THE INTERFACE ELECTRONICS FOR AN ULTRASONIC MATRIX TRANSDUCER FOR 3D TRANSESOPHAGEAL ECHOCARDIOGRAPHY

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In this paper, the design considerations of a mixed-signal integrated circuit for a 2D matrix ultrasonic transducer will be presented. The IC and the matrix transducer will be put into the tip of a transesophageal (TEE) probe for 3D echocardiography. The challenges associated with the interface electronics include: addressing the huge amount of elements, do the beam steering in the transmission mode and beam forming in the reception mode; keep the power consumption as low as possible; fit the electronics into a limited space, etc. The block diagram and the design constraints of the IC will be discussed. A layout scheme for the IC and the matrix transducer will also be described.

Keywords: matrix ultrasonic transducer, Interface electronics, echocardiography.

1. INTRODUCTION

As compared to conventional Ultrasound-Imaging Techniques [1] the sophisticated 3D imaging technique can produce a more authentic image of the heart. The 3D echocardiography requires the acquisition of a volumetric data set, where each image (sectional plane) is defined with respect to its exact position in space [2]. The development of a 2D matrix ultrasonic transducer provides the ability to generate beams of ultrasound that can be steered in two perpendicular directions, which can cover a pyramidal volume for imaging.

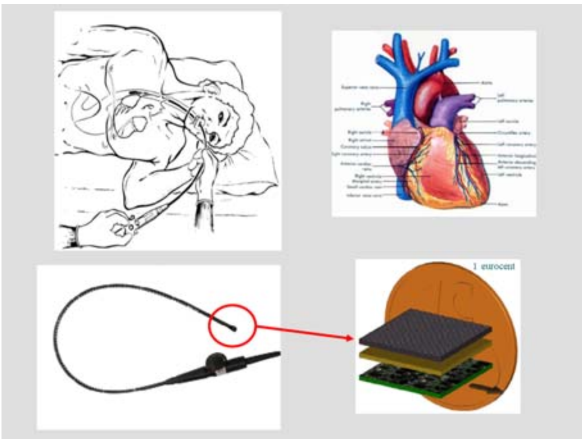

Fig. 1 TEE probe for 3D echocardiography

In our research project, we are designing a mixed-signal integrated circuit (IC) for a 2D matrix ultrasonic transducer with about 2500 elements. The IC and the matrix transducer will be put into the tip of a transesophageal (TEE) probe for 3D echocardiography, see Fig.1. The challenges associated with the interface electronics are presented in section 2. The block diagram and the design considerations of the IC are discussed in section 3. In section 4, a layout scheme for the IC and the matrix transducer is described. The article ends with a conclusion.

2. CHALLENGES

The ultrasonic transducer is made from piezo-electric material [1], which shows capacitive behavior. When we would directly connect the array elements, using coaxial cables, with an external mainframe, the capacitance associated with the cabling would seriously degrade the performance. Besides, the number of cables would be so large that the bundle will become too stiff to be swallowed by patients. Therefore, it is necessary to put electronics close to the transducer. Using smart signal processing, the amount of connecting cables can be reduced. Connections of the IC with the transducers are made using flip-chip technology or other advanced interconnection techniques [3]. Possible side effects of the connection scheme, such as: crosstalk between elements, influence to the acoustic properties, etc., still should be carefully investigated.

Though it is better to include as much as possible of the electronics into the tip of the TEE probe, there exists a limit, which is the space of the probe tip (less than $2cm^3$). So, compact circuit design and efficient use of the small space offer other challenges for this research project. The number of channels is huge (>2000). Therefore, the power consumption of all the front-end electronics is a very critical specification. According to [4], the temperature of the TEE probe tip should be kept below 40ºC. As a result, low-power IC design is highly demanded.

3. SYSTEM DESCRIPTION

Figure 2 shows the block diagram of the ultrasound system, which mainly consist of a 2D matrix transducer, a control block, a transmitter and a receiver. The latter two are separated by a T/R switch. The control block coordinates the transmission and reception events in the pulse-echo system. It is connected to the external user interface, which can be programmed. Its functions include: addressing the transducer elements both in transmission and reception modes, generating the delay pattern that sets the desired transmit focal point, set the coding for transmission pulses if necessary, etc. The control block is a digital system, which should be realized by digital circuits.

To make sufficient acoustical power, the ultrasonic transducers require a high voltage pulser (~100V) [5]. A high-voltage (HV) IC process is required to implement the pulser. Usually, the high-voltage transistors are very large, and demand large current to charge their capacitive gates. Therefore, a driving circuit is necessary to provide sufficient driving capability for these HV transistors.

The T/R switch block contains a protection circuit, which blocks the high voltage pulse from the transmitter side to the receiver side and prevents the low voltage receiver from being damaged. Meanwhile, during reception, the ultrasonic transducer works as a source with high source impedance. In order to have maximum power transfer, a matching network between the transducer and the receiver is required.

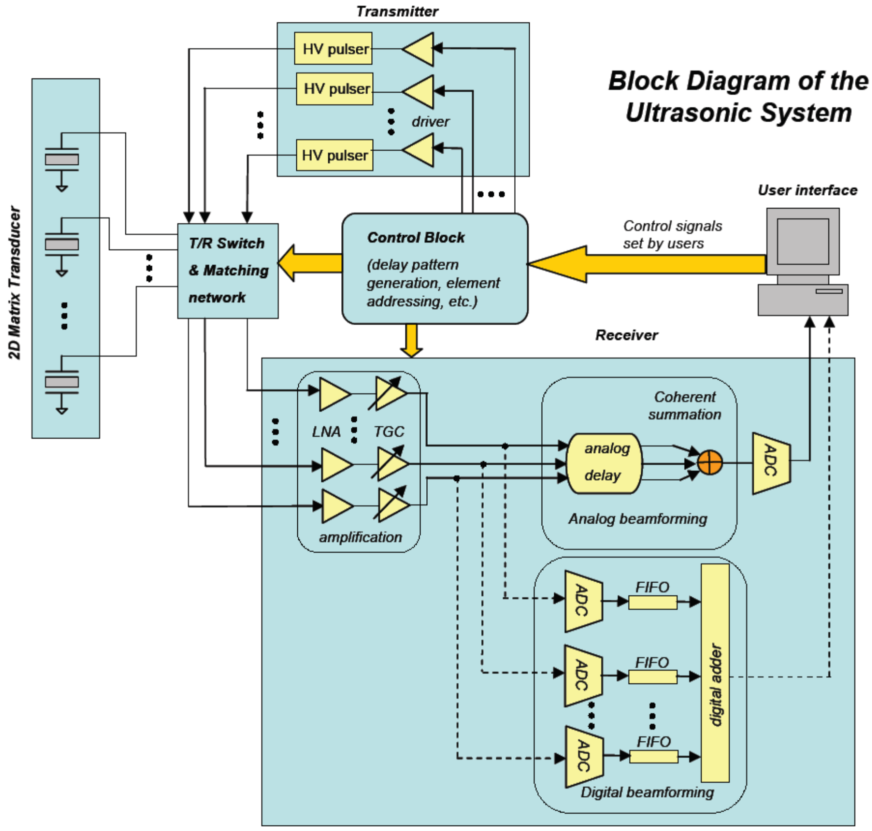

Fig.2 Block diagram of the ultrasound system

Followed by the T/R switch is the receiver circuitry, which mainly consists of a low-noise amplifier (LNA), a time-gain-compensated (TGC) amplifier and a beam-former. The dynamic range of the LNA should be large enough to interface the echo signal from several micro-volts (from deep tissue) to several hundred milli-volts (from near field tissue).

The echo from the deep tissue is attenuated more than the echo from the near field tissue, and also the return time is longer. In order to maintain the image uniformity, a TGC amplifier should be used to provide the echo signals with increased gain along with time. After amplification, beam-forming is performed, which can be implemented in either the analog domain (solid line in Fig.2) or the digital domain (dashed line in Fig.2).

For a proper choice, between analog beam-forming (ABF) and digital beam-forming (DBF), the following differences have been considered: The channel-to-channel matching of analog delay lines tends to be poor. Moreover, the number of delay steps is limited by the number of taps at the delay line. The digital delay lines offer the advantage to be more precise and to be flexible for programming and reprogramming. However, the DBF requires more electronics than ABF. Therefore, for a transducer matrix with more than 2000 channels, if DBF is applied to all channels, the system complexity and power consumption will be very high. In the present design, before making the final choice, many trade-offs need to be balanced.

4. LAYOUT SCHEME

A layout scheme for the IC and 2D transducer is shown in Fig.3. For each transducer element, a HV pulser, a T/R switch, a matching network and a LNA will be attached. The total chip area should be controlled within $2cm^2$. Other electronics (e.g. control block and receiver beam-forming circuitry) can be placed at the extended region, see Fig.3.

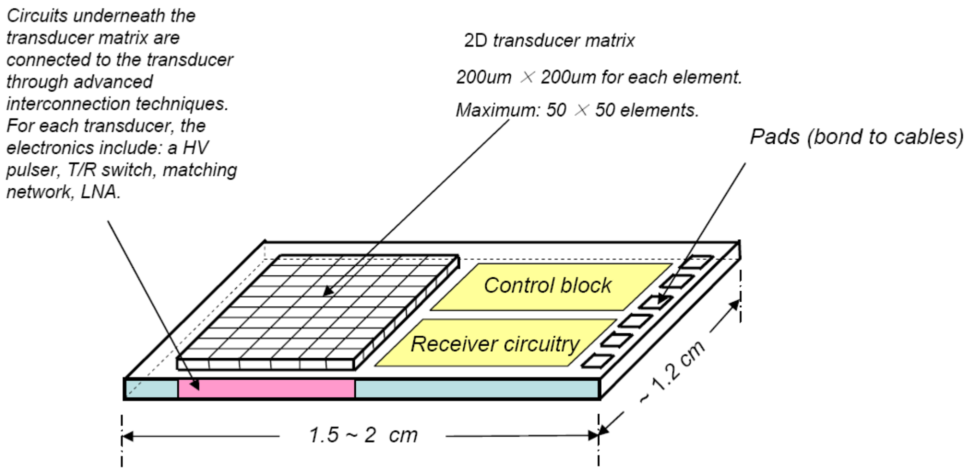

Fig. 3 Layout scheme of the front-end integrated circuit and the 2D matrix transducer

5. CONCLUSION

In this article, the design challenges of a mixed-signal integrated circuit for a 2D matrix ultrasonic transducer are presented. The block diagram of the ultrasound system is given together with the descriptions and design considerations for each function block. A layout scheme for the IC and the 2D matrix transducer is also introduced. The final design will be applied in a transesophageal (TEE) probe for 3D echocardiography.

6. REFERENCES

[1] Richard S.C.Cobbold, "Foundations of Biomedical Ultrasound", *OXFORD University Press*, 2007.

[2] Th.Binder, "Three-Dimensional Echocardiography-Principles and Promises", *Journal of Clinical and Basis Cardiology*, 2002; 5 (Issue 2), pp.149-152.

[3] R.Tummala, "SOP:What is it and why?", *IEEE Trans. Advanced Packaging*, vol.27, pp.241-249, 2004.

[4] Thomas Koshy, Arun Vijayakumar, Prabhat Kumar Sinha, "Unrecognized Descending Thoracic Aortic Compression by Transesophageal Echocardiographic Probe in an Infant Undergoing Cardiac Surgery", *Journal of Cardiothoracic and Vascular Anesthesia*, Volume 21, Issue 5, Pages 724-726.

[5] J.V.Hatfield, N.R.Scales, A.D.Armitage, P.J.Hicks, Q.X.Chen and P.A.Payne, "An Integrated multi-element array transducer for ultrasound imaging", *Sensors and Actuators A*, 41-42, 1994, pp.167-173.