

Antenna for Energy Harvesting in Wireless Connected Objects

Nizar Sakli, Chayma Bahar, Chokri Baccouch, Hedi Sakli

Abstract—If connected objects multiply, they are becoming a challenge in more than one way. In particular by their consumption and their supply of electricity. A large part of the new generations of connected objects will only be able to develop if it is possible to make them entirely autonomous in terms of energy. Some manufacturers are therefore developing products capable of recovering energy from their environment. Vital solutions in certain contexts, such as the medical industry. Energy recovery from the environment is a reliable solution to solve the problem of powering wireless connected objects. This paper presents and study a optically transparent solar patch antenna in frequency band of 2.4 GHz for connected objects in the future standard 5G for energy harvesting and RF transmission.

Keywords—5G, IoT, wireless communications, antenna, solar cell.

I. INTRODUCTION

IN recent years, wireless communications systems are continuously growing, which leads to the use of large numbers of mobile equipment. So, we are facing the energy feeding problem. RF and solar energy harvesting is one of the emerging technologies allowing to solve the power feeding problem. Powering wireless communications systems from environmental energy sources is a very promising solution to improve their energy independence. Among the recoverable energy sources, electromagnetic and solar waves are considered to be the most promising due to their availability in our environment.

The development of communicating sensors responds to a growing need to measure and control the evolution of environmental parameters such as the behavior of civil or military buildings (Fig. 1). Among the many fields of application, we can cite the military field which first looked at wireless sensors in order to study the movements of enemies, or to analyze a battlefield before going there.

The technology of communicating sensors is the subject of research in the environmental field to detect and prevent natural disasters such as fires, or in the agricultural environment in order to optimize soil management. Wireless sensors are also used in monitoring hostile environments or

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Fig. 1 Examples of communicating sensor applications

engineering structures such as bridges, dams and tunnels. In the medical field, we note the implantation of autonomous sensors in the human body, making it possible to collect and record physiological data and transmit them to a medical center in order to remotely monitor the state of health of patients.

In the market, the majority of communicating sensors are powered by cells or batteries whose lifespan is limited to a certain number of cycles. When they are scattered in locations that are sometimes inaccessible and in harsh environments, maintaining these sensors is difficult. So, the key to the large-scale development of this technology lies in increasing their energy autonomy.

How do we supply energy to the tens of billions of sensors that will invade us with the boom in the Internet of Things (IoT)? The stake is not only ecological; it is also a question of performance. While external batteries require tedious recharging work, implementing the energy source directly on the sensors, which equip connected objects, is one way to improve both their capacities and their autonomy.

In this work, a viable solution is to harvest energy environment and then provide enough energy to the devices to perform their operations. This will significantly eliminate the need for the battery as an energy source and increase the device life time. This survey aims at providing a comprehensive study on energy harvesting techniques as promising and alternative solutions to power IoT devices. We present the main design challenges of IoT devices in terms of power and energy and provide design considerations for a successful implementations of self-powered IoT devices.

II. PROBLEM AND APPROACH

A. Study Problem

IoT applications have specific requirements such as long range, low data rate, low power consumption and cost efficiency. Widely used short range radio technologies (e.g. ZigBee, Bluetooth) are not suitable for scenarios that require long range transmission. Solutions based on cellular communications (e.g. 2G, 3G and 4G) may provide greater

coverage, but they consume excessive power from the device. Therefore, the demands of IoT applications have led to the emergence of a new wireless communication technology: Low Power Wide Area Network (LPWAN).

One of the major challenges of communicating objects is energy consumption. A large part of the new generations of connected objects will only be able to develop if it is possible to make them fully energy self-sufficient. Even if the use of batteries or cells solves part of this problem by providing a battery life which can be significant, it introduces many problems such as maintenance incompatible with certain applications and pollution of the environment. The recovery of solar energy is therefore a very attractive solution although the amount of energy obtained is generally quite low. Our goal is to provide a standalone sensor solution based on a solar energy harvesting system that can be implemented in different applications.

Currently there are two main ways to maximize the lifespan of a communicating object. The first way is to store energy together with the systematic reduction in energy consumption by various sensor blocks (especially the radio block) while the second way is to get energy from the environment. Indeed, renewable energies such as wind and solar energy as well as vibratory energy have become promising sources to provide part of the energy balance of the collector or to completely replace the batteries used to have an Autonomous Communicating Sensor in Energy. Harvesting solar energy then became a key element in extending the life of wireless sensors. This technique allows not only to power the sensor for different classes of applications, but also to overcome all the worries caused by the use of batteries. So to ensure energy neutral operation, it is necessary to know and predict the amount of energy that can be recovered at any time. To overcome this challenge, we have proposed energy-autonomous connected objects as a result of this work. These objects or sensors will be equipped with small antennas that collect energy and which are also used for transmitting their data.

A communicating sensor is made up of four main units: the measurement or data acquisition unit (the sensor), the information processing unit (the processor), the transmission unit (the transceiver) and the power supply unit or power source.

B. Future of IoT in Solar Energy

The concept of the IoT is defined as an interconnection between the object and the Internet. The use of this term is based on several communication protocols. The IoT was discovered in 1990 with different communication technologies such as RFID (radiofrequency identification), Bluetooth, Wi-Fi, Zigbee, Sigfox and Lora [1]-[3]. In recent years, the increasing energy needs of connected objects have become a hot topic in the Internet of Things field. This aims to reduce the energy consumption of connected systems. Today, we are faced with major problems: the non-renewable storage of fossil fuels (gas, oil) and nuclear and of course the negative effects of this combustions on our environment (pollution, global

warming, etc.). The optimal solution for these problems is the implementation of the exploitation of renewable energies (solar, wind turbines, geothermal, etc.) which have better economic and ecological characteristics. In this case, solar energy recovery is a promising solution to extend the life of the connected object and extend the autonomy of wireless systems. On this scale, photovoltaics is an abundant, clean source that converts light (photons) into electrical voltage.

Currently, the energy autonomy of communicating systems has become a very important subject, in terms of the use of batteries or cells on the scale of billions of connected objects. Even if the use of batteries ensures autonomy but they introduce major problems such as environmental pollution and the lifespan of a communicating object. For these reasons, solar energy recovery (the Photovoltaic Effect) has become a promising solution for ensuring the energy autonomy of connected objects in many fields of application. Indeed, this solution makes it possible to transform light into electrical energy.

C. Approach

As part of our research and development work within the company EITA Consulting, we offer an original solution: to couple RFID tags, wifi module, Bluetooth module and xBee module at the base of future IoT sensors to photovoltaic cells. We first need to determine the power produced in real time from a photovoltaic cell to supply our communicating objects. Following this, we are offering a hybrid solar cell antenna system for energy harvesting and radio frequency transmission. It is an integration of a miniature antenna and a small photovoltaic cell. The proposed approach of our solar cell antenna solution is shown in Fig. 2.

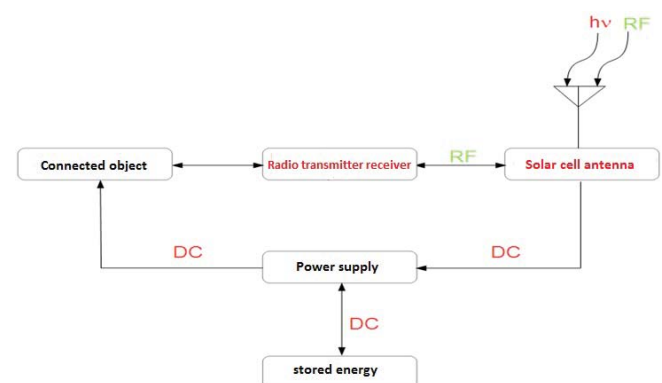


Fig. 2 Proposed solution

III. SOLAR CELL ANTENNA FOR CONNECTED OBJECTS

In this paper, transparent solar patch antennas for wireless communications with operating frequency of 2.4 GHz are designed. Solar antenna combines two applications in one device: the energy harvesting and RF transmission [4]-[7]. In order to investigate the performance, instead of using copper, several types of TCO have been used as the conducting patch of the antenna which is Indium Tin Oxide

(ITO) films, conductive silver-coated thin film (AgHT-4) and (AgHT-8) [8]-[10]. Since, the main problem of the solar antenna that have been designed using non-transparent material and semi-transparent material are including bulky, have complicated design, and also experiencing shadowing effect that causing the degradation of total solar efficiency [11]-[15].

A. Design

The antenna designed in this paper comprises of two parts, which are the antenna part and the solar part [16]-[23]. Fig. 3 shows the design of the rectangular microstrip patch as the radiating element and the structure of the solar cell which consists of three main layers, anode lattice, silicon, and cathode. The material used in this design for the anode and cathode layers are silver and aluminum, respectively.

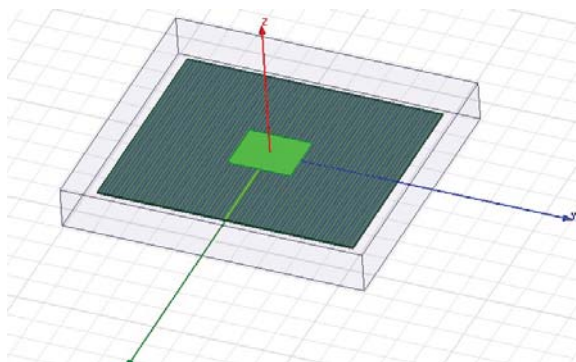


Fig. 3 Solar Cell Antenna

Transparent solar antenna has been designed and will be discussed in this paper. Polysterene materials have been used as the transparent substrate with dielectric constant, ϵ_r of 2.6 and thickness of 0.7 mm. As for the radiating patch and ground layer, TCO thin films are used and varied to Indium Tin Oxide (ITO) films, conductive silver-coated thin film, AgHT-4, and AgHT-8 with sheet resistance, RS of 10 Ω /sq, 4.5 Ω /sq, and 8 Ω /sq respectively. The dimensions of a rectangular patch antenna are guided mainly by the properties of the dielectric substrate. Table I shows the optimized width and length of each transparent antenna. Even though the properties of the conducting materials are varied, the optimized dimensions of all three transparent antennas are similar as the same substrate used.

TABLE I
 PATCH DIMENSIONS

Parameters	Copper	ITO	AgHT-4	AgHT-8
Patch width (mm)	45.8	45.84	45.6	45.6
Patch length (mm)	37.9	37.92	37.75	37.75

IV. RESULTS AND ANALYSIS

A. Return Loss and Bandwidth

Fig. 4 shows the frequency response of transparent and non transparent antenna with resonance frequency of 2.4 GHz,

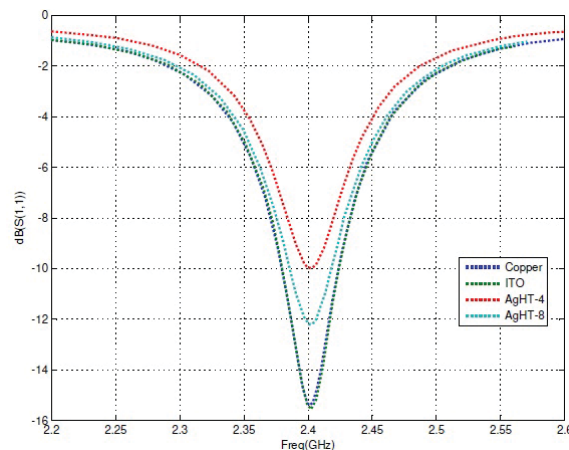


Fig. 4 Return loss of Solar Cell Antenna

TABLE II
 RETURN LOSS AND BANDWIDTH RESULTS

Conducting material	Copper	ITO	AgHT-4	AgHT-8
Return loss(dB)	-15.3	-15.8	-10	-12.18
Bandwidth (MHz)	44	45	-	35

and Table II shows the results summary of return loss and bandwidth of the design.

Transparent antenna that gives the best performance in terms of return loss and the highest bandwidth is the ITO. As predicted, the bandwidth of the transparent and non transparent antenna shows less difference due to its equal substrate thickness.

B. Gain, Radiation Pattern, VSWR, and Radiation Efficiency

Table III shows the summarization of gain, VSWR, and the radiation efficiencies. As shown in the table, nontransparent antenna in copper gives the highest gain and all transparent antennas give similar results of gain, but ITO gives slightly better value than others, and then followed by AgHT-4. The VSWR and radiation efficiency of all antennas are satisfactory which are nearly to 1 and higher than 50% respectively. But again, ITO gives the best efficiency compare to the other transparent antennas.

TABLE III
 GAIN, VSWR, AND RADIATION EFFICIENCY RESULTS

Conducting material	Copper	ITO	AgHT-4	AgHT-8
Gain(dB)	3.49	2.49	2.096	2.052
VSWR	1.45	1.42	1.53	1.08
Rad. Efficiency (%)	86.33	81.12	75.62	73.44

Fig. 5 represents a prototype of energy-autonomous connected objects based on the integration of a miniature copper antenna (operating at the 2.4 GHz frequency) with a photovoltaic cell produced by our research team.

V. CONCLUSION

From the results shown above, it is obvious that transparent antenna proposed gives good performance with highest current

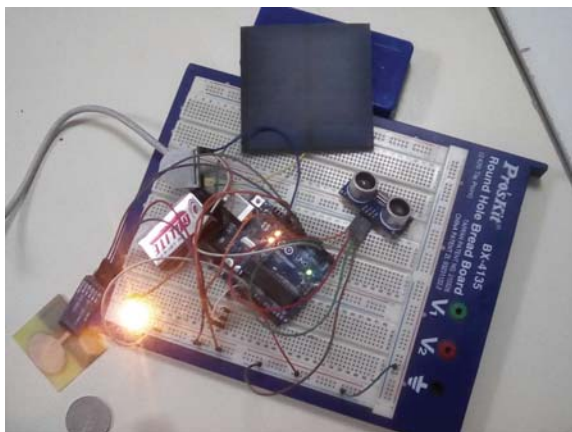


Fig. 5 Connected objects with Solar cell antenna prototype

density, gain, efficiencies. It provides also great performance in terms of bandwidth but with minor differences compared to nontransparent antenna in copper. The advantage of using a transparent solar cell antenna compared to that with a non-transparent solar cell antenna is to allow a large area of electrical energy recovery. We conclude that wireless communications systems can transmit their data and harvest electrical power for their power supply with this proposed 2.4 GHz transparent solar antenna.

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