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Evaluation of Waveform Candidates for 5G Wireless Communications

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***Abstract*—In this paper, we evaluate the waveform candidates for 5G wireless communications such as FBMC and UFMC and 4G's cyclic prefix CP-OFDM. Measured results for 1.4 MHz and 3 MHz waveforms show a 5 dB reduction in ACPR between FBMC and UFMC. Simulation and measured output power spectra of the power amplifier for 3 MHz and 10 MHz waveforms are match very well.**

Index Terms— CP-OFDM, FBMC; UFMC; Spectral Efficiency; ACPR.

I. INTRODUCTION

It is predicted that the mobile broadband traffic will be increased by 1000-fold during the next decade [1]. The rising popularity of bandwidth-hungry applications such as high-definition video streaming and multimedia file sharing calls for faster data rates with low latency connection. Once 5G is up and running, development of the IoT will accelerate until IoT applications such as smart cars and smart home appliances are a part of everyday life which will drive artificial intelligence (AI) and virtual reality (VR). The increase in internet traffic will require constant connectivity, efficient management systems and an architecture that is able to handle the number of devices. With capability objectives for 5G, such as 20 Gbits/s peak data rate, 106 devices/km2 connection density and 1 ms latency, improvements must be made upon the current 4G cellular technology [2]. One improvement at the heart of this advancement is the use of alternative waveforms that can achieve better spectral efficiency for various input power levels and increasing bandwidth.

Orthogonal frequency-division multiplexing (OFDM) has been the major waveform used for 4G with good robustness against multi-path propagation but with drawbacks such as large side-lobes which leads to high adjacent channel interference (ACI) and inter-carrier interference (ICI) which should be avoided for 5G networks. Its cyclic prefix technique (CP-OFDM) reduces spectral efficiency significantly [3]. The spectrum efficiency of 5G is expected to be three times higher than CP-OFDM as the 10% of the bandwidth reserved as guard bands needs to be reduced enormously [2]. The reduction of these guard bands should ensure that the spectral efficiency is maintained over larger bandwidths.

Currently, there are several multicarrier waveform candidates that are being considered for 5G to address these limitations. The two leading candidates at the moment are FBMC and UFMC. Filter-bank multicarrier (FBMC) implements subcarrier filtering to achieve better spectral efficiency and overcomes the strict synchronization specifications of OFDM whilst Universal Filter MultiCarrier (UFMC) has comparable spectral efficiency to FBMC, but has reduced filter length requirement and is achieved by performing filtering operation per sub-band instead of per subcarrier [4]. This paper represents evaluation of the nonlinear behaviourr of a nonlinear power amplifier using 4G CP-OFDM signal in comparison with 5G FBMC and UFMC signal. The two leading 5G waveform candidates were evaluated and compared for bandwidths up to 50 MHz at different input power levels. Experiments were also carried out to evaluate the spectral efficiency performance for the 4G (CP-OFDM) and 5G waveform candidates (FBMC, UFMC) at different input power levels for different bandwidths.

A. CYCLIC PREFIX OFDM (CP-OFDM)

The basic principle of CP-OFDM system is to use narrow, mutually orthogonal subcarriers. CP-OFDM is the most prominent waveform, widely used in LTE. The signal design consists of a large number of closely spaced sub-carriers and cyclic prefix length to carry data and control information. To design the signal, the end of the CP-OFDM symbol is and placed at the beginning of the symbol, for every symbol. In the cellular wireless transmitter system, CP-OFDM exhibits robustness against multi-path propagation but has drawbacks in its implementation. In the multi-path channel systems the orthogonality between signal subcarriers cannot be easily accomplished. CP-OFDM signals use CP longer than time spread introduced by the channel, which leads to decrease of spectral efficiency. Due to its rectangular pulse, CP-OFDM has high OOB (out-of-band) emissions [5]. This results in larger side lobe levels with the elimination of sharp transition edges. There is spectral leakage at the end of each CP-OFDM symbol due to waveform discontinuity and this could limit its applications for 5G networks. Therefore, new multicarrier modulation scheme are proposed to overcome above drawbacks.

B. FBMC

Filter Bank Multi-Carrier (FBMC) transmits data by filtering each sub-carrier individually rather than the whole sub-band. The frequency domain localization and time domain localization are controlled by using prototype filters, which results in low side lobe levels in contrast to CP-OFDM. 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 [5]. One major advantage of FBMC over other waveform candidates (such as CP-OFDM, GFDM and UFMC) is that it enables fundamental spectral efficiency at low signal processing complexity. Better performance can be achieved comparable to CP-OFDM with the help of multiple prototype filters between spectrum confinement and orthogonality among adjacent sub-carriers [6]. This waveform provides better performance in frequency selective channel with long delay spread and low Out-of-Band emissions and it's a potential candidate for the 5G wireless transmitters and has the capability to maintain system performance over a wide bandwidth.

C. UFMC

Universal Filtered Multi-Carrier (UFMC) is a waveform enhancement of CP-OFDM used in 4G LTE wireless transmitters. It works on the drawbacks of CP-OFDM whilst trying to retain its advantages such as high PAPR, flexibility and MIMO capability. UFMC filters a group of consecutive sub-carriers to reduce the out-of-band emissions and ICI between the adjacent users during asynchronous transmission. This in turn provides the shorter impulse response in time domain. UFMC is spectrally more efficient compared to CP-OFDM because of the reduced guard bands in adjacent channels[7]. This makes UFMC a better candidate to CP-OFDM for the 5G wireless transmitters.

II. Results

In this section, CP-OFDM, UFMC and FBMC signals are evaluated and compared at different saturation input levels of the nonlinear power amplifier. The centre frequency of 700 MHz was chosen as one of the potential 5G bands below 6 GHz (sub-6GHz). All three signals with 3 and 10 MHz channel bandwidth are passed through the PA at 700 MHz. Simulations were performed using Keysight's Agilent design software(ADS). Experimental data for the Mini-Circuits ZFL-500 PA was extracted and used in ADS. In order to evaluate the level of the nonlinear distortion, power spectra of CP-OFDM, 5G FBMC and UFMC signals at the output of the PA are shown in Fig. 1 and Fig. 2.

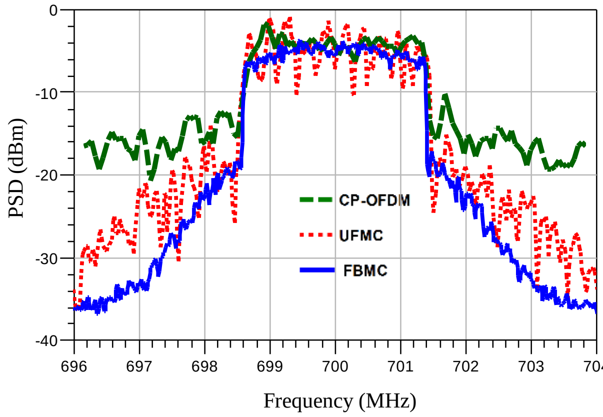

Fig. 1. Simulated output power spectra of the PA for 3 MHz waveforms.

Fig. 1 and Fig. 2 show the effect of nonlinear distortion of the PA on all three signals. As can be seen from Fig. 1, the Adjacent channel power ratio (ACPR) for 5G FBMC signal is about 16 dB more when compared to CP-OFDM and about 10 dB for UFMC. Also for Fig. 2, a 6 dB improvement in UFMC ACPR over FBMC whilst CP-OFDM maintained its 16 dB poorer ACPR. For higher bandwidth of 10 MHz, whilst the spectral efficiency of UFMC increases with respect to FBMC, CP-OFDM still maintains its poor spectral performance.

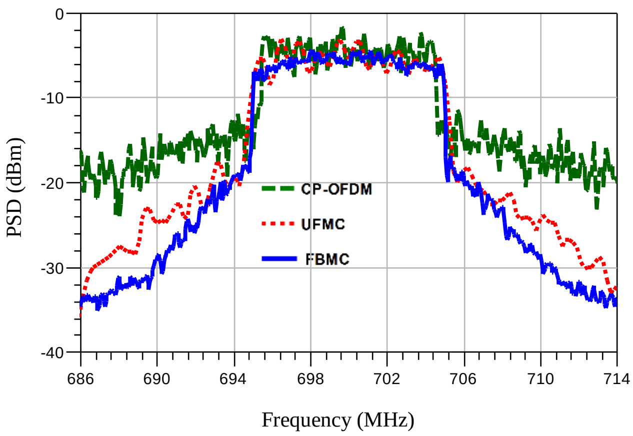

Fig. 2. Simulated output power spectra of the PA for 10 MHz waveforms.

LTE can only support a maximum of 20 MHz whilst 5G is expected to use a minimum carrier bandwidth of 100 MHz.

Experiments were carried out using the measurement setup shown in Fig. 3. It consists of Keysight MXG N5182A signal generator used to emulate wireless transmitter. A Mini-Circuits ZFL-500 PA was used as device under test (DUT) for measurement. This DUT was fed by a CP-OFDM and then with 5G FBMC and UFMC signals. All signals were tested at 700 MHz 5G band with the same input power and measurements were taken.. The input power was varied to show the effect of nonlinear distortion introduced by PA. The signal was downconverted by Keysight VSA and captured by 89600 VSA software running on the PC.

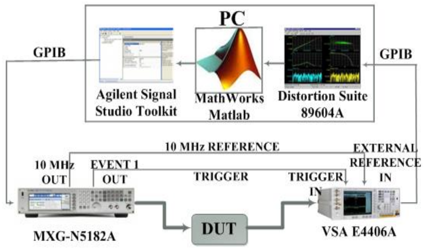

Fig. 3. Measurement setup.

In order to evaluate the level of the nonlinear distortion, introduced by PA to the wireless transmitter, the output power spectra of the 1.4 MHz CP-OFDM, FBMC and UFMC signals at input power level of – 15 dBm is shown in Fig. 4.

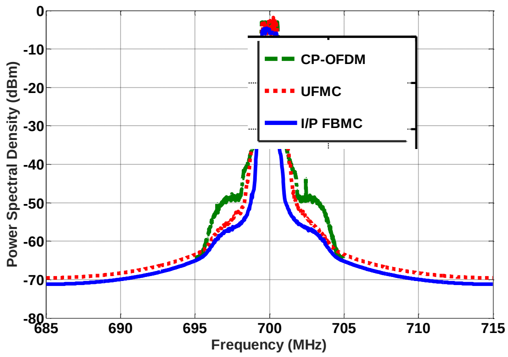

Fig. 4. Measured ouput power spectra of the PA for 1.4 MHz bandwidth

To observe how FBMC and UFMC respond to different levels of distortion, one saturation input power level of the PA (-10 dBm) is utilised. Measured results of the PA with UFMC and FBMC signals for a 3 MHz bandwidth are shown in Fig. 5 for input power of -10 dBm.

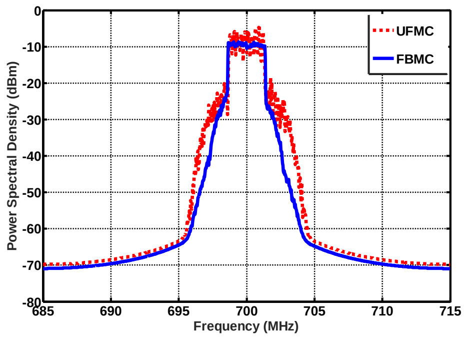

Fig. 5. Measured output power spectra of the PA for 3 MHz bandwidth and input power of -10 dBm

III. Conclusion

This paper evaluates the performance of 5G potential waveform candidates in comparison with its 4G equivalent. CP-OFDM, UFMC and FBMC have been evaluated for 3 MHz and 10 MHz channel bandwidths and different input power levels for nonlinear distortions at the 700 MHz as one of potential 5G frequency bands. Measured and simulated results were in very good match for 3 MHz FBMC and UFMC 5G waveforms.

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