Application Note

Coherently Sampling in High-Speed Data-Converter Testing

Rob Reeder

ABSTRACT

Bad Fast Fourier Transfer (FFT) data captures can cause you to misunderstand the true performance of your high-speed or RF analog-to-digital converter (ADC). Some engineers like to coherently sample and capture data (which means to have the analog input frequency and clock frequency locked in phase with a reference frequency), while others do not necessarily need to. However, in either setup, there can be a need to refresh some details to present good data in your next design review.

Table of Contents

Trademarks

All trademarks are the property of their respective owners.

1 Introduction

Although there seems to be a lot of material about coherent and non-coherent sampling methods online, there is little guidance as to why you can use one sampling method versus the other. Most of the information that is available does not include the steps necessary to accurately take a measurement. There are details to keep in mind.

This article discusses the differences between coherent and non-coherent sampling in terms of an ADC test setup.

2 Coherent Sampling

Coherent sampling typically means you can take the 10MHz reference output used for the sample clock on one signal generator and connect the reference output to the 10MHz reference input used for the analog input signal on the other signal generator. Simply connecting the two signal generators together does not mean that the signal generators are phase-locked automatically, so for the reference lock to actually lock, you also need to select, enable, or initiate the signal generator with the 10MHz reference input in the signal generator's menu selection.

The signal generator can typically display a message such as EXTREF, indicating that the two signal generators are reference-locked together. See Figure 2-1.

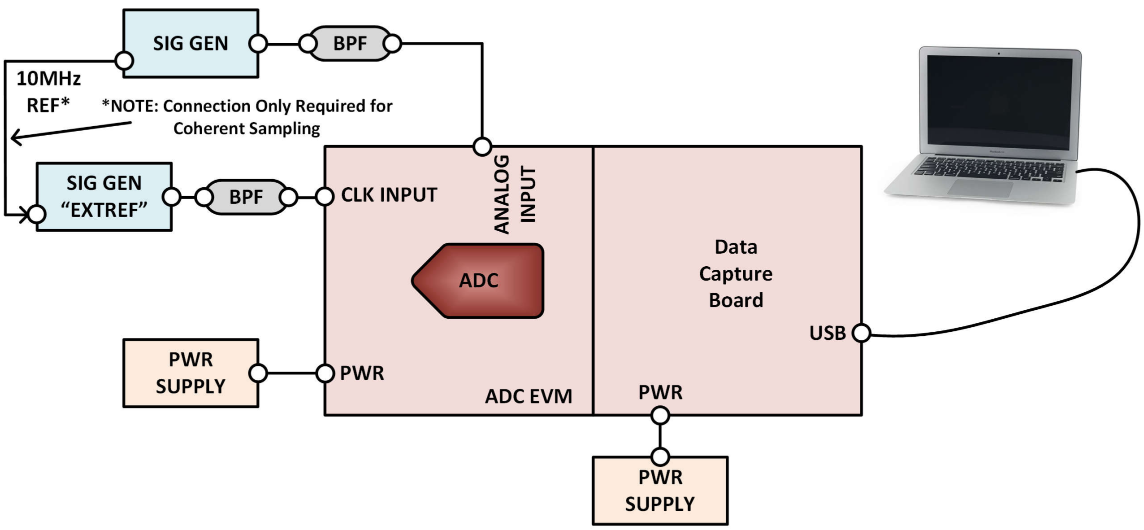

Figure 2-1. Typical Test Measurement Setup for FFT Data Capture

Next, select No Windowing or Rectangular Windowing in the FFT capture, enter the ADC sampling rate, and set the number of FFT points in the data-capture program or graphical user interface (GUI). Make sure that the data-capture board hardware can handle the number of FFT points. Then determine and calculate the exact analog input frequency and enter that frequency in the signal generator; you can also have to enter the frequency in the data-capture software. Figure 2-2 shows an example of a valid coherent sampled FFT data capture using the Texas Instruments (TI) ADC12DJ5200RF.

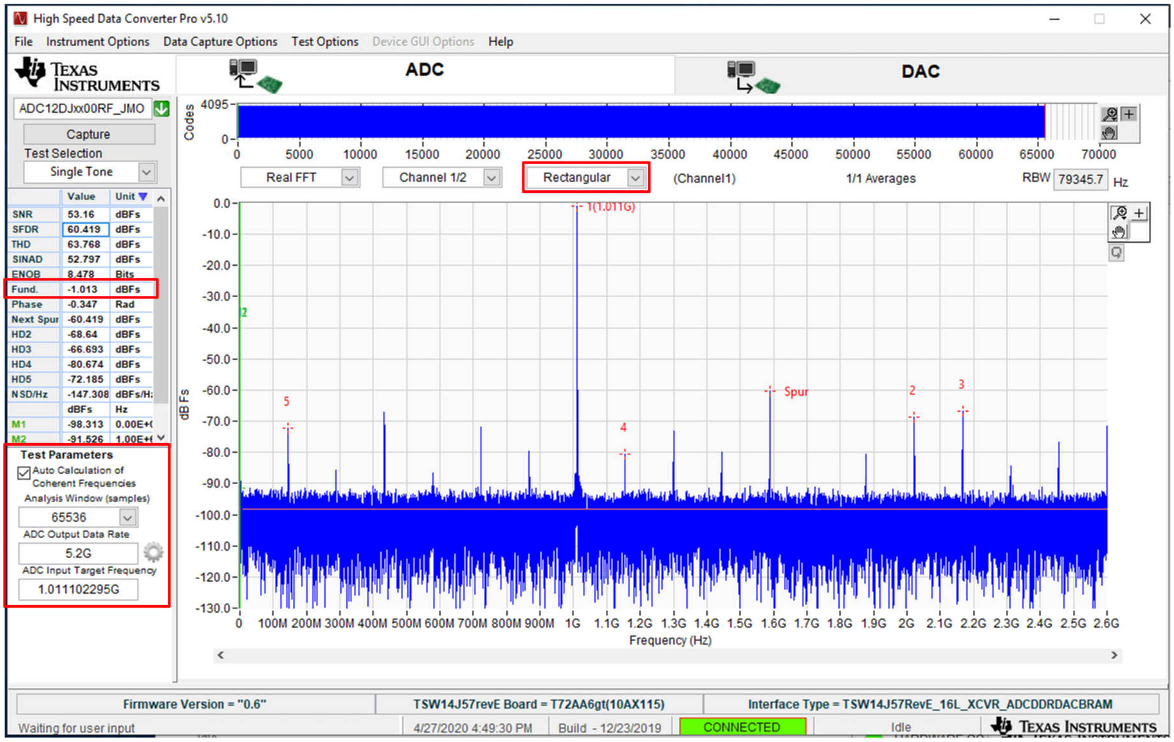

Figure 2-2. Example FFT Plot of the ADC12DJ5200RF Using Coherent Sampling

Coherent sampling makes sure that all of the FFT points are *bin centered* – that the fundamental and harmonic energy only reside in one bin or point in the FFT and can be placed at that exact location for measurement calculations such as the signal-to-noise ratio (SNR) and spurious-free dynamic range (SFDR). Figure 2-3 is a zoomed-in plot of the FFT around the fundamental bin. Note that the fundamental level, -1 dBFS, is the same as what is represented in the FFT plot.

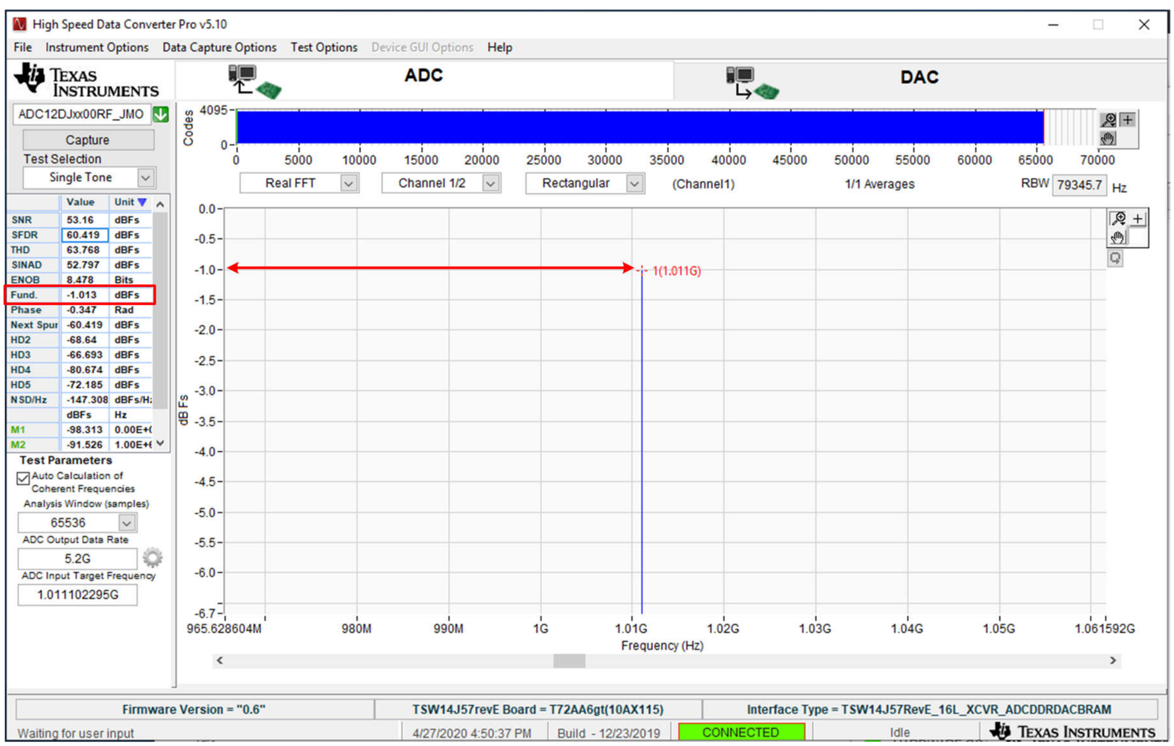

Figure 2-3. Example FFT Plot of the ADC12DJ5200RF Using Coherent Sampling Zoomed in Around the Fundamental Bin

3 Coherent Calculations

Now is the time to do a bit of math. The ADC12DJ5200RF, which we used in the example FFT plots previously, has an ADC sampling frequency (Fs) of 5,200MSPS, 65,536FFT points and an analog input frequency of 1,011MHz. Going through the calculations, this equals an analog input of 1011.102295MHz. Enter this frequency into the signal generator and data-capture software.

One way to perform these calculations is to download TI's high-speed data converter pro software, which is a GUI for evaluating TI high-speed data converter and analog front-end platforms.

This software can automatically calculate the exact coherent frequency when you select Auto Calculation of Coherent Frequencies under Test Parameters in the bottom-left corner.

Here is the math for calculating the coherent input frequency. There are three main parameters:

- Fs – the sampling frequency of the ADC.
- N – the number of points in the FFT. N must be a number that can be represented with a power of 2, such as 1,024, 2,048 or 4,096.
- Fin – the analog input frequency.

Plugging in the values for the ADC12DJ5200RF into these parameters, you have:

- Fs = 5,200MHz.
- N = 65,536.
- Fin = 1,011MHz.

The first thing you'll need to calculate is the FFT bin size or frequency resolution, commonly known as the resolution bandwidth (RBW). RBW is the smallest difference between two frequency bins displayed on an FFT plot, expressed as Equation 1.

$$RBW = \frac{Fs}{N} = \frac{5200MHz}{65536} = 79345.704 \; Hz \tag{1}$$

Next, calculate the FFT bin number corresponding to a Fin of 1,011MHz Equation 2.

$$bin \;\; number = \frac{Fin}{RBW} = 12741.710769 \tag{2}$$

As you can see, the bin number is not an integer value, which means that the energy of the 1,011MHz signal is not contained in a single FFT bin; this is also leaking into adjacent bins. To get coherent sampling, you need to bin-center the input signal – contain all energy to a single bin.

To obtain a bin-centered (coherent) signal, you must round the bin number to an integer number. In our example, rounding the bin number can give you a value of 12,742.

Next, recalculate the Fin based on the rounded bin number to obtain the coherent input frequency (Equation 3):

$$\text{coherent Fin} = \text{round (bin number)} \times \text{RBW} = 12{,}742 \times 79345.703125\text{Hz} = 1011.0229492\text{MHz} \tag{3}$$

The Fin value calculated in Equation 3 is coherent, but you can further improve the FFT performance measurement by choosing a bin number that is a prime number. Doing so, can eliminate signal-quantization periodicity; in other words, you can prevent the ADC from hitting the same codes along the input signal over and over in a periodical manner. Choosing a prime number as a bin number also prevents the harmonics from landing on top of each other, an effect shown in Figure 3-1.

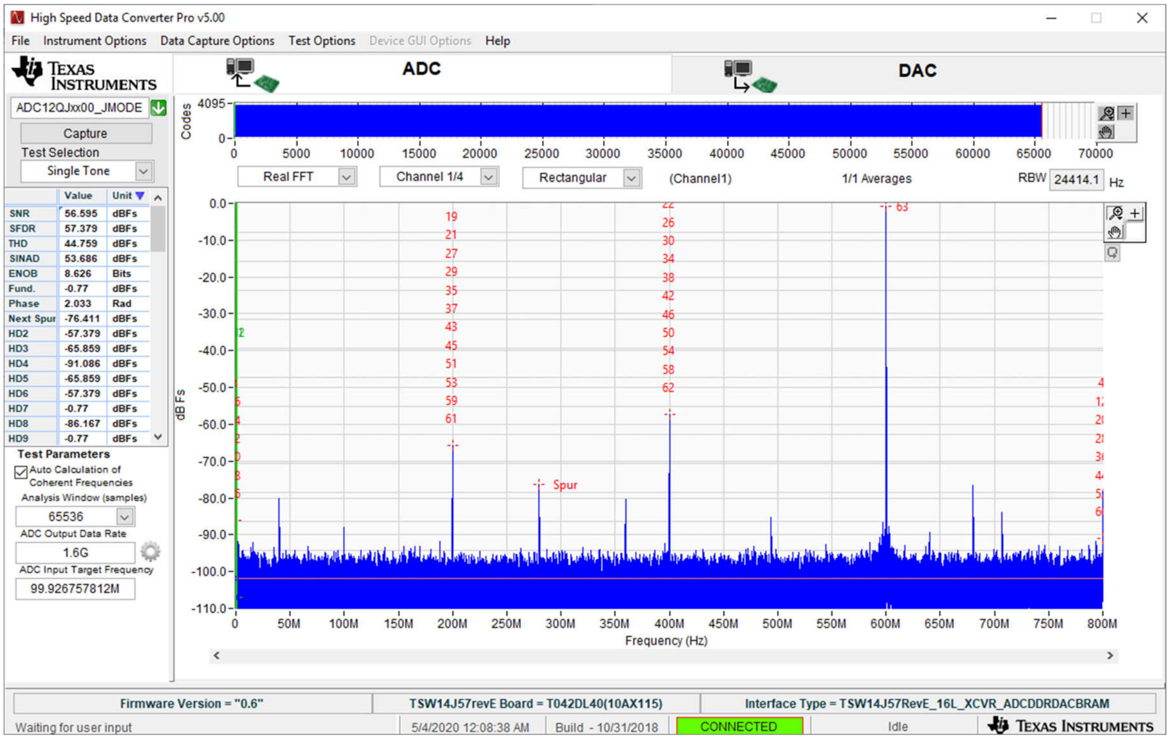

Figure 3-1. Coherent Sampling Without Using a Prime Bin Number

Next, you can need to modify Equation 3 and round the bin number integer value to the nearest prime number. Now, you can redo the calculation to find Fin Equation 4.

$$\text{coherent Fin} = \text{nearest prime number (round (bin number))} \times \square \quad \geq \tag{4}$$

Again using the example, the nearest prime bin number obtained earlier, 12,742, become 12,743. Plugging in the example values into Equation 4, the recalculated Fin using the nearest prime bin number becomes:

$$\text{coherent Fin} = 12{,}743 \times 79345.703125\text{Hz} = 1011.1022949\text{MHz} \tag{5}$$

Figure 3-2 shows an improved FFT measurement by choosing a prime bin number. Notice that none of the higher-order harmonics fold on top of each other as they did in Figure 3-1, thus enabling a more accurate evaluation of the ADC.

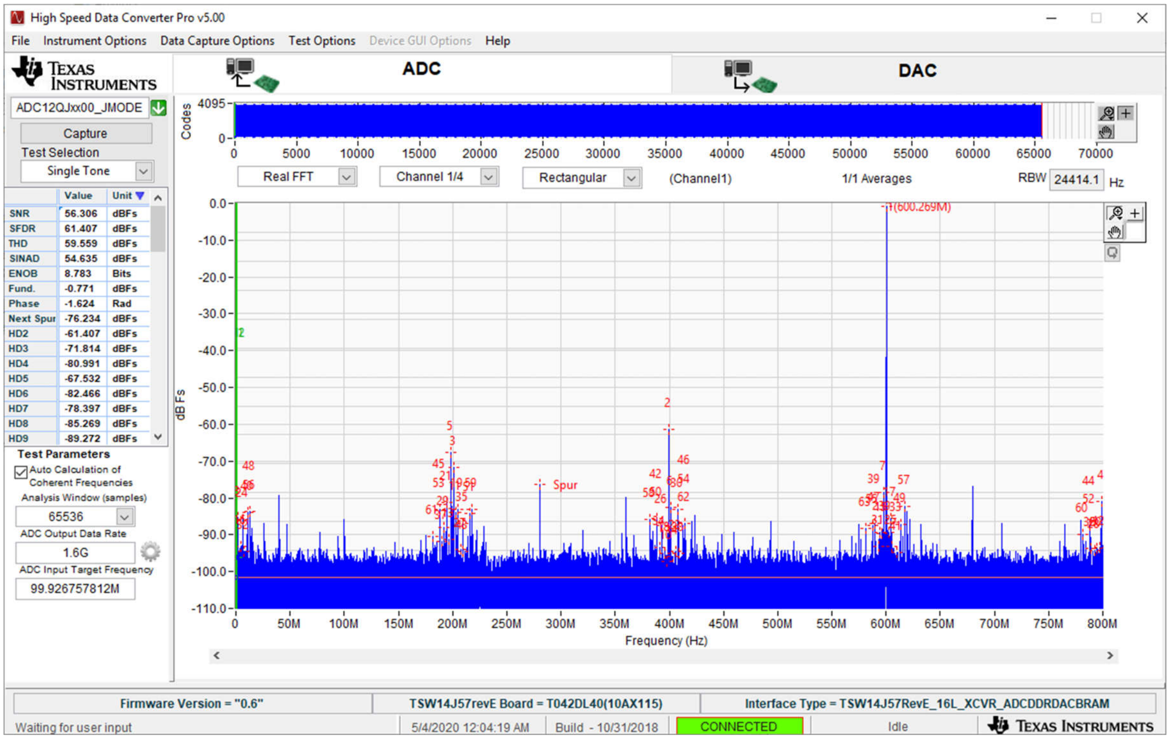

Figure 3-2. Coherent Sampling Using a Prime Bin Number

4 Noncoherent Sampling

Noncoherent sampling is when your analog input frequency and clock frequency are not reference-locked together. If you are using a setup similar to that shown in Figure 2-1, there is no need to use the 10MHz reference connection to lock the two signal generators together. Instead, you can *smear* the analog input frequency. For example, if you want to sample a 100MHz analog input signal, smearing means that you can instead use something close to 100MHz that is a prime number: 99.1235MHz or 101.1235MHz. Smearing makes sure that the ADC does not sample on the exact sample point along the sine-wave input signal each time, but instead *walks* along the signal and samples many points.

In your FFT data-capture program, using a windowing option like Blackman-Harris, this can make sure that the FFT capture spreads out the samples appropriately on the edges and prevents discontinuity between FFT captures. See Section 5 section later in this article for more information.

Figure 4-1 illustrates a valid noncoherent-sampled FFT data capture.

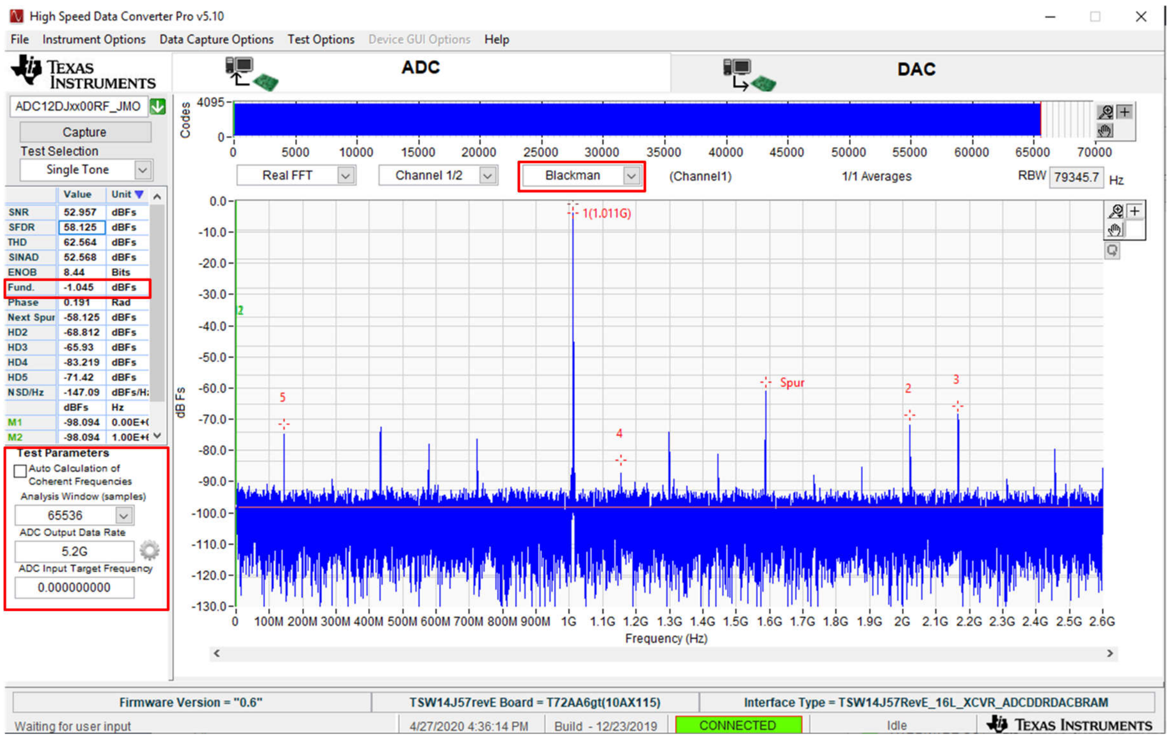

Figure 4-1. Example FFT Plot of the ADC12DJ5200RF Using Noncoherent Sampling

Noncoherent sampling makes sure that all FFT points are smeared appropriately. The fundamental and harmonic energy reside in more than one bin or point in the FFT capture and are available for measurement calculations such as SNR and SFDR.

Figure 4-2 is a zoomed-in plot of the FFT around the fundamental bin. The fundamental level is different roughly -3.5 dBFS; versus the value listed in the parametric table to the left, roughly -1 dBFS. The harmonic levels can appear differently as well. Again, this is because the FFT capture includes data from multiple points or bins and is the collective power summation of those bins. This is the -1dBFS number reflected on the left of the parametric table and in Figure 4-2.

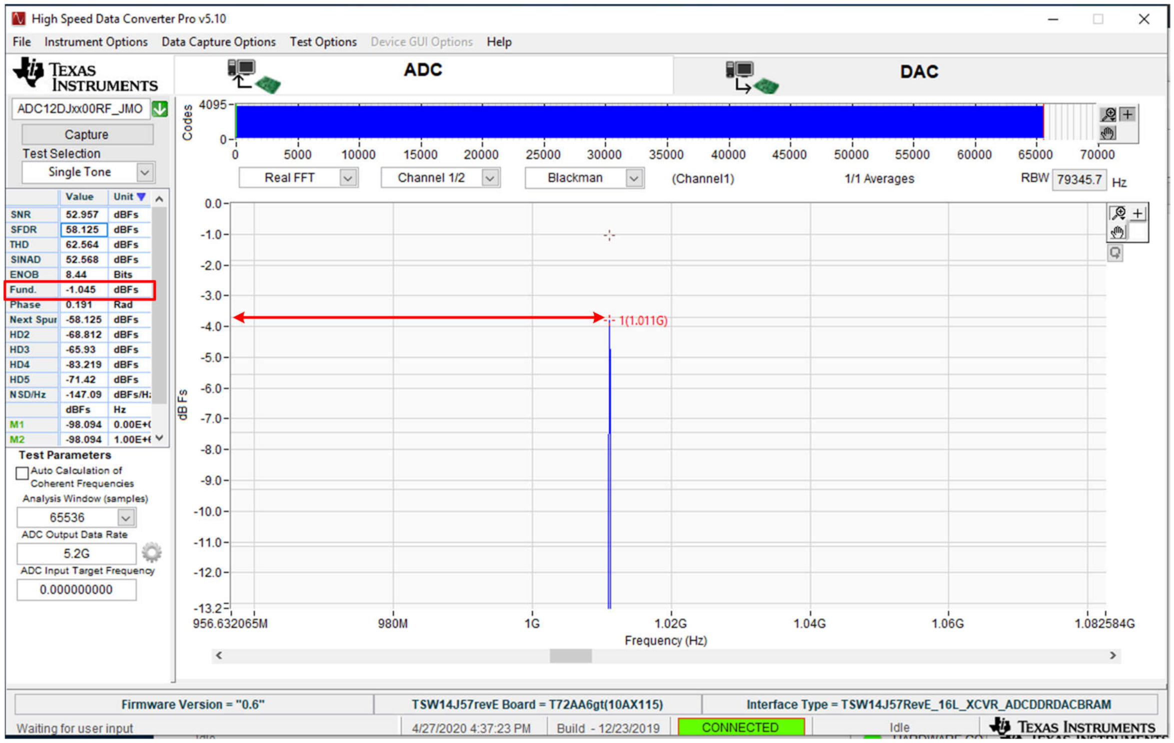

Figure 4-2. Example FFT Plot of the ADC12DJ5200RF Using Noncoherent Sampling Zoomed in Around the Fundamental Bin

5 Why We Window

When computing an FFT, you need to assume that an integer number of cycles of the signal need to fit in the number of samples analyzed in the FFT. Also, if you were to take the sampled waveform and put the sampled waveform end to end, you create a continuous sampled signal. Figure 5-1 shows a coherent signal example that completes five cycles in a 1,024 sample data set. Notice how the sine wave's start and end points blend into each other seamlessly, creating a continuous signal without any interruptions, jumps or discontinuities.

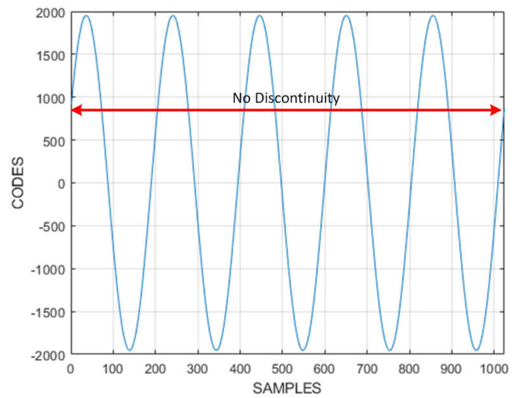

Figure 5-1. Coherent Signal

Figure 5-2 shows a noncoherent sine-wave signal. You can see that the start and end points of the sine wave do not coincide with each other, and if placed end to end can cause huge discontinuity. The resulting signal can end up being noncoherent, and you can see the signal power smeared across bins in the FFT measurement.

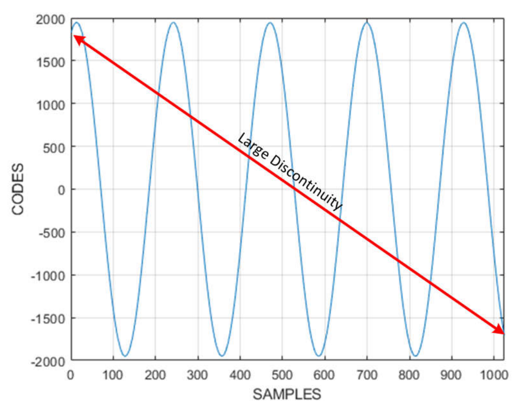

Figure 5-2. Noncoherent Signal

This is where applying a window function can make the difference between a coherent and noncoherent sampling. Window functions, Blackman-Harris, Hamming, etc., have specific shapes associated with them; however, there are several different functions from which to choose. By default, TI's high-speed data converter pro software uses the Blackman-Harris window function. Multiplying the window function with the noncoherent signal and zeros at both ends, removing any discontinuity and creating a more accurate FFT plot. Figure 5-3 shows an outline of the Blackman-Harris window function.

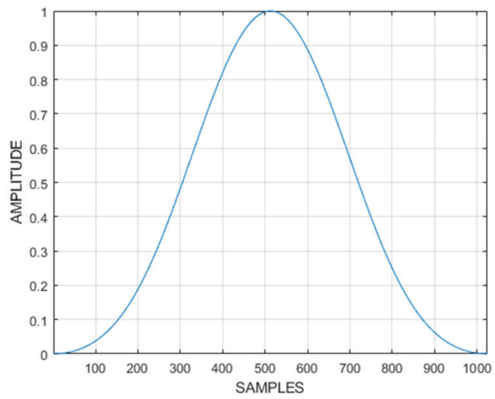

Figure 5-3. Blackman-Harris Window Function

When multiplying a noncoherent signal like that shown in Figure 5-2 with the window function shown in Figure 5-3, the output signal can be the windowed version of the noncoherent signal, as shown in Figure 5-4. You can see that both ends are zeroed out and that there is no discontinuity between end points.

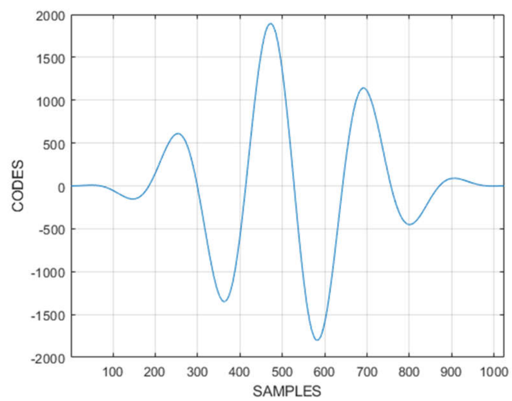

Figure 5-4. Noncoherent Signal Multiplied With the Window Function

6 Common FFT Follies

Figure 6-1, Figure 6-2, and Figure 6-3 emphasize some invalid FFT data captures that can lead to an inaccurate understanding of ADC performance. Our aim is to aid those designers new to ADC testing from an evaluation module or a system-level design standpoint who use FFT data captures to determine the overall performance of a signal-chain design.

The first FFT signature type is known as an FFT burp, illustrated in Figure 6-1. This FFT signature shows a wide skirt around the fundamental frequency and occurs when the designer intends to coherently sample but does not have the correct analog input frequency, or uses incorrect calculations. Notice that the SNR/SFDR performance is far from the ADC's data sheet performance specification.

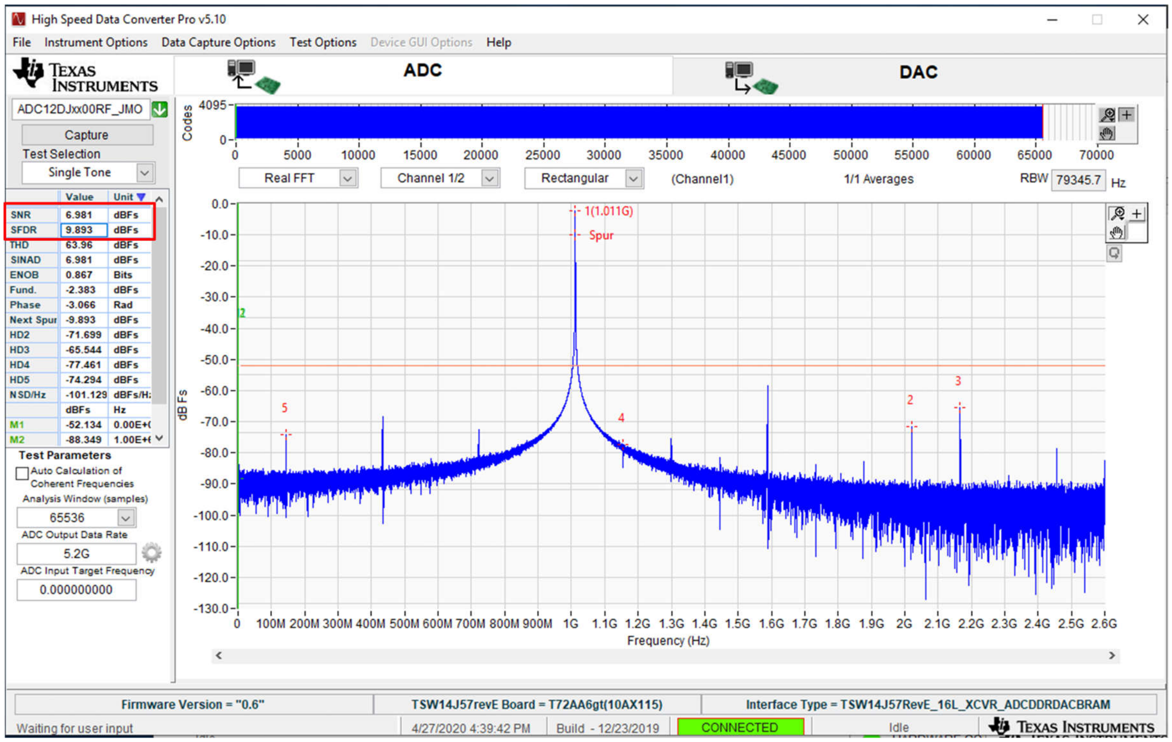

Figure 6-1. Coherent Sample That Results in an FFT Burp

Figure 6-2 shows another FFT signature type called the *FFT picket-fence* effect, which occurs when the user is almost accurate noncoherently sampling at the exact same place along the analog input signal. The issue here is that the analog input frequency is not a prime number, and therefore is not smeared enough in frequency to walk along the input signal at various points. In this case, the Fs = 5,200MSPS and the analog frequency is exactly 1000.0000MHz, which is not prime. Using a prime number like 1011.1235MHz, for example, can make sure enough smearing to accurately sample the analog input signal.

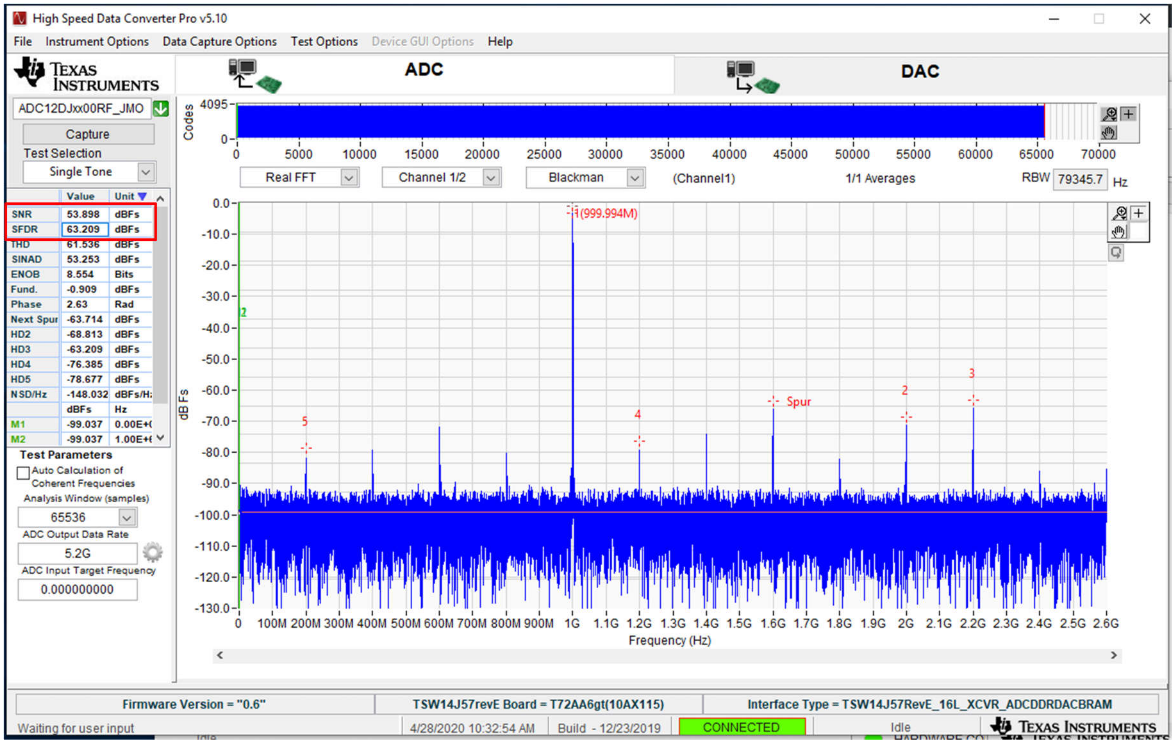

Figure 6-2. FFT Picket-Fence Effect When Noncoherently Sampling

The third signature type is called *FFT binning*. FFT binning is similar to an FFT picket fence, but is a direct multiple of the sampling rate. For example, as shown in Figure 6-3, Fs = 5,200MSPS and the analog input frequency is exactly one-fifth the sample frequency, or 1040.0000MHz.

What happens here is that, again, the same points along the analog input signal are sampled, but at such a rate that all of the harmonics fold on top each other – HD2 and HD3 in Figure 6-3, as well as the fundamental and HD4. You can easily fix the FFT binning effect by using a random prime number such as 1041.1359MHz.

Figure 6-3. FFT Binning Effect When Noncoherently Sampling

7 Summary

This article has dispelled the confusion on coherent sampling versus noncoherent sampling test methods and proper FFT data capture for various high-speed/RF ADCs. The next time you are in the lab collecting data on your signal-chain ADC design, you need to have confidence in presenting accurate FFT data collection measurements and rectify any FFT burping, picket fence and binning follies.

8 References

- *Coherent Sampling Calculator Online Calculation Tool*.
- *The FFT, Fundamentals and Concepts*, Robert W. Ramirez
- Texas Instruments, *ADC12DJ5200RF 10.4GSPS Single-Channel or 5.2GSPS Dual-Channel, 12-bit, RF-Sampling Analog-to-Digital Converter (ADC)*
- Texas Instruments, *DATACONVERTERPRO-SW High-Speed data Converter Pro Software*.