Papoulis-Gerchberg Hybrid Filter Bank Receiver for Cognitive-/Software-Defined Radio Systems

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Abstract— **Emerging Software-Defined Radios (SDRs) should be prepared to deal with wide-band sparse-spectrum RF signals. This requires the availability of advanced analog-to-digital front-ends with a fast sampling rate, large dynamic range and capable of handling high peak-to-average-power-ratio (PAPR) signals. A Hybrid Filter Bank (HFB) receiver solution was recently proposed by the authors to address such demanding requirements in the SDR context, with special emphasis on the RF analog part. In this paper, as further research, a maximally-decimated five-channel HFB for its intermediate-frequency (IF) part is shown. Unlike its previously reported RF counterpart, it makes use of the Papoulis-Gerchberg algorithm to attain a more efficient implementation in terms of computational cost and reconfigurability. For this HFB-based IF SDR receiver, the digital filters compensating the analog design imperfections are evaluated and real-time signal-reconstruction tests for wide-band and narrow-band signals are carried out. A sensitivity discussion is also provided.**

I. Introduction

Software-Defined Radios (SDRs) and Cognitive Radios (CRs) have become very promising solutions to support modern wireless communications applications [1]. Spectral dynamic access, frequency recognition, inter-operability and reconfigurability are some of the main features which have made SDRs and CRs top priorities either for military or civilian purposes [2]. However, several challenges must be first faced up before having a fully-operative SDR system with these characteristics. For example, its receiver block must be capable of sensing ultra-broad-band spectrums while dealing with very high and low power signals at the same time. This demand can hardly be attained with state-of-the-art analog-to-digital converters (ADCs) owing to the irreconcilability between sampling speed and resolution [3]. Even in the future, such requisites may never be achieved due to the slow evolution of the ADC technology in relation to the More's Law [4].

The aforementioned limitations can be circumvented through a receiver approach inspired on a "Hybrid Filter Bank" (HFB), where the input signal is frequency multiplexed into several bandpass sub-bands that are subsequently converted to the digital domain through sub-sampling [5]. Thus, this parallel structure alleviates the sampling-rate requirements for the ADCs as signal components with narrower bandwidths must be handled by them (see Fig. 1). Consequently, improved trade-offs in terms of conversion resolution become feasible and, therefore, the receiver dynamic range is increased. The HFB is completed by means of a digital synthesis stage, where digital filters are utilized to eliminate the aliasing components coming from the sub-sampling and the amplitude and phase distortions inherent to the real analog frequency multiplexer. Several methods to properly evaluate the synthesis digital filters have been presented. Moreover, in [6] and putting attention to the inversion of the RF part, it was shown by the authors that a nearly perfect reconstruction is possible with this alternative. This means that the overall HFB receiver behaves just like a single ADC with improved performance and an extra time delay attributable to the digital filtering action.

In this work, as further research, a maximally-decimated five-channel HFB for an intermediate-frequency (IF) SDR receiver is described. Unlike its RF counterpart of [6], it exploits the Papoulis-Gerchberg algorithm to improve computational cost and system reconfiguration. A proof-on-concept IF SDR receiver prototype is developed and reconstruction experiments for narrow-band and wide-band signals exhibiting 16-level quadrature amplitude modulation (QAM) are performed.

II. HFB Design Methodology

Fig. 1 shows the conceptual structure of the conventional M-channel maximally-decimated HFB to be employed in the SDR IF receiver. If a limited bandwidth B is assumed for the input signal $x(t)$ after being filtered by an anti-aliasing filter, then the bandpass sampling formalism can be applied to it [7]. In this case, under sub-sampling, the required sampling rate for the HFB-based receiver is $f_s = 2B/M$, which is M times lower than in a traditional direct-sampling receiver. This sampling-rate reduction enables better trade-offs to be attained in terms of conversion resolutions which will result on an increased receiver dynamic range. However, the analog frequency channelizer splitting the input signal into different frequency sub-bands irremediably causes phase and magnitude distortion in each channel, as non-ideal filters are used. Also, aliasing terms may appear owing to both the sub-sampling process and the finite selectivity of the analog filters. Nevertheless, these undesired effects can be compensated at the digital level through a properly designed digital synthesis filtering stage. The method adopted here for the evaluation of this synthesis block, carefully described in [8], is summarized below.

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