Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
Wireless Vehicle Presence Detection Using Self-Harvested Energy

By

Frazer K. Noble

A thesis in partial fulfilment of the requirements for the degree of

Master of Engineering

In

Mechatronics

Massey University,

Albany,

New Zealand

2009
Abstract

Rising from the “excess demand” modern societies and economies place on limited road resources, congestion causes increased vehicle emissions, decreases national efficiency, and wastes time (Downs, 2004). In order to minimise congestion’s impacts, traffic management systems gather traffic data and use it to implement efficient management algorithms (Downs, 2004). This dissertation’s purpose has been the development of a distributable vehicle presence detection sensor, which will wirelessly provide vehicle presence information in real time. To address the sensor’s wireless power requirements, the feasibility of self-powering the device via harvested energy has been investigated. Piezoelectric, electrostatic, and electromagnetic energy harvesting devices’ principles of operation and underlying theory has been investigated in detail and an overview presented alongside a literature review of previous vibration energy harvesting research. An electromagnetic energy harvesting device was designed, which consists of: a nylon reinforced rubber bladder, hydraulic piston, neodymium magnets, and wire-wound coil housing. Preliminary testing demonstrated a harvested energy between 100mJ and 205mJ per axle. This amount is able to be transferred to a 100Ω load when driven over at speeds between 10km/h and 50km/h. Combined with an embedded circuit, the energy harvester facilitated the development of a passive sensor, which is able to wirelessly transmit a vehicle’s presence signal to a host computer. The vehicle detected event is displayed via a graphical user interface. Energy harvesting’s ability to power the embedded circuit’s wireless transmission, demonstrated the feasibility of developing systems capable of harvesting energy from their environment and using it to power discrete electronic components. The ability to wirelessly transmit a vehicle’s presence facilitates the development of distributable traffic monitoring systems, allowing for remote traffic monitoring and management.
Acknowledgements

First and foremost, I would like to offer my deepest gratitude to the mentors of this research: Dr. Johan Potgieter, Dr. Fahkrul Alam, and Dr. Peter Xu; who, with their guidance and tuition allowed for the completion of this dissertation.

For their invaluable advice and services, I would also like to thank Eddie Rodgers, Jamie McIntyre, and Gordon Hein.

As usual, the unconditional support of my family and loved ones is something always appreciated; as such, I would like to acknowledge my mother and father, Cristine and David Noble; my brother and sister, Rhys and Frances-Elise Noble; partner, Monique Hall; grandparents, Dawn and Kingsley Collins, and Stella and Jack Noble. Their support, both direct and indirect, provided a bastion of confidence during times of difficulty.

For those who I have gained knowledge from indirectly, your work has provided a rich source of information that has only furthered my own abilities, and I thank you.

Lastly, I would like to thank the staff and lecturers of Massey University's School of Engineering and Advanced Technology at Albany for the interest shown in the project and their freely given advice.
## Table of Contents

Abstract.......................................................................................................................... i  
Acknowledgements ......................................................................................................... ii  
Table of Contents .......................................................................................................... iii  
List of Figures ................................................................................................................ v  
List of Tables ................................................................................................................ vii  

**Chapter 1** Introduction .......................................................................................... 1  

**Chapter 2** Literature Review ................................................................................. 5  
  2.1 Introduction............................................................................................................ 5  
  2.2 Wireless Sensor Nodes ....................................................................................... 6  
  2.3 Electromagnetic Vibration Energy Harvesting ................................................... 9  
  2.4 Piezoelectric Vibration Energy Harvesting ....................................................... 12  
  2.5 Electrostatic Vibration Energy Harvesting ....................................................... 13  
  2.6 Conclusion......................................................................................................... 14  

**Chapter 3** Foundation of Energy Harvesting ....................................................... 18  
  3.1 Vibration Harvesting’s Inertial Transduction Mechanism ................................ 18  
  3.2 Piezoelectric Energy Harvesting ....................................................................... 20  
  3.2.1 Piezoelectric Energy Harvesting Theory ....................................................... 20  
  3.2.2 Principle of Piezoelectric Vibration Energy Harvesting ............................... 25  
  3.3 Electrostatic Energy Harvesting ........................................................................ 26  
  3.3.1 Electrostatic Energy Harvesting Theory ....................................................... 26  
  3.3.2 Principle of Electrostatic Vibration Energy Harvesting ............................... 30  
  3.4 Electromagnetic Energy Harvesting .................................................................... 31  
  3.4.1 Electromagnetic Energy Harvesting Theory .................................................. 31  
  3.4.2 Faraday’s Law of Induction and Lenz’s Law .................................................. 32  
  3.4.3 Principle of Electromagnetic Energy Harvesting ......................................... 33  

**Chapter 4** Vehicle Presence Detection Sensor and Reception System Design .... 35  
  4.1 Introduction......................................................................................................... 35  
  4.2 Electromagnetic Energy Harvester Design ....................................................... 36  
  4.3 Design of a Energy Harvesting Device Interface and Vehicle Presence Detection Embedded Circuit ................................................................. 43
4.4  Embedded Microcontroller’s Sensing Application ..........58
4.4.1  PIC16F688 Microcontroller ........................................58
4.4.2  Embedded Sensing Application Overview ................62
4.4.3  Embedded Sensing Application Source Code ..........63
4.5  Wireless Transceiver Design ........................................72
4.6  Vehicle Detected Graphical User Interface .....................77
4.6.1  Graphical User Interface Application Overview ..........77
4.6.2  Graphical User Interface Design ................................78
4.6.3  Graphical User Interface Application Source Code ....80

Chapter 5 System Integration and Testing ........................................90
5.1  Testing of Individual System Components .......................90
5.1.1  Electromagnetic Energy Harvester Testing ..................90
5.1.2  Embedded Microcontroller’s Application Testing .......99
5.1.3  Wireless Transceiver Testing ....................................105
5.1.4  Graphical User Interface Application Testing ..........105
5.2  System Integration and Testing ......................................107

Chapter 6 Conclusion .................................................................109
References .....................................................................................112
### List of Figures

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1: General structure of a wireless sensor node</td>
<td>6</td>
</tr>
<tr>
<td>Figure 2: Inertial transduction mechanism schematic</td>
<td>19</td>
</tr>
<tr>
<td>Figure 3: Traffic monitoring system’s architecture</td>
<td>36</td>
</tr>
<tr>
<td>Figure 4: Traffic monitoring sensor’s architecture</td>
<td>36</td>
</tr>
<tr>
<td>Figure 5: CAD model for proposed electromagnetic energy harvester</td>
<td>38</td>
</tr>
<tr>
<td>Figure 6: Wire-wound coil housing and coils</td>
<td>39</td>
</tr>
<tr>
<td>Figure 7: Opposing series and series coil configurations’ voltage waveforms</td>
<td>40</td>
</tr>
<tr>
<td>Figure 8: Combined bladder and hydraulic piston</td>
<td>41</td>
</tr>
<tr>
<td>Figure 9: Wire-wound coil housing, coils, and adapter</td>
<td>42</td>
</tr>
<tr>
<td>Figure 10: Magnetic load and adapter</td>
<td>42</td>
</tr>
<tr>
<td>Figure 11: Completed energy harvesting device and test platform</td>
<td>43</td>
</tr>
<tr>
<td>Figure 12: Vehicle presence detection sensor’s embedded architecture</td>
<td>44</td>
</tr>
<tr>
<td>Figure 13: Microchip’s PIC16F688 microcontroller</td>
<td>44</td>
</tr>
<tr>
<td>Figure 14: Linear Technology’s LTC3401 DC/DC converter</td>
<td>45</td>
</tr>
<tr>
<td>Figure 15: Digi’s XBee 802.15.4 (Series 1) ZigBee module</td>
<td>46</td>
</tr>
<tr>
<td>Figure 16: MBRS130LT3 surface mount Schottky power rectifier</td>
<td>46</td>
</tr>
<tr>
<td>Figure 17: Rectifier schematic</td>
<td>47</td>
</tr>
<tr>
<td>Figure 18: Comparison of general purpose and Schottky diode rectifiers</td>
<td>47</td>
</tr>
<tr>
<td>Figure 19: General purpose and Schottky diode rectifiers’ output voltage measured across a 100Ω load</td>
<td>48</td>
</tr>
<tr>
<td>Figure 20: Schottky diode charge pump and rectifier comparison circuit</td>
<td>49</td>
</tr>
<tr>
<td>Figure 21: Schottky diode and rectifier circuit’s output</td>
<td>49</td>
</tr>
<tr>
<td>Figure 22: LTC3401 circuit schematic</td>
<td>50</td>
</tr>
<tr>
<td>Figure 23: Rectifier and soft start circuit schematic</td>
<td>51</td>
</tr>
<tr>
<td>Figure 24: Rectifier and soft start circuit’s simulated outputs</td>
<td>51</td>
</tr>
<tr>
<td>Figure 25: Sensor’s embedded circuit schematic</td>
<td>55</td>
</tr>
<tr>
<td>Figure 26: Routed embedded circuit’s PCB board</td>
<td>55</td>
</tr>
<tr>
<td>Figure 27: Sensor’s fabricated embedded circuit and components</td>
<td>57</td>
</tr>
<tr>
<td>Figure 28: Wireless transceiver’s circuit schematic</td>
<td>74</td>
</tr>
<tr>
<td>Figure 29: Routed wireless transceiver’s PCB</td>
<td>75</td>
</tr>
</tbody>
</table>
Figure 30: Wireless transceiver's fabricated board and components .......... 77
Figure 31: Graphical user interface's communication window ...................... 80
Figure 32: Graphical user interface's settings window .................................. 80
Figure 33: Waveform measured across the load at 10km/h ......................... 91
Figure 34: Waveform measured across the load at 20km/h ......................... 93
Figure 35: Waveform measured across the load at 30km/h ......................... 94
Figure 36: Waveform measured across the load at 40km/h ......................... 95
Figure 37: Waveform measured across the load at 50km/h ......................... 96
Figure 38: General purpose diode rectifier circuit schematic ....................... 97
Figure 39: Rectified waveforms generated at 10km/h and 30km/h ............... 98
Figure 40: Rectified and smoothed waveform measured across the load ......... 99
Figure 41: EEPROM SFRs' and variables' contents before EE_Read method execution ........................................................................................................ 100
Figure 42: EEPROMM SFRs' and variables' contents after EE_Read method execution ........................................................................................................ 101
Figure 43: EEPROM SFRs' and variables' contents before EE_Write method execution ........................................................................................................ 102
Figure 44: EEPROM SFRs' and variables' contents after EE_Write method execution ........................................................................................................ 102
Figure 45: EUART's SFRs' and variables' contents before Transmit method execution ........................................................................................................ 103
Figure 46: EUART's SFRs' and variables' contents after Transmit method execution ........................................................................................................ 104
Figure 47: SIM UART1's output window ...................................................... 104
Figure 48: Graphical user interface demonstrating reception of a vehicle detect event ........................................................................................................ 108
# List of Tables

<table>
<thead>
<tr>
<th>Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1: Electromagnetic energy harvesters' device characteristics</td>
<td>16</td>
</tr>
<tr>
<td>Table 2: Piezoelectric energy harvesters' device characteristics</td>
<td>16</td>
</tr>
<tr>
<td>Table 3: Electrostatic energy harvesters' device characteristics</td>
<td>16</td>
</tr>
</tbody>
</table>