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Applying System-in-Package Technology to 16-bit Digital Receiver Design

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This article describes a new SiP module that simplifies digital receiver design by combining the driver and anti-aliasing filter circuitry with a high-performance analog-to-digital converter

The relentless need to compress design cycle time requires first-time success for circuit design and board layout, yet extracting all of the performance from high-speed, high-resolution data converters often requires skills and experience that only a few possess. This is especially true in high-speed receivers as part of down-conversion chains in high-speed instrumentation or high-sensitivity wireless base stations, where the latest generation of analog-to-digital converters (ADCs) now have sample rates over 100 MHz and resolution up to 16-bits. Applying System-in-Package (SiP) technology bridges the experience gap and helps keep pace with increasing performance and time-to-market demands.

SiP technology is commonly used in consumer applications and has been successfully applied to DC/DC converters to help designers overcome design challenges for a wide range of applications. Linear Technology is now applying this technology to high-speed 16-bit receivers. Years of applications expertise have been packaged with their industry-leading high-speed ADCs and latest amplifiers to achieve the highest performance solution in a space-saving form factor. The LTM9001 µModule™ Receiver Subsystem integrates a 16-bit, 130 Msps ADC with a fixed gain amplifier, anti-aliasing filter and bypass capacitance, as shown in Figure 1 (on next page).

Dissecting the Module

The µModule receiver consists of wire-bonded die, packaged components and passives

mounted on a high performance, four-layer substrate. Several different versions of the LTM9001 will be available. The LTM9001-AA, as the first release, is configured with a 16-bit, 130 Msps ADC. The amplifier gain is 20 dB with an input impedance of 200 ohms and an input range of ±250 mV. The matching network is designed to optimize the interface between the amplifier outputs and the ADC inputs under these conditions. Also, there is a second order bandpass filter designed for 162.5 MHz, ±25 MHz to prevent aliasing and to limit the noise from the amplifier.

Subsystem Analysis

RF signal chain analysis uses the 50-ohm single-ended signal path as the most basic assumption. The math works out best with 50 ohms or multiples thereof. Differential signal paths are commonly 200 ohms and are easy for the RF engineer to accommodate. A traditional ADC input is not an easily-matched multiple of 50 ohms and is in fact a complex, switched-capacitor structure that kicks back current pulses at the sample rate and is thus challenging to use in quick RF calculations.

For example, the RF engineer wants to

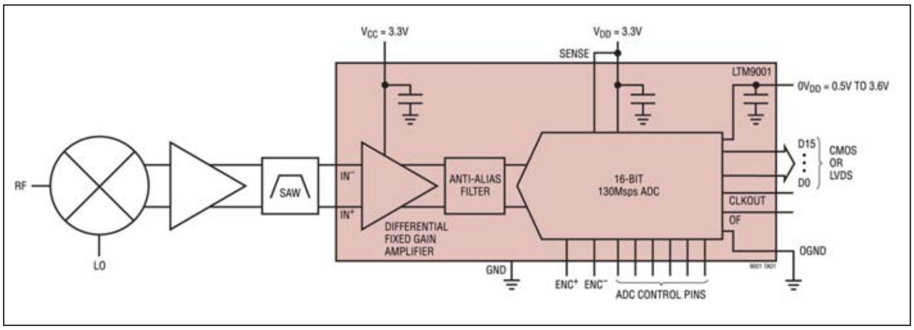

Figure 1 · This simplified IF receiver diagram demonstrates how the LTM9001 eliminates the need to design and implement the critical driving circuitry for the ADC.

know the input power capability of the ADC in dBm, but this is never given on ADC data sheets. The next best thing is to know the input voltage range and the input impedance to calculate power. The input range is specified for a traditional ADC, but the impedance, as mentioned, is not a fixed, resistive number. The LTM9001-AA, however, with its ±250 mV input span and 200-ohm differential input impedance, allows the input power to be easily calculated as –14 dBm.

The low noise, low distortion amplifier stage provides gain without adding significant noise or distortion to the signal. Despite the low noise of the amplifier, noise is multiplied by the gain of the amplifier, so higher gain unavoidably adds noise to the system. However, the input range of the amplifier is proportionately smaller due to the gain, and this smaller input range allows for lower distortion from the preceding components.

In RF terms, noise figure (NF) is commonly used. Noise figure is the ratio of the output noise power of a device to the portion attributable to thermal noise in the input termination, usually specified at room temperature. In ADC data sheets, noise is specified by its signal to noise ratio (SNR) or similar measurements. SNR is the ratio between the RMS amplitude of the fundamental input frequency and the RMS amplitude of all other frequency components, except the first five harmonics. Amplifiers may specify both, but neither term is universally applicable since they infer certain conditions such as the 50-ohm impedance implied in the NF measurement or the Nyquist bandwidth implied for SNR. Amplifiers may also specify noise in nanovolts-per-root-hertz (nV/√Hz), which allows you to do the translation. The LTM9001 specifies 72 dB SNR with the 200-ohm input impedance and a bandwidth-limiting filter. By using the SiP technology, this eliminates the steps required to convert NF to nV/√Hz, convert SNR to nV/√Hz, take the root-sum-square of the values in the allotted bandwidth and then convert the result back to SNR.

Differential Filter Design

The anti-alias filter between the ADC driver and the ADC inputs limits the wideband amplifier noise and helps preserve the high SNR of the ADC. State-of-the-art ADCs and drivers are differential, and designing filters for differential signals is more complicated than traditional single-ended designs. While the design can be implemented using two single-ended filters, the result is somewhat less robust than a true differential filter. The most obvious difference is that differential designs use a parallel component between the two signal paths instead of a component to ground for each single-ended path. With a ground reference, mismatch of two single-ended filters may introduce imbalance, resulting in differences in phase or amplitude. These differences exacerbate the imperfection of the ADC sample-and-hold circuitry, causing an increase in second harmonic distortion.

The anti-alias filter integrated in the LTM9001 is a simple two-pole L-C type differential design. It is entirely contained within the LTM9001 so no design is required. The design is characterized and 100% tested, with SNR and distortion fully specified over temperature. In the case of the LTM9001-AA, the filter is a 50 MHz bandpass centered at 162.5 MHz. Other versions of LTM9001 with different filter frequencies and bandwidths are in development.

Circuit Layout

Extracting the full performance from 16-bit, high-speed ADCs requires careful layout in addition to good circuit design. Printed circuit board (PCB) layout has a significant impact on the performance even if the circuit topology and component values are correct. The RF layout designers have lists of "good practices" depending on the operating frequency of the circuit. Such lists include recommendations such as avoiding sharp corners and keeping the signal paths symmetric and isolated from the clock inputs and digital outputs. A common mistake is to assume that an IF of 140 MHz means that optimum high frequency layout techniques are not required. But for high-performance ADCs like the one in the LTM9001, the bandwidth of the sample-and-hold is over 700 MHz. High frequency noise can be picked up by the sample-and-hold, reducing the SNR. This is an area that requires extensive experience.

Another simple example is the placement of supply bypass capacitors. A common problem with traditional ADC board layouts is excessive noise due to long traces from the bypass capacitors to the ADC. Good

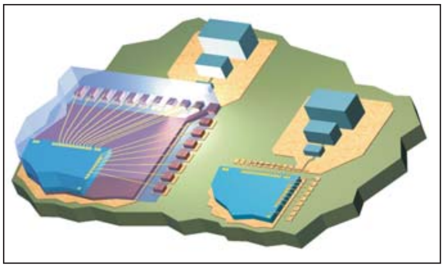

Figure 2 · Comparison of bond wire lengths in standard packages and SiP.

practice is to locate the capacitor as close as possible to the supply pin of the device. In discrete designs, the die is wire-bonded to the leadframe of the IC package. The bypass capacitor is then slightly further away, even in the best circumstance. The package size is determined by the number of pins on its periphery as well as the area required to adequately dissipate the power of the device. Therefore, the bond wires are considerably longer than those in the µModule receiver, 3.5 mm (left image) as compared to 0.8 mm (right image) in Figure 2. As a result, the internal bypass capacitors in the LTM9001 are much closer to the die than is possible in a discrete design. Thus, the LTM9001 has a much smaller “AC footprint,” reducing the risk of collecting noise from unintended sources and raising the noise floor.

Both the supply side and the grounded side of the capacitor should be close to the device. Relative to the supply pin, should the capacitor return to the upstream or downstream side of the amplifier? Where should the ADC bypass capacitors return? It depends on the design and layout of the IC, which is not described in the data sheet. In many cases it does not matter, but in some cases a particular supply pin delivers power to the input stage or output stage of the amplifier, so returning to the upstream side or the downstream side is significant. In this regard, the designers of the LTM9001 have the unique advantage of working with the designers of the individual amplifier and ADC components to achieve the best placement possible.

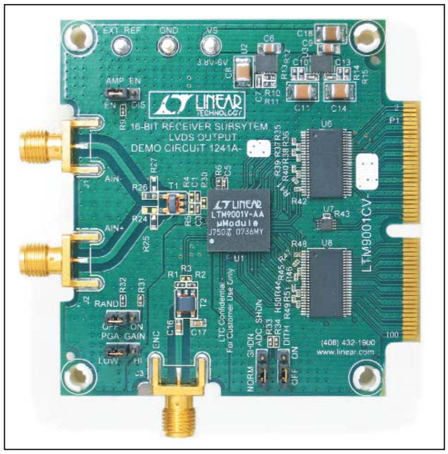

Figure 3 · A photo of the LTM9001 evaluation board.

A discrete, differential bandpass filter will have series inductors in each side of the signal path. Good layout practice suggests that both inductors will be side by side for best symmetry. A general rule is that they should be one body-width apart—close enough to eliminate the far field effect, but not so close as to couple and reduce their effective inductance. There are many such rules, and most RF layout designers know them. But this portion of the design is often on the digital board and may be done by someone not engaged with RF layout on a consistent basis.

The LTM9001 substrate design incorporates these considerations, which are learned through years of applications experience. Furthermore, the entire collection of careful layout, proper circuit design and high-performance components is fully characterized and tested as a unit. While it is possible to purchase a matched set of components, the LTM9001 extends that concept to purchasing the layout, assembly and packaging of a matched set of over 30 components. The result is an important portion of a digital receiver system that requires very few external components (see Figure 3). The LTM9001 not only saves considerable time in design and layout, but potentially reduces the number of costly board revisions.

Conclusion

The relentless trend of compressing the design cycle time with higher levels of performance and higher frequencies is often in conflict with the need for experience working with these components and the time required to gain that experience. Even with a perfect circuit design, minor layout issues like placement of supply bypass capacitors can impact performance. SiP technology, now being applied to high-sensitivity, high-speed receivers, not only integrates IC components of differing process technologies with passive components, it also effectively integrates much of the layout skill required to maximize performance. By bridging the experience gap, these µModule receivers improve first-time success and accelerate the design cycle.

Product Notes

The LTM9001 line offers semi-customization (minimum order required)—the device can be configured for various sampling rates, and the differential ADC driver can be substituted with fixed gain versions ranging from 8 dB up to 26 dB. The anti-aliasing filters can also be configured as lowpass or bandpass filters, accepting input frequencies up to 300 MHz. The LTM9001 is packaged in a 11.25 × 11.25 mm LGA package, utilizing a multi-layer substrate, and occupies approximately half the space of the discrete implementation. The LTM9001 is available in production volumes, priced at $82.00 each in 1,000 piece quantities.

Linear Technology Corp.
www.linear.com/LTM9001

Note: LTM® is a registered trademark and µModule™ is a trademark of Linear Technology Corp.