THE UNIVERSITY OF QUEENSLAND

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ENGINEERING PROJECT PROPOSAL

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The following document details the chosen field of research and proposed engineering project that Mitchell Elder will be undertaking as his Bachelor of Electrical Engineering Final Thesis, ENGG4802, at the University of Queensland. An overview of the relevant information is provided to give background knowledge into the chosen field and present prior research efforts in the field. A proposal is presented that stipulates the contribution to the chosen field that the student hopes to achieve through 26 weeks of research and development. A project plan is outlaid, detailing a chronological series of tasks that will culminate in the presentation of a final thesis report of the results of the project.

ENERGY HARVESTING FOR WIRELESS SENSOR NETWORKS

The Purpose - Wireless Sensor Networks

The continuous research and development of complementary MOSFET technologies has lead to great reductions in the size and power consumption of modern electronic circuitry. These developments have led to an increase focus on the feasibility and design of Wireless Sensor Networks [1]. The proposed networks would be comprised of thousands or even hundreds of thousands of wireless devices or 'nodes', which would collect and transmit desired data to either a central collection point or a neighbouring node. There are many proposed topologies on how the nodes should be distributed as well as various routing protocols and standards, all of which aim to minimise power consumption and maximise data integrity [2]. These proposed networks present the possibility of replacing long, high power transmission with many low power and low cost wireless devices.

Wireless sensor networks have extensive possibilities for application in a variety of industries. Such proposed implementations include;

- **Environmental Monitoring**
    - Light, temperature, humidity, ambient audio levels, etc
- **Structural monitoring**
- **Interactive and control**
    - RFID, Real time locators, process automation, vehicle sensors
- **Surveillance**
- **Remote Medical Sensing and Monitoring**

More and more possible applications and implementations will continue to emerge as the technologies are developed and made available.

Current designs of the nodes consist of a sensor or actuator (or combination of the two), a micro processing unit for collecting and manipulating data, and a radio transceiver for receiving and sending the collected data. These devices derive their value from their distribution; their ability to be implemented in various locations that are random and most probably difficult to access and being relatively mobile [3]. Such devices operate in a pulsed power fashion with an X% duty cycle, spending (100-X)% of their lifetime in a sleep state where their power consumption is at a bare minimum and only waking to a peak consumption state to take measurements or transmit and receive data.

Supplying power to this sort of device appears to be the most challenging technological hurdle still to be overcome [4]. The obvious solution would be to supply the node with power via wire from a designated power supply. However this most obvious solution is also the most illogical as it immediately undermines the value of such devices being random and mobile in distribution and implementation [3].

The next logical choice would be the next most common mobile power supply; a battery. However this choice is also not the optimal one. While other sectors of modern technology have advanced and developed at a continuous rate, it can be seen in the Figure 1 that battery energy densities have begun to plateau in recent years. This will defiantly have a stagnating effect on the development and mobility of portable electronic devices in coming years. Even though this is the case, batteries are one of the most common mobile power supplies on the market and must be seriously considered for application with wireless sensor network nodes.

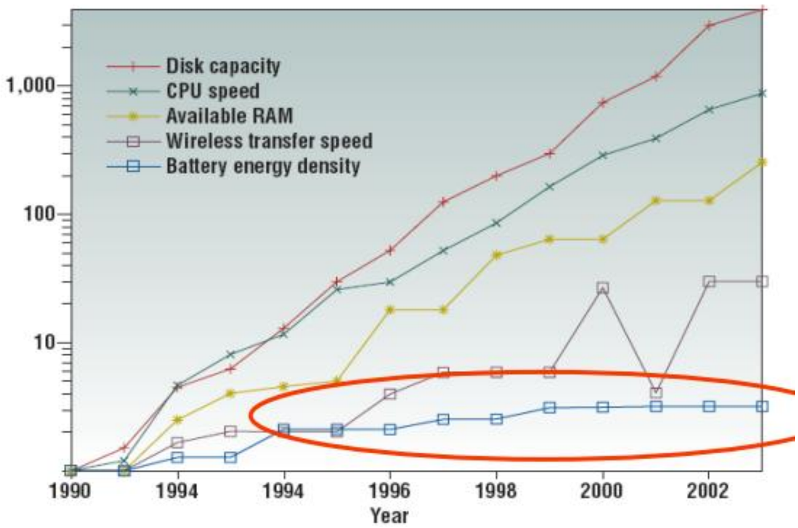


Figure 1
Mobile Computing Improvement – Paradiso, *et al.* Pervasive Computing, IEEE, 2005.

If a node has an average power consumption of 100µW and is powered by a 1cm^3 lithium battery containing 2,880J of energy, [5] then the life expectancy of that design would be less than a year. The cost of and time spent replacing the batteries in a few devices of a small network every year would be acceptable. However the task of replacing thousands or hundreds of thousands of batteries annually in nodes that are widespread and in difficult to access locations is neither practical nor desirable [1]. The other option would be to use a battery with the capacity to supply power for the entire life of the node. However, this class of battery would dominate both the cost and the size of the node, making this option unattractive.

Other less common power supplies such as micro-fuel cells, micro-heat engines, and even radioactive power sources are being considered for implementation however all are still in a development phase and not readily available. It occurs then that the development of a suitable power supply is the major factor hindering the final development and deployment of wireless sensor networks into the industries that await their advent.

The Possibility - Energy Harvesting

Energy Harvesting, also known as Energy Scavenging or Power Harvesting, is the art of converting and storing ambient energy as electrical energy that can be used to power electronic devices. This is not a new concept. People have tried and tested many methods of storing and converting energy from various sources. The windmill and waterwheel are two examples of energy harvesting techniques that have existed for centuries.

The term energy scavenging is used in applications where the ambient energy sources of the implementation environment are unknown or highly irregular, while energy harvesting refers to implementations where the ambient energy sources are well characterised and regular [2]. In the field of wireless sensor networks, one would hope that sufficient research was undertaken for each implementation to determine whether there is sufficient, if any, ambient energy sources in the desired environment to be harvested to power the nodes.

Unlike power sources such as batteries that are fundamentally energy reservoirs, energy harvesting sources are usually characterized by their power density rather than energy density. Energy reservoirs have a characteristic energy density, so the desired lifetime of their operation determines the average power output they are capable of supplying. In contrast, power scavenging sources have a characteristic power density, so the period of time that the source is available determines how much energy can be derived from it. Therefore, the primary metric for comparison of energy harvested sources is power density, not energy density [6]. Table 1 summarises and compares the power densities of energy harvesting sources and the energy densities of fixed capacity energy reservoirs.

Table 1[6]

Power Source	P/cm^3 (µW/cm^3)	E/cm^3 (J/cm^3)	P/cm^3/yr (µW/cm^3/Y)	Secondary Storage Needed	Voltage Regulation	Comm. Available
Primary battery	—	2880	90	No	No	Yes
Secondary battery	—	1080	34	—	No	Yes
Microfuel cell	—	3500	110	Maybe	Maybe	No
Ultracapacitor	—	50–100	1.6–3.2	No	Yes	Yes
Heat engine	—	3346	106	Yes	Yes	No
Radioactive (^{63}Ni)	0.52	1640	0.52	Yes	Yes	No
Solar (outside)	15,000[a]	—	—	Usually	Maybe	Yes
Solar (inside)	10[a]	—	—	Usually	Maybe	Yes
Temperature	40[a,b]	—	—	Usually	Maybe	Limited
Human Power	330	—	—	Yes	Yes	No
Air flow	350[c]	—	—	Yes	Yes	No
Pressure Variation	17[d]	—	—	Yes	Yes	No
Vibrations	200	—	—	Yes	Yes	Limited
Strain induced	200	—	—	Yes	Yes	Limited

Note: Values shown are actual demonstrated numbers except in two cases, which have been italicized.
[a]Denotes sources whose fundamental metric is power per *square* centimeter rather than per *cubic* centimeter.
[b]Demonstrated from a 5°C temperature differential.
[c]Based on reported values at an air velocity of 5 m/s and 11% conversion efficiency.
[d]Based on a 1-cm^3 closed volume of helium undergoing a 10°C temperature change once per day.

There are many technologies emerging on the market that aim at converting these ambient energy sources into useable electrical energy. Each has its own unique output characteristics (open circuit voltage, short circuit current and maximum power operating point). It is apparent that no single energy harvesting technique is universal to all implementations. Technologies would have to be chosen on an application-by-application basis depending on which types of energy sources are available in the chosen environment. Series and parallel connections of such technologies provide a higher, more reliable output but this kind of system becomes undesirable as its cost and size grow proportionally to the improvement in output and quickly dominate the size and cost of the device they would be powering. It would be desirable to develop a universal means of converting the electrical energy derived from energy harvesters, that are both apt in size and cost, and storing it in a form that is suitable for powering electronic devices.

The Project Proposal

The proposed thesis will be to design and evaluate a novel power converter and energy storage system. This type of device could be used in conjunction with energy harvesting technologies to provide an attractive solution to the problem of powering wireless sensor network nodes.

Using modern power electronic techniques and devices, the project will aim to;

- Provide a universal means of converting energy from sources with differing output characteristics.
- Provide a means of collecting and storing energy from multiple energy sources.
- Develop a technique, using only capacitors, of storing and delivering power to pulsed power electronic devices such as wireless sensor network nodes.
- Summarise these developments by stipulating a method of designing energy harvesting power supplies on an application-to-application basis.
- Provide proof of concept by relating the findings back to wireless sensor networks and design a system that sufficiently powers an appropriate dummy node **.**

The proposed thesis is highly relevant in the current electronics world. Wireless Sensor Networks are ever approaching their advent into the market and energy harvesting is gaining more and more attention. This paper answers an IEEE ‘call for papers’ from 2008 in the field of Energy Harvesting, directly targeting the call for novel power electronic converters for energy harvesting systems [7].

The Power Electronics

The following section provides an overview of the modern power electronics that will be considered in the design.

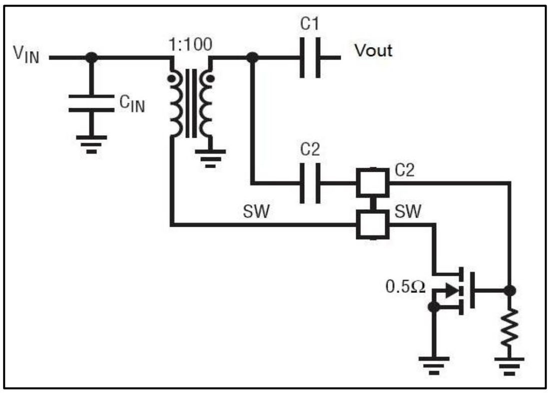
1. **Power converters**

   There are a number of different circuit topologies that allow the conversion of electrical energy.

   - DC–DC converters- Step up(Buck), Step Down(Boost), Step-up/step-down(buck-boost), Full bridge Converters
   - DC-AC inverters
   - AC-DC rectifiers- both controlled DC output and uncontrolled DC Output[8]

For this project, Step up converter circuit topologies will be the main focus as they do not require complicated external switching circuits that require relatively high input voltages to operate. The circuit topology shown in figure 2, which is presented as the recommended converter to be used with the chosen power management system, boasts the ability to produce desirable output voltage from inputs as little as 20mV[9].

Figure 2 – DC-AC Converter



2. Power Management

Power management systems serve the purpose of a buffer between the sources, loads, and energy storage elements. Single integrated circuits can rectify and regulate the input voltage to produce a desired output voltage and to shunt excess energy so as to not exceed this voltage level. They control the distribution of power to their outputs and connected storage elements in order to maximise performance and ensure sufficient power is available when loads require it. An example of one of these power management systems is the LTC3108-1 from Linear Technology. The block diagram of the system is presented in figure 3 below.

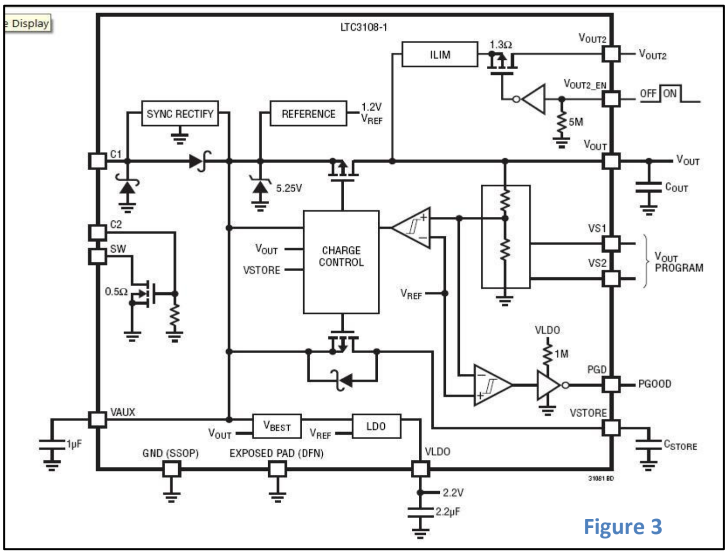


Figure 3

The input voltage is rectified and either distributed to one of the output or storage capacitors or is shunted to ground by the 5.25V Zener diode if all capacitors have been charge to this voltage. The output voltage, Vout, can be programmed to one of four voltages using the VS1 and VS2 pins. The charge control delivers power to the output pin constantly if the Vaux pin is held above the low drop out voltage of 2.2V. Once the output voltage is reached, the charge control distributes the rest of the power to the capacitor bank on the Vstore pin. This store of energy can be used to supply the Vout pin and provide voltage holdup while under peak loads [9]. An example of the charge sequence for a Vout of 3V can be seen below in figure 4.

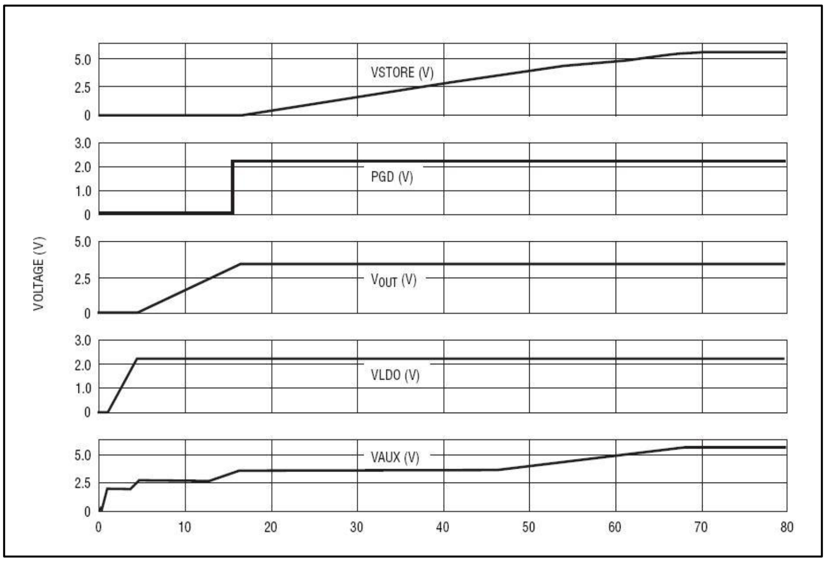


Figure 4 – Time not to scale

3. Super Capacitors

Recent developments in the manufacturing of electric double layer capacitors have seen a great improvement in their power density per volume. These capacitors, termed Super capacitors, achieve a higher energy density than standard capacitor but keep many of their desirable qualities such as long life, high current densities and short charge times [6]. Super capacitors have been disregarded as potential replacements for batteries due to their inferior energy density. The energy density of super capacitors, 50-100J/cm^3, is about one order of magnitude lower than rechargeable batteries at 1000-3000J/cm^3.

Current super capacitors have relatively low operating voltages compared to other types of capacitors, ranging from 1.8V to 5.5V. The use of series connections of super capacitors is usually dismissed as the topology requires extra voltage balancing circuitry, which adds extra power loss to the storage design. Examples of such balancing circuitry can be seen in figure 5.

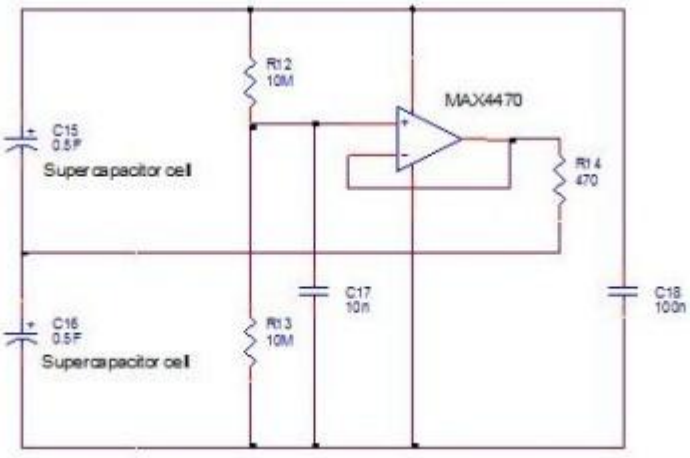


Fig 5: Low current active balance circuit

Parallel combinations of super capacitor, whose total capacitance is the sum of the individual capacitances, can be formed to produce an energy storage bank. Such a device could equal a battery in energy density but would be in the order of 100 times larger in volume making it less desirable.

However, Super capacitors may prove to be the optimal energy storage device for pulsed power loads. In applications where the power is pulsed from a peak power consumption state to a minimum or almost negligible power consumption state, the strengths of super capacitors could be utilised and they could prove to be the most appropriate storage device for this type of application. A combination of capacitors, together with the multiple outputs of the LTC3108-1, would be able to supply peak currents, while maintaining set voltage levels, for finite intervals and then recharge in the periods where the power consumption is at a minimum.

The Project Plan

- **Choose a power management device suitable for the application.** This has been completed. Linear Technology's LTC3108-1 has been chosen to be evaluated as the power management system in the converter design. This integrated circuit comes in either SOP16 or DFN12 packages and is available on the consumer market. Product samples have been requested from linear technologies to be used in the research and development of this project. The LTC3108-1 serves a variety of purposes that are relevant to the proposed project which include rectification of the input signal, programmable regulation of the output signal, and control and sequencing of power distribution between the outputs and storage elements. The LTC3108-1 also allows for expansion of design through the accessibility of a variety of key nodes within the package. These will be useful in creating unique designs for collecting and storing energy from multiple sources

- **Choose an appropriate DC to AC power converter.** The LTC3108-1 application information recommends the use of a Step Up Converter that uses a type of resonant oscillator to control the required switching element. This type of converter allows for voltages as low as 20mV [9] to be boosted to useable levels using a combination of a single transformer, two capacitors and a MOSFET. The main advantage of this type of converter over others is that it does not require any complicated, power consuming switching circuits to control the oscillations. Product samples from various suppliers have been requested to test the performance of different circuit topologies of this type of converter.

- **Choose an energy storage element.** Super Capacitors have been chosen as the sole storage element in the system design. A more effective way of implementing these capacitors with the LTC3108-1 has been realised which will allow for 100% utilisation of the energy stored on them. This application will provide a very appropriate means of storing and delivering power to electronics that operate in a pulsed power fashion like the proposed wireless sensor nodes. Product samples have been requested from various companies and others have been ordered from distributors.

- **Design of Printed Circuit Boards for Experimentation.** Some of the components including the LTC3108-1 and the transformers are only available in surface mount packages, making them extremely difficult to experiment with unless they are mounted on a specially designed printed circuit boards. Therefore a number of breakout boards have been designed to make experimentation with different component types and values easier. These will be manufactured at the University of Queensland Electrical and Technological Support Group Laboratory.

- **Design of experiments.** A number of specially designed experiments will need to be stipulated in order to collect the required data. These will need to collect data on the following areas;
    - Time to first charge of output capacitor.
    - Time to first full charge of storage capacitor.
    - Allowable current draw periods for various loads.

  Each of these experiments will need to collect data for a wide range of combinations of different circuit components in the system and for a wide range of source voltages.

    - Time allocated: 3 Weeks-Begin week 6
    - Goal: To have completed the design of a range extensive experiments that will collect the required data by the end of week nine DATE.

- **Progress Seminar preparation and presentation**
    - Time allocated: 2 Weeks
    - Goal: Start in Week 9 and Present in Week 11

- **Implementation of experiments and data.** A significant amount of time is going to be necessary to collect a significant amount of relevant data. Access to power supplies, oscilloscopes and function generators found in the university's electronics laboratories will be required but may only available at certain times. Therefore booking and organisation of access times to the required laboratories will need to be done ahead of schedule.
    - Time allocated: 6 Weeks

- Goal: To begin experimentation in week 10 and to have all the required data collected and compiled by the end of the second week of the second semester 9/3/2012.

- **Poster and Abstract preparation and submission**.
  - Time allocated: 2 Weeks- Begin 23/04/2012
  - Goal: Hand in on 11/5/2012
- **Analyse a system that uses a current Energy Harvesting technology as the power source.**
  - Time allocated: 1 Weeks
  - Goal: Complete by the 16/03/2012

- **Engineer a specialised converter system to meet the power requirements of a dummy node and implement.**
  - Time allocated: 1 Weeks
  - Goal: Complete by the 16/3/2012

- **Prove the concept by powering a dummy node using the developed converter design and an energy harvesting technology as the power source.**
  - Time allocated: 2 Weeks
  - Goal: Complete by the 30/3/2012

- **Prepare Final Presentation.**
  - Time allocated: Continuous
  - Goal: Complete by and present on the 24/5/2012

- **Compile Research into Final Thesis.**
  - Time allocated: Continuous
  - Goal: Complete by the 1/6/2012

OHS Risk assessment

The experiments that will be undertaken in the research and development of this project fall into the ETSG's **Medium** hazard level. DC supplies, no greater than 5.25V, will be intentionally supplied to any circuit. This is also the maximum output voltage of the proposed system. There may be significantly higher AC output voltages at the output of the Step Up converter. If the maximum recommended input voltages for the system are adhered to, then these voltages should be less than 40Vac. However it is a possibility that experimentation may push the output voltage above this level, in which case the projected would enter a **High** hazard level state and supervision will be sought out.

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