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Low Noise Silent Switcher μModule and LDO Regulators Improve Ultrasound Noise and Image Quality

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Abstract

This article presents a brief introduction to ultrasound imaging systems and provides a detailed analysis of some of challenges and solutions in ultrasound power management design. Four main design considerations are discussed: system noise level, switching noise, electromagnetic interference (EMI), and the ultrasound thermal dissipation related to its power supply. This article will also explain how the Silent Switcher® μModule® and low noise LDO technology can help solve the most common problems and improve system noise and image quality.

Introduction

The ultrasound market has grown rapidly following the introduction of the first digital ultrasound (by GE) in 2000. Ultrasound technology has shifted from static-based to dynamic and from black and white to color doppler. A growing number of ultrasound applications has led to increased component requirements such as those related to the probe, AFE, and power system.

In the field of medical diagnostics, there are ever increasing demands for higher image quality in ultrasound imaging systems. One of the key techniques for improving image quality is to enhance the signal-to-noise ratio (SNR) of the system. The different factors that affect noise will be discussed below, especially the power supplies.

How Does Ultrasound Work?

An ultrasound system is composed of transducers, transmitting circuits, receiving circuits, back-end digital processing circuits, control circuits, a display module, etc. The digital processing module usually comprises a field programmable gate array (FPGA), which generates the transmit beamformers and corresponding waveform patterns according to the configuration and control parameters of the system. The transmit circuits' driver and the high voltage circuit then generate a high voltage signal to excite the ultrasound transducers. The ultrasound transducer is usually made of PZT ceramic. It converts a voltage signal into ultrasound waves that enter into the human body while receiving the echoes produced by the tissues. The echoes are converted into a small voltage signal and passed to a transmitting/receiving (T/R) switch. The primary objective of the T/R switch is to prevent the high voltage transmit signal from damaging the low voltage receive analog front end. The analog voltage signal after signal conditioning, gaining, and filtering is passed to the integrated ADC of the AFE and then converted into digital data. The digital data is transmitted through a JESD204B or LVDS interface to the FPGA for receive beamforming and then to the back-end digital parts for further processing to create the ultrasound image.

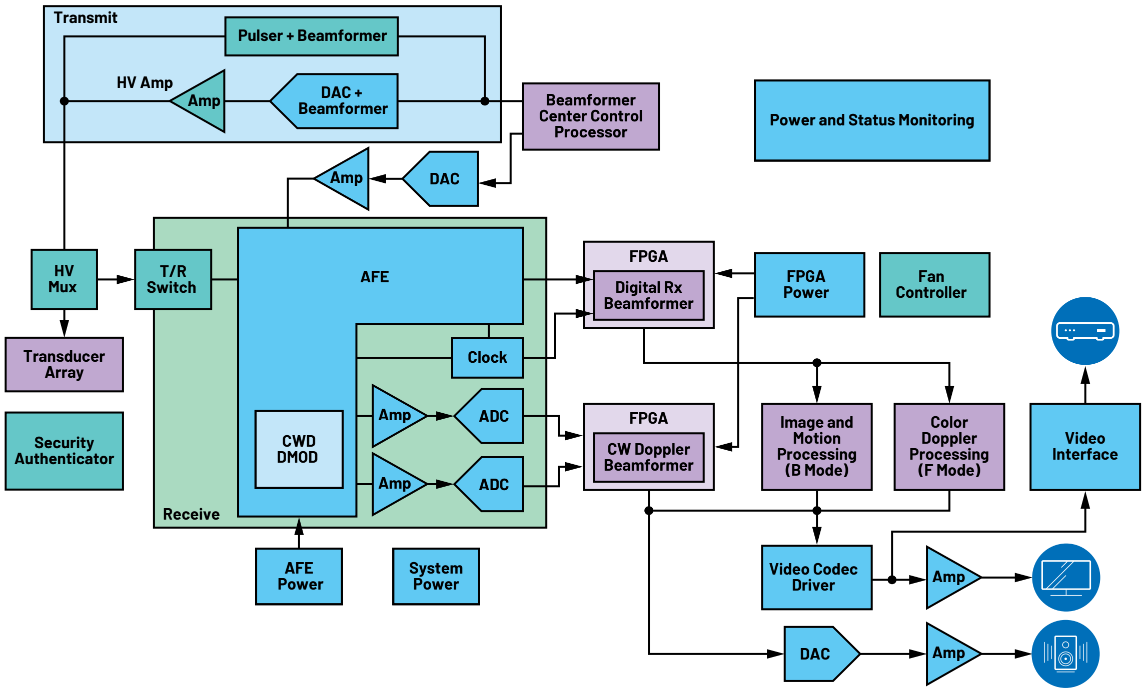

Figure 1. Ultrasound system block diagram.

How Does a Power Supply Influence Ultrasound Systems?

From the ultrasound architecture described above, system noise can be affected by many factors such as the transmit signal chain, the receive signal chain, TGC gain control, clocking, and power supplies. In this article, we will discuss how the power supply can affect noise.

There are different kinds of image modes in an ultrasound system, and each image mode has different requirements for the dynamic range. This also means that the SNR or noise requirements depend on the varying image modes. 70 dB dynamic range is required for black and white mode, 130 dB is required for pulse wave doppler (PWD) mode, and 160 dB is required for continuous wave doppler (CWD) mode. The noise floor is important for the black and white mode, and it impacts the maximum depth the smallest ultrasound echo can be seen in the far field, which is called penetration, one of the key features of black and white mode. The 1/f noise is particularly important for the PWD and CWD modes. Both PWD and CWD images include the low frequency spectrum below 1 kHz, and the phase noise impacts the doppler frequency spectrum higher than **1 kHz. As the ultrasound transducer frequency is typically from 1 MHz to 15 MHz,** it will be affected by any switching frequency noise within this range. If there are intermodulated frequencies within the PWD and CWD spectrums (from 100 Hz to 200 kHz), the obvious noise spectrums will appear in the doppler images, which is unacceptable in the ultrasound system.

On the other hand, a good power supply can improve ultrasound images by taking into account the same considerations. There are several factors a designer should understand when designing a power supply for an ultrasound application.

Switching Frequency

As mentioned, it is necessary to avoid introducing unexpected harmonic frequency into the sampling band (200 Hz to 100 kHz). It is easy to find this kind of noise in a power system.

The majority of switching regulators use a resistor to set the switching frequency. The error of this resistor introduces different switching nominal frequencies and harmonics on the PCB. For example, 1% accuracy resistors provide ±1% error and 4 kHz harmonic frequency in a 400 kHz DC-to-DC regulator. A better solution is to select power switchers with a sync function. The external clock will send a signal to all regulators via the SYNC pin so that all regulators switch at the same frequency and same phase.

Also, some regulators feature a variant switching frequency of 20% for EMI consideration or higher transient response, which leads to 0 kHz to 80 kHz harmonic frequency in a 400 kHz power supply. Switching regulators with constant frequency help avoid this issue. ADI's family of Silent Switcher voltage regulators and μModule regulators features constant frequency switching, but at the same time keep excellent EMI performance without spread spectrum on and keep excellent transient response.

White Noise

There are also many white noise sources in an ultrasound system, which leads to the background noise in ultrasound imaging. This noise mainly comes from the signal chain, clock, and power.

Adding an LDO regulator at the analog power pin of the analog processing component is common now. ADI's next-generation LDO regulators feature around 1 μV rms ultralow noise that covers current from 200 mA to 3 A. The circuit and specifications are shown in Figure 2 and Figure 3.

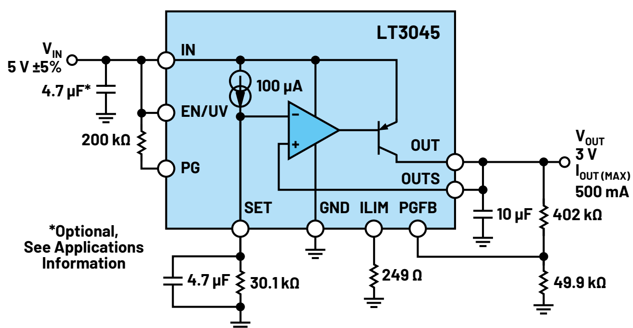

Figure 2. Next-generation low noise LDO regulator.

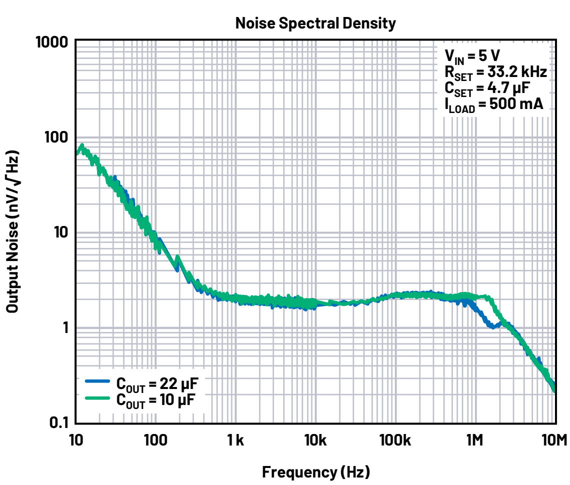

Figure 3. The low noise spectrum density in the next-generation LDO regulator: LT3045.

PCB Layout

When designing a data acquisition board in an ultrasound system, it is easy to notice the trade-off between a high current power part and a highly sensitive signal chain part. Noise from switching power supplies will easily be coupled in the signal path trace and this is not easy to remove from data processing. The switching noise is usually generated from the switching input cap (Figure 4) and the hot loop generated by the up or down side switches. Adding a snubber circuit can help manage electromagnetic emission; however, it decreases efficiency at the same time. Silent Switcher architecture can help improve EMI performance and maintain high efficiency even at a high switching frequency.

Handheld Digital Probe

In addition to heating due to the absorption of ultrasound, the temperature of tissues near a transducer is strongly influenced by the temperature of the transducer itself. Ultrasound pulses are produced by applying an electrical signal to the transducer. Some electrical energy is dissipated in the element, lens, and backing material, causing transducer heating. Electronic processing of received signals in the transducer head may also result in electrical heating. Conduction of heat from the transducer face can result in a temperature rise of several degrees Celsius in superficial tissues. The maximum allowable transducer surface temperatures (T_{SURF}) are specified in the IEC standard 60601-2-37 (Rev 2007).[1] These are 50°C when the transducer is transmitting into air and 43°C when transmitting into a suitable phantom. This latter limit implies that skin (typically at 33°C) can be heated by up to 10°C. Transducer heating is a significant design consideration in complex transducers, and, in some circumstances, these temperature limits may effectively restrict the acoustic output that can be achieved.

The safety standard IEC 60601-2-37 Rev 2007[1] limits the temperature of the transducer surface to less than 50°C when running in air and to less than 43°C when in contact with a phantom at 33°C (for externally applied transducers) or at 37°C (for internal transducers). It is often these temperature limits (rather than the limit on the maximum intensity in the beam) that restrict the acoustic output of a transducer. Silent Switcher devices have the highest efficiency converting power (with a wide switching bandwidth up to 3 MHz) to the different voltage domains of the digital probe. This means the power losses during power conversion are minimal. This helps the cooling system as there's not much additional power loss in the form of heat.

Silent Switcher μModule Regulators Help a Lot

Silent Switcher μModule regulator technology is the best choice in ultrasound power rail design. It was introduced to help improve EMI and switching frequency noise. Traditionally, we should take care of the circuit and layout design on the hot loop for each switching regulator. For a buck, as shown in Figure 4, a hot loop contains an input cap, a top side MOSFET, a bottom side MOSFET, and parasitic inductance introduced by wiring, routing, bounding, etc.

Silent Switcher modules feature two major design approaches:

Firstly, as shown in Figure 4 and Figure 5, by creating an opposite hot loop, most of the EMI will be reduced due to bidirectional emission. Nearly 20 dB will be optimized by this approach.

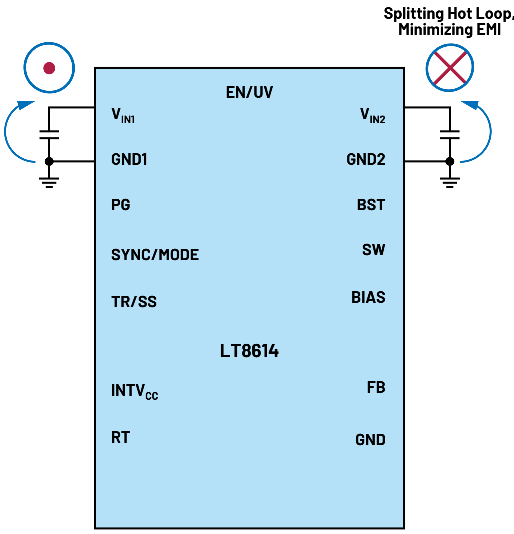

Figure 4. Splitting a hot loop's schematic.

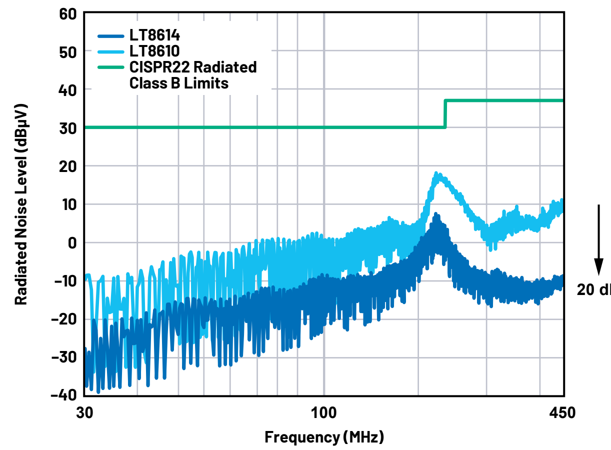

Figure 5. A comparison of silent switching and nonsilent switching EMI performance.

Secondly, as shown in Figure 6, instead of direct bonding surrounding the chip, a copper pillar flip-chip package in a Silent Switcher module helps to reduce parasite inductance and optimize spike and dead time.

In addition, as shown in Figure 7, Silent Switcher technology offers high power density design and enables large current capability in a small package, keeping low theta JA and resulting in high efficiency (for example, LTM4638 enabling 15 A in a 6.25 mm × 6.25 mm × 5.02 mm package).

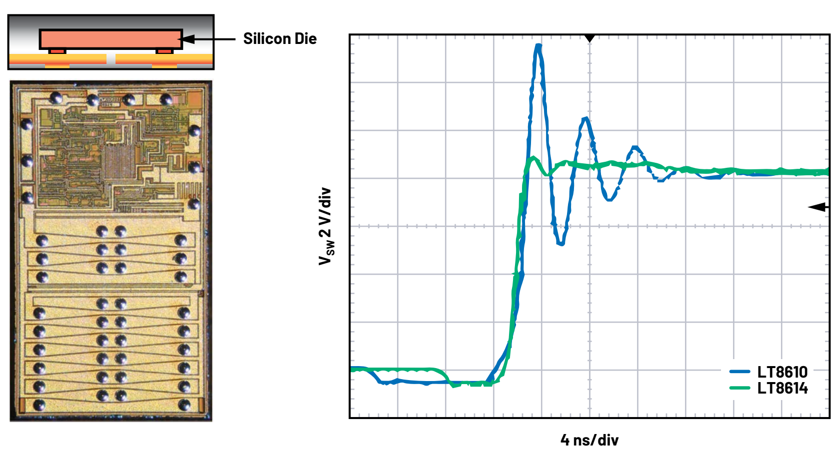

Figure 6. A copper pillar flip-chip package and its performance (LT8614) compared with a traditional bounding technique (LT8610).

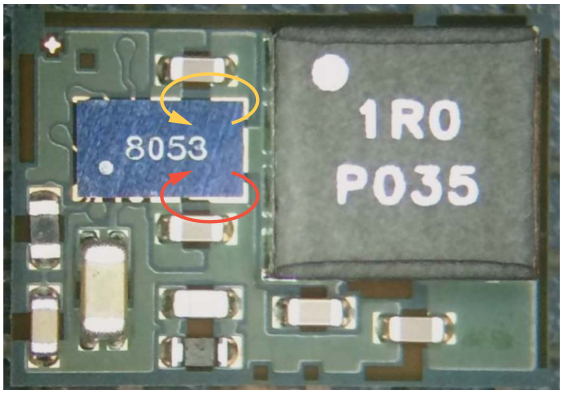

Figure 7. Silent Switcher μModule regulator in-package view.

Table 1. Silent Switcher Products Summary

	Low Frequency Noise	Switching Noise Harmonics	High Thermal Performance
Architecture	Ultralow noise reference in Silent Switcher 3 device	Silent Switcher technology plus Cu pillar package	Silent Switcher technology plus heat sink in package
Feature	Same performance as an LDO regulator in terms of low f noise	Low EMI, low switching noise Fast switching frequency, tiny dead slot	High power density Smaller thermal resistance
Benefit in Application	Removing the necessity of post-LDO regulator while keeping the same image quality	High frequency with high efficiency Higher frequency, smaller filter size	Minimize degrading for the same current level

Table 2. Popular Ultralow Noise Power Solutions with Silent Switcher Technology

	Switching Frequency	Control Mode	Switching Jitter	Power Stage Architecture	EMI	RMS Noise
LTM8053-1	200 kHz to 3 MHz	Fix frequency peak current	Small	Silent Switcher 2 module	Ultralow	0.8 μV rms (with LT3045)
LTM8060	200 kHz to 3 MHz	Fix frequency peak current	Small	Silent Switcher 2 module	Ultralow	0.8 μV rms (with LT3045)
LT8625S	300 kHz to 4 MHz	Fix frequency peak current	Small	Silent Switcher 3 converter	Ultralow	4 μV rms (without LT3045)

What's more, many Silent Switcher μModule regulators also feature fix frequency, wide frequency range, and peak current architecture, enabling low jitter and fast transient response. Popular products in this portfolio are listed in Table 2.

Conclusion

ADI's Silent Switcher power μModule regulator and LDO products provide a total solution for ultrasound power rail design, minimizing system noise levels and switching noise. This helps to improve the image quality. They are also helpful to limit temperature increase and simplify PCB layout design complexities.

Reference

[1] IEC Standard 60601-2-37. 2007.

About the Author

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About the Author

Hugh Yu earned his master's in electronic and information engineering in 2001 from the Nanjing University of Posts and Telecommunications, China. He worked as a senior ultrasound hardware engineer at GE Medical System, China, between 2002 and 2005, and worked as a research scientist at Siemens Corporate Technology China between 2005 and 2010. He is currently a healthcare systems application manager at Analog Devices, Shanghai, China.