Strategy for Microwave Energy Harvesting From Ambient Field or a Feeding Source

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***Abstract*—Wireless energy transfer has been demonstrated using microwave electromagnetic support. Significant efficiencies are reported in the case of large dimension systems. Lots of embedded systems require a small power supply but with a large degree of integration where standard contactless energy transfer techniques suffer from poor efficiency. In such systems, RF input energy is rectified using rectenna circuits. The latter circuits are optimized for a given input RF power and cannot accommodate the two possible ways of energy transfer: the dedicated transfer (high power) or the harvesting of ambient energy (low power). This paper presents a novel rectenna architecture tunable for 900 MHz–2.45 GHz operation, able to process RF input power in the −30 to +30 dBm (dB miliwatt) range with a peak efficiency of 80%.**

***Index Terms*—Contactless energy supply, energy harvesting, rectenna, switch.**

I. Introduction

THE last decade has been characterized by massive development of a wide range of portable electronic devices, consumer devices like smartphones, and industrial applications, like wireless sensor networks [1]–[3]. These devices offer many functions but their autonomy is limited because of the tradeoff on batteries regarding size and power density. Batteries need to be periodically recharged. Most often the charge relies on a wall plug charger, which somehow limits the portability of a wireless device. Wireless supply systems should improve the availability, the reliability, and the user-friendliness of portable electronic devices.

There are several different approaches to wireless power supply. Near-field inductive coupling works on very small distances, typically limited to a few centimeters, but is characterized by very good efficiencies [4], [5]. This approach is widely used for wireless recharging of the internal battery of consumer items like an electric toothbrush or wireless mouse.

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Magnetic resonant coupling between two structures (usually circular coils) allows energy transfer in the near-field area. Transmitter and receiver are quite large [6]–[8] and energy can only be transferred over distances of the same order of magnitude as emitter and receiver sizes. Efficient energy transfer is only achieved near an optimal operating point [9]. Transmitter-to-receiver efficiencies can reach 70% over distances less than 1 m but wall-to-load efficiency is below 20%.

Energy can also be transmitted based on a radiative high-frequency (HF) field (often above 1 GHz). High power transfer over several kilometers has been achieved with efficiencies sometimes in excess of 70% [10], but the number of viable applications at these power levels tend to be limited due to health and safety regulations and the impact of large antenna.

This technique is used more often to supply ultrahigh frequency radio-frequency identification (UHF RFID) devices [11], [12] at distances in excess of 10 m using HF radio waves [13]–[15]. The concept of wireless energy transfer can also be applied in order to supply low-power electronic devices like industrial sensors or sensor networks. These devices can either be supplied exclusively by the energy from the microwave beam [16], [17] or by batteries that can be remotely recharged [18]. The wall-to-load efficiency is unfortunately very low (1% range).

Using UHF electromagnetic waves for power transfer applications is compatible with system miniaturization, but a tradeoff is often required between antenna size and power transfer efficiency. The transmitter-to-receiver power transfer efficiency is evaluated by the Friis equation [19]. High-gain antennas improve energy transfer efficiency, but higher gain usually means bigger antenna. In small miniaturized systems, the antenna size is limited, but it is still possible to design rather small antennas with relatively good directivity and gain [20]. A solution in the case of small receiver antenna is to use a high-directivity transmitter antenna or higher transmitted power levels in order to ensure a desired energy density (in mW/cm^2) at receiver level. The focus is then to optimize the RF-to-dc energy conversion efficiency at receiver level.

The basic operating principle of an electromagnetic energy receiver and converter is shown in Fig. 1. The incident electromagnetic energy is captured by the receiving antenna and fed to the RF–dc rectifier under the form of an HF sine wave. The rectifier transforms the energy into a dc voltage and current. The association of a receiving antenna and an RF–dc rectifying circuit is currently named a rectenna (rectifying antenna). It is the key element of a microwave energy transfer system. The dc voltage output level of the rectenna is often too low to ensure