A Combined 90/900 MHz IC Architecture for Power-Assisting in IoT Applications

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Abstract—**In this work we present a combined 90/900 MHz Energy Harvesting Architecture for IoT device power assisting. The harvester takes advantages from a dedicated diplexer and a power manager for battery life enhancement purposes. The system has been optimized in the 900 MHz frequency range by analyzing a probabilistic approach used for modeling the possible amount of Global System for Mobile communication (GSM) energy that could be harvested while a fixed power downlink scenario has been adopted for the 90MHz band. A preliminary IC system with a 0.18µm CMOS SMIC technology has been designed and optimized at 90 and 900 MHz while discrete element board, to be integrated with the proposed IC, with commercial components has been developed and tested. Concerning simulation results on the IC design they have confirmed that the integrated system handles an incoming power typically ranging from -25 dBm to 5 dBm by rectifying the variable input signals into a DC voltage source with an average 50% efficiency.**

Keywords—**Radio frequency energy harvesting, rectifiers, probabilistic modelling, dual band energy harvesting.**

I. INTRODUCTION

Nowadays energy recovery from environmental power sources is an innovative and appealing way to capture and store energy for small, wireless and autonomous devices commonly used in wearable electronics, low voltage or low power circuit and systems, and, more and more, on Wireless Sensor Network (WSN) systems [1–5].

Energy Harvesting (EH) is the process of scavenging ambient energy from sources in the surrounding environment. It is an attractive method for overcoming the energy limitations of conventional battery powered wireless devices. As a consequence, efficient harvesters can potentially lead to significant reduction in the costs associated with replacing batteries periodically.

The best-known EH collectors are large solar panels and wind generators, which have become major alternative energy sources for the power grid. But small embedded devices must rely on energy scavenging systems that can capture milliwatts of energy from light, vibration, thermal, or biological sources. Since the output from EH devices is usually small and intermittent, a system must be carefully designed in order to include a boost converter, a charge controller for a rechargeable Li-Ion or thin-film battery, a regulator for the microcontroller unit and other loads, sensors, and a wireless connectivity module.

EH systems are able to catch environmental energy and to convert it in a usable electric power [6-16]. Among these, several radio frequency harvesters have been proposed in the literature being the main objective to achieve high efficiency in converting the available RF energy into DC energy. Furthermore, the capability of handling incoming signals in a wide dynamic range and spectrum represents a new important step towards the performance improving of commercial harvesters, mainly located into "unknown" environments, for the implementation of "fully autonomous portable systems" [17-19]. Recently, RF EH became a popular topic, and, to be more specific, GSM energy harvesting, since it is available everywhere. From an electronic point of view, there are physical limitations that do not facilitate the realization of EM energy harvesters as, in particular, for what concerns the antenna and rectification section.

Although present RF ambience power level is weak, it could be used for enhancing the performance of low-power devices, or even make them fully autonomous. Hereby, we considered RF sensor tags based on RFIDs technology as a potential application, due to microwatts of power consumption. These systems are widely used in product identification applications. For these systems a typical conservation of energy starts by reusing energy that has already been expended. The latter is readily available in electromagnetic (EM) form, from broadcast AM and FM radio waves to the many wireless devices that transmit signals around us, such as cellular base stations and short-distance wireless local area networks (WLANs). The process to harvest or scavenge this "used" energy starts with a dedicated receiver, which is able to collect the available wireless RF signals and to convert them into a DC usable electric power that directly feeds a low power circuitry, or can be stored, as shown in Fig. 1. The decision on storage or usage should be applied if tag is found in the reader interrogation range. Then, the power would be used to enhance overall RFID sensitivity in terms of overcoming performance flops. These are crucial since RFIDs performances are hardly dependent on the

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environments where they were installed. It is well known that metallic environments are not EM friendly for tags not designed to work in such conditions. It is important to note that this approach may be used for all other, low-power IoT scenarios to make system more reliable or even autonomous.

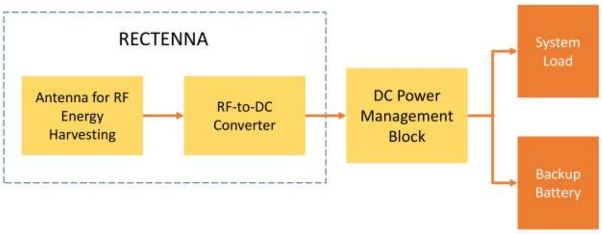

Fig. 1. Block scheme of a typical harvester block

In this paper, we consider the dual GSM plus FM radio EH, due to available power levels that could be harvested almost everywhere. The key points of the designed circuit are the capability to manage input signals over a wide power range together with the high energy conversion efficiency in the full band. First, we provide the application scenario and an analytical and experimental analysis on present ambient GSM power levels. In fact, since GSM signal consists of uplink and downlink channels, each of them should be observed. While downlink power level is always present and relatively constant (small power variations during the day), uplink power depends on the number of mobile phones close to the GSM energy harvester. Due to uncertainty of the number of mobiles, we use for the optimization of the EH circuits a probabilistic approach used for modeling the possible amount of GSM energy that could be harvested. Results obtained at simulation level using a 0.18μm CMOS SMIC technology and measured results on first discrete elements are shown. In Section II, a brief overview of the application scenario is proposed while Section III proposes an approach in modelling the available power for circuitry accurate design. In Section IV the IC proposed architecture, and simulation results are shown. Finally, Section V provides appropriate conclusions.

II. APPLICATION BENEFITS

Conventional way for IoT devices to be powered is mostly through the batteries that may last for years. Since new IoT device designs are becoming more power-efficient, RF power scavenging will have important role in making them autonomous. One of the possible ways to employ proposed enhancement is through passive RFID system operating in sub-GHz band, since power requirements of given tags are in the range of microwatts [23]. These tags can be passive, or Battery-Assisted Passive (BAP), both exploiting backscattering as a communication technique. BAPs are more reliable than passive since the battery is used to power tags' circuitry and therefore extend interrogation range. However, after some time, batteries deplete and should be replaced. This becomes a problem for the RFID concept, since the system employs many tags. Therefore, the proposed energy scavenging mechanism may be viable solution for BAP tags.

This proposal aims to create hybrid passive/BAP solution where the battery is replaced by the suggested harvester. Once the harvester is attached, and surrounding energy is scavenged, this hybrid tag will behave as a BAP tag. It could be read from greater distances, while being more reliable and applicable for different scenarios where pure passive is not enough. Overall performances of such device will depend on the available spectrum power levels, and consequently, they should be presented in probabilistic manner. Those will depend on the different circumstances such as distance from the base stations, number of mobile phones in the surrounding area or the antenna gains as well as losses inserted by the RF hardware. Similar solution, but much narrower with on-purpose remote power transfer was given in [26]. However, hereby, by using this solution we find it even more viable since the technique and hardware exploits additional energy available in both GSM and FM-radio spectrum, making it more efficient. Additionally, this prototype implementation could be performed by using standard BAP IC, such as one given in [27] and related antennas for GSM and FM radio. As the system will highly depend on the available spectrum power level, the usage for improving RFID range and reliability is viable due to the matching power constraints, while for other IoT devices it could be certainly used once power requirements become appropriate.

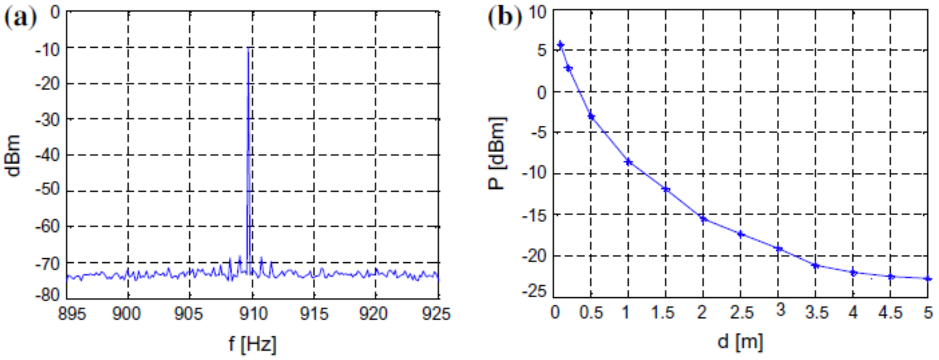

Fig. 3. a) GSM signal strength when mobile phone calling is active 1m away from the measuring antenna and b) GSM signal strength when the mobile phone is moving away from the measuring antenna [15]

III. DUAL BAND ENERGY HARVESTING

In this section we introduce specifications of each band where RF EH is considered. It is important to note that this separate analysis should be applied whenever both downlink and uplink appear as a part of the communication system.

A. FM band

Generally, throughout the world, the FM broadcast band falls within the VHF part of the radio spectrum. Usually, the frequency range from 87.5 to 108.0 MHz is used, or some portion thereof, with few exceptions. The radiated power, for each channel, is regulated in each country and remain fixed in downlink.

B. GSM band

On the other hand, the GSM allows the use of duplex operation, since each band has a frequency range for the uplink and a separate range for the downlink. In the case of harvesting GSM energy, one should consider the contribution from both downlink and uplink GSM bands. For this purpose, we use the same approach in [15], given as follows: in order to characterize the available free power, a GSM-900 signal spectrum has been observed by means of a spectrum analyzer, performing measurements with a quarter wave ground plane antenna (3 dBi gain). An example of GSM channel is depicted in Figure 3(a) when the mobile phone is ringing one meter far from the measuring antenna of the spectrum analyzer. Trivial example of integrating such channel shows that an additional power of 10 dBm (100 μW) which can be used to be harvested is obtained. When the ringing mobile phone is moving away from the initial point, the picture changes as depicted in Figure 3(b), where signal level is exponentially dropping. As a consequence, moving mobile phone to the harvester during the ringing can provide additional power. If EH system is near GSM base station or there are more mobile phones in the neighborhood of the harvester, more energy of course could be harvested. As these available levels highly depend on the environment, this has to be modelled appropriately and analyzed in respect to distance from base station and number of mobiles around EH system. On the other hand, GSM Downlink energy is always available and is dependent on the existing number of near base stations and the distance from them. In this case, the total downlink GSM power was measured with spectrum analyzer at a fixed location [15]. It oscillates around -26 dBm (2.5 μW) as shown in the histogram in Figure 4. Measured data can be well fitted with log-normal distribution with parameters μ=0.95 and σ=0.1. Concerning the uplink GSM power, it is dependent on the number of nearby mobile phones in an active call. This number inside a determined radius distance can be modeled with Poisson distribution. Since downlink and uplink power distributions can be considered independent, probability distribution of a total power can be obtained by their convolution and is shown in the Figure 5. By taking advantage of the previously probabilistic description of the GSM available power and the FM regulated emitted power, the EH architecture depicted in Fig. 4 has been designed and optimized. By using this approach, it is possible to consider the amount of available power that can be harvested in terms of its probability available in spectrum.

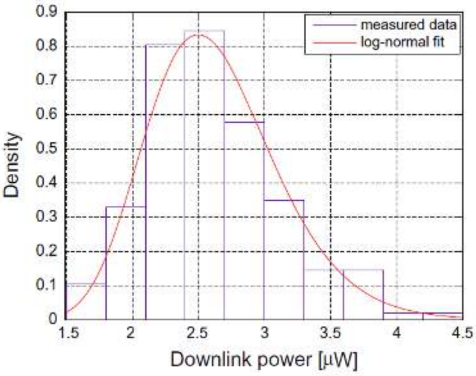

Fig. 4. GSM downlink power distribution

IV. SYSTEM ARCHITECTURE DESIGN

In Fig.6 the complete block scheme of the conceived architecture is shown. The RF front end of the device is composed of two external antennas, an RF transformer and a matching network designed to match the antenna to the rest of the system with a minimum of power reflection. Since a single, dual band antenna design is very difficult to achieve, because of the large frequency distance between the two RF bands, two discrete external antennas have been simulated to harvest energy from the two RF mentioned sources. The antennas for the moment are considered as commercial objects to be further integrated in the system as future step. This solution also allows to have more available power density, since the received power is greater with two separated antennas then with a single one, because of the bigger total effective area. Differently from the previous published paper [21], a power combiner or diplexer has been used both at simulation level and discrete prototype board to merge the two signals, so the power can be harvested by a single channel system.

The block scheme of the designed diplexer is shown in Fig. 7 while Fig. 8 shows its circuital implementation and Fig. 9 its prototype discrete element board. Fig. 10 shows the measured results of the standalone diplexer. The whole system is conceived for operating in two separate bandwidths (the GSM

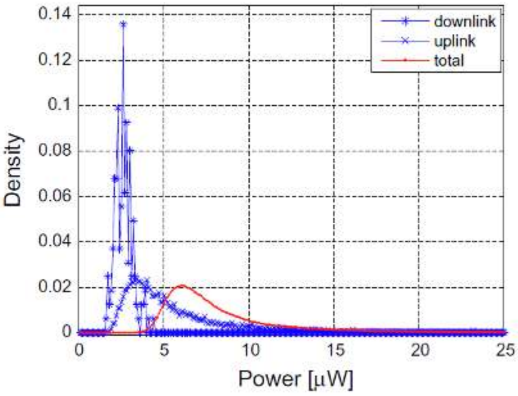

Fig. 5. GSM power density: uplink, downlink, and total power

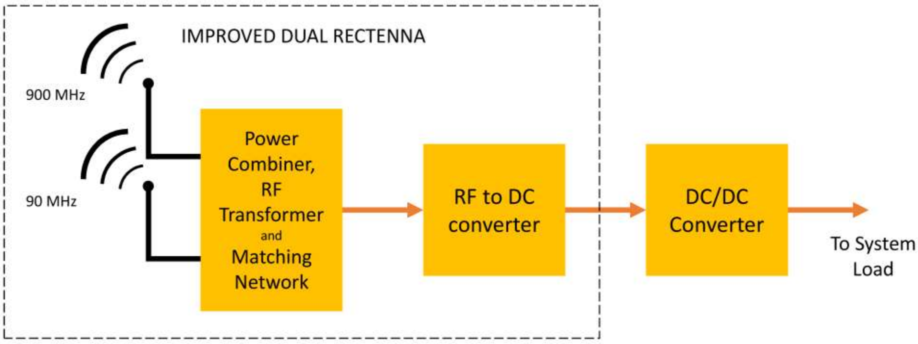

Fig. 6. Proposed architecture for the improved harvester

sub-band of 900 MHz and the FM radio channel around 90 MHz). At IC level design, the regulation and storage section have not been considered. Therefore, this circuit block has been implemented by means of commercial components (e.g. the LT3108 from Linear Technology). In this case it has been used the already developed prototype board.

The IC system evaluation, using an optimized version of the already presented circuit [20, 22] is performed at simulation level using a 0.18µm CMOS SMIC technology (see Fig. 11). The measured parameters of the diplexer have been used for simulations. Resulting data of the whole chain, considering also the external diplexer, show a power conversion efficiency vs. frequency as depicted in Fig. 12 for the 90MHz input and Fig. 13 for the 900MHz input signal. These results demonstrate the feasibility of the proposed solution and a good reliability in terms of its performances. Finally, in Fig.14 it is also reported, accordingly with the available power predictions here developed, the total GSM power vs. Probability Density and Harvester Conversion Efficiency.

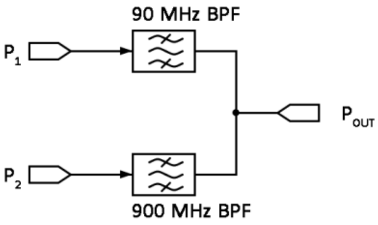

Fig.7. Block scheme of the proposed Diplexer

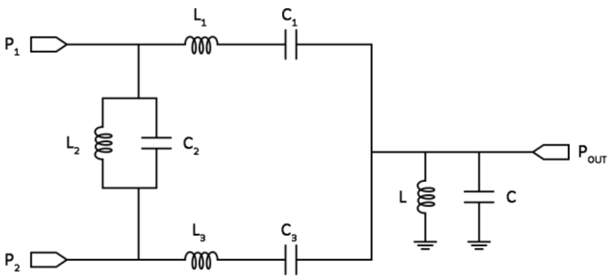

Fig.8. Circuital implementation of the proposed Diplexer

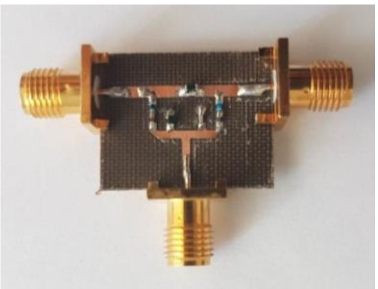

Fig.9. Implemented diplexer

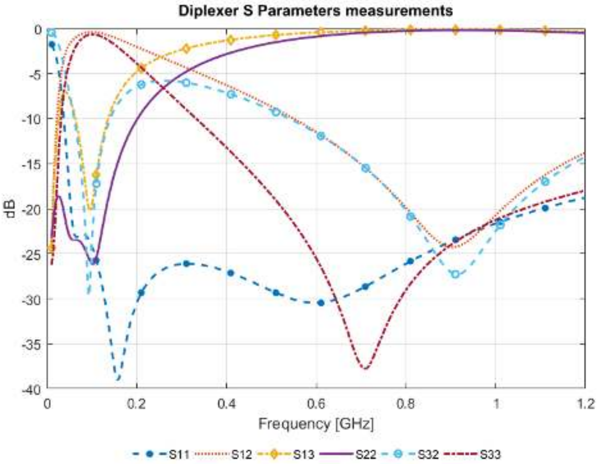

Fig. 10. Measured and simulated diplexer results

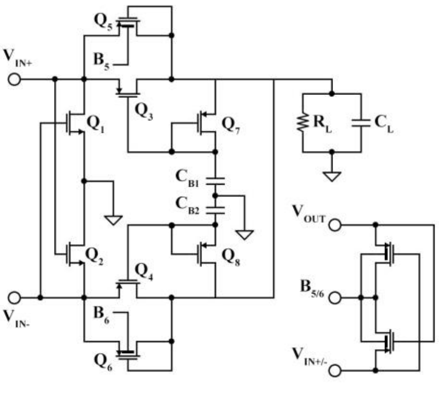

Fig. 11. Schematic of full-wave low-power channel rectifier as proposed in [21, 24]

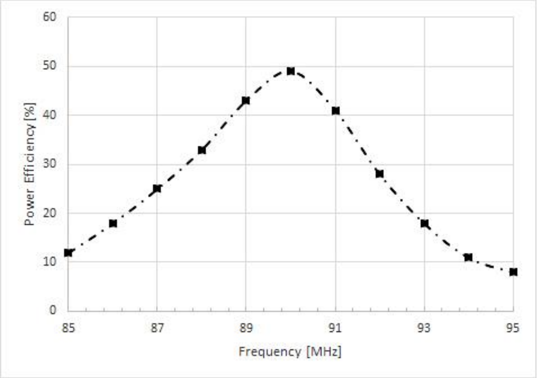

Fig. 12. Conversion efficiency for a 90 MHz input power

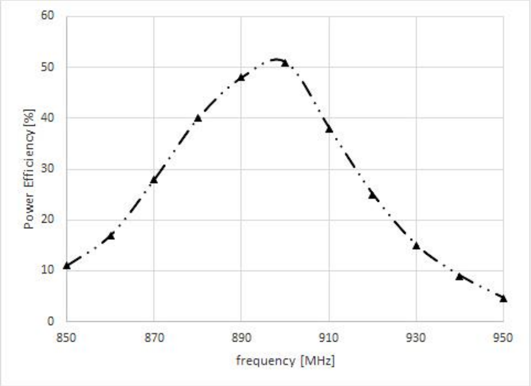

Fig. 13. Conversion efficiency for a 900 MHz input power

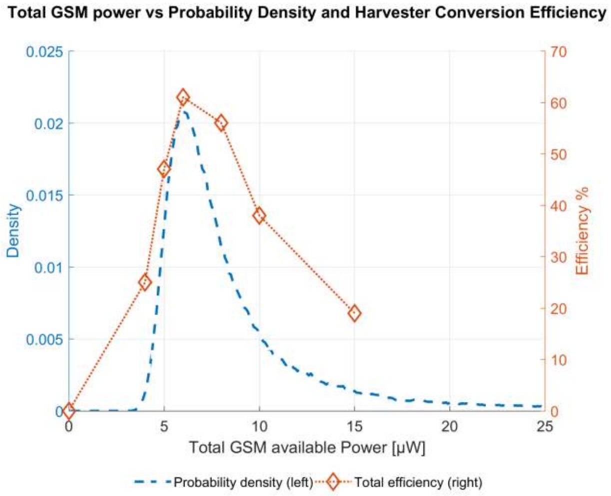

Fig. 14. Probability Density and Harvester Conversion Efficiency vs Total GSM power

V. CONCLUSIONS

We have here presented a combined 90/900 MHz Energy Harvesting Architecture for IoT deviccs power assisting. The system combines power from two bands through the usage of manufactured diplexer. Once the energy is harvested, it could be used either for direct usage or for storage in later use. The preliminary results, obtained at measured simulation level, are promising for EH application as for portable smart tags.

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