DATA CONVERSION IN ADVANCED COMMUNICATION SYSTEMS

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Abstract: This paper presents an overview of state of the art applications of Digital to Analog and Analog to Digital converters when embedded into a Digital Communication System (DCS). Three DCSs are considered: the Terrestrial Digital Video Broadcasting (DVB), the Digital Audio Broadcasting (DAB), and the Global System for Mobiles (GSM). For each system the role of converters is identified, along with the minimal performance requirements. The advantages of Sigma-Delta converters upon traditional converters are then outlined and the usage of Sigma-Delta converters is discussed as a mean to improve performances of DCSs.

Keywords: Digital Communication Systems, Sigma-Delta converters.

1   INTRODUCTION

In last years digital communication systems (DCSs) have been intensely developed and now tend to replace analog systems due to their better performances. It is well known that digital transmission allows operations such channel coding and interleaving, which are a powerful ally against channel impairments. Digital transmission of analog signals involves the analog-to-digital (A/D) conversion of data in the transmitter and the digital-to-analog (D/A) conversion in the receiver, a feature which often is not critical in the design of a DCS, as the baseband analog signal does not require a high sampling rate. Thus the performance of the D/A and the A/D conversion has generally low influence on the quality of transmitted signal.

However, most recent implementations of DCSs often take advantage of D/A and A/D conversion in new ways, like direct digital modulation. The main feature of this technique is that the signals to be transmitted are not provided by analog circuitry. Instead of generating and modulating an analog carrier, for each possible symbol a sampled and quantized version of the corresponding modulated carrier is stored in the transmitter. So whenever a signal has to be transmitted, its sampled version is fed to a D/A converter followed by a lowpass filter for signal smoothing; the output of the filter is the analog modulated signal, and goes to the RF part of the transmitter. The receiver shows a dual architecture; after the RF to baseband conversion the received signal is A/D converted and the transmitted symbol is identified.

The performance of D/A and A/D converters, when used in this way, greatly influences the overall performance of the system, because they operate directly on the modulated signal feeding/coming from the RF part of the transmitter/receiver, so each distortion, noise or spurious signal introduced by the D/A or A/D converter adds to it directly. A metrological characterization of these devices is then a useful mean to identify the minimum requirements to be satisfied by the system as a first step in a performance optimization process.

In the following the role and the requirements of A/D and D/A converters are analized for three modern DCSs, the Digital Video Broadcasting (DVB), the Digital Audio Broadcasting (DAB) and the Global System for Mobiles (GSM). The main aim of this work is to analize the possibility of using Sigma-Delta converters in place of traditional ones, taking advantage of their superior performances. Moreover state of the art on the market standalone D/A and A/D converters compliant to DCS requirements are analized. The performances of traditional converters will then be compared to the performances of Sigma-Delta converters. As D/A and A/D converters used in GSM systems are usually part of larger integrated devices, some GSM chipsets are also considered.

2   A/D AND D/A CONVERTER REQUIREMENTS IN DVB-T SYSTEMS

A good example of direct digital modulation is the European Digital Terrestrial Television standard, the DVB-T [1]. This broadcasting system is based on COFDM (Coded Othogonal Frequency Division Multiplexing), a technique which splits the data stream to modulate multiple carriers (6817 in the 8K mode) and achieves a low overall symbol rate, countering multipath phenomena. Clearly, generating thousands of carriers by analog circuitry is not a practical solution so in DVB-T the carrier generation and modulation are performed through an Inverse Fast Fourier Transform (IFFT) of digital mapped data

followed by a D/A conversion. The receiver has a specular structure, and performs an A/D conversion followed by an FFT algorithm. In this case not only the usage of D/A and A/D gives better performance, but it is the only feasible way! Fig.1.a) shows the simplified block structure of a DVB-T exciter. The term exciter defines the part of the transmitter which receives in input the data to be transmitted and outputs the low power modulated and RF upconverted signal. In a DVB-T exciter first the digital data (an MPEG-2 transport stream) undergo channel coding and interleaving, then they are splitted throughout a serial to parallel conversion in groups of n bits. Each group of bits is mapped into a 2^n-QAM (Quadrature Amplitude Modulation) constellation symbol and modulates a single carrier. In other words the symbols are phasors and the exciter associates them to the carriers. The order 2^n of the modulation can be selected by the broadcaster and ranges from 4 to 64. For example if the 16-QAM option is selected the encoded and interleaved data are split into groups of four bits, then each group, is translated in a 16-QAM symbol. The symbols modulate the carriers alltogether throughout IFFT followed by D/A conversion of the real part of its output.
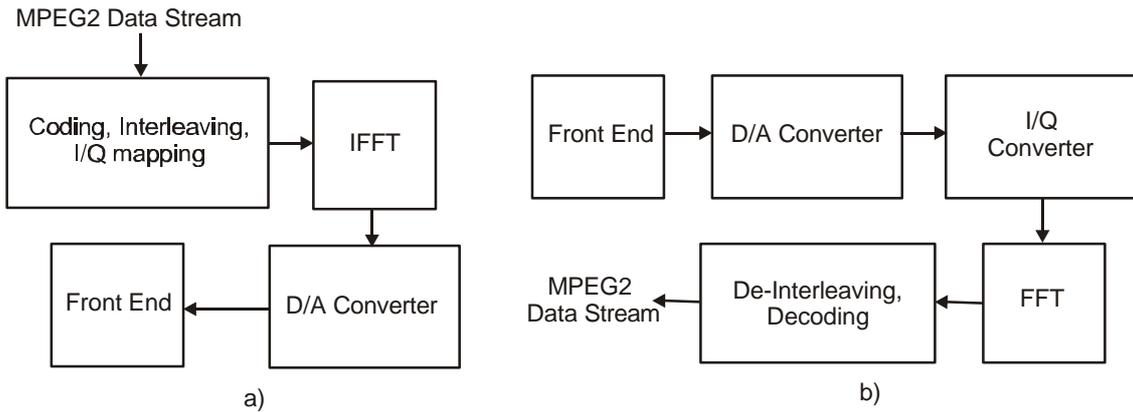

Fig.1 Simplified block diagrams of an OFDM transmitter (a) and an OFDM receiver (b)

Fig.1.b) shows the simplified block diagram of a receiver. After a RF to baseband down-conversion, the received signal is A/D converted, thus obtaining an estimate of the real part of the output of the exciter IFFT, then the IQ Conversion block reconstructs the imaginary part of the signal. The complex signal undergoes a FFT which outputs an estimate of the transmitted 2^n-QAM symbols, and the symbols are demapped into the corresponding n bit groups. After a parallel to serial conversion the bit stream is decoded and deinterleaved, and the original MPEG-2 transport stream is reconstructed.
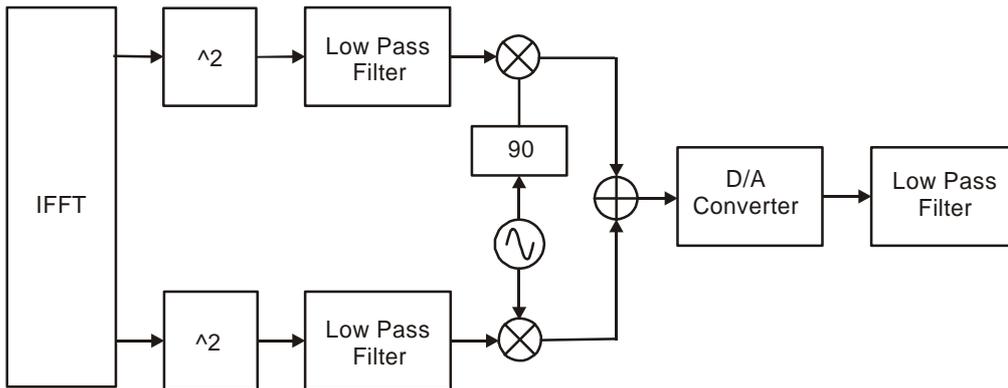

Fig.2 Digital IF upconverter block diagram

A sampling rate of about 9.14 Msample/s (which equals the system clock frequency [1]) and a resolution of 10 bits are typical of early DVB-T transmitters, and these characteristics can be assumed as the minimum requirement for A/D and D/A converters when used in DVB-T COFDM modulation. As regards the transmitter, the manufacturers tend to realize digitally at least one IF upconversion (fig. 2), which is obtained through an upsampling (zero insertion) of the IFFT output, followed by anti-alias digital filtering and multiplication by a digital carrier. Such a strategy allows the achievement of a better

frequency stability and reproducibility, moreover it replaces analog filtering with digital filtering, which offers better performances but implies more severe requirements to the converters.

A common approach is to digitally upconvert the signal to an IF equal to one quarter of the sampling rate, so that the digital upconverted signal is centered around the $\pi/2$ rad frequency. It should be noticed that generating a $\cos(n\pi/2)$ carrier and multiplying it by a generic signal is very easy to implement. In early exciters supporting digital IF upconversion [2] the signal was upsampled by a factor of 2, leading to a 18.28 system clock and to a 4.75 Mhz IF. The D/A and A/D converters used in such exciters had then a resolution of 10 bits and a sampling rate of about 18.28 Msample/s. These features have been further enhanced throughout the usage of higher IF frequencies and resolutions, so now the newest exciters have on board D/A converters with a 27.42 Msample/s sampling rate [3] and a 12 bit resolution.

The accuracy requirements are not completely defined, because DVB is an open standard. This means that the standard specifies the main features of the system, some mathematical aspect and the characteristics of the emitted signal, but does not provide any information about the system implementation, which is left to the manufacturers. However something can be indirectly inferred from the specifications of the emitted signal. Infact the D/A converter performances have to comply at least with them while actual requirements will be more severe, because the nonideality of RF conversion and power amplifier blocks are to be taken in account. In particular, minimal requirements are 60 dB of SNDR and a 32 dB attenuation of inband intermodulation products relative to the mean power spectral density of the wanted COFDM signal [4].

A standalone A/D converter with a resolution of 12 bits, a sampling rate of 40 Msample/s a SNDR of 68.3 dB and a SFDR of 79dBc, obtained through a multistage differential pipelined architecture is [8]; these performances comply with the requirements of a DVB-T receiver. Moreover a 12 bit segmented current source D/A converter with a maximum speed of 125 Msample/s and a 70 dBc SFDR is on the market, which could be used in a DVB-T transmitter [9]. The high speed of the device could allow to digitally upconvert the baseband modulated signal to higher frequencies, and eventually to render obsolete the usage of an analog IF conversion.

3   A/D AND D/A CONVERTER REQUIREMENTS IN DAB SYSTEMS

Similar performances are required by DAB, the European digital radio standard [5], which is based on COFDM too. The standard requires a resolution of 8 bits and a frequency of 2.048 Msample/s [6], however manufacturers have improved these features on their own, and a commercial has a D/A converter on board with a resolution of 16 bits, a clock of 2.048 Msample/s, and a declared SNR of 97 dB [7].

Manufacturers provide also a 16 bit D/A converter with a 2.5 Msample/s sampling rate, a 5mA full scale output and a 31 pA/$\sqrt{Hz}$ noise power (at 1kHz) is proposed [10]. Moreover a 16 bit Sigma-Delta A/D converter with 88.5 dB SNDR, 100 dBc SFDR, -96 dB of Harmonic distortion and a 2.5 Msample/s sampling rate, obtained from a clock of 20 MHz is available [11]. As this device allows the selection of various oversampling ratios (1, 2, 4, 8) higher speeds can be achieved at the cost of a lower resolution. This feature can be of interest for example in a DVB-T receiver.

4   A/D AND D/A CONVERTER REQUIREMENTS IN GSM SYSTEMS

The last digital communication system we will consider here is the GSM [12], the well known digital cellular system standard, which uses D/A and A/D converters in several ways. Fig.3 shows the block diagram of a GSM handset; in the following the converters used in the transmitter branch will be described. The analog signal at the output of the microphone is firstly digitized by the audio A/D converter. Then the sequence of digital samples feeds the channel encoder. The requirements of the audio A/D converter are not severe, that is 13 bits of resolution and 8 ksample/s sampling rate .

Conversely, the transmission D/A converter operates on the coded modulated data and outputs the baseband modulated signals which feeds the RF part of the handset. The characteristics of this D/A converter have been determined through the analisys of some GSM chipsets on the market [13],[14]. They show a resolution of 10 bits and a sample rate up to 4 Msample/s. As noticed before the performance of the transmission D/A converter (and of the corresponding A/D converter in the receiver branch) affects directly the performance of the overall system. A minimal requirement for the spurious free dynamic range is -36 dBc for mobile stations, -47 dBc for GSM900 base transceiver stations and -57 dBc for DCS1800 base transceiver stations. The dynamic range of the devices should be at least 70 dB [15],[16].
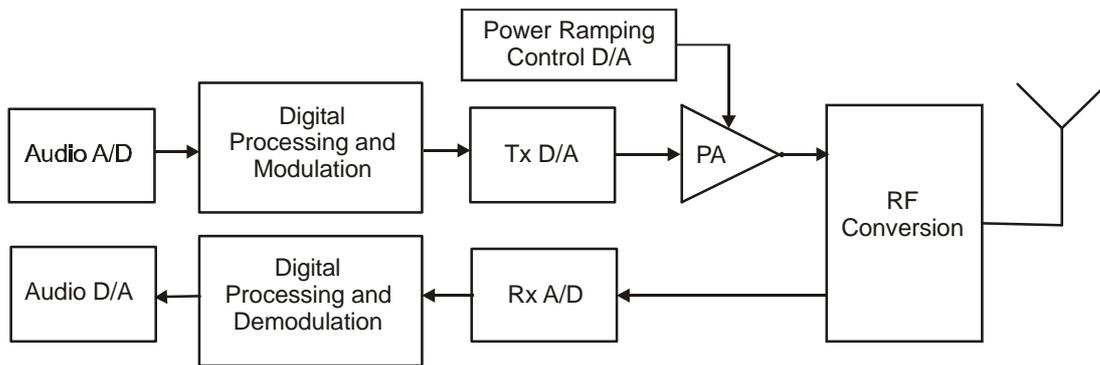
Fig.3 Simplified block diagram of a GSM/DCS1800 mobile station

Another GSM feature in which D/A converters are required is the power ramping control. GSM mobile stations are divided in device classes, depending on their maximum output power. For each GSM device class a standard power vs. time graph is specified, along with the allowed tolerance on the power levels [16]. These levels are generated from digital data using a 10 bit D/A converter which drives the power amplifier. The allowed tolerance level specified for the emitted RF signal could then be used to infer a set of minimal requirements to which the D/A converters should comply. The same approach is used also for the automatic gain control and the automatic frequency control.

5   USAGE OF SIGMA-DELTA CONVERTERS IN DCSs

Sigma-Delta converters offer superior performances respect to no-feedback converters due to their quantization noise shaping and low distortion feature. Provided that they can sustain the clock requirements their usage could improve the performance of a DCS. Moreover they are easy to integrate into low power consunming CMOS chips. This makes then good candidates for receivers, especially in mobile communication systems. For example some GSM chipsets manufacturers already use Sigma-Delta D/A converters instead of traditional ones. Moreover a multibit Sigma-Delta A/D converter with a resolution of 13 bits, a sample rate of 1.4 Msample/s, a dynamic range of 77 dB and a SNDR of 71 dB has been proposed for the receiver of a DECT cellular phone [17].

As regards Digital Direct Modulation based systems, the usage of a IF bandpass sigma-delta A/D converters has been proposed [18] as a mean to improve performances of DVB-T receivers, because it would replace analog filtering and downconversion with digital processing. The bandpass architecture has been shown to work better if the sampling rate to IF ratio is equal to 4 [18] so the bandpass A/D sigma-delta conversion in the receiver can be considered a good complement for the digital IF upconversion in the transmitter. Some authors [19] have recently underlined the possibility of designing variable centrer frequency Sigma-Delta bandpass converters. This could eventually lead to a new form of digital tuning in receivers, implemented throughout programmable converters. Moreover a programmable converters could be used in a versatile multistandard receiver. Such an approach could be easily extended to DAB and GSM system too, because these systems require lesser performances to their converters.

6   CONCLUSIONS

The importance and the role of A/D and D/A converters in DCSs have been discussed and outlined, along with their performance requirements. The use of Sigma–Delta modulators has been analized as a mean to improve performances respect to traditional converters. Some state of the art applications of Sigma-Delta converters in DCSs have been identified. Expected future developments of this activity are a deeper identification of converters requirements, obtained throughout careful modeling of the converters together with the systems in which they are embedded, followed by a compared analisys of the effects of both traditional and Sigma-Delta converters impairments on the overall system performances, and the design of Sigma-Delta converters to be used in place of traditional ones in DCSs.

REFERENCES

[1]   ETS 300 744 "Digital Video Broadcasting (DVB) Framing Structure, Channel Coding and Modulation for Digital Terrestrial Television (DVB-T)".
[2]   Itelco "DVB-T exciter datasheet BB-IF1," document 40200030.
[3]   Rhode & Schwartz "DVB-T modulator SBD-M datasheet".

[4] DVB Document A014 Rev.1, "Measurements Guidelines for DVB Systems".
[5] ETS 300 401 "Radio broadcasting systems; Digital Audio Broadcasting (DAB) to Mobile, Portable and Fixed Receivers".
[6] EN 300 798 "Digital Audio Broadcasting (DAB); Distribution interfaces; Digital baseband In-phase and Quadrature (DIQ) interface."
[7] Itelco "DAB exciter description," published in Internet at http://www.itelco-usa.com/dab/exciter.htm.
[8] Analog Devices, "Complete 12-Bit, 40 MSPS Monolithic A/D Converter," AD9224 Datasheet.
[9] Analog Devices, "12-Bit, 100 MSPS+ TxDAC D/A Converter," AD9762 Datasheet.
[10] Analog Devices, "16-Bit High-Speed Current-Output DAC," DAC16 Datasheet.
[11] Analog Devices, "High Speed Oversampling CMOS ADC W/16-Bit Resolution at a 2.5 MHz Output Word Rate," AD9260 Datasheet.
[12] S. M. Redl, M. K. Weber, M. W. Oliphant, *An Introduction to GSM*. Artech House Publishers, 1995.
[13] Philips Semiconductors, "Baseband and audio interface for GSM," PCF50732 Datasheet.
[14] Analog Devices "GSM/DCS1800/PCS1900 Baseband Processing Chipset," AD20msp415 Datasheet.
[15] ETS 300 607-1 "Digital Cellular Communication Systems (Phase2); Mobile Station (MS) Conformance Specification; Part 1: Conformance Specification".
[16] GSM 05.05 "Digital Cellular Telecommunication Systems (Phase2+); Radio Transmission and Reception".
[17] A. R. Feldman, B. E. Boser*,* and P. R. Gray, "A 13-Bit, 1.4 MS/s Sigma-Delta Modulator for RF Baseband Channel Applications" *IEEE J. Solid-State Circuits,* vol. 33, pp.1462-1469, Oct. 1998.
[18] Juan Carlos de Mateo Garcia, Ana Garcia Armada, "Effects of Bandpass Sigma-Delta Modulation on OFDM Signals", *IEEE Trans. On Consumer Electronics,* Vol. 45, No. 2, May 1999.
[19] Mohammed Al-Janabi, Izzet Kale, Richard C.S. Morling, "Narrow-Band Variable Center Frequency Single-Loop and Multistage Sigma-Delta Modulators for Bandpass Signals", *IEEE Trans. On Instrumentation and Measurements,* Vol. 48, No. 5, Oct 1999.

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