AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
Electronics and Communications Engineering Department

Energy Harvesting Solution for Wireless Sensors in IoT Applications

A Thesis

Submitted in partial fulfillment of the requirements of the degree of Doctor of Philosophy in Electrical Engineering

(Electronics and Communications Engineering)

Submitted by:

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STATEMENT

This dissertation is submitted to Ain Shams University in partial fulfillment for the degree of Doctor of Philosophy in Electrical Engineering (Electronics and Communications Engineering), 2020.

The work included in this dissertation was carried out by the author at the Electronics and Communications Engineering Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt.

No part of this thesis was submitted for a degree or a qualification at any other university or institution.

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ABSTRACT

Energy Harvesting Solution for Wireless Sensors in IoT Applications

by

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DOCTOR OF PHILOSOPHY IN ELECTRICAL ENGINEERING THESIS

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Internet of Things (IoT) is applied for connecting physical devices with the internet using wireless sensors. Consequently, the IoT sensors can be fixed or buried in hard-to-reach areas. Primary batteries (non- rechargeable batteries) are used to power sensors instead of the complex wire cables. However, non- rechargeable batteries only are not the ideal solution for powering the IoT sensors due to their essential replacement after a certain time. Therefore, energy harvesting in conjunction with rechargeable batteries or supercapacitors should be applied to store the harvested energy and deliver the power to the IoT sensors besides to the non- rechargeable batteries.

Different opaque, transparent antennas single element and arrays are designed, fabricated, measured and applied for radio frequency energy harvesting (RF-EH). Moreover, an indoor, outdoor survey on the RF spectrum at different locations and time slots are presented for determining the frequencies of maximum ambient radio frequency power. A 2×2 opaque linearly polarized antenna array with high gain is introduced for increasing the amount of the harvested power at low level of energy density. However, the environment of indoor and outdoor causes multipath effects which makes a depolarization of the received ambient waves. This leads to decrease the efficiency of the energy harvesting system because the received EM waves have unknown angle of incidence. This problem is handled by designing opaque dual linearly polarized antenna array with simple and low-profile structure to be suitable for radio frequency energy harvesting. Furthermore, different rectifier circuits are implemented in order to convert the received ambient AC power to DC power for charging the IoT sensors batteries. Two different Schottky diodes of HSMS 2850 and SMS 7630 are used to design rectifier circuits. All the proposed antennas are integrated with rectifiers, matching circuits and tested.

Transparent antennas on glass for radio frequency energy harvesting (RF-EH) are of great interest furthermore, it can produce new communicating surfaces implemented on building windows, car glazing, solar panels and IoT. Consequently, transparent antennas, single element and array based on two different transparent thin films of commercial indium tin oxide (ITO) and new developed silver sandwiched ITO (AgITO) heterostructure thin films are designed, fabricated, measured and utilized for RF-EH system. The RF/DC sputtering is functionalized to deposit the AgITO on both sides of soda-lime glass (SLG) substrate, obtaining sheet resistance (Rs) blow 1Ω/Sq. that is coupled with ~52% transparency (T) at wavelength of 550 nm. The associated 3 thin films deposition parameters were optimized in order to obtain very low ohmic interfacial contact resistance. AgITO promotes transparent microstrip structure of the proposed array as well as the transparent T-junction power divider. The AgITO transparent antenna array achieved a measured peak gain of 2.3 dBi at 5.8 GHz. To the best of our knowledge, this is the first developed AgITO thin-film based transparent antenna array. Moreover, it was utilized for radiofrequency energy harvesting, DC output volt=161.4 mV with a conversion efficiency of 32.9% at 5.8 GHz as the RF received power was -10 dBm. Furthermore, commercial ITO with thickness of 150nm and high Rs =8 Ω/Sq. on SLG substrate was used to fabricate CPW transparent ITO antennas of T=93% at wavelength of 550 nm.

<u>Key Words:</u> Internet of Things, *Rectenna*, *Energy Harvesting*, *Schottky Diode*, *Transparent Antenna*, *Transparent Conductor*, *Thin Film*, *Indium Tin Oxide.*

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