Chapter 7
Performance Evaluation of Different Rectifying Antenna Systems for RF Energy Harvesting:
Rectifying Antenna Systems for RF Energy Harvesting

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ABSTRACT

The radio frequency (RF) energy harvesting is found as an attractive alternative to existing energy resources. This chapter deals with the design and performance evaluation of different rectifying antenna circuits for RF energy harvesting. The rectifying antenna i.e. rectenna consists of an antenna to grab the RF energy and rectifier to convert the RF energy to DC power. Different circularly polarized microstrip antennas e.g. shorted square ring slot antenna and crossed monopole antenna with step ground plane are studied. The antennas are combined with voltage doubler circuits with various stages and bridge rectifier. The electromagnetic simulator CST Microwave Studio is used to design and optimization of antenna structures. The rectifier circuits are designed using SPICE software. Later the prototype of the antennas and rectifiers are fabricated and tested in the laboratory environment. The detailed study on the performance of the rectenna circuits are evaluated in terms of conversion efficiency.

INTRODUCTION

The global energy demand driven by the developed and rapidly developing countries is rising very fast (Ghosh et al., 2014). The development of a sustainable, long-term solution to meet the energy need of the world is an important area of research of the recent time. The energy harvesting techniques from surrounding energy sources e.g. heat, light, radio frequency (RF) energy are developing as environment

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friendly energy sources (Vinoy & Prabhakar, 2014). The huge proliferation of cell tower installation in recent years and abundance of RF energy due to broadcast and cellular towers has made it an attractive means for energy harvesting. The RF energy harvesting needs a suitable module with appropriate antennas to grab the energy available in different transmission bands and a rectifying circuit for the rectification of the RF signal to DC power. Thus the device is basically a combination of antenna and rectifier and called as rectifying antenna or rectenna (Brown, 1984). The harvested DC power can be used for recharging the batteries of wireless devices like mobile phones or stored to power sensor networks. The wireless sensor networks (WSN) consists of spatially distributed sensor nodes. The WSNs play major role in the area of structural monitoring, habitat monitoring, healthcare systems etc. Energy supply has been a key limiting factor to the lifetime of WSNs as the sensors are generally powered by the onboard batteries. The batteries gradually run out of energy. The solar or other alternative energy sources are not available always (Vinoy & Prabhakar, 2014). In this situation, the energy harvesting technique using electromagnetic energy specifically in RF / microwave frequency range provides a solution to overcome these problems.

The amount of harvested power depends on the available RF power, characteristics of antenna and efficiency of the antenna and rectifier. In India, the major sources of RF radiation are the cell towers in the CDMA (Code Division Multiple Access) with frequency range 869 – 890 MHz, GSM 900 (935 – 960 MHz) and GSM 1800 (1810 – 1880 MHz) frequency bands (Arrawatia et al., 2011). However, the available RF power to the input of the RF energy harvesting system is relatively low due to the path loss and restriction on the allowable power for transmission. This requires the use of broadband, high gain antenna and efficient rectifier with impedance matched with the antenna to avoid the mismatch loss.

This chapter deals with the design and performance evaluation of different rectenna circuits for RF energy harvesting. The circularly polarized microstrip shorted square ring slot antenna and broadband crossed monopole antenna with step ground plane are used. The antennas are combined with voltage doubler circuits with various stages and bridge rectifier. The RF to DC conversion efficiency of different combinations of antenna and rectifier (rectenna) circuits are evaluated to perform a comparative study. Later the prototype of the antennas and rectifiers are fabricated and tested in the laboratory environment.

The chapter starts with a brief literature review studying and evaluating the existing rectifying antenna models for RF energy harvesting thoroughly (Section 2) leading to the main objective of the work (Section 3). The design of rectenna module with different antenna and rectifier structures are presented in Section 4. The formulation of overall efficiency of the rectenna circuits in terms of the antenna and rectifier efficiency is given in Section 5. The simulated and measured results for different antenna and rectifier circuits and discussions are presented in Section 6. This leads to the direction of future research (Section 7) and conclusion of the work (Section 8).

BACKGROUND

The rectenna i.e. rectifying antenna was invented and named by Brown (Brown, 1984). It is mainly used for receiving power where there is no physical connection. The transmission of power by radio waves was demonstrated first by Heinrich Hertz (Brown, 1984). Later Nicolas Tesla carried out the experiments on the transmission of power by radio waves (0'Neill & Genius, 1944; Cheney, 1981). The radio frequency (RF) energy harvesting had been investigated in the 1950s using the high power microwave sources. However, due to the technologies available at the time, it was then researched as a proof of the concept rather than