Technical Article

How RF FDAs enhance test systems with RF sampling ADCs

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Higher data rates in wireless communication systems and the use of narrower pulses in radars to resolve close targets require greater performance and bandwidth requirements in test and measurement instruments. Radio-frequency (RF) test and measurement instruments such as high-bandwidth oscilloscopes and RF digitizers use RF sampling analog-to-digital converters (ADCs) that simultaneously digitize signals from DC to multiple gigahertz.

RF sampling ADCs replace mixers followed by narrowband ADCs which reduces system complexity and improves the performance of wideband test and measurement instruments, radars and wireless transceivers.

Designers typically use a single-ended gain block in cascade with a passive balun to drive RF sampling ADCs. However, there are drawbacks to this approach that limit the achievable performance. In this article, we will discuss these drawbacks and illustrate how an RF fully differential amplifier (FDA) can help you maximize the performance of your RF sampling ADCs.

DC-coupling RF sampling ADCs

RF sampling ADCs accept differential inputs in order to reject common-mode noise and interference and improve second-order distortion. Because of their wide bandwidth, system designers use transformer-based passive baluns to convert single-ended RF signals to differential signals to drive RF sampling ADCs. However, passive baluns operate from hundreds of kilohertz or tens of megahertz on the low-frequency side based on the bandwidth that they support. Thus, the use of a passive balun to drive RF sampling ADCs in test and measurement instruments limits the lowest frequency that can be digitized.

The DC-coupled TRF1305 RF FDA performs single-ended to differential conversion with a usable large-signal bandwidth that covers DC to 6.5GHz, while providing gain. Figure 1 shows the TRF1305 RF FDA driving an RF sampling ADC in a DC-coupled application. RF sampling ADCs have a narrow input common-mode range, and operation outside this common-mode range degrades ADC performance. Single or split flexible power supplies, along with output common-mode control, make it easier to match the TRF1305's output common mode to the ADC's input common mode. These features make this amplifier versatile in DC-coupled RF test and measurement instruments such as high-bandwidth oscilloscopes, arbitrary waveform generators and RF digitizers.

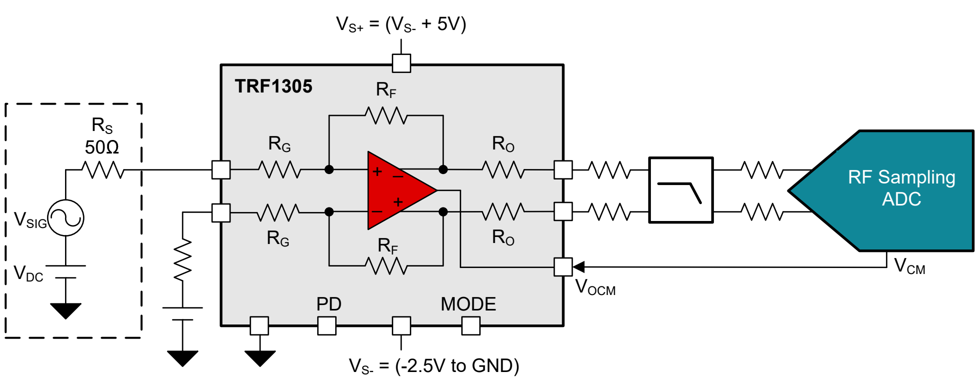

Figure 1. The TRF1305 RF FDA DC coupled to an RF sampling ADC

Improved linearity

Nonlinearity of components in a signal chain affects the detection of small signals in the presence of large interfering signals. Second-order nonlinearity is not very important in narrowband systems because the nonlinearity created falls outside the frequency band of interest and is generally filtered out. However, that is not the case with wideband systems. When the input signal bandwidth covers multiple octaves, the second-order nonlinearity of the signal appears in band. For example, consider an RF sampling ADC used with an RF bandwidth of 0.5GHz to 2GHz. The second-order nonlinearity of a signal at 0.5GHz occurs at 1GHz, which is twice the frequency. However, this second-order nonlinearity is less than the 2GHz maximum frequency of interest and has to be minimized, since it's not possible to filter it out.

RF sampling ADCs are designed to minimize second-order nonlinearity when their inputs are driven by balanced differential signals. Wideband passive baluns may have poor gain and phase imbalance on their differential output, leading to unbalanced signaling and degradation of the linearity performance of ADCs [1]. RF gain blocks used to amplify the signal before the passive balun have poor second-order nonlinearity given their single-ended operation. RF FDAs such as the TRF1305 and TRF1208 incorporate feedback techniques that help achieve improved gain and phase imbalance on the differential outputs. The differential nature of the amplifiers minimizes second-order distortion and enhances linearity of the overall system while providing signal amplification.

Protecting ADCs from damage

In many test and measurement and aerospace and defense systems, the user inputs are unknown. The RF ADCs at the core of these systems are sensitive to high power levels and overdrive. These ADCs also tend to be high performance, and are often one of the most expensive components in the signal chain. That's why it's important to carefully design the signal chain such that the preceding components do not damage the ADC. RF FDAs are designed to be linear when driving RF sampling ADCs to full scale.

Figure 2 shows the output saturation level when the TRF1208 FDA is overloaded with continuous wave input at 4GHz. The TRF1208 has 16dB of gain and its output saturates to 3.6Vpp at about 2dBm of input power into the FDA. Therefore, using RF FDAs to drive the ADCs inherently limits power during an overload caused by output clipping.

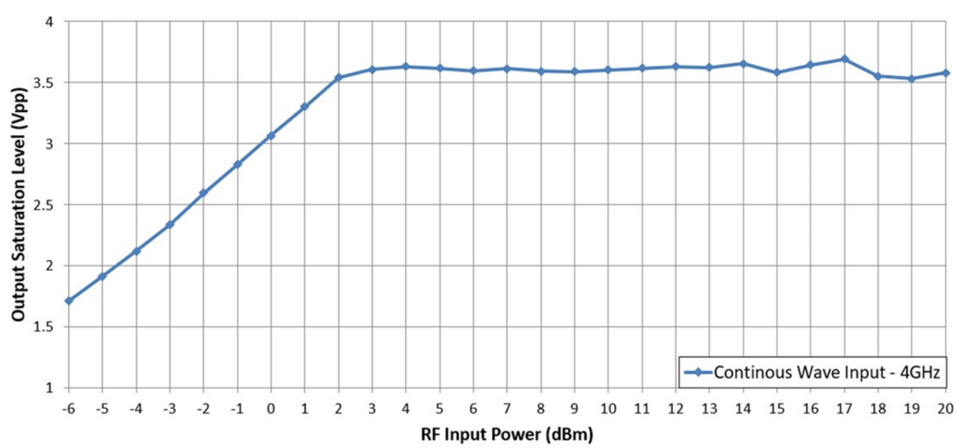

Figure 2. The differential output of the TRF1208 FDA clamps at 3.6Vpp when overloaded with a continuous wave input at 4GHz

As shown in Figure 3, designing an attenuator pad between the FDA and the ADC bounds the voltage swing at the ADC pins, protecting the ADC from damage and simplifying system design considerations while offering more design flexibility.

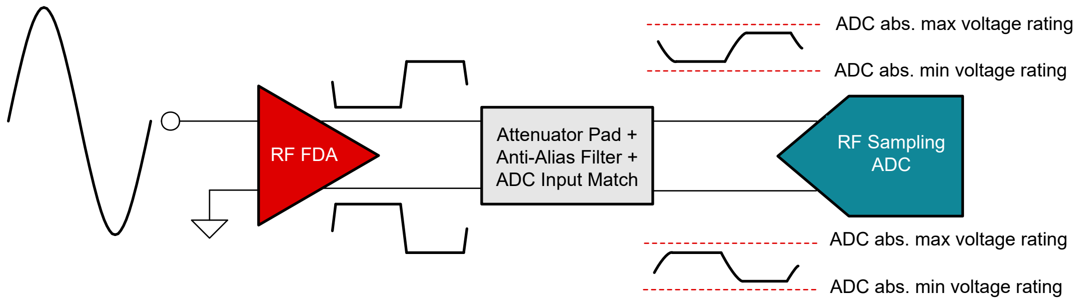

Figure 3. Output of RF FDA clips when overloaded, limiting signal power into the ADC

Conclusion

The advancement and adoption of RF sampling ADCs simplifies the system architecture of RF test and measurement instruments by reducing the number of components and board size. RF FDAs such as the TRF1305 tailored for ADC drive applications further simplify system architectures with single-ended to differential conversion of signals from DC to over 6.5GHz. The use of wideband RF FDAs paired with RF sampling ADCs in receive signal chains offers enhanced system performance, while lowering component count, board size and system cost.

Additional resources

- Order the TRF1305EVM on TI.com and get started today.
- Read the article, "Advantages of using differential to single-ended RF amplifiers in a transmit signal chain design."
- Learn more from the application note, TRF1208, TRF1108 active balun interface with Xilinx RFSoC data converters.
- Check out TI's RF and microwave products.

References

1. Reeder, Rob. "A close look at active vs. passive RF converter front ends". Planet Analog, Jan. 26, 2022.

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