DESIGN OF A PR NMD CHANNELIZER-BASED UP CONVERTER FOR TRANSMIT DOWNLINK OF COMBINED 3GPP LTE AND UMTS RADIOS

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ABSTRACT

In this paper we present a novel application of perfect reconstruction (PR), non maximally decimated (NMD) polyphase channelizers whose assembly gives life to a compact Digital Up Converter (DUC) for combined Third Generation Partnership Protocol (3GPP), Long Term Evolution (LTE) radio and Universal Mobile Telecommunications System (UMTS) radio, which are Wideband Code Division Multiple Access (WCDMA) based. The design of the PR NMD synthesis-analysis chain has been optimized to maximize the performance according to the specific application scenario. The first tier synthesizers are small PR NMD N-to-2 polyphase down converters with $N \epsilon \{4,6,8\}$. They accomplish the pre-processing task of decomposing the input spectra, which are wider than the analysis channelizer channels, and of aliasing their fragments to base-band while reducing the sample rate to 7.68 Msps. The analysis channelizer, which is an 80-path PR NMD, 1-to-40, polyphase up converter, accomplishes the task of recombining the spectral fragments at the desired center frequencies while increasing the input sample rate to 307.2 Msps.

1. INTRODUCTION

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 [4]. A further processing block for performing multi-carrier mixing and combining is required for multiple signal bandwidth configurations (e.g. four 5 MHz wide bandwidths or two 10 MHz wide bandwidths). Generally, the base-band signal is processed through a channel filter before being given as input to the DUC so that the out-of-band power is attenuated to meet the spectral mask requirements. However, because the LTE base-band signal is OFDM-based [4],[8], the Power Spectral Density (PSD) of the input signal to the channel filter already has a natural attenuation starting from the edge of the occupied bandwidth (i.e. 90% of the total channel bandwidth). 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 [4].

Half-band filters are definitely a good option to consider when implementing an interpolation with a factor of two because they require much less computational power (and thus less hardware) 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 the 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 case. In particular the input sample rate, the desired output sample rates and the signal bandwidths are equal for the two systems. In the UMTS case the output sample rate must be wide enough to accommodate multiple WCDMA channels with some flexibility in carrier spacing. 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 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.

Notice that the main differences between 3GPP LTE and UMTS systems are the modulation format of the input signal and its shaping. However, these differences are not crucial and they do not affect the design of the PR NMD channelizer-based DUC. Therefore, in the following we will mainly refer to LTE signals specifying, when necessary, the differences with the WCDMA case.

The desire, common in the wireless industry, of achieving multi-purpose radios while maintaining good performance, low computation complexity, and cost reduction drives us to explore novel designs for digital up converter architectures. In this paper we present a DUC for combined 3GPP LTE and UMTS radios. The proposed architecture is based on polyphase filter banks. The need to accommodate a wide variety of input signals which are involved in the specific application case, drives us through a novel perfect reconstruction synthesis-analysis chain of NMD polyphase channelizers. The result is a customized solution which guarantees good performance and great efficiency.

The paper is organized in four main sections. In Section 1 the goals are specified and the proposed solution is anticipated. In Section 2 the proposed architecture is presented and some basics on PR NMD polyphase channelizers are provided. Also the reasons for which they have been selected to serve our purposes is explained in this section. In Section 3 simulation results to demonstrate the correct functionality of the DUC are given while Section 4 provides the conclusions along with ideas for new research developments in this area.

2. PROPOSED DUC

Figure 1 shows the high level block diagram of the proposed design which is composed of two tiers NMD channelizers that create a PR synthesis-analysis chain. In the same figure are also indicated the lengths of the filters composing each path of the channelizers along with the input and output sample rate.

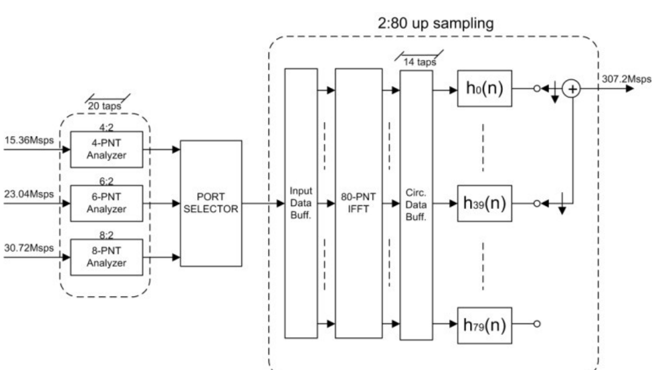

Figure 1: Proposed DUC; First tier N-Path N:2 PR NMD Down Converter Channelizers and Second Tier 2:80 PR Up Converter Channelizer.

The first tier channelizers are small N-path synthesizers 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 to avoid the spectral folding at the channel band edge. The authors derived the form of the N-to-2 down sampler channelizer in an earlier paper [9]; For clarity, its block diagram is represented in Figure 2. More details on this architecture can be found in [1], [2], [9]. The designed low-pass prototype filters for the small channelizers are 40-tap long. This length guarantees 80dB out-of-band attenuation and very good in-band ripple level. Because the total length has to be spread over all the paths, the filter gives a considerably small workload per path.

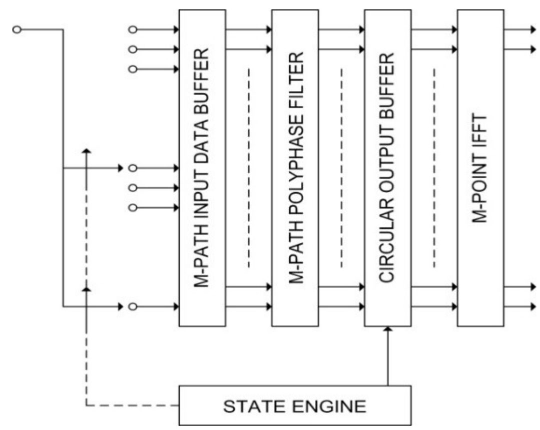

Figure 2: Polyphase Synthesis Channelizer; Input Commutator and Data Buffer, M-Path Polyphase Partitioned Filter, Circular Data Buffer and M-Point IFFT.

The selection of the synthesis channelizer sizes (number of paths as well as IFFT size) has been driven by the specifications given by this application case. In particular, it has been driven by the input 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. Notice, in fact, that the input sample rates of both 3GPP LTE and WCDMA signals are: $f_s \in \{7.68, 15.36, 23.04, 30.72\}$ Msps while the desired output sample rate is 307.20 Msps. It is easy to recognize that 307.2 Msps is an integer multiple of the smallest input sample rate and in particular it is 40 times bigger than 7.68 Msps. This observation drives us through the selection of the sizes for the channelizers. The first tier channelizers decompose the input spectra, which are wider than 5 MHz, and simultaneously translates the fragments, by aliasing, to base-band. The output sample rate at each channelizer port is 7.68 Msps. Depending on the input sample rate and signal bandwidth one of the possible three synthesizers is selected. For example, if the input signal bandwidth is 10 MHz with a sample rate equal to 15.36 Msps, it will be delivered to the 4-to-2 synthesizer that will fragment its total bandwidth in three slices. These spectral slices will be found lying in base-band with an output sample rate of 7.68 MHz at the output ports of the synthesizer. Clarifications on this specific example can be obtained by looking at Figures 3 and 4 in the next section of this paper. The synthesis channelizer accomplishes the task of reducing the input sample rate, whatever it is, to 7.68 Msps.

After the input sample rate has been reduced it is time to up sample the time series to 307.2 Msps and to up convert the signals to a desired center frequency. This is the task of the, 2-to-80, analysis up converter channelizer. The selection of the designed output center frequency happens by feeding the signals to the proper ports of the analysis channelizer. This channelizer 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 actually 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 (if compared to the existing half-band filter based DUC). Remember that the reason for using non maximally decimated channelizers is to avoid spectral folding problems which damage the signal when it is critically sampled [2]. On the other side the condition that the composite response of the synthesis-analysis chain is a Nyquist pulse (-6dB at the nominal band edge) guarantees that no signal energy is lost during the partitioning and re-assembling processes.

Because the output sample rate is an integer multiple of 7.68 Msps and all the input sample rates are also integer multiples of 7.68 Msps, the proposed design does avoid additional computation that would be required if arbitrary interpolators would have been included in the architecture.

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. We have perfect knowledge of the signal bandwidths and of the desired high center frequency locations. If the desired center frequency is not an integer multiple of the input sample rate (which does not usually happen for LTE and WCDMA communications in which the signals are translated to quarter sample rate [3],[4]), additional pre-processing blocks have to be applied to the design [1], [2]. In particular an additional mixer could be needed to pre-apply the desired frequency offset to the signal. It is important to notice that the pre-processing tasks would be done at the beginning of the synthesis-analysis chain when the signal sample rate is low, this implies that the pre-processing has a relatively small impact on the total computation complexity of the DUC.

3. SIMULATION RESULTS

Figure 3 shows the base-band signal we are providing as input to the proposed DUC. It is a 10 MHz wide OFDM signal, with 1024 IFFT points and 600 subcarriers which are loaded. The sample rate is 15.36 Msps. This is a typical LTE scenario, as specified in [4]. The goal is to up convert two of those bandwidths to the quarter output sample rate (307.2/4 MHz).

Figure 4 shows the outputs of the first tier down converter channelizer. The signal has been delivered to a 4-to-2 synthesis channelizer which places four equally spaced filters along the spanned frequency range ([-7.68, 7.68] MHz). The synthesis channelizer decomposes the signal bandwidth into three fragments. Each of them has been shifted, by aliasing, to base-band with an output sample rate of 7.68 Msps.

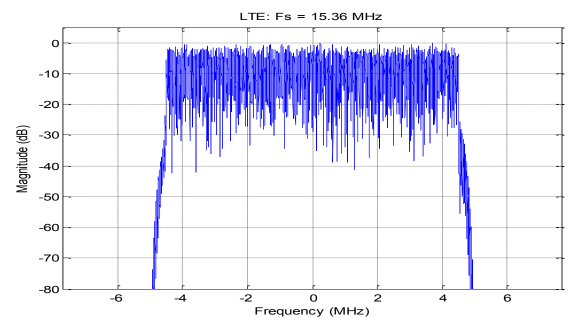

Figure 3: Input Signal to the Synthesis-Analysis Chain, 10 MHz Bandwidth Sampled at 15.36 Msps.

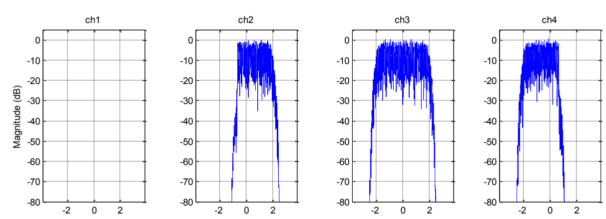

Figure 4: Outputs from the First Tier, 4:2, Down Converter Channelizer; 7.36 Msps Sample Rate.

Notice the frequency mapping of Figure 4: channel 3 corresponds to the channel of the synthesis channelizer (filter of the bank) which is centered at zero frequency, hence it captures most of the input signal. Channels 2 and 4 are the channels corresponding to the two filters adjacent to the zero frequency channel on its left and right side respectively, and they capture the left-most and right-most portions of the signal bandwidth. Channel 1 corresponds to the left-most and right-most channels lying on the spanned frequency range of Figure 3 and it is empty because no signal power is present in that part of the spectrum.

Figure 5 shows, in the normalized frequency domain, the frequency response of two of the four filters which compose the bank. It is clear, from this figure, that the filters overlap at -3dB which guarantees that the PR property in the synthesis-analysis chain has been verified. Remember that this property allows to de-assemble and perfectly re-assemble the signal bandwidths. i.e. no energy loss occurs during the signal processing.

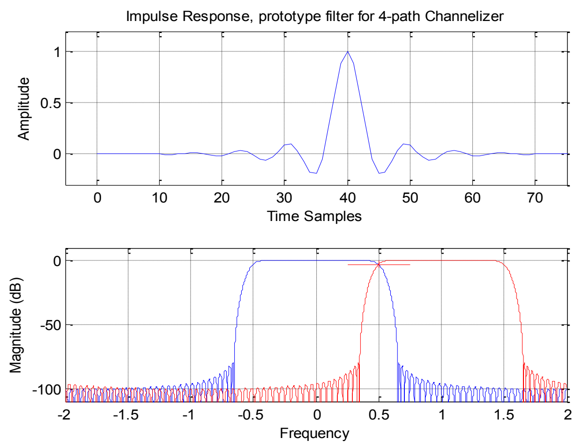

Figure 5: Perfect Reconstruction Property. The Filter of the Synthesis Channelizer Overlap at -3dB.

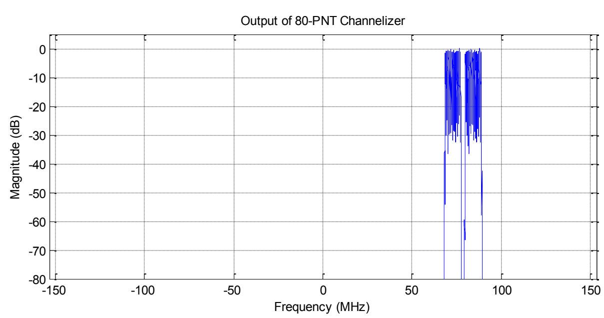

Figure 6: Final Output of the DUC; Two 10 MHz Bandwidths Centered at 76.8 MHz with an Output Sample Rate of 307.2 Msps.

Figure 6 shows the output spectrum of the proposed DUC. The four output ports of the 4-to-2 synthesizer have been delivered, by the port selector, to the input ports of the 2-to-80 up converter channelizer. In particular, they have been delivered to ports [58:61] which alias the (recombined) signal to 71.8 MHz and to ports [61:64] which alias the signal to 81.8 MHz. As expected, the two 10 MHz bandwidths are centered at 76.8 MHz which is the quarter output sample rate. As seen in the picture, the output sample rate is correctly 307.2 Msps, which is exactly 40 times bigger that the input sample rate. Notice that, very similar results would have been obtained if an UMTS signal was used for demonstration purposes.

4. CONCLUDING REMARKS

In this paper we have presented a new application of PR NMD polyphase channelizers. The desire of achieving DUCs for combined 3GPP LTE and UMTS base stations has driven us to design a new synthesis-analysis chain that minimizes the computation complexity and maximizes the performance. The synthesis channelizers are small N-to-2 down converters which decompose the input spectra, when necessary, while aliasing all of them to base-band with a reduced sample rate. The analysis channelizer is an 80-path up converter which performs 1-to-40 up sampling of the input time series and aliases the spectral fragments to desired center frequency. The proposed design is an optimized solution which guarantees great flexibility and low computation complexity when compared to the standard half-band filter based DUC designs for LTE and UMTS.

5. REFERENCES

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