UNIVERSITI TEKNOLOGI MARA

RF-TO-DC
CONVERTER CIRCUIT
INTEGRATED WITH ANTENNA
DESIGN OF 2.45 GHZ AND 5 GHZ
WI-FI ENERGY- HARVESTING
SYSTEM FOR ULTRA-LOW
POWER APPLICATIONS

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ABSTRACT

Recent ambient-energy-harvesting technology advances low-power electronic devices in a green and self-sustaining environment. This technology exploits sun, heat, vibration, thermal, and radio-frequency energies. Due to its accessibility and easy scavenging, radio-frequency (RF) energy harvesting is the most prominent one compared to other sources. Nonetheless, the received power strength from naturally ambient RF signals is relatively low in many environments. To address this challenge, researchers have developed more efficient RF-energy-harvesting systems to capture and convert small amounts of the RF energy into a DC power for ultra-low applications. This includes designing and optimising a frequency range of antennas with enhanced harvesting efficiency, with the characteristics of capturing a wider range of RF signals. Various rectification techniques have also been explored to improve conversion efficiency and RF-input power extraction. However, many studies have harvested energy with power levels around -30 dBm, covering only some ambient RF energy since Wi-Fi signals might exceed -50 dBm. Thus, developing a new converter circuit, integrated with the antenna that could scavenge even the small amounts of the ambient RF energy, would be significant for the RF-energy-harvesting system. On top of that, with the intention of minimising overall manufacturing and assembly costs, a novel microstrip rectangular patch antenna, integrated with a non-complex converter circuit design, is presented in this study. Since the RF-harvesting system focuses on harvesting the RF power from the ISM Wi-Fi bands of 2.45 GHz and 5 GHz, a harvester antenna operating a broad ambient signal spectrum and covering both frequency bands with an omnidirectional radiation pattern and a minimum gain of 3 dBi, has been designed. It consists of a rectangular patch with a rectangular slot positioned in the centre, and the upper rectangular patch serves as a parasitic element. The designed antenna has undergone an evolutionary design process with a parametric analysis of the co-planar waveguide position, rectangular slot, and parasitic element. The antenna structure has been optimised until both targeted Wi-Fi frequency bands have been met and fulfilled the requirements for a good performance in terms of reflection coefficient, impedance matching, radiation pattern, and gain. The optimisation antenna has then been connected to the converter circuit to examine the signal characteristics of the harvesting system before further fabrication. The antenna design has exhibited the return losses of -13.353 dB and -13.292 dB, gains of 3.18 dBi and 3.97 dBi, and impedance matching of 50.29 Ω and 50.37 Ω at 2.45 GHz and 5 GHz, respectively, with the operating bandwidth of 4.196 dB. For the part of the converter circuit design, though the design has posed unique challenges due to the ultra-low power levels of the ambient Wi-Fi signals, the non-complex design, which has comprised the minimal components of the capacitor, inductor, and an SMS7630 Schottky diode, it has successfully operated with the extremely low incident power as low as -50 dBm. The converter circuit configuration has been proved by mathematical modelling expressions, and a subsequent analysis has been performed to determine the performance of the designed converter. The performance evaluation of the harvester antenna integrated with the converter circuit has also been examined. The results indicate that the energy-harvesting circuitry could efficiently harvest power from an ambient RF source that emits a signal strength with an input power as low as -50 dBm. Moreover, the 33.3 mJ of energy harvested, 0.687 mW of power, a voltage of 449.3 mV, and a current of 1.53 mA have demonstrated that the system could reliably be employed for ultra-low power applications.

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CHAPTER ONE
INTRODUCTION

1.1 Research Background

There are various kinds of wireless electronic applications that have been rapidly developed in line with the advancement of integrated electronics towards higher frequencies with smaller power consumption and a lower energy supply. In most applications, it is not always feasible to use disposable batteries in electronic devices due to their size and cost. This is because disposable batteries can be expensive, especially if the devices require frequent battery replacements. This cost factor has become significant when considering the long-term operational expenses of maintaining a large number of devices or deploying devices on a large scale.

Practically, an energy source for a wireless sensor is an onboard battery. As the wireless sensor does its dedicated task, the battery is constantly depleted as the sensor consumes energy. When the amount of stored energy is insufficient, the battery needs to be replaced. The process of changing the battery is normal, especially in situations with a limited number of wireless sensors. However, the process will be time-consuming for a huge installation of wireless sensors. Another problem with conventional power-supply methods is the possibility of power interruptions, which reduce reliability. Since it is inconvenient to power up circuits by the traditional method of using wall plugs or costly batteries, it is an increasingly popular alternative for harvesting energy sources, especially when a remote application is installed.

Recently, researchers have proposed a system that is capable of supplying energy and automatically charging itself. This type of system is known as an energy-harvesting system [1]–[6], in which the idea of wireless energy harvesting consists of radiating wireless power to free space and converting the wireless power to functional electrical energy, as raised by Heinrich Hertz and Nikola Tesla [7]. Research on energy harvesting has drawn an increased attention to address issues with insufficient energy accessibility. Energy harvesting gathered from the environment and natural resources can power personal and low-power electronics, enabling sustainable and environmentally friendly operations [8]. It has emerged as a feasible alternative to a conventional battery plug-in method for energising electronic devices. This technology