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Analyse comportementale d'un circuit récupérateur d'énergie en présence de signaux complexes

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Abstract:
This paper shows the incidence of the modulation scheme and of the input power on the RF to DC rectifier conversion efficiency. A commercial energy harvesting (EH) P21XXCSR-EVB evaluation board from Powercast Corporation is used as measurement target and several waveforms are employed to evaluate the rectification efficiency. With a continuous wave as reference, QPSK, QAM and OFDM waveforms usage demonstrates that digital modulated signals can lead to a better efficiency. Thus, by selecting a high peak to average power ratio (PAPR), and under certain conditions, the performances of the energy harvesting circuit are enhanced.

Résumé:
Cet article montre l'incidence du choix de la modulation et de la puissance du signal d'entrée sur l'efficacité d'une conversion RF-DC d'un circuit récupérateur d'énergie. Un circuit commercial de la société Powercast, le convertisseur P21XXCSR-EVB, est utilisé comme système récupérateur d'énergie RF et plusieurs formes d'onde sont générées afin de tester l'efficacité du redresseur. Avec comme référence une onde sinusoïdale, l'utilisation des formes d'ondes de type QPSK, QAM et OFDM montrent qu'un signal modulé permet d'atteindre une meilleure efficacité. Ainsi, en choisissant un rapport PAPR élevé, et sous certaines conditions, les performances du redresseur sont améliorées.

1 Introduction

In the context of the Internet of Things, RF energy harvesting is justified, for example, in applications sensitive to the weight and volume of the wireless sensor. The example of an insect localization study presented in [1] allows to understand the interest of this technology. Conventional batteries, solar panels or piezoelectric collectors can not meet the requirements in terms of small dimension and weight that are minimizing the impact on the insects's theft. Therefore, the RF energy harvesting is an evident choice to supply such sensors.
In energy harvesting systems, energy recovered from ambient sources is converted by a rectifier into a DC voltage which is either stored or is directly power supplying the connected object [2]. In this context, several research works are focusing on the improvement of the RF rectifier contained by the energy harvesting device in order to increase its conversion efficiency [3, 4].
Among the energy harvesting alternatives, the recovery of electromagnetic (EM) field has received a lot of attention. Several works are giving some measurement methodologies and shown results in study case [5, 6]. The RF-DC rectifier achieves relative performance, with low efficiencies, below 5% for an input power level of -35 dBm [7]. In their work ([7]), circuits and antennas are proposed and implemented to obtain maximum power. As a rule, whether in experimental prototypes or commercially available receptors, it is found that the sensitivity of an RF energy recovery device is in the order of -20 to -30 dBm [8]. Moreover, the main drawback of the EM energy recovery is that the amount of the available energy is variable and unpredictable, leading mostly on a reduced efficiency.
Another approach presented in the literature is the simultaneous transmission of data and energy [9]. Wireless energy transmission (WPT) uses an intentional EM signal, transmitted at a certain frequency and with a certain amount of average power to supply devices at great distances [10]. The emitted power level is known and most of the time is constant, which makes it possible to carry out the design of the optimal operation of the RF to DC rectifier circuit of EM energy.

Several works proposed to improve the RF-DC conversion efficiency of the rectifier circuits by selecting the most suitable waveform for the transmitted EM signal. In [11, 12], the use of multi-tones or chaotic signals has been explored as a way to improve the conversion efficiency in WPT systems. Their work has shown that signals with a time varying envelope can provide better efficiency because they are able to activate RF-DC receivers for lower average input power levels compared to constant envelope signals of the same average power.
In [13], the authors shown how the use of waveforms specifically selected or conceived in WPT systems can lead to better RF-DC conversion efficiency. Signals with different waveforms such as the OFDM signals, white noise and chaotic ones have been sent in order to test the performance of an RF-DC rectifier circuit operating at 433MHz. Performance is also compared with constant and single carrier envelope signals.
In this paper, the optimum signal waveform improving the EH efficiency is studied on a commercial rectifier, the Powercast's P21XXCSR[14]. M-PSK, M-QAM and multi-carrier signals are used in order to investigate which waveform gives an optimal efficiency.

2 Experimental setup

When high peak-to-average power ratio is one of the major drawbacks in digital communication systems using OFDM modulation [15], in the RF energy harvesting domain, this cons is used to overcome the limitation imposed by the rectifier's threshold voltage. The high PAPR of the OFDM signal allows to reach the maximum peal voltage. For example, the commercial rectifier studied in this paper use a Schottky diode and, for the same total average power of the input signal, high PAPR will turn on this diode for lower input power levels. To evaluate the energy harvesting circuit, we propose the use of digital modulated signals, i.e 16-PSK and 16-QAM with a symbol rate of the both complex signal of 1MSPS. A root-raised cosine filter with a roll-off factor of 0.35 is used to perform channel matching and reduce the bandwidth of each modulated signal. A multi-tone signal with a $\pi/4$-DQPSK modulation and OFDM signal with the same symbol rate (1MSaps) are also generated by the means of the Keysight's ADS software. All experimentation were made at 904 MHz as central carrier frequency.
P21XXCSR-EVB power harvester evaluation board is used to perform DC voltage measurements. This board converts RF energy into DC power and stores it in a capacitor to provide an intermittent or regulated output. Figure 1 describes the measurement setup to evaluate the P2110 RF-DC converter with modulated signals input. All signals described above are generated by a vector signal generator, the Keysight's ESG4438C. As the input power range of the Powercast evaluation board is -20 dBm to +23 dBm, the input signal was set to vary from -20 dBm to +20 dBm. An oscilloscope is connected to the V_{OUT} output to measure the DC voltage.

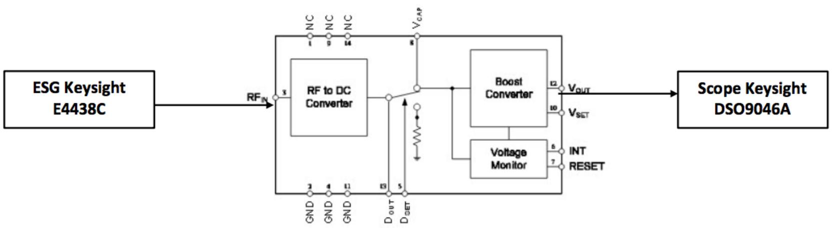

Figure 1 – Measurement platform

3 Measurement results

As can be seen from Figure 2, there is a certain difference in terms of EH performance when a signal modulated is 16-QAM is used. On the one hand, the obtained voltage is always greater then to a phase modulated signal or without modulation, but on the other hand, rectifier harvests a voltage of 100 mV for low power input of -15 dBm. This can be explained because, for this kind of modulation, the amplitude varies over the time. This amplitude variation offers more power compared to a continuous wave or a PSK modulation.
As before, there is no significant difference in terms of the device performance in the case of using of a continuous wave and of a $\pi/4$-DQPSK mono-carrier signal. It can be remarked that the OFDM signal offers a better efficiency when the power level is superior to -15 dBm.
The measurements presented here confirmed once again that the signal used to perform the energy harvesting plays an important role on the overall efficiency.

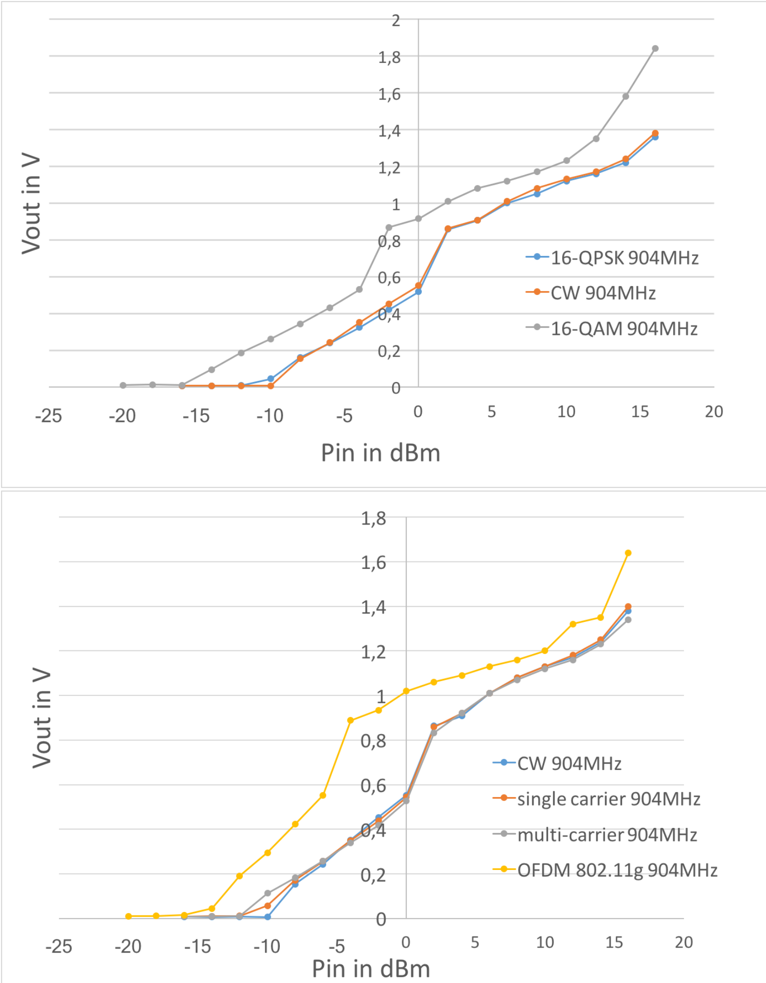

Figure 2 – Output voltage at the V_{out} pin with several waveforms, versus power RF input signal

4 Conclusion

This paper have shown once again that the RF energy harvesting efficiency is strictly related to the waveform used to covey this energy. The set of measurements presented here demonstrated that signals with high PAPR gives more RF to DC efficiency conversion compared to continuous wave signals or even simple carrier modulated signals. The work presented here will continue with the characterization of the Powercast energy harvester efficiency in the presence of other high PAPR signals such as FBMC (filter bank multi carrier) or chaotic signals.

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