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This is a copy of the author's accepted version of a paper subsequently to be published in the proceedings of the IEEE MTT-S Wireless Power Transfer Conference (WPTC), part of Wireless Power Week (WPW2019), London, UK, 17 - 21 Jun 2019.

The final published version is available online at:

https://doi.org/10.1109/WPTC45513.2019.9055635

Impact of 5G Waveforms on Energy Harvesting Rectifier Performance

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Abstract—**In this paper, an evaluation of impact of 5 MHz 5G FBMC waveforms on energy harvesting rectifier performance is presented. The 5 MHz 5G FBMC signals are used in Matlab. The simulated CCDFs of the rectifier for 5 MHz 5G signals at different input powers at 1.5 GHz are illustrated**

Keywords—**Rectifiers, FBMC, Peak-to-Average-Power Ratio (PAPR), Complementary Cumulative Distribution Function (CCDF).**

I. INTRODUCTION

The emergence of microwave power transmission (MPT) plays a vital role in wirelessly powered circuits such as RF identification (RFID) and other low power wireless sensors [1]. The total efficiency of the microwave wireless system depends mainly on the RF-DC conversion efficiency of the rectifier circuits which has made high efficiency rectifier design very important.

Recent researches have focused on different topologies to improve RF-DC conversion efficiency performance. Some of such topologies and models have been proposed in [2] – [5]. It was found that the electromagnetic energy is generally not constant due to the varying input power and operating frequency which leads to input impedance variation. The impedance variation degrades the rectifier performance due to the nonlinearity of the rectifying device. Another drawback from some of these improvements was due to load variation at the output of the rectifier which also leads to input impedance modification that can cause efficiency to deteriorate. To overcome the drawbacks and boosts robustness against the input power and output load variations, some further techniques were developed. Some of those solutions included resistance compression networks [6] which helped to improve the input impedance variation issue but still had bandwidth efficiency issues.

Recent works have now focused on the performance of rectifiers under different signal types rather than just considering the matching network and device selection. Previous work had considered single and two tone modes of operation. It has been observed when investigating multi tone signals that high peak-to-average power ratio (PAPR) may lead to a higher RF-DC conversion efficiency than its equivalent signal with the same input power [7]. This work optimizes the RF-DC efficiency performance by identifying the optimal load resistance whilst achieving a high PAPR using digitally modulated signals.

II. ENERGY HARVESTING RECTIFIERS

The design of the rectifier circuit is essential to achieve the best RF-dc conversion efficiency, for this purpose a single stage, full-wave; peak to peak rectifier has been used [7]. A single stage rectifier with/without branch line coupler is designed. Full wave rectifiers can achieve higher RF to DC efficiency than the half-wave. In this design the zero-bias Schottky diodes (Skyworks SMS7630) have been selected as the rectifying components. The selection of the commercially available Schottky diodes has been made considering the lowest zero-bias capacitance C_{j0} and the highest saturation current I_s, since these are the two parameters directly responsible for the RF-DC conversion efficiency. Fig. 1 shows the schematic of the designed and optimised rectifier without BLC. The schematic of the designed and optimised rectifier with BLC is shown in Fig. 2. At the input of the rectifier a T-type matching network was used to assure the highest power transfer between input and output power through converting the $50\,\Omega$ input impedance of the antenna to match the conjugate input impedance of the rectifier. Then, the BLC and the rectifier are combined. The results are obtained and analysed in the next section for RF CCDF of 5 MHz FBMC waveforms and efficiency performance.
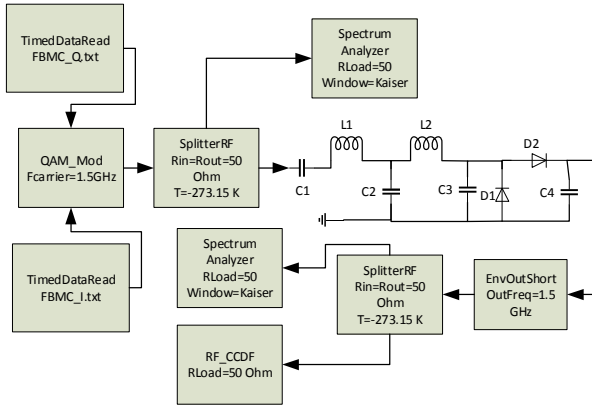
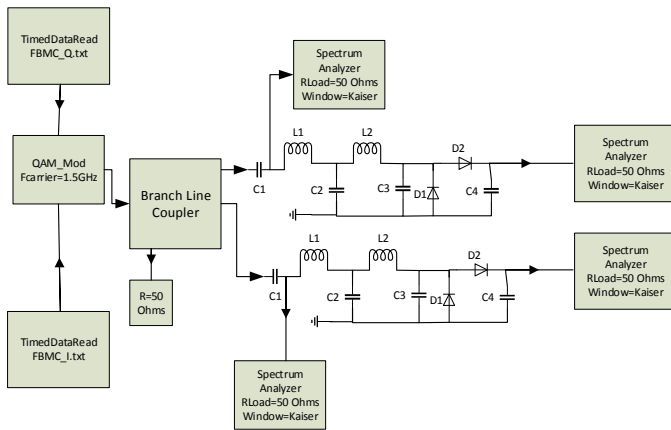Fig. 1: Schematic of the rectifying circuit without BLC

Fig. 2: Schematic of the rectifying circuit with BLC

III. RESULTS

To evaluate the nonlinear properties at the energy harvesting rectifier's output the 5 MHz FBMC waveforms are used. FBMC transmits data by filtering each sub-carrier individually rather than the whole sub-band. FBMC signal can achieve better spectral efficiency as it does not use cyclic prefix and respects Nyquist rate. In contrast to CP-OFDM, the low side-lobes, steep slope at the edges of the signal band and the use of larger number of subcarriers during transmission all help to improve spectral efficiency at the output of the wireless transmitter [8].The 5G FBMC waveforms were generated using Matlab. Simulation results were obtained using the model of the signal generator in Keysight's Agilent ADS software.The CCDF argument (Signal Range in dB) is represented as the ratio of a given power level (P in dBm) over the average power (P_A in dBm). CCDF depicts the fraction of time it takes the instantaneous power of the signal to be equal or greater than the CCDF argument. The CCDF curve shows the probability that the instantaneous signal power will be higher than the average signal power by the certain amount of dB.

The independent axis of the CCDF curve shows power level in dB with respect to the signal average power level (0 dB corresponds to the signal average power level).

The CCDF of 5G FBMC signals and their corresponding PAPR value for the designed rectifier is described below. Waveform comparison and CCDF results are evaluated at the same bandwidth and different input power levels. Simulated CCDF and PAPR (P/P_A in dB) of the energy harvesting rectifier without coupler with 5 MHz 5G FBMC signals at input power levels of -10 dBm, 0 dBm and 10 dBm are presented in Fig. 3. Fig. 5, and Fig. 7 respectively. In the Fig. 5, we can see that the instantaneous signal power exceeds the average signal power (0 dB) for about 30 % of the time. Also, we can see that the instantaneous signal power exceeds the average signal power by -10 dB only about 72 % of the time.

The simulated CCFD of various output power spectra densities of the rectifier with coupler with 5 MHz FBMC at input power of -10 dBm, 0 dBm and 10 dBm are shown in Fig. 4, Fig. 6 and Fig. 8 respectively. In the Fig. 6, we can see that the instantaneous signal power exceeds the average signal power (0 dB) for about 30 % of the time. Also, we can see that the instantaneous signal power exceeds the average signal power by -10 dB only about 70 % of the time.

Fig. 9 also shows the RF-dc conversion efficiency of the rectifier with coupler versus output load (R_{LOAD}) for a two-tone input power of 12.2 dBm at 1.5 GHz.
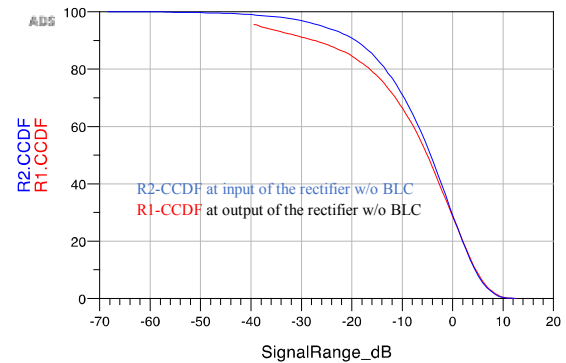

Fig. 3. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier without BLC at input power of -10 dBm
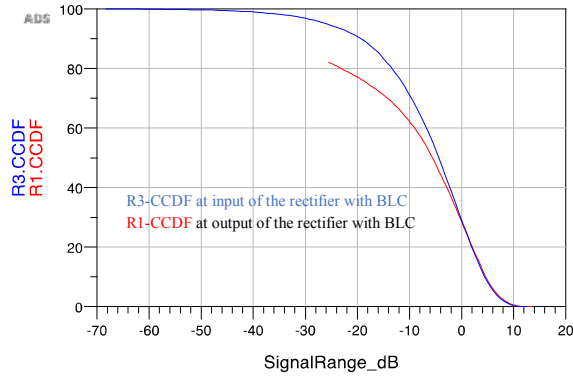
Fig. 4. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier with BLC at input power of -10 dBm.
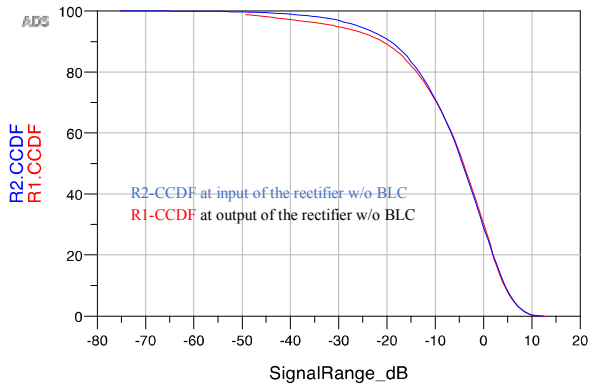

Fig. 5. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier without BLC at input power of 0 dBm
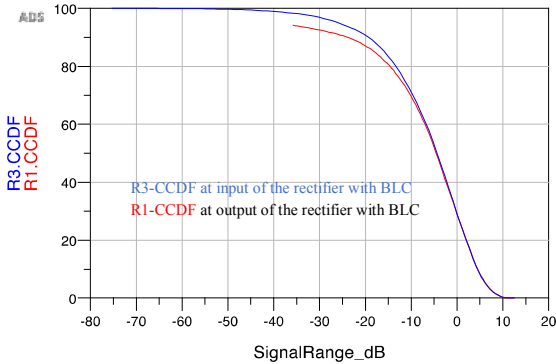

Fig. 6. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier with BLC at input power of 0 dBm
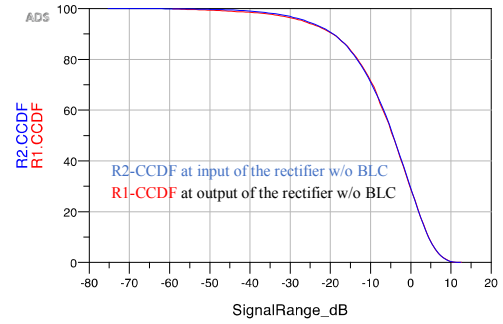

Fig. 7. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier without BLC at input power of 10 dBm.
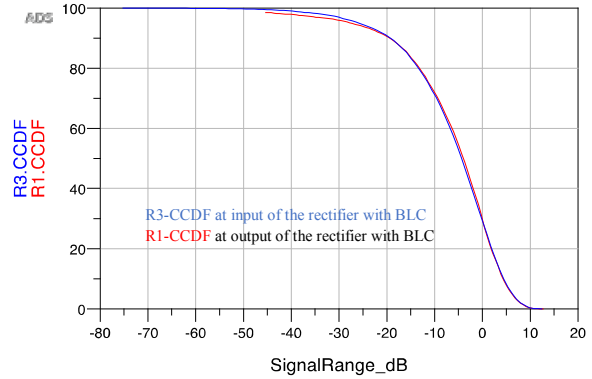

Fig. 8. Simulated CCDF of 5 MHz FBMC waveforms of the rectifier with BLC at input power of 10 dBm
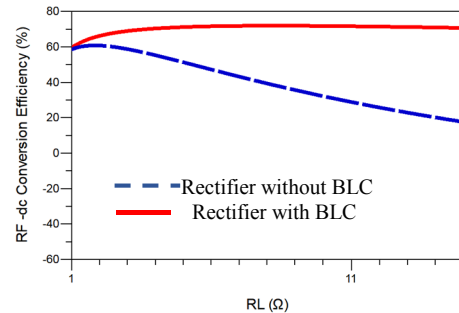

Fig. 9. Simulated efficiencies of the rectifiers with and w/o BLC versus output load (R_{LOAD}) in kΩ with input power of 12.2 dBm at 1.5 GHz

IV. CONCLUSION

In this paper, the impact of 5 MHz 5G-FBMC waveforms on energy harvesting rectifier performance has been investigated. The 5 MHz FBMC signals have been used to observe the CCDF effects. The proposed rectifier configuration will be very effective for the next generation low power sensor networks, IoT (Internet of Things) and 5G applications.

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