COMPAS-XL - Outstanding Number of Channels with a New Phased Array System

Gottfried SCHENK, Uwe VÖLZ , Elmar DOHSE, BAM, Berlin, Germany
Lukas BAUER, MAZ Brandenburg, Werder, Germany

Abstract. This paper presents a novel phased array system based on a modular architecture. An outstanding number of total 1024 channels can be achieved by expanding a master modul (64 channels) with up to 15 slave modules (64 channels each). A modul-unit consists of a motherboard, equipped with digital and interface stages, and transmitter and receiver boards. An on-board PCI-104 processor-board provides data processing. The interface and beam-forming stages are implemented by the means of a cost-friendly programmable technique (FPGA).

Introduction

For several years a remarkable number of phased array systems have become available in the field of NDT. Specifications comprise high channel-numbers and small instrument extensions along with an increased system bandwidth and sample rates of 100 MSPS and more. An evolution, which started in the early 1980s with bulky analogue instruments, and was primarily induced by the exceptional progress in microelectronics. Figure 1 shows the main components of a phased array system.

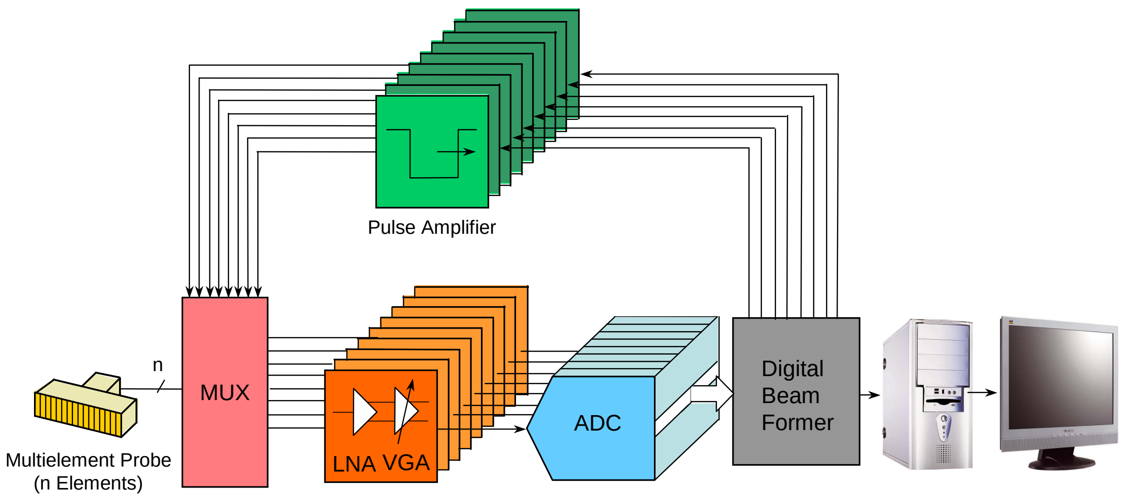

Figure 1. Components of a phased array system

Since Gordon Moore predicted the annual doubling of transistors integrated on a chip in 1965, well-known as "Moore's Law" [1], chip-structures have become so small, that it is even feasible to implement most of the electronic components of a phased array system into a single chip. Therefore concepts to transfer a relevant number of stages into the probe are already on the way in medicine diagnostics and are due to reduce interconnects to the control instrument [2].

Unlike medicine diagnostics, designers of NDT-instruments dispose of smaller budgets. Therefore highly-sophisticated solutions are often not practicable, as single chip implementations, front-end electronics integration into the probe and the application of sigma-delta technique are based on cost-intensive ASIC-designs (application specific integrated circuits) [3]. This paper describes a novel phased array ultrasonic system, which utilizes the technique of field programmable gate arrays (FPGA). These devices combine the benefits of ASIC-technique: high integration and software-based design methods, with the feasibility of re-programmability and system-reconfiguration at much lower costs [4],[5].

Primary object of the development is the availability of an inspection system that covers most of the relevant applications in automated ultrasonic testing. This means, the instrument has to be adaptable to applications with low channel requirements (small linear arrays) as well as 2-dimensional soundfield control, with the demand of channel numbers of 500 or more (matrix arrays). This implies a modular structure with single units, which may be interconnected to a system of several hundred channels.

System Architecture

1.1 Modular Hardware Concept

The basic conceptual idea is to assemble a variable system from identical units. Therefore the COMPAS–XL consists of independent modules with on-board transmitter stages, receiver stages und and beam-forming stages. A proprietary bus system, the interbus, may tie 16 of these module units together. Digital stages, IO-stages and power supply components are assembled on the main-board, while transmitter stages, receiver stages and a clock unit are located on separated boards, mounted as mezzanines to the main-board. The overall-size of such a module unit is 233,4 mm length, 280 mm width and 50 mm height (standard 6U height, figure 2).

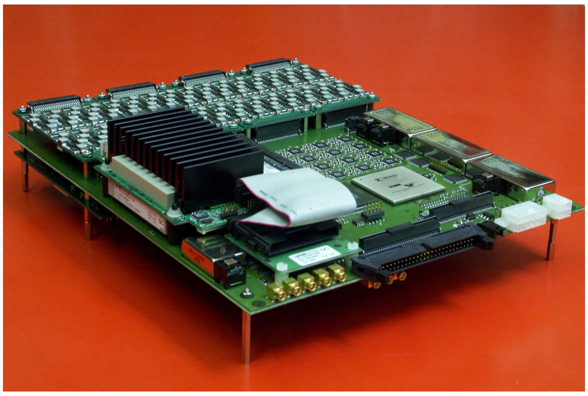

Figure 2. COMPAS-XL module unit

The complete system consists of a master module and 15 slave modules. The master module is distinguished from the slave modules only by being assembled with a PCI-processor board. This internal processor basically serves as an interface stage, but it may also be used for system control if a stand alone system is required. In this case mass storage is performed by the means of an on-board flash card. Figure 3 shows a system consisting of 16 modules with 1024 channels altogether.

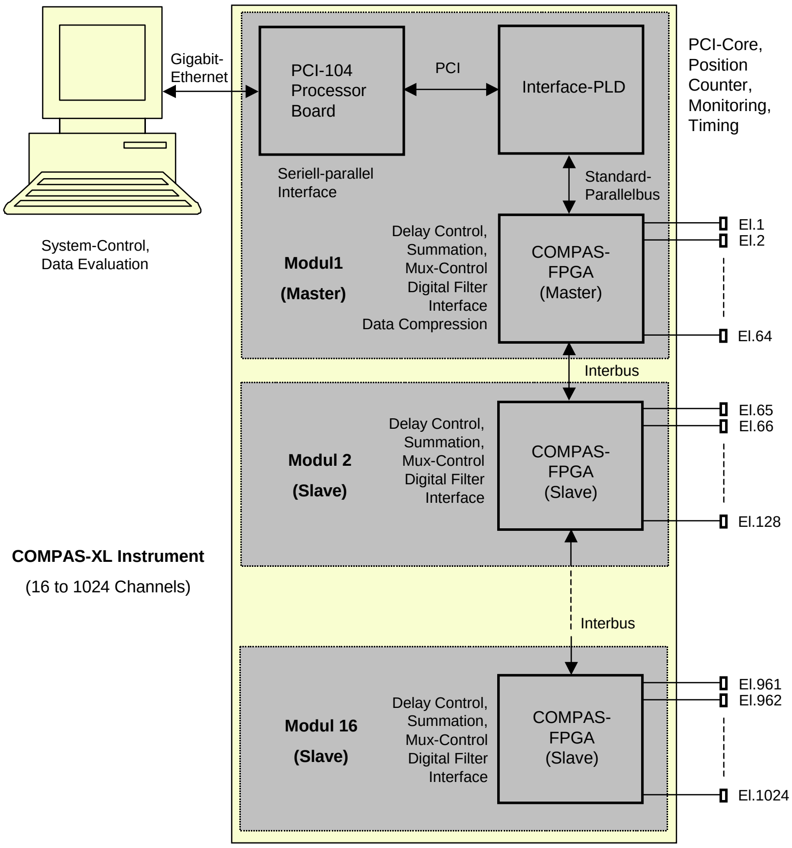

Figure 3. Architecture of the COMPAS-XL

1.2 Main Board Unit

A highly assembled main board unit is the backbone of the COMPAS-XL instrument. It contains the digital stages and serves as a carrier for the mezzanine boards.

A very advanced FPGA-device is the heart of this main board unit. It contains all digital functions, such as interfacing, delay control, multiplexer control, data compression and an IIR-filter unit. The chip is in-circuit reprogrammable, so that system redesign may be performed easily by implementing a modified program code. The remarkable amount of 957 connection pins serve as a gate to the environmental circuitry, for which ball grid array technique (BGA) is employed. System complexity and EMI-aspects lead to the necessity of a multilayer board with 16 layers.

1.3 Transmitter

COMPAS-XL transmitter modules dispose of 16 channels each. 4 Modules may be mounted on a main board. The specifications are:

- Pulser type: negative rectangular
- Pulser width: 20 ns to 2500 ns
- Amplitude: 0 to 250 V
- Delay extension: 0 to 20 µs
- Delay increment: 1 ns

1.4 Receiver

Analogue amplification with programmable gain is used to adapt the level of the echo-signals of an element to the input of the ADC. Therefore COMPAS-XL receiver module disposes of voltage controlled gain amplifier stages (VGA) with an ultralow noise preamplifier for accurate gain adjustment. The control voltage is set by a cascade of digital-to-analogue converters (DAC). COMPAS-XL receiver modules dispose of 64 input channels, which are multiplexed to 16 amplifier channels. The specifications are:

- Amplifier type: linear
- Bandwidth: 0,4 MHz to 20 MHz (-3dB)
- Gain range: 70 dB
- Accuracy: < 1 dB
- Mux: 4 : 1
- Time-gain-control: 35 dB and 1000 increments

1.5 Digitizer

As in all digital ultrasonic equipment analogue-to-digital converters (ADC) serve as a bridge from the analogue to the digital world. The analogue echo signals received from each sensor element have to be translated into the digital code. The module-units of the COMPAS-XL system dispose of independent ADC-stages for each channel. The specifications are:

- ADC-type: Sampling
- Sampling rate: 100 MSPS
- Quantisation: 12 bit
- Input range: 2 V_{pp}

1.6 Digital Beamformer

In receiver mode, the reflected pulses from a particular indication have to be aligned in time for each channel after analogue-to-digital conversion [6]. An advanced digital delay technique, which covers a range from 1 ns increments up to an overall delay of 20 µs, is applied in the FPGA. Internal signal-delay compensation provides perfect channel-to-channel matching. Thus programmable soundfield control, such as the variation of the angle of incidence or the adjustment of the focal point, may be performed for transducer frequencies up to 20 MHz.

The ensuing digital summation stage forms a data word of total 18 bits. Digital offset control provides correct signal levels. The specifications are:

- Digital delay extension: 0 to 20 µs
- Delay increments: 1 ns
- Offset control: 6 bit
- Summation data word: 18 bit
- Overload indication: triggered from each receiver channel
- Data format: RF-mode or full-wave-rectification
- Data compression: pixel
- Hardware gates: 4

1.7 Software

As phased array technology is utilized at BAM since the early eighties, a comprehensive bundle of programs for various functions and applications is available for the COMPAS-XL. It implies software routines for loading the unit with control parameters and for data processing, programs for data evaluation and numerical data reconstruction, and special software tools for testing and monitoring the system during operation. Beyond such application, specific software was implemented in a number of industrial applications in which BAM phased array technology came to use.

- Operating system: Win XP
- General control software: UTcontrol
- General evaluation software: UTview
- Soundfield simulation: Array Calculus
- Probe design: UTprobe
- System test: UTcheck
- Image reconstruction: A-scan, B-scan, TD-scan, C-scan, Echotomography, TOFD, SAFT

Applications

The COMPAS-XL is suitable for all possible tasks in ultrasonic testing. It may be applied tas a multichannel conventional technique as well as for high-definition applications such as 3-D soundfield control. On account of its modular structure and its feasibility for very high channel numbers it is predestined for innovative solutions. Such as the automated inspection of drilled railway axles with a rotation scanner probe system (figure 4), by which the mechanical rotation of several conventional probes should be replaced by rapid electronical scanning and for which the COMPAS-XL is foreseen as control instrument [7]. Other possible applications are [8]:

- Railway wheel-set inspection
- Turbine inspection
- Inspection of nuclear power plant components
- Weld inspection
- In-line inspection of rods and pipes

- Inspection of aircraft components
- Fast rail inspection
- Inspection of girth welds on pipeline lay barges

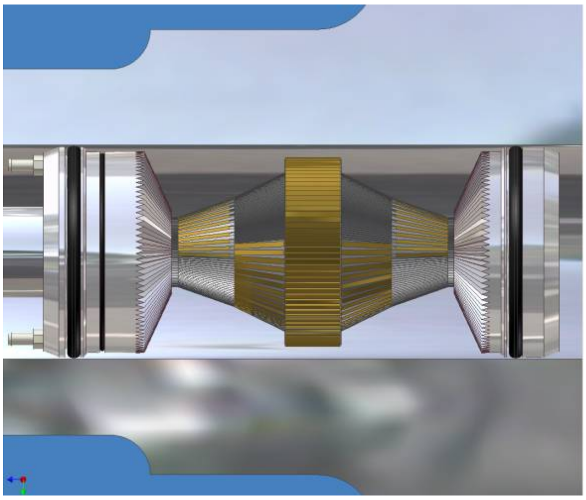

Figure 4: Rotation scanner for the examination of drilled railway axles

Conclusion

This paper presents a novel phased array instrument with the capability of controlling linear or 2-D arrays with channel numbers up to 1024. Its modular architecture makes it ideal for various applications, including manual inspection and automated inspection in industrial environments. In contrast to recently presented concepts, such as sampled phased array technique, the COMPAS-XL is based on a full channel delay technology, which allows time-critical applications required for rail inspection and the in-line inspection of industrial products (e.g. pipes and rods) in real-time.

In a long tradition of instrument design at BAM the COMPAS-XL represents the fourth generation of ultrasonic phased array system developments. As a contribution to the increasing world-wide tendency in NDT toward a broad use of this powerful technique - with its obvious opportunities: increased detection reliability, increased defect sizing, decreased inspection time, decreased number of probes and improved flexibility [8].

References

[1] Vollmer, A.: „Alles Gute zum Geburtstag! Der Transistor wird 50 Jahre alt," Elektronik 26, 1997.

[2] Geib, H.: „Weniger Risiken und Nebenwirkungen. Cintinous-Time-Delta-Sigma-Wandler in der Medizintechnik," Design & Elektronik 03, 1997.

[3] Vermesan, O., et al.: High temperature phased array ultrasonic system with integrated front end electronics," IEEE Ultrasonic Symposium, ISBN: 0-7803-9382-1, Rotterdam (2005).

[4] „ASICs auf breiter Front angreifen," Markt&Technik Nr.39, 2004.

[5] Weik, U.: „FPGAs in Theorie und Praxis," Elektronik 6, 2006.

[6] Brunner, E.: Ultrasound System Considerations and their Impact on Front-End Components," Analog Devices, Inc., 2002.

[7] Boehm, R., Spruch, W.: „Phased array rotation scanner probe system for ultrasonic testing of sleeve shafts," ECNDT Berlin 2006, CD-ROM.

[8] Wüstenberg, H., Schenk, G.: Entwicklung und Trends bei der Anwendung von steuerbaren Schallfeldern in der ZfP mit Ultraschall," DGZfP-Jahrestagung Mainz 2003, CD-ROM.