	2.45
Band Width (MHz)	50	50	50
S11	-23.5	-19.3	-29.5
Simulation Time (s)	240	94	0.14

### III. THE PROPOSED PARASITIC ANTENNA

The bandwidth of an antenna is an important parameter for some systems. In order to enhance band width, various methods can be applied such as utilization of additive stubs, using antennas array, and adding radiating elements. In our case, we chose to use the parasitic antenna technology to expand the bandwidth of the structure of the square patch.

#### A. The Proposed Design

The parasitic antennas have multilayer geometries. The proposed structure was built from the design described in the previous section. Indeed, we place a parasitic element patch close to our square patch. We used the same type of substrate as the first structure. We also determined the dimensions of the parasitic element to resonate at a frequency slightly higher to 2.45 GHz. The proposed structure presents a size of 31mm\*31mm\*8.5mm (Fig. 3).

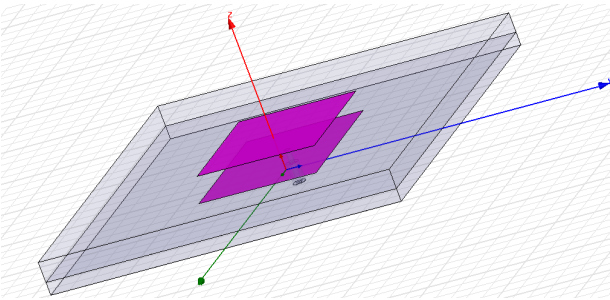


Fig. 3. The parasitic antenna.

#### B. The Electrical Model of Parasitic Antenna

In order to find the model of the parasitic antenna, we applied the same technique as a multilayer's antenna. And then, we calculate the different parameters with taking on consideration of all the physical significations. The electrical model is presented in Fig. 4.

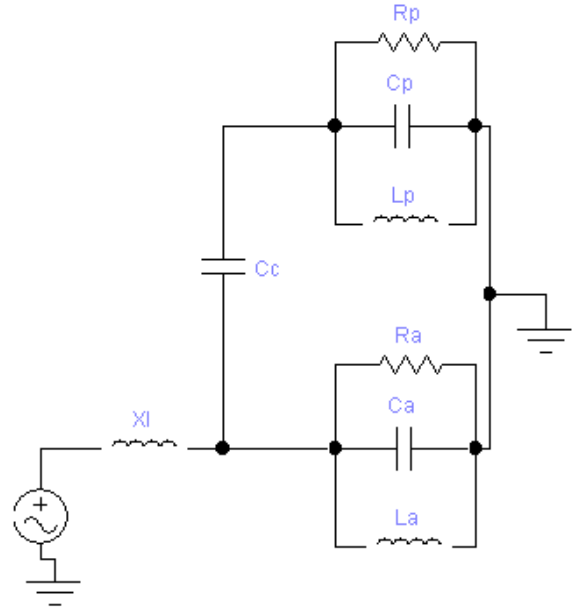


Fig. 4. The electrical model of new antenna.

The proposed model is constructed by applying a simple technique where we replace each part of the structure by its model. The method can be described by three steps:

- The square patch was replaced by electric model where the parameters are determined using the equations developed.
- The parasitic patch is modeled while considering the square patch as a virtual ground plane. The parameters  $R_p$ ,  $L_p$  and  $C_c$  are calculated using the same equations of the active patch.
- The capacitances  $C_c$  replace all the coupling capacitance between the two square elements and the ground plane, it can be calculated by the equation 1, [14]:

$$C_c = \frac{\epsilon_0 \epsilon_r}{\pi} \ln \coth \left( \frac{\pi S}{4h} \right) + 0.65 C_f \left\{ \frac{0.02}{S/h} \sqrt{\epsilon_r} + \left( 1 - \frac{1}{\epsilon_r^2} \right) \right\}, \quad (1)$$

where:

$S$  is the distance between the active antenna and the parasitic element;

$C_f$  is the capacitance of fringe and it can be calculated using the equation 2:

$$C_f = 2C_{f1}, \quad (2)$$

where  $C_{f1}$  is the dynamic capacity of the side of the square patch, equation 3:

$$C_{f1} = \frac{1}{L} \int_0^L C_{elstat}(\epsilon) \cos^2 \left( \frac{n\pi x}{L} \right) dx = \frac{1}{\gamma_n} C_{elstat}(\epsilon). \quad (3)$$

With  $C_{elstat}$  is the static capacitance of the same side and it

can be calculated by the equation 4:

$$C_{elstat}(\varepsilon) = \left[ \frac{Z(W, H, \varepsilon_r = 1)}{cZ^2(W, H, \varepsilon_r)} - \frac{\varepsilon_0 \varepsilon_r W}{H} \right] L. \quad (4)$$

### C. Simulation Results

In the Fig. 5, one can notice that there is good agreement between results obtained either by using the HFSS or the electric model with a slight difference in bandwidth.

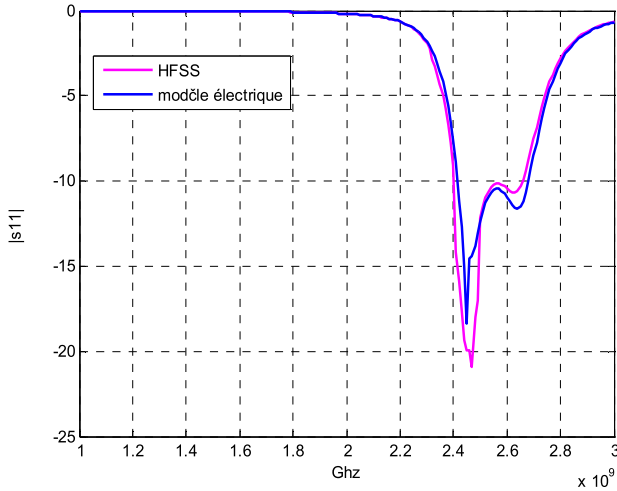


Fig. 5. Simulation results of SRR antenna and the electrical model.

As can be seen in the figure above, the structure presents a large bandwidth when we compare with the square patch. Besides, the electrical model gives the same results and with a simulation time very reduced.

Given the specificity of the electric model built and its speed, it was important to control the bandwidth of this structure based on the parameters of the proposed model. Our study showed that the variation of the coupling capacitance  $C_c$  modifies the BP. Indeed,  $C_c$  basically depends on the area occupied by the two metal blocks, the permittivity of the substrate between them and the distance between them.

The simulation of the electrical model based on the value of  $C_c$  gave us the following results (Fig. 6).

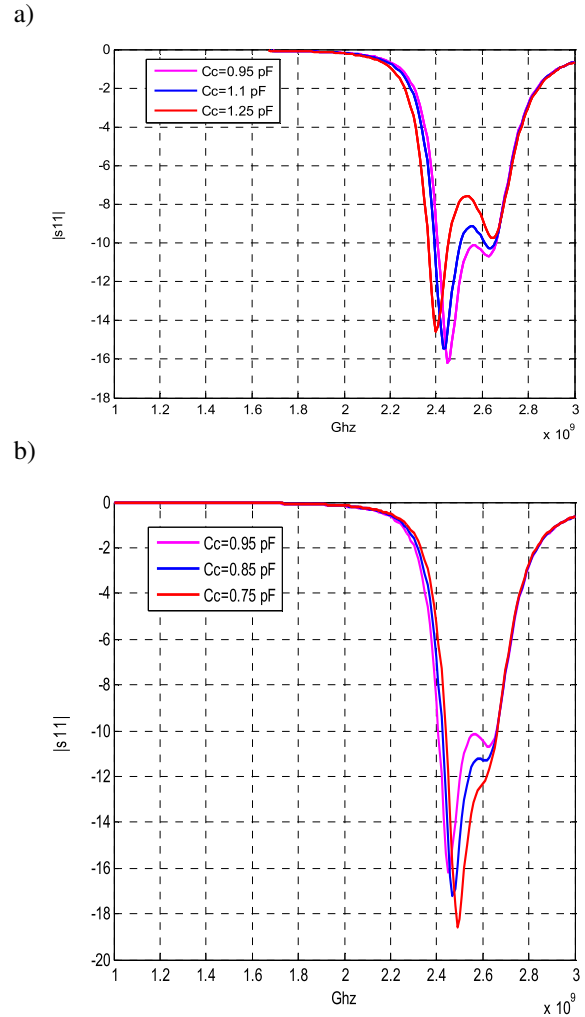


Fig. 6. Change in BW from the parasitic antenna according to  $C_c$ : a) When increasing  $C_c$ ; b) when decreasing  $C_c$ .

As can be seen, in the figure above, the enlargement of the bandwidth is obtained depending on the value of  $C_c$ . Thus, for a capacitance value less than or equal to  $C_c$  0.95 pF,  $|S_{11}|$  is less than -10dB and there is an increase of the bandwidth that is of the order of 200MHz.

Finally, Due to the accuracy of the model built and the reduced simulation time, it was important to control the bandwidth BW of this structure based by analyzing the proposed model.

## IV. CONCLUSION

The antennas have properties and characteristics by which they are valued. These characteristics vary from one application to another. The choice of a design method of an antenna is defined according to the requirements set by the application. Thus, each method is effective in cases of well-defined. In our application, we chose to electrical modeling tool for analyzing parasitic antenna structures referred to applications of RFID. This tool offers certain advantages. First, this tools help as to simulate the structures in a simple, fast and efficient ways. Secondly, once the model is built, we can track changes in the parameters of antennas based on changes in the geometry of the antenna, the position and the nature of the excitation. Third,

we can determine the geometric parameters of the parasitic antenna. Finally, we can integrate so easy antenna structures in RFID systems.

These benefits will be very important in the case of our study. Indeed, in our future works, we will propose new antenna structures for TAG and RFID Readers. All these structures will be analyzed by means of electrical modeling.

#### REFERENCES

- [1] K. Finkenzeller, *RFID Handbook*, 2nd ed. Munich, Germany: Giesecke & Devrient GmbH, 2003.
- [2] A. Galehdar, D. V. Thiel, and S. G. O'Keefe, "Antenna Efficiency Calculations for Electrically Small, RFID Antennas," *IEEE Antenna Wireless Propagation Letters*, vol. 6, pp. 156–159, 2007.
- [3] S.-L. S. Yang and K.-M. Luk, "Design of a Wide-band L-probe patch antenna for pattern reconfiguration or diversity applications," *IEEE Transactions on Antennas and Propagation*, vol. 54, no. 2, 2006.
- [4] J. Agbinya et al., "Mapping and recognition of Radio Frequency Culter in Various Environments in Australia," *International Journal of Electronics and Telecommunication*, vol. 56, no. 2, pp. 137–144, June 2010.
- [5] S. .Tedjini, T. P. Vuong, and V. Beroulle, "Antennas for RFID tags," in *Joint sOc-EUSAI conference*, Grenoble, France, October 2005.
- [6] F. Elek et al., "A Uni-Directional Ring-Slot Antenna Achieved by Using an Electromagnetic Band-Gap Surface," *IEEE Transactions On Antennas And Propagation*, vol. 53, no. 1, January 2005.
- [7] C. Balanis, *Antenna Theory, Analysis and Design*, 2nd ed. John Wiley & Sons, 1997.
- [8] M. H. Varkiani et al., "Design of an Ultrawideband CPW-Fed monopole Antenna With a Band- Notch Function," *International Journal of Electronics and Telecommunication*, vol. 57, no. 1, pp. 109–113, March 2011.
- [9] R. T. Long, R. J. Dorris, S. A. Long, M. A. Khayat, and J. T. Williams, "Use of parasitic strip to produce circular polarisation and increased bandwidth for cylindrical dielectric resonator antenna," *Electronics Letters*, vol. 37, no. 7, pp. 406–408, 2001.
- [10] J. Anguera, E. Martnez, C. Puente, C. Borja, and J. Soler, "Broad-Band Dual-Frequency Microstrip Patch Antenna With Modified Sierpinski Fractal Geometry," *IEEE Transaction On Antennas And Propagation*, vol. 52, no. 1, January 2004.
- [11] N. Kumprasert and W. Kiranon, "Simple and Accurate Formula for the Resonant Frequency of the Circular Microstrip Disk Antenna," *IEEE Transaction On Antenna AND Propagation*, vol. 43, no. 11, November 1995.
- [12] A. Ferchichi, N. Fadlallah, N. Sboui, and A. Gharsallah, "Analysis and design of Printed Fractal Antenna by Using an Adequate Electrical Model," *International Journal of Communication Networks and Information Security*, vol. 1, no. 3, December 2009.
- [13] A. Ferchichi, N. Sboui, and A. Gharsallah, "An Electrical Model to Sierpinski Gasket Patch Antenna," in *The Fifth Advanced International Conference on Telecommunications*, Venice/Mestre , Italy, Mai 2009, pp. 284–288.
- [14] I. Bahl, *Lumped Elements for RF and Microwave Circuits*, 2nd ed. Artech House, 2003.