

# AFE5812 Analog Front End for Industry Ultrasound

Xiaochen Xu



## 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 ( $R_L$ ) and lateral ( $R_A$ ) resolutions for an ultrasound image are linearly proportional to the acoustic wavelength in the medium:

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

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

where

- $c$  is the sound velocity in the medium
- $f$  is the ultrasound frequency
- $Z_f$  the focal distance
- $2r$  the transducer aperture
- $\tau_{-6dB}$  the  $-6$  dB duration of the received echo when a transducer is excited by an impulse signal.  $\tau_{-6dB}$  proportionally equals to the  $N$  period of the received echo

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 $\rho$ [Kg/m <sup>3</sup> ]	$Z = \rho c$ [Rayl]	Attenuation Coefficient [dB/MHz×cm] at 1 MHz
Water	1480	1000	$1.48 \times 10^6$	0.0022
Sea Water	1530	1025	$1.57 \times 10^6$	0.002~0.006
Aluminum	6374	2700	$17.1 \times 10^6$	0.01
Castor Oil	1480	969	$1.43 \times 10^6$	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 ( $Z=\rho c$ ) of these two media, where  $\rho$  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  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$  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  $70^{\circ}\text{C}$ . 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  $-40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ .

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

## IMPORTANT NOTICE FOR TI DESIGN INFORMATION AND RESOURCES

Texas Instruments Incorporated ("TI") technical, application or other design advice, services or information, including, but not limited to, reference designs and materials relating to evaluation modules, (collectively, "TI Resources") are intended to assist designers who are developing applications that incorporate TI products; by downloading, accessing or using any particular TI Resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this Notice.

TI's provision of TI Resources does not expand or otherwise alter TI's applicable published warranties or warranty disclaimers for TI products, and no additional obligations or liabilities arise from TI providing such TI Resources. TI reserves the right to make corrections, enhancements, improvements and other changes to its TI Resources.

You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications (and of all TI products used in or for your applications) with all applicable regulations, laws and other applicable requirements. You represent that, with respect to your applications, you have all the necessary expertise to create and implement safeguards that (1) anticipate dangerous consequences of failures, (2) monitor failures and their consequences, and (3) lessen the likelihood of failures that might cause harm and take appropriate actions. You agree that prior to using or distributing any applications that include TI products, you will thoroughly test such applications and the functionality of such TI products as used in such applications. TI has not conducted any testing other than that specifically described in the published documentation for a particular TI Resource.

You are authorized to use, copy and modify any individual TI Resource only in connection with the development of applications that include the TI product(s) identified in such TI Resource. NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT OF TI OR ANY THIRD PARTY IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information regarding or referencing third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of TI Resources may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI RESOURCES ARE PROVIDED "AS IS" AND WITH ALL FAULTS. TI DISCLAIMS ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESS OR IMPLIED, REGARDING TI RESOURCES OR USE THEREOF, INCLUDING BUT NOT LIMITED TO ACCURACY OR COMPLETENESS, TITLE, ANY EPIDEMIC FAILURE WARRANTY AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY YOU AGAINST ANY CLAIM, INCLUDING BUT NOT LIMITED TO ANY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON ANY COMBINATION OF PRODUCTS EVEN IF DESCRIBED IN TI RESOURCES OR OTHERWISE. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, DIRECT, SPECIAL, COLLATERAL, INDIRECT, PUNITIVE, INCIDENTAL, CONSEQUENTIAL OR EXEMPLARY DAMAGES IN CONNECTION WITH OR ARISING OUT OF TI RESOURCES OR USE THEREOF, AND REGARDLESS OF WHETHER TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES.

You agree to fully indemnify TI and its representatives against any damages, costs, losses, and/or liabilities arising out of your non-compliance with the terms and provisions of this Notice.

This Notice applies to TI Resources. Additional terms apply to the use and purchase of certain types of materials, TI products and services. These include; without limitation, TI's standard terms for semiconductor products (<http://www.ti.com/sc/docs/stdterms.htm>), [evaluation modules](#), and [samples](http://www.ti.com/sc/docs/sampterm.htm) (<http://www.ti.com/sc/docs/sampterm.htm>).

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2018, Texas Instruments Incorporated