AFE5812 Analog Front End for Industry Ultrasound

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TEXAS INSTRUMENTS

Key Words

NDT, Sonar, High Frequency Ultrasonic Receiver

Introduction

Ultrasound is a sound wave, and the sound wave's frequency is typically higher than the audible range of 20KHz. Ultrasound imaging is used in both medical and industry applications. Medical ultrasound imaging systems use frequencies that range from 1-MHz to 20-MHz, with sub-millimetre resolution for evaluating internal organs. Industry ultrasound imaging systems can be used for seafloor mapping (<1m resolution) to tiny defect (<50um) detection in silicon wafers. As a result of broad applications, industry ultrasound requires a wider frequency range, for example 20-KHz to 100-MHz. Both industry and medical ultrasound systems use a similar architecture. To achieve a desired image resolution or field of view, a single channel or up to thousands of channels can be selected.

Similar to any imaging modality, image quality is an important topic in medical ultrasound imaging. Common criteria, such as spatial resolution and imaging penetration, are settled primarily by the transducer characteristics and acoustic wave propagation theories. Both axial (R_A) and lateral (R_L)resolutions for an ultrasound image are linearly proportional to the acoustic wavelength in the medium:

$$R_L \approx \frac{Z_f}{2r}\frac{c}{f} = \frac{Z_f}{2r}\lambda \quad (1)$$

$$R_A \approx \frac{c}{2}\tau_{-6dB} = \frac{N}{2}\lambda$$

where

- c is the sound velocity in the medium
- f is the ultrasound frequency
- Zf the focal distance
- 2r the transducer aperture
- τ-6dB the –6 dB duration of the received echo when a transducer is excited by an impulse signal.τ-6dB proportionally equals to the N period of the received echo (2)

Hence, higher frequency operation achieves better resolution. In practice, it is not feasible to improve image quality by only increasing the transducer frequency. A higher frequency transducer requires thinner piezoelectric material, which demands more advanced fabrication techniques at a much higher cost. While a higher frequency acoustic wave is easily attenuated in medium as listed in Table 1.

Table 1. Acoustic Properties of Solid and Liquid

Name	Longitudinal Velocity c [m/s]	Density ρ [Kg/m^3]	Z = ρc [Rayl]	Attenuation Coefficient [dB/MHz×cm] at 1 MHz
Water	1480	1000	1.48×10^6	0.0022
Sea Water	1530	1025	1.57×10^6	0.002~0.006
Aluminum	6374	2700	17.1×10^6	0.01
Castor Oil	1480	969	1.43×10^6	0.553
Air	343	1.31	450	11.98

When the media is inhomogeneous, partial energy of the acoustic wave can be reflected at a boundary of two media. The unreflected acoustic wave continues with its propagation until it gets reflected at the next boundary, or attenuated completely.

The reflection(R) and transmission(T) coefficients are determined by the difference of acoustic impedances (Z=ρc) of these two media, where ρ and c are the density and sound velocity of media respectively, assuming the wave propagation direction is perpendicular to the boundary.

$$R = \frac{Z_1 - Z_2}{Z_1 + Z_2} \quad (3)$$

$$T = \frac{2Z_1}{Z_1 + Z_2} \quad (4)$$

Industry Requirements

Two cases can be observed to understand the demanding requirements from industry applications: one is the sonar application using a range of 20-KHz to 50-KHz signals for seashore mapping, which requires signal detecting from 100s meters or even kilometers away after high attenuation. The other case is Non-Destructive Testing (NDT), where 10~50MHz signals are used to detect tiny defects in high speed train rail, oil pipe, and silicon wafer.

A large mismatch between the metal and air or oil coupling layer leads to extremely high reflection, for example, strong signals at the surface in NDT.

Meanwhile, huge attenuation in Sonar and tiny defect in NDT result in very weak received signal. Both of these cases demonstrate the fundamental challenges of industry applications, a wider frequency range, a wider dynamic range, and from –40°C to +85°C operation temperature range in the field. TI has been working on addressing these applications over the years.

TI's medical ultrasound analog front ends, such as the AFE5805 and AFE5808 families, has gained great success in medical applications. These devices mainly target hospital applications, which only require a commercial temperature range, for example, 0 to 70°C. Additionally, medical applications do not require the wide range of frequencies and dynamic ranges as industry applications do. Thus, some trade-offs were made for medical ultrasound analog front ends. The AFE5808 and AFE5805 families are not perfect fits for handling sonar frequency lower than 100KHz and extreme high amplitude signals over 2 Vpp.

In the past several years, the success of highly integrated medical ultrasound AFEs drive industry designers to seek suitable single chip AFEs. With more than 10 years of expertise, TI has leveraged on medical applications, and released the AFE5812 device to address market needs. The AFE5812 was designed in TI's proprietary BiCMOS process and CMOS process. The device includes an amplifier die (LNA, VCAT, PGA and LP filter) and an ADC die to achieve the best performance with the lowest power. Then, advanced package technology was used to deliver a single chip solution. Based on the millions of AFEs' production experience, the AFE5812 supports a full industry temperature range from –40°C to +85°C.

The AFE5812 device has been successfully used in >50 MHz ultrasound imaging systems and <100 KHz sonar systems.The AFE5812 device has three core improvements compared to the previous medical AFEs.

The first improvement is the AFE5812 device is designed to achieve much wider operation frequency. The used bipolar transistors have very low 1/f noise and very high ft. As a result, the signal chain of AFE5812 device can support wide industry applications ranging from less than 20-KHz to more than 50-MHz. Even though the AFE5812 device's ADC operates from 10-MSPS to 65-MSPS, advanced signal processing can be used for signals outside of the Nyquist frequency range. For example undersampling techniques have been successfully deployed in telecommunication applications.

Secondly, in many industry applications, performance is the biggest concern rather than power consumption. Typically, the maximum accepted signal is limited by the AFE's power supply and transistor's threshold voltage . The AFE5812 device's LNA is based on a 5-V supply compared to 3.3-V supply used in the AFE5808/5 family. Thus, the AFE5812 device's power consumption is slightly higher than the medical AFEs. As a return, the AFE5812 device can maintain stability as long as input signal amplitude is below 4Vpp. In most industry applications, like NDT, the maximum signal is at the surface between the transducer and the object. These signals do not carry useful information, but these signals can saturate front ends and trigger unexpected AFE behaviors. The AFE5812 device's high tolerable signal range ensures a fast and consistent overload recovery performance. This has been proven in extreme applications like oil pipe inspection.

Lastly, the AFE5812 device has built-in digital I/Q demodulator and decimator. The demodulator and decimator moves the computation extensive operations from FPGAs to on-chip custom logics. The demodulator and decimator also significantly reduce the total output data amount, especially for sonar applications. ADC can oversample <100 KHz signal at 10 MSPS, and the on-chip decimation operation highly improves the SNR. As a result, the output SNR is close to 16-bit <1-MSPS ADC's.

Summary

TI's latest AFE5812 device solves the challenges from industry ultrasound applications. NDT, sonar, high frequency ultrasound, industry inspection and et cetera are just a few solution examples. Higher integration and lower power analog front-end solutions are still being developed for both medical and industry ultrasound receivers. These receivers ease the system design and reduce time to market. Newer AFE58JD28 and AFE58JD32 devices continue to support both medical and industry applications.

References

Xiaochen Xu, etc.“Challenges and Considerations of analog front ends design for portable ultrasound systems”, 2010 IEEE Utlrasonics symposium.

Ziad O. Abu-Faraj, etc. “Handbook of Research on Biomedical Engineering Education and Advanced Bioengineering Learning”, ISBN. 978-1466601222, 2012.