Receiver Technology

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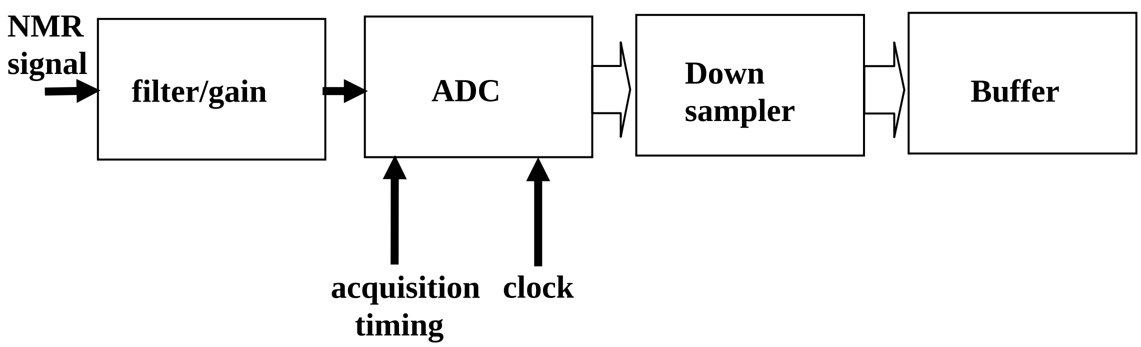
Since the introduction of the NMR phased array (Roemer et al., 1990), and the application of accelerated parallel MRI (Pruessmann et al., 1999, Sodickson and Manning, 1997), it has become increasingly clear that the use of a large number of RF coils for signal reception offers substantial increases in SNR and acceleration rates. The optimal number of coils is dependent on application and field strength and might exceed 100 for whole body applications at high field. Because these coil signals have to be received, amplified and digitized independently, the result is an increased complexity of the MRI receiver. At the same time, with the advent of digital radio in the early 1990's, receiver technology has developed rapidly as well, with increased performance, and reductions in size and cost made possible by improvements in semiconductor technology. Currently, MRI scanners are becoming available with 32 independent channels based on digital receiver technology, and this high number is likely to grow substantially in the near future. In the following we will review some of the issues involved in designing a digital receiver for use with MRI.

Digital Receiver System Overview

The primary role of the receiver in an MRI scanner is to convert the analog coil signals into digital format. The design of a modern digital receiver centers around an analog to digital



converter (ADC), which samples the analog NMR signal and converts it into digital format. Important characteristics of the ADC are its conversion bandwidth and resolution. The conversion bandwidth equals half the digitization rate. State-of-the-art ADCs such as the Analog Devices AD6645 allow conversion bandwidths of over 50 MHz at 14 bit resolution. Since NMR frequencies are generally well above 50 MHz, usually an alias of the NMR signal is detected.

Prior to input into the ADC, the NMR signal needs to be amplified and filtered. Amplification serves to match the voltage range of the NMR signal to the input range of the ADC, in order to engage its full dynamic range. Analog filtering serves to reduce noise and interference signals that alias into the ADC conversion band from outside the target band around the NMR Larmor frequency. In addition, depending on Larmor frequency, down-modulation might be required to bring the signal frequency to within the input band of the ADC. However, with the high input bandwidth of state-of-the art ADC's (~200 MHz for AD6645), direct digitization (without down-modulation) is possible for NMR fieldstrengths of at least 3.0 Tesla (Bodurka et al., 2004).

The choice of ADC digitization rate is to some extent dependent on the master clock of the NMR exciter. To avoid phase errors between excitation and reception, the digitization clock of the ADC needs to be synchronized to the clock of the NMR exciter frequency generator. This can be effectively accomplished by choosing a digitization frequency that is a multiple of the exciter clock. In addition, it is beneficial to avoid digitization frequencies that put the Larmor alias at around 0 Hz. For optimal phase stability of the output signal, a digitization clock is required that has minimal noise and jitter.

After digitization, digital down-sampling is performed to reduce the amount of data. This can be done with dedicated chips such as Graychip GC4016. The output bandwith and center frequency is can be adjusted to match those of the MRI signal bandwidth and (aliased) center frequency. An added advantage of down-sampling is the increase in dynamic range, which amounts to 1 bit for every factor of 4 of down-sampling.

Receiver Design Issues and Specifications

The general issues involving the development of a digital receiver include cost, complexity, scalability, and upgradeability. Scalability is important since the target number of channels is uncertain and is likely to increase in the near future. Furthermore, it is beneficial to develop the receiver around a commercially available digitizer and commonly used bus architecture (e.g. PCI), as it reduces the need for software and hardware redesigns during upgrades.

Important specifications for an NMR receiver include those for dynamic range and (output) bandwidth. The dynamic range has to exceed the maximum SNR of the NMR signal to avoid non-linearities and clipping on one hand, and the introduction of digitization noise on the other. The SNR is dependent on a number of factors including NMR field strength and homogeneity, coil design, and volume of interest. Under most conditions, SNR is below 84 dB, or 14 digital bits, suggesting that an output dynamic range (after down-sampling) of 16 bits is sufficient. The required output bandwidth of the receiver is dependent on the gradient strength during acquisition and the field of view (FOV). For proton MRI at FOV's of 40 cm, 160 kHz of bandwidth is required for each unit (in Gauss/cm) of gradient strength. Today's gradient technology allows for combined (i.e. oblique axis) gradients of up to 10 G/cm, which translates in a bandwidth requirement of 1.6 MHz. This requirement can be readily met with current ADC technology.

Future Developments

The rapidly increasing number of detector coils in human MRI puts high demands on receiver technology. Since digital receivers are developing at a high pace as well, it is expected that they will not form a limiting factor for widespread application of large-scale coil arrays.

References:

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