Design of a Low Complexity Filter Bank Satisfying LDACS1 Spectral Mask Specifications for Base-Station Receivers in Air-Ground Communications

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Abstract—The sustained air traffic growth worldwide has resulted in the need for upgrading the existing global air traffic management (ATM) system. Consequently, a new standard called L-band Digital Aeronautical Communication System (LDACS) is being developed for the air-ground communications component of the next generation ATM systems. Amongst the options being considered for LDACS, the LDACS type 1 (LDACS1) is the most superior and mature candidate and is likely to be the final choice for deployment. The presence of previously deployed and operational legacy systems in the L-band has led to stringent spectral mask specifications for LDACS1, to ensure there is no interference caused to the former. In this paper, we propose the design of a digital filter bank which can satisfy the LDACS1 spectral mask specifications while also achieving low complexity of implementation. Design of the proposed filter bank is based on the improved coefficient decimation method. With the help of a design example, we show that when compared with the discrete Fourier transform based filter bank, the proposed filter bank achieves 71.49% reduction in multiplication complexity.

Keywords—LDACS1; air-ground communication; filter bank; improved coefficient decimation method (ICDM); low complexity.

I. INTRODUCTION

Numerous statistical studies and forecasts show that the air transportation industry has seen a tremendous growth in the past few decades and will continue to do so in the future [1, 2]. As a consequence, the current global air traffic management (ATM) system is predicted to reach its capacity limits in the next few years (around 2020-2025). The International Civil Aviation Organization (ICAO) has therefore undertaken the task to upgrade the multiple decade old ATM system that is currently being used worldwide. Two major projects have been initiated with the support from ICAO which aim to achieve this task of modernizing the ATM systems: Single European Sky ATM Research (SESAR) [3] in Europe and Next Generation National Airspace System (NextGen) [4] in the United States. While tackling the ATM capacity limit problems in Europe and United States respectively, SESAR and NextGen also aim at providing a truly global solution to the challenge of setting up a highly efficient, effective and safe ATM system for the future.

To realize next-generation ATM systems, the ICAO has recommended setting up a future communications infrastructure (FCI) consisting of distinct data link technologies for supporting air-ground communications, air-air communications, satellite based communications and communications in and around airports [5]. Following this recommendation, a new standard called L-band digital aeronautical communication system (LDACS) is being developed for the air-ground communications component in the FCI [6-10]. Among the various candidate technologies being considered for LDACS, LDACS1 (L-band digital aeronautical communication system type 1) proposed by the European Organization for the Safety of Air Navigation, i.e., EUROCONTROL is the most superior and mature candidate for final selection and deployment [9, 10]. As per ICAO’s recommendation, the air-ground communication systems under the FCI will have to use L-band (960-1164 MHz) for their operation and co-exist with the legacy systems operating in the L-band [5]. Consequently, an option being considered for the deployment of LDACS1 is an inlay approach between adjacent channels of the distance measuring equipment (DME), which covers the frequency range 962–1213 MHz. To ensure non-interfering co-existence of LDACS1 and DME channels, stringent spectral mask specifications have been selected and are documented in the LDACS1 specification documents [6-8]. These spectral mask specifications have to be satisfied for using LDACS1 channels for communication.

We recently proposed a low complexity channel filter which can be used in the LDACS1 transceivers onboard aircrafts for operating upon a single LDACS1 channel of interest [11]. In ground base-station receivers, digital filter banks are required to simultaneously extract multiple LDACS1 channels being transmitted by different aircrafts. In these filter banks, all the subbands used for extracting LDACS1 channels have to satisfy the stringent spectral mask specifications. The conventional filter bank design techniques such as the per-channel approach and the discrete Fourier transform (DFT) based filter bank [12] can be used to realize a filter bank for
LDACS, but these techniques do not offer a solution to optimally satisfy the non-uniform attenuation specifications of the LDACS spectral mask; instead these techniques provide filter banks having subbands that satisfy the most stringent attenuation specification. This will increase the filter orders involved and hence the implementation complexity and power consumption. To address this research problem, we present a low complexity filter bank that provides subbands which satisfy the LDACS spectral mask specifications by achieving different attenuations at different frequencies as desired. Our filter bank employs the recently proposed improved coefficient decimation method (ICDM) [13, 14], which can provide variable frequency responses by selectively using coefficients from a single set of prototype filter coefficients.

The rest of this paper is organized as follows: Section II presents a brief overview of LDACS1 and the ICDM. Section III presents the proposed filter bank along with its comparative analysis. Section III presents the conclusions of our work.

II. BRIEF OVERVIEW OF LDACS1 AND ICDM

A. L-band Digital Aeronautical Communication System type 1 (LDACS1)

LDACS1 is a broadband transmission system with a frequency division duplex (FDD) configuration and is based on the orthogonal frequency division multiplexing (OFDM) modulation technique. It features highly efficient transmission concepts similar to those used in modern mobile communication systems. It is closely related to the Broadband Aeronautical Multi-Carrier Communication (B-AMC) and TIA-902 (P34) technologies [6-8]. OFDM is highly suitable for use in the L-band since it allows for flexible occupation of the spectrum. As a result, the spectral gaps between channels of the legacy systems in L-band can be exploited very efficiently by LDACS1, ensuring high transmission capacity while preserving the channel allocations of the legacy systems. In the inlay deployment approach of LDACS1, forward link (ground base-station to aircraft station) and reverse link (aircraft station to ground base-station) channels are separated by 63 MHz and are allocated in the ranges 985.5-1008.5 MHz and 1048.5-1071.5 MHz respectively. The aircraft station LDACS1 transmitter and receiver can thus utilize 23 forward link and 23 reverse link channels. LDACS1 channel bandwidth is set to approximately 500 kHz and its channels are allotted at 500 kHz offset from DME channels, which are themselves separated by 1 MHz in the L-band.

To ensure non-interfering co-existence of LDACS1 and DME channels in the L-band, spectral mask specifications in terms of relative attenuation at particular frequencies away from the center frequency of a LDACS1 channel are specified in the LDACS1 specifications proposals [6-8]. Fig. 1 shows the desired LDACS1 spectral mask as given in the updated LDACS1 system specifications proposal [8]. The LDACS1 specification states that within the out of bound domain, the spectral density of the LDACS1 signal should fall within the spectral mask shown in Fig. 1. In Fig. 1, the 0 dBr level is the average LDACS1 transmitter in-band power density. The values of the different frequency breakpoints on the x-axis and the corresponding attenuation levels on the y-axis are listed in Table I.

Table I. The different values on the frequency axis have been computed based on the channel bandwidth of LDACS1, with $B_{occ} = 498.05$ kHz. In our work presented in this paper, we have designed the proposed channel filter based on the LDACS1 spectral mask specifications listed in Table I.

B. Improved Coefficient Decimation Method (ICDM)

The improved coefficient decimation method (ICDM) was recently proposed by us in [13]. It constitutes two sets of operations which can be used to operate upon the coefficients of a prototype filter for obtaining variable frequency responses-coefficient decimation method (CDM) and modified coefficient decimation method (MCDM). In CDM, the coefficients of a low-pass prototype filter are decimated by a factor $M$, i.e., every $M$-th coefficient is retained and all others are replaced by zeros, to obtain a multi-band frequency response with its subbands located at even multiples of $\pi/M$. Similarly, in MCDM, the coefficients of a low-pass prototype filter are decimated by a factor $M$, i.e., every $M$-th coefficient is retained and the sign of every alternate retained coefficient is reversed after replacing all non-retained coefficients by zeros, to obtain a multi-band frequency response with its subbands located at odd multiples of $\pi/M$. Based on the ICDM, we proposed non-uniform digital filter banks in [13, 14] for multi-standard channelization in software defined radio based mobile communication systems. In this paper, we propose an ICDM-based uniform filter bank for single-standard, i.e., LDACS1 channelization. In the proposed filter bank design technique, ICDM is used to obtain multi-band frequency responses from which the desired LDACS1 subbands can be extracted. The design procedure of the proposed filter bank is presented in the following Section III.
III. PROPOSED ICDM-BASED FILTER BANK

In this section, we first present the design procedure for the proposed filter bank, followed by a specific design example to illustrate the different steps involved in the design procedure. The section concludes with the complexity comparison of the proposed filter bank with the DFT-based filter bank design technique.

A. Design Procedure

The primary component of the proposed filter bank is a low-pass prototype filter which is suitably operated upon to obtain the desired LDACS1 subbands. The prototype filter specifications are selected based on the sampling frequency and the number of desired subbands, and its coefficients are obtained using filter design tools.

**Step-1: Prototype filter design**

The low-pass prototype filter is designed using the Parks-McClellan algorithm to compute the desired finite impulse response (FIR) filter coefficients. Fig. 3 shows the frequency responses of the four masking filters and the four resultant subbands. It can be observed that the obtained subbands have their spectral masks shaped such that they adhere to the LDACS1 spectral mask specifications. Also, the transition bandwidths are kept as wide as possible to achieve low filter orders for the different masking filters. This helps to keep the overall complexity of the filter bank low.

**B. Design Example**

In this sub-section, we present a design example to illustrate the realization of the proposed filter bank. The LDACS1 specifications propose recommendations for oversampling factors of at least four while performing channelization, to help mitigate the impact of interference while operating LDACS1 as an inlay system [8]. Consequently, as the channel bandwidth of LDACS1 is approximately 500 kHz, the minimum sampling frequency computes to be 4 MHz. Thus, as four LDACS1 channels can be allotted in a bandwidth of 4 MHz, we consider an example of designing a filter bank with four LDACS1 subbands. Fig. 3 shows the frequency responses of the four masking filters and the four resultant subbands that are obtained. It can be observed that the obtained subbands have their spectral masks shaped such that they adhere to the LDACS1 spectral mask specifications. This can be observed better from the frequency response of SB1 which is shown in Fig. 4 with the desired LDACS1 spectral mask superimposed on it. From figures 3 and 4, it can be noted that the four obtained subbands satisfy all the desired LDACS1 attenuation specifications as listed in Table I.

Along with their conventional usage for obtaining required subbands from a multi-band frequency response, masking filters are also used for shaping the spectral mask of obtained subbands to meet the desired LDACS1 attenuation specifications. The obtained subbands can thus be used for extracting LDACS1 channels from the input signal. The dual role played by the masking filters to individually obtain the desired subbands as well as shape their spectral masks is a novel feature of the proposed filter bank design technique.
Fig. 3. Frequency responses and corresponding operations involved in obtaining desired subbands of the proposed filter bank.

Fig. 4. Frequency response of Subband 1 (SB1) along with the desired LDACS1 spectral mask.
The complexity of a digital filter bank is mainly dependent on the number of multipliers required for its implementation, as multipliers are the most resource-consuming blocks in the realization of digital filter bank circuits. The total number of multipliers required for implementing the proposed filter bank is the sum of the multipliers required to implement the prototype filter and the masking filters. In the proposed filter bank’s implementation, the symmetry property of FIR filter coefficients can be exploited while implementing the prototype filter as well as the masking filters, thereby reducing the number of multipliers required by a factor of two. Also, further reduction is possible due to the elimination of stopband filter coefficients after performing ICDM operations. For example, for the design example discussed in Section III-B, as $M=2$ is used in the ICDM operations, half of the prototype filter coefficients are eliminated. The cumulative reduction in required number of multipliers due to the symmetry property as well as the ICDM operations results in significant reduction in overall complexity of the proposed filter bank.

If the DFT-based filter bank [12] is to be designed for LDACS1, the most stringent stopband attenuation specification listed in Table I has to be considered. This is because the DFT-based filter bank cannot provide subbands with multiple attenuation levels as desired for LDACS1. Therefore, while using the DFT-based filter bank, -76 dB has to be considered as the minimum required stopband attenuation. This will result in a higher overall complexity of filter banks designed using the DFT based approach.

For comparing with the proposed filter bank designed in Section III-B, a filter bank is designed using the DFT-based filter bank design technique [12] (a filter bank is designed with 8-channels, of which every alternate channel can be used for LDACS1). The total number of multipliers required to realize the proposed filter bank and the DFT-based filter bank are listed in Table II. It can be noted that when compared with the DFT-based filter bank, the proposed filter bank offers 71.49% savings in multiplication complexity. Therefore, if the proposed filter bank is used in the ground base-station LDACS1 receivers, the large savings in multiplication complexity will result in significant reductions in hardware area utilization as well as power consumption. From Table II, it can also be noted that the proposed filter bank provides a constant group delay of 69 samples, which corresponds to 17.25 µs for a sampling frequency of 4 MHz. The DFT-based filter bank does not provide a constant group delay as it is not a single-rate filter bank.

<table>
<thead>
<tr>
<th>Filter Bank Type</th>
<th>Number of Multipliers</th>
<th>Group Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFT-based filter bank [12]</td>
<td>221</td>
<td>NA</td>
</tr>
<tr>
<td>Proposed filter bank</td>
<td>63</td>
<td>69</td>
</tr>
</tbody>
</table>

IV. Conclusion

In this paper, we proposed a filter bank which can be used in ground base-station receivers for extracting multiple LDACS1 channels being transmitted by different aircrafts. The proposed filter bank employs the improved coefficient decimation method (ICDM) in its design. With the help of a design example, we showed that when compared with the discrete Fourier transform (DFT) based filter bank, the proposed filter bank offers 71.49% savings in multiplication complexity, which corresponds to the total number of multiplications required for implementing the filter bank designs. Thus, it can be concluded that the proposed low complexity filter bank is highly suitable for use in LDACS1 ground base-station receivers for air-ground communication.

REFERENCES


