

# DESIGN OF SOLAR HARVESTED SEMI ACTIVE RFID TRANSPONDER WITH SUPERCAPACITOR STORAGE

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**Abstract.** *This paper presents the analysis, design and manufacture of a low cost, low maintenance and long-range prototype of RFID transponder with continuous operability. A prototype of semi-active RFID transponder is produced with a range that can be extended via a DC input to allow all of the readers signal power to be reflected via backscatter modulation. The transponder is powered via solar harvested power which is selected over other energy harvesting technologies as it provides a greater energy density and lower cost. Solar has one major drawback in terms of providing a steady DC voltage in it needed a constant supply of sunlight. A method of power storage is proposed, and the use of a supercapacitor over a rechargeable battery is used as it has a longer lifespan due to higher recharge rates. The prototype underwent a series of experiments in various working environments and proves an effective solution in providing long lasting operability. The paper concludes the use of solar harvesting with supercapacitor storage has potential for further uses in external remote sensors used in the Internet of Things.*

## Keywords

*Energy earvesting, internet of things, RFID, solar, supercapacitor.*

## 1. Introduction

Energy harvesting or scavenging is the process of generating power for low-power electronic devices, from external sources such as solar, thermal, vibration or ambient RF waves [1]. It is mainly used for small, wireless autonomous devices, like those used in wearable

electronics, wireless sensor networks, and especially Internet of Things (IoT) devices. Many research papers are therefore focused on a design of energy harvesting devices.

A comparison of the physical needs and the energy requirements of processing and communication of the IoT nodes are discussed in [2]. The author concludes the both wire IoT devices and best batteries and processors are impractical due to limited lifetime or installation. Limits of each technology, e.g. solar cells, harvesting radio signals, capture of vibration, are also presented.

Authors in [3] describe prototyping of semi-active UHF RFID tag with solar panel and wireless power receiver. They showed the possible extension of the RFID tag. However, switching of external power sources has to be improved by predefined conditions. The concept of harvesting radio signals in other bands (digital TV, GSM900, GSM1800, 3G) is discussed in [4]. Authors highlight the practical feasibility of exploiting freely available sources of RF energy. However, the condition of full integration of power management module into the rectifier has to be fulfilled. Authors in [5] conclude solar harvesting transponders offer a low cost, high energy density solution that could operate in internal and external environments, however they fall short in offering continuous operability where a constant supply of light is needed.

The use of vibration harvesting is introduced in [6]. The main disadvantage is the need to be in a proximity to a vibration source. Vibration energy harvesting as a promising approach is considered for the future underground sensor networks in [7]. Varying environmental conditions have to be however studied in future work.

Furthermore, research papers focus on improvement of energy harvesting devices by antenna design [8], [9],

[10], [11], DC-DC charge pump [12], rectifiers [13], [14], management policy [14], [15], [16] or regulators [17].

Supercapacitor as a storage device is described in [18]. Authors conclude the proposed modelling of power harvester with the piezoelectric generator is sufficient to drive RFID tag. The RFID tag operating at 13.56 MHz with supercapacitor is presented in [19]. Authors describe a wireless tag for an intraocular pressure within the eye.

This paper proposes the analysis, design and manufacture of long range, low cost, low maintenance Ultra High Frequency (UHF) RFID transponder prototype with continuous operability in semi-active mode, i.e. the power supply is used to provide voltage to the chip. The prototype is measured in order to verify its operational reliability.

The rest of the paper is organized as follows: Section 2. describes prototype design, Section 3. presents measurement results and evaluation and the conclusion are presented in Section 4.

## 2. Design of RFID Semi-Active Transponder with Supercapacitor

The complete RFID transponder system consists of five separate components, Fig. 1. The RFID Chip requires

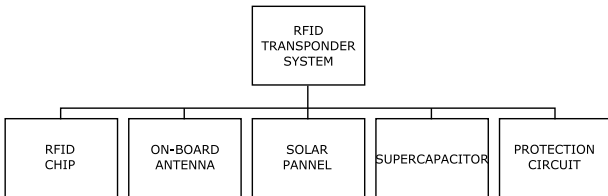


Fig. 1: Designed components of RFID transponder prototype.

long range capability and functional operation in the semi-active mode when a DC power source is added. The EM 4325 chip is the most suitable as it offers an advanced feature set such as onboard temperature sensor with superior reading range and reliability compared to purely passive RFID solutions. The range of battery operating voltage of the EM 4325 is between 1.25 V and 3.65 V.

To maximise the transponders range an On-Board antenna with an impedance that is the complex conjugate of the EM 4325 as suggested in [2] is needed to correct a phase shift between system voltage and current. The complex impedance of the chip is shown in Eq. (1). The complex impedance of the antenna has an equal real part with the imaginary part equal in magnitude, but opposite in sign in Eq. (2). Simulated

surface current distribution for dipole antenna is depicted in Fig. 2. The reactance of the opposite sign is achieved by the capacitance between each half of the antennas which dielectric of the substrate of the board is Isola 410 FR-4 epoxy laminate.

$$Z_{CHIP} = R_{CHIP} + jX_{CHIP} = 7.4 - j122, \quad (1)$$

$$Z_{ANTENNA} = R_{CHIP} - jX_{CHIP} = 7.4 + j122, \quad (2)$$

where  $Z_{CHIP}$  is the input impedance of the chip,  $Z_{ANTENNA}$  is the impedance of the antenna,  $R_{CHIP}$  is the real part of the  $Z_{CHIP}$ , i.e. resistance,  $X_{CHIP}$  is the imaginary part of the  $Z_{CHIP}$ , i.e. reactance,  $j$  is the imaginary unit.

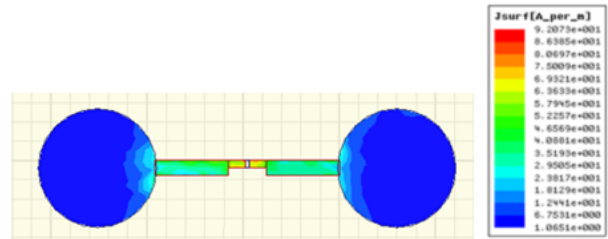


Fig. 2: Dipole surface current distribution.

The value of supercapacitor is selected on basis of discharge time. This is equated for a range of super capacitors from 1–50 F with a maximum voltage of 2.7 V, the lowest operating voltage of the chip 1.25 V and its maximum operating current of 8.6  $\mu$ A, Eq. (3). Figure 3 shows discharge rates of fully charged super capacitors can theoretically power the chip for up to 50 days. From this a 10 F supercapacitor is selected.

$$DischargeTime = C \cdot \frac{(V_{capmax} - V_{capmin})}{I_{max}} [s], \quad (3)$$

where  $C$  is the capacitance in F,  $V_{capmax}$  is the initial (maximal) supercapacitor voltage in V,  $V_{capmin}$  is the

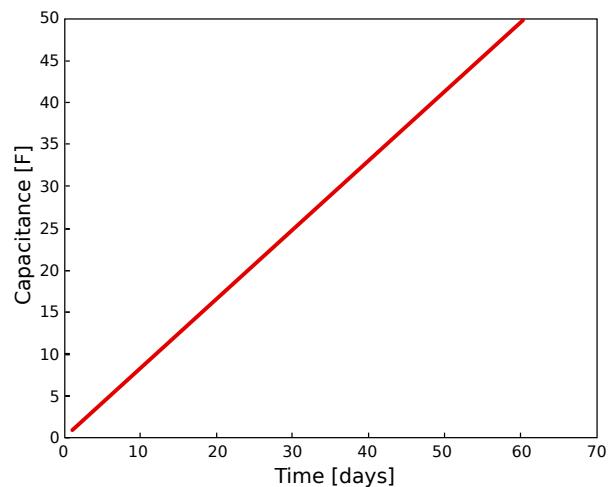


Fig. 3: Power duration of EM 4325 when powered with a supercapacitor.

ending (minimal) supercapacitor voltage in V and  $I_{max}$  is the discharge current in A.

The solar harvesting system consists of a monocrystalline photovoltaic panel sized  $180 \times 130 \times 3$  mm, with the maximum voltage and current of 6.0 V and 333 mA giving a total power of 2 W.

To protect the supercapacitor, a protection circuit is required to provide a steady 2.7 V input. The easiest way of achieving this is with a simple voltage regulator using a Zener diode. Figure 4 shows the voltage regulator circuit needed, here a Zener diode conducts when the voltage reaches the diode's reverse breakdown voltage. The Zener is rated at 2.7 V, so anything over that will be passed to ground thus proving a steady input into the super capacitor. The blocking diode is used to prevent the supercapacitor discharging overnight through the solar panel.

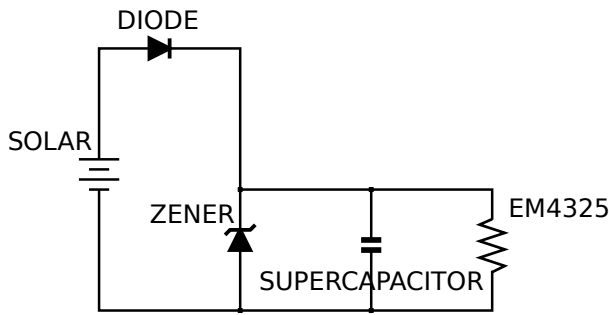


Fig. 4: A protection circuit realized by voltage regulator.

The design of the PCB is using Eagle (Easily Applicable Graphical Layout Editor) Software. Figure 5 shows the PCB board layout with all components labelled.

Figure 6 shows the EM 4325 and the 6 pin header connector. Pins 1 and 8 overlay each side of the Ant-

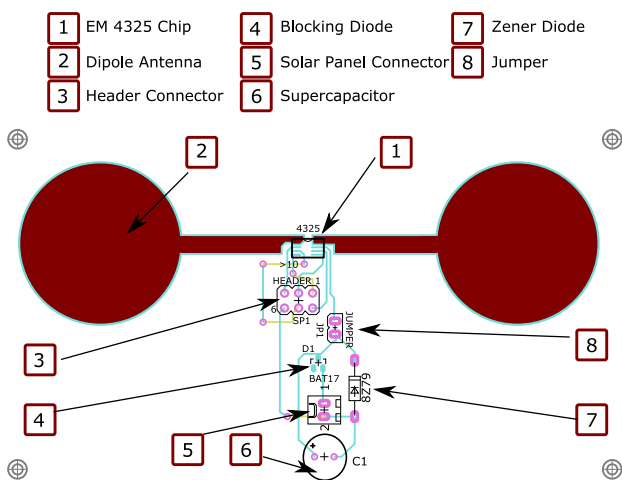


Fig. 5: The PCB board layout of designed RFID transponder.

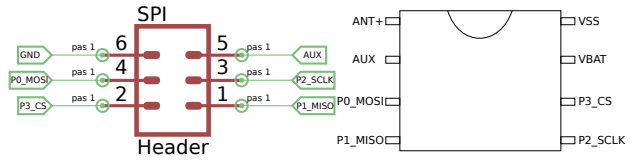


Fig. 6: Pin header (left) and EM 4325 pin layout (right).

tenna while the remaining 6 pins connect with the header connector to allow for the EM 4325 to be programmed via its SPI bus. Pin 7 of the EM 4325 is the VBAT input, which is connected to the supercapacitor via a Jumper that can be removed so the chip can operate without power i.e. in passive mode. The supercapacitor has to be placed as far from the chip as possible to minimise the effect of noise. Realized prototype is depicted in Fig. 7.

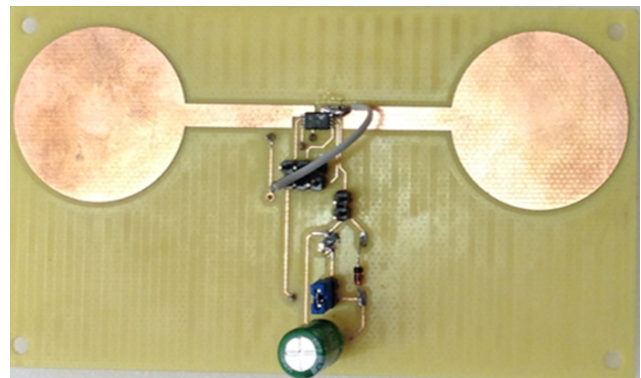


Fig. 7: Realized prototype of RFID transponder with super capacitor.

### 3. Measurement and Results

The effectiveness of the designed solution is verified by series of tests which are devised to check the UHF RFID transponder operability, as well as the effectiveness of the selected harvested power source and supercapacitor storage device.

A reading distance is measured for different transmitted power levels of UHF RFID reader. The results depicted in Fig. 8 naturally shows increasing reading distance with increasing transmitted power level of RFID reader. The peaks of the curves are caused by measurement in indoor environment where multipath propagation occurs.

Series of tests concerning the charging time of the supercapacitor via the solar panel are also performed. To replicate different environments, the complete system is set up in different light intensities which are measured using the Lux meter. The full system is set and

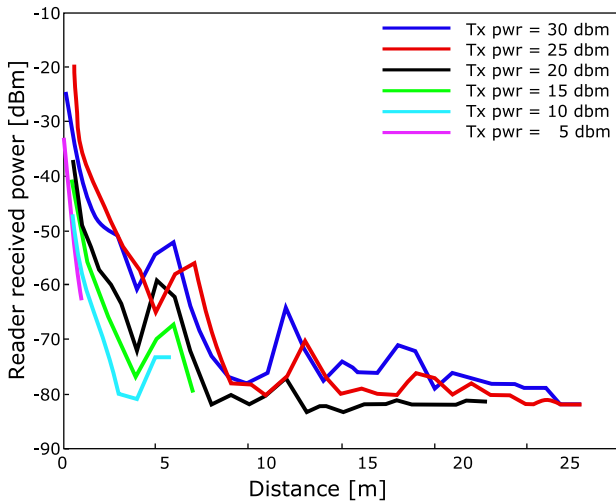


Fig. 8: Reading distance of the prototype for different transmitted power levels of UHF RFID reader.

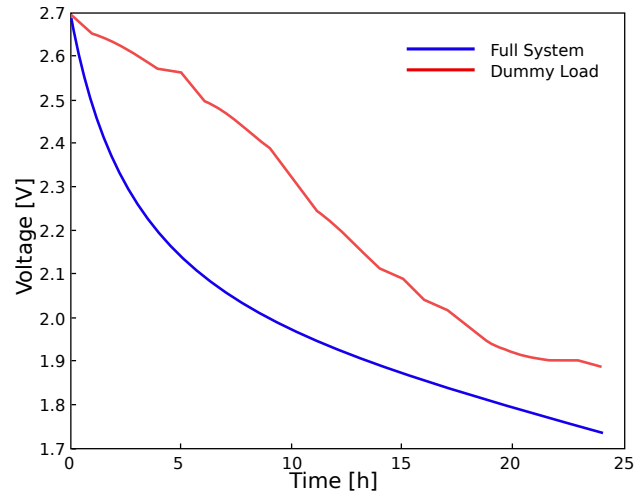


Fig. 10: Discharge test of the realized prototype of RFID transponder with super capacitor.

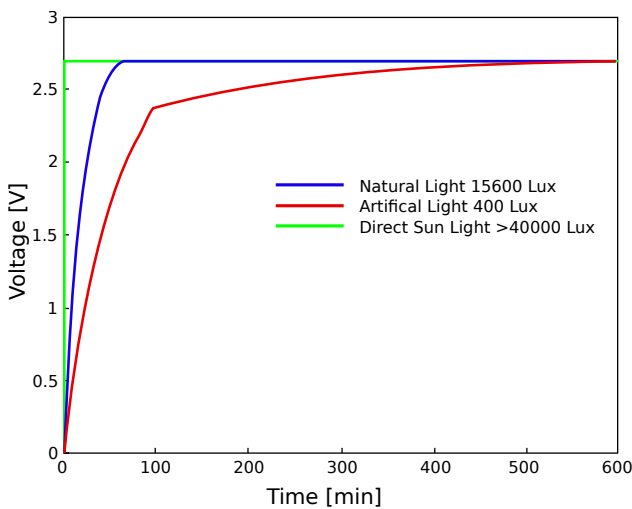


Fig. 9: Charge test of the realized prototype of RFID transponder with super capacitor.

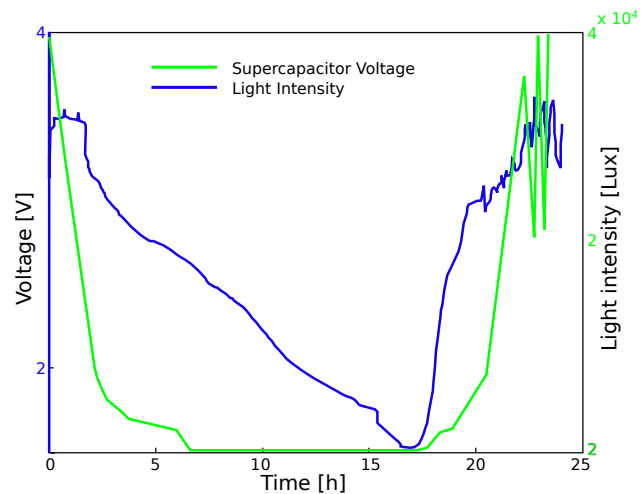


Fig. 11: Soak testing of the realized prototype of RFID transponder with super capacitor.

the voltage level of the supercapacitor is read at an interval of 1 second and stored on a computer. The first test carried out is in natural light with a light intensity of 15600 Lux and took 68 min to charge fully. The second used artificial office lighting of around 400 Lux and took 600 min to charge fully. Lastly, direct sunlight is used which has a Lux level in excess of the light meters maximum range which is in excess of 40000 Lux and only took 92 s to charge fully.

The test which can verify the ability of the prototype to be operational throughout the night is also performed. To ensure the supercapacitor gives enough power to the chip when there is no sunlight a discharge test is carried out. This is essentially a full system test with the solar panel removed, and the voltage level of the supercapacitor is taken at regular time intervals via a multimeter and stored on the computer. The test

confirms the prototype is able to be operational several hours without solar panel when fully charged.

The soak testing is performed for 24 hour period of time in order to see its overall functionality. The test is started at 12 p.m. The weather conditions are bright sunshine with no cloud cover although the panel receives some shade due to other buildings. The prototype is set up with the solar panel left on a window ledge to replicate a real world situation and show charging rates for different times of day. The supercapacitor voltage levels are taken at an interval of 1 minute while the light level is taken at an interval of 30 minutes. Figure 11 shows the voltage of the supercapacitor for varying light conditions depending upon the time of day. As expected the supercapacitor charges quicker in brighter light but charges to around 3.3V rather than the protection circuit design maximum of 2.7 V. The supercapacitor slowly discharged when no

light is available to around 1.6 V which was less than expected but well within the bounds of EM 4325 voltage requirements (1.25–3.65 V). The voltage fell far quicker than in the discharge test this was attributed to leakage through the blocking diode. The supercapacitor voltage increases again with sunrise to its maximum level.

## 4. Conclusions

The paper describes a design of UHF RFID semi-active transponder with super capacitor. The proposed prototype is measured in order to determine the effectiveness the designed solution. The RFID transponder consists of the EM 4325 chip, On-Board dipole antenna, monocrystalline photovoltaic panel, 10 F supercapacitor and protection circuit realized by the voltage regulator. Measurement results show the maximal reading distance is more than 25 m (at transmitted power level of RFID reader 25 dBm and 30 dBm), time needed to fully charge of the prototype for different light sources (92 s for direct sunlight, 68 min for natural light and 600 min for artificial office lighting), operational time of the prototype without light source is more than 20 h and soak testing which confirms an operational reliability. The measured voltage value falls quicker than in the discharge test due to the blocking diode allow leakage through the night. It can be fixed by a replacement of blocking diode with a charge controller with a low-voltage disconnect function.

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