Electronic Design

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What Should Proper High-Speed Converter Passband Flatness Look Like? (Part 2)

Part 1 covered the fundamental frequency response measurement method and how to use it to measure the analog input bandwidth for an ADC. Part 2 discusses the DAC's analog output and offers tips to avoid effects such as standing waves.

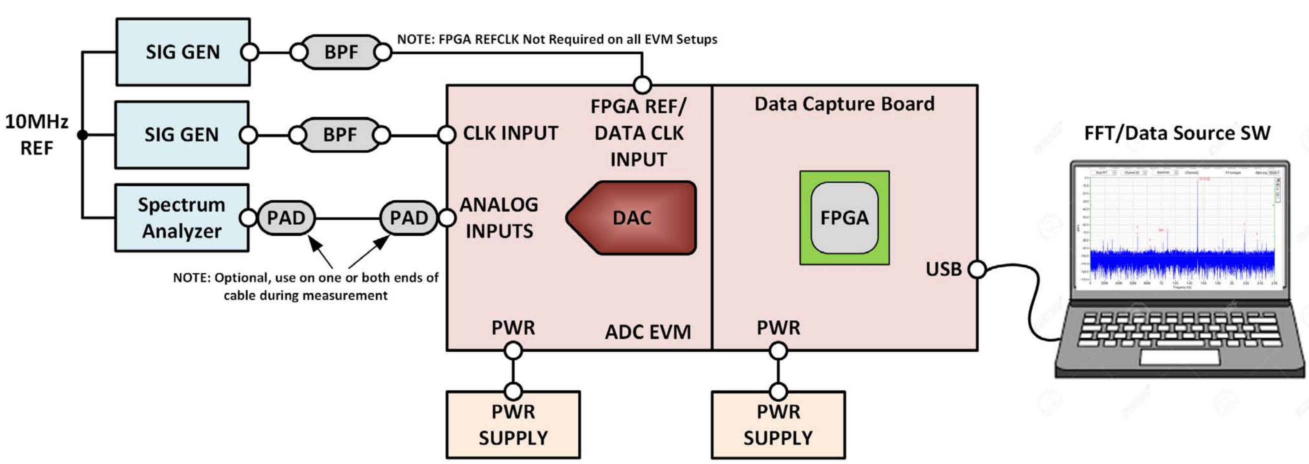
Although using the fundamental frequency-response measurement method to measure the flatness frequency response of a digital-to-analog converter (DAC) is like the one described for analog-to-digital converters (ADCs) in Part 1, there are a few differences. The first step is to set up the DAC's evaluation board with your preferred DAC configuration for testing. Your setup for the measurement should look like *Figure 1*.

This setup uses a PC to control a data-source board with a field-programmable gate array (FPGA) 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 DAC's evaluation board as well as to the data-source board. It's important to have all clock inputs and spectrum analyzers reference-locked by connecting the reference frequency outputs and inputs of the equipment.

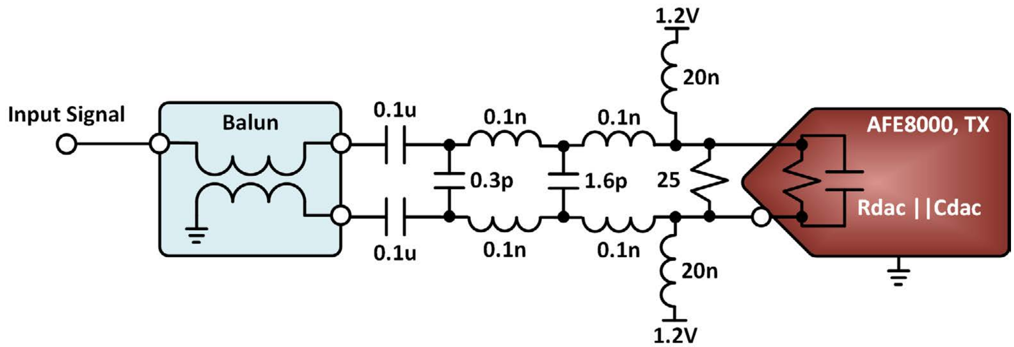
Finally, the DAC analog output connects to a spectrum analyzer to measure its output in the frequency domain. We recommend frequency planning accordingly to prevent any spurs or harmonics from disrupting your measurement.

Some DACs can have different output modes or filters to suppress spurs or flatten the frequency response. You must know the mode in 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 for the use



1. Shown is the fundamental frequency-response measurement method setup for a DAC.



2. Here's an example of an output network connected to the DAC.

of the inverse sinc() filter to flatten the frequency response of the sample-and-hold output. Other DACs have different filters for different Nyquist zones. For this reason, we don't 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 DAC's output tone and make appropriate adjustments to the settings of the spectrum analyzer. Usually, when measuring the frequency passband flatness, a continuous-wave tone ensures that all of the DAC's power output is in a single frequency bin. Try to make the span of the spectrum analyzer very narrow and reduce the resolution bandwidth until the fundamental amplitude is stable.

Once you've verified the setup, pick 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 spectrum analyzer's marker. This will help set the amplitude reference of the spectrum analyzer. Although this is an extra step, it ensures that you don't overdrive the spectrum analyzer and collect poor measurement results.

Next, provide the DAC with an input tone set at the starting frequency. Then 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 RF source. For example, you could disconnect the cable from the DAC's analog output 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 your DAC.

Subsequently, without changing the amplitude of the signal generator, sweep the signal generator's output while connected to the spectrum analyzer's input across the same intended measurement frequency range to record the fundamental shown by the spectrum analyzer only from the signal generator. This will capture the losses in the cable and spectrum analyzer across that frequency range. Subtracting this loss from the DAC measurement will obtain a more accurate result.

Adapting the Method for a DAC with Digital Upconversion Enabled

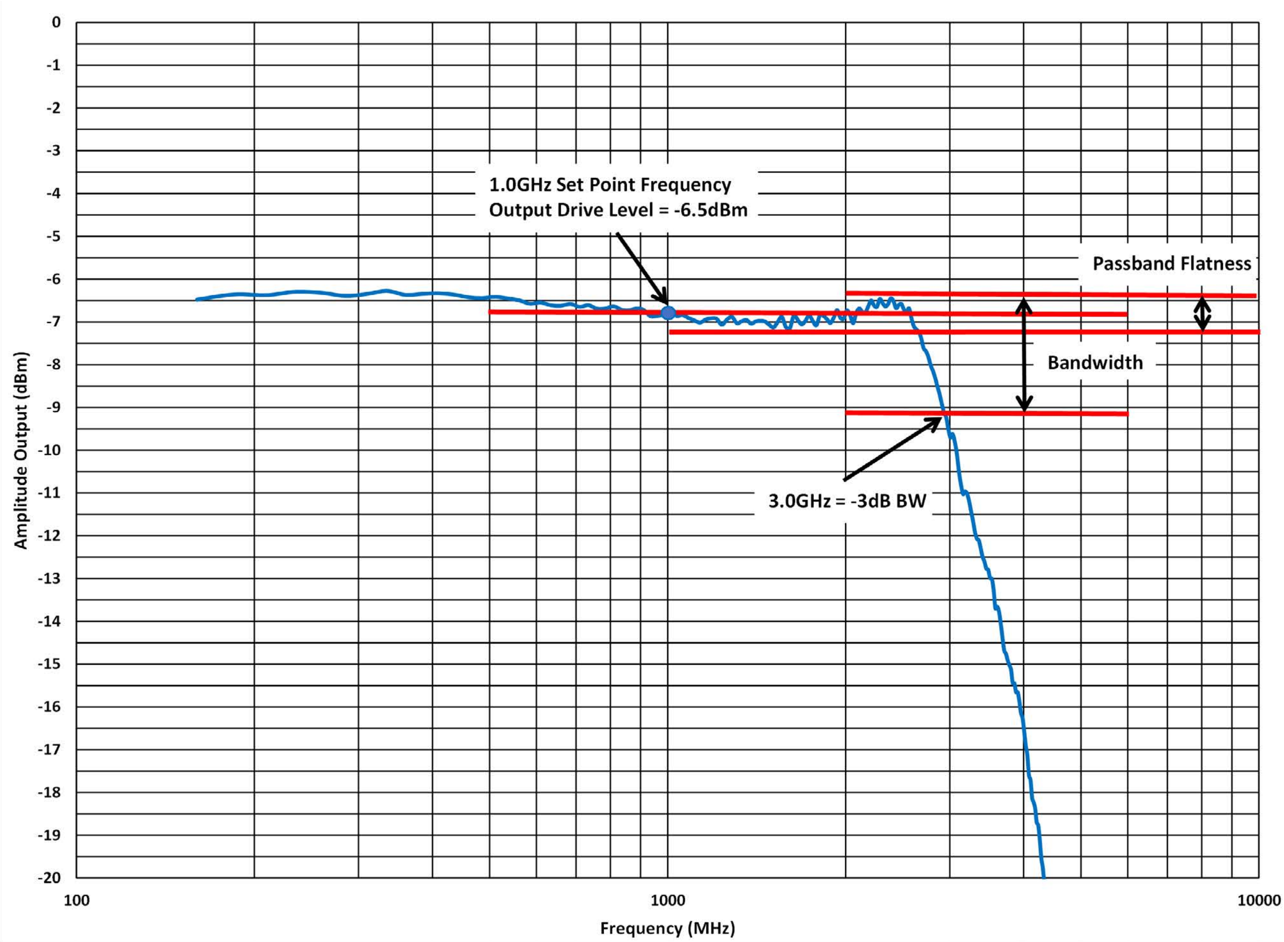
The steps we've just described will work for a DAC that uses real sampling—meaning one that doesn't use a digital upconverter (DUC) to transform the chosen signal from baseband to the chosen frequency. For a device that uses complex mixers in the transmitter chain, such as the AFE8000 from Texas Instruments (TI), a step must be added to the process of taking a pass-band flatness sweep: Adjust your numerically-controlled-oscillator (NCO) frequency so that the DAC's output frequency is at the appropriate frequency to sweep the output across the frequency band of interest. You can handle the NCO for the DAC's DUC as done in Part 1 for capturing an ADC's bandwidth when using an NCO.

As an example, see *Figures 2* and *3*, which illustrate an example output network for the transmitter channel and the data taken from the TXH channel of the AFE8000 with a matching network with 3 GHz of bandwidth.

A Note on Passband Flatness Measurements

Lastly, we recommended in either case—ADCs or DACs—that when performing this measurement, you use some in-line attenuation pads connected to the input/output cable, on one or both ends. We recommend 3- to 6-dB attenuation pads. Then, 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 converter's analog input/output from the signal generator or spectrum analyzer is to deal with any



3. This graph depicts the output passband flatness response of an AFE8000 DAC with digital upconversion enabled.

standing waves caused by impedance mismatches.

Remember that the signal generator or spectrum analyzer is expecting a good, stiff 50-Ω impedance match to maximally transfer power to the load ADC (or to receive it from the DAC). The input/output impedance of the converter is never going to be a solid 50 Ω across frequency, especially over a multi-gigahertz span and when the bandwidth begins to roll off.

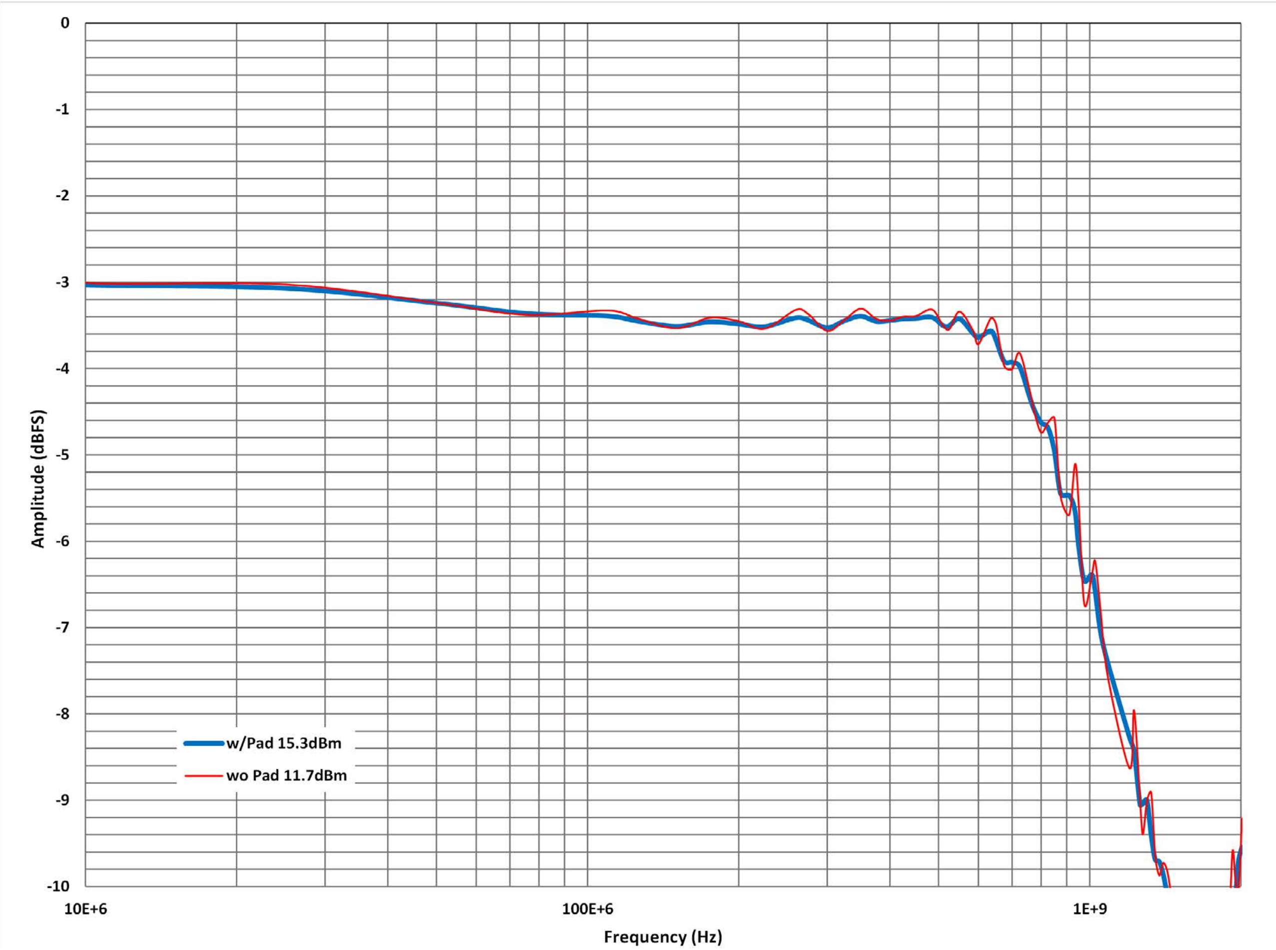
Standing waves will accumulate and show up in measurements, causing extra ripple across the measured frequency band if not dealt with by adding additional losses to the connection path. For example, the two measurements depicted in *Figure 4* were collected in the same way, except that one measurement had an attenuation pad on one end of the cable and the other measurement did not.

Attaining the Best ADC and DAC Bandwidth Results

In conclusion, a data converter's analog input or output bandwidth is an important requirement when evaluating these devices to integrate into your system design, especially as converters move into the gigahertz 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 front-end 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 your setup, position your NCO appropriately when using digital features such as a DDC and DUC, and adjust for any output modes or filters used within the DAC's output response. Finally, add lossy pads on the equipment cable to minimize standing waves. Adhering to these recommendations will help produce the best bandwidth results and mitigate ripple in your next design.

Rob Reeder is currently the application engineer for high-speed converters at Texas Instruments (TI) in Dallas. Rob's earlier experience includes RF design at Raytheon Missile Systems in Tucson, Ariz., including analog receivers and signal processing applications. He was also a system application engineer with Analog Devices in the High-Speed Converter and



4. Shown is ADC output response with and without 4 dB of attenuation on the cable.

RF Applications Group in Greensboro, N.C., for over 20 years. Rob has published over 130 articles and papers on converter interfaces, converter testing, and analog signal-chain design for a variety of applications. He received his MSEE and BSEE from Northern Illinois University in DeKalb, IL, in 1998 and 1996, respectively.

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