Application Note

Evaluating High-Speed, RF ADC Converter Front-end Architectures

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ABSTRACT

In this article, defining and understanding the performance trade-offs when designing a new receiver front end is considered. Here a comparison of various active receiver front-end design approaches are reviewed, including low noise amplifiers (LNA), fully differential amplifiers (FDA), and passive wideband baluns.

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1 Introduction

When comparing baluns, LNAs and FDAs, understand the metrics involved when designing a wideband, high-performance analog-to-digital converter (ADC), analog input interface need to be considered.

2 Comparing AC Performance Trade-offs and Understanding Input Network Metrics

Following are five active (amplifier) or passive (balun) analog input network metrics that can help keep the input network design focused and on track:

- The input network input impedance or voltage standing wave ratio (VSWR):a unit less parameter that shows how much power is reflected into the load over the bandwidth of interest. The input impedance of the network is the defined or specified value of the input stage of the analog input network (for example, the load); usually 50Ω.
- The application bandwidth: this is the beginning and ending frequencies used in the system, typically –3dB from a reference point.
- The passband flatness: this is usually defined as the amount of fluctuation or ripple tolerable within the specified bandwidth: 1dB or +0.5dB for example. These levels can be increased or decreased, or defined with a slope.
- AC performance: single-tone: the signal-to-noise ratio (SNR), spurious free dynamic range (SFDR) and two-tone: third-order intermodulation distortion (IMD3).
- The input drive level: is a function of the bandwidth, input impedance and VSWR specifications. This level sets the gain or amplitude required for a full-scale input signal at the converter. The level is highly dependent on the front-end components: the balun, amplifier and anti-aliasing filter and can be one of the most difficult parameters to achieve.

These metrics encapsulate the entire front-end interface design, not just the analog-to-digital converter (ADC). Considering these metrics first can help decide between an active or passive front end.

The following section shows five different front-end designs to compare these metric trade-offs, as shown in Figure 2-1.

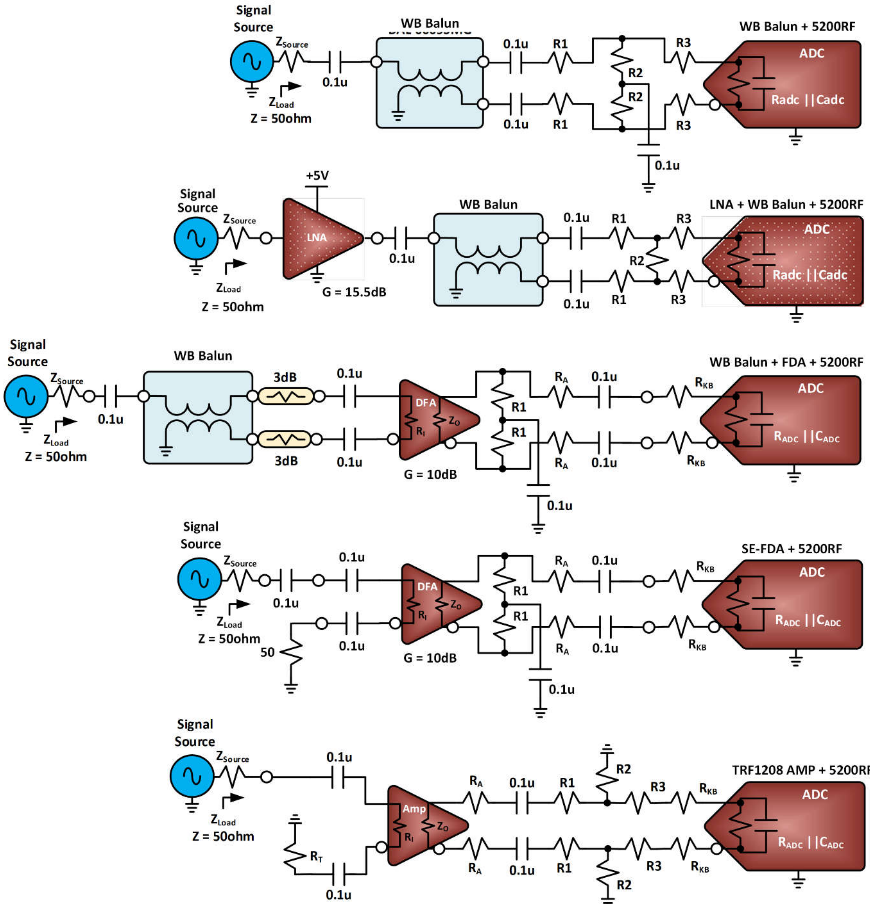

Figure 2-1. Five Front-end Designs: Balun Only, an LNA, a Balun Plus an FDA, a Single-Ended FDA and the TRF1208

2.1 Comparing AC Performance Trade-offs Between Architectures

Figure 2-2 shows the input bandwidth and input drive level trade-offs across a frequency up to 10GHz comparing the five different front ends. The front-end bandwidth for each design gives an indication of the –3dB bandwidth and input drive level required to reach –6dBFS at 1.4GHz. For example, looking at the TRF1208 design, this only takes a –16dBm input signal to reach –6dBFS of the full-scale value of the ADC. Conversely, this takes approximately 1dBm to achieve the same level using a WB balun. Between the two, this is a difference of 17dBm of signal strength that is required from the previous stage. The balun and wideband interface network create loss and therefore drive up the noise figure number of the entire signal chain. Baluns create loss, which is also true of the LNA and FDA front-end designs that include a balun for the single-ended to differential signal conversion.

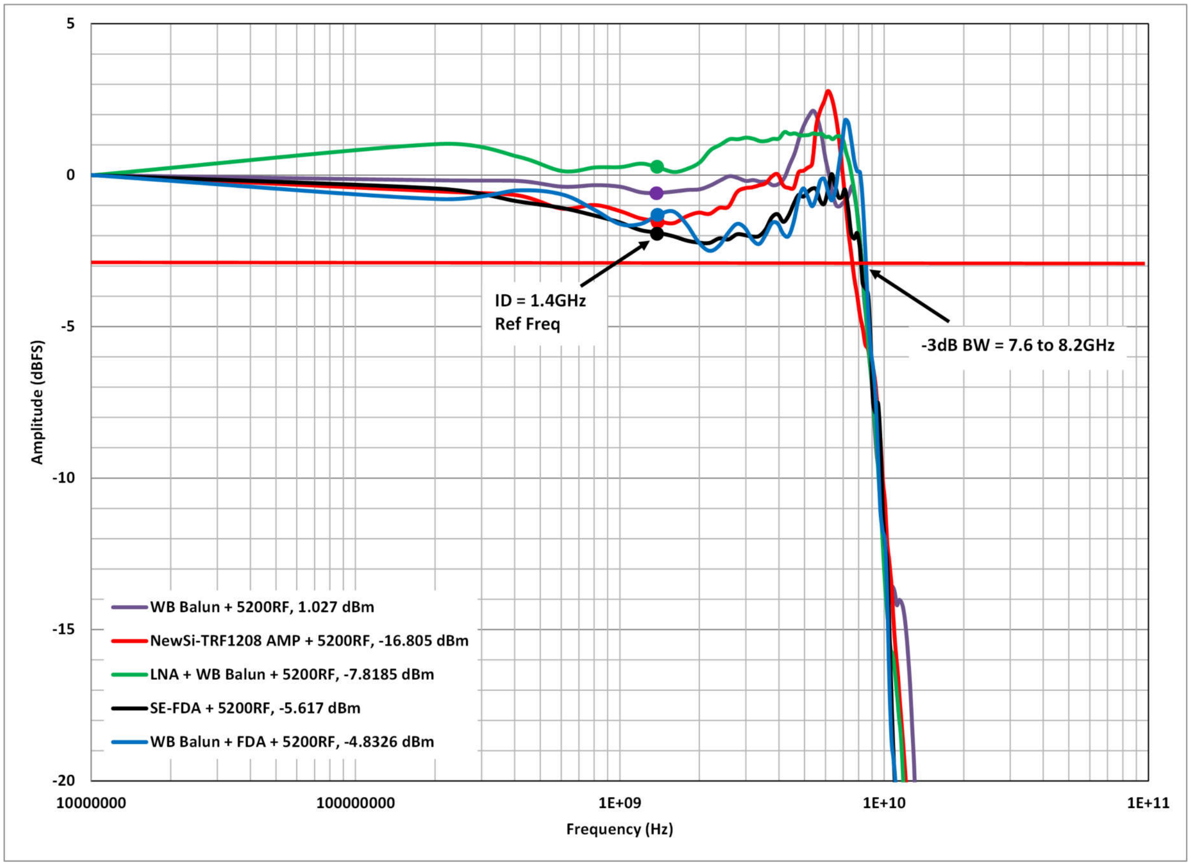

Figure 2-2. Frequency Response Comparison of the Five Front-End Designs

As discussed, baluns have loss, so the wideband balun interface requires the most signal drive strength, which requires a +1dBm signal level at the primary of the balun to achieve –6dBFS on the output of the ADC. Since all other comparisons use an active amplifier device (all of which have inherent gains), the input drive level required is much less: anywhere from –5 to –16dBm. Further analysis can be done on each front-end network work to *even out* the gains and input network losses. However, this information does provide some indication of what to expect before diving deeper into AC performance.

Frequency sweeps were conducted over the same bandwidth to capture and compare the AC performance, i.e. - SNR, SFDR and IMD3 performance. These three tests are typical standards used to make comparison trade-offs when designing with high-speed converters.

Figure 2-3 shows the trade-offs in SNR between the various configurations.

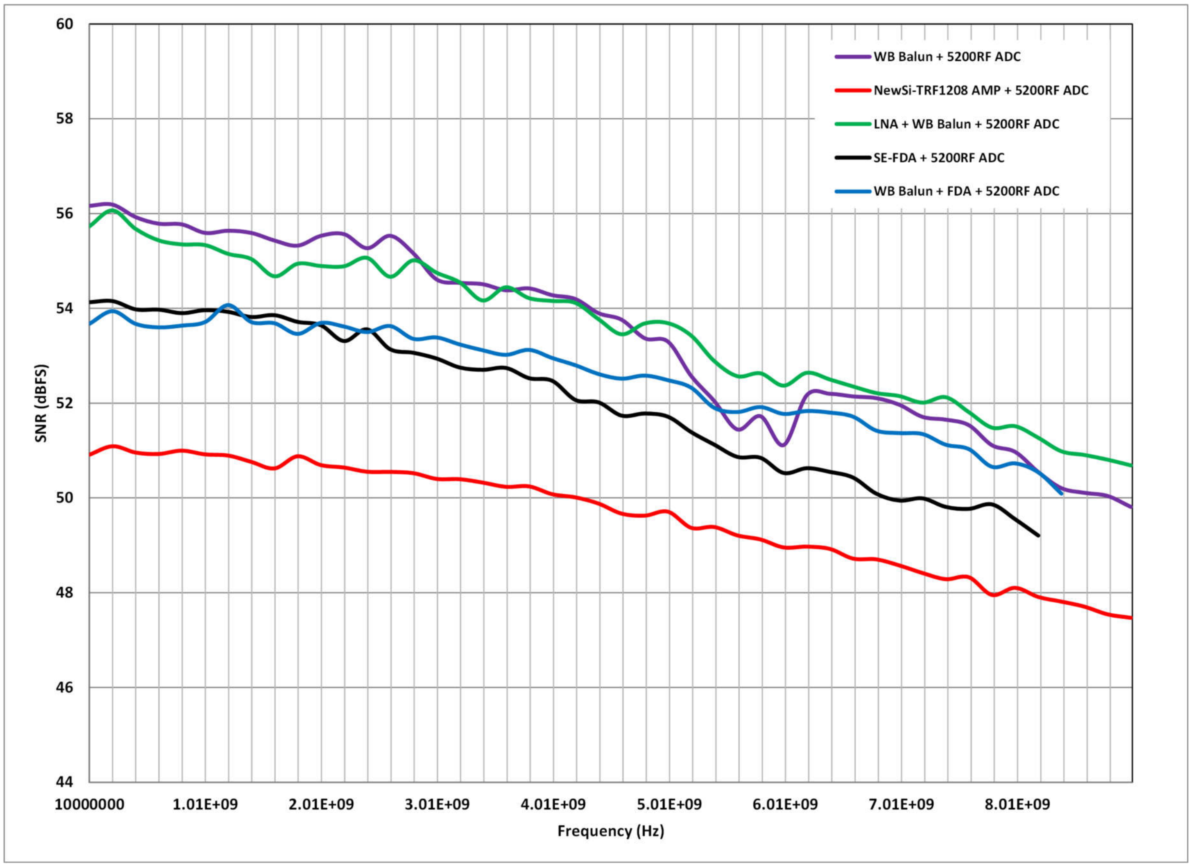

Figure 2-3. SNR Comparison of the Five Front-End Designs

Looking at the purple curve as the baseline performance, this can be seen that the wideband balun interface offers the best SNR performance over the entire bandwidth of the converter. The green curve representing the LNA approach is second, as these types of active devices typically have a very low noise figure, with about 1dB to 2dB of added noise. The FDA comes in third place, as the FDA has more wideband noise than the LNA but less than the TRF1208 design. There is a slight issue with common-mode noise cancellation when using the FDA in a single-ended input configuration, since the inherent design on the input is to expect a fully differential input signal. Using this type of configuration affects the SNR slightly.

The TRF1208 comes in last; however, the device has more output noise because this has a higher gain than the FDA in comparison. Remember that a higher active gain can gain self-generated noise. For example, with a 2GHz analog input signal, the TRF1208 has a gain equal to 16dB and a noise figure equal to 8dB at –166.7dBm/Hz, which yields -150.7dBm/Hz of output noise. The FDA has a gain equal to 10dB (S2D) and a noise figure equal to 11dB at –163.3dBm/Hz, yielding –153.3dBm/Hz of output noise.

All of the designs are configured for the widest bandwidth possible, as shown in Figure 2-2 . In any active design, reducing the bandwidth by using an anti-aliasing filter in-between the outputs of the amplifier and the inputs of the ADC helps reduce the wideband noise outside the bands of interest and the noise the converter *sees*, therefore pushing the SNR back toward the baseline performance, as shown in Figure 2-1 (WB Balun and 5200RF configuration).

Figure 2-4 shows the SFDR dynamic range from a linearity perspective over a 10GHz frequency sweep between the various front-end configurations. SFDR is a single-tone measurement that provides a good perspective on any limiting harmonics, for example, second harmonic, third harmonic, fourth harmonic, and so on within the frequency of interest.

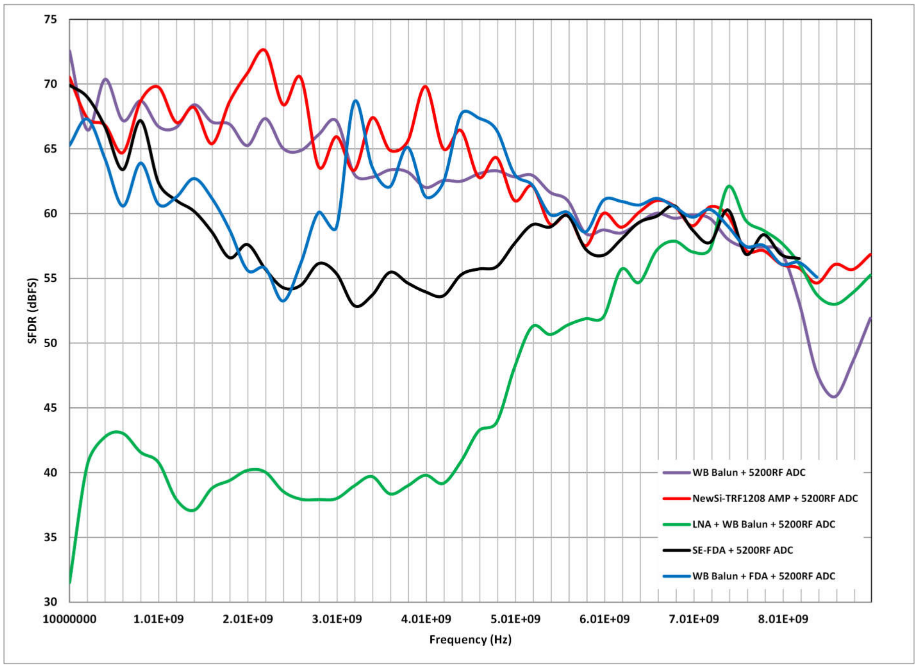

Figure 2-4. SFDR Comparison of the Five Front-End Designs

Looking at the purple curve as the baseline performance, the wideband balun interface yields the best SFDR possible over the entire bandwidth of the converter. The green curve representing the LNA shows very degraded performance, particularly at the lower band up to 5GHz, as the even order distortion or HD2 always dominates given the single-ended nature of the LNA. The HD2 eventually falls out of the bandwidth of the ADC.

The FDA design has some third-order domination in the 0.5 to 3.5GHz area when using the differential front-end approach. More even-order degraded dominance is evident in the 0.5GHz to 5GHz range when using the single-ended approach.

The TRF1208 design stays on par with the passive baseline front end all the way, giving true testament that this amplifier is an option for wideband front ends that require an active device.

Another common converter test metric is two tone, which gives rise to IMD3 results or third-order inter-modulation distortion and more quickly emulates real-world system application signals. Simply put, two-tone measurements actively measure two signals injected into the front-end interface at the same time. These two signals are typically offset by 10MHz from each other and driven to the same level, or –7dBFS each. Figure 2-5 shows IMD3+ (2 × F1 + F2 and2 × F2 + F1) results. While captured, Figure 2-5 does not include IMD3– (2 × F1 - F2 and 2 × F2 - F1) for clarity in illustrating the performance differences.

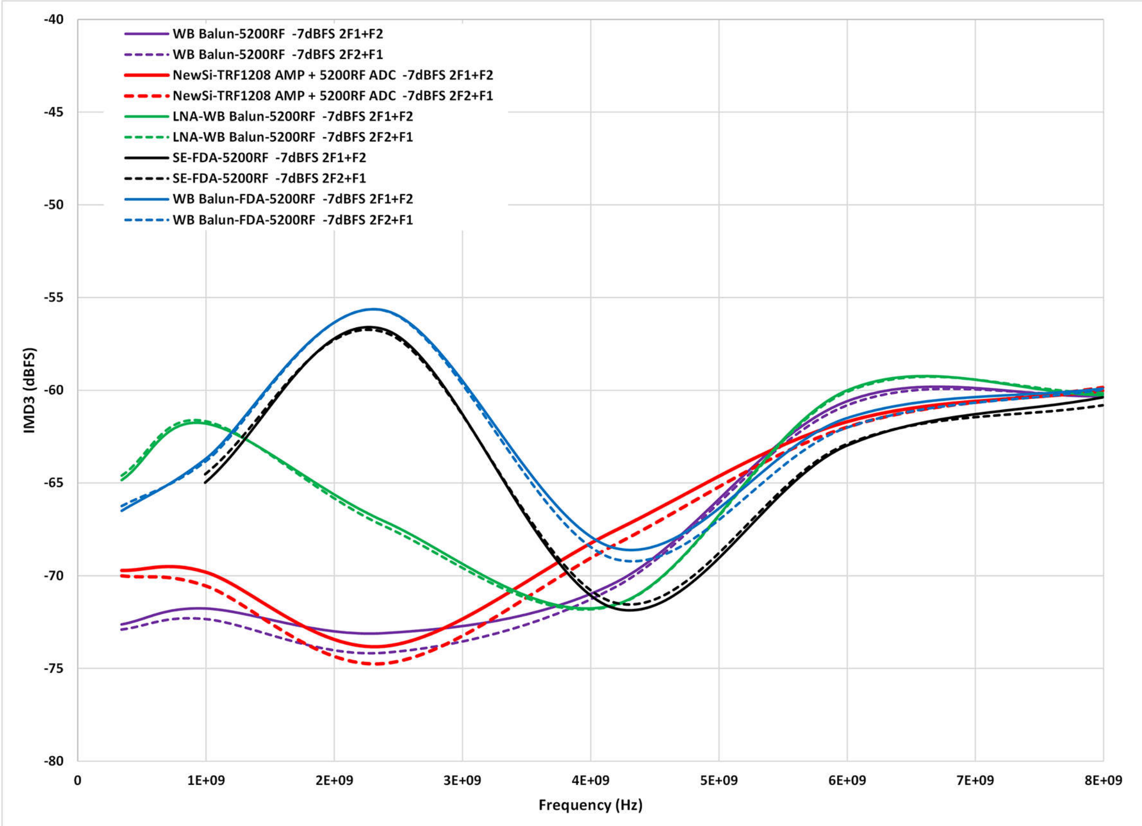

Figure 2-5. IMD3 Comparison of the Five Front-End Designs

With the purple curve again illustrating the baseline performance, the wideband balun interface yields the best IMD3 performance possible over the entire bandwidth of the converter. The green curve, representing the LNA, shows degraded performance relative to the wideband balun interface. The blue and black curves representing the FDA interfaces are degraded in performance as well relative to the baseline up to 5GHz. The TRF1208 design stays on par with the passive baseline front end for the entire frequency sweep. This amplifier yields a clear advantage that this amplifier is an option for wideband front-end requirements.

Note in this front-end comparison is that the FDA evaluated has two power supplies, one negative, and consumes 1.8 W of power to keep the noise low. This is a method to drive the noise down, increase the headroom of the amplifier and throw more power at the design. The LNA dissipates the least amount of power; only 0.275 W with a single 5V supply. The TRF1208 runs off a single 5V supply and consumes 0.675W.

3 Summary

The goal for of this application note is to provide a quick-start guide to some useful and familiar comparisons of ADC analog front-end interface designs, as well as provide an introduction to the newly TRF1208 TI wideband amplifier. With any new wideband front-end design, TI recommends evaluating the metric trade-offs first and plan accordingly upfront as provided in the first section. By reviewing and understanding these trade-offs up front, an appropriate selection can be made between baluns and amplifier front-end architectures for your next high-speed receiver design.

4 References

- Texas Instruments, *High-Speed, Analog-to-Digital Converter Basics*, application note.
- Texas Instruments, *Transcending the Multi-GHz Bandwidth Barrier: Active vs. Passive Converter Front Ends*, application note.
- Texas Instruments, *Unraveling the Practical Mysteries Behind RF Converter Front Ends*, presentation.

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