AN AUTOMOTIVE BROADBAND SAMPLING RECEIVER FOR ANALOG AND DIGITAL BROADCASTING STANDARDS

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ABSTRACT

Software configurable receivers become necessary for automotive terminals to handle the increasing number of broadcasting standards in a car. This contribution presents a software configurable receiver for analog and digital audio and video standards. To achieve superior performance the signal of two antennas are sampled and processed in a signal processing unit based on an FPGA and DSPs.
The contribution presents the different parts of the receiver including the requirements and the realization of the analog frontend and the digital signal processing.

1. INTRODUCTION

In the last decade the number of audio and video broadcasting standards has significantly increased. Today existing broadcasting standards include both analog and digital systems, with different quality of audio and video information. Some of the systems support the transmission of additional data, such as traffic information, alternative frequencies, services available in the area, etc. A car entertainment system should be able to demodulate all of them, and provide the driver and passengers with the high quality audio and video signal and with the most recent information.
If a separate on-board terminal is installed for every service, cars would be filled-up with lot of communication equipment, and due to limited possibilities of communication among the terminals, diversity reception using different standards would require very high programming overhead. A solution which enables us to overcome these problems is a software receiver.
The architecture and implementation details of a multiband multimode software receiver for broadcasting services will be described in this paper. The hardware architecture of such a receiver is presented in Section 2. Requirements on the analog part and its performance are analyzed in Section 3, and in Section 4 the architecture of the software for digital signal processing is described.

2. HARDWARE CONCEPT

To achieve an optimum in flexibility and modularity and to avoid EMC problems, the signal processing for all channels is realized each on a separate board and connected with a backplane to the analog frontends. Digital steering signals, the amplified analog IF signal of the frontend and power are shared between the modules over the backplane. The sampling head is placed as a piggiback board on the digital part to reduce EMC radiation by the high speed digital lines.
Fig 1 shows the components included in the prototype.

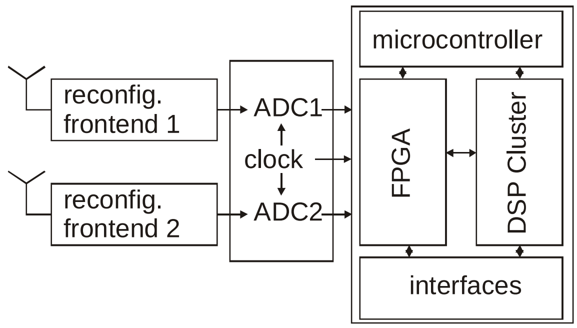

Fig 1: Block diagram of the receiver

Each analog frontend consists of a reception module for each wanted frequency range. A microcontroller on each frontend acts as a slave of the digital signal processing unit, and its task is to set up the different frontend parameters and to enable direct steering of the frontend via a RS232 interface for test purpose. The low jitter clock generation [2] is part of the ADC piggiback board.

It is possible to switch between two different sampling frequencies.

The digital signal processing contains enough processing power for downconversion, filtering and baseband processing of two channels in parallel. For optimum integration in cars an optical MOST interface is implemented. An on-board MPEG decoder provides an analog video stream for test purpose.

3. ANALOG SIGNAL PROCESSING

In a first realization step the frontend is able to handle the FM frequency range from 88 to 108MHz and the DVB-T frequency range between 470 and 861MHz. It should be possible to extend it to AM/DRM (0,1 – 10MHz), DAB (174-230MHz) and the satellite based digital audio broadcasting services Sirius / XM Sat Radio at 2,3GHz. The frequency plan is shown in Fig 2.

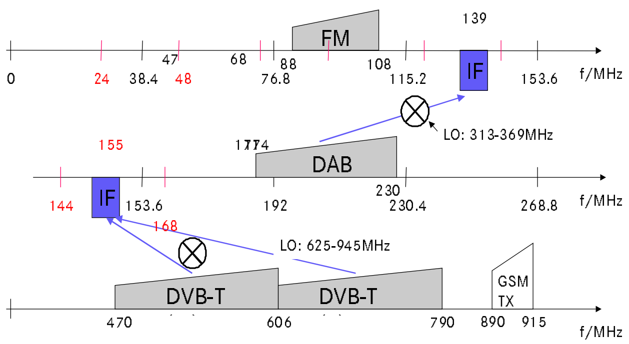

Fig 2: Frequency plan

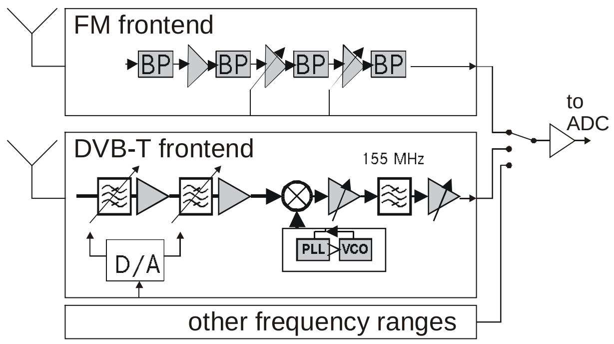

Fig 3: Block diagram of the analog frontend

Because of limited signal processing power for DVB-T and FM two different sampling rates are used. For FM the signal is directly sampled [1] with a sample rate of 76,8MHz so that the wanted signal between 88 and 108MHz appears at 11,2 to 31,2MHz after sampling [5]. The DVB-T signal is mixed down to an IF frequency of 155MHz and sampled after IF filtering with a sample rate of 48MHz. The signal will finally appear at 11MHz. A block diagram of the frontend is shown in Fig 3.

Direct sampling of the FM signal requires that the analog to digital converter is able to handle the whole dynamics of the FM band. Slow fading of the input signal is adapted by digital programmable amplifiers whereas fast fading has to be handled in digital domain.

The main task of the input stages is to suppress out of band interferers that may appear in the wanted signal band after sampling. A 4-stage filter based on low cost printed LC resonators has been built up. The frequency response is shown in Fig 4. For FM the highest signal levels can be expected in the wanted signal band so that the filtering fulfills the requirements.

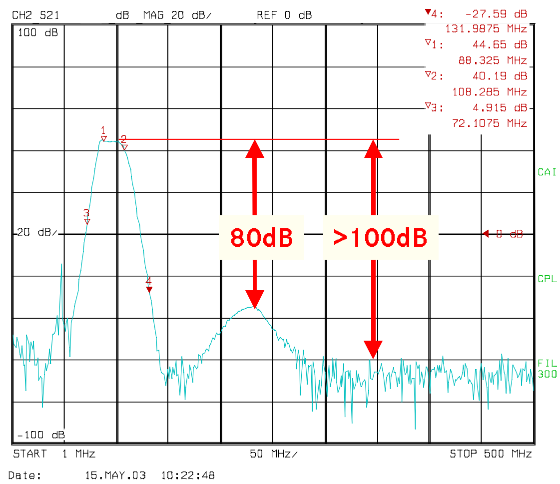

Fig 4: Frequency response of the FM input filter

The requirement on the analog to digital converter is a signal to noise ratio of about 90dB related to a signal bandwidth of 400kHz and a spurious free dynamic range (SFDR) of 95dB. Specially regarding the SFDR, care has to be taken when designing the ADC driver stages.

For the reception of DVB-T, an analog downconverting stage is implemented to achieve a fixed intermediate frequency of 155MHz. To avoid IF disturbing by the mirror frequency, an adjustable analog input filter is used. It is based on LC resonators with varactor diodes and can be controlled over a digital to analog converter by the micro controller. A suppression of more than 80dB of the mirror frequency 310MHz above the used channel is realized. The frequency response is depicted in Fig 5. After downconversion the amplification can be directly set by the digital signal processing unit to achieve an optimum amplitude at the input of the analog to digital converter.

By using an IF bandwidth of about 10MHz all standards in this frequency range can be handled so it is only a question of digital signal processing to process them.

Because DVB-T uses an 8k OFDM modulation scheme, the influence of phase noise of the local oscillator is critical [3][4]. At 100kHz offset we achieve –110dBc phase noise which is according to simulations sufficient for DVB-T.
An analog switch selects between the input modules and provides an attenuation of about 40dB to suppress interference from the unused receiver parts.

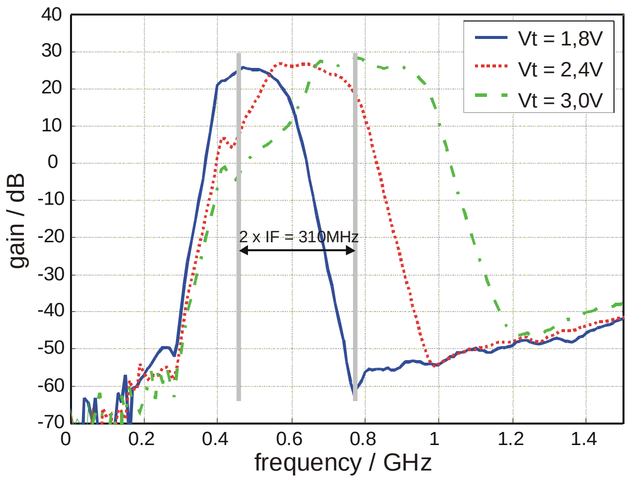

Fig 5: Transfer characteristic of the DVB-T input filter for different tuning voltages

4. DIGITAL SIGNAL PROCESSING

Modulation schemes used in the broadcasting systems considered for implementation include analog amplitude and frequency modulation (AM, FM), single carrier QAM (satellite channels for Sirius and XM Radio), and multicarrier OFDM (DRM, [6], DAB, [7], IBOC, DVB-T, [8], and terrestrial network for Sirius and XM Radio). The basic configurations of receivers for these three groups of modulation schemes are illustrated in Fig 6, Fig 7 and Fig 8, respectively. All depicted blocks are implemented in software.
In the first step only FM and DVB-T systems will be implemented. However, some building blocks of the multicarrier OFDM receiver have the same structure as corresponding building blocks for single carrier QAM receiver, and to enable software reuse, parameters necessary for both receivers were analyzed and implemented in a single software routine.
A common building block for all three types of receivers is the digital downconversion (DDC) block. It includes frequency shift to the baseband and signal filtering. In QAM receiver, a small carrier frequency offset is usually corrected after the decimation block. However, in OFDM receiver the carrier frequency offset should be corrected before demodulation (FFT), and we can use the frequency control input of the DDC to correct the carrier frequency offset in QAM receiver, too. In AM receiver, the control frequency input of DDC is used to implement a PLL.
Interpolator and symbol demapper are necessary in both QAM and OFDM receiver, and have basically the same structure. The reason for the use of interpolator in OFDM receiver is to correct offset of the sampling frequency, and in QAM receiver, interpolator is used to correct the sampling phase. If the large oversampling factor is used, QAM receiver does not need an interpolator. Although interpolator is used for two different reasons in these two receiver types, its structure is the same, and it an be implemented in a single software routine.
Symbol demapper for both receivers can also be implemented in a single software routine. The difference is that in multicarrier case, the routine has to be called in a loop, to demap a symbol on each sub-carrier.
Equalizer, timing estimator and frequency control or frequency offset estimation are necessary in both receivers. However, different algorithms are used, and there is no need to implement them in the same software routine. Even for the systems with the same modulation scheme (e.g. DRM and DVB-T), pilot carriers have different positions in the time-frequency trellis. Since these blocks use pilot symbols to estimate channel impulse response, symbol timing and frequency offset, and since the receiver performance strongly depends on the performance of these three blocks, these three blocks will be implemented separately for each system, [9]. Furthermore, for automotive application, these blocks have to be much more complex than in the case of a stationary receiver. They should be able to follow changes in the channel impulse response, which arises because the vehicle is moving, and changes in the carrier frequency offset due to Doppler shift.

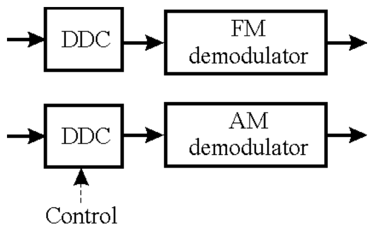

Fig 6: Structure of FM and AM receiver

Although not depicted in Figures 7 and 8, error control coding is used in all digital broadcasting systems. In the considered systems, convolutional codes, interleavers, Reed-Solomon code, BCH code and CRC, or combination of these methods is used. The library containing corresponding decoders has been created.

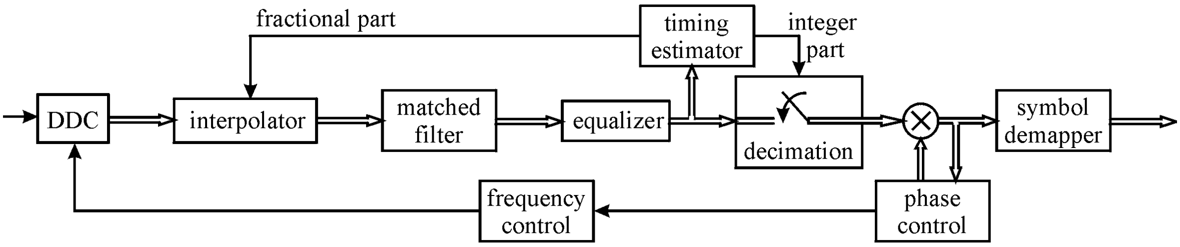

Fig 7: Typical architecture of a single carrier QAM receiver

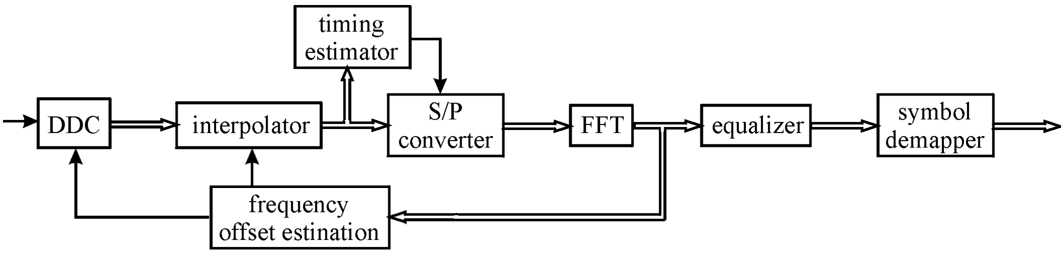

Fig 8: Typical architecture of an OFDM receiver

5. SUMMARY

The architecture of the software configurable automotive receiver for analog and digital audio and video broadcasting services is presented. Characteristics of the analog frontend are documented, and an overview of software architecture for digital signal processing is given. Software structure is modular, and the possibility of software reuse for different standards is discussed. The digital board is equipped with optical MOST interface, which enables the data transfer to a multimedia infrastructure for audio and video data distribution.

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