Application Note

Proper High-Speed A/D Converter Passband Flatness Revealed, Part 1

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ABSTRACT

With analog input or output bandwidth in high demand, understanding converter bandwidth, also known as a passband flatness measurement, is paramount. Passband flatness measurements can sometimes be confusing or misleading. Whether a user is sampling in the MSPS- or GSPS frequencies, the same principles apply in uncovering the required bandwidth of the converter, the analog input and output network connecting to the converter, or both.

In this two-part series, this document discusses the fundamental frequency response measurement method as this applies to both analog-to-digital converters (ADCs) and digital-to-analog converters (DACs), with or without internal digital downconverter (DDC) or digital upconverter (DUC) functions. This method a user to measure and characterize the analog bandwidth for the converter in a receiver design.

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1 Introduction

Today, there are effectively three methods to measure passband flatness:

- The fundamental frequency response measurement method, which is typically used when collecting the input/output network and converter bandwidth response together.
- The vector network analyzer (VNA) method, which uses a VNA to collect only the bandwidth of the converter response, enabling a precise and accurate measurement of just the converter. This method effectively deembeds the analog input/output network connections [1-3].
- The input pulse method, which uses a high-frequency pulse generator to input a high-frequency square wave. In this method, the user effectively inputs a pure pulse response and cross-correlates the output-captured response of the ADC vs. an ideal square wave. Add a bit of math into the mix, and a user can effectively extract the bandwidth of the converter.

This series focuses only on the fundamental frequency response measurement method as this applies to both ADCs and DACs, using the ADC12DJ5200RF and the AFE8000 from Texas Instruments (TI) as our example test cases. The first installment focuses on ADCs and the second installment discusses DACs. This document offers guidance on how to set up and test bandwidth for both ADCs and DACs in real and bypass mode for the ADC12DJ5200RF, and with complex digital features enabled such as DDCs and DUCs for the AFE8000.

2 Fundamental Frequency Response Measurement Method: ADC

The fundamental frequency response measurement method uses a data-capture program such as TI's HSDCPro to collect the fast Fourier transform (FFT) fundamental level only across your bandwidth of interest. For example, if the analog front end looks like the one shown in Figure 2-1, using a wideband balun, there is a simple resistive input network between the secondary outputs of the balun and the analog inputs of the ADC. This type of input network is common in wideband input networks [4].

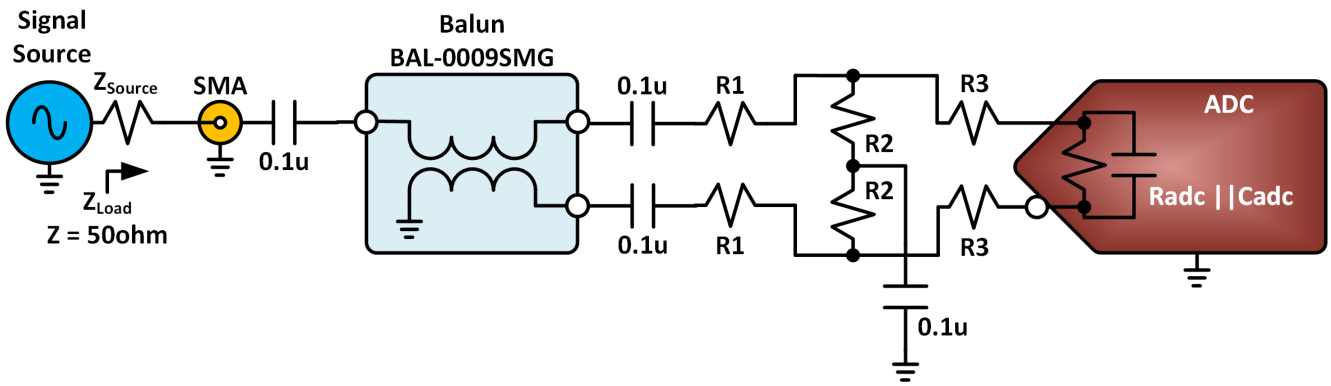

Figure 2-1. Example Input Network Connected to the ADC

Set up the converter evaluation module (EVM) or board design for the measurement; Figure 2-2 shows a basic setup. Configure the EVM as normal using the user's guide, for both hardware and software, to verify valid data capture. Use low-noise power supplies with sufficient current ratings and low phase noise signal generators for the clocking signal inputs as well as the analog input signal, along with adequate filters to suppress any noise and harmonics created by the signal generators.

In this measurement, do not filter the analog input; this allows the signal generator to sweep across multiple frequencies of interest, without attenuation from the filter, to collect the passband flatness or bandwidth measurement. The FFT data capture software (HSDCPro, Matlab, Python) allows the collection of the appropriate data at each frequency step that is set.

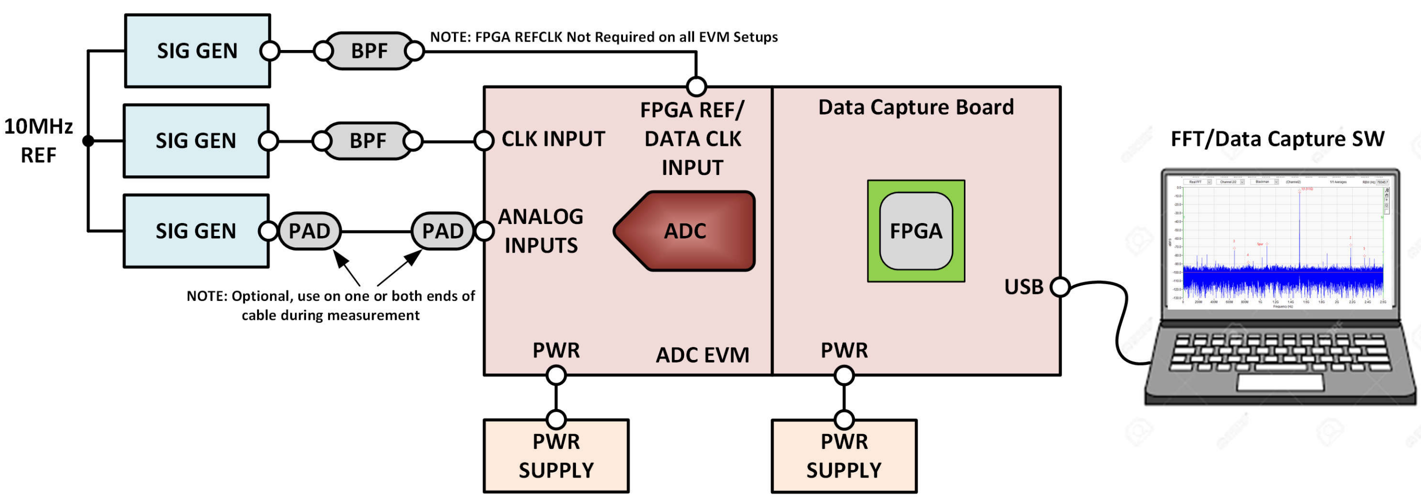

Figure 2-2. Fundamental Frequency Response Measurement Method Setup for an ADC

The next step is to determine the start and stop frequencies for the passband flatness sweep measurement, and a reference point frequency to set the initial analog input drive level. If the user is taking the reference point frequency by hand, take at least five to ten data points across each Nyquist zone to get a good idea of the bandwidth contour.

If the user is interested in a narrow or partial band of frequencies, or if there is a passband antialiasing filter on the input network to the ADC, use the center frequency of the band of interest as the reference point frequency.

If the user is interested in a more wideband measurement or sweep, using about one-third the bandwidth as the setpoint frequency makes sure that the frequency is not too low or too high, where a user can experience rolloff on the upper or lower bands of the measurement. The data sheet of the ADC12DJ5200RF specifies a bandwidth of about 8GHz. Since one-third of 8GHz is roughly 2.67GHz, that is the set point frequency. See Figure 2-3.

Set or adjust the setpoint level at that frequency with the signal generator connected to the analog input. This is the amplitude of the fundamental signal in the FFT capture and is the input drive level specification. Adjusting the setpoint level a bit lower than –3dBFS or –6dBFS makes sure that there is enough headroom, since the signal bandwidth of interest might move up and down over the start and stop frequency setpoints of the measurement.

Note the level in decibel milliwatts that is used on the signal generator. Note that the value of the amplitude of the signal generator output setting only records the output at the signal generator; the amplitude level can differ at the point of entry, such as the SMA connector in the EVM or the user's own board, because of cable losses or *RF plumbing* and connectors that are in line with this connection. Take additional steps to calibrate out any cable or other losses from the measurement in order to obtain a better understanding of the actual signal level as the signal enters the input network front end on the EVM.

Once the setpoint frequency and input drive level has been adjusted, leave it; there is no need for further adjustment on the signal generator level. This value provides a calibration point of the signal amplitude required not only at the setpoint frequency, but across the frequency sweep. Move only the frequency setting on the signal generator to the starting frequency point on the sweep and take an FFT capture. Record the fundamental amplitude in the FFT capture for the starting frequency and each point after as the user sweeps across frequency. Continue to do so until the sweep has reached the stopping frequency.

Once you have reached the end of the sweep, organize the data into two columns: one for each frequency step point, and another for the fundamental amplitude level in the FFT captured using preferred data capture software.

Take the plus and minus levels from the resulting measurement to determine the actual signal amplitude across the swept measurement or resulting pass-band flatness curve, as shown in Figure 2-3. In this case, since the setpoint frequency is set to –3dBFS, a –6dBFS point results in –3dB of bandwidth. Review the example in Figure 2-3 on how to properly note these parameters in the resulting measurement sweep.

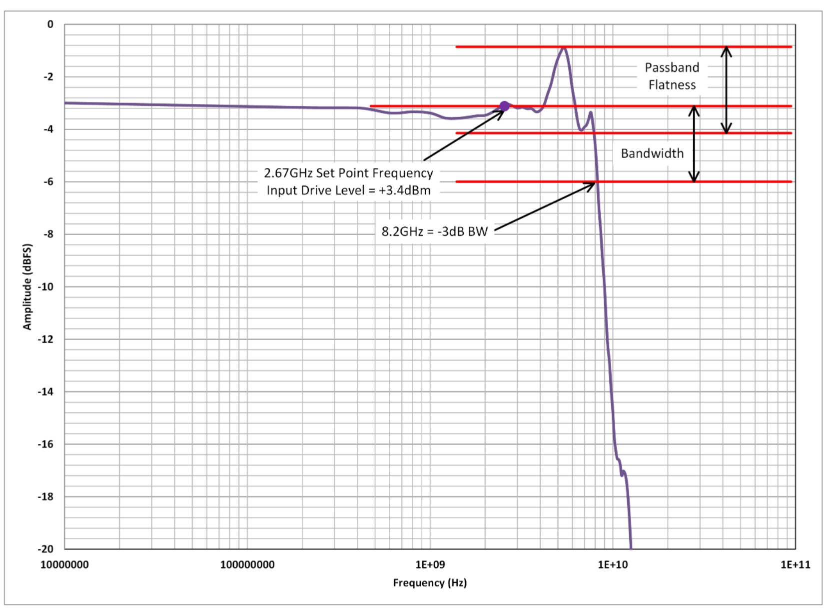

Figure 2-3. ADC12DJ5200RF ADC Input Pass-Band Flatness Response: Bypass Mode

3 Fundamental Frequency Response Measurement Method: ADC With DDC Enabled

The ADC example uses real sampling, sometimes called bypass mode; it does not use an internal DDC to downconvert the preferred signal to baseband. For a device that uses complex mixers in the receiver chain, such as the AFE8000, taking a proper passband flatness sweep requires a few more steps. Adjust the numerically controlled oscillator (NCO) frequency such that the user captures the input signal appropriately as the input is swept across frequency.

There are two main approaches for this type of measurement. The first approach is to set the NCO to one frequency and then sweep the input across the frequency covered by the pass band of the DDC decimation filter, usually around 80%.

We recommend this approach only when meeting two conditions:

- The post-DDC bandwidth can entirely cover the bandwidth. Because of the DDC decimation filters, any input outside of the pass band is attenuated, invalidating the accuracy of the measurement.
- When the receiver chain is operational in your application, keep the NCO at the frequency where the measurement is recorded. This is a requirement, because to get the most accurate measurement, the NCO must be kept at one frequency so that you can also capture effects such as the pass-band ripple of your DDC decimation filters. If you were to move your NCO after making the pass-band flatness measurement, the pass band shifts, therefore introducing some error. This condition mainly applies to older converters with embedded DDCs, as current DDC technology has advanced enough to have devices with an in-band peak-to-peak ripple <0.2dB.

If both conditions are true, the one change to the measurement procedure described is to set the NCO frequency such that the DDC passband covers the whole bandwidth.

If one or both conditions are not true, the second approach is to change the NCO frequency while sweeping the input signal across the bandwidth the user is measuring. For example, a user may need to measure a 1GHz band centered around 2GHz with 101 points by sweeping your input tone from 1.5GHz to 2.5GHz in steps of 10MHz, while always keeping the NCO a certain distance (such as 10MHz) from your input tone. This method does not capture effects such as the in-band ripple of the DDC filters, since this moves the NCO along with the input tone. Therefore, it assumes that the in-band ripple of the DDC filters is small enough to ignore when compared to the variability of other outside factors.

Make sure to frequency plan accordingly to avoid putting the NCO frequency close to any Nyquist boundaries, which can cause undesired spurs and images to show up on the spectrum.

If using the second approach, the one change to the measurement procedure described is to always keep the NCO frequency a certain frequency off from your input signal across the whole procedure, including while sweeping the input signal. Keeping the NCO frequency 10MHz off from the input signal is common.

4 Summary

This first installment in a two-part series covered how to use the fundamental frequency response measurement method to measure the bandwidth response of an ADC. An analog input or output bandwidth of a data converter is an important requirement when considering integration into system design, especially as converters move into the gigahertz range and beyond. The second installment of this series, dedicated to DACs, includes tips to avoid effects such as standing waves from disturbing the measurement.

5 References

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.

Electronic Products, *Unraveling the full-scale mysteries of your RF converter’s analog inputs*

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