World Applied Sciences Journal 30 (Innovation Challenges in Multidiciplinary Research & Practice): 103-109, 2014
ISSN 1818-4952

DOI: 10.5829/idosi.wasj.2014.30.icmrp.16

Design and Implementation of an Internal Rechargeable Powering Source for Zigbee Transponders

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Submitted: Jan 5, 2014; **Accepted:** Feb 24, 2014; **Published:** Mar 12, 2014

Abstract: Wireless technology has become a new emerging technology in healthcare industry. Efforts have been made by many researchers to integrate Zigbee wireless network transponders with sensors to measure patients' temperature, heart rate, oxygen saturation, respiratory rate and etc. and monitor them continuously from remote locations in hospitals. This transponder requires internal power supply or battery to run its internal circuitry. It was found that life time of the battery is one of the major issues in the monitoring device as it uses certain amount of power to power up components in the device. This may cause interruption in the monitoring process that leads to serious consequences. This work is discussing on the design and implementation of external powering mechanism using rechargeable battery to replace the conventional lithium coin cell battery that can only sustain for few hours if continuous monitoring is implemented. Prototype to recharge the battery externally using USB input was developed and was tested using three different types of batteries. Each battery is connected in with the transponder for powering and also to the recharging circuit prototype to test whether sufficient power and current is provided to power it up. Their performances were observed based on the applicability, lifetime, size, cost and efficiency. It was found that 3.7V lithium polymer battery is giving optimum performances and is proposed as external power source for developed Zigbee transponders.

Key words: Battery · Rechargeable circuit · Zigbee · Wireless monitoring · Transponder

INTRODUCTION

The expanding of wireless technology applications has triggered many researchers with bunch of ideas in improving the existing products that are currently being used. As this emerging technology on combination of RF frequencies and wireless sensor network technology is being implemented in healthcare industry its reliability and stability are the most important criteria to meet [1]. Zigbee technology has been a choice of many researchers wireless sensor network. The Zigbee is a combination of the RF frequency range and its own Zigbee protocol from Zigbee Alliance provides an advantage in either emerging the technology with other wireless technology or to stand alone. The developed transponder with sensor or sometimes is also called as tag is used as a monitoring device to collect sufficient amount of parameters from test subjects. These data are transmitted to the reader for interpretation or monitoring purposes. These tags are used to read the data continuously at longer distance and time, therefore a reliable and longer discharging time is preferable [2].

In this technology the Zigbee transponder is embedded either with heartbeat, blood pressure or temperature sensors and is to be worn by the patient and its reading is to be monitored from remote locations. Reading obtained from each patient will be sent to the reader placed at nurse station in every 15 minutes or as required. This data is transmitted using RF frequency technology that uses electromagnetic field [3]. To ensure the tag is transmitting the data continuously, it must have reliable power source that does not fail during transmitting the data and the monitoring process.

Conventional method of powering any wireless transponder is by internal 3V coin cell battery which normally results on the lifetime of the transponder will depend on the lifetime of the battery. Continuous monitoring that uses a time interval of for example less than 15 minutes of each data transmission or without long period of sleep mode may require the battery to be

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replaced due to vast depletion of battery source [4]. Replacements of batteries would lead to insufficient in terms of cost and require training to the medical professionals to handle the devices. This will also lead to inefficiency in the monitoring process for data collection. This project is focusing on the development of prototype that works as an internal battery charger and is used to charge up the three types of batteries chosen using USB port. Series of experiments were conducted to investigate the capability of the prototype to charge up the batteries and the maximum time taken for the battery to be fully charged was observed. Once these batteries were fully charged, they were connected to the tag to ensure they have enough power and current to wake the tag up. Times taken for the batteries power to decay were recorded and this was done for data transmitted in every second. The prototype was improvised many times to obtain the efficiency needed and to make it workable and meet the requirements of the tag.

LITERATURE REVIEW

Many researchers have developed numerous methods in solving the power sourcing issue of a transponder. Even though the Zigbee transponder provides an advantage of low powered, but the discharging time of the power source still depends on the battery capacity and current used in the designed device.

These methods are obtained through different implementations such as (i) developing an ultra-low-power tags with multiple power domains (ii) the use of Delta Sigma analogue to digital converter (ADC) in for the use in sensor tags, (iii) design and development of smart sensors that enables low power consumption for integration with tags, and also (iv) energy balanced method by implying pseudo code for relay node select algorithm.

With current vast technology on renewable energy, the researchers also implement the idea of harvested energy into developed tags. The energy harvester technology discussed are formed from variety or sources such as Micro –Electro Mechanical System (MEMS) which converts the mechanical vibration from piezoelectric, acceleration, electrostatic and electromagnetic to electrical power as a power source to power up the tag. The mechanical vibration is produced as a harvested energy to the technology [5, 6] and the Thermoelectric Generator (TEG) method introduces the Seebeck effect from the environment which designed to potentially provide power to devices that uses low power operation i.e. human heat. The design is built on the basis of a thermal model of the device, which includes the human body as one of its important elements [7-11].

Aside from introducing renewable energy sources, researchers also have been designing the internal circuitry for the transponder in terms of low powered circuit components and also enable better wake up and sleep mode scheme of the data transmission to enable better power consumption during transmission. As discussed in [4,12-13,19], with suitable microcontroller and wireless transceiver not only be able to lower the power consumption and enable longer discharge time, but also be able to provide better distance in transmission.

In this design of device, multiple choices of batteries are tested to ensure the sufficient voltage and current sources to the internal charging circuitry. Comparison of six (6) types of battery (Li CR2032 Coin, Li-Ion CR2032 Rechargeable Coin, Li- Ion CR2450 Rechargeable Coin, VL3032 Rechargeable Coin, Nokia BL-5B and Li-Po) was made according to using current capacity, type of electrolyte, voltage, weight, cost and cycle hours as main requirements and three (3) were chosen which are Panasonic VL 3032 Rechargeable Coin Battery, Nokia BL-5B and 3.7V Lithium Polymer Battery.

Panasonic VL-3032, a rechargeable coin battery, based on handbook in [14] is a battery that has nominal voltage of 3V and capacity of 100mAh and has the highest energy density compared to other type of batteries such as NiCd and NiMh. So, the lifetime of the battery is expected to be longer. This battery is using Lithium Vanadium Pent-oxide technology and weight about 6.2g. In details, the positive electrode of the battery contain 5~21wt% of Vanadium pent-oxide and the negative electrode contain 0.2~2wt% of Lithium alloy [15].

The second type of battery chosen was Nokia BL-5B which is used normally for Nokia brand hand phones. Based on its datasheet, this battery has nominal voltage of 3.7V and capacity of 890mAh which makes it valid to be chosen to investigate the capability of developed charging circuit to charge up the battery. It has maximum charged voltage of 4.2V and weight only 20g.

Lastly, Lithium-polymer (LiPo) battery was also chosen for this work. Lithium-polymer battery is an advanced version of Lithium-ion battery. It differs from the other type of battery due to the type of electrolyte it used. The electrolyte is bonded to a solid thin layer of polymer, which is placed between positive and negative electrode materials and have high conducting collector current. The design of the battery is as shown in Fig. 1 [16].

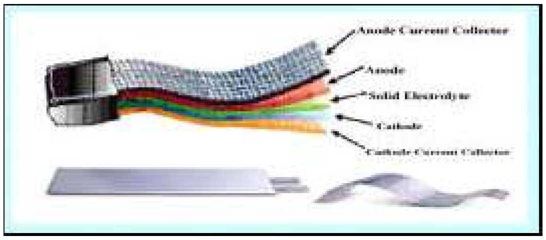

Fig. 1: Example of a One-column figure caption

Lithium ion battery is the common battery used to power up transponders and it has been widely used in other devices as well as cell phones, cameras, laptop and computers. In this work, after few tests and investigations was carried out as discussed in Section V and taken into consideration of its optimum performance and cost, lithium ion rechargeable battery was selected as an internal battery for the wireless transponder and it can be recharged by the developed recharging circuit. Some aspects were taken into consideration when using this battery to retain its safety, battery life and durability. The properties of lithium battery are depending on the chemical nature of the electrode material.

During charging and discharging of the battery, the lithium which is originally present in the electrolyte and at the positive electrode, will chemically react to one or other electrode, inserting and intercalating into the bulk material. When the process occurs, it actually changes the chemical identity of the electrode [17]. In charging process, the lithium is more stable at the positive electrode. The power supply needs to detach the lithium from the positive electrode to form the Li+ ion and push them to the negative electrode for charging process to happen.

The only process that must occur at the meso scale (smaller than an electrode, larger than a molecule) is the transportation of lithium ions through the electrolyte and in the active particles, with the reversible reaction of the lithium at appropriate location within the electrode. So if any unwanted mechanism occurs during the process it will result in battery inefficiency and failure. The design of the charging circuit will also determine battery life time because this lithium ion battery is very sensitive and requires a proper charger that can control the current flows when the battery is fully charged [18].

PROTOTYPE DESIGN AND DEVELOPMENT

The prototype for charging up the three types of batteries chosen was developed to ensure the charging process is possible. Dual operational amplifiers and a transistor were used to create a lithium battery charger as shown in Fig. 2. Operational amplifiers were used as voltage comparator. As well known, an operational amplifier has two incoming input which is positive (V+) and negative (V-) where V+ is the input of non-inverting input and V- is the inverting input. An ideal op-amp amplifies the input voltage by the equation below.

$$V_{out} = A_{out} (V_{+}-V_{-}) \quad (1)$$

The voltage of the connected battery will be reduced before it enters the op-amp by the voltage divider set by the resistors. When the input voltage is low, the output voltage of the op-amp will also be low which will cause the forward bias of blue led to have positive value hence allowing the current to flow through it. The transistor BD140 is used as a switch to limit the current and voltage to be fed into the battery. When base voltage is less than 1V, the transistor will turn off. This base voltage is depending on the voltage output of the op-amp and voltage from the Vcc. When the battery voltage is at 3.8V, the transistor will turn off and the circuit will stop feeding the current and voltage into the battery. This explanation shows the process of current flow to charge and discharge the battery. This will then produce the maximum charging voltage and current transmission of the circuit to the battery.

Before transferring this prototype design to breadboard and PCB, it was simulated to ensure the results obtained are as expected and to ensure that the design is not damaging the battery to be connected to it later. Once the simulation results were as expected, the prototype was built on the breadboard for further testing. Many testing were done on the breadboard and the design was improvised many times until the design in Fig. 2 was obtained. This design was then digitally drawn to be Printed Circuit Board (PCB) form as shown in Fig. 3 before the actual PCB is built or manufactured as shown in Fig. 4.

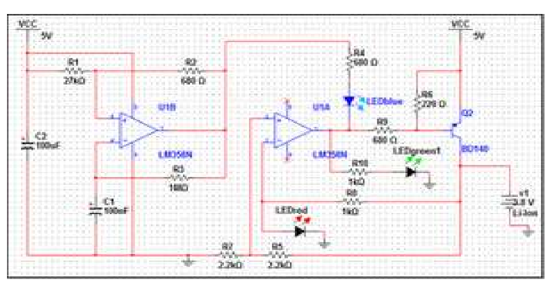

Fig. 2: Prototype circuit design

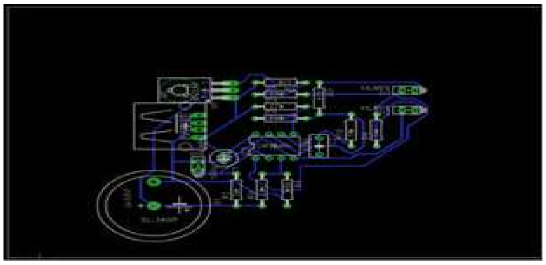

Fig. 3: PCB layout design

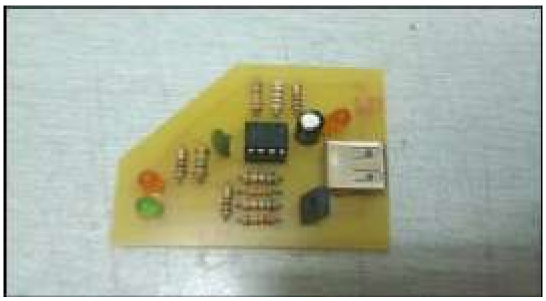

Fig. 4: Printed PCB circuit

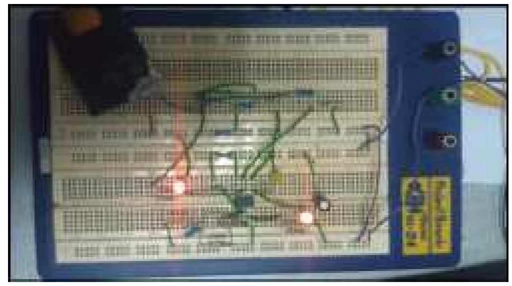

Fig. 5: Battery charging process (preliminary prototype)

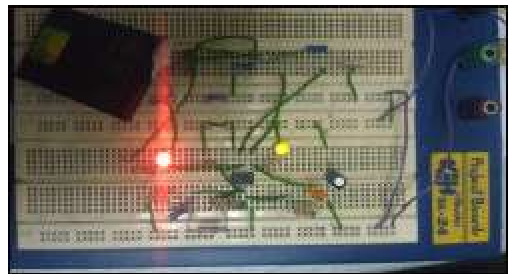

Fig. 6: Full charged battery (preliminary prototype)

Fig. 7: Recharging circuit connected to the transponder circuit

METHODOLOGY

As discussed earlier, the developed charging circuit will be tested with the three types of batteries. The batteries are Panasonic VL 3032 Rechargeable Coin Battery, Nokia BL-5B and 3.7V Lithium Polymer Battery. In this work, the Nokia BL-5B battery is used as the main battery for benchmarking as it is a 3.7 V battery and also capable in providing sufficient discharge time and amount of current to be supplied to the device.

These tests started by charging up all the batteries using the developed charging circuit. The fully charged batteries were then integrated to the transponder which has been embedded with heartbeat sensor. The discharge time for each battery recorded in time during the discharging. This configuration is as show in Fig. 5. In real application, the tag needs to transmit a data in every 15-20 minutes but for this testing; the tag was programmed to transmit data at every second through its transmitter to the receiver at the receiving end. All the transmitted data were recorded to ensure no data lost or no interruption in the transmitting process.

To test the circuit, orange led was used to replace the green led that is shown in the PCB design in Fig. 3, which is to indicate the charging status. Yellow LED was used to replace the blue LED to indicate the fully charging status. When the circuit is connected to the power source, the red LED will always light up. When the circuit is in the charging process, the orange and red LED will turn on as shown in Fig. 5. When the battery is already fully charged, the orange LED will turn off and the yellow LED will turn on as in Fig. 6.

Before the battery was integrated to the tag, the voltage of each battery was recorded to ensure that it was fully charged. When the power supply was connected to the tag, every pulse of heartbeat transmitted to the reader was indicated by the blinking led. This led blinked in every second. The battery was re-measured in every 30 minutes to record how much it has dropped from the previous reading until the tag stop transmitting the signal. The drained battery was recharged using the recharging circuit and its voltage was measured in every 30 minutes to know how long it took to charge up the drained battery to the maximum. The connected battery charger and transponder is shown in Fig. 7.

RESULTS AND DISCUSSIONS

This section discusses on the results obtained after the charging circuit was tested to the three types of batteries that were connected to the tag as discussed earlier.

Nokia BL-5B: The first test was conducted using Nokia BL-5B battery and it nominal voltage is 3.7 V. This nominal voltage works perfectly with the charging circuit design. Even though the maximum charging voltage of the battery is 4.2V, it has been set to have maximum voltage of 3.9 V only to suit with the tag maximum voltage requirement. The maximum voltage of the tag is +-3.3 V. From the battery output, the voltage of the battery was regulated to 3.3V so that it will not damage the tag. Few tests have been conducted when fully charged battery was connected to the tag. Voltage of the battery was measured in every 1 hour to record its discharging amount from the previous reading. The drained battery was recharged using the recharging circuit and its voltage was measured in every 30 minutes to know how long it took to charge up the drained battery to the maximum. The discharging and charging time of the battery is as shown in Fig. 8 and Fig. 9 respectively.

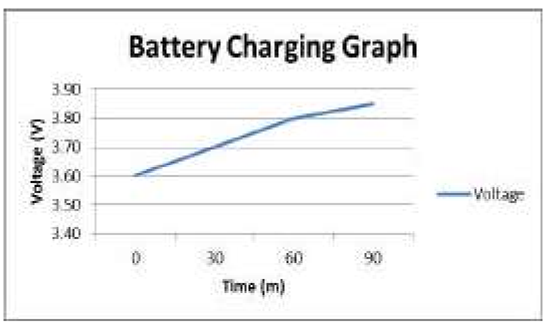

Fig. 8: Nokia BL-5B battery Discharging time

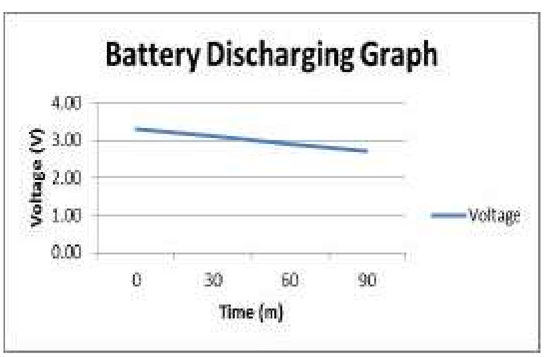

Fig. 9: Nokia BL-5B battery Discharging time

During the implementation of the battery to the tag as shown in Fig. 8, the fully charged battery voltage was at 3.15V. The discharging process was recorded in every hour and after 8 hours of continuous data transmission; voltage of the battery was at 2.8V which was at the tag's minimum voltage. It was observed that the tag was still continuously transmitting the data without any problem. So it can be concluded that this battery shall be used for up to 8 hours for continuous data transmission which occurs in every second. The charging process only took about 90 minutes.

VL 3032 Rechargeable Coin Battery: For VL 3032 rechargeable coin battery, the nominal voltage is 3V. It has been modified to meet requirement of the existing circuit by limiting the maximum charging voltage to 3.2V. When the battery was integrated to the real tag, it failed to wake the tag up and the tag failed to transmit any signal. After several testing and measuring, it was found that the maximum current drawn from the battery was too low to turn on the tag. Minimum current consumption for the tag is 70mA but the battery failed to generate that current to power up the tag. The indicator light at the tag was dimmed to indicate not enough supply and no data was able to be transmitted to the receiver. This battery therefore cannot be considered as external powering source for the tag.

3.7 Lithium Polymer Battery: The nominal voltage of this battery is 3.7V and is ideal for the design of this charging circuit. As in the previous type of battery, the output voltage was regulated before connected to the tag to suits the tag's power requirement. Few tests have been conducted when fully charged battery was connected to the tag. Voltage of the battery was measured in every 30 minutes to record its discharging amount from the previous reading. The drained battery was recharged

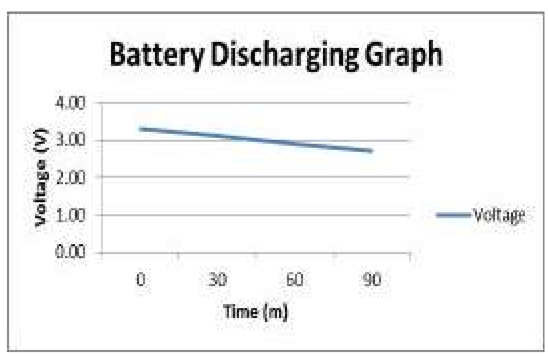

Fig. 10: 3.7V Lithium Polymer battery Discharging time.

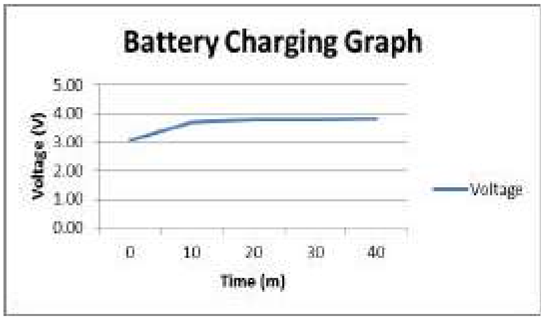

Fig. 11: 3.7V Lithium Polymer battery Discharging time

using the recharging circuit and its voltage was measured in every 30 minutes to know how long it took to charge up the drained battery to the maximum. The discharging and charging time of the battery is as shown in Fig. 10 and Fig. 11 respectively.

While the measurement stops after 90 minutes, it was observed that the polymer battery can still transmit the signal for about up to 2 hours. After 2 hours, the tag cannot transmit any data to the receiver anymore.

CONCLUSION

In conclusion, Nokia BL-5B has the longest transmitting time with minimum charging time. But it has limitation in terms of size as it is too big to be integrated to the tag and more costly. Due to these reason, the Nokia battery was made as a benchmark for other batteries. It was used on the first place with an intention to ensure the charging circuit worked and can be used to power up the tag. The best choice is to use 3.7V Lithium Polymer Battery as it is small to integrate to the tag with lower cost. Time taken for this tag to fully discharging was about 2 hours for data transmission at every second. This means in two hours, the tag has transmitted about 7200 data. If the transmission time is set at every 10 to 15 minutes, this battery shall last for more than 6 days considering some leakage is happening. If the battery can last this long, this is enough to support the tag uses by the patient in the hospital as most patient is normally warded for less than 3 days.

FUTURE WORK

The external powering source for the tag is to ensure continuity of power supply to the tag and no interruption. The efficiency of the charging circuit plays an important role to maintain the lifetime of the battery inside it. There are a few ways to improve the efficiency of the circuits; one of them is to re-create the circuit using battery management IC. By using this IC, the charging current and the charging voltage is ideally set inside the IC. This is a protection measure as the limit is already set and built inside the IC. More tests need to be conducted whether this IC is compatible to the design or not.

ACKNOWLEDGMENT

The authors would like to extend their sincere gratitude to Universiti Teknologi PETRONAS, for the assistants, guidance and support in all phases of this research.

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