Enabling Technology for Tomorrowâ€™s Ultrasound Imaging

By Chester Kaufman, STMicroelectronics
Development Engineer - Medical

In recent years, the landscape of ultrasound imaging technology has changed dramatically due to advancements in semiconductor and transducer technology. For instance, hand-carried ultrasound products have gone from niche products to main stream, and are today the fastest growing segment in ultrasound. Ultra-small form factor ultrasound products like the GE VScan and the Siemens P10 are opening new markets for ultrasound, targeting the much talked about â€˜ultrasound stethoscopeâ€™. The vision is to have ultrasound available as part of a routine doctor visit, detecting possible health issues at a much earlier stage. Ultrasound cart-based systems are achieving higher and higher channel count and signal integrity for improved image quality. One of the biggest advancements in recent years can be found in the ultrasound probe, which has evolved from a simple passive linear array of piezoelectric elements to a 2D array driven by active electronics in the probe head. These new active probes can produce 3D and 4D (3D in real time) volumetric images of the human anatomy, making ultrasound useful for new applications in medical diagnostics.

Figure 1: An example of a 3D sonogram produced by 2D ultrasound probe

All of these major advancements have been made possible by the confluence of two driving factors:
1. The continued improvement of ultrasound transducer material physics for improved frequency bandwidth, and transmission and receiver efficiency.
2. Semiconductor processes and standard products that make new advancements possible for ultrasound applications.

The Transducer element
The piezoelectric transducer element converts electric signals into ultrasound energy transmitted into the body, and then converts reflected ultrasound energy into electrical energy. This is similar to how an audio speaker can be used as a very inefficient microphone as well as a more efficient speaker. The piezoelectric material used for an ultrasound transducer remained fundamentally the same for about the first 40 years of ultrasound, composed of PZT (Lead Zirconium Titanate) ceramics. The electromechanical efficiency of this material stayed roughly the same over those 40 years which was a fundamental limiting factor in ultrasound image quality. This required all the advancements in ultrasound performance to come from material processing expertise, probe integration design, electronic design improvements, and image processing software. New piezoelectric crystals were developed in the 1970s that showed improved electromechanical efficiency, and in the 1990â€™s further development on this piezoelectric crystal material produced a major improvement in electromechanical efficiency over PZT ceramics. Philips has developed this material further for ultrasound probe applications, now called PureWave Crystal technology and first used in probes in 2004. PureWave transducer material measures over 80% more efficient than PZT ceramics, with major improvements in bandwidth as well. Other ultrasound companies have also been investing in material improvements to increase the efficiency and bandwidth of their ultrasound probes, and new probes from GE boast improved bandwidth and high frequency performance.

The Semiconductor Advances
Previously, the transducer characteristics and cable impedance often required drive voltages above 300V to obtain maximum ultrasound transmit power. This required hundreds of discrete 400V to 600V transistors per ultrasound system (1 pair per channel typical). With the advancements in transducer efficiency described above, the required transmit voltage and current have been dramatically reduced.

At the same time, semiconductor companies have been improving their high voltage BCD (BiCMOS DMOS) process capabilities to be able to mix 200V High Voltage/high current devices with low voltage analog and control circuits. Now, output stages that used to require complicated discrete circuits and power FETs can be integrated onto newly developed High Voltage Transmitter ICs, like the STHV748 from STMicroelectronics.

The STHV748 is a 4 channel 190V transmitter IC, which is an example of a leading ASSP (Application Specific Standard Product) for ultrasound. Semiconductor advances in both IC design and process advancements have greatly improved the receive circuit integration and performance as well. Previously, the receiver path for

ultrasound systems required several high performance expensive ICs including Low Noise Amplifiers, Variable Gain Amplifiers, Anti-Aliasing Filters, and High Speed ADCs.

Often, ultrasound companies chose to develop receiver ASICs to meet their cost and performance targets. Today, the high performance receiver components are integrated into ultrasound receiver ASSPs available from Analog Devices, Texas Instruments and others, greatly reducing the complexity and cost to design an ultrasound receiver. The new Transmitter and Receiver ASSPs available are one of the key reasons why the hand carried ultrasound market has boomed in recent years, as portable systems that used to require ASICs (Application Specific Integrated Circuit) to reduce the size and power consumption are now possible with off the shelf components.

Figure 2: An example of a portable ultrasound system

The ultrasound ASSPs have also enabled low cost ultrasound systems with acceptable performance, making ultrasound more available to developing countries and improving patient care in those areas.

2D array Probes: Transducer and Semiconductor technology meet
In order to view volumetric images that could inspect shapes in the body instead of slices of the shape, a new design of ultrasound probe was required. Linear array probes like the one pictured in Figure 3 can only produce slices of image, like drawing a cross section picture on a piece of paper.

Figure 3: A typical curved 1D linear ultrasound probe

To make a volume image requires a matrix of ultrasound elements that can send and receive from multiple points around the object that is being imaged, much like carving a statue out of a block of wood. You can see the difference between the image from a 1D probe and a 2D probe in Figure 4.

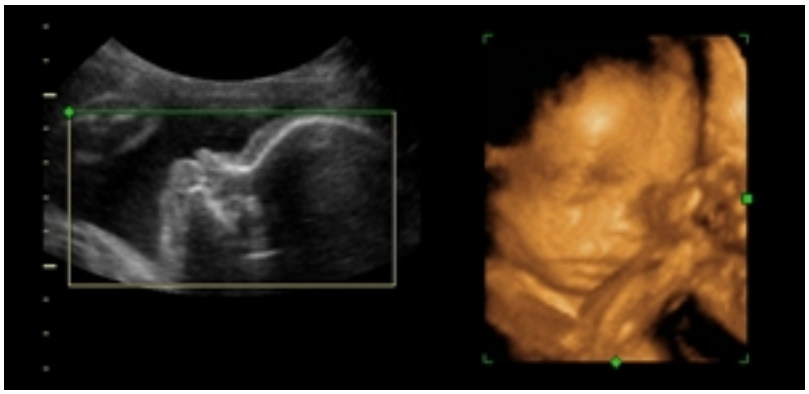

Figure 4: A comparison of 2D images produced by a 1D probe (left) and 3D images produced by a 2D probe (right)

These new 2D probes are made by dicing up the PZT, PureWave, or other advanced transducer element into an X/Y grid, like the X/Y pixels grid on a TFT display. Typically these elements are in the 100 to 250 um range, with 50 um saw curfs that are filled with polymer material.

Depending on the desired application, the number of transducer elements on these new 2D probes range from about 2000 to about 9000 elements. However, ultrasound systems that these probes need to connect to only support 128 to 256 channels, making additional electronics in the probe head required. In fact, the entire transmit and receive signal chain needed to be replicated, and intelligence added to reduce to amount of channel connections back to the system.

This required a mixture of digital control logic, beamforming capabilities, high voltage transmit capability, and good analog performance for the receive path. The first generation of these probes had up to 120 custom chips per probe because previous generations of high voltage processes did not meet all of these requirements in a single process.

Today, processes like .18 um 140V BCD8S-SOI from STMicroelectronics are making transmit, receive, digital control logic, and beamforming functions easier to integrate into a single IC. This marriage of ultrasound transducer and semiconductor technology advancement is dramatically changing the effectiveness of ultrasound imaging. With these new Real Time 3D imaging capabilities,

ultrasound is finding new uses such as 3D breast scans to replace or augment mammography exams, complete heart exams in real time, determining whether a tumor is cancerous our not without a biopsy, and more.

Looking forward: Silicon ultrasound transducers??
As the marriage of semiconductor processes and ultrasound transducer develops, many are projecting that a new breed of ultrasound probe will take over the market based on CMUT (Capacitor Micromachined Ultrasound Transducer) technology. CMUTs are mechanical structures manufactured on silicon with standard semiconductor processing techniques, show in figure 5. Some of the advantages that CMUT transducer technology promises are lower cost by using standard silicon processing techniques, higher integration with electronics due to the possibility of combining CMUT transducers and Transmit/Receive circuits on the same silicon wafer, and better acoustic matching to human tissue.

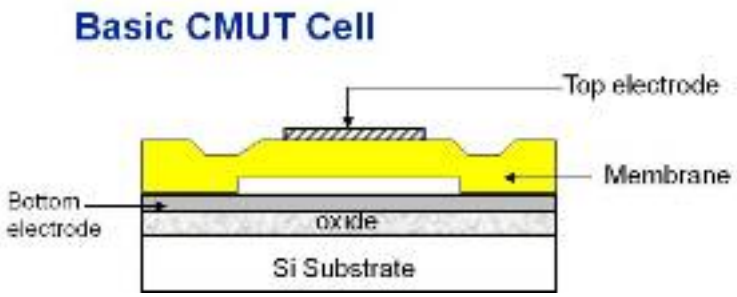

Figure 5: A cross section view of a basic CMUT cell

CMUT research has been in progress for some time at universities and other research labs. In fact, Siemens Ultrasound purchased CMUT startup company Sensant in 2005 to develop CMUT for commercial applications. However, several technical issues have been identified with CMUTs, including reliability issues due to charge build up inside the cell, lower overall sensitivity, lower imaging depths, and acoustic crosstalk from element to element on the same silicon die. To this authorâ€™s knowledge, Hitachi Ultrasound is the only major company to announce a commercially available CMUT-based ultrasound probe to date. If the technical issues can be addressed, it is quite probable that CMUT technology will play a growing role in advancing ultrasound performance and lowering overall system price.

As ultrasound systems continue to push both ends of the spectrum, from extremely

low cost, low power portable systems to high end active probes to produce 4D images, off the shelf standard products (ASSPs) and advanced mixed signal High Voltage processes will play a major role in enabling breakthroughs in ultrasound performance, cost, and power consumption.

References:

1. 4Z1c Real-Time Volume Imaging Transducer: ACUSON SC2000 Volume Imaging Ultrasound System; Gregg Frey, M.S., Richard Chiao, Ph.D.; Siemens Healthcare Sector
2. Realizing dramatic improvements in the efficiency, sensitivity and bandwidth of ultrasound transducers: Philips PureWave crystal technology; Jie Chen, PhD Corporate Staff; Rajesh Panda, PhD Transducer Technologies Manager; Bernie Savord, MS Philips Principal Scientist
3. cMUTs and electronics for 2D and 3D imaging: Monolithic integration, in-handle chip sets and system implications; Chris Daft, Paul Wagner, Brett Bymaster, Satchi Panda, Kirti Patel and Igal Ladabaum; Siemens Medical Solutions
4. CMUT vs. PZT Transducers; Engin Dikici

Source URL (retrieved on *03/14/2014 - 4:44am*):
http://www.wirelessdesignmag.com/product-releases/2011/07/enabling-technology-tomorrow%C3%A2%E2%82%AC%E2%84%A2s-ultrasound-imaging