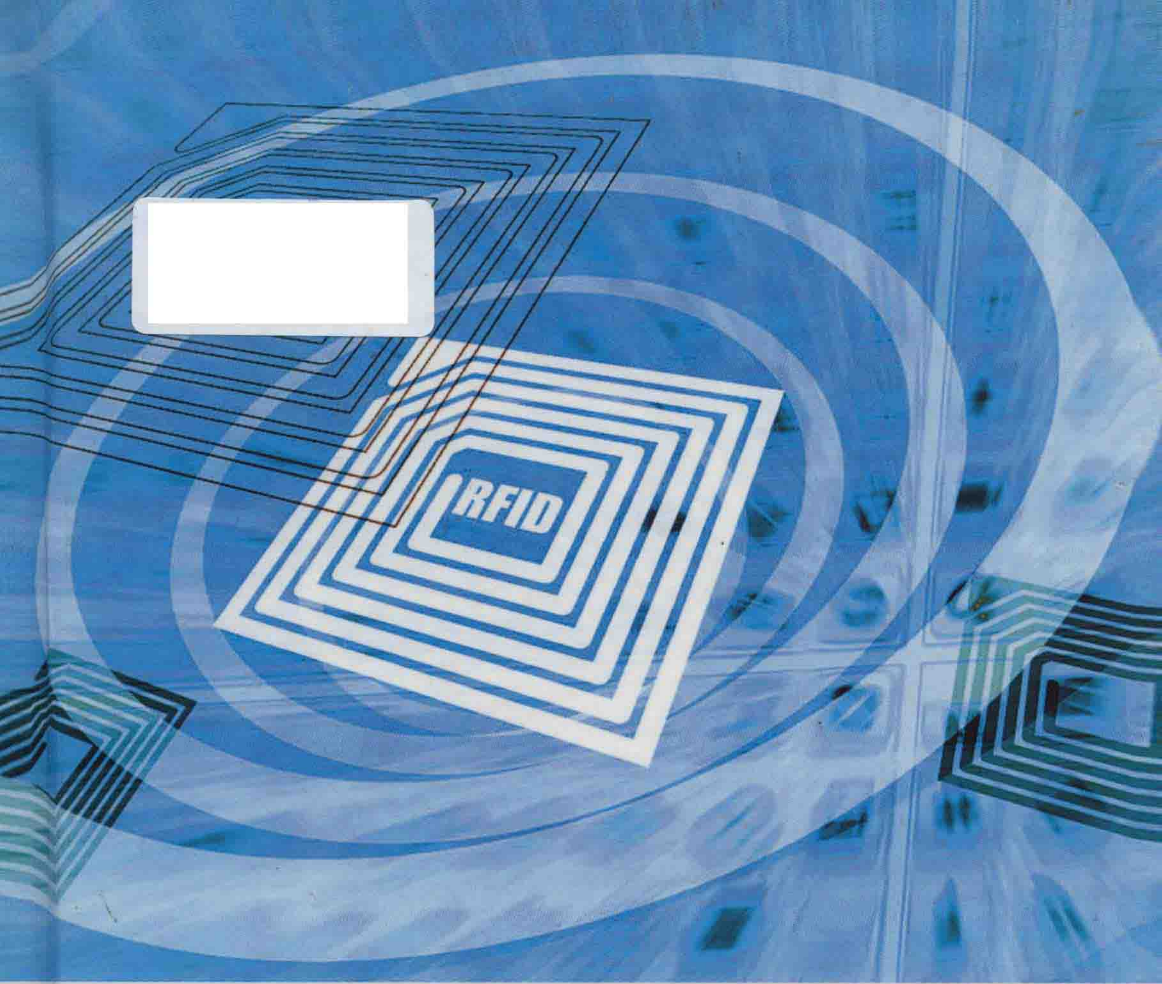

Chipless RFID based on RF Encoding Particle

Arnaud Vena, Etienne Perret
and Smail Tedjini

Realization, Coding and Reading System

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Remote Identification Beyond RFID Set

coordinated by
Etienne Perret

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Preface

Automatic identification and data capture (AIDC) systems have greatly altered consumers' habits, the monitoring of goods, and services in general. The barcode is the best illustration of this. It was invented in 1949 and has been exploited industrially since 1974. It is still today at the top of the traceability of goods field, where it has been the engine of a distribution market that has become global. Today, the barcode is visible on every purchased product and can even replace in some cases the traditional train ticket or even the movie ticket. The latter can also be used either printed on paper or displayed on a smartphone screen.

In parallel, telecommunication technologies have experienced considerable growth during these last decades. The miniaturization of components has made possible the development of mobile devices with increasingly compact and versatile features. In a few years, we have gone from the bulky landline phone to the smartphone, which allows us to connect to the Internet, to receive many television channels and to navigate in the whole world via the global positioning satellite system. Other developments are underway and will allow the development of reconfigurable and cognitive wireless communicating objects.

In recent years, we have seen the growth of radio frequency identification (RFID) technologies, since manufacturers have begun to pay close attention to what radio frequency waves could bring to the field of identification. Thus, in the urban transport network, we have gone from the paper or magnetic ticket to the contactless card. The improvements provided by this technology are major. For example, passage rates have increased, the maintenance of ticket reading or selling machines has been reduced and the interoperability between different transport networks has been made possible due to the quantity of the onboard information. In addition, logistics platforms seek to gradually replace the barcode with UHF RFID tags for the management and traceability of goods. The main interest is to save time in handling during the control of all objects, which are present on a pallet of goods. This control can be performed without unpacking the palette, remotely and in a fraction of a second. RFID technologies have also brought a lot of new opportunities to the security field. In fact, their performance has opened the way for the reliability of automatic machines and access control.

Despite the benefits brought by RFID technologies, their growth is still restricted by the unit cost of a tag, especially if we compare it to the barcode. In fact, in some applications, the objects to be identified can sometimes have a lower unit price than the price of an RFID tag. It is, therefore, understandable that the conventional RFID technology that uses an antenna connected to a chip cannot be applied in these cases. Thus, in recent years, the study of *chipless RFID* has been of increasing interest and research continues to intensify in this subject. In terms of performance and application, chipless RFID is at the border between the barcode and conventional RFID technology. For this reason, it is sometimes called a "radio frequency barcode". As its name indicates, a chipless tag has no electrical circuit, i.e. no active element and, *a fortiori*, no battery. Therefore, the tag ID is not contained in a non-volatile memory but is directly linked to its geometry in the image of a radar target. In fact, it is the physical structure of the label which, when subjected to an incident electromagnetic wave, will create a suitable electromagnetic signature.

Chipless RFID is a relatively recent technology. We will see that the first published works date back to 2002 and that its application potential is undoubted. However, for technical reasons, there are today very few commercial applications based on its principle. In this book, we will examine how it is possible to remove the technological barriers to allow the development of this new path of RFID technology as an entire identification system. The crucial points for improvement are the increase in the coding capacity, the reduction of the label surface and the possibility to print the tag in order to reduce its unit cost. In parallel, the definition and the design of a reading system (which respects the RF standards) that allows us to detect chipless RFID tags in a robust way is also a blocking point, which will be discussed, as well.

In Chapter 1, a general presentation of the different RFID technologies is given. A brief historical introduction will precede the review of the large families of the systems and applications of RFID technology. We will analyze the strengths and weaknesses of each one.

In Chapter 2, we will focus on the latest developments of the different chipless RFID systems. This will allow us to address the current limitations of this technology and to define the different axes of improvements to consider. To do this, we will place the chipless RFID at the heart of the global identification market.

In Chapter 3, we will address the major issue in chipless RFID, in this case, the coding of information in an RFID tag. In fact, increasing the coding capacities is a major issue that will allow us to impose chipless technology as a real alternative to the current identification technologies: barcodes and conventional RFID technology. One of the objectives is, in particular, to match the coding capacity of EAN13 barcodes. We will introduce performance criteria that will allow us to assess the coding effectiveness of a device according to the occupied bandwidth and the surface required. Different coding techniques will be presented and compared.

In the first section of Chapter 4, we will discuss general information concerning the operating mode of a chipless RFID tag in a spectral signature. An electric model and an analytical model of the basic elements that are contained in the tags will be presented and compared to the results of simulations. Performance criteria, which allow us to evaluate each design, will be introduced. In addition, the design rules, which lead to a particular design taking into consideration the bandwidth and the surface, will be presented and applied on different concepts of chipless RFID tags. The problem of reading chipless tags related to the variability of the surrounding environment will also be addressed and a self-compensation method will be proposed.

The technological barriers related to the low manufacturing cost of chipless tags will be studied in Chapter 5. In the first section of Chapter 5, we will present the manufacturing mode related to the conventional electronics industry, followed by the manufacturing principles of the paper industry. A characterization of potentially usable materials will be proposed, before concluding with a comparison of the performance achieved with these two implementation modes. In the second section, we will present the technical measures developed specifically for the characterization of chipless RFID tags, in a confined space with a metallic cavity, and in an open space using a bistatic radar approach. Two approaches will be explored: the frequency approach using a vector network analyzer and the temporal approach based on the use of an ultra-wideband (UWB) pulse generator and a wideband oscilloscope. The standardization aspect for the UWB communications will be addressed, which will allow us to define the possible detection performance. A reader concept based on the use of a UWB localization radar will be implemented for the detection of chipless RFID tags. To conclude this chapter, signal formatting and decoding will be addressed.

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May 2016

Contents

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Introduction to RFID Technologies

1.1. Introduction

In this chapter, Radio Frequency IDentification (RFID) technologies will be presented from a general point of view. A brief historical reminder will allow us to return to the applications and the context of the development of the first RFID systems up to the latest advances. The major RFID technologies will be reviewed and grouped according to their operating frequency, their ability to be detected in the near-field or in the far-field and their passive or active nature from an energy point of view. Their performances will be compared and will constitute the reference values for the following chapters, which will focus on the development of chipless RFID.

1.2. The history of RFID

The origin of RFID undoubtedly goes back to the great idea that Brard had in the 1920s to create a form of communication by radiowave between a transmitter (base station, which today is called an "RFID reader") and a device which today is called a "tag" [BRA 24]. The latter is remotely powered by the transmitter. It is composed of a tunable resonant circuit and a switch that allows the modification of the wave which is backscattered by the tag, thus ensuring a modulation of the signal for the communication with the reader. Here, we find the fundamental principle of RFID that still remains at the core of the current systems: a simple tag remotely powered by the reader, with two separate states to establish communication.

Subsequently, the practical implementation of RFID coincided with the World War II and the very important efforts focused on the development of radar. Indeed, it was during this period of unrest that the major technological advances took place and, in particular, RFID [BRO 99]. The British invented the Identification Friend and Foes (IFF) system, a radio frequency transponder system that permitted the identification of allied from enemy planes with the use of encoded signals.

In the former USSR, in 1945, Léon Theremin [GLI 00] invented an espionage system, which was completely passive, allowing it to convert an audio signal into a radio frequency signal with the use of a cavity covered by a diaphragm sensitive to sounds (see Figure 1.1). An antenna is inserted in this cavity, whose volume is altered by the sounds, as shown in Figure 1.1. Thus, the cavity can be considered as a variable load which evolves over time according to the incident sound signal.

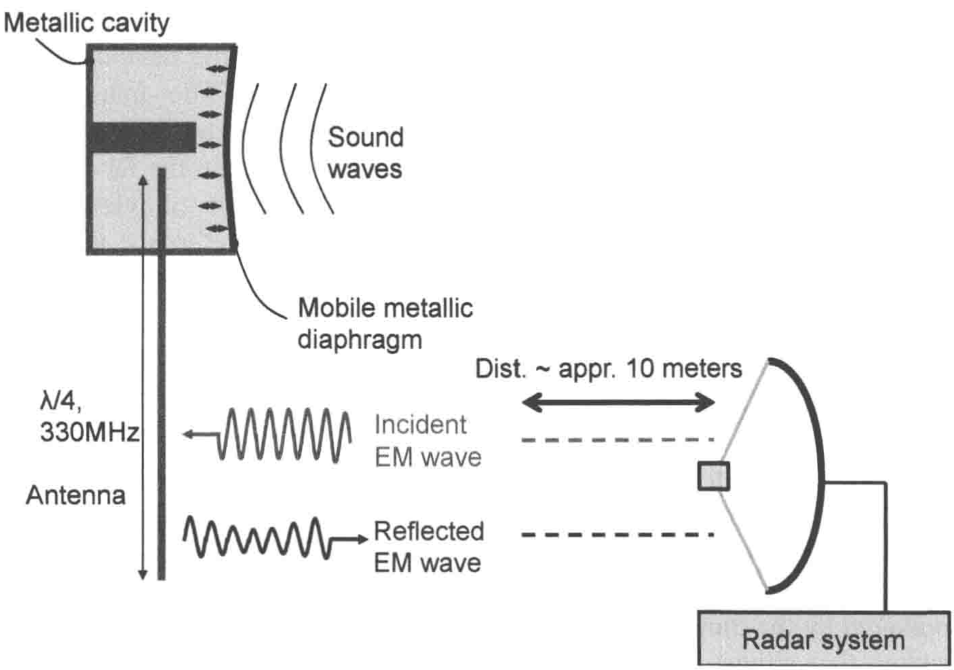

Figure 1.1. *Principle of the listening system "The Thing", invented by Léon Theremin*

The power level of the electromagnetic wave reflected by this antenna will, therefore, vary the rhythm of the sound waves, thus creating an amplitude modulation. This invention may be regarded as the first RFID technology without a chip, even though the identification aspect is not considered in this device. To conclude on this particular period, which is truly the creation of RFID in practice, in 1948, Stockman [STO 48] envisaged the use of what is today known as "RFID" for telecommunication purposes, for various applications using the principle of modulation of the wave power, reflected by a remote transponder. He thus incorporated the principle introduced some years before by Brard. Subsequently, in the 1950s, practical experimentations were developed, along with the patents for the application of this technology [HAR 52, VOG 59].

For almost 20 years, the discipline was explored primarily in the military field, and with the advent of the transistor and the miniaturization of the components, the RFID has become an attractive research discipline [LAN 05]. For example, in 1964, Harrington [HAR 64] introduced the theory concerning the reflection of electromagnetic waves by antennas connected to varying loads.

The first application, which was a commercial success, took place in 1970 with the *electronic article surveillance* anti-theft systems, the transponders of which are the equivalent of tags with a 1-bit chip. Since then, RFID has been the point of interest for large companies such as General Electric and Philips. Other applications emerged, such as the identification of livestock in 1978, with a system marketed by Identronix Research in California. Since the 1980s, research concerning the RFID has not stopped developing. Each application requires specific needs and performances. The constraints vary significantly depending on the operating environment, which explains why the proposed technologies are constantly changing and why research in this area is growing. In the space of 20 years, we have seen the development of electronic toll collection systems to control the access of vehicles on motorways, contactless transport tickets, RFID passports and more recently contactless bank cards. All of these new applications have permanently changed our everyday lives. Even though the principle of chipless RFID was introduced by Léon Theremin in the 1940s, it is only since the 2000s that the research on this very promising subject has started growing. Potentially, chipless technology is expected in the near future to compete with the optical barcode which, up to this moment, is the most used and widespread means of identification.

1.3. RFID technologies

As mentioned above, the wide variety of applications requiring the remote identification of objects explains, in part, the great diversity of RFID technologies that can be found. Thus, the constraints on the reading range, on the nature of the objects to identify (metallic or non-metallic), on the environment of the usage of tags, etc., are particularly diverse. However, the lack of standardization for many years has enabled the emergence and thus the proliferation of competing technologies for the same application.

1.3.1. *General operating principle*

Despite the incredible number of technological parameters that make up the current RFID systems, the operating principle can be described in a general way. An RFID system is composed of one or several RFID readers, connected or not to supervising computers, which can create a link with databases. These readers allow the identification of objects due to RFID tags that are attached to them, as shown in Figure 1.2.

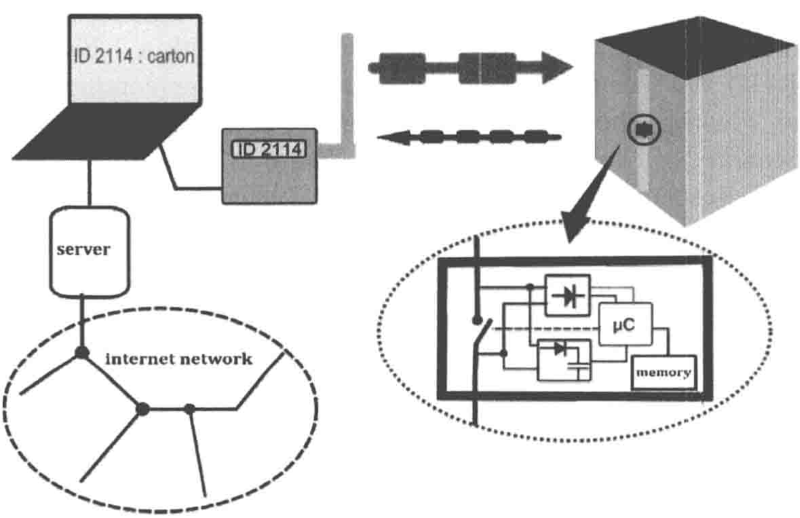

Figure 1.2. *Operating principle of an RFID system*

From an application perspective, we refer to an open system when the tag ID is universal and the association between the ID and the object can be found on a remote server (see Figure 1.2). The barcode is a well-known