Performance Analysis of Post-OFDM Waveforms in 5G Wireless Environments

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***Abstract*-The performance analysis of the post-OFDM waveforms such as FBMC and UFMC as a potential 5G modulation waveforms at n78 (3.3–3.8 GHz) and at n258 (24.5 – 27.5 GHz) 5G FR 2 frequency bands is presented. The Power Spectrum Density (PSD) and linearity of the power amplifier (Mini-Circuits ZX60-V62+) for a 100 MHz FBMC waveform which has the lowest OOB (out-of-band) emission is about 28 dB better in comparison with UFMC and 30 dB at saturation power level of the power amplifier (Analog Devices HMC 930A) for a 100 MHz channel bandwidth. Measured output power spectra results of the power amplifier fed with 3 MHz UFMC and FBMC modulated waveforms at 0.7 GHz for the input power of -10 dBm are presented.**

Keywords—CP-OFDM; FBMC; UFMC; 5G; PSD, Spectral efficiency;, OOB; and ACPR.

I. INTRODUCTION

Due to the growing popularity of 5G and IoT smart devices mean that there is going to be a massive connection of these devices to the network which must deliver higher date rates, and low latency. The advent of IoT means that there is going to be a massive connection of smart devices to the network at the same time. 5G aims to achieve 1000 times more data capacity as LTE and 1 Gbps per user anywhere, a peak data rate of more than 50 Gbps per cell for downlink, 25 Gbps for uplink, cell edge data rate of 1 Gbps for downlink, 0.5 Gbps for uplink at 10/30 km/h and ultra-low latency of less than 1 ms [1]-[3]. The uplink 4G/5G scheme such as Single-carrier frequency division multiple access (SC-FDMA) has some advantages such as low implementation complexity, low peak-to-average power ratio (PAPR) and ease of application to massive multiple-input and multiple-output (MIMO) systems. However, SC-FDMA system has high out-of-band emission and is very sensitive to inter-user frequency offsets and solving these problems has been challenging. Hence, it is imperative to find a flexible waveform that will be able to meet these new demands and overcome the draw backs of the 4G/LTE signal. It was suggested that as an alternative to SC-FDMA for 5G networks, various modulation waveforms are being considered, such as the filtered OFDM (f-OFDM), filter bank multicarrier (FBMC), universal filtered multicarrier (UFMC), and generalized frequency division multiplexing (GFDM) schemes. Among those waveforms, FBMC has the lowest OOB emission and thus, inter-user interference caused by inter-user frequency offsets can be eliminated by using only one guard subcarrier. Also, inter-carrier interference caused by a multipath fading channel can be overcome without using a cyclic prefix 5G could permit different the use of different waveforms for different applications and systems [4]. The two potentialy leading 5G waveform candidates such as Filter-bank multicarrier (FBMC) and Universal filtered multicarrier (UFMC) as possible alternatives to OFDM as the waveform in the current 5GNR specification will be evaluated for severalk channel bandwidths up to 50 MHz or more within the power amplifier's nonlinear region [5]–[6].

As an alternative to SC-FDMA for next-generation networks, various modulation waveforms are being considered, such as the filtered OFDM (f-OFDM), filter bank multicarrier (FBMC), universal filtered multicarrier (UFMC), and generalized frequency division multiplexing (GFDM) schemes. Among those waveforms, FBMC has the lowest OOB emission and thus, inter-user interference caused by inter-user timing/frequency offsets can be eliminated by using only one guard subcarrier. Also, inter-carrier interference caused by a multipath fading channel can be overcome without using a cyclic prefix (CP) [5]-[6].

An evaluation and performance analysis of the nonlinear distortion behavior of RF power amplifiers using FBMC and UFMC modulated waveforms is presented in this paper. Both waveforms were evaluated and compared for bandwidths up to 50 MHz at the PA's nonlinear region. The paper is organised as follows. Section II considers the modulated waveforms characteristics that form the basis of this paper. In section III, simulation and experimental results for UFMC and FBMC waveforms are evaluated and presented. The conclusion is described in section IV.

II. Post- OFDM Waveforms

Here we will briefly describe Universal filtered multicarrier (UFMC) and Filter-bank multicarrier (FBMC) as potential post-OFDM 5G waveforms [7]. In contrast to Cyclic Prefix (CP) OFDM which greatly reduces the bandwidth efficiency, FBMC is a type of modulation scheme, which is derived from OFDM which overcomes the drawbacks of OFDM. Unlike OFDM, there is no CP or guard time requirement in FBMC. Therefore, FBMC provides the high spectral efficiency at the output of the wireless transmitters compared to OFDM with designing a proper prototype filter and minimizes the interference between the adjacent subcarriers. The main FBMC's advantages stem from the shaping ability of each subcarrier individually and the availability of many pulse shaping filters. There are filters fully orthogonal in both domains while being very sensitive against impairments in one domain, e.g., rectangular, raised cosine, etc. FBMC introduces a filter-bank to permit efficient pulse shaping for the signal conveyed on each subcarrier. It is an array of band-pass filters that separates the input signal into multiple subcarriers, with each carrying a single frequency sub-band of the original signal [8]. This waveform provides better performance in frequency selective channel with long delay spread and low Out-of-Band (OOB) emissions and have the properties to be a successful 5G signal for wireless transmitters and has the capability to maintain system performance over a wide bandwidth. Although FBMC, has been considered for use in some developing technologies, although it is not in real use for many applications yet. Actually, FBMC is considered as an alternate waveform to OFDM in the 3GPP RAN study phase I during 3GPP Release 14. A development of OFDM using banks of filters that are implemented is FBMC. The main aim of the FBMC is to overcome some of the disadvantages such as the fact that the cyclic prefix (CP) required for OFDM is not needed thereby freeing up more space for real data. The cyclic prefix is essentially a copy of part of a transmitted symbol in OFDM that is appended at the beginning of the next. When carriers are modulated in an OFDM system, sidelobes spread out either side. With a filter bank system, the filters are used to remove these and therefore a much cleaner carrier result. Systems using OFDM modulation are less complicated than FBMC. This results from the exchange of FFT/IFFT modules by the filter banks. The detail theoretical analysis of FBMC is described in [9]. UFMC is a filter technique between OFDM and FBMC. It uses a filter with sub-bands to achieve more spectral efficiency and robustness [10]. An UFMC multicarrier system has n subbands, and each subband has binary data mapped to a digital subcarrier. Next, the subbands are converted into time domain by an Inverse Fast Fourier Transform (IFFT) of N points. The detail theoretical analysis of UFMC is described in [11].

III. Results

This section evaluates, filter bank multicarrier (FBMC), and universal filtered multicarrier (UFMC) modulated waveforms of the RF power amplifiers at the compression point at 5G spectrum below 6 GHz and above 6 GHz for 5G NR deployment, where one operator could obtain 100 MHz or more spectrum. The frequency band n78 (3.3–3.8 GHz) 5G NR FR1 and n258 (24.5 – 27.5 GHz) 5G FR 2 frequency bands were chosen as it is two of the main 5G bands below and above 6 GHz. The modulated waveform with channel bandwidth of 100 MHz, was fed into RF power amplifier (Mini-Circuits ZX60-V62+)/(Analog Devices HMC 930A) models at 3.5/27 GHz. Simulated output power spectra of the RF power amplifier fed by OFDM, FBMC and UFMC waveforms are shown in Fig. 1, and Fig. 2, respectively. In this study, we used Keysight's SystemVue communication physical layer simulation software. For a 100 MHz channel bandwidth OFDM, UFMC and FBMC waveforms are evaluated, and their simulated output power spectra are shown in Fig. 1. to Fig. 2., respectively. The PSD (Power Spectrum Density) of the power amplifier (Mini-Circuits ZX60-V62+) for FBMC waveform is about 28 dB better in comparison with UFMC for a 100 MHz channel bandwidth as shown in Fig. 1. Fig. 2 also show about 30 dB better spectral efficiency and linearity of the power amplifier (Analog Devices HMC 930A) for a 100 MHz FBMC waveform.

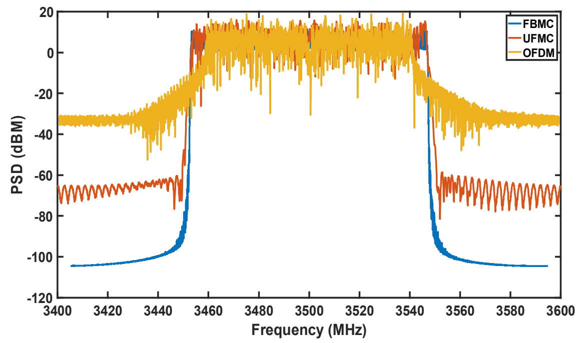

Fig. 1. Output power spectra simulation of the PA for 100 MHz channel Bandwidth and 0 dBm input power.

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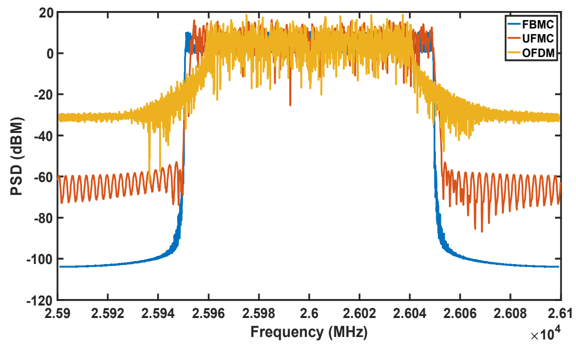


Fig. 2. Output power spectra simulation of the PA for 100 MHz bandwidth and 0 dBm input power.

In the generic transmitter architecture shown in Fig. 3, the transmitting radio frequency signal by the antenna is filtered by the band selection filter and amplified by the RF power amplifiers (Mini-Circuits ZX60-V62+ and Analog Devices HMC 930A).

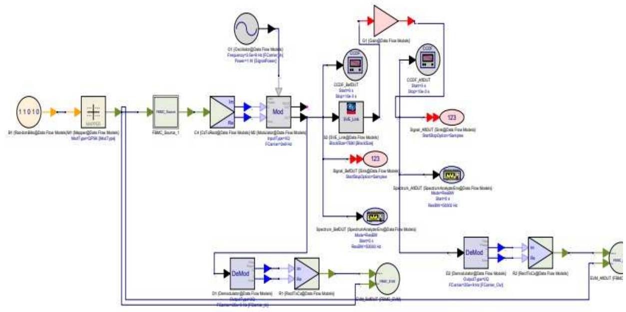
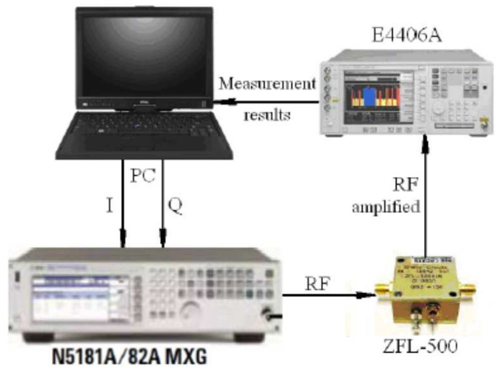
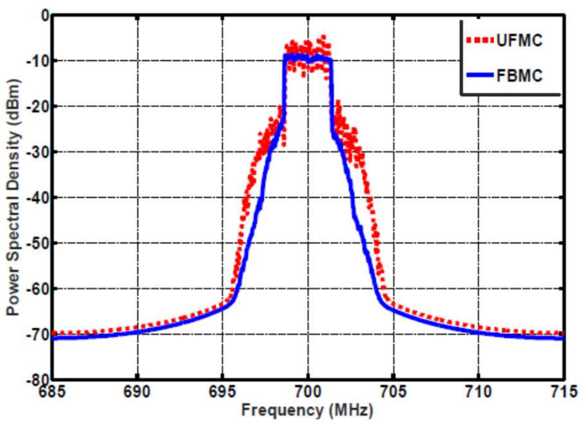


Fig. 3. Simulation setup for transmitter architecture.

The experimental setup composed of the Keysight MXG N5182A signal generator, a power amplifier (Mini-Circuits ZFL-500) as device under test (DUT) is shown in Fig. 4a. Measured output power spectra of the power amplifier fed with a 3 MHz UFMC and FBMC modulated waveforms at 0.7 GHz for input power of -10 dBm are shown in Fig. 4b.



(a)



(b)

Fig. 4. (a) Experimental setup and (b) output power spectra measurement of the PA at 0.7 GHz.

IV. Conclusion

This paper evaluates the performance of the two potentially post-OFDM leading 5G waveform candidates such as FBMC and UFMC at n78 (3.3–3.8 GHz) 5G NR FR 1 and at n258 (24.5 – 27.5 GHz) 5G FR 2 frequency bands. The channel bandwidth of interest was 100 MHz. Simulated results of the power spectrum density of the power amplifier (Mini-Circuits ZX60-V62+) show that the power spectra density and linearity improvement of FBMC over UFMC has been achieved about 28 dB for channel bandwidth of a 100 MHz. The power spectral density and linearity improvement of 100 MHz FBMC over UFMC has been achieved about 30 dB at saturation power level of the power amplifier (Analog Devices HMC 930A). These two 5G modulated waveforms have been experimentally evaluated at saturation power levels for nonlinear distortions of the power amplifier (Mini-Circuits ZFL 500).

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