A REDUCED PAPR PR-NMDFB BASED DUC ARCHITECTURE FOR TRANSMIT DOWNLINK OF COMBINED 3GPP LTE AND UMTS SIGNALS

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ABSTRACT

This paper describes a step forward in the utilization of non-maximally decimated filter banks (NMDFBs) with perfect reconstruction (PR) property in modern software defined radios. In particular, here we apply the tone reservation (TR) technique for reducing the peak to average power ratio (PAPR) to a PR analysis-synthesis chain which has been designed for a combined Third Generation Partnership Protocol (3GPP), Long Term Evolution (LTE) and Universal Mobile Telecommunications System (UMTS) digital up converter (DUC). The DUC architecture was proposed in an early paper and the efficacy of the design has been tested in an industrial environment and verified for being prototyped on real chips. Similar to orthogonal frequency division multiplexing (OFDM) systems, the proposed architecture is affected by the PAPR issue. Here we borrow the TR reservation technique which was developed in the OFDM scenario and we apply it to the proposed architecture. Of course, given the difference between OFDM and NMDFB systems, different design constraints have to be taken into account. Preliminary simulation results show good performance in reducing the crest factor (CF) which, along with the limited workload required by the proposed architecture, encourage us to implement this solution in the next generation of communication chips.

Index Terms— non-maximally decimated filter bank, polyphase channelizers, LTE, UMTS, software radio.

1. INTRODUCTION

Driven by the need to achieve versatile and performing digital communication architectures, we proposed, in earlier papers [11-12], a novel application of PR-NMDFBs, or polyphase channelizers, whose assembly gives life to a compact DUC for combined 3GPP LTE and UMTS radios. UMTS signals are Wideband Code Division Multiple Access (WCDMA) based. The PR NMD synthesis-analysis chain that we proposed, which, for completeness, is depicted in Fig. 1, has been designed to reach the required performance according to the specific application scenario specified in [2-3]. Its workload is low enough to be implemented on commercially available Field-Programmable Gate Arrays (FPGAs).

Standard 3GPP LTE digital front ends for transmit downlink are generally implemented as a cascade of half-band filters performing successive 1-to-2 up sampling [3]. A further processing block for performing multi-carrier mixing and combining is required for multiple signal bandwidth configurations. Because the LTE base-band signal is OFDM-based [4-5], the power spectral density (PSD) of the input signal to the channel filter has a natural attenuation starting from the edge of the occupied bandwidth (i.e. 90% of the total channel bandwidth) and no extra channel filter is required. Typical input sampling rates to an LTE DUC are 7.38, 15.36, 23.04, 30.72 Msps while the desired output sampling rate is 307.2 Msps [3]. Half-band filters are a good option to consider when implementing an interpolation with a factor of two because they require much less hardware resources for a filter realization. This is due to the fact that every odd indexed coefficient in the half-band impulse response is zero except the center tap and even indexed coefficients are symmetric. However, the computation complexity of a half-band filter based DUC mainly depends on the input signal configuration and on the input/output sample rate ratio requirements. Also, because such a system is tailored to the input signal and to the output requirements, it lacks generality and cannot be utilized if the specifications change.

UMTS digital front end for transmit downlink shares more than one characteristic with the LTE scenario. In particular the input sample rate, the desired output sample rates and the signal bandwidths are equal for the two systems. Because of the similarities between the two scenarios, as for the LTE radios, current UMTS digital front ends for 3G base stations are also implemented as cascades of half-band filters performing 1:2 successive up sampling. Mixers are also included in the design for performing frequency translations of the input spectra in the multiband case [3]. It is clear that, as for the LTE case, the workload of such a system depends on the input signals and also, such a system lacks generality and cannot be utilized when different input and/or output specifications are given.

978-1-4799-2893-4/14/$31.00

The positive feedback received from the industrial world encourages us to proceed further in the NMDFB-based DUC design including in the architecture a PAPR reduction algorithm. It has been verified that the proposed DUC provides the same workload as the standard half-band based DUCs for single LTE and UMTS\WCDMA signals. However this engine provides much more flexibility and it becomes much more efficient than conventional architectures in the software radio scenarios in which multiple signals have to be simultaneously up converted and the dynamic spectrum optimization is a goal to be reached.

The base-band LTE signal is OFDM based and, as expected, it is affected by high PAPR. In addition to this, the PAPR of the up converted composite signal and, of course, its crest factor (CF), increases due to the summing operator at the output of the proposed architecture (see Fig.1 for details). A series of techniques to reduce the PAPR in OFDM systems have been developed in the recent years [10]. In standard 3GPP LTE digital front end chips for transmit downlink those techniques are usually applied in base-band at the output of the half-band interpolator chain [2]. In our case, it does not provide any advantage to apply a CF reduction technique at the output of the base-band LTE signal generator, given that the final summation of the up converted signals is responsible for it. We should in fact take into account for a correction architecture at the output of the second tier synthesis channelizer where the PAPR is highest. This, in standard architectures, would have the disadvantage of performing the peak correction at the highest sample rate when the signals are already being up converted, which usually is computationally intensive in a communication system. However in our case, the same channelizer will be used, off-line, for shaping the clipping noise spectrum and it has been verified that the adopted technique is affordable and can be implemented on currently available FPGAs.

The technique we selected for the CF reduction is the tone reservation [9]. This correction method reduces the PAPR of a signal by subtracting spectrally shaped pulses from signal peaks that exceed a specified threshold. The cancellation pulses are designed to have a spectrum that matches the requirements and introduces acceptable out-of-band interference.

The novelty of this paper consists of applying the TR technique to a novel architecture for combined LTE/WCDMA signals whose advantages, in terms of flexibility, computational complexity and workload have been provided theoretically [1], [11-12] and verified in an industrial environment.

2. SYSTEM OVERVIEW

Figure 1 shows the high level block diagram of the design we proposed which is composed of two tiered NMDFBs that create a PR analysis-synthesis chain [11]. The first tier channelizers are small N-path analyzers which decompose the input spectra in equally wide fragments while performing N-to-2 down sampling, $N \in \{4,6,8\}$. The choice of using non-critically sampled channelizers offers the advantage of avoiding the spectral folding at the channel band edge [1]. The form of the N-to-2 down sampler channelizer has been derived in [7] and more details on this architecture can be found in [1], [7], [12]. The designed low-pass prototype filters (LPPFs) for the small channelizers are 40-tap long. This length guarantees 80dB out-of-band attenuation and small in-band ripple level.

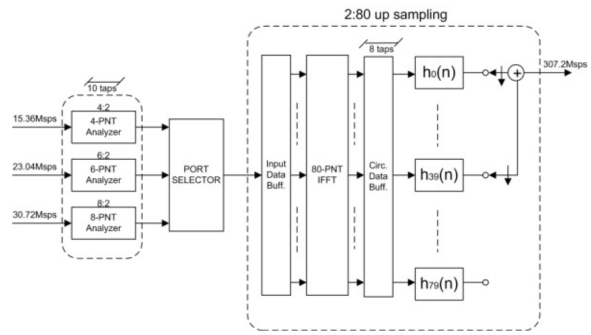

Figure 1: Proposed DUC for Combined WCDMA and LTE Signals.

The selection of the synthesis channelizer dimensions (number of paths as well as IFFT size) has been driven by the input signal sample rates and by the desired output sample rate according to the goals of minimizing the computation complexity and maximizing the performance as well as the flexibility of the design. The first tier channelizers decompose the input spectra, which are wider than 5 MHz, and simultaneously translate their fragments, by aliasing, to base-band. The output sample rate at each synthesis channelizer output port is 7.68 Msps. After the input sample rate has been reduced, the time series needs to be up sampled to the desired 307.2 Msps and the signal fragments have to be recomposed and up converted to the appropriate center frequency. This is the task of the, 2-to-80, synthesis up converter channelizer which is a PR NMD polyphase filter bank that spans the whole frequency range from $-f_s/2$ to $f_s/2$, where f_s=307.2 Msps. By enabling the proper input ports we allow this engine to alias the signal bandwidths to the center frequency of the corresponding filter in the bank. The low-pass prototype filter for this engine is 1120-tap long, which again implies 80dB of out-of-band attenuation and an acceptable in-band ripple. The total length of the filter is spread over the 80 paths which results in a total filter length for each path of the bank to be 14 taps. This number implies a considerably low workload per path.

A port selector block is responsible for delivering the outputs of the synthesis channelizers to the appropriate ports of the 80-path polyphase up converter channelizer. Notice that in the transmitting scenario, we have perfect knowledge of the signal bandwidths and of the desired high center frequency locations.

3. PROPOSED ARCHITECTURE

The tone reservation technique, first introduced for reducing the PAPR in OFDM systems [8-10], utilizes spectrally shaped pulses to be subtracted from the signal peaks exceeding a specified threshold. The basic idea in OFDM systems is to reserve a small set of bins, or frequency tones, for designing the spectral shaped pulse that is responsible for the peak cancellation. The problem of optimizing the selection of these reserved tones can be formulated in many different ways. The most common way is to formulate the selection as a convex problem that can be solved exactly [10]. The achievable amount of PAPR reduction depends on the number of reserved tones and of their location within the entire range of available frequency bins. This method leads to large reductions in PAPR without introducing additional complexity at the receiver. However, in some cases, the set of tones reserved may represent a non-negligible fraction of the available bandwidth and can result in a significant data rate reduction. In OFDM systems, given the orthogonality of the subcarriers, the spectral shape and positioning of the cancellation pulse does not introduce out-of-band interference. However, in our scenario (NMDFBs), in which there is no orthogonality between subcarriers, the spectral shape of the cancellation pulse and its positioning must be carefully selected. In non-OFDM systems, the cancellation pulses have to be designed to have negligible out-of-band interference because we do not want to infect the spectra of interest. In our scenario we have multiple signals sharing the same frequency range from -307.2/2 to 307.2/2 and, all of them contribute, in time domain, to the PAPR growth. The most general rule would be to follow the OFDM example and use frequency bins, or channels, which are not used for transmitting signals of interest. However, in the NMDFB scenario, when multiple signals are simultaneously up converted, this choice does not provide significant reduction in the error vector magnitude (EVM). Also, we need to take into account that, in the software defined radio scenario, signals from other sources could be present in the spectrum and they must be preserved. The optimal pulse shape would be obtained if we could replicate exactly the base-band spectral version of the signal of interest (LTE+UMTS/WCDMA), but this, of course, is not a feasible option because the cancellation pulse spectrum would leak in the up converted signals of interest leading to non acceptable EVM values. Thus the design of the cancellation pulse has to be done by trading off between the fact that no spectral interference has to be created and that the spectrum of the cancellation pulse should match the spectrum of the information signals. Notice that, in allocating spectral resources to the cancellation pulse we can use the spectral portion which has been allocated for the WCDMA signal. In fact, given the spread spectrum nature of this signal the EVM will not be significantly affected.

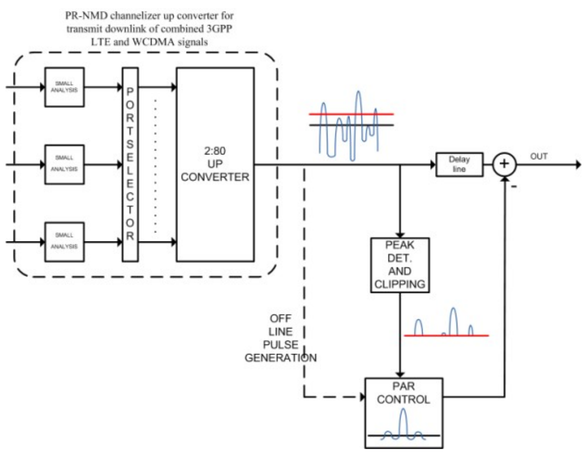

Figure 2: Proposed DUC for Combined WCDMA and LTE Signals with TR Algorithm.

4. SIMULATION RESULTS

In this section we present some simulation results demonstrating the correct functionality of the proposed method. A scenario in which only UMTS and LTE signals are present has been selected here for clarity of presentation. However, the proposed architecture has been tested in much more complex scenarios in which additional signals have been considered in the frequency range of interest. Those signals could be generated by other sources or they could be the effect of a more intensive utilization of the proposed DUC.

In Fig. 3 we show the spectrum and the time domain view of the composite signal. The saturation threshold that we selected has been depicted in red.

Fig. 4 shows the clipped time series and the effect of the clipping operation on the signal spectrum. It is clear from this figure that the clipping causes spectral leakage and it is not a selectable option.

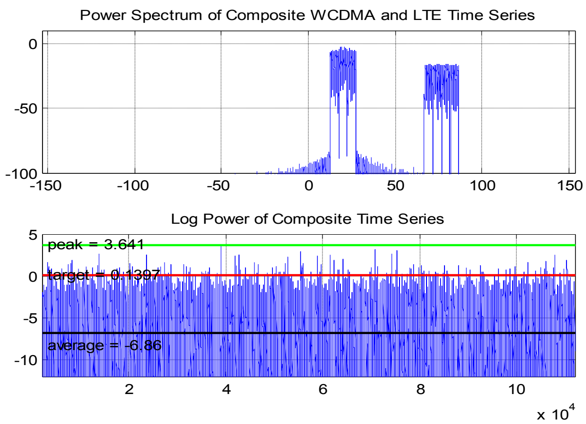

Figure 3: PSD and Time Domain View of Combined WCDMA and LTE Signals.

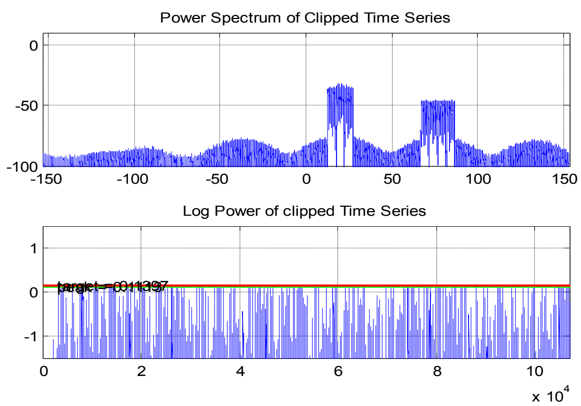

Figure 4: PSD and Time Domain View of Clipped WCDMA and LTE Signals.

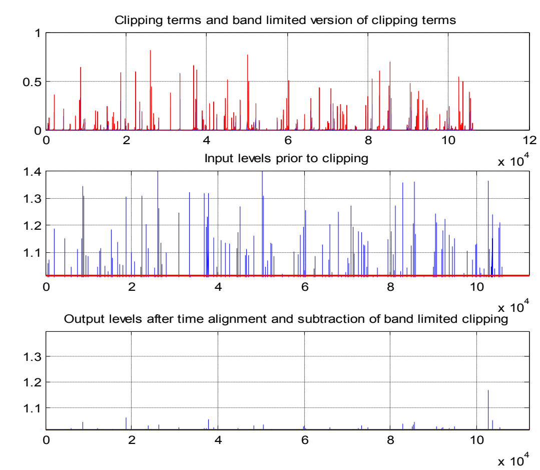

Figure 5: Time Domain View of Peaks Exceeding the Saturation Threshold and Their Filtered Version (Red, Upper Subplot), Clipping Levels Before (Middle Subplot) and After Correction (Lower Subplot).

Figure 5 describes, in the upper subplot, the clipped pulses in blue and, superimposed, in red, their filtered versions; the peaks which pass the threshold are re-depicted, for clarity, in the middle subplot while, in the lower subplot, the same peaks after the tone reservation technique has been applied, are depicted. In this case only one iteration has been run for the cancellation. It was sufficient for providing us the required EVM [2]. When better performance needs to be achieved the same algorithm can be run multiple times until the desired values will be obtained.

For clarity, Fig. 6 shows a zoom of the upper subplot of Fig. 5.

Figure 7 shows the EVM of the UMTS real and imaginary signal components, after the TR has been applied. The convergence of the red dots on a single bin location demonstrates the correct functionality of the proposed architecture.

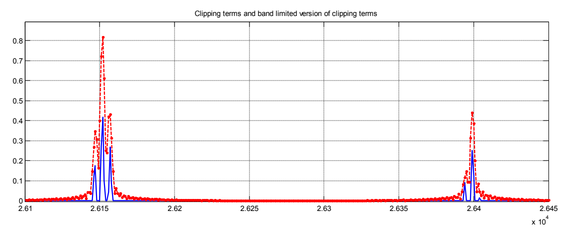

Figure 6: Zoom of the Upper Subplot of Fig. 5.

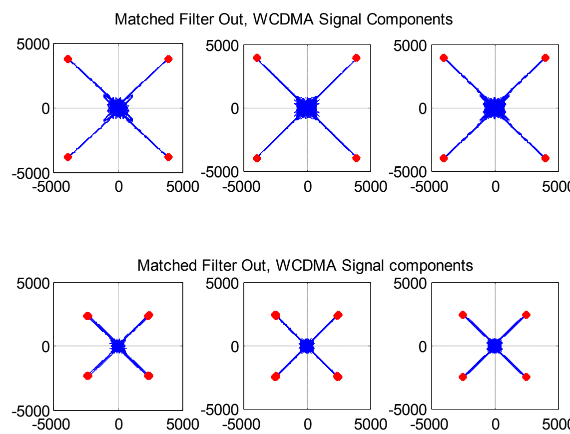

Figure 7: EVM for WCDMA Signal Components After the TR Algorithm has been Applied.

5. CONCLUSIONS

In this paper we have applied the TR technique to a novel analysis-synthesis chain of PR channelizers for combined LTE and UMTS signals which are WCDMA based. The goal is to reduce the PAPR at the output of the proposed DUC. The positive feedback provided by the industry for implementing and prototyping the proposed architecture has encouraged us to proceed forward with the design. The simulation results demonstrate the correct functionality and the good performance of the proposed method.

6. REFERENCES

[1] E. Venosa, f. harris and F. Palmieri, *On Software Radio: Sampling Rate Selection, Design and Synchronization*, Springer Science + Business Media, LLC 233 Spring Street, New York, NY 10013, USA.

[2] Ed Hemphill, Helen Tarn, Michel Pecot, David Hawke, Jorge Seoane, and Paul Popescu, "High Density WCDMA Digital Front End Reference Design," Xilinx Application Notes, Document Available on Request.

[3] Helen Tarn, Ed Hemphill, and David Hawke, "3GPP LTE Digital Front End Reference Design,"Xilinx Application Notes, Document Available on Request.

[4] E. Dahlman, S. Parkvall, J. Sköld, *4G LTE/LTE-Advanced for Mobile Broadband,* Academic Press, 30 Corporate Drive, Burlington, MA 01803, 2011.

[5] A. Ghosh, J. Zhang, J.G. Andrews, R. Muhamed, *Fundamentals of LTE,* Prentice Hall, Upper Saddle River, New Jersey 07458, 2010.

[6] 3GPP TR 36.804 v0.7.1 (2007-10), 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Base Station (BS) radio transmission and reception; (Release 8).

[7] fred harris, Elettra Venosa, Xiaofei Chen and Baskar D. Rao, "Polyphase Analysis Filter Bank Down-Converts Unequal Channel Bandwidth with Arbitrary Center Frequencies " on *Springer Analog Int Circ Sig Proc Journal*, DOI 10.1007/s10470-011-9746-y.

[8] Luqing Wang; Tellambura, C., "Analysis of Clipping Noise and Tone-Reservation Algorithms for Peak Reduction in OFDM Systems," *Vehicular Technology, IEEE Transactions on* , vol.57, no.3, pp.1675,1694, May 2008.

[9] Behravan, A.; Eriksson, T., "Tone reservation to reduce the envelope fluctuations of multicarrier signals," *Wireless Communications, IEEE Transactions on* , vol.8, no.5, pp.2417,2423, May 2009.

[10] Lim, Dae-Woon; Heo, Seok-Joong; No, Jong-Seon, "An overview of peak-to-average power ratio reduction schemes for OFDM signals," *Communications and Networks, Journal of* , vol.11, no.3, pp.229,239, June 2009.

[11] Xiaofei Chen, fred harris, Chris Dick and Elettra Venosa, " Design of a PR NMD Channelizer-Based Up Converter for Transmit Downlink of Combined 3GPP LTE and UMTS Radios," *Proc. of* SDR 2013, Whashington DC, January 2013.

[12]fred harris, Elettra Venosa, Xiaofei Chen and Chris Dick, " Design of PR NMDFB Based Up and Down Converters for Transmit Downlink and Receive Uplink of Combined 3GPP LTE and UMTS Radios**"** on Springer Analog Int Circ Sig Proc Journal, DOI 10.1007/s10470-013-0106-y.