Compact beamforming in medical ultrasound scanners

This Ph.D. project was carried out at the Center for Fast Ultrasound Imaging, Technical University of Denmark, under the supervision of Prof. Jørgen Arendt Jensen, Assoc. Prof. Jens Sparse and Prof. Erik Bruun. The goal was to investigate methods for efficient beamforming, which make it possible to fit a large number of channels on a single integrated circuit. The use of oversampled analog-to-digital (A/D) converters with the corresponding beamforming was identified as a particularly promising approach, since it provides both inexpensive and compact A/D conversion and allows for much more compact implementation of the beamformer compared to the case where conventional A/D conversion is used. The compact and economic beamforming is a key aspect in the progress of medical ultrasound imaging. Currently, 64 or 128 channels are widely used in scanners, top-of-the-range scanners have 256 channels, and even more channels are necessary for 3-dimensional (3D) diagnostic imaging. On the other hand, there is a demand for inexpensive portable devices for use outside hospitals, in field conditions, where power consumption and compactness are important factors.

The thesis starts with an introduction into medical ultrasound, its basic principles, system evolution and its place among medical imaging techniques. Then, ultrasound acoustics is introduced, as a necessary base for understanding the concepts of acoustic focusing and beamforming, which follow. The necessary focusing information for high-quality imaging is large, and compressing it leads to better compactness of the beamformers. The existing methods for compressing and recursive generation of focusing data, along with original work in the area, are presented in Chapter 4. The principles and the performance limitations of the oversampled delta-sigma converters are given in Chapter 5, followed by an overview of the present architectures of oversampled beamformers. Then, a new architecture is introduced, which has the potential of achieving the highest image quality that an oversampling beamformer can provide. That architecture has been implemented using VHDL, and estimates for its performance have been obtained. The results indicate that a 32-channel beamformer reaches the target operation frequency of 140 MHz, thereby providing diagnostic image with dynamic range of 60 dB for an excitation central frequency of 3 MHz. That image quality is comparable to that of the very good scanners currently on the market. The performance results have been achieved with the use of a simple oversampled converter of second order. The use of a higher order oversampled converter will allow higher pulse frequency to be used while the high dynamic range in the end image is preserved. The logic resource utilization of a Xilinx FPGA device XCV2000E-7 is less than 45 % when a 32-channel beamformer is implemented. The maximum number of channels that can fit in that FPGA device is 57, due to the fact that too many of the available gates take part in the routing when the channel number is increased.