A high performance multi-channel RF Receiver for Magnet Resonance Imaging Systems

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Introduction:

The rapidly increasing number of detector coils in clinical Magnet Resonance Imaging (MRI) puts high demands on receiver technology [1]. The matrix coils of the Total imaging matrix (Tim) system allow the use of a scalable number of receiver channels as a function of desired acceleration factor for parallel imaging and/or desired signal to noise ratio [2], [3], [4]. Thus, depending on the particular measurement, a high number of receiver channels have to be processed simultaneously. The main goals for the receiver design have been proton and multi nuclear capability (at 1.5T & 3T), parallel acquisition of 8 input channels per receiver module at full performance, an extremely wide dynamic range (DR), lowest electromagnetic interference (EMI) and compactness.

Technical Description:

To minimize physical dimensions and system complexity the 8-channel receiver module is divided into two branches, each having four independent receiver channels. Coming from an input signal selector every MR signal is down-converted in an image reject mixer (IRM) to an intermediate frequency (IF) of about 1.5MHz before it passes the IF amplifier and the IF filter. The IRM suppresses the noise of the particular unwanted image band by more than 40dB independent of the nuclei of interest and RF-frequency respectively. By an interleaving-circuit all four IF paths of a bundle are routed to one ADC unit (Figure 1).

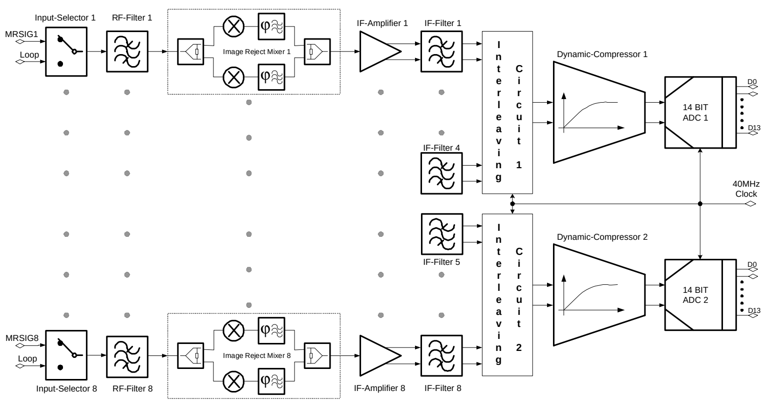

Figure. 1: Receiver module block diagram

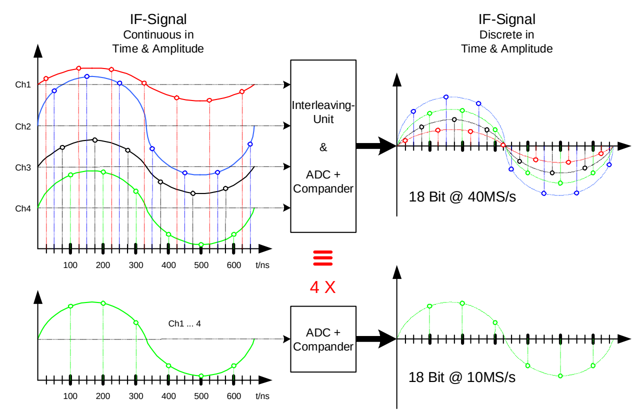

Figure. 2: Assembling of the interleaved data-stream
Equivalence of interleaved & 4 single data-streams

The 14 bit ADC runs on a fixed sample rate (SR) of 40MS/s. As a result, each receiver channel is continuously sampled with the full SR of 10MS/s and a bandwidth (BW) of up to 1MHz regardless of the number of channels in use. The interleaved data-stream contains exactly the same information as the sum of four data-streams generated from four single ADCs would do if running at a SR of 10MS/s (Figure 2). No restrictions in terms of MR signal DR or BW have to be made even though all 8 channels are always processed at one time.

Although the evolution of ADC performance has progressed very fast over the last couple of years, the ADC DR is still the bottleneck in a high performance receiver chain. It will take some more years until available high speed ADCs come with enough bits to meet the DR requirements of a state-of-the-art MRI system. Several techniques to overcome this problem have been published in the literature [5]. The architecture of this receiver is based on a purpose-designed signal-amplitude compressor/expander (compander) technique eliminating the need for automatic gain control within the receiver which would constrain performance and system flexibility. The outstanding high DR of 164dB/Hz at a SR of 10MS/s corresponds to an effective number of bits of 16 (ENOB). As the DR of a physical ADC suffers from the appearance of various noise sources [6], an ADC running at this SR without companding would need about 18 bit of resolution to reach the same performance; a still unrealistic number for available devices.

Since the dynamic compression has to be done in the analog domain the design of such a system is an extremely demanding task. Beside the basic functionality (DR and compression characteristic), reproducibility, voltage offsets, stability over temperature and aging have to be considered. These items are effectively addressed by implemented compensation circuits. A careful balancing of the individual gains inside the chains ensures a self-dithering of the ADC and thus prevents spurious due to noise shaping. The amplitude expansion is done in real-time by mapping the ADC output values to a 18 bit look up table. As part of the final production test, the necessary expansion characteristics are calculated from measurement data for each single device and stored into an on-board memory.

High speed optical fibre links are used for the communication between the receiver boards and the image processing unit to minimize EMI. Power supply filters and shielding chambers have been applied for the same reason. An option to switch the receiver input selector to an external path enables the system to close different signal loops to ensure a proper operation of all components within the loop and to reduce downtimes due to service.

Conclusion and perspective:

A high performance multi channel RF receiver for MRI is described. The key parameters DR and compactness are tackled with two techniques, interleaving and dynamic companding (resulting in 18 bit data words), assumedly unknown in this field so far. No restrictions in terms of MR signal DR (164dB/Hz) or BW (up to 1MHz) have to be made even though all 8 channels are always processed at one time. The trend-setting performance of the receiver was a prerequisite for the implementation of the first Tim system. An upgraded version for 7T MRI Systems passed the prototype status already.

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