Rarely Asked Questions—Issue 129 Who Ate My dBs?

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Question:

I am setting my signal generator to output a CW tone at a certain power, which per my math, should give a –1 dBFS signal at the ADC. However, I am seeing –15 dBFS! Who ate all of my dBs?

Answer:

Quite often, the ADC (analog-to-digital converter) performance is specified at –1 dBFS. Some data sheets specify the distortion at 0.5 dB below full scale. Whether it is 1 dB or 0.5 dB below full scale, it is done so as to prevent clipping of the signal if one were to run the ADC inputs at full-scale (0 dBFS). Benchtop RF signal generators usually output signals in dBm. In order to achieve –1 dBFS on a 1.7 V p-p full scale ADC, one would only require 7.6 dBm signal level (based on a reference impedance of 50 Ω). However, when you do that, the ADC's single tone FFT output shows –6.7 dBFS. Is someone eating all the dBs? The answer lies right under the nose ... of the ADC that is. It is the ADC's front-end network. Let us take a closer look at the default front-end network for the AD9680 ADC.



Figure 1 : Default front-end network for the AD9680 evaluation board

The single-ended-to-differential conversion is done by a wideband balun, the BAL-0006SMG. A quick look at the data sheet for the BAL-0006SMG indicates that it has a 6 dB insertion loss across it. The matching network which follows the balun (R_s and R_{SH}) adds another 6 dB. This matching network is required to provide a wideband match to the balun output. There is a small amount of insertion loss presented by the series resistance in front of the ADC (R_{kB}). This resistor helps in improving third harmonic performance by reducing the kickback coming from the ADC's sample and hold stage. So let us work our way outward of the ADC to see how much power out of the signal generator is needed to get a -1 dBFS signal at the ADC. A reference impedance of 50 Ω is used for the math. For a default full scale level of 1.7 V p-p, a –1 dBFS signal would be 1.515 V p-p . Since the loss across the 10 Ω resistor is pretty small, we can assume that this is the voltage out of the termination network. The balun termination has a 6 dB loss across it, so the swing on each leg of the balun should be roughly twice the 1.515 V. This results in a single-ended input of about 3.03 V p-p. Therefore, the signal generator has to provide a signal that corresponds to about 3.03 V p-p or roughly 14 dBm. Note that this is not including the insertion loss through a band-pass filter or connector cables. So, revisiting Figure 1 again, this time with some annotations, we arrive at Figure 2. -1 dBFS



Figure 2. Front-end network with band-pass filter and signal generator.

Looping back to our question once more, the premise that a 7.6 dBm signal would be needed to get a –1 dBFS signal at the ADC is correct, if there is nothing besides the signal generator in front of the ADC. Okay, maybe throw in a balun. Now that there are other components (such as wideband balun, matching network, and kickback control) they all contribute to insertion loss that results in an attenuated signal at –6.7 dBFS. So, you can safely say "my front end ate all the dBs." You see, math is never wrong.

Equations that help:

dBFS =
$$20 \log \left(\frac{V_{IN}}{V_{FS}} \right)$$

where $V_{\mbox{\tiny IN}}$ is the input voltage, and $V_{\mbox{\tiny FS}}$ is the full-scale voltage

$$V_{\rm rms} = 0.3535 \times V \rm p-p$$

where V_{rms} is the rms voltage, and V p-p is the peak-to-peak voltage

 $P_{\rm dBm} = 10 \log \left(\frac{V_{\rm rms}^2}{R \times P_0}\right)$

where P_{dBm} is the signal generator power in dBm, V_{rms} is the rms voltage, R is the system impedance (50 Ω in this case), P_0 is 1 mW.



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