

1-1-2007

## **A wireless sensor node architecture using remote power charging, for interaction applications**

Matthew D'Souza

*University of Queensland, dsouza@itee.uq.edu.au*

Konstanty Bialkowski

*University of Queensland*

Adam Postula

*University of Queensland, adam@itee.uq.edu.au*

Montserrat B. Ros

*University of Wollongong, montse@uow.edu.au*

Follow this and additional works at: <https://ro.uow.edu.au/infopapers>



Part of the [Physical Sciences and Mathematics Commons](#)

---

### **Recommended Citation**

D'Souza, Matthew; Bialkowski, Konstanty; Postula, Adam; and Ros, Montserrat B.: A wireless sensor node architecture using remote power charging, for interaction applications 2007, 485-492.  
<https://ro.uow.edu.au/infopapers/1570>

---

# A wireless sensor node architecture using remote power charging, for interaction applications

## Abstract

The wireless sensor node architecture proposed in this paper is optimized for use in a wireless interactive point, listen and see system. In particular, we focus on developing a wireless sensor node that can be remotely charged by harvesting microwave energy. The current system implementation allows a user to access information from a remote sensor via their mobile computing device. These sensors are limited in complexity due to the limited power available, and are cumbersome since manual intervention is required to replace its batteries. We propose a system where battery powered wireless sensor nodes can be recharged by harvesting energy from a microwave Radio Frequency (RF) signal source. The remote power charging module of the wireless sensor node architecture consisted of an antenna array and a rectification circuit. A prototype of the antenna array and rectification circuit of the remote power charging module for the wireless sensor node was constructed and is presented in this paper.

## Keywords

wireless, sensor, node, architecture, using, remote, power, charging, for, interaction, applications

## Disciplines

Physical Sciences and Mathematics

## Publication Details

D'Souza, M., Bialkowski, K., Postula, A. & Ros, M. (2007). A wireless sensor node architecture using remote power charging, for interaction applications. In Proceedings 10th Euromicro Conference on Digital System Design Architectures, Methods and Tools DSD 2007 (pp. 485-492). Los Alamitos, California: IEEE Computer Society Press.

# A Wireless Sensor Node Architecture Using Remote Power Charging, for Interaction Applications

Matthew D'Souza, Konstanty Bialkowski,  
Adam Postula  
*School of Information Technology and  
Electrical Engineering,  
The University of Queensland,  
Brisbane QLD Australia  
{dsouza, ksb, adam}@itee.uq.edu.au*

Montserrat Ros  
*School of Electrical, Computer and  
Telecommunications Engineering,  
University of Wollongong,  
Wollongong NSW Australia  
montse\_ros@uow.edu.au*

## Abstract

*The wireless sensor node architecture proposed in this paper is optimized for use in a wireless interactive point, listen and see system. In particular, we focus on developing a wireless sensor node that can be remotely charged by harvesting microwave energy. The current system implementation allows a user to access information from a remote sensor via their mobile computing device. These sensors are limited in complexity due to the limited power available, and are cumbersome since manual intervention is required to replace its batteries. We propose a system where battery powered wireless sensor nodes can be recharged by harvesting energy from a microwave Radio Frequency (RF) signal source. The remote power charging module of the wireless sensor node architecture consisted of an antenna array and a rectification circuit. A prototype of the antenna array and rectification circuit of the remote power charging module for the wireless sensor node was constructed and is presented in this paper.*

## 1. Introduction

This paper proposes a wireless sensor node architecture that forms part of a system used for locality aware information access in the point, listen and see (PLS) system. The PLS system could be used for interaction in museums, exhibitions, galleries, and similar venues and provides auxiliary information to the visitors of exhibitions. The system facilitates a seamless and natural method of retrieving information by pointing to the object of interest and receiving audio and visual information about that object on a mobile computing device such as a personal digital assistant (PDA) or mobile (cell) phone.

Although conceived for exhibitions, the PLS system can be applied to other interactive situations

that provide location specific information to users. It is especially useful when an object or item can be selected from a list of items by pointing to it. Various other interactive applications can be envisaged for using the system in tourism, recreation (e.g. location-based games), warehouse inventory or retail applications

The proposed wireless sensor node architecture incorporates a remote power charging mechanism. An interactive pointer device and wireless sensor system for use with the PLS system was developed and is presented in this paper. The proposed wireless sensor node must meet a number of requirements, such as low visibility (as to improve aesthetics), manageability (as to remove the need for human intervention), and improve mobility (allow the sensor node to be easily moved/transported).

The proposed sensor node uses an antenna array to harvest microwave energy. The harvested power is used to charge the energy source of the sensor node. This meets the requirement of manageability, as no physical connection or human interaction required to charge the node. This combined with remote pointer allows the wireless sensor node to be placed in locations suitable for interaction but not necessarily convenient for maintenance.

Currently implementations of wirelessly powered devices use RFID [3] (Radio Frequency Identification) and SAW [17] (Surface Acoustic Wave) technologies. These devices feature no power storage device (battery), and harvest energy from the communication signal. Noted disadvantages of using RFID technology for the interactive PLS application are its limited range and limited support amongst mobile computing devices.

This paper is organized into 7 sections. Section 2 presents a review of related work. Section 3 describes a typical user scenario. Section 4 discusses the implementation of the wireless sensor system

infrastructure, pointer and wireless sensor node architecture. Section 5 discusses the proposed wireless charging module for the wireless sensor node architecture. Preliminary experiments are also presented by Section 5. Future areas of investigation are discussed in section 6 and conclusions are drawn in section 7.

## 2. Related Work

The Exploratorium guidebook as describe by Hsi [7] deploys infrared beacons, 802.11b wireless LAN and HP Jornada PDAs. When a user with a PDA comes within range of an infrared beacon, a uniform resource locator (URL) number is sent to the PDA via infrared. The Hypertext Transfer Protocol (HTTP) is then used by the PDA to request and receive the information via the 802.11b LAN connection. One of the disadvantages of this approach is the use of infrared technology for interaction. The user must be within line of sight of the infrared beacon. The use of 802.11b LAN connections restricts the types of mobile computing devices that can be used.

Interactive pointer devices are more commonly known as remote controls and are used in everyday life to control devices such as television sets. Pointers can be classified in terms on the communication medium used. Most commonly used pointers use infrared as a communications link. There are projects to develop pointers that use laser light. One such project described by Ringwald [15] developed a laser pointer linked to a PDA so that it can control devices remotely. One of the reasons for using laser rather than infrared is that it provides the user with a better visual mechanism to point at a device as suggested by Cavens et al [1]. So far pointers have not been used with guidebook wireless networks or other similar wireless network applications that require the user to select information.

Ros, et al [16] explored the use of localized services with mobile computing devices for a context aware multimedia guidebook application with an interactive pointer. A network of Bluetooth information point stations were placed at locations of interest. The information point stations with laser sensor nodes allowed user's to connect and receive information content via a Bluetooth file and serial transfer. The laser sensor nodes are used to detect the intuitive pointer. A disadvantage of this system is that the laser sensor nodes were battery powered and could be attached to the information point station via an RS232 cable. This limits the placement of the sensor nodes.

## 2.1. Wireless Powering

A commonly used wireless power mechanism is employed in RFID devices. The Texas Instruments RFID TIRIS system [8], [9], involves transmission of power via electromagnetic induction. The transmission signal also contains data. This method is commonly used in passive RFID. A more complex method involving an IC being powered via an electromagnetic RF field [4] has been studied by IBM. Higher frequency systems which use wireless power transmission include a 13.56MHz system [14] by Motorola, and a 5.8GHz system [2] to a wireless sensor. The higher frequencies allowed these applications to use a higher data rate and also the distance mentioned in these articles was greater than that of the lower frequency systems.

Hagerty et al [6] describe a system that can harness ambient microwave energy from the 1-10GHz frequency range. Retrodirective antenna arrays [13] are also being studied for use in typical wireless sensor applications, such as asset tracking [5] and remote sensor deployments [12].

## 3. Usage Scenario

In a typical application of our system information point stations along with wireless sensor nodes are placed at specific tourist icons such as monuments or along exhibits in a museum. The information point stations (IPS) form part of an information point network (IPN) as shown in Figure 1.

As the user roams around the museum or tourist site, he/she may choose to access information when approaching a point of interest using their mobile computing device (MCD). Once the user's MCD establishes a connection to the IPN via the nearest IPS, the user views a menu of information items as seen in Figure 1, related to that point of interest. Each information item is associated with a wireless sensor node. To select an item to view or listen to, the user intuitively aims their pointer to a wireless sensor node to access that particular item. The corresponding item is then downloaded via Bluetooth from the IPN and seamlessly executed by the MCD. Information items can be audio, text or image files.

## 4. Information Point Network Implementation

The network consists of information point stations (IPS) with wireless sensor nodes placed at specific locations of interest. Each IPS connects via Ethernet to a central server as shown in Figure 1. Each IPS contains a wireless Bluetooth transceiver which is

used to communicate to the user's mobile computing device (MCD). The wireless sensor nodes consist of a laser sensor and an infrared transceiver (optical channels). The user selects to view information by aiming the pointer device at a sensor device. The requested information is then viewed or listen to on the user's MCD. The wireless sensor nodes and interactive pointer device can be seen in Figure 2.

#### 4.1. Interactive Pointer

When activated, the pointer continuously transmits an ID sequence to activate the remote sensor node. The wireless sensor node responds with a unique ID specifying the sensor. With this unique ID, the MCD can, via Bluetooth, query the IPS for information pertinent to that sensor node. Figure 3 outlines this system.

The pointer transmitter circuit consists of a laser diode with associated driver circuitry. The laser diode was used to communicate with the targeted wireless sensor because it visually allows a user to easily aim pointer at a wireless sensor node. The MSP430 [19] microcontroller from Texas Instruments encodes the data stream using Manchester encoding, and manages communication with the MCD via RS232. This microcontroller is chosen for its low power consumption. The pointer also contains an infrared transceiver to receive the wireless sensor node's ID.

#### 4.2. Wireless Sensor Node Architecture

The wireless sensor node is a standalone entity. It consists of a laser sensor and an infrared transceiver. Once the interactive pointer's ID has been detected, the wireless sensor node responds by transmitting its ID via the Infra-red channel to the pointer ID. The wireless sensor node architecture can be seen in Figure 3. The laser sensor receives the modulated data stream via two OPT101 [18] monolithic photo-diode receiver circuits. This integrated circuit consumes minimal power, and includes an internal amplifier, leading to a simple receiver design. Two receiver circuits are employed to increase the effective viewing angle of the sensor. The infrared transceiver is used to convey information to the user's MCD via the pointer device. The MSP430 is used here to demodulate the waveform. The power for this device is a 3V rechargeable Lithium coin cell battery. As shown in Figure 3, it is proposed that the battery will be trickled charged using by a power recharging module. This is described in further details in section 5.

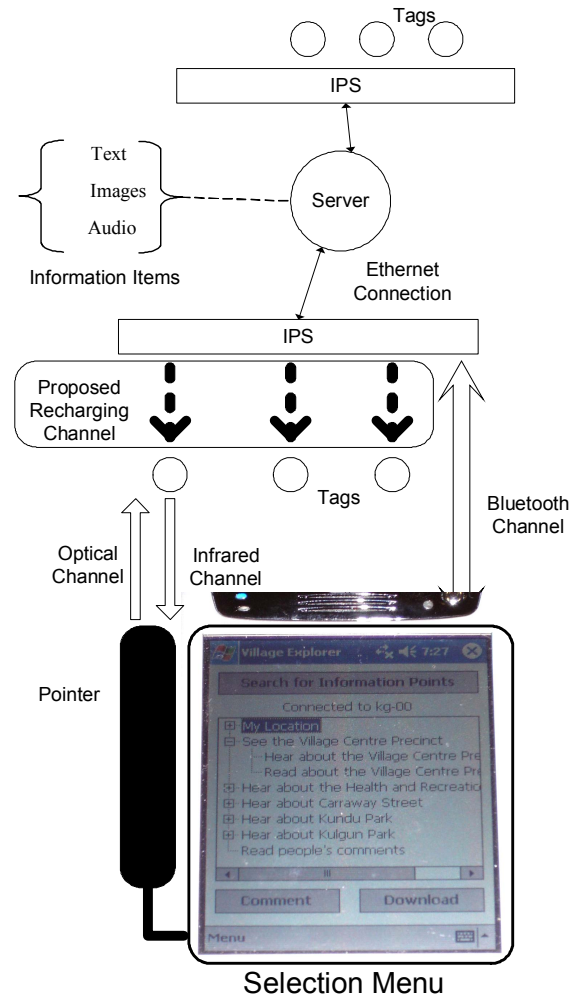


Figure 1 - Information Point Network Infrastructure

#### 4.3. Information Point Station

The information point station (IPS) is connected via an Ethernet network to a central server to form the information point network as shown in Figure 1. The information point station is an embedded Linux platform. Each IPS has a Bluetooth transceiver that communicates with a user's mobile computing device. As shown in Figure 3, a proposed addition to the IPS is a power recharging module that is used to provide energy to remotely charge the wireless sensor nodes. More details on the remote power module are presented in section 5.



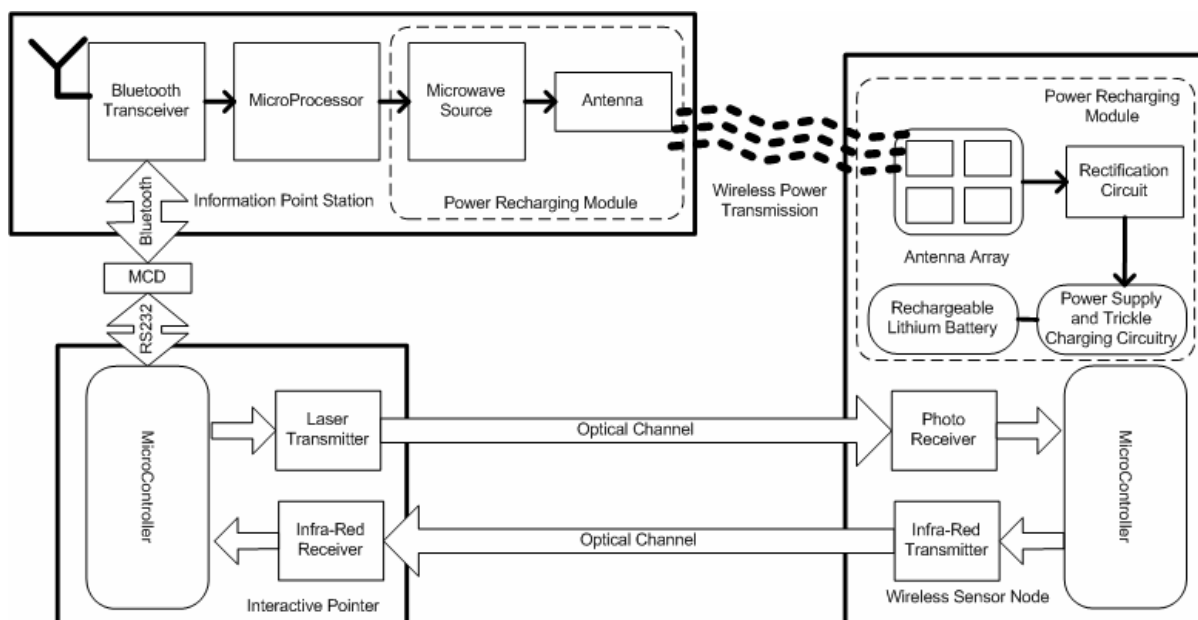
**Figure 2 – Interactive Pointer and Wireless Sensor Node**

#### 4.4. Power Recharging Mechanism

This section describes the power recharging mechanism in detail, presents power budget estimations and discusses the experimental setup and preliminary results obtained. The architecture of the power recharging module for the wireless sensor node is shown in Figure 3. It consists of an antenna array connected to a rectification circuit. The antenna array

is used because the voltage received via one antenna is insufficient to power the microcontroller. Thus an array of antennas is employed to generate the required voltage and power.

The rectification circuit is shown in Figure 4. The diode used in this circuit is a Schottky Barrier Diode. The rectification circuit forms a resonant circuit with a non-linear element (the diode). The output of the rectification circuit is a DC bias voltage which



**Figure 3 – Architecture of Wireless Sensor Node, Interactive Pointer and Information Point Station**

recharges the battery of the wireless sensor device.

Due to the design complexity of the node, the power beamed by the information point station is not sufficient to fully power the wireless sensor node. Thus a battery is used to store energy so that the sensor device can maintain operation. The output of the rectification circuits are summed, and used to trickle charge the battery. Prototypes of the antenna array and rectification circuitry were constructed and are discussed in section 5.2.

As shown in Figure 3, it is proposed that the power recharging module on the information point station emits a high-frequency RF signal which powers and charges all wireless sensor nodes in close proximity to it.

#### 4.5. Battery Recharging Requirements

Rechargeable Lithium Ion batteries Renata ICP603 [21], was considered for use in the wireless sensor node. The minimum power required to recharge the ICP603 battery at 1mA trickle charging is 4.2mW though the time required would be more than 3 hours. In order to charge at a faster rate, the power required is 42mW at a current of 10mA. The ICP603 was considered due to its small physical size and capacity of 330mAh.

### 5. Harvested Microwave Power Analysis and Regulations

This section discusses the how much power can be harvested from a microwave source with regard to associated regulations. Since microwave power has adverse effects on biological systems [10], [11], there are legal limitations applied to the maximum power level (or density) that can be transmitted from an antenna. Keeping to these levels leaves little power available to power an integrated circuit or processor.

The amount of power that can be transmitted is limited by regulatory organizations, such as the FCC

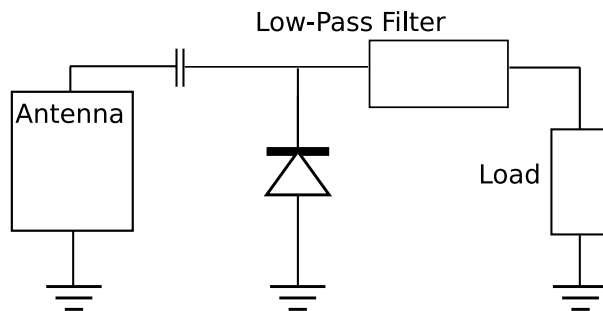


Figure 4 - Signal Rectification Circuit

and ETSI. The amount of power that can be received by the remote sensor from the interrogator is based on Equation 1 [20].

$$P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi R} \right)^2 \quad (1)$$

In this equation,  $P_r$  is the power received by the receiving antenna,  $P_t$  is the power received by the transmitting antenna,  $G_t/G_r$  describes the gain of transmitting and receiving antenna respectively and  $R$  is the distance between both antennas.

In Figure 5 the theoretical maximum signal strength at the receiver, based on several distances is shown. Since regulatory organizations specify maximum power in terms of equivalent isotropic power, the  $G_t$  is fixed. In Figure 5, a number of receiver gains are shown. In reality, there will be further losses due to polarization mismatch, or multi-path effects. These problems can be mitigated using better antennas which use sophisticated designs or via signal processing techniques.

Comparing this to the maximum available power as graphed in Figure 5, there is an estimated 100mW of available power which is feasible to power a device of reasonable complexity. However, this maximum power does not take into account losses due to mismatch between antennas and signal distortion due to the wireless channel.

This deviation from the maximum could be up to a factor of 30dB, and this would leave little power available for powering any type of electronic circuit. Therefore a form of power or battery storage is needed and a system of trickle-charging is required to recharge the battery.

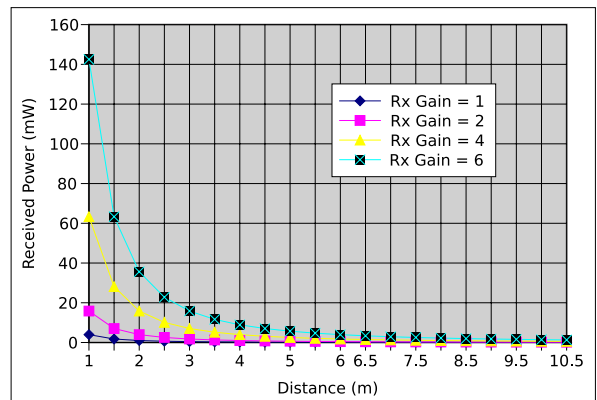
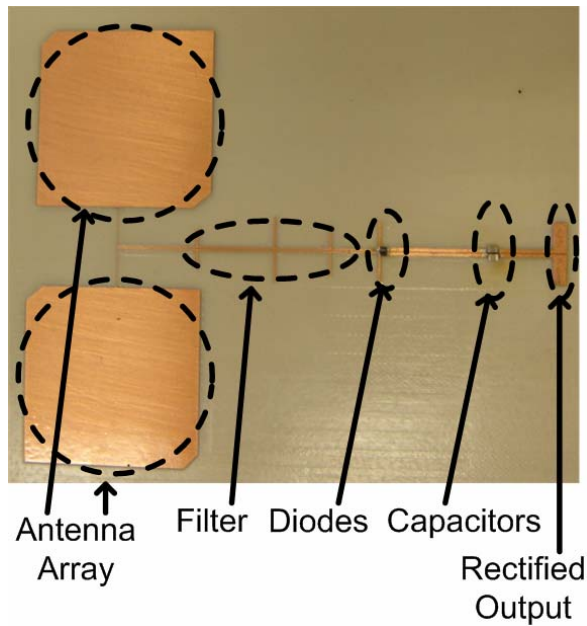


Figure 5 - Theoretical Maximum Signal Strength at Receiver at 2.4GHz





**Figure 6 - Prototype of Antenna Array and Rectification circuit**

### 5.1. Experimental Setup

Prototypes of the antenna array and rectification circuitry were constructed and tested but not integrated with the wireless sensor node. The prototype antenna array was manufactured on RO4003 substrate which has a dielectric constant of 3.6. It consists of two parallel circuits used to boost the power and voltage of the received signal. Each circuit has a filter, diode and capacitor for the rectification circuit. The antenna array and rectifier can be seen in Figure 6.

The experiment setup as seen in Figure 7, involved using a vector network analyser (VNA) as a signal source connected to an amplifier and two custom made antennas. The VNA was put into single frequency mode, in order to produce a continuous waveform. The amplifier provides an amplification of 30dB for frequencies of 2.2GHz to 2.7GHz. The total

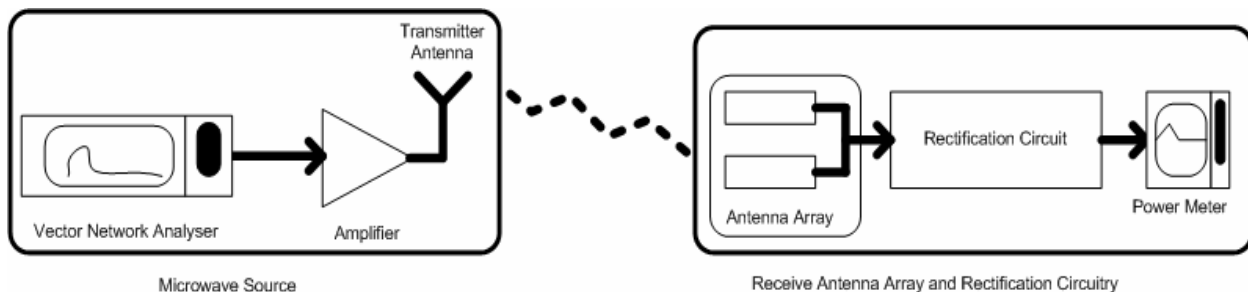
transmitted power was 15W. The transmit antenna used was a printed wide band monopole with an omni directional radiation pattern.

The amount of received power was measured directly from the output of the rectification circuit, using a power meter. Figure 8 shows the received power with respect to distance. As seen from Figure 8 the maximum power of 15mW at a distance of 0.6m, would be suitable for recharging the wireless sensor node in terms of power received.

## 6. Future Work

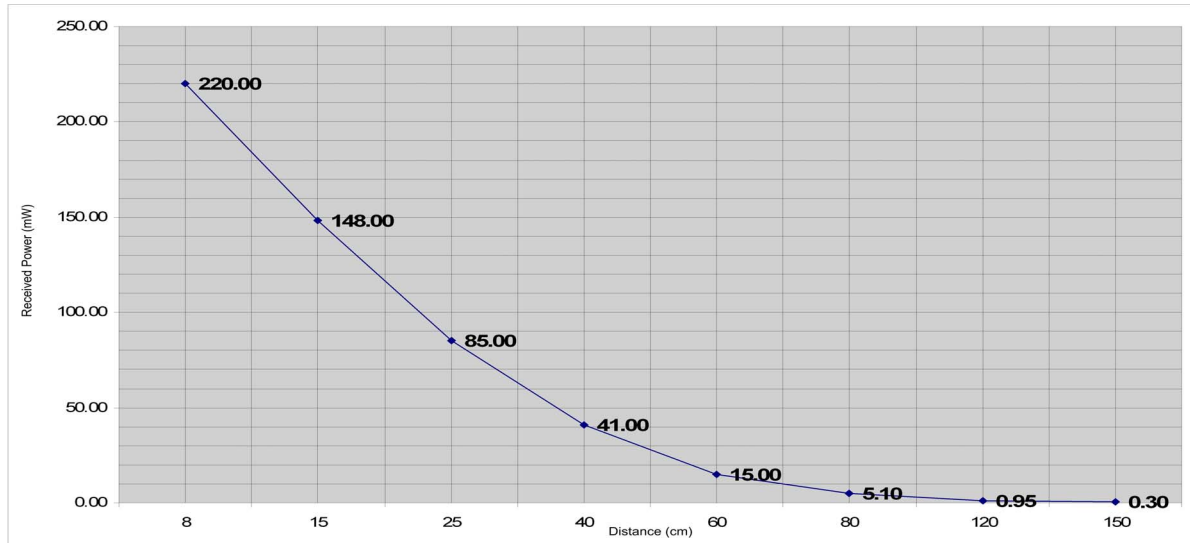
Although functional prototypes of the wireless sensor node, interactive pointer and information point station were created, there are a few issues that require further investigation. Issues with integrating the antenna array and rectification prototypes to the wireless sensor node will be addressed. The issues are to do with the power recharging module of both the wireless sensor node and information point station. This involves experimenting with different types of antennas, particularly directional sensitive antennas in order to improve the transfer of wireless energy from the information point station to the wireless sensor node. Investigations into reducing the size and increasing the receiving gain of the antenna array will also be looked at.

A suitable microwave transmitter for the power charging module of the information point station needs to be investigated. Step-up voltage converters required to increase the rectified voltage to trickle charge a 3V rechargeable battery will also be looked at. Investigations will also be conducted in the use of multiple antennas that are part of the antenna array, for not only for power charging but also to provide a two-way communications link to the information point station.



**Figure 7 - Experimental Setup**





**Figure 8 - Measured Received Power vs Distance**

## 7. Conclusion

This paper has proposed an improvement to a wireless sensor system used for the interactive point, listen and see (PLS) system. Specifically, a wireless sensor node architecture that uses energy harvesting for recharging a battery was presented. Energy was harvested from a microwave RF source. The remote power charging module of the wireless sensor node architecture consisted of an antenna array and a rectification circuit. A prototype of the antenna array of the remote power charging module for the wireless sensor node was constructed and tested. The maximum received power was 15mW from a 15W source at a distance of 0.6m. The minimum power required to recharging the lithium Ion battery was 4.2mW. Over larger distances, it was found that using the prototype antenna array has reduced harnessed power levels. This can have implications on the recharge cycle of the battery source of the wireless sensor node.

The main advantage of the wireless sensor node is that the use of microwave energy harvesting removes the need battery replacement and allows the wireless sensor node to be placed in unreachable locations. Future work includes integrating the remote power charging module with the wireless sensor node and investigating how the remote charging unit can be improved in its efficiency in receiving RF energy using directional antennas. A passive implementation of the wireless sensor node will also be investigated.

## 8. References

- [1] D. Cavens, F. Vogt, S. Fels, and M. Meitner, "Interacting with the big screen: pointers to ponder," in CHI '02 extended abstracts on Human factors in computing systems. Minneapolis, Minnesota, USA: ACM Press, 2002, pp. 678-679.
- [2] Kai Chang and B. Strassner. Passive 5.8-GHz radio-frequency identification tag for monitoring oil drill pipe. IEEE Trans. Microwave Theory and Techniques, 51(2):356-363, 2003.
- [3] Raghu Das. RFID Explained: An Introduction to RFID and Tagging Technologies. White paper, IDTechEx, 2002.
- [4] D. Friedman, H. Heinrich, and D.-W. Duan. A low-power CMOS integrated circuit for field-powered radio frequency identification tags. IEEE Solid-State Circuits Conference, pages 294-295, 474, Feb. 1997.
- [5] V.F. Fusco, T. Brabetz, and N.B. Buchanan. A 62/66 GHz frequency offset retrodirective array. IEEE MTT-S Int. Microwave Symposium Digest, 1:315-318, 2002.
- [6] J.A. Hagerty, F.B. Helmbrecht, W.H. McCalpin, R. Zane, and Z.B. Popovic. Recycling ambient microwave energy with broad-band rectenna arrays. IEEE Trans. Microwave Theory and Techniques, 52(3):1014-1024, Mar. 2004.
- [7] S. Hsi, "The Electronic Guidebook: A study of user experiences using mobile web content in a museum setting", IEEE International Workshop on Wireless and Mobile Technologies in Education, 2002.

- [8] U. Kaiser and W. Steinhagen. A low power transponder IC for high performance identification systems. IEEE Custom Integrated Circuits Conference, pages 335-338, 1994.
- [9] U. Kaiser and W. Steinhagen. A low-power transponder IC for high-performance identification systems. IEEE Solid-State Circuits Journal, 30(3):306-310, Mar. 1995.
- [10] J.C. Lin. Radio frequency exposure and safety associated with base stations used for personal wireless telecommunication. IEEE Antennas and Propagation Magazine, 44(1):180-183, Feb. 2002.
- [11] J.C. Lin. Space solar-power stations, wireless power transmissions, and biological implications. IEEE Microwave Magazine, 3(1):36-42, Mar. 2002.
- [12] R.Y. Miyamoto, T. Itoh, and Yongxi Qian. Active retrodirective array for remote tagging and wireless sensor applications. IEEE MTT-S Int. Microwave Symposium Digest, 3:1431-1434, June 2000.
- [13] R.Y. Miyamoto, T. Itoh, and Yongxi Qian. An active integrated retrodirective transponder for remote information retrieval-on-demand. IEEE Trans. Microwave Theory and Techniques, 49(9):1658-1662, Sept. 2001.
- [14] P. Rakers, L. Connell, T. Collins, and D. Russell. Secure contactless smartcard ASIC with DPA protection. IEEE Solid-State Circuits Journal, 36(3):559-565, 2001.
- [15] M. Ringwald, "Spontaneous Interaction with Everyday Devices Using a PDA", Workshop on Supporting Spontaneous Interaction in Ubiquitous Computing Settings at Ubicomp 2002, Gothenburg, , Sweden, 2002.
- [16] M. Ros, M. D'Souza, M. Chan, K. Bialkowski, A. Postula, N. Bergmann and A. Toth. "Using Wireless Sensors as Selection Devices for a Multimedia Guidebook Scenario" *Workshop on Real-World Wireless Sensor Networks* (RealWSN 2005), Stockholm, Sweden, 20-21 June 2005
- [17] G. Scholl, C. Korden, E. Riha, C.C.W. Ruppel, U. Wol, G. Riha, L. Reindl, and R. Weigel. SAW-based radio sensor systems for short-range applications. IEEE Microwave Magazine, 4(4):68-76, Dec. 2003.
- [18] Texas Instruments. Monolithic photodiode and single-supply transimpedance amplifier. <http://focus.ti.com/lit/ds/symlink/opt101.pdf>.
- [19] Texas Instruments. MSP430 ultra-low-power MCUs. <http://focus.ti.com/lit/ml/slab034h/slab034h.pdf>.
- [20] F. T. Ulaby. Applied Electromagnetics. Prentice Hall, 1999 edition, 1999.
- [21] Renata Batteries. ICP603028-SC Rechargeable Lithium Polymer Battery. [http://www.renata.com/pdf/lithium\\_polymer\\_batteries/Data%20Sheet ICP603028-SC.pdf](http://www.renata.com/pdf/lithium_polymer_batteries/Data%20Sheet ICP603028-SC.pdf).