

# A DESIGN STUDY OF A WIRELESS POWER TRANSFER SYSTEM FOR USE TO TRANSFER ENERGY FROM A VIBRATION ENERGY HARVESTER

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**Abstract.** A wirelessly powered remote sensor node is presented along with its design process. The purpose of the node is the further expansion of the sensing capabilities of the commercial Perpetuum system used for condition monitoring on trains and rolling stock which operates using vibration energy harvesting. Surplus harvested vibration energy is transferred wirelessly to a remote satellite sensor to allow measurements over a wider area to be made. This additional data is to be used for long term condition monitoring. Performance measurements made on the prototype remote sensor node are reported and advantages and disadvantages of using the same RF frequency for power and data transfer are identified.

## 1. Introduction

This paper presents a case study into the integration of RF power transfer [1] with vibration energy harvesting which is being performed by the University of Southampton and Perpetuum Ltd. In the prototype integrated system energy is harvested using a Perpetuum vibration energy harvester and condition monitoring device [2] which is attached to the wheel bearing mount on a train, the existing Perpetuum sensor node is able to harvest more energy than it requires for its sensing and radio communications. This surplus harvested energy can then be used to wirelessly power a remote satellite sensor to increase the sensing capabilities of the system as a whole, with the remote measurements being transmitted back to the Perpetuum sensor node for onward transmission. The motivation for this novel approach is that in many deployment cases the optimum locations for both energy harvesting and sensing purposes are not coincident. In the rail bogie environment a cabled interconnection is impractical and an alternative route to provide power to the remote sensor is required. In this work this is achieved using RF power transfer at 915 MHz to transfer power over a distance of up to 1 m. The sensor measurements made by the remote satellite node are transferred back to the main sensor node over a single direction RF link operating at 915 MHz which shares an antenna with the RF energy transfer system.

## 2. System Specification

The first stage in the design was to draw up a list of key specifications of the wirelessly powered sensor node as these requirements will drive the design process, these specifications are as follows:

- Power to the remote sensor node is to be from harvested RF energy.



- Measured data from the remote sensor node will be transmitted to a local data sink over a unidirectional RF link from where it will be relayed over the existing data infrastructure.
- The power transmitter and local data sink will be connected to the existing Perpetuum vibration energy harvesters, and will be required to operate from harvested energy surplus to their needs.
- Power and data are to be transferred using a single antenna at each end of the power and data link over a distance of up to 1 m, with both power and data operating at circa 915 – 920 MHz.
- The wirelessly powered satellite sensor node is to store the harvested RF energy until it has sufficient to perform the desired measurements and then transmit the results to any available data sink.
- Target measurement and reporting rate is to transmit from the satellite sensor node at least once an hour to permit tracking of long term changes over time.
- Initially the satellite sensor is to measure the local temperature, with scope for adding further analogue sensors for other monitoring purposes.

From these requirements it can be seen that, as with most energy harvesting applications, the first consideration must be the total energy requirements of the satellite sensor node. Within the sensor node the highest energy consuming item is expected to be the wireless data communications, therefore the device selected should be as low power as possible whilst still able to achieve the anticipated communications range. Other components such as microprocessors and sensors should be selected to be low power, ideally with very low power sleep modes so that their power consumption during inactive periods is minimized. To operate the node from the harvested RF energy it is necessary to store the harvested energy until sufficient is available to operate the node. This energy store, typically a supercapacitor, should be sized such that it can contain sufficient energy to meet the node's requirements but is not excessively sized. Too much capacity will cause the node to take longer to harvest sufficient energy to reach the required start-up voltages.

### 3. System Design and Implementation

Given the outline requirements that have been established from the initial specification the design and implementation of the remote sensor node can be performed. Initially a block level approach is taken to designing the system, with the actual functional implementation following on from this stage.

#### 3.1. System Block Level Design

The block level design of the wirelessly powered remote sensor is shown in Figure 1, this design consists of seven main function blocks whose functions are as follows:

*Patch Antenna:* This is used both to harvest the transmitted RF energy and for communication back to the data sink attached to the main Perpetuum wheel vibration energy harvester.

*RF Switch:* The purpose of the RF switch is to isolate the RF energy harvester from the patch antenna during data transmission so that the RF energy associated with the transmission is not directly re-absorbed by the harvester but is radiated out to provide the communications link.

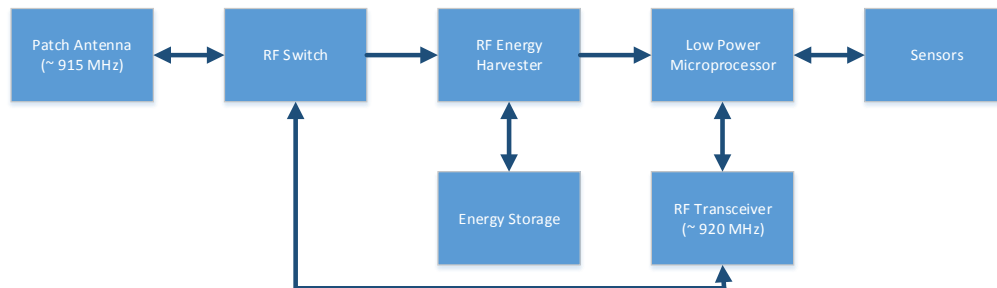
*RF Energy Harvester:* This section of the design takes the received RF energy, converts it back to electrical energy and then manages the storage and voltage regulation of this harvested energy to provide a suitable power supply to operate the rest of the sensor node's electronics.

*Energy Storage:* The role of the energy storage is to store the energy harvested from the RF source until a sufficient quantity has been harvested to enable operation of the sensor node.

*Low Power Microprocessor:* The microprocessor serves to control the operation of the sensor node, perform the measurements from the sensors and format the data ready to transmit using the RF transceiver module at the appropriate time.

*Sensors:* The initial sensing capability for the node is a single temperature sensor which measures the environmental temperature in the vicinity of the node. The node also has the capability to add two further, off-board, analogue sensors to add further sensing capacity.

*RF Transceiver:* The RF transceiver serves to take the data package prepared by the microprocessor and transmit it to the data sink attached to the RF energy source transmitter and main Perpetuum wheel-mounted vibration energy harvester.



**Figure 1.** Block level design of remote sensor node.

### 3.2. Hardware Implementation

To implement the prototype system design it was decided to use pre-manufactured modules for the RF energy harvester and radio communications. The RF to DC harvesting and conversion being achieved with a Powercast P2110B module, which also provides a DC-DC boost convertor to boost and regulate the voltage from the energy storage element to the level required by the rest of the node. The radio data communication link is realised using an LPRS eRA900TRS Easy Radio module which takes serial data from the microprocessor and encodes and transmits it.

The RF switch is implemented as a normally closed switch, so when it is not powered it directs the incoming RF energy to the harvesting circuitry, when the RF data transmission is desired it is then powered so that it opens and isolates the harvesting circuitry from the radio module and antenna.

The energy storage is implemented using a low-ESR double layer supercapacitor.

The low power microprocessor used is an XLP device from Microchip which has a very low power consumption sleep mode and the ability to gate the power to all of the internal function modules, such as the ADC, so that they are only powered when required. The microprocessor also controls the power supply to the radio module and the sensors so that they are only powered when they are needed.

The realised prototype wirelessly powered sensor node is shown in Figure 2, the patch antenna is not shown but connects to the SMA connector on the board and provides both harvesting and communication functionality.



**Figure 2.** Prototype satellite sensor.

### 3.3. Software Implementation and Satellite Sensor Operation

The operation of the remote sensor node is controlled by the software programmed into the microprocessor, the steps in the node operation are as follows:

The node harvests sufficient RF energy until it has sufficient stored to enable full operation of the sensor node. The microprocessor is first powered up (sensors and radio module remain off) and the microprocessor sleeps in a low power mode until there is a pause in the RF power transmission. The microprocessor then wakes up, powers up the sensors and measures their values, after which they are then powered down again. A measurement is also made of the internal band-gap reference to scale the measured sensor values. The measured data is then formed into a data packet, with a node identification string and a checksum. The RF energy harvester is isolated from the antenna and the

radio powered up and the data packet transmitted. After transmission, the radio is powered down again, the RF energy harvester is reconnected to the antenna, the microprocessor shuts itself down and the node returns to harvesting and storing energy ready for the cycle to repeat.

#### 4. Satellite Sensor Node Performance

A Powercast RF energy 3W source was used to provide the RF energy to test the operation of the prototype satellite sensor node and a local data sink consisting of an Arduino Due and an LPRS Easy Radio module connected to a terminal window on a PC to display the received data. Using the experimental setup it was verified that the sensor node would harvest energy from the RF source and charge the energy storage supercapacitor. Once the supercapacitor was sufficiently charged the DC-DC boost converter commenced operation and the microprocessor was powered up. Once powered up the microprocessor was observed to remain in the low sleep mode and periodically check if the RF energy source was still present. When the RF source was switched off the microprocessor commenced its measurement cycle, followed by transmitting the data package which was received and decoded by the local data sink.

During the node's operation its total energy consumption was measured, a full measurement cycle consisting of the three ADC input channels and the band gap reference, followed by transmitting the RF data packet twice with a 2 s interval between the transmissions, requires 143 mJ of energy over 2.25 s. This figure includes all the operational overheads such as the DC-DC convertor losses.

The DC-DC boost convertor operates with the supercapacitor voltage between 1.02 V and 2.3 V. With a 3 W source the time taken for the supercapacitor to charge over this range was 52 s. Based on the energy used by the RF transmitter a source of ~50 mW should be able to fully charge the supercapacitor in around 37 minutes. In use the supercapacitor does not get fully discharged before the measurement and transmission cycle completes, so the charging time will be further reduced.

#### 5. Discussion and Conclusions

The use of the same frequency for both the energy transfer and data communications has both advantages and disadvantages. The advantages include reduced node size and cost due to only needing one antenna and the ability to harvest energy from data communication between other nodes and sensors operating at the same frequency. The main disadvantage is that the RF energy transmission can block the data transmission and therefore requires the energy broadcast to be paused periodically to permit the remote node to transmit its data. In a system with multiple RF energy sources these pauses may need to be synchronised. In this work the target application requires that the satellite node be as compact as possible so the advantage of a single antenna outweighs the inconvenience of having to pause the RF energy transmission.

Ongoing work in the project is aiming to further reduce the energy usage of the satellite sensor node through the use of an integrated microprocessor and RF transceiver with enhanced power control over the RF system, the revised system will then be tested in its target deployment environment and the effects of this environment on the propagation of RF energy investigated.

#### References

- [1] Visser H J and Vullers R J M 2013 RF Energy Harvesting and Transport for Wireless Sensor Network Applications: Principles and Requirements, *Proc. IEEE* **101** 1410–1423
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