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# Efficient and uncomplicated RF harvester circuit for Powering an Ultralow-Power Wake-up Radio

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**Abstract**—Using Radio Frequency (RF) energy to power ultra-low power devices is an appropriate solution to reduce the dependency on batteries for low power consumption connected devices. However, providing a regulated Direct Current (DC) voltage from RF power is a challenging task. This work presents a simple and efficient rectifier which has an RF/DC conversion efficiency of 29 % and outputs a DC voltage of 227 mV from an input RF power of  $-20$  dBm at 848 MHz. This performance is sufficient to operate a commercial Power Management Integrated Circuit which regulates the DC output voltage of the rectifier and outputs a power of 324 nW aiming to power supply an ultralow power consumption Wake-up Radio Receiver. The required RF power, to output a regulated DC voltage, is so far the lowest reported in the literature for an RF harvester designed with off-the-shelf components and using a continuous wave (CW) signal.

**Index Terms**—rectifier, RF harvesting, wireless power transfer, power management integrated circuit, ultralow power wake-up radio.

## I. INTRODUCTION

In a context of an increasing deployment of the Internet of Things (IoT), the correct operation of these devices is limited by their batteries. Duty cycled IoT consume high energy due to the idle listening of their transceivers. The use of Wake-Up Radio receivers (WURx), driving the IoT on demand, reduces the required energy since the main node is in a deep sleep state most of the time [1]. Moreover, making the WURx independent of the main battery and powering it with RF energy will extend its lifetime [2]. One of the main goals to power a WURx with RF energy is to efficiently transform this fluctuating kind of power into a regulated Direct Current (DC) voltage. In [3], the authors propose an architecture capable to supply, from RF power, a regulated DC voltage for powering a sub- $\mu$ W WURx. As depicted by Fig. 1, depending on the power level, the RF signal received by an antenna is rectified with high efficiency by one of the two RF rectifiers. The obtained DC voltage is regulated by a Power Management Integrated Circuit (PMIC). Key building blocks of this architecture are the rectifiers which design is complex due to their nonlinear components. Although [3] shows good performance, this paper only presents simulation results. This work presents measurement results of an architecture similar to the one in [3] with the differences that a shunt topology is used with a simple strategy for matching the rectifier with the

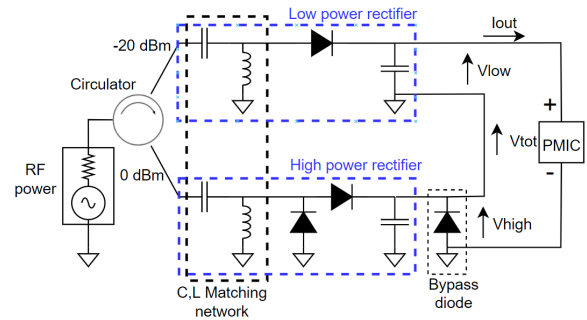


Fig. 1. Architecture for efficient harvesting of energy from two levels of the RF field while supplying a regulated output voltage.

RF source and that only one rectifier optimized at low power is employed. For the uncomplicated design, measurement results show that with a  $-20$ -dBm continuous wave (CW) signal of 848 MHz at the input of the rectifier, the PMIC can provide a constant voltage and a power of 324 nW. To the best knowledge of the authors, it is the first system capable to output a regulated voltage from an RF power as low as  $-20$  dBm using off-the-shelf components and a CW signal.

## II. RECTIFIER DESIGN

As aforementioned, a key block of an RF harvester is the rectifier of which design is a complex task due to its nonlinear components and dependence on the frequency and power level of operation. In [4], a shorted transmission line (TL) which acts as an inductance is used in series with the diode to compensate its capacitive behaviour in a shunt topology. The rectifier is designed for 0 dBm input power at a frequency of 2.45 GHz, resulting in a reasonable shorted line length. In the present work, a similar principle is used; however, the rectifier is designed at 868 MHz, leading to a significantly longer TL which reduces the quality factor (Q factor) of this branch, consequently reducing the RF/DC conversion efficiency of the rectifier. To reduce the length of the shorted TL, a high Q-factor inductance is used in combination with the shorted TL as showed in Fig. 2.

Using Keysight ADS, the values of the required components were determined in simulation. A BAT15 Infineon diode is used due to its low forward threshold voltage and low series

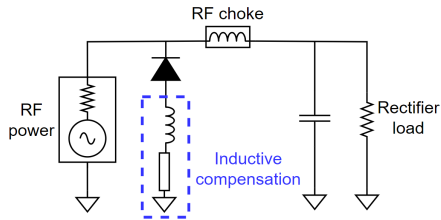


Fig. 2. Shunt topology using an inductive compensation as matching network.

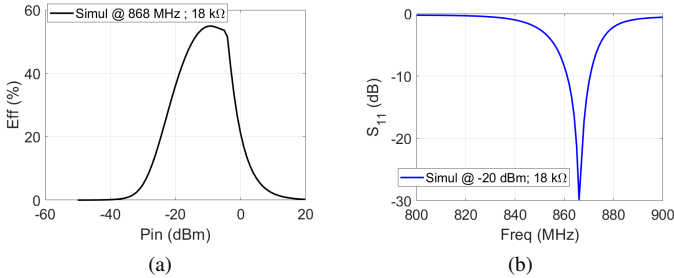


Fig. 3. Simulation results a) Efficiency and b)  $S_{11}$  at -20 dBm when the rectifier is loaded with a load resistance of 18 k $\Omega$ .

resistance which reduce the RF losses at low power. In simulation, the use of an ideal inductance of 135 nH leads to good matching between the rectifier and a 50- $\Omega$  RF power source and boosts the efficiency at -20 dBm when the rectifier is loaded with a 18-k $\Omega$  resistor. This 135-nH inductance is achieved with a 2712sp-27N Coilcraft coil and a 17 mm TL. The rectifier is implemented on a RO4350 substrate, an RF choke is used to block the fundamental and harmonics frequencies from the load, and finally a 1 nF capacitor is used for smoothing the output DC voltage of the rectifier. Simulation results are shown in Fig. 3. When the rectifier is loaded with a 18-k $\Omega$  resistor, at 868 MHz and -20 dBm, the RF/DC conversion efficiency is 36 % and the reflection coefficient,  $S_{11}$  is -30 dB at 868 MHz.

### III. MEASUREMENT RESULTS

The fabricated rectifier prototype is shown in Fig. 4 connected to a commercial PMIC BQ25570 from Texas Instruments. The dimensions of the rectifier are  $1.9 \times 3.2$  cm<sup>2</sup>. First  $S_{11}$  has been measured using a R&S ZVA 50 vector network analyzer with the rectifier loaded with 18 k $\Omega$ . Measurements show an  $S_{11}$  of -27 dB at 848 MHz, resulting in a shift of 20 MHz from the designed frequency and representing a relative error of 2.3 %. For measuring the RF-to-DC conversion efficiency, the rectifier is fed with an 848-MHz CW signal using a R&S SMBV100A vector signal generator. The DC voltage is measured at the output of the rectifier using a Keithley 195 DC meter. First, the load of the rectifier was varied at input power of -20 dBm to find the optimal experimental load at this point of operation which is around 18 k $\Omega$ . Then for a 18-k $\Omega$  load, the input power was swept. Measurement results are shown in Fig. 5. These results show an efficiency of 29 % and an output voltage,  $V_{load}$  of 227 mV, respectively, for an input power of -20 dBm. Differences between simulations and

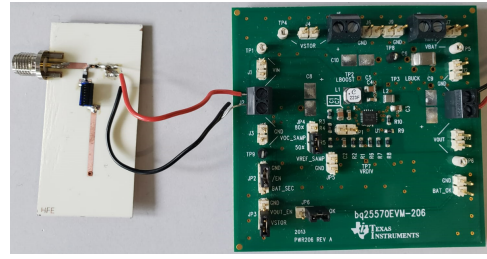


Fig. 4. Fabricated rectifier connected to a BQ25570 PMIC.

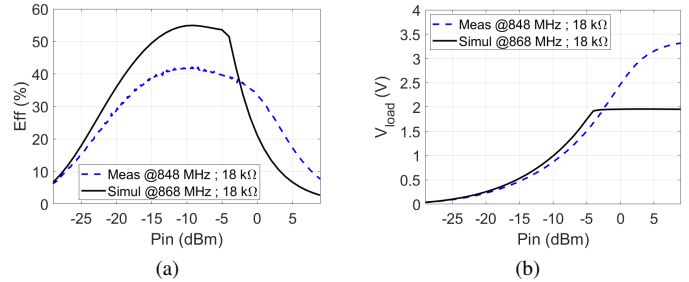


Fig. 5. Measurement results, a) efficiency and b) output voltage,  $V_{load}$  at 848 MHz while the rectifier loaded with 18 k $\Omega$ .

measurements may be due to the uncertainties introduced by the tolerance values of the components. Finally, the rectifier was connected to a BQ25570 PMIC. With a -20 dBm input signal at the input of the rectifier, the PMIC is capable to work in normal mode without disabling its load, hence providing a continuous regulated voltage of 1.8 V and an output power of 324 nW.

### IV. CONCLUSIONS

A simple and efficient rectifier for RF harvesting at low powers is proposed in this work, an inductive compensation to the capacitive behaviour of a diode in a shunt topology is used to match the rectifier to the RF source. At 848 MHz and for a power of -20 dBm, the rectifier has an efficiency of 29 % and outputs a DC voltage of 227 mV. These results are enough to operate a commercial BQ25570 PMIC over its minimum limits specified on its data-sheet. The PMIC outputs a regulated voltage and a power of 324 nW. The RF input power required to output a regulated voltage from an RF power as low as -20 dBm is so far the lowest reported in the literature using off-the-shelf components and a CW signal.

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