A LOW COMPLEXITY DIGITAL CHANNEL FILTER FOR LDACS1 IN FUTURE AERONAUTICAL COMMUNICATION SYSTEMS

[1]ABHISHEK AMBEDE, [2]A. P. VINOD

[1,2]School of Computer Science and Engineering, Nanyang Technological University, Singapore.
E-mail: [1]abhisheka@ntu.edu.sg, [2]asvinod@ntu.edu.sg

Abstract- The air traffic has seen a tremendous growth worldwide in the last few decades and is forecast to grow at a rapid pace in the future as well. Therefore, there is an urgent need to upgrade the decades-old analog communication based air traffic management (ATM) systems that are currently being used and replace them with new and efficient digital communication based ATM systems to facilitate the air traffic growthbeing observed worldwide. Consequently, the International Civil Aviation Organization (ICAO) is developing a new standard for air-to-ground communications, namely the L-band Digital Aeronautical Communication System (LDACS). Out of the different candidate technologies being considered for LDACS, the LDACS type 1 (LDACS1) is the most superior and mature candidate. The channel filters used in LDACS1 transceivers have to adhere to stringent spectral mask specifications to ensure minimal interference with the legacy systems already deployed in the L-band. This paper presents a design technique to realize a low complexity digital channel filter for LDACS1.Our channel filter employs two low order sub-filters in cascaded formto shape the resultant frequency responseaccording to the required LDACS1 spectral mask. We show that if our channel filter is compared with the conventional one, 43.56% and 45% reductions are observed in multiplication complexity and group delay respectively.

Index terms- Channel filter, low complexity, LDACS1, air-to-ground communication.

I. INTRODUCTION

Numerous studies and growth forecasts show that the air traffic has seen tremendous growth over the past few decades and it will continue to grow at a rapid rate in the future [1, 2]. For example, a forecast study by the EUROCONTROL Statistics and Forecast Service STATFOR estimates that in 2035, there will be 14.4 million flights in Europe alone (most likely scenario prediction). This will be an approximately 50 percent increase over the number of flights in 2012 [2]. Such high growth is being estimated by numerous studies for other regions of the world as well. The current air traffic management (ATM) systems that are used worldwide are based on decades-old analog communication technology. It is expected that the capacity of these analog ATM systems will saturate within the next few years and therefore, there is an urgent need to upgrade them using modern and efficient technologies. The International Civil Aviation Organization (ICAO) has recognized this need and has begun the process of setting up a future communications infrastructure (FCI) [3].With the aim of upgrading the current ATM systems and setting up a modern and efficientworldwide FCI, the ICAO has supported two ongoing major projects: Single European Sky ATM Research (SESAR) [4] in Europe and Next Generation National Airspace System (NextGen) [5] in the United States.

The FCI is proposed to consist of multiple data-link technologies for catering to the different stages of a flight such as landing, takeoff, taxing, in-flight etc. One of the most critical data links amongst those is the air-to-ground communication data-link. After studying and analyzing the spectrum which can be allotted to this data-link, the ICAO has allotted the L-band (960-1164 MHz) for the future air-to-ground communication systems to operate in. The new standard being developed for air-to-ground communications is called the L-band Digital Aeronautical Communications System (LDACS). There are two candidate technologies that are being evaluated for selection for the LDACS - LDACS type 1 (LDACS1) and LDACS type 2 (LDACS2). Through analytical studies and prototype testing, it has been observed that the LDACS1 has superior performance when compared with the LDACS2 [6-8]. Therefore, the research activities around the world have mainly focused on LDACS1 thereby making it a mature and strong candidate for final selection and deployment. Thus, we too have focused on LDACS1 in our work.

The LDACS will be deployed along with existing systems which are already operating in the L-band, such as thedistance measuring equipment (DME) which operates in the range 962–1213 MHz. Therefore, to study the interference to the operation of these legacy systems in the L-band and thereafter selecting the least interfering solution, different deployment options are being considered for LDACS [6]. One of the deployment options is an inlay approach, wherein the LDACS1 channels will occupy spectral gaps between adjacent channels of the DME. While operating alongside the DME, it is to be ensured that the LDACS1 channels' spectral mask doesn't not interfere with the DME channels. Therefore, there are stringent specifications prescribed for the LDACS1 spectral mask in the LDACS1 specification document [6]. The channel filters used for operating upon individual channels in the LDACS1 transceivers on-board aircrafts will thus have to adhere to these stringent spectral mask specifications. As the aircrafts are powered by batteries, the different communication systems used have to ensure minimal energy consumption. Thus, along with the constraint of adhering to spectral mask specifications, the channel filters have to also achieve low complexity so as to assist in lowering the overall energy consumption.

To address these design challenges, we propose a channel filter in this paper for LDACS1 based air-to-ground communication. Our channel filter employs two low order sub-filters in cascaded formto shape the resultant frequency response according to the required LDACS1 spectral mask. We show that significant reductionscan be achieved in multiplication complexity and group delay due the usage of cascaded low order filters.

Following are the rest of the contents of the paper: Section II briefly presents the relevant LDACS1 specifications. Section III presents the design of the proposed channel filter. The comparative analysis of our proposed channel filter is also presented in this section. Our conclusions are provided at the end of the paper.

II. LDACS1 SPECIFICATIONS

The LDACS1 employs orthogonal frequency-division multiplexing (OFDM) modulation in its operation[6]. OFDM enables flexible utilization of the allotted spectrum. This feature enables the deployment of LDACS1 alongside the legacy aeronautical communication systems operating in the L-band, thereby enhancing the transmission capacity while ensuring minimal interference to the legacy systems. The channel bandwidth of LDACS1 is selected to be498.05 kHz. Also, the allotment of LDACS1 channels is to be done at 500 kHz spacing from the adjacent DME channels, which are allotted at 1 MHz spacing between each other. The LDACS1 transceivers have to adhere to strict spectral mask specifications to ensure minimal interference to the operation of DME. The LDACS1 specifications proposal [6] prescribes the spectral mask specifications for LDACS1. The LDACS1 spectral mask as provided in [6] is shown in Fig. 1. According to the LDACS1 specification proposal [6], in the out of bound domain, the spectral density of the LDACS1 channel should be limited to be within the spectral mask shown in Fig. 1. It is to be noted that the 0 dBr

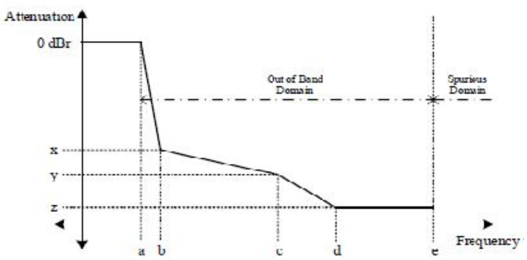

Fig. 1. LDACS1 spectral mask.

Table 1. LDACS1 spectral mask specifications [6].

	Frequency (kHz)	Attenuation (dBr)
a = $B_{occ}/2$	249.025	0
b = 1.35*a	336.184	x = -40
c = 2.5*a	622.563	y = -56
d = 3.1*a	771.978	z = -76
e = 5*a	1245.125	z = -76
$\geq$ e	$\geq$ 1245.125	<spurs>

level shown in Fig. 1 is the average LDACS1 transmitter in-band power density. Table 1 lists the different frequency points (x-axis) away from the center frequency of a LDACS1 channel and the corresponding required minimum attenuation values (y-axis). The x-axis frequency values are calculated using the prescribed channel bandwidth of LDACS1, i.e.,B_{occ} = 498.05 kHz. It is to be noted that the desired attenuation values increase as we move away from the center frequency of the LDACS1 channel. This helps to avoid interference to the adjacent DME channels as well as neighboring LDACS1 channels. The spectral mask specifications shown in Table 1 have been followed in this work.

III. PROPOSED CHANNEL FILTER

This section presents the design of the proposed channel filter. The primary aim of the design is to obtain the required spectral mask for LDACS1 while also ensuring low complexity of the filter implementation. The proposed channel filter design involves two sub-filters that are cascaded together. Let these two sub-filters be termed as Filter I and Filter II. The design parameters of the two sub-filters are chosen to achieve the specifications prescribed for the LDACS1 spectralmask. These parameters are listed in Table 2. The LDACS1 specification proposal prescribes an oversampling factor of minimum four while performing filtering for channelization [6]. Therefore, as the LDACS1 channel bandwidth is approximately 500 kHz, we

Table 2. Sub-filter design parameters.

Parameter	Filter I	Filter II
Order	90	20
Passband edge frequency	0.1245	0.1245
Stopband edge frequency	0.1681	0.3113
Attenuation (dB)	- 40.5	- 36

choose the sampling frequency to be 4 MHz. The filter parameters listed in Table 2 are normalized with respect to half of the sampling frequency, i.e., the Nyquist frequency. The two finite impulse response (FIR) sub-filters are designed and their coefficients are computedwith the help ofMATLAB Filter Design and Analysis Tool [9].

The frequency responses of the two sub-filters are shown in figures 2 and 3. As discussed above, our channel filter is obtained by cascading the two sub-filters. Cascading the filters modifies the resulting frequency response such that its shape meets the required spectral mask specifications. The frequency response of the proposed channel filter is shown in Fig. 4. The required LDACS1 spectral mask is also shown in Fig. 4 and is superimposed on the frequency response of the channel filter. From Fig. 4, it can be observed that the spectral characteristics of our channel filter satisfy all the specifications for LDACS1 communication.

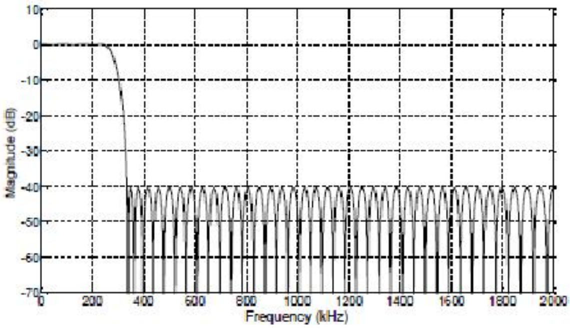

Fig.2. Frequency response of Filter I.

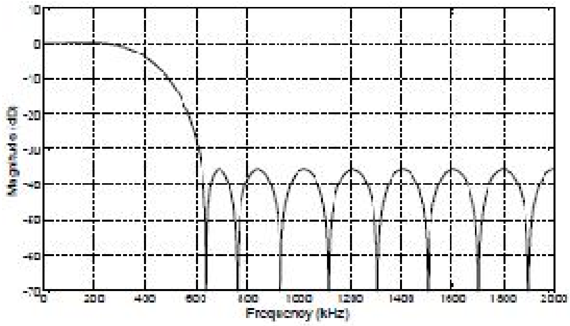

Fig.3. Frequency response of Filter II.

The implementation complexity of a channel filter affects the overall energy consumption of the LDACS1 transceiver. This complexity is primarily dependent on the total number of multipliers involved in implementing the channel filter. In our case, the total number of multipliers involved is the sum of the multipliers required to implement the two sub-filters. It can be noted that while implementing FIR filters, the symmetry of their coefficients can be exploited such that only half of the coefficients need to be implemented, using the transposed direct-form FIR

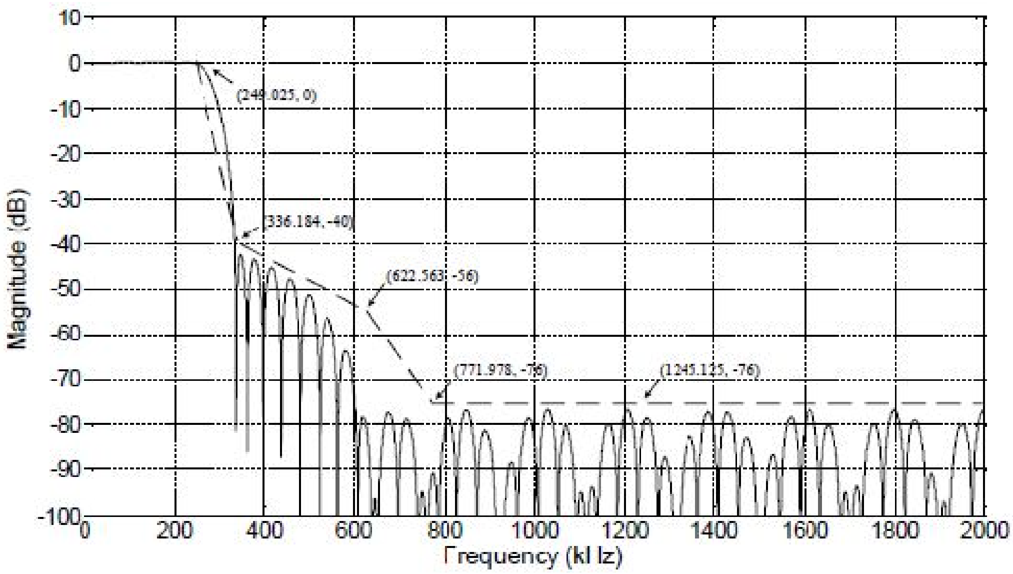

Fig. 4. Frequency response of proposed channel filter superimposed with the desired LDACS1 spectral mask.

filter architecture [10]. Filter I and Filter II can be implemented using 46 and 11 multipliers respectively, and thus the total number of multipliers required to implement the proposed channel filter is 57. As the two sub-filters are cascaded, the group delay of the proposed channel filter is the sum of the group delays of Filter I and Filter II. Thus, the group delay of the proposed channel filter is 55 samples. In units of time, this corresponds to 13.75μs as the sampling frequency is 4 MHz.

Conventionally, a single digital FIR filter is designed to be used as a channel filter by considering the most stringent attenuation specification. Thus, if a channel filter is to be designed for LDACS1 using the conventional approach, it has to be designed for an attenuation specification of -76 dB as listed in Table 1. For normalized passband and stopband edge frequencies as 0.1245 and 0.1681 respectively, the order of an FIR filter is computed to be 200 using MATLAB. Therefore, for the conventional approach, the number of multipliers required would be 101. Also, the group delay involved will be 100 samples, which corresponds to 25µs for a sampling frequency of 4 MHz.

Table 3 presents the comparative analysis of the conventional channel filter and the proposed channel filter in terms of the total number of multipliers required for their implementation as well as their group delays. From Table 3,it can be notedthat the proposed channel filter shows 43.56% reduction in multiplication complexity when compared with the conventional channel filter. Also, a 45% reduction is achieved in group delay, which enables higher speeds for the filtering operation.

Table 3. Comparative analysis.

	Total multipliers required	Group delay	
		In samples	In µs
Conventional channel filter	101	100	25
Proposed channel filter	57	55	13.75
Percentage reduction achieved	43.56%	45%	45%

CONCLUSION

LDACS1 is a standard currently under development for the future air-to-ground communications. We proposed a digital channel filter for LDACS1 in this paper. Our proposed channel filters satisfies the stringent LDACS1 spectral mask specifications while also providing low complexity and low group delay. It employs two cascaded low order sub-filters to achieve the desired shape of the LDACS1 spectral mask. It was shown that the proposed channel filter offers 43.56% reduction in multiplication complexity if compared with the conventional channel filter, which ultimately provides low complexity of implementation and thus energy consumption. Also, a 45% reduction is achieved in group delay, which enables higher speeds for the filtering operation. Due to these advantages, our channel filter is a promising candidate to be employed in the LDACS1 transceivers on-board aircrafts.

REFERENCES

[1] Forecasts and Performance Analysis Division (APO-100), Office of Aviation Policy and Plans, "FAA Aerospace Forecast: Fiscal Years 2016-2036", Federal Aviation Administration (FAA), 2016; https://www.faa.gov/data_research/aviation/aerospace_forecasts/ (accessed in June 2016).

[2] STATFOR, the EUROCONTROL Statistics and Forecast Service, "Challenges of Growth, Task 4: European Air Traffic in 2035," EUROCONTROL, Jun. 2013; http://www.eurocontrol.int/statfor (accessed in June 2016).

[3] Schütz, W; Schmidt, M., "Action plan 17—Future communication study: Final conclusions and recommendations report," EUROCONTROL/FAA, Brussels, Belgium, November 2007.

[4] SESAR homepage: http://www.sesarju.eu (accessed in June 2016).

[5] NextGen homepage: http://www.faa.gov/nextgen (accessed in June 2016).

[6] Sajatovic, M; Schnell, M., "Updated LDACS1 prototype specification," SESAR Joint Undertaking Report EWA04-1-T2-D2, 2010.

[7] Neji, N.; de Lacerda, R.; Azoulay, A.; Letertre, T.; Outtier, O., "Survey on the future aeronautical communication system and its development for continental communications," *IEEE Transactions onVehicular Technology*, vol. 62, no. 1, pp. 182-191, January 2013.

[8] Schnell, M.; Epple, U.; Shutin, D.; Schneckenburger, N., "LDACS: future aeronautical communications for air-traffic management," *IEEECommunications Magazine*, vol. 52, no. 5, pp. 104-110, May 2014.

[9] MATLAB Filter Design and Analysis Tool (FDATool): http://www.mathworks.com/help/signal/examples/introduction-to-the-filter-design-and-analysis-tool-fdatool.html (accessed in June 2016).

[10] Proakis, J. G.; Manolakis, D. G., "*Digital Signal Processing*," Pearson Education, 4th edition, 2007.

★★★