A De-Cresting Technique for Polar Transmitters Using Envelope-Tracking (ET) and SiGe Power Amplifiers for Mobile-WiMAX

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Abstract — A decresting algorithm for mobile WiMAX has been developed using time domain clipping and filtering processes for a polar transmitter (TX) using Envelope-Tracking (ET) and a monolithic SiGe power amplifier (PA). RF/Analog/Digital system and circuits co-design simulations have been performed for mobile WiMAX with 64 QAM OFDM modulation format. It is found that higher power-to-average ratio (PAR) decresting can improve the adjacent channel power ratio (ACPR) and the overall TX system efficiency, but at the cost of its EVM degradation. Our system simulations show that careful design of signal decresting can improve the overall polar TX system efficiency from 28.1% to 30.3% while the TX output can still meet the stringent WiMAX TX mask and EVM specs.

Index Terms — Polar transmitter, mobile WiMAX, Power Amplifier (PA), decresting, clipping ratio (CR), PAR, Envelope-Tracking (ET).

I. INTRODUCTION

In order to reduce the Peak-to-Average Ratio (PAR) of wideband Orthogonal Frequency Division Multiplexing (OFDM) signal to improve the power-added-efficiency (PAE) of wireless portable transmitters, various techniques have been proposed. Techniques that clip the time domain signal to a predefined level are effective [1]; however, they suffer from out-of-band radiation and in-band clipping noise. Filtering can be applied after the clipping to reduce out-of-band radiation and to satisfy in-band spectral mask requirements, albeit with the price of increased BER and output spectrum regrowth.

Out-of-band radiation can be filtered either in time domain using a low-pass filter, or in frequency domain by using an FFT/IFFT pair. For example, Li and Cimini Jr. introduced a direct clipping and filtering algorithm in the time domain [2], where an OFDM signal with 128 subchannels was used and filtering was done directly after clipping at baseband before the OFDM signal was up-converted to RF. They defined Clipping Factor (CF) as $CF = A / \delta$, where $A$ is the clipping level and $\delta$ is the average level of the OFDM signal. Pauli and Kuchenbecker developed clipping and filtering in the digital domain focusing on the reduction of out-of-band radiation [3]. Helaoui et al. compared the results of hard clipping vs. soft clipping with rectangular window filter and also with equiripple filter [4]. They showed filtering after clipping could effective reduce out-of-band radiation. Different from hard clipping in [2], they used indirect control clipping and the clipping factor in their analysis was defined as the maximum output divided by the maximum input of the clipper. Chen introduced a clipping and filtering process in the envelope path for 802.11g OFDM signal with 12dB PAR [5]. The OFDM signal is divided into envelope and phase paths and detected by envelope and phase detectors, respectively. After the envelope clipping, both paths will go through a mixer and a FIR low pass filter. Here, clipping ratio (CR) is defined as $CR = 20 \log (V_{\text{peak}}/A_{\text{clip}})$, where $V_{\text{peak}}$ is the peak amplitude of envelope signal and $A_{\text{clip}}$ is the clipping voltage. When CR of 5 and 10 dB are applied, PAR may reduce by 3 and 5 dB, respectively. EVM would increase as CR goes higher. Wang and Tellambura investigated filtering in the frequency domain and showed that it can have better reduction ratio of out of band radiation than iterative clipping and filtering (ICF) techniques [6]. Zhu et al. proposed novel frequency filtering by introducing phase factor [7]. Ojima and Hattori further developed peak-windowing using a clipping and filtering process [8]. Considering FFT/IFFT will introduce additional system complexity, this paper focus on the filtering process in time domain using a low pass filter for a decresting algorithm developed for our polar TX with ET and a SiGe monolithic PA using the Advanced Design System (ADS) tool. Our RF/Analog/Digital system/circuits co-design simulations show that we can successfully reduce PAR of mobile WiMAX signals by decresting, which can improve TX system output spectrum distortion while also meeting the system EVM spec.

Fig. 1 Simplified block diagram of a RF polar TX system using ET technique. Realistic SPICE models of envelope amplifier and SiGe monolithic PA, validated by measurement, were used in simulations.
II. Decresting Algorithm for WiMAX Using ADS

Our WiMAX wideband ET-based polar TX simulation bench is shown in Fig. 1 [9]. Realistic SPICE models of our envelope amplifier and monolithic SiGe PA were in these simulations, which were validated by our measurement data [10]. Fig. 2 shows our decresting algorithm developed in ADS. We adopt the indirect control clipping in time domain as it is flexible in reducing signal PAR, using scaling with a clipper [4]. The original 802.16e WiMAX 64QAM baseband signal will split into three channels: one goes through a hard limiter that sets a hard upper bound; the other subtracts the signal after limiter and then filters through a FIR low pass filter (this can be seen as the error signal, which will be amplified by a scaling to control the TX signal PAR); the last channel will then subtract the error signal to get the decrested baseband signal, while a RF modulator is then used to upconvert the decrested signal to RF. FIR filtering is used to effectively reduce out-of-band distortion. Time delay in the algorithm is used to adjust delays caused by the FIR low pass filter. The clipping level is set based on the probability of TX signal level. When CR= 4 dB and 6.7 dB, for example, PAR will be reduced from 11.7 dB to ~9 dB and ~7.5 dB, respectively. Fig. 3 shows the simulated WiMAX waveforms before and after decresting algorithm with CR = 4 dB as an example.

![Decresting Algorithm Diagram](image)

![WiMAX Waveforms](image)

Fig. 2 Simplified block diagram of the decresting algorithm developed in ADS. The decrested signal will be fed into both amplitude path and RF path of the polar TX.

![WiMAX Waveforms](image)

Fig. 3 Simulated WiBro waveforms before and after decresting (clipping ratio= 4 dB); the power of this WiBro signal is 10dBm.

![Envelope Amplifier](image)

Fig. 4 Pictures of our discrete linear-assisted switch mode envelope amplifier board (TOP) and our 2-stage monolithic SiGe PA die (BOTTOM).

Fig. 4 shows the pictures of our discrete linear-assisted switch mode envelope amplifier (or “split-band” envelope amplifier) and our 2-stage SiGe PA. SPICE simulations and measurement are matched very well for both of our envelope amplifier and PA. For example, the measured efficiency of our envelope amplifier is 55% (in the condition of V_{DD}= 5.5 V and R_{load}= 22 Ω that mimics the collector of the PA at P_{out}= 18 dBm). The measured PAE of the 2-stage PA is ~50%, while 1-stage PA PAE ~62% [9, 10].
Fig. 5 Polar TX output spectra with/without decresting at several supply voltage $V_{DD}$ ($P_{out}= 18$ dBm, $P_{in}= 11$ dBm, CR= 6.7 dB, 60-order FIR filter)

Fig. 6 Polar TX output spectra with/without decresting by using different CR ($P_{out}= 18$ dBm, $P_{in}= 11$ dBm, $V_{DD}= 5$ V, 60-order FIR filter)

Fig. 7 Comparison of TX system EVM and ACPR vs. Clipping Ratio ($P_{out}= 18$ dBm, $P_{in}= 11$ dBm, $V_{DD}= 5.5$ V, 60-order FIR filter); Output spectra of all cases can pass the 802.16e TX mask.

Fig. 8 Constellation diagram of WiMAX signal at the ET-based polar TX output with decresting process (i.e., CR= 4 dB, EVM = 3.1%, and the TX output spectrum passed the 802.16e TX mask).

The main benefits of using the decresting algorithm are: (1) reducing clipping at the envelope amplifier to make TX output more linear; and (2) lowering the supply voltage of the envelope amplifier to improve its efficiency and the overall polar system efficiency. From SPICE simulations, the efficiency of our envelope amplifier improves from 51% to 55% when $V_{DD}$ reduces from 6 V to 5.5 V. System efficiency of the polar TX is defined as the product of PA collector efficiency with the drain efficiency of the envelope amplifier (i.e., ignoring power dissipation of PA driver, RF modulator and digital circuits, which may degrade system PAE by <5%).

With decresting alone, our polar TX efficiency has increased from 28.1% to 30.3%. However, system Error-Vector-Magnitude (EVM) simulations show EVM increases with higher CR, suggesting much clipping hurts the WiMAX signal generation fidelity and there is a design trade-off of CR vs. ACPR and PAE improvement [5]. Since the EVM spec for 64QAM mobile WiMAX is 3.1%, Fig. 7 shows that CR needs to be ≤4 dB to meet this spec at $V_{DD}= 5.5$ V. Fig. 8 shows the constellation of WiMAX signal at the ET-based polar TX output with decresting process (i.e., CR= 4 dB, EVM = 3.1%, and the TX output spectrum passed the 802.16e TX mask). With additional predistortion, we expect to reduce $V_{DD}$ to 5 V and keep EVM below 3.1% to improve system efficiency to 32.5% (i.e., 4.4% higher).
III. CONCLUSIONS

A decresting algorithm for mobile WiMAX has been developed for an ET-based polar TX system with monolithic SiGe PAs. Our RF/Analog/Digital system and circuits co-design simulations show that with decresting process alone, one can increase polar TX system efficiency to 30.3% with reduced TX ACPR but at the cost of EVM degradation. Through careful design of clipping ratio, our system simulation showed that the efficiency of our ET-based TX has been improved to 30.3% while meets the tough 802.16e linearity specs (i.e., EVM = 3.1%). We expect that further work on PA digital predistortion algorithm will improve system efficiency more and still meets the stringent WiMAX linearity spec (i.e., TX mask and EVM).

REFERENCES