Battery-less Near Field Communication Sensor Tag Energy Study with ContactLess Simulator

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***Abstract*—ContactLess Simulator (CLS) was used to simulate a smart tag composed of a Near Field Communication (NFC) circuit, a microcontroller unit and a temperature sensor. More precisely, our study focuses on battery-less electronic systems: sensor and microcontroller are supplied by the NFC circuit. To prove such a system can function, energy budget has to be explored; this is the aim of this simulator. This paper describes the battery-less electronic system we considered, and simulation results prove that each NFC reading of the tag will recharge it for 44 cycles of autonomous functioning (temperature sensing, data logging).**

Keywords-Simulation; Modeling; NFC; Microcontroller; MCU; Energy harvesting.

I. INTRODUCTION

Internet of Things (IoT) is now a well-known ecosystem where physical small and smart objects interact trough communicating networks. These networks are wired or wireless; the trend is the closer to the object, the more often wireless. Small size and wireless communication give faster and easier installation and deployment. Typical architecture of these objects is also composed of several parts from this list: sensors, actuators, central processing unit, communicating device.

Wireless powering systems exist since several years, and are nowadays widespread in powering systems, such as smartphones wireless chargers [1]. Moreover, certain lightweight systems communicate at the same time they power the object. It is the case in RadioFrequency IDentification systems (RFID). They are composed of an emitter and a receiver that is called tag. The emitter sends radiofrequency waves in order to power and communicate at the same time. A classical tag receives radiofrequency waves to power itself, and sends its unique identification number. Near Field Communication (NFC) is based on RFID. It permits very short communications at a high frequency, in a full peer-to-peer mode. NFC inherits characteristics from RFID, network and smart card. It is suitable for secure communications; as an example, smartphone payment is possible with NFC.

This paper focusses on energy study of a NFC battery-less tag. The energy is the major constraint of these systems. A new simulator has been developed in order to study these electronic systems. It is called CLS: ContactLess Simulator. Section II describes the existing simulators in this field. Section III specifies the hardware NFC we consider. Section IV presents the models that are implemented in the simulator. Section V details the test-case results.

II. RELATED WORK

RFID and NFC simulators are numerous. As RFID and NFC systems are electronic and communicating objects, they can be studied at different levels: low-level (hardware, software) or high-level (protocol, network). Many studies involve hardware platforms, like [2]. This study does not consider the so-called "simulation platforms" that are in reality hardware-based measurements system. It is only focused on simulation, with no hardware interaction.

Low-level simulations focus hardware or radiofrequency aspects. For example, Ahn et al. [3] describe a MATLAB-Simulink model of a radiofrequency transceiver in order to provide a quick evaluation of the performances according to noise and non-linearity of each individual block in the transceiver.

Cheng et al. [4] present studies on physical link (emitter, air, receiver) and radiofrequency propagation aspects. Deckmar et al. [5] gives a MATLAB Simulink NFC model for radiofrequency modulation study.

High-level simulations consider protocols, network and communication performance. RFIDSIM is a more complete simulator that considers physical link and protocol [6]. It provides a realistic physical layer and permits a multi-interface and multi-channel analysis. Others higher-level simulators focus on communication protocol and communication performance, such as the well-known NS-3 simulator. NFC models and protocol study have been developed over NS-3 [7].

Thus, RFID or NFC simulators that consider energy aspects are missing. We have developed a graphical simulator for NFC systems. Novelty is that it is focused on energy, and simulations that were done were validated by hardware measurements. We consider energy harvesting from NFC emitter and energy balance according to the tag electrical consumption. The wireless-supplied tag is not only composed of a classical NFC circuit, but of a more complex smart system. It is described in Section III.

III. CONSIDERED NFC SYSTEM

A typical NFC system is composed of an emitter and a tag. It is shown in Fig. 1. The emitter sends energy and data. Tag is supplied at this moment, and it answers requests. The tag is often composed of a NFC circuit that comprises 2 main blocks: energy harvesting block and data decoding block.

The energy harvesting block converts the received electromagnetic field into usable energy in order to supply the circuit. The data decoding block demodulates the signal in order to recover the bit-stream.

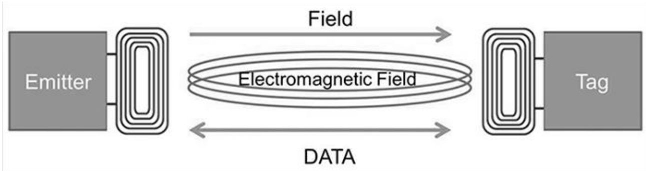

Figure 1. Typical Architecture of NFC system [8].

We consider an active tag (also called dynamic NFC tags) composed of a NFC circuit, a microcontroller unit (MCU) and a temperature sensor. Communication can thus be initiated by the microcontroller, so that communications are event-driven. Neither NFC circuit nor microcontroller nor sensor are externally supplied by a battery as it is classically the case. The only energy source comes from electromagnetic field while NFC communications occur between emitter and tag. To aim this, we choose the ST-Microelectronics M24LR04E chip. It is 13.56 MHz NFC ISO 15693 and ISO 18000-3 mode 1 compatible and it has an energy harvesting analog output that permits to supply other circuits on the board (i.e., microcontroller). The global system is shown in Fig. 2.

IV. Simulator and models

The CLS simulator has been written in Visual C# in order to be easily portable on Microsoft 64-bit Windows operating systems. It is part of the Visual Studio Community, a free tool for academic research.

Graphical user interface is drawn in a horizontal way, from Emitter on the left towards Load (Electronic system) on the right. Fig. 3 shows the main window of CLS simulator.

As it is shown in Section II, several circuits compose the system, so they have been modeled separately. Models are high-level (at electronic system level), written in C#.
Emitting power and antenna gain permit to calculate radiofrequency output power, in other terms the magnetic field H in mA/m. Frequency and distance between antennas lead to radiofrequency signal attenuation. Emitter model

The emitter is modeled according to:

- emitting power
- frequency of the radiofrequency carrier
- distance between emitter and tag antennas
- emitter antenna gain

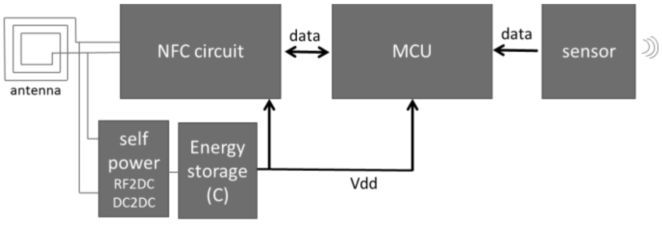

Figure 2. Considered battery-less smart tag.

A. Tag antenna model

The emitter and tag antennas are PCB coil antennas in our prototype. Antenna gain is used to calculate propagation losses. According to above calculations, radiofrequency signal strength is known at tag antenna input. Tag antenna gain attenuation thus gives the signal after antenna.

B. NFC circuit model

NFC circuit has the task to demodulate the radiofrequency signal. Principle is to extract the low frequency information carried in the high frequency: the carrier. High frequency permits propagation in the medium (air, plastic packages, etc.). Once the information is decoded, an answer can be send toward he emitter. Network-like communications occur in NFC. As this functionality is not the key point of this study, only the electrical consumption of this block is considered.

C. Self power and energy storage blocks

Several blocks in NFC circuit are considered. RF2DC block receives the radiofrequency signal and converts it to a DC (voltage and current) signal. The aim is to create a power supply. Conversion goal is to extract the maximum electrical power.

RF2DC is part of the self-power block in Fig. 2. It extracts electrical power from the radiofrequency signal carrier. M24LR04E circuit has been modeled for this power conversion task. The datasheet of this circuit gives H field from radiofrequency strength and output power from H field. Then, the required current at output has to be known in order to calculate the output voltage *Vout* according to the output current *Isink*. These curves are given in datasheet and have been measured.

DC2DC block converts the RF2DC output, in order to create a usable voltage for electronic devices. Electrical power is given according to efficiency of blocks. As power is set, a good balance between voltage and current has to been chosen. It is the role of this DC2DC block.

Energy storage parameters are used to calculate the amount of energy that can be saved in a capacitor. Parameters are capacitance value (in nF) and total losses (leakages in fA) of switches and capacitor. The role of this module is to simulate the energy that can be stored (according to the power input from DC2DC bloc) and the energy that can be used (according to the supplied load and leakages). It will lead to an energy budget analysis.

D. Microcontroller and sensor models

Microcontroller is modeled as an electrical load according to its activity. This load can also vary over time. Microcontroller and sensor require a minimal voltage and consume a nominal current. In model, electrical power is calculated according to:

- microcontroller and sensor brand and model
- microcontroller oscillator type
- microcontroller operating frequency

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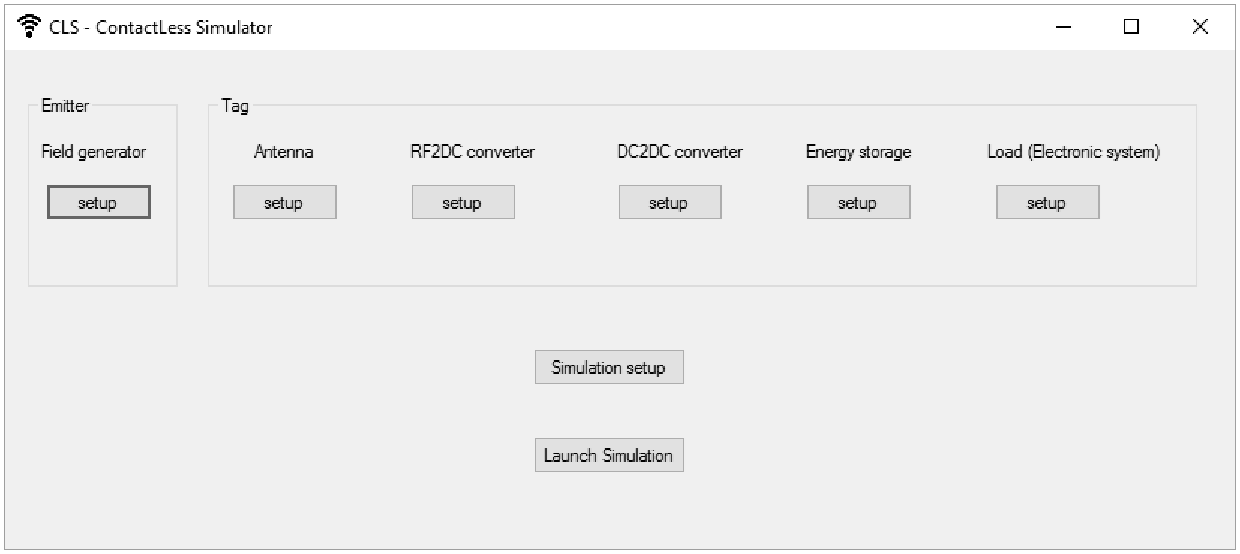

Figure 3. Simulator graphical user interface

Microchip PIC18LF2525 and Maxim MAX6613 are used. MAX6613 analog output is connected to ADC input of microcontroller. MAX6613 is supplied with an output pin of microcontroller. Supply voltage is also the same for both components.

For microcontroller, Microchip PIC18LF2525, oscillator type can be external RC (up to 4 MHz), external XTAL (crystal oscillator, up to 40 MHz), or internal oscillator. For internal oscillator, user can select from the internal 8MHz source down to the INTRC 31KHz source.

Several frequencies are available according to frequency post-scaler in the microcontroller. Frequency (in KHz) is the primary oscillator frequency that must match one possible configuration according to the oscillator type.

Supply voltage is then entered. All the parameters are taken from Microchip PIC18LF2525 (MCU) and MAX6613(temperature sensor) datasheets. Design goal specifies which value is to maximize: voltage or current. Indeed, RF2DC and DC2DC blocks output a given power, and the couple voltage and current can vary. This option also configures the simulation in order to search the maximum current point or the maximum voltage point. The other parameter (for example voltage if current is the design goal) is displayed as a result. Designer has to it take into account in design as a constraint; if the value of this other parameter is unreal, parameters concerning the hardware have to be changed, for example the microcontroller speed.

V. TESTCASE RESULTS

To present how the simulation behaves, the test-case has been simulated. All parameters that are entered in setup windows are sum up in Table II. Results are those in Fig. 4. Simulation time for a static analysis is a few milliseconds. At receiver (tag), magnetic field H is calculated. It depends on emitter power, distance, and antennas gains.

TABLE I. PARAMETERS USED FOR TEST EXAMPLE

Emitting power	50 mW
Frequency	13560 MHz
Distance	5 mm
Duration	5 s
Antennas gain (emitter & tag)	-3 dBi
RF2DC & DC2DC converters	Equations from M24LR04E
Capacitance	1000 nA
Switches leakages	100 fA
Microcontroller brand/model	Microchip / PIC18LF2525
Microcontroller Oscillator	Internal oscillator, 31KHz
Microcontroller Voltage	2V to 5.5V
Sensor Voltage	1.8V to 5.5V
Simulation setup	Design goal = current

The harvesting part gives output of RF2DC and DC2DC parts in the M24LR04E. As design goal of this analysis is the current, the simulator will try to extract nominal current from harvesting part. Nominal current is fixed by the required current from the electrical load (MCU and sensor).

Thus, the simulator firstly calculates the nominal current with the help of the electrical load. Analysis. This current is calculated from MCU and sensor parameters: PIC18LF2525 requires 15.05µA when running from internal oscillator at 31KHz. MAX6613 consumes 7.5µA. Simulator then calculates the harvesting possible voltage output for a sink current of 22.55µA.

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Figure 4. Results Window

From M24LR04E datasheet curves in the model, simulation gives 2.67v. Fig. 4. shows that the required power for load is 67.64µW but the harvester can only provide 60.2µW. As a result, the required voltage 3v is not reached. Designer will have to deal with a 2.67v supply, or decrease the load current consumption in order to increase voltage supply.

Energy calculations have also been implemented in simulator. It considers electrical power consumption and active time. Active time for the emitter is duration of the electromagnetic field. Result window thus displays 301µJ for 5s duration. Active time for the MCU and sensor is the time while MCU and sensor are running. Its energy is then 6.76µJ for 100ms (temperature sensing, analog to digital conversion and data storage in MCU). This result will permit the designer to plan how many cycles this This sensor node could run with a single electromagnetic charge. It is 44 cycles for this example. For this functionality becomes possible, an energy buffer must be used. It will be implemented soon in simulator.

VI. Conclusion and Future Work

We presented a concrete energy analysis with ContactLess Simulator, that is a novelty. Its graphical interface is fully based on forms where parameters are set. It was used to graphically configure a NFC system composed of an emitter and a smart tag. Tag is battery-less (self-supplied), it thus comprises an energy harvesting module, with a RF2DC and DC2DC converter, a microcontroller unit (MCU) and a sensor. Each hardware block is configured by a setup window form. Simulation can be tuned for one design goal: search maximal voltage or search maximal current. This choice depends on designer priority. A launch button runs the simulation and displays a result window. Several electrical outputs are calculated: electromagnetic field at tag input, harvested power (voltage and current), harvested energy for a single contactless energy intake, required power (voltage and current) for the microcontroller and sensor, required energy for a main program loop. Result analysis on a test-case shows that the harvested power is a bit weak (60.2µW) compared to the required power (67.64µW). According to the design goal, fixed to prioritize current, harvested voltage is 2.67v instead of 3v. Electronic design can thus be refined with this simulator. Energy calculation permits to think about a better use of the energy. Indeed, harvested power is weak, but harvested energy (301µJ) is much bigger that required energy (6.76µJ). Feasibility is also possible with smart energy management; we will detail them soon. Further releases of the simulator will support transient analysis and more electronic circuits in library.

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