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# A Novel Design of Low Energy Oscillator Based Ultrasound Sensor Edge for Intravascular Applications with CMUT Technology

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**Abstract:** Aim-Capacitive micro-machined ultrasonic transducer (CMUT) is a transducer where the energy transduction is due to change in capacitance. This paper proposed an oscillator based ultrasonic sensors can be mainly used to intravascular applications and other medical field applications such as liver, stomach, liver, heart, tendons, muscles and joints. The readout circuits are validated with a capacitive micro machined ultrasonic transducer and a current-to-frequency chip. The CMOS CMUTs are integrated with a current amplifier circuit on the same chip and the current-to-frequency chip provides the current-to frequency readout interface. Ultrasound waves does not use any ionizing radiation, has no known harmful effects and provides a clear images of soft tissues that don’t show up well on x-ray images, thus there is no radiation exposure to the patient. The ultrasound is usually between 2 and 18MHz and also higher frequencies provide better and clear quality images. The ultrasound images are captured in real-time; they can show the structure and movement of the body's internal organs, as well as blood flowing through blood vessels. The current amplifier is utilized and integrated with the CMUT cells to minimize the parasitic capacitance. Relaxation oscillators with injection locking are employed to attain low-power consumption. Also, the instance-based output signal can be further digitized with a time-to digital converter. Both chips are fabricated in an 180nm CMOS MEMS process technology. The CMUTs are designed with 1MHz to 4MHz cells for intravascular diagnosis applications.

**Key words:** CMUT · Currentamplifier · Relaxationoscillator · MEMS

## INTRODUCTION

An ultrasonic transducer is a device that converts the alternate current into ultrasound, as well as the reverse, sound into alternate current. The capacitive micro-machined devices are fabricated by using silicon micro-machining technology (MEMS technology), which is particularly useful for the fabrication of transducer arrays. The oscillator based ultrasonic sensor interface that can be applied to intravascular applications. While compared to the piezoelectric transducer, CMUT has several major advantages such as a wider temperature range, better mechanical impedance matching and the possibility of system integrations for miniature medical electronic devices. Intravascular ultrasound (IVUS) is a medical imaging methodology using a specially designed catheter with a miniaturized ultrasound probe attached to the distal end of the catheter. Thus the proximal end of the catheter is attached to computerized ultrasound equipment. It allows the application of ultrasound technology, such as piezoelectric transducer or CMUT, to observe from the inside of the blood vessels out through the surrounding blood column, visualizing the inner wall of blood vessels in living individuals. The arteries of the heart (the coronary arteries) are the most frequent imaging target for Intravascular Ultrasound. IVUS is mostly used in the coronary arteries to determine the amount of athermanous plaque built up at any particular point in the pericardial coronary artery. The progressive accumulation of plaque within the artery wall over decades is the setup for plaque which, in turn, leads to heart attack and stenos is (narrowing) of the artery (known as coronary artery lesions). IVUS is used to determine the both plaque volumes within the wall of the artery and the degree of stenos is of the artery lumen. It can be especially useful for situations in which angiographic imaging is considered unreliable[1].

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In medical applications, a catheter is a thin tube made from medical grade materials serving a broad range of functions. Catheters are medical devices that can be inserted to the body for treat diseases or perform a surgical procedure. By modifying the material or adjusting the way catheters are manufactured, it is possible to tailor catheters for intravascular, cardiovascular, urological, neurovascular and ophthalmic applications. Catheters can be inserted into a body cavity, duct, or blood vessel. Functionally, they permit drainage, administration of fluids or gases, approach by surgical instruments and also perform a wide variety of other tasks depending on the type of catheter. The process of inserting a catheter is called as catheterization. In mainly uses, catheter is a thin, flexible tube ("soft" catheter) though catheters are available in varying levels of stiffness depending on the applications. A catheter is left inside the some part of the body; either temporarily or permanently, may be referred to as an indwelling catheter (for example, a peripherally inserted central catheter). A permanently inserted catheter may be referred to as a permcath (originally a trademark) [2].

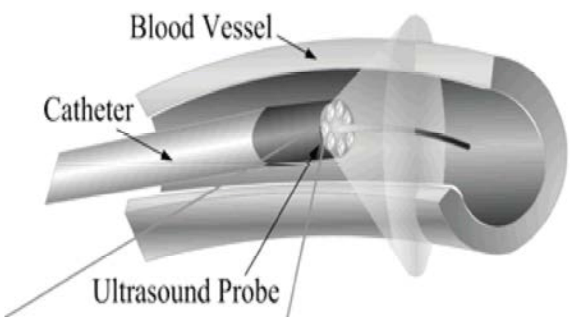


Fig. 1: Oscillator based ultrasonic sensor interface for intravascular applications

Ultrasound imaging is based on the same principles involved in the sonar used by bats when a sound wave strikes an object; it bounces back, or echoes. By measuring these echo waves, it is possible to determine how far away from the object is as well as the object's size, shape and consistency. In medicine, ultrasound is used to detect the changes in appearance, size or shape of organs, tissues and vessels or to detect abnormal masses, such as tumors. In an ultrasound examination, a transducer both sends the sound waves and receives the echoing waves. When the transducer is pressed against the skin, it directs the small pulses of inaudible, high-frequency sound waves into the body. While the sound waves bounce off internal organs, fluids and tissues, the sensitive microphone in the transducer records tiny modify in the sound's pitch and direction. These signature waves are immediately measured and displayed by a computer, which in turn generates a real-time picture on the monitor. One or more frames of the moving pictures are naturally captured as still images and short video loops of the images may also be saved [3].

Doppler ultrasound is a special application of ultrasound that measures the direction and speed of blood cells as they move through vessels. The movements of blood cells causes a change in pitch of the reflected sound waves are called the Doppler Effect. A computer can collects and processes the sounds and creates graphs or color pictures that represent the flow of blood through the blood vessels. The ultrasound reflections establish the images of the blood vessel. Typically, three modes are available in the ultrasonic diagnosis systems; there are A-mode, B-mode and M-mode. A-mode is the amplitude of the reflected wave, which represents the amount of the reflected ultrasound waves. B-mode shows a multiple combinations of the intensity in the A-mode, which displays the acoustic impedance of a two-dimensional cross-section of the vessels. And, M-mode illustrates the A-mode images varying with time on the horizontal axis. B-mode is clinically the most important diagnostic tool, because the B-mode requires converting the analog ultrasonic signals into their digital forms for further digital signal processing [1].

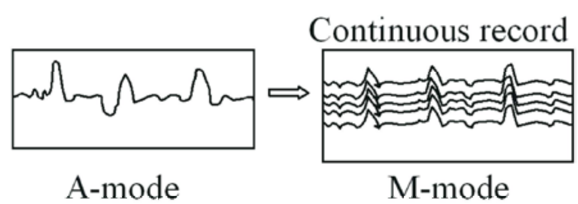


Fig. 2: The images of A-mode and M-mode

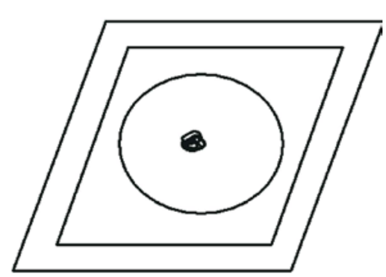

Fig. 3: Image of B-mode

**Cmut Structure:**

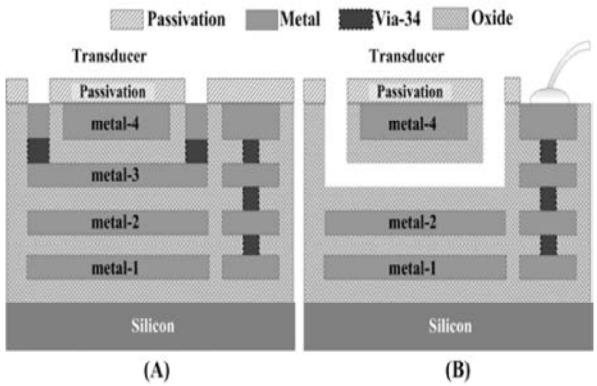


Fig. 4: The cross section view of the CMUT structure, (A) Before post Processing (B) after post processing

The detailed cross section plots of the CMUT structure is shown in Figure 4. In this work, the membrane is created with the metal-4 and metal-2 layers, which function as the upper and bottom electrodes. Moreover, the metal-3 forms the sacrifice layer to constitute the suspended structure. The passivation layer would be enclosed on the top of the die except for the openings for the etchant holes. The etchant holes are collected of the metal-4, via-34 and metal-3. The air gap will be formed after metal-3 was removed [4].

**The Proposed Readout Circuit**

**System Architecture:** The overview of the proposed system is increasing the bandwidth for creating the clear image of blood vessel. The CMOS CMUTs are included with a current amplifier on the same chip and the current-to-frequency chip presents the current-to frequency readout interface. Relaxation oscillators with injection locking are employed to realize the low-power consumption. Also, the time-based output signal can be auxiliary digitized with a time-to digital converter. Both the chips are fabricated in an 180nm CMOS MEMS process technology. The represented block diagram of system architecture is shown in Figure 5[5].

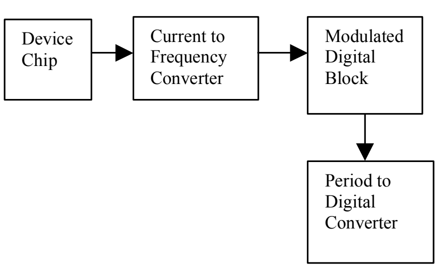


Fig. 5: Block diagram of system architecture

**MEMS PROCESS:** Micro-Electro-Mechanical Systems or MEMS, is a technology that is most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of micro fabrication. The stable physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several millimetres. The types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics [6].

The one main condition of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. The term used to describe MEMS varies in different parts of the world. In the United States they are predominantly called MEMS, while the some other division of the world they are called “Microsystems Technology” or “micro machined devices”. While the functional elements of MEMS are miniaturized structures, sensors, actuators and microelectronics, the most notable (perhaps most interesting) elements are the micro sensors and micro actuators. Micro sensors and micro actuators are appropriately categorized as “transducers”, which are defined as devices that convert the energy from one form to another. In the case of micro sensors, the device usually converts a measured mechanical signal into an electrical signal. The fabrication of MEMS develop from the process technology in semiconductor device fabrication, i.e. the basic techniques are deposition of material layers, patterning by photolithography and etching to produce the required shapes[7].

**Current Amplifier:** Since the sensed biomedical signals are naturally with miniature magnitudes and the operation environment is potentially noisy. If the sensing elements are connected to the amplifier using wire bonding, the parasitic capacitances from the bond pads and the bonding wires boost the total input capacitance, which degrades the noise performance significantly [5]. The current amplifier is exploiting and integrated with the CMUT cells to minimize the parasitic capacitance and enhance the sensitivity of the overall ultrasonic system. In this work, the initial capacitance of the CMUT cells is 270 fF. The induced current with the pressure from 0.10 MPa to 0.50 MPa ranges from 3 μA to 11 μA. The induced current will then be amplified by the current amplifier to improve the sensitivity of the readout circuit.

It adopted a simple architecture for the current amplifier to lower the flicker noise from the transistors [6]. The architecture of current amplifier is shown in Figure 4. $M_1$ and $M_2$ provided an equivalent resistance $r_0$ to convert $I_{CMUT}$ to influence the gate voltage of $M_4$. Accordingly, this gate voltage of $M_4$ will be further amplified by the common-source amplifier. The output current $I_{inj}$ of the current amplifier can be expressed in (1).

$$I_{inj} = I_{CMUT} \times (r_{01} // r_{02}) \times \frac{g_{m4} r_{02}}{1+g_{m4} R} \times R_{out} \quad (1)$$

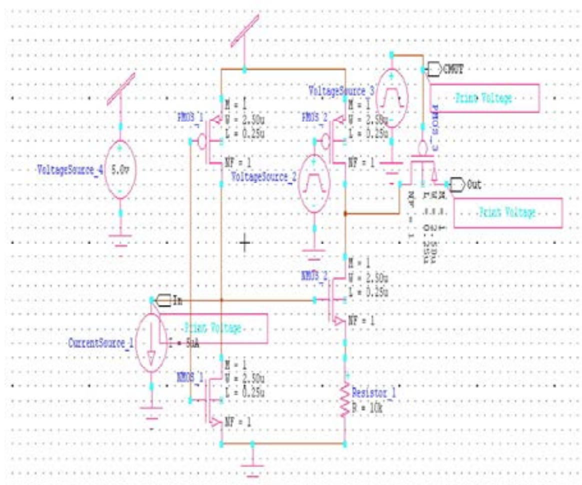

Fig. 6: The circuit diagram of current amplifier

In this work, the current amplifier provides a gain of 52dB to satisfy the overall system requirements. The induced current from CMUTs after the current amplifier, $I_{inj}$, will be in the range of 90.1 µA to 100.43 µA [8].

**Relaxation Oscillator:** The relaxation oscillator is further classified into two types. There are

- Sensing relaxation oscillator
- Reference relaxation oscillator

Relaxation oscillators are generally used to create a low frequency signals for such applications as blinking lights and electronic beepers and clock signals in some digital circuits. The term relaxation oscillator is also applied to dynamical systems in many diverse areas of science that produce a nonlinear oscillations that produces a non sinusoidal repetitive output signal and can be analyzed using the same mathematical model as electronic relaxation oscillators. Relaxation oscillations are described by two alternating processes on different time scales; a long relaxation period during which the system structure approaches an equilibrium point, alternating with a short impulsive period in which the equilibrium point shifts. The period of a relaxation oscillator is mostly determined by the relaxation time constant. Relaxation oscillations are a type of limit cycle and are deliberate in nonlinear control theory [9].

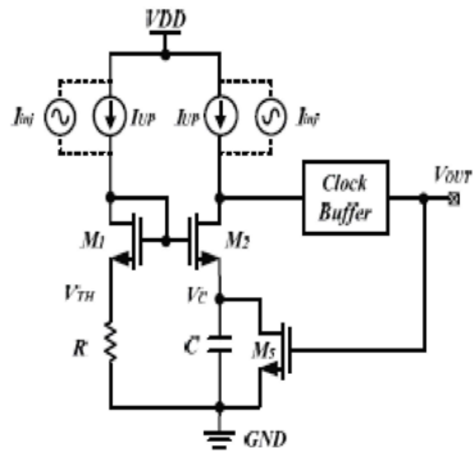


Fig. 7: Circuit diagram of current-mode relaxation oscillator.

The oscillation frequency of a relaxation oscillator can be expressed in (2).

$$F = \frac{I_{UP}}{V_{TH} \cdot C} = \frac{1}{R.C+\tau} \quad (2)$$

Where τ is the delay introduced by the clock buffer and the switches. $V_{TH}$ is the reference voltage and $I_{UP}$ is the dc charging current.

**Measurement Result:** We inflict a waterproof package for CMUT chip and measured in the underwater environment. JSR DPR300 ultrasonic pulser is used as the ultrasound emission source and measured by a 2.25MHz probe. The output waveform shows the measurement results that the ultrasonic signal increases the output frequency and generates the modulation pulse width. Figure 8. Shows the output signal of the current amplifier. The ultrasonic current received from the CMUTs is around 3 µA to 11 µA. After the current amplifier, the injection ac current is about 90.1 µA to 100.43 µA. Figure 9. Shows that the simulation output waveform of the relaxation oscillator. Thus the relaxation oscillator consumes the power is 1.452mW to 5.823mW at the input supply current is 5µA to the current amplifier circuit. The delay factor is obtained in 1.89993e-010 at the relaxation oscillator circuit [10,11].

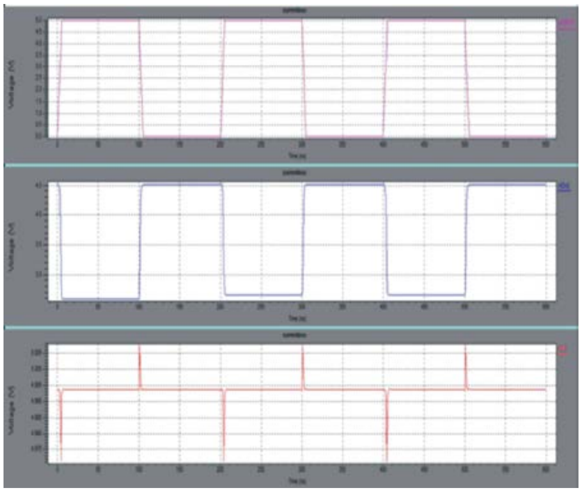

Fig. 8: Output waveform of current amplifier

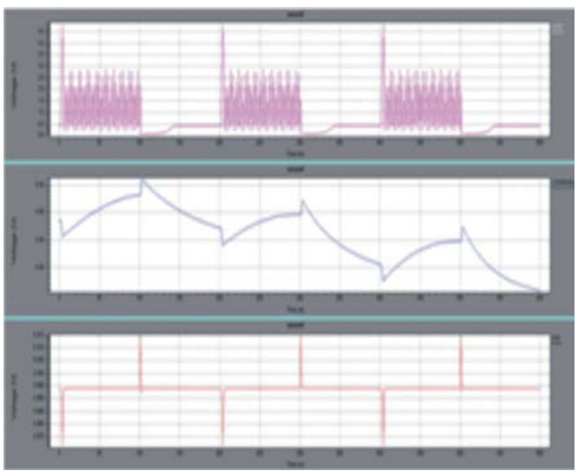

Fig. 9: Output waveform for relaxation oscillator

## CONCLUSION

In this paper a low-power oscillator-based ultrasonic sensor interface for intravascular medical applications is obtained. The proposed system incorporates the CMUTs with the current amplifier and the current-to frequency converter on two chips. Both of them were fabricated in TSMC 180nm CMOS process. The low-power design of battery-powered devices such as portable medical equipment is an essential objective to reduce the system cost as an increased energy demand has to be covered by a higher battery capacity. In future work we can use Frequency Divider (FD) and multiplexer to reduce the power consumption. The Frequency Divider component produces an output that is the clock input divided by the specified value. They can be used for improving the presentations of electronic counter measures equipment, communications systems and laboratory instruments.

## REFERENCES


1. Cheng, T.C., C.W. Hsu, H.C. Wang, B. Parviz and T.H. Tsai, 2016. A Low-Power Oscillator-Based Readout Interface for Medical Ultrasonic Sensors, IEEE.
2. Chiang, Y.H. and S.I. Liu, 2013. A Submicrowatt 1.1-MHz CMOS Relaxation Oscillator with Temperature Compensation, IEEE Trans. Circuits Syst. II, Exp. Briefs, 60(12): 837-841.
3. Denier, U., 2010.Analysis and design of an ultralow-power CMOS relaxation oscillator, IEEE Trans. Circuits Syst. I, Reg. Papers, 57(8): 1973-1982.
4. Garcia-Garcia, H.M., M.A. Costa and P.W. Serruys, 2010. Imaging of coronary atherosclerosis: Intravascular ultrasound, Eur. Heart J., 31(20): 2456-2469.
5. Gurunet, G., P. Hasler and F.L. Degertekin, 2011. Front-End Receiver Electronics for High-Frequency Monolithic CMUTon-CMOS Imaging Arrays, IEEE Trans. Ultrason. Ferroelectr. Freq. Control., 58(8): 1658-1668.
6. Kim, I., H. Kim, F. Griggio, R.L. Tutwiler, T.N. Jackson, S. Trolier-Mc Kinstry and K. Choi, 2009. CMOS Ultrasound Transceiver Chip for High-Resolution Ultrasonic Imaging Systems, IEEE Trans. Biomed. Circuits Syst., 3(5): 293-303.
7. Kuratli, C. and Q. Huang, 2000. A CMOS ultrasound range-finder microsystem, IEEE J. Solid-State Circuits, 35(12): 2005-2017.
8. Liao, Y.T., H. Yao, A. Lingley, B. Parviz and B. Otis, 2012. 3-_W CMOS Glucose Sensor for Wireless Contact-Lens Tear Glucose Monitoring, IEEE J. Solid-State Circuits, 47(1): 335-344.
9. Przybyla, R., S. Shelton, A. Guedes, R. Krigel, D. Horsley and B. Boser, 2012.In-air ultrasonic rangefinding and angle estimation using an array of aln micromachined transducers, in Hilton Head Solid-State Sensors, Actuators and Microsystems Workshop, pp: 50-53.
10. Przybyla, R.J., H.Y. Tang, A. Guedes, S.E. Shelton, D.A. Horsley and B.E. Boser, 2015. 3D Ultrasonic Rangender on a Chip, IEEE J. Solid-State Circuits, 50(1): 320-334.
11. Christina, Karthikeyan J. Jasmine, 2016. Review of Ultrasound Transducers for MedicalApplications with CMUT Implementation, International Journal of Advanced Engineering and Global Technology, 4(6): 1385-1391.