Application Note

Proper High-Speed D/A Converter Passband Flatness Revealed, Part 2

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ABSTRACT

This is the second installment of a two-part series describing a method for measuring the analog input or output bandwidth of a data converter. The first installment covered the fundamental frequency response measurement method and how to use the method to measure the analog input bandwidth for an analog-to-digital converters (ADC). In this second installment, the document discuss the digital-to-analog converter's (DAC) analog output and offer some tips to avoid effects such as standing waves from disturbing the measurement.

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1 Introduction

Today, there are effectively three methods to measure pass-band 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 converter's bandwidth 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 ADC output-captured response 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 devices from Texas Instruments (TI) as our example test cases. The first installment focuses on ADCs and the second installment discusses DACs. This document offers on how to set up and test bandwidth for both ADCs and DACs in real and bypass mode for the ADC, and with complex digital features enabled such as DDCs and DUCs for the AFE.

2 Fundamental Frequency Response Measurement Method: DAC

Although the process for measuring the flatness frequency response of a DAC is similar to the one described for ADCs in the first installment, there are a few differences. The first step is to set up the DAC's evaluation board with the preferred DAC configuration for testing. The setup for the measurement must look like Figure 2-1.

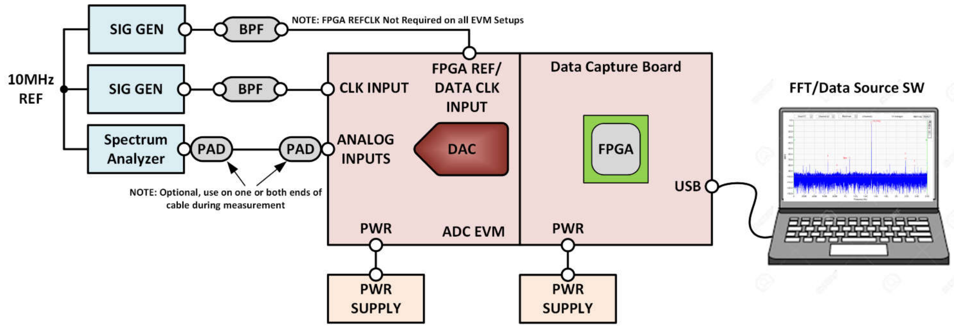

Figure 2-1. Fundamental Frequency Response Measurement Method Setup for a DAC

Some DACs can have different output modes or filters to suppress spurs or flatten the frequency response. Verify the mode on which the DAC is operating, and if there are any restrictions when using that mode. For example, some DACs employ an inverse sinc() filter that runs at the DAC's update rate; this allows the inverse sinc() filter to be used to flatten the frequency response of the sample-and-hold output. Other DACs have different filters for different Nyquist zones; for this reason, TI does not recommend sweeping across different Nyquist zones of the DAC when using internal filters without making sure that the mode of operation supports doing so, or if you can change the mode of operation accordingly.

After connecting the setup, verify the output tone of the DAC and adjust the settings of the spectrum analyzer appropriately. Usually, when measuring the frequency passband flatness, a continuous wave tone makes sure that all of the power out of the DAC is in a single frequency bin. With this in mind, try to make the span of the spectrum analyzer very narrow and reduce the resolution bandwidth until the fundamental amplitude is stable.

Once the setup is verified, select the start and stop frequencies for the sweep measurement, then check the output of the DAC at a few points along the band that you're planning to sweep using the marker of the spectrum analyzer. This helps set the amplitude reference of the spectrum analyzer. Although this is an extra step, this makes sure that the user does not overdrive the spectrum analyzer and collect poor measurement results.

Next, provide the DAC with an input tone set at the starting frequency and start sweeping across the band of interest by changing the frequency of the input to the DAC while recording the amplitude output as shown by the spectrum analyzer at every frequency. Note the collected data in two columns: column A equals each frequency step point, while column B equals the fundamental amplitude level as shown in the spectrum analyzer.

To account for the behavior of the spectrum analyzer and the losses of the cables, we recommend sweeping both the cable and the spectrum analyzer across frequency using a constant radio frequency (RF) source. For example, the user can disconnect the cable from the analog output of the DAC on the system board or evaluation module, and then connect this cable and any RF adapters in the measurement setup to the output of a signal generator. Set the signal generator to a constant amplitude; preferably near the amplitude of the output of the DAC. Then, without changing the amplitude of the signal generator, sweep the signal generator's output while connected to the input of the spectrum analyzer across the same intended measurement frequency range to record the fundamental shown by the spectrum analyzer only from the signal generator. This captures the losses in the cable and spectrum analyzer across that frequency range. Subtracting this loss from the DAC measurement obtain a more accurate result.

This setup uses a PC to control a data source board with an FPGA or field-programmable gate array, to provide and control the data that goes to the digital inputs of the DAC in the evaluation board. All of the necessary power and clock inputs connect to the evaluation board of the DAC as well as to the data source board. It is important to have all clock inputs and spectrum analyzers reference locked by connecting the reference frequency outputs and inputs of the equipment. Finally, the DAC analog output connects to a spectrum analyzer in order to measure the output in the frequency domain. TI recommends frequency planning accordingly to prevent any spurs or harmonics from disrupting the measurement.

3 Fundamental Frequency Response Measurement Method: DAC with DUC Enabled

The steps discussed work for a DAC that uses real sampling, meaning one that does not use a digital upconverter (DUC) to upconvert the chosen signal from baseband to the chosen frequency. For a device that uses complex mixers in the transmitter chain, such as an AFE from Texas Instruments (TI), there is a step that you must add to the process of taking a passband flatness sweep. This step is to adjust your numerically controlled oscillator (NCO) frequency such that the output frequency of the DAC is at the appropriate frequency to sweep the output across the frequency band of interest. Handle the NCO for the DAC DUC similarly to the description in the previous installment of this series for capturing a bandwidth of the ADC when using an NCO. As an example, see Figure 3-1 and Figure 3-2, which illustrate an example output network for the transmitter channel and the data taken from a TX channel of the AFE with a matching network of 3GHz of bandwidth.

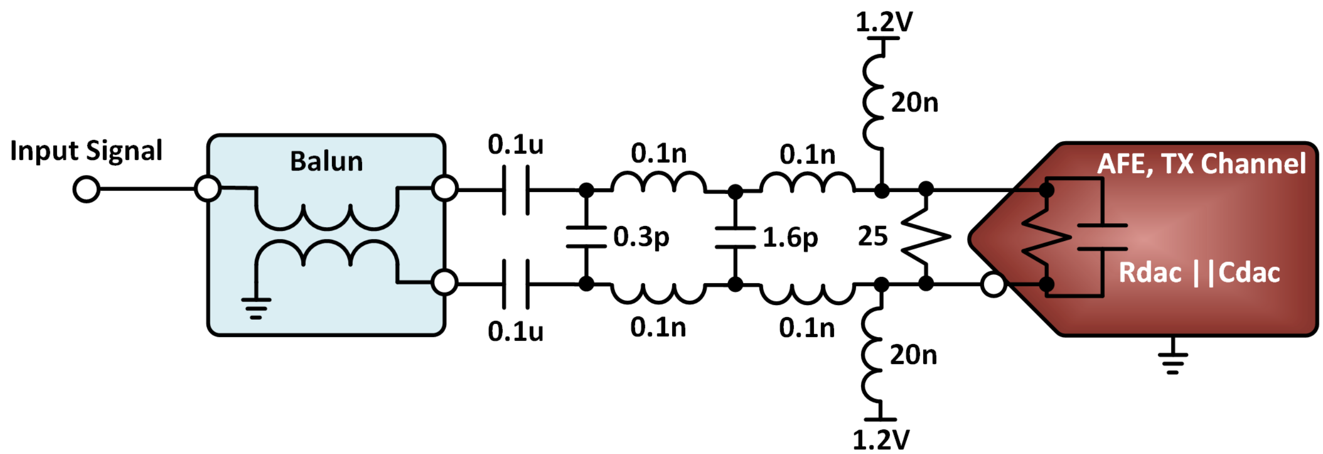

Figure 3-1. Example Output Network Connected to the DAC

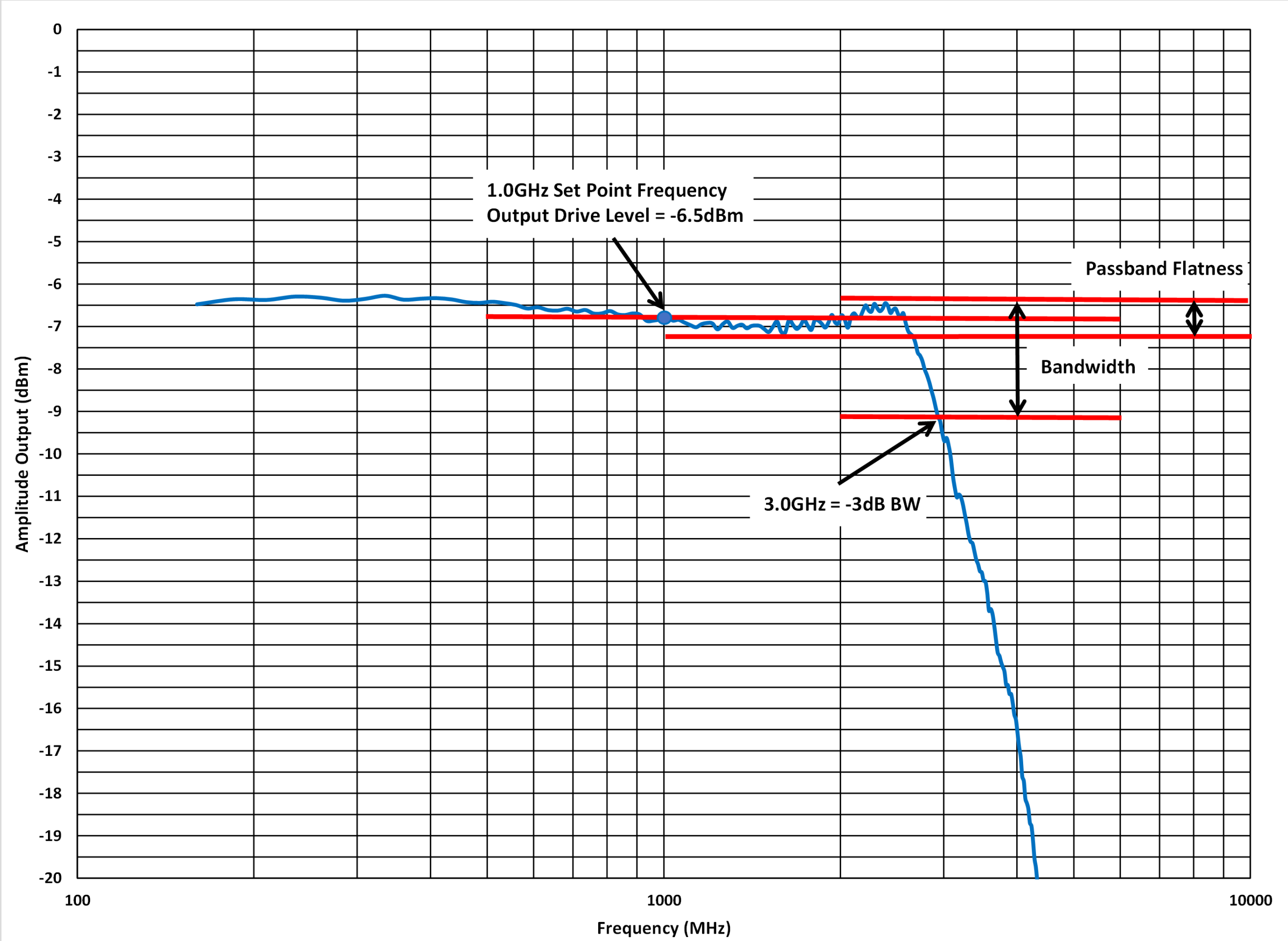

Figure 3-2. AFE DAC Output Pass-band Flatness Response: DUC Enabled

4 A Note on Passband Flatness Measurements

Lastly, TI recommends that in either case, ADCs or DACs, that when performing this measurement the user uses some in-line attenuation pads connected to the input/output cable, on one or both ends. TI recommends 3dB to 6dB attenuation pads. Back calibrate this additional loss out of your measurement following the steps in this article. The main reason for additional lossy pads on the input/output cable to the analog input/output of the converter from the signal generator or spectrum analyzer is to deal with any standing waves caused by impedance mismatches.

Note that the signal generator or spectrum analyzer is expecting a good, stiff 50Ω impedance match to maximally transfer power to the load ADC (or to receive power from the DAC). The input/output impedance of the converter is never going to be a solid 50Ω across frequency, especially over a multigigahertz span and when the bandwidth begins to roll off. Standing waves accumulate and show up in measurements, causing extra ripple across the measured frequency band if not dealt with by adding additional losses to the connection path. For example, see Figure 4-1. Both of these measurements were collected in exactly the same way, except that one measurement had an attenuation pad on one end of the cable and the other measurement did not as noted in the legend in Figure 4-1.

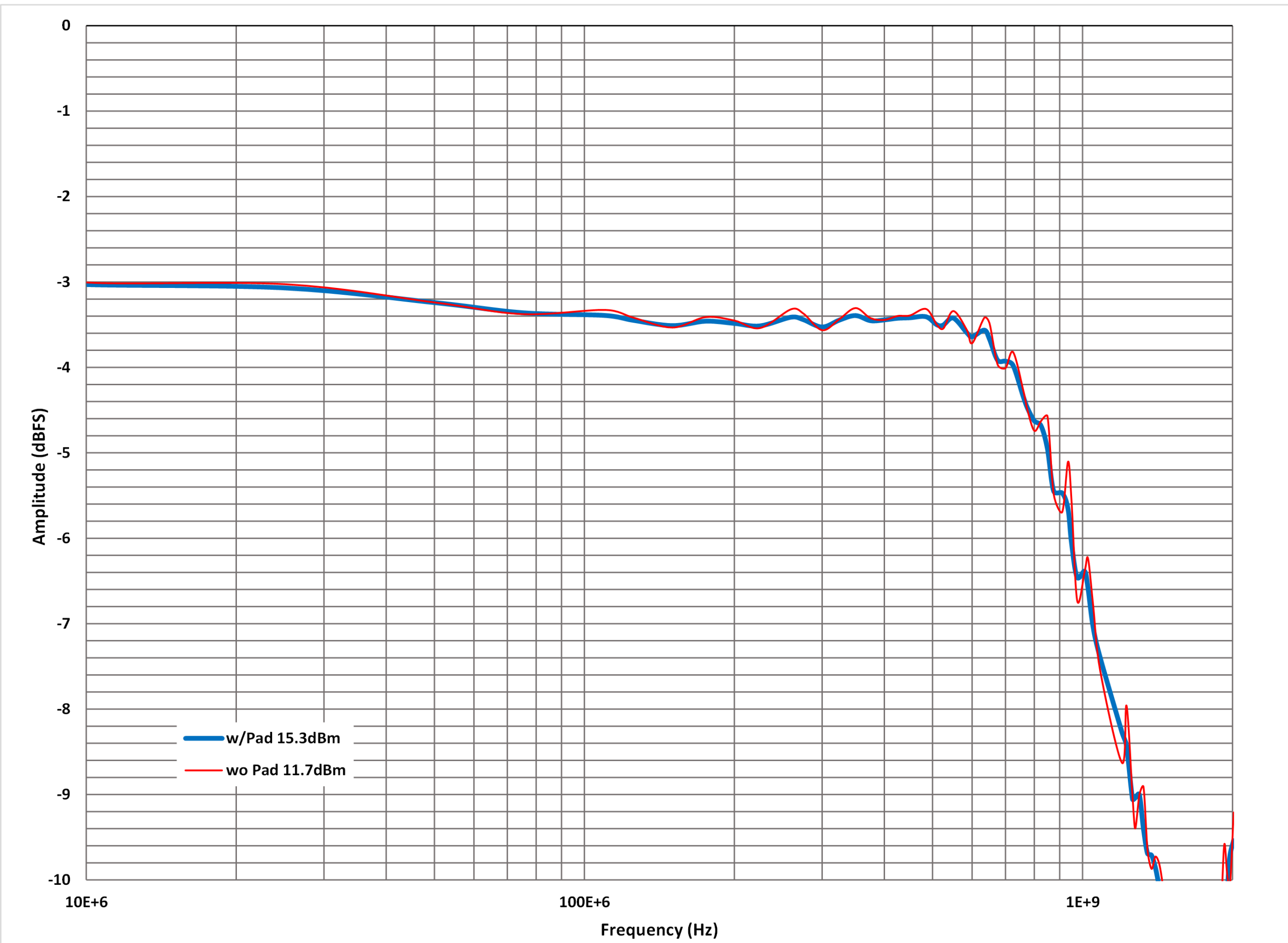

Figure 4-1. ADC Output Response With and Without 4dB of Attenuation on the Cable

5 Summary

The analog input or output bandwidth of a data converter is an important requirement when evaluating one to integrate into the system design, especially as converters move into the GHz range and beyond. Using the fundamental frequency response measurement method is an effective way to properly measure and collect the bandwidth response of the data converter and the frontend network used to acquire all passband flatness metrics.

When capturing the bandwidth for either an ADC or a DAC, remember to back calculate out any additional connection losses in setup, position the NCO appropriately when using digital features such as a DDC and DUC, and adjust for any output modes or filters used within the output response of the DAC. Finally, add lossy pads on the equipment cable to minimize standing waves. Adhering to these recommendations helps produce the best bandwidth results and mitigate ripple in the next design.

6 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.
- Reeder, Rob. 2020. *Unraveling the full-scale mysteries of your RF converter's analog inputs*. Electronic Products, April 13, 2020.