Application Note

The 3rd dB: Why a Lossy Attenuation Network Pad Works Well With RF ADCs

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ABSTRACT

One common question received from customers using an RF ADC, particularly when developing a passive analog frontend design, for example, using a balun or transformer to couple to the ADCs analog input pins, is: *why is there a resistive 3 to 6db attenuation network between the balun and ADC*? *This creates a lot of signal loss!* What is the purpose of this three-resistor network? Six actually, since the input is differential.

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1 Introduction

Start with a simple block diagram setup as shown in Figure 1-1 with a balun, attenuation pad and ADC. This line up is typical of what you can find on a standard high-speed or RF ADC evaluation board. The attenuation pad is the component in controversy; on why does a designer implement a frontend network in this manner? Why not simply connect the balun outputs directly to the ADC's input pins? The ADC data sheet shows that the ADC's input impedance is 100Ω differential in most cases, that is, for internal input buffered style high-speed ADCs.

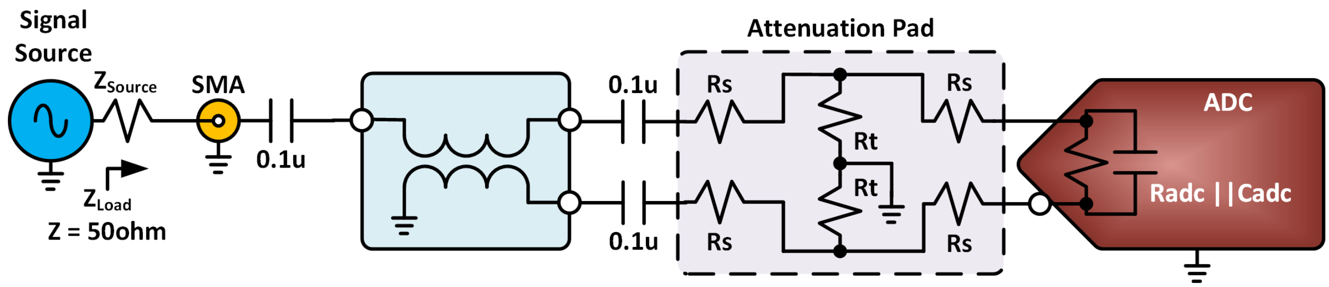

Figure 1-1. Generic ADC Signal Chain Block Diagram with Attenuation Pad

2 3 to 6dB Reasons Why

Here are five rubber stamp answers which can give some insight on why this type of input network is needed:

- The 3-6db input network is there because on any general evaluation platform, EVM, for any ADC manufacturer, the applications group has to design an EVM attempting to cover the full analog bandwidth (BW) range that the ADC is capable of covering. Also, there are all sorts of customers and end users with widely varying applications so this input network approach is generic enough to handle 95% of what a customer can apply, analog signal-wise, into the ADC's analog inputs. If needed, the customer can later, decrease BW, make changes, or modify the input network to design to their specific end application.
- The 3-6dB input network is necessary for applications requiring the widest attainable BW of the ADC. Some customers and applications need the full BW capability of the ADC. The resistive network provides a good generic network that satisfies both the balun and ADC impedance requirements. See Figure 2-1.

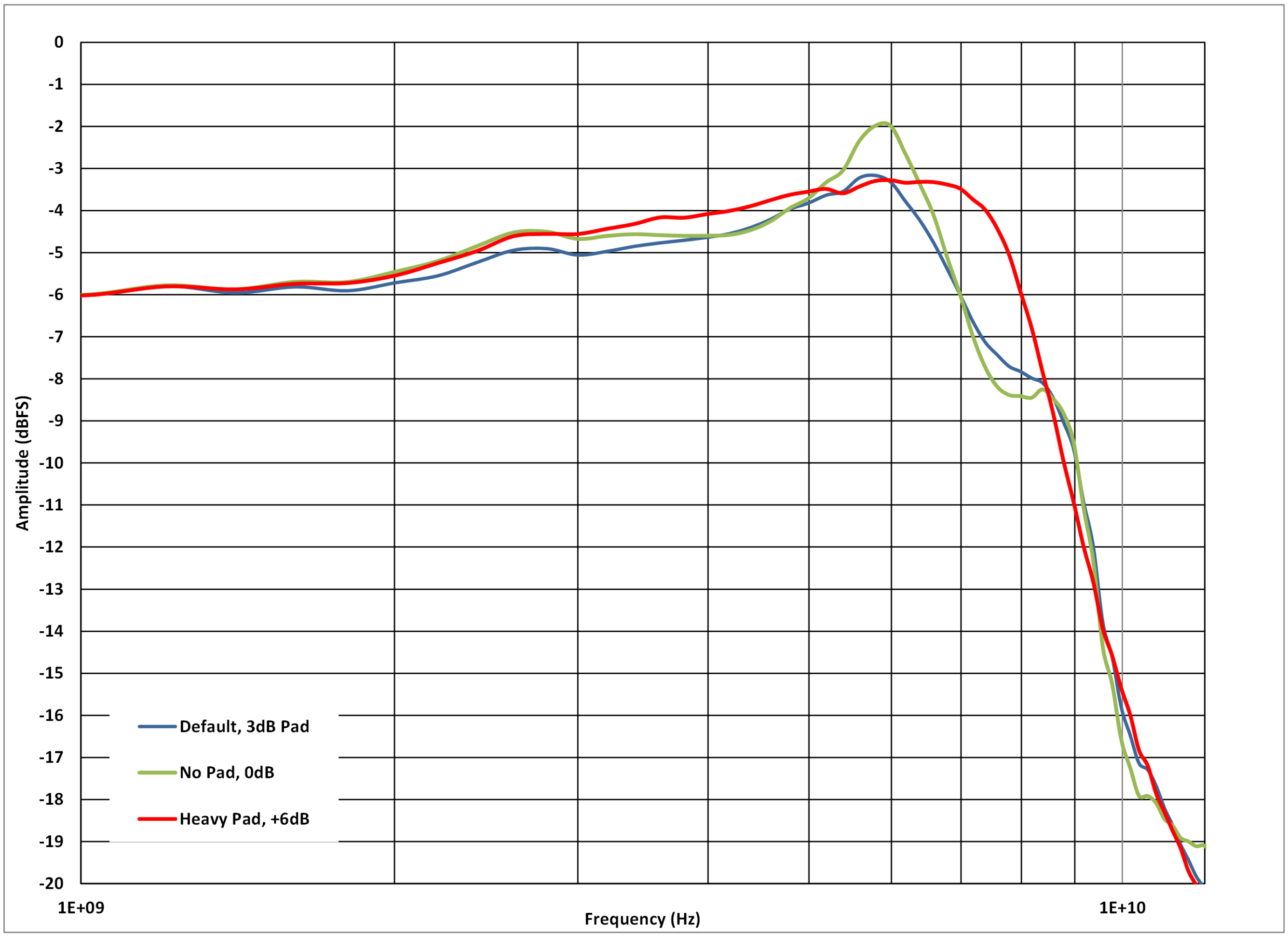

Figure 2-1. Bandwidth Response of Balun and ADC With and Without Attenuation

- The 3-6db input network is needed for wider band balun in general. This type of network provides a *stiff* impedance over a wide range of frequencies. Keep in mind the balun was characterized with a VNA, which is a calibrated 50Ω environment over any frequency range. When measuring the balun, the VNA provides a reference plane that is more or less right at the point of each of the baluns primary inputs or secondary outputs. So naturally if the balun was characterized this way, the balun can want to *see* the characterized impedance close to the inputs or outputs to resolve the baluns natural characterized frequency capability. Go ahead, remove those three resistors on either side of the differential and let's review the difference.
- Figure 2-2 shows exactly what can happen if you replace the attenuation network with a straight, pass-through connection. See how the BW rolls off much faster without that lossy or matching pad if we just use two pass-through interconnections between the balun outputs and ADC's analog inputs.

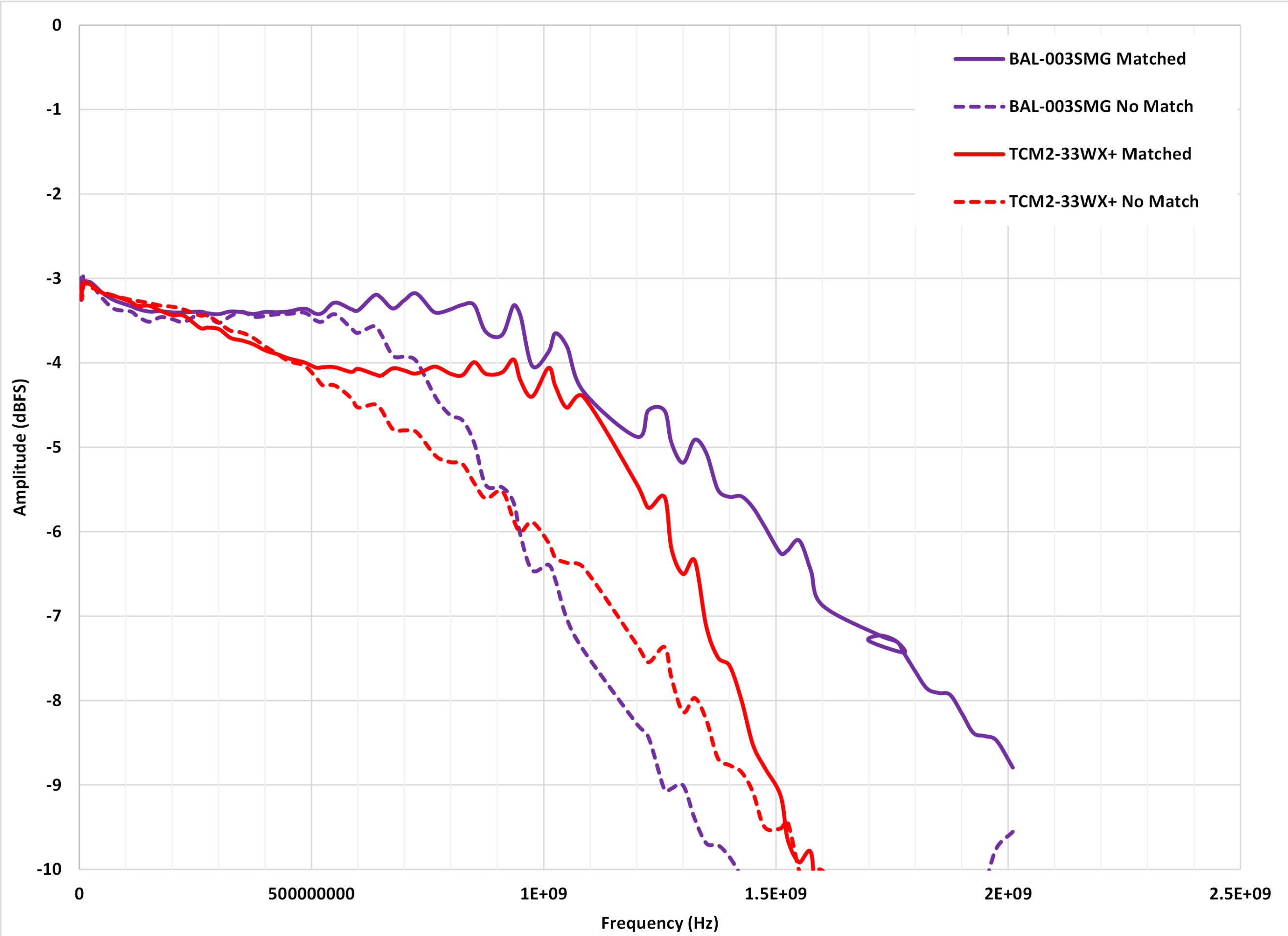

Figure 2-2. ADC3669 and Balun BW Comparison: Match (solid lines) vs. Un-matched (dashed lines)

- The 3-6db input network is needed because the ADC's input impedance is not exact and even if the data sheet says this is 100Ω differential, unfortunately it is not. See Figure 2-3, here is a measurement example of an SDD11 s-parameter smith chart of the ADC12DJ5200RF analog inputs. Does that look like 100Ω differential across all frequencies to you? I agree, this does not. It seems that lately, an increasing number of designers consider the data sheet impedance specifications as literal (and fixed) values, when in reality these only act as reference under specific conditions. So please be mindful, and plop down a real termination resistor on your PCB at, or near, any input or output to resolve a better impedance match across a wide range of RF frequencies. Oh, and did I mention that most all IC process nodes have variation on the order of ±20% for any or all specified resistive terminations?

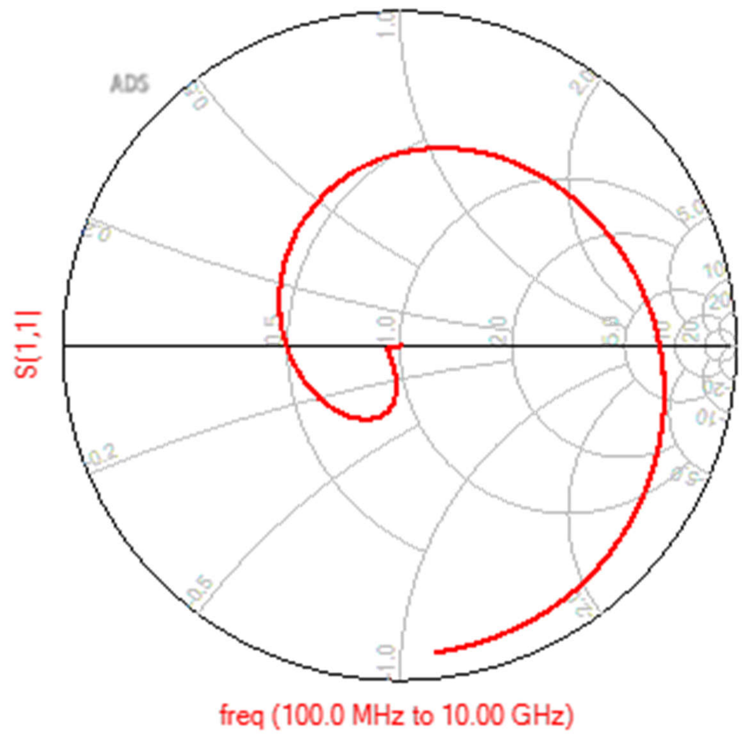

Figure 2-3. SDD11 S-Parameter of the ADC12DJ5200RF Analog Inputs

- The last reason the 3-6db input network is needed, as frequency bandwidths go up and up, we are at 10GHz now, next week this is 20GHz and so on. This drives the need for a wideband match as indicated in the above points. However, placing a stiff impedance lossy pad also helps to resolve any mismatch in impedance required by both the outputs of the balun and inputs of the ADC. As you know, any mismatches in impedance starts to create standing waves, which in turn causes ripples in the passband or band of interest. By placing the lossy pad in between the balun outputs and ADC's inputs, this helps to resolve this mismatch and ultimately *kills* those standing waves quickly without disrupting with AC performance, for example, SFDR or spurious free dynamic range. Notice in Figure 2-4 how the ripples and reflections disappear quickly above 1GHz whenever the 3-6db pad is implemented.

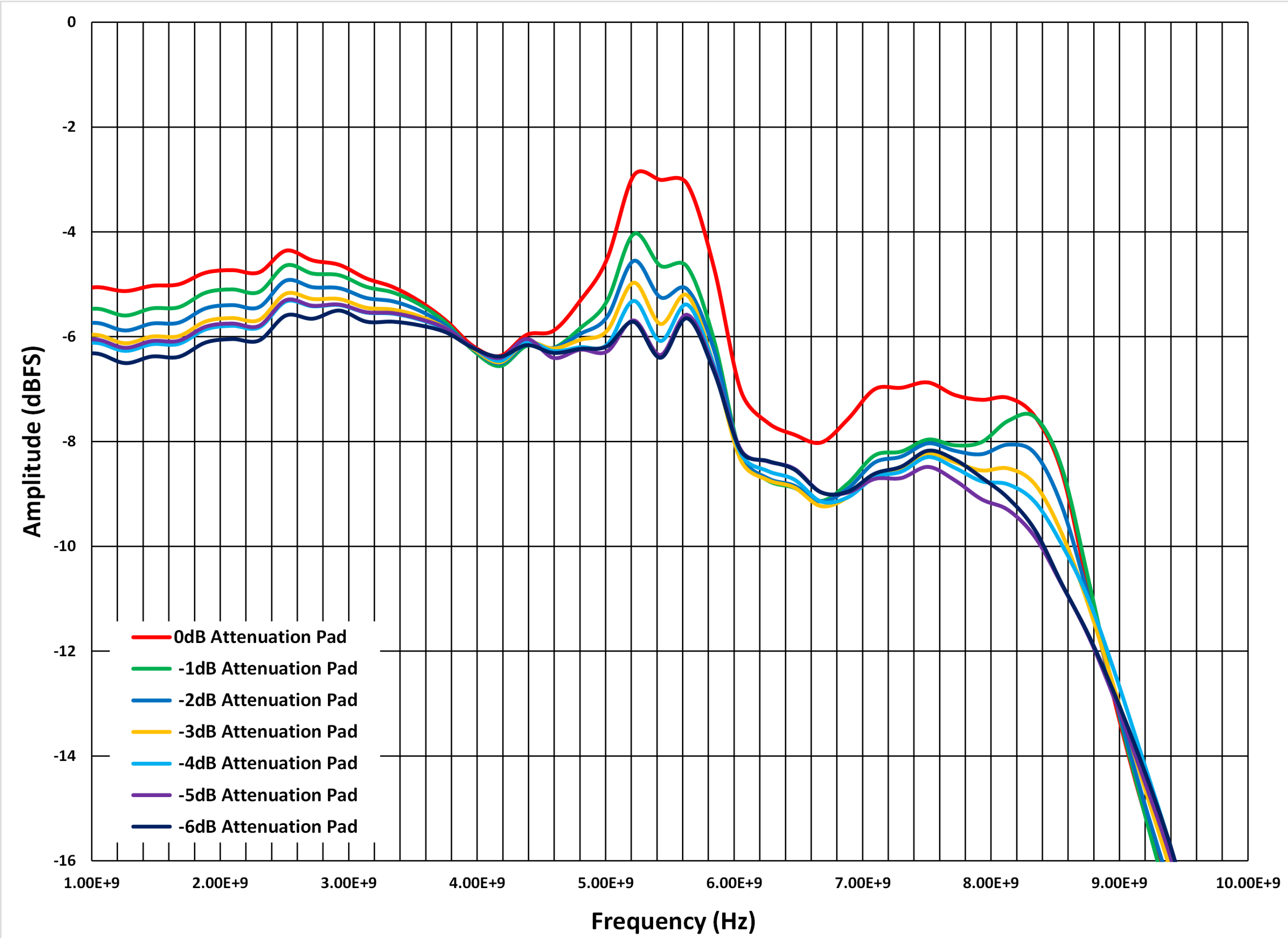

Figure 2-4. Attenuation Pad vs. Ripple Reduction

3 Summary

In summary, there are five good reasons why a 3-6db matching pad is useful when sandwiched between the balun outputs and ADC’s analog inputs.

1. Facilitating support of the customer EVM across a broad range of application bandwidths.
2. Providing an efficient method to use the full bandwidth capabilities of an ADC.
3. Makes for a stiff balun output impedance.
4. Makes for a solid ADC input impedance.
5. Mitigates passband ripple and standing waves.

While this can seem counter intuitive that a lossy balun or interface network is not always attainable, particularly when designers do not see any improvement in noise figure (NF) calculations or signal chain lineup analysis, the value cannot be understated. For passive interface networks, this has proven to be beneficial and effective and is almost always required for wideband or high frequency applications exceeding the 3-4GHz range.

4 References

- Texas Instruments, *ADC12DJ5200RF 10.4GSPS Single-Channel or 5.2GSPS Dual-Channel, 12-bit, RF-Sampling Analog-to-Digital Converter (ADC)* data sheet.
- Planet Analog, *A close look at active vs. passive RF converter front-ends*.
- Texas Instruments, *Unraveling the practical mysteries behind RF converter front ends*, seminar.
- Texas Instruments, *The Fine Art of Passive Matching a High-Speed A/D Converter Analog Input Frontend*, application note.
- Texas Instruments, *So What Are S-parameters Anyway?*, technical article.
- Texas Instruments, *So, What's a VNA Anyway?*, technical article.
- Texas Instruments, *So, What's the Deal with Frequency Response*, technical article.