



**CMOS RECTIFIER DESIGN WITH POWER  
MANAGEMENT FOR INDOOR LIGHT AND RF  
ENERGY HARVESTING WIRELESS SENSOR  
NODES**

by

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for the degree of

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# Certificate of Original Authorship

I, Jefferson A. Hora declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Electrical and Data Engineering, Faculty of Engineering and IT 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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# List of Publications

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# List of Symbols

Symbol	Description
$V_j$	voltage across both diode
$V_T$	thermal voltage at 25°C
$q$	electron charge ( $1.6 \times 10^{-19}$ Coulombs)
$I_0$	dark/reverse saturation current of the P-N diodes ( $1 \times 10^{-9}$ A)
$k$	Boltzmann's constant ( $1.38 \times 10^{-23}$ J/K)
$T_c$	absolute temperature (K).
$J_{sc}$	short-circuit density in mA/cm <sup>2</sup>
$n$	diode ideality factor (1 for an ideal diode)
$R_{sh}$	shunt resistance
$I_{PV}$	Photovoltaic output current
$I_D$	diode current
$I_L$	photogenerated current or load current
$I_{sh}$	current lost due to the shunt resistance
$V_{PV}$	photovoltaic output voltage
$R_s$	equivalent small series resistance
$V_{oc}$	maximum voltage difference across the cell in a forward-bias sweep in the power quadrant
$\lambda$	photon excitation or wavelength
$I_{sc}$	short-circuit current
$A$	surface area
$G$	irradiance of the incident light
$\eta$	Photovoltaic efficiency
$P_{PV}$	Power of the photovoltaic cell
$E$	illuminance expressed in lux
$I$	candlepower with a cd unit
$D$	measured distance of the point from the light source in meter
$G_{RX}$	RF harvester's receiving antenna gain
$\alpha_p$	<i>p</i> -type–Seebeck coefficient value of the thermocouple
$\alpha_n$	<i>n</i> -type–Seebeck coefficient value of the thermocouple
$\Delta T_{TEG}$	temperature difference of the two distinct materials in a TEG [K]
$K_{in}$	thermocouple's internal thermal conductivity

# Abstract

There is a vast potential for using wireless sensor networks and IoT devices to improve the efficiency and quality of manufacturing operations. It will also enable energy efficiency, increase demand for responsive building, interconnected and full-operational smart grid systems, and other futuristic next-level energy and infrastructure systems. These promising devices are expected to work autonomously for years with no recharging, no human intervention, and no updates.

There are two possible solutions to address the energy needs of these power-hungry devices. One is the reduction of the power consumption of the device's internal circuitry, and the other is the continuous-intermittent charging of the device battery through ambient energy harvesting to extend longevity. Henceforth, this work focused on the integrated circuits design and implementation of the energy harvesting and power management component blocks for its future integration on the system-on-chip IoT device.

The harvesting performance relies on the circuit design integrity of the rectifier circuit block, which is the essential building block of all sources of energy harvesting systems. Thus, this thesis presents novel circuit design techniques for CMOS-based rectifiers with an enhanced voltage-conversion ratio and power conversion efficiency. Two rectifiers are designed in 65-nm CMOS technology to develop indoor light and 2.4-GHz RF energy harvesting using the split-capacitor and auxiliary path techniques in the cross-coupled differential drive structure. Moreover, the unconventional DC-DC boosting technique for processing the voltage required by the load from a single unit of 0.5-V rating PV cell is also highlighted in this thesis. Utilizing a rectifier circuit block instead of the conventional charge-pump circuit after signal pre-processing from the oscillator and buffer driver circuit block offers an alternate technique for the system energy harvesting design that requires dual or multiple energy sources, like RF+PV harvesters.

This thesis also proposes a power-management circuit design implementation in 65 nm CMOS technology to possibly reduce the power consumption of the internal circuitry of the sensor node device. The study explored using a power-down control mechanism implementation to a particular circuit block of the power management and energy harvesting unit with the preliminary performance of the DC-DC boost and LDO block.