UTS UNIVERSITY OF TECHNOLOGY SYDNEY

RF Self-Powered Sensor to Design Fully Autonomous IoT Devices

by Majid Amiri

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under the supervision of A/Prof. Mehran Abolhasan, A/Prof. Justin Lipman and Dr. Negin Shariati Moghadam

University of Technology Sydney
Faculty of Engineering and Information Technology

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STATEMENT OF ORIGINALITY

I, Majid Amiri declare that this thesis, is submitted in fulfilment of the requirements for the award of the degree of doctor of philosophy, in the faculty of Engineering and Information Technology at the University of Technology Sydney. This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Majid Amiri
February 22, 2022

ABSTRACT

The need for continuous, accurate and autonomous sensors has increased significantly given the rapid growth of the Internet of Things (IoT). Sensors collect data for a specific measurable phenomenon. Data may then be transmitted to a controller or cloud service for processing. Alternatively, data may be (pre)processed on the sensor device prior to transmission. Sensors are a necessary element of IoT devices. Sensors are designed to detect specific phenomenon and covert this into digital data that can be leveraged for analytics and machine learning to determine future actions.

The energy consumed by a sensor has a direct impact upon the IoT device and its application and requirements. Depending upon the phenomenon being sensed, supporting continuous operation may be critical as discontinuities in sensing may result in the sensing of a phenomenon missing vital data points thereby limiting accuracy. Further continuous sensing increases the overall energy consumption of the IoT device, reducing overall lifetime of operation of the IoT device or the need for frequent battery replacements. Self-powered sensors provide a promising solution to produce autonomous sensors that can operate both indefinitely and free from energy source limitations. Self-powered sensors can acquire energy using varying types of ambient energy.

Recently, various ambient energy sources have been used to implement self-powered sensors. However, these structures require specific requirement to provide electricity. Alternatively, ambient electromagnetic (EM) waves in the environment can be used as a new power source due to the ubiquitous wide spread modern use of wireless communication. However, the available energy levels of ambient EM signals is low. Therefore, to harness EM signals, a highly efficient receiver is required. The use of a rectenna is a common solution to convert EM signals to electricity, however there is still need for EM energy harvesting to be significantly improved. Metamaterials are a promising solution to address this problem. Literature has shown metamaterial perfect absorbers (MPAs) are promising candidate for both sensing and EM energy harvesting. This thesis explores potential uses of MPAs for highly efficient EM harvesting and passive sensing of phenomenon.

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List of Publications

Peer-reviewed Journal Papers

1. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, " Remote water salinity sensor using metamaterial perfect absorber" *IEEE Transactions on Antennas & Propagation*, 2022, early access, DOI: 10.1109/TAP.2022.3161485.
2. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, "Highly efficient polarization insensitive EM energy harvester using metamaterial absorber" *IEEE Transactions on Industrial Electronics*. (Under review)
3. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, "RF-self powered sensor for fully autonomous soil moisture sensing" *IEEE Transactions on Microwave Theory & Techniques*. (Minor revision)
4. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, "Soil moisture remote sensing using SIW cavity based metamaterial perfect absorber" *Scientific Reports*, vol. 11, no. 1, pp.1-17, 2021.
5. **M. Amiri**, F. Tofigh, N. Shariati, J. Lipman, and M. Abolhasan " Review on metamaterial perfect absorbers and their applications to IoT" *IEEE Internet of Things Journal*, vol. 8, no. 6, pp. 4105-4131, Sep. 2020.
6. **M. Amiri**, F. Tofigh, N. Shariati, J. Lipman, and M. Abolhasan "Wide-angle metamaterial absorber with highly insensitive absorption for TE and TM modes" *Scientific Reports*, vol. 10, no. 1, pp.1-13, 2020.
7. **M. Amiri**, F. Tofigh, N. Shariati, J. Lipman, and M. Abolhasan "Miniature tri-wideband Sierpinski–Minkowski fractals metamaterial perfect absorber" *IET Microwaves, Antennas and Propagation*, vol. 13, no. 7, pp. 991-996, 2019.
8. F. Tofigh, **M. Amiri**, N. Shariati, J. Lipman, and M. Abolhasan " Polarization-insensitive metamaterial absorber for crowd estimation based on electromagnetic energy measurements" *IEEE Transactions on Antennas & Propagation*, vol. 63, no. 3, pp. 1458-1467, Nov. 2019.
9. F. Tofigh, **M. Amiri**, N. Shariati, J. Lipman, and M. Abolhasan "Crowd estimation using electromagnetic wave power-level measurements: A proof of concept" *IEEE Transactions*

on *Vehicular Technology*, vol. 69, no. 1, pp. 784-792, Nov. 2019.

10. F. Tofigh, **M. Amiri**, N. Shariati, J. Lipman, and M. Abolhasan "Low-frequency metamaterial absorber using space-filling curve" *Journal of Electronic Materials*, vol. 48, no. 10, pp. 6451-6459, 2019.

Peer-reviewed Conference Papers

1. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, "Multi-band SIW Cavity Based Metamaterial Perfect Absorber" Asia Pacific Microwave Conference (APMC), 2021.
2. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, " Perfect EM Waves Absorption Using Metamaterial Structures" 17th Australasian Symposium on Antennas (ASA), 2021.
3. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, " Ultra Wideband Dual Polarization Metamaterial Absorber for 5G frequency spectrum" 14th European Conference on Antennas and Propagation (EuCAP), Copenhagen, Denmark, IEEE 2020.
4. **M. Amiri**, M. Abolhasan, N. Shariati, and J. Lipman, " Miniature tri-wideband fractals metamaterial perfect absorber to crowd sensing" 4th Australian Microwave Symposium (AMS), 2020.

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LIST OF ABBREVIATIONS

ABC	Acrylonitrile Butadiene Styrene
AC	Alternating Current
ADS	Advanced Design System
BW	Bandwidth
CP	Circularly-Polarization
CPW	Coplanar Waveguide
DC	Direct Current
DNG	Double Negative Material
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
EMC	Electromagnetic Cage
ERR	Electric Ring Resonator
ESA	Electrically Small Antenna
FSS	Frequency-Selective Surfaces
IoT	Internet of Things
ITU	International Telecommunications Union
MPA	Metamaterial Perfect Absorber
PCB	Printed Cicuit Board
PCR	Polarization Conversion Ratio
RF	Radio Frequency
SIW	Substrate-Integrate-Waveguide
SRR	Split-Ring Resonator
TE	Transverse-Electric
TENG	Triboelectric Nanogenerator
TM	Transverse-Magnetic
UWB	Ultra-Wideband
VHF	Very High Frequency
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
5G	Fifth Generation