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What Should Proper High-Speed Converter Passband Flatness Look Like? (Part 1)

This two-part article series explains the fundamental frequency-response measurement method as applied to both ADCs and DACs, with or without internal digital downconverter or digital upconverter functions.

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 tricky or misleading. Whether you're sampling in the megasample- or gigasample-per-second ranges, the same principles apply in uncovering the necessary bandwidth of the converter, the analog input/output network connecting to the converter, or both.

In this two-part series, we will cover the fundamental frequency-response measurement method as it 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 will enable you to measure and characterize the analog bandwidth for the converter in your next receiver design.

Today, there are three methods for measuring 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 precisely and accurately measure the converter's bandwidth response. This method effectively de-embeds the analog input/output network connections.[1-3]
- The input pulse method, which uses a high-frequency square wave from a pulse generator. In this method, the user effectively inputs a pure pulse response and cross-correlates the ADC's output-captured response vs. an ideal square wave. Add a bit of math into the mix, and you can extract the bandwidth of the converter.

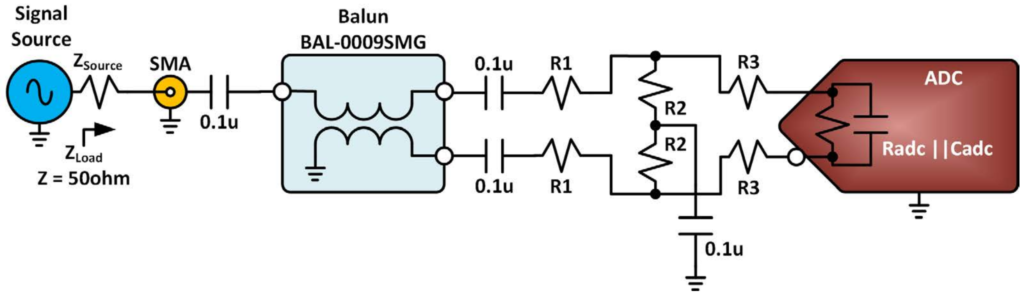
This series will focus only on the fundamental frequency-response measurement method as it applies to both ADCs and DACs, using Texas Instruments' (TI's) ADC12DJ5200RF ADC and the AFE8000 multi-channel transceiver as our example test cases. The first installment will focus on ADCs, while the second will cover DACs.

We will offer 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.

Measuring an ADC's Fundamental Frequency Response

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

Set up the converter evaluation module (EVM) or your own board design for the measurement. *Figure 2* illustrates a basic setup. Configure the EVM as you normally would as shown in the user's guide, for both hardware and software,



1. Shown is an example of an input network connected to the ADC.

to ensure 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. Adequate filters should also be employed to suppress any noise and harmonics created by the signal generators.

In making this measurement, don't filter the analog input. This allows for 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, or Python) makes it possible to collect the appropriate data at each frequency step you set.

The next step is to determine the start and stop frequencies for the pass-band-flatness sweep measurement, and a reference-point frequency to set the initial analog input drive level. If you're taking the reference-point frequency by hand, take at least five to 10 data points across each Nyquist zone to get a good idea of the bandwidth contour.

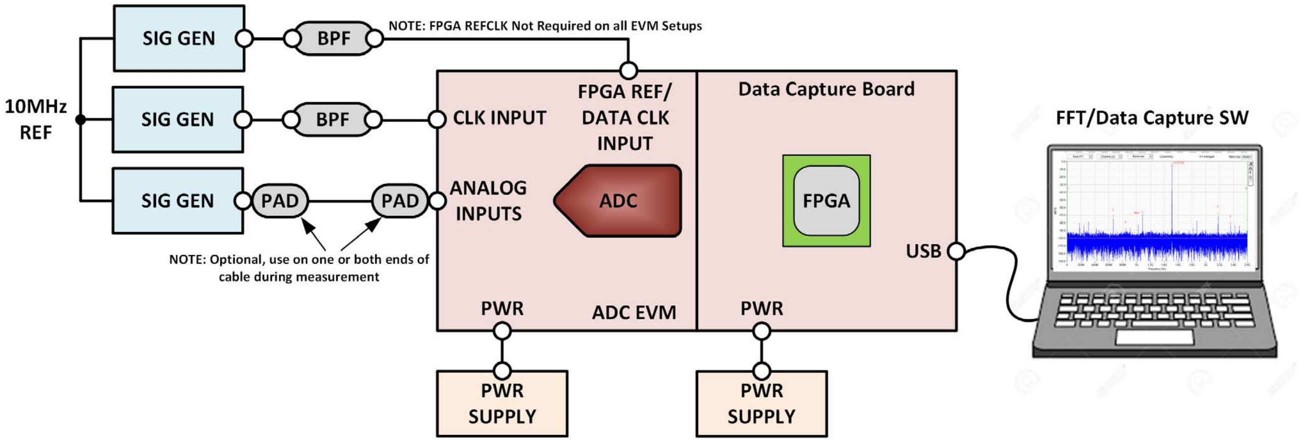
If you're only interested in a narrow or partial band of frequencies, or if you have implemented a passband antialiasing filter on your input network to the ADC, use the center frequency of the band of interest as the reference-point frequency.

Or if you're interested in a more wideband measurement or sweep, using about one-third the bandwidth as the setpoint frequency will ensure that it isn't too low or too high. This could otherwise induce roll-off on the upper or lower bands of the measurement. The datasheet of the ADC12DJ5200RF specifies a bandwidth of about 8 GHz. Because one-third of 8 GHz is roughly 2.67 GHz, that will be the setpoint frequency *(Fig. 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 your input drive level specification. Adjusting the setpoint level a bit lower than –3 dB_{FS} or –6 dB_{FS} ensures enough headroom, as the signal bandwidth of interest might move up and down over the measurement's start-and-stop frequency setpoints.

It's important to note the level in decibel milliwatts that you used on the signal generator. Keep in mind that the value of the signal generator's amplitude-output setting records only the output at the signal generator.

The amplitude level could differ at the point of entry, such as the SMA connector on the EVM or your own board, because of cable losses or RF plumbing and connectors that might be in line with this connection. You can take additional steps to calibrate out any cable or other losses from the measurement to obtain a better understanding of the actual signal level as it enters the input network front end on the EVM.



2. This image depicts the setup for measuring the fundamental frequency response of an ADC.

Once you've adjusted the setpoint frequency and input drive level, leave it as is. There's no need for further adjustment of the signal-generator level. This value gives you 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 you sweep across frequency. Continue to do so until the sweep has reached the stopping frequency.

Once you reach 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 your preferred data capture software.

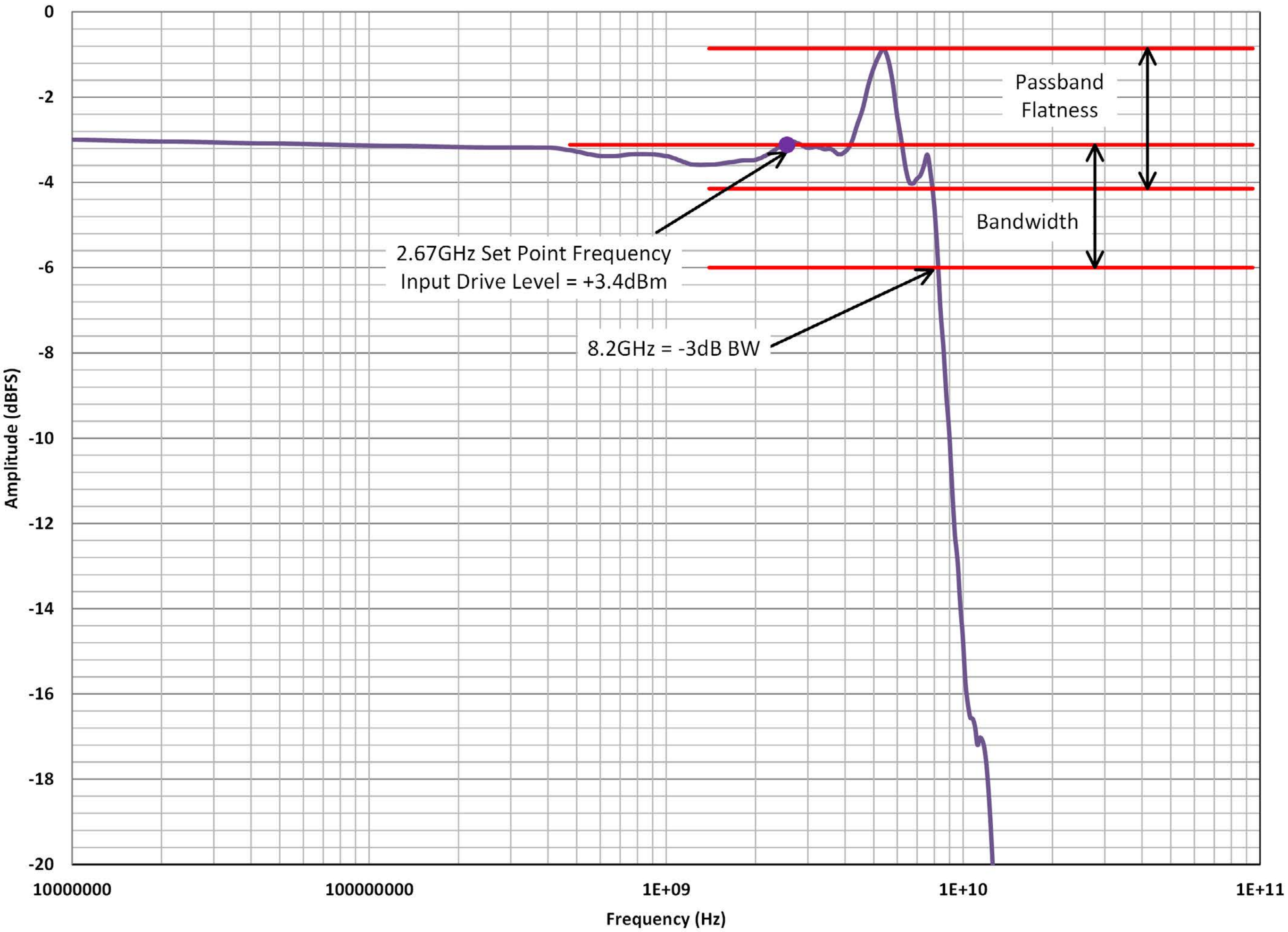
You can take the plus and minus levels from the resulting measurement to determine the actual signal amplitude across the swept measurement or resulting passband flatness curve *(Fig. 3, again)*. In this case, since the setpoint frequency is set to –3 dB_{FS}, a –6 dB_{FS} point results in –3 dB of bandwidth. Review the example in *Figure 3* for a way to properly note these parameters in the resulting measurement sweep.

Measuring the Fundamental Frequency Response of an ADC with DDC Enabled

The ADC example uses real sampling, sometimes called bypass mode. It doesn't utilize an internal DDC to down-convert 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. You will need to adjust your numerically controlled oscillator (NCO) frequency such that you can capture the input signal appropriately as you sweep your input across frequency.

There are two main approaches for this type of measurement. The first is to set your NCO to one frequency and then sweep your input across the frequency covered by the DDC



3. This graph shows the ADC12DJ5200RF ADC's input passband flatness response in bypass mode.

decimation filter's passband, usually around 80%.

We recommend this approach only when meeting two conditions:

- The post-DDC bandwidth must entirely cover the bandwidth you're trying to use. Because of the DDC decimation filters, any input outside of the passband will be attenuated, invalidating the accuracy of the measurement.
- When the receiver chain is operational in your application, you will keep your NCO at the frequency where you will record the measurement. This is a requirement, because getting the most accurate measurement means you must keep the NCO at one frequency to be able to also capture effects such as the passband ripple of your DDC decimation filters. If you were to move your NCO after making the passband flatness measurement, you would be shifting the passband, 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 of <0.2 dB.

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 aren't true, the second approach is to change your NCO frequency while sweeping the input signal across the bandwidth you're measuring. For example, you may need to measure a 1-GHz band centered around 2 GHz with 101 points by sweeping your input tone from 1.5 GHz to 2.5 GHz in steps of 10 MHz, while always keeping the NCO a certain distance (such as 10 MHz) from your input tone.

This method doesn't capture effects such as the in-band ripple of the DDC filters because it 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. This could otherwise cause undesired spurs and images to show up on your spectrum.

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

Conclusion: The Importance of ADC Bandwidth

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. A data converter's analog input or output bandwidth is an important requirement when considering its integration into your system design, especially as converters move into the gigahertz range and beyond.

The second installment of this series, dedicated to DACs, will include tips to avoid effects such as standing waves from disturbing your measurement.

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Reeder has published over 130 articles and papers on converter interfaces, converter testing, and analog signal-chain design for a variety of applications. Rob received his MSEE and BSEE from Northern Illinois University in DeKalb, IL, in 1998 and 1996, respectively. When Rob isn't writing papers late at night or in the lab hacking up circuits in the lab, he enjoys hanging around at the gym, listening to EDM, building rustic furniture out of old pallets, and, most importantly, chilling out with his family.

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