Effect of signals with a time-varying envelope on RF-energy harvesting and wireless power transfer efficiency

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***Abstract*—This paper presents the design of an RF energy harvesting circuit when excited by signals with a time-varying envelope such as multi-tone signals or digitally modulated signals with random modulation. The input matching network and the output load of a rectifier circuit are simultaneously optimized using harmonic balance in order to maximize its RF-DC conversion efficiency. The presence of a time-varying envelope results in an optimum load which is different than the one when continuous wave (CW) signals are used. As a result, there is a range of load values where signals with a time-varying envelope result in a better RF-DC conversion efficiency compared to CW signals. A UHF rectifier prototype is built and its performance is evaluated experimentally showing good agreement with simulation.**

***Index Terms*— wireless power transfer, rectifier, harmonic balance, multi-tone, RF-DC conversion efficiency, optimization**

I. Introduction

THE RF-DC conversion efficiency of rectifier circuits has been the object of numerous research works due to the recent interest in wirelessly powered circuits for radio frequency identification (RFID) and other low power sensor applications as part of the Internet-of-Things (IoT) [1], but also due to the recent application potential of energy harvesting [2] and wireless power transfer technologies [3].

In this work we optimize the performance of rectifiers under signals with time-varying envelope and for different loads. It is verified that the optimal load leading to a maximum RF-DC conversion efficiency depends on the PAPR of the input signal.

As a result there is a range of load values where signals with time-varying envelope can perform better than CW signals in terms of efficiency. A prototype UHF rectifier was designed and fabricated and its performance under different multi-tone and randomly modulated signals and load values was investigated.

The paper is structured as follows: in section II the rectifier prototype is described. In section III, the input signal parameters and characteristics are defined and discussed. In section IV the measurement results are presented, and finally, in section V the conclusions of this work are summarized.

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II. Rectifier Design

A UHF rectifier was designed and optimized using harmonic balance simulation. The circuit, shown in Fig. 1, consists of an RF source with $R_s = 50\ \Omega$, connected in series to a Schottky diode (D) followed by a shunt capacitor (C_L) and a resistive load (R_L). A matching network (T-Type) and harmonic filter was placed between the source and the diode in order to maximize power transfer, filter undesired harmonics and maximize RF-DC conversion efficiency. The rectifier efficiency is defined as the ratio between the dc power delivered to the load $P_{L,dc}$ over the average RF power delivered by the source P_A.

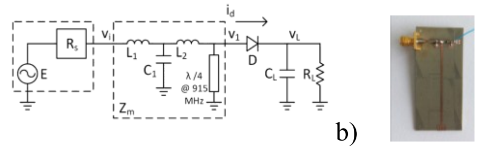

Fig. 1. Designed rectifier: a) circuit diagram, b) fabricated prototype.

III. Signal description

The complementary cumulative distribution function (CCDF) expresses the probability that the instantaneous power of a signal has a higher or equal value than the CCDF argument. The CCDF argument is given as the ratio of instantaneous power over average power. The signal peak to average power ratio (PAPR) can be identified from its CCDF curve. In this paper we considered as PAPR the argument of CCDF corresponding to a 0.01% probability. The measured CCDF of different modulated signals is shown in Fig. 2 and Fig 3 there is shown the measured CCDF of various multi-tone signals.

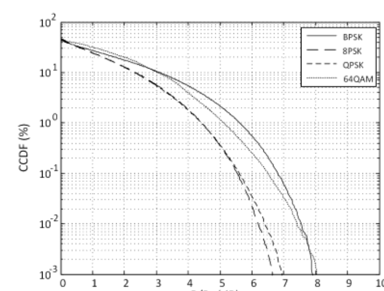

Fig. 2. Measured CCDF of modulated signals with β = 0 and 500 KBPS symbol rate.

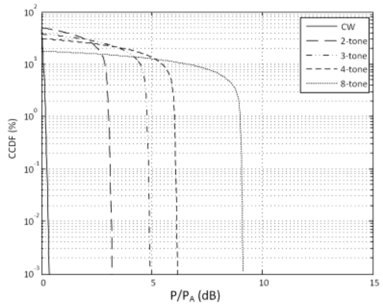

Fig. 3. Measured CCDF and PAPR of multi-tone signals.

IV. Measurements

The rectifier RF-DC conversion efficiency obtained for different modulated signals of the same average power versus different output load R_L values is shown in Fig. 4. The performance of the various modulated signals is also compared to that of a continuous wave (CW) input signal. One can see that the load value corresponding to a maximum efficiency is different for each of the applied signals. There is a region corresponding to lower R_L values where CW has better RF-DC conversion efficiency than modulated signals with higher PAPR. As the load is increased, the efficiency of the CW signal eventually begins to decrease and the efficiency of modulated signals becomes better than the CW. Specifically, signals with higher PAPR present better efficiency at higher load values.

The same trend was observed at different input (average) power levels of -20 dBm and 0 dBm. As the average power is increased the RF-DC efficiency values are larger for all signals considered.

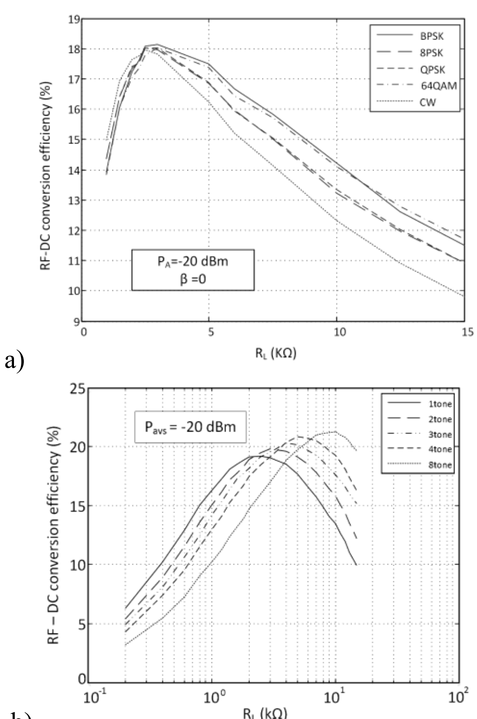

Fig. 4. Measured RF-DC conversion efficiency of a) randomly digital modulated signals and b) multitone signals.

It has also seen that signals with the same PAPR and different CCDFs curves present different behavior in terms of efficiency. In that case, the signal with a high instantaneous power variance (IPV) presents better efficiency at high load values. Due to that it has been seen that the IPV of the signal is a parameter that defines more accurately the behavior of the efficiency of the signal.

V. Conclusions

The optimization of rectifier circuits under signals with time-varying envelope is presented. Deterministic multi-tone signals and stochastic randomly modulated signals are considered, and the dependence of the RF-DC conversion efficiency on the rectifier load is investigated. It is shown that for a series diode rectifier the optimum load is slightly reduced as the average input power increases and it is increased as the signal PAPR is increased. A UHF prototype was designed, fabricated and tested showing good agreement with simulation.

The results from this work have led to two journal publications [4][5] and in addition, we have investigated the design of ultra wideband RF energy harvesters and the work led to one IMS conference publication [6].

Career Plans

Once graduated, the career plans are to grow as a telecommunication engineer in the industry world. Trying different topics in order to check what I want to do in the future. I am changing to the project management field, but, in an upcoming future I want to continue researching, at least to take a research Ms Degree.

The MTT-S Scholarship program has shown me that the research world is a huge world full of opportunities, due to that, I want to continue researching in a future.

Due to familiar matters I could not attend to the conference but it was a honor just the fact of have been invited.

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