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RFID: A key technology for Humanity

La RFID : une technologie clé au service de l'humanité

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ABSTRACT

The RFID (Radio Frequency IDentification) technology is a well-known wireless application for traceability, logistics, and access control. It became ubiquitous in industry and our daily life (ticketing, payment, passports, car keys, etc.). RFID is nowadays a standardized technology; its inherent advantages, which are unitary, identification, wireless communication, and low cost of tags, provide it with decisive practical benefits that drive new developments in terms of concepts and applications. This trend is largely confirmed by the market forecast, but also by its implementation in the area of health (smart hospital), assistance to persons, anti-counterfeiting, as well as by its perspective in terms of new paradigms for distributed ambient intelligence and the Internet of Things. The first part of this paper briefly reviews the fundamental concepts of the RFID technology, and shows its link with the radio science. A state of the art including the presentation of current performance and developments is also summarized. The second part illustrates the impact of RFID to the service of our society with a focus of applications in the field of autonomy and handicap. Finally, the last part highlights a panorama of perspectives and the future directions of RFID applications dedicated to the service of Humanity.

RÉSUMÉ

La RFID (radio par identification) est aujourd'hui une technologie sans fil bien connue pour ses applications en traçabilité, logistique et contrôle d'accès. Elle est devenue omniprésente dans l'industrie et notre vie de tous les jours (tickets de transport, systèmes de paiement, passeports, clés de voiture, etc.). Technologie standardisée, ses avantages inhérents (identification unitaire et télé-alimentation) et le coût modeste des tags lui procurent des avantages pratiques déterminants qui impulsent de nouvelles évolutions, aussi bien applicatives que conceptuelles. Cette tendance est largement démontrée, que ce soit par les projections économiques en termes de croissance et de marchés, son succès déjà actuel dans les secteurs de la santé (« Intelligent Hospital ») et de l'assistance aux personnes, ses aptitudes dédiées aux applications d'anti-contrefaçons, ou encore ses promesses pour les paradigmes naissant d'intelligence ambiante distribuée et d'Internet des objets. Le premier volet de ce papier rappelle brièvement les fondamentaux conceptuels de la RFID et leur lien avec les radiosciences. L'état de l'art, les performances et les développements actuels

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sont résumés. Dans un deuxième volet, l'impact de la RFID au service de notre société avec un focus d'applications autour de l'autonomie et du handicap est présenté. Le dernier volet dresse un panorama des perspectives et tendances futures, annonciateurs de l'évolution grandissante des applications visées par la RFID et de la place qu'elle prendra au service de l'humanité.

1. Introduction

On 4 August 1945, the Soviet Union offered to the U.S. ambassador a magnificent gift, in which it has embedded a spying device called "The Thing" developed by L. Theremin [1]. This device, which was not discovered until years later, operated the backscattering technique to spy the conversations of the ambassador. The first tag was born! The concept of radio communication by reflected waves, known also as backscatter principle, has been explained and published by H. Stockman for the first time in 1948 [2]. One decade later, in the 1960s, the anti-theft system EAS (Electronic Article Surveillance) became the first consumer application based on the backscatter technique.... The modern RFID (Radio Frequency IDentification) was born! More than seventy years after the discovery of its operating principle, nowadays the RFID is a well-known wireless application for traceability, logistics, access control, and became ubiquitous in industry and our daily life (ticketing, payment, passports, car keys, etc.).

RFID is a standardized technology, its inherent advantages, which are unitary identification, wireless communication, and low cost of tags, provide it with decisive practical benefits that drive new developments in terms of concepts and applications [3]. Thus, RFID has become, and will continue to be more and more desirable for implementing applications at the service of our society and humanity. This trend is largely confirmed by the market forecast, but also by its implementation in the area of health (smart hospital) [4], assistance to persons, anti-counterfeiting, and its perspective in terms of new paradigms for distributed ambient intelligence and the Internet of Things. Nowadays there are already thousands of RFID applications in more than hundred countries worldwide, and many of these applications are at the service of our society and Humanity.

This review paper is divided into three main parts. In the first part, the fundamental concepts of RFID technology and its link with radio-science are presented. The second part focuses on the state of the art and current developments. The following part is dedicated to a panorama of RFID applications in the fields of autonomy and handicap, and therefore highlights the impact of RFID for our society. Finally, promising perspectives and future directions of the RFID technology are highlighted.

2. The physics behind the RFID

RFID is a contactless technology with as initial and main function (as given by its name) the identification of objects, animals, and people associated with a transponder (so-called tag) that can be brought, stuck, attached, implanted, etc. The communication is established between a dedicated reader and the tag, and the information captured by the reader is generally distributed to a remote database. For instance, the ID for an object, the so-called "Electronic Product Code" (EPC), is constituted of only 96 bits (indicating company name, object type/class, and serial number) allowing relative low data transfer between tag and reader.

The concept of passive RFID communication is based on the retro-modulation or so-called backscatter principle: an emitter (reader in emission mode) radiates an electromagnetic wave with given frequency and constant amplitude; this wave is both the energy source for the target (the tag) and the retro-modulated wave support in order to send the ID target; the receiver (reader in reception mode) demodulates the information message, then sends it to the database. Therefore, any RFID system is composed of three main elements: the tag that embeds specific information of the item on which it is attached, the reader that empowers the tag and reads the information stored within it and a data base that processes the information and performs the global RFID application.

The tag is certainly the most emblematic device of RFID system. Indeed, among the criteria and properties that the tag must perform, one can highlight at least: passive character, reduced size and cost, compliant with support material and enough electromagnetic robustness to the environment. It is also worth noting that the tag is often a fully passive device and responds to the reader request thanks to the backscatter method. A simplified model of any tag is depicted in Fig. 1. The tag includes an antenna loaded by an impedance (equivalent to input impedance of the RFID chip) that can have two different values (Z_{match} and Z_{reflect}) thanks to an electronic switch (usually a transistor). The two main configurations of tag communication that correspond to the two states are depicted Fig. 2. Indeed, under the same incident CW signal from the reader, each state corresponds to a certain absorbed and certain reflected signal from the tag.

In practice, the RFID chip integrates several essential blocs, in particular a rectifier that is able to convert the RF reader signal into a dc to feed all the other circuitry of the chip. It also contains a demodulator, a modulator using the backscatter

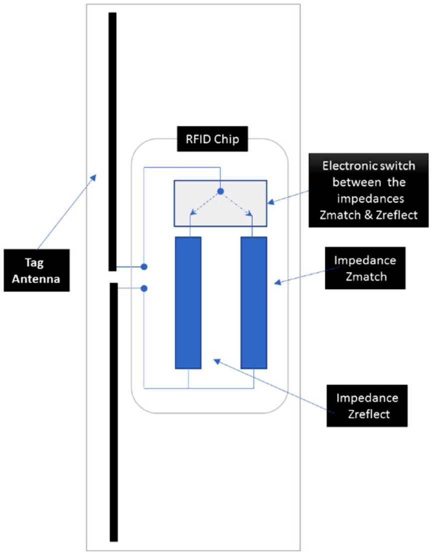

Fig. 1. Simplified tag architecture.

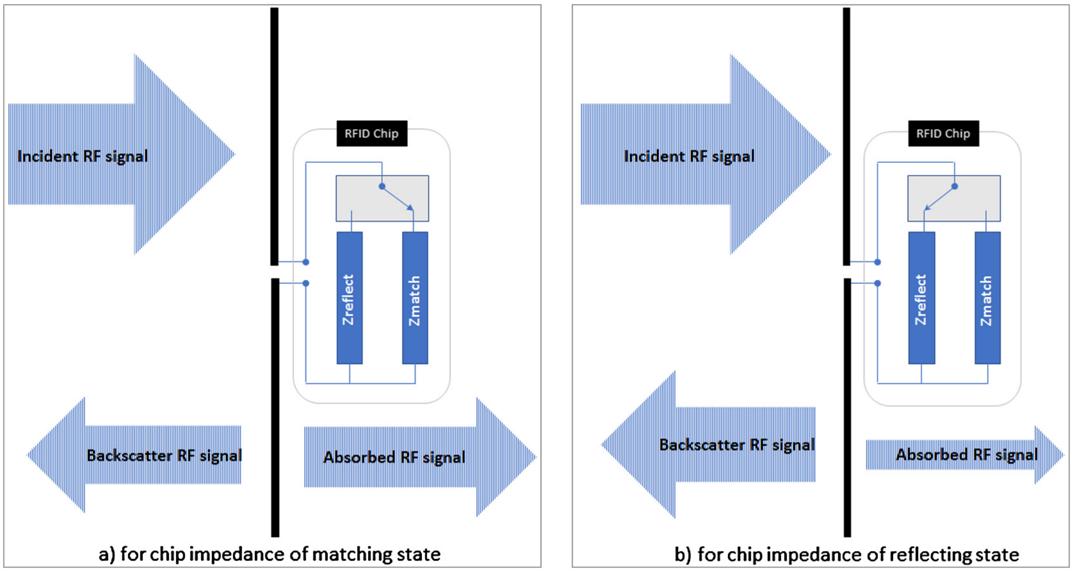

Fig. 2. Backscattered and absorbed RF signals in RFID communication.

method and a digital section (that notably integrates a state machine and memory). Typical architecture of RFID chips is given in Fig. 3.

Otherwise, there are two categories of RFID: Near Field, allowing a communication distance of some tens of centimeters, and Far Field, which allows typical communication distance of some meters. The main difference between the two categories is the operating frequency, and therefore, the type of tag and reader antennas. For Near Field case, loop antennas at both reader and tag are used, and the communication is achieved by magnetic coupling between the two loop antennas, which limits the communication distance. For Far Field case, UHF or microwave antennas are used, which allows longer communication distances up to 25 meters.

Consequently, depending of the target application, there is a multitude of tags of different shapes and sizes. However, a common denominator are the three main components of tags: the substrate (material support) and the antenna, whose choices also depend largely on the applicative environment (in terms of both ergonomics and performance), and the dedicated chip (integrating intelligence, processing functions and memory). The technological advances in RFID field, in particular RFID chips, are very rapid, and today some chips have activation power as low as few µW and could integrate diverse sensing capabilities. These developments open the field of investigation for increasingly sophisticated applications of the Internet of Things (IoT) paradigm.

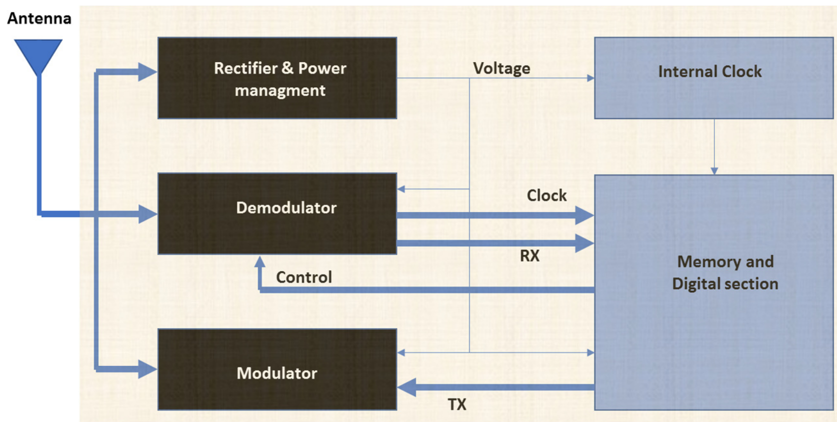

Fig. 3. Simplified architecture of RFID chip.

Numerous variant and different standards exist and are summarized in Table 1. They primarily depend on the geographical location (for instance, the authorized frequencies in Ultra High Frequencies (UHF) are not the same in Asia, in the United States or in Europe, and the associated techniques for the physical layer can be different, with more or less latitude, also implying more or less capabilities for future functionalities!), the involved frequencies (microwaves, UHF, High Frequencies (HF), Low Frequencies (LF), etc., which determine the possible read ranges), and also tag autonomy (fully or partially passive, or active). It is worth noting that these standards will evolve in future years or that new RFID standards will be introduced.

3. RFID at the service of humanity: focus on the fields of autonomy and handicap

The examples of applications are numerous, and it would be illusory to make an exhaustive list. Each day, millions of people use RFID systems without even knowing them: passes, badges for motorway tolls or access to workspaces, passports, electronic car keys, cargo tracking, etc.: RFID is ubiquitous and increasingly seamless. Nowadays RFID has become almost unavoidable for applications related to access control and logistics, for which it is used for its main application: identification.

However, the RFID technology is also used for less common applications and offers specific services. In particular, RFID is deployed in order to offer solutions for helping and monitoring people at risk (such as the elderly and children) and/or with a disability. In this context, one of most significant applications aims to improve the mobility of people with visual impairment. Notably, Sesamonet is a system designed in 2006 that is declined in various forms and several similar systems have been developed [5–8]. The concept of these systems is to put tags in the soil; the tags can be interrogated with a white electronic cane (that includes a reader) and their ID implicitly gives the position; the information is sent via sound to the person. These systems can be implemented in buildings or outdoor environments and also can interact with the environment: detecting a pedestrian crossing, interrogating a public portal, and so on. Among the different standards, RFID LF or HF have been chosen because they are well known and also deployed in many other situations and, on the other hand, they are more precise and secure because of their limited read range and their robustness to environment (RF transmission possible even in the presence of metal, tissue, or water). Alternative approaches propose to replace the white “reader” cane by including this function in the harness of the guide dog or in a kind of band around the ankle. Additional approaches based on other techniques have also been studied (such as the use of ultrasonic obstacle detectors or Wi-Fi localization or ZigBee network), but the use of passive RFID tags is fairly little contested. Finally, mixed solutions coupling other technologies with RFID seem to be the most promising way for future applications. For assistance, monitoring and autonomy for people with disabilities and/or elderly, a variety of applications exploiting RFID identification are summarized in Table 2.

As demonstrated by these examples, the LF and HF RFID technologies are widely deployed in many applications dedicated to autonomy and disability. In most cases, the identifying system is coupled with another information, capture and/or communication technologies. RFID is increasingly integrating intelligent environments with tagged domestic products and recognizable via voice synthesis and where home automation is becoming ubiquitous. These new services have more and more significant advantages for people with disabilities, but also for everyone [20,21].

4. New perspectives and trends for future applications of RFID

The potential of RFID does not stop to ID functionality: its properties drive new developments in both sensors and wireless sensor networks, IoT, and distributed ambient intelligence. While the vast majority of the applications cited use RFID technology in its original frequency ranges (i.e. LF or HF), the next steps of evolution are expected in the UHF frequency range with great new functionalities and capabilities. The large interest in UHF RFID is primarily due to its long read range and the versatile character and geometry of the tag antenna. Indeed, for LF and HF RFID, the antenna is mainly a magnetic

Table 1
Main characteristics of RFID standards.

	Frequency range	Read range	Coupling type	Existing standards	Applications at the service of Humanity
LF	125 kHz 134 kHz	∼0.1 m	Magnetic Near field	11784/85, 14223, 18000-2	Smart card, ticketing, access, animal tagging, laundry...
HF	13.56 MHz	∼1 m	Magnetic Near field	18000-3.1, 15693, 14443A, B, C	Small item management, supply chain, anti-theft, library...
UHF	900 MHz 902–928 MHz US 868–871 MHz Europe 950–956 MHz Asia	∼2–20 m	Electromagnetic Far field	EPC C0, C1, C1G2, 18000-6	Transportation vehicle ID, access, security, supply chain, large item management...
Microwaves	2.4 GHz	∼10 m	Electromagnetic Far field	18000-4	Transportation vehicle ID, road toll, access, security, supply chain, large item management,...

Table 2
Applications examples of RFID at the service of health and handicap.

Context and applications	Use of RFID	RFID type	Coupling with other information and/or communication technologies	Ref.
Temperature monitoring of students with disabilities enrolled in Taiwan	Identification of people	HF	Dedicated Web application	[9]
Monitoring of the health and motor activity of wheelchair users	Identification of wheelchairs	LF	Smart sensor networks (standard IEEE 1451.4) + data transfer (standard IEEE 802.15.4)	[10]
Connectivity between patient and his environment	Identification of people and objects	NFC	6loWPAN technology IoT type architecture	[11]
Home medication	Identification (and location) of drugs	NFC	PDA reader	[12–14]
Automatic guiding and payment system for shopping	Identification of objects	LF	Zigbee	[15]
Voice assistance in librairies	Identification of books and compact disks	LF	Wireless transmission at 433 kHz	[16]
Solution to the dysfunction of sensory integration in young children	Identification of people	LF	Sensor networks, database, virtual reality	[17]
U-Learning and E-Learning	Identification of people and objects	LF	Bluetooth, Wi-Fi	[18]
Serious therapeutic games in language disorders	Identification of people and objects	LF	Physiological sensors, Wi-Fi, bluetooth, tablet	[19]

Table 3
Evolution of RFID chip sensitivity and read range for ETSI regulation. (Estimated theoretical read range considering: operating frequency at 868 MHz, reader power 2 W ERP, reader antenna gain 2 dBi, tag antenna is ideal dipole and perfect matching between RFID chip-tag antenna.)

Year	Sensitivity (dBm)	Read range (m)
1997	−8	5.07
1999	−10	6.38
2005	−12	8.03
2007	−13	9.01
2008	−15	11.34
2010	−18	16.02
2011	−20	20.16
2014	−22	25.38

loop (very rarely capacitive coupling is used). So very specific tag antennas in UHF RFID can be designed, which allow different radiation patterns and performance. Another feature is the rapid evolution of RFID chip sensitivity, which allows a read range of more than 25 m (Table 3).

Indeed, in addition to its advantages in terms of tag size, reading distances, data rates and collision management protocols compared to LF and HF standards, UHF RFID also has a very important potential, in particular in the areas of localization and of information capture: concerning the localization, the exploitation of the phase makes it possible to foresee precisions of the order of a few centimeters [22–24]; for sensors, numerous sensor tags already exist for measuring variables such as temperature, pressure, humidity, deformation, gas, displacement, etc. [25–28]. For designing sensor tags, two approaches are envisaged: tags coupled with specific sensors or tags incorporating internal transduction functions. In addition to the inherent identification information that represents an advantage compared to conventional sensors, sensor tags act as input–output nodes of a data (which may be heterogeneous) capture infrastructure, with consequently many application perspectives; and in passive UHF RFID, with a control of the energy consumption [28–30] and a weak footprint on the hardware level. Other developments in UHF RFID are also being studied, as, for example: conjointly near-field and far-field applications allowing the combination of the advantages in each case [31], the exploitation of the harmonics generated by the nonlinearities of the chips [32,33] or tag-to-tag communications [34–36]. This evolution (and even revolution) of the RFID opens up a wide range of perspectives and will lead to new application ideas.

New RFID standards may also emerge and associated applications accordingly. Numerous works concern the so-called “chipless” RFID, which consists in eliminating the chip: the identifier is included in the electromagnetic signature of the radiating structure of the tag itself [37]. This approach has as drawback of requiring more complex readers than traditional readers, but it has the advantage of being totally passive and (as seen for UHF RFID) it also offers many possibilities in terms of tag-sensors. The increase in frequency to the millimeter wave domain (MMID, MilliMeter wave Identification) is also considered, and this, always with the potential of disposing tag-sensors [38,39]. Several recent technological advances also make it possible to envisage new perspectives: extremely fine and flexible tags combined with printed sensors, printed batteries, photovoltaic cells; tags in 3D printing technology; more important memories integrated within tags with thus more processing capabilities; tags-actuators; etc.

5. Conclusion

Finally, while RFID technology is now a well-known technology and is already present in many applications of our everyday life, it continues to develop and renew itself. RFID is still one of the “top-ten” key technologies and will remain as such thanks to its potential for very sophisticated applications like the paradigm of the IoT and its numerous exploitations, in particular for the service of Humanity.

A final important point concerns the contribution of RFID to the concept of green and recyclable technologies. Indeed, even if the vast majority of RFID components are not really “green” or eco-compatible, several works have demonstrated the design of tags using unconventional substrates such as fabrics, papers, woods, trees, plants, etc. Moreover, RFID technology, by its functional characteristics, makes a positive contribution in terms of waste recycling management, reduction of emitted RF power levels, and electromagnetic pollution [40].

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