TEXAS INSTRUMENTS

Application Report
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Using Windowing With SNRBoost^{3G} Technology

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ABSTRACT

Coherency is a well-known requirement when using FFT techniques to examine the spectrum of the output of an analog-to-digital converter (ADC). SNRBoost^{3G} technology results in loss in coherency, and this can be seen as an unstable noise floor in the spectrum. Windowing of the ADC output is a well-known solution to restore coherency and stable spectrum.

However, windowing also modifies the amplitude of the fundamental signal and the SNR values. This masks the real improvement in SNR due to the SNRBoost^{3G} technology.

This application report explains the scaling caused by different window functions that can be used to recover the actual SNR of the original signal (prior to windowing).

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1 Introduction

FFT techniques are commonly used to examine the spectrum of the output of an analog-to-digital converter (ADC). One of the requirements when using FFT is to ensure coherency between the analog input signal and the sampling clock of the ADC.

When using an ADC with SNRBoost^{3G} technology, loss in coherency is observed. This can be seen as an unstable noise floor in the spectrum. Windowing of the ADC output is a well-known solution to restore coherency and stable spectrum. However, windowing also modifies the amplitude of the fundamental signal and the SNR values. This masks the real improvement in SNR due to SNRBoost^{3G} technology.

This application note explains the scaling caused by different window functions that can be used to recover the actual SNR of the original signal (prior to windowing).

2 SNRBoost3G Technology Causes Loss in Coherency

SNRBoost3G technology works by improving the noise within a select band of frequencies. At the same time, the noise degrades outside the selected frequency band (Figure 1).

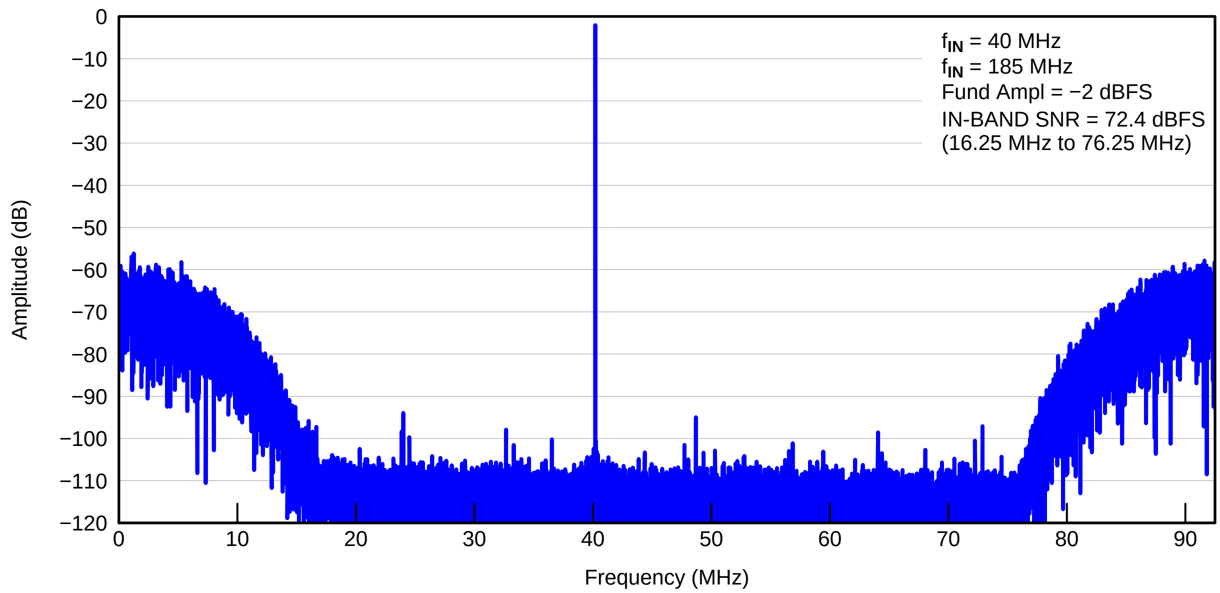

Figure 1. Spectrum of Signal With SNRBoost3G On

Note that although the noise in the selected band improves with SNRBoost3G enabled, the noise over the entire band degrades (compared to SNRBoost3G disabled). For example, the full-band SNR is 66.91 dBFS with SNRBoost3G disabled and 32.73 dBFS with SNRBoost3G enabled (Figure 2).

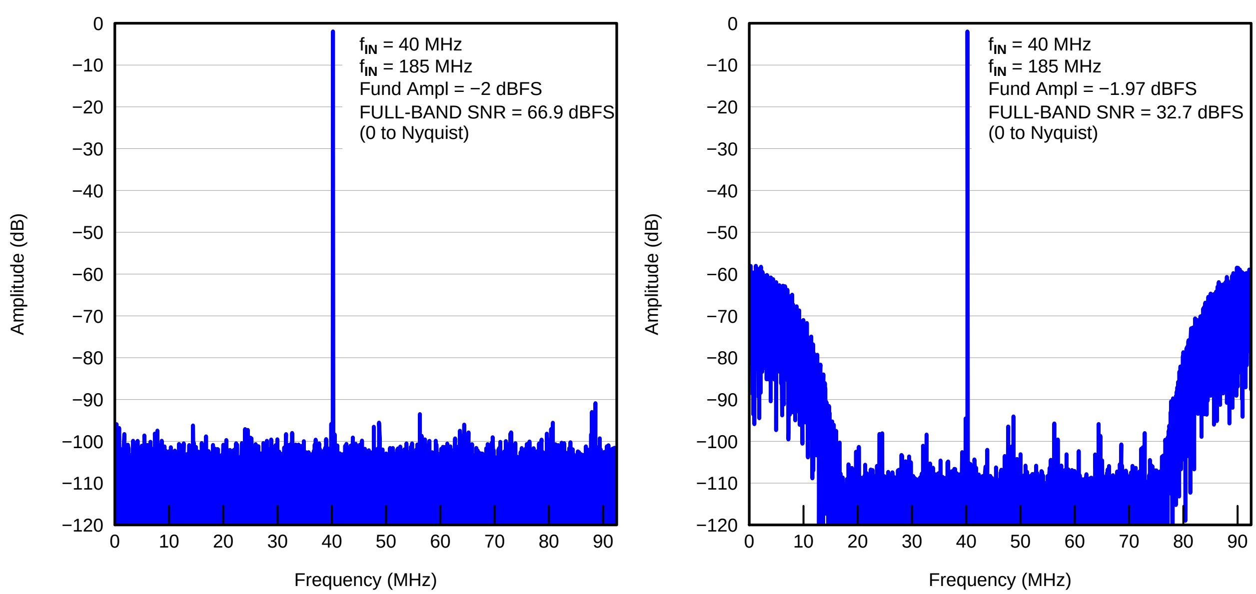

Figure 2. Full-Band SNR Comparison With SNRBoost3G Disabled and Enabled

In the time domain, this SNR degradation shows up as an increase in the range of code variations. For example, the output code range is 1 LSB with SNRBoost3G disabled and 113 LSBs with SNRBoost3G enabled (Figure 3).

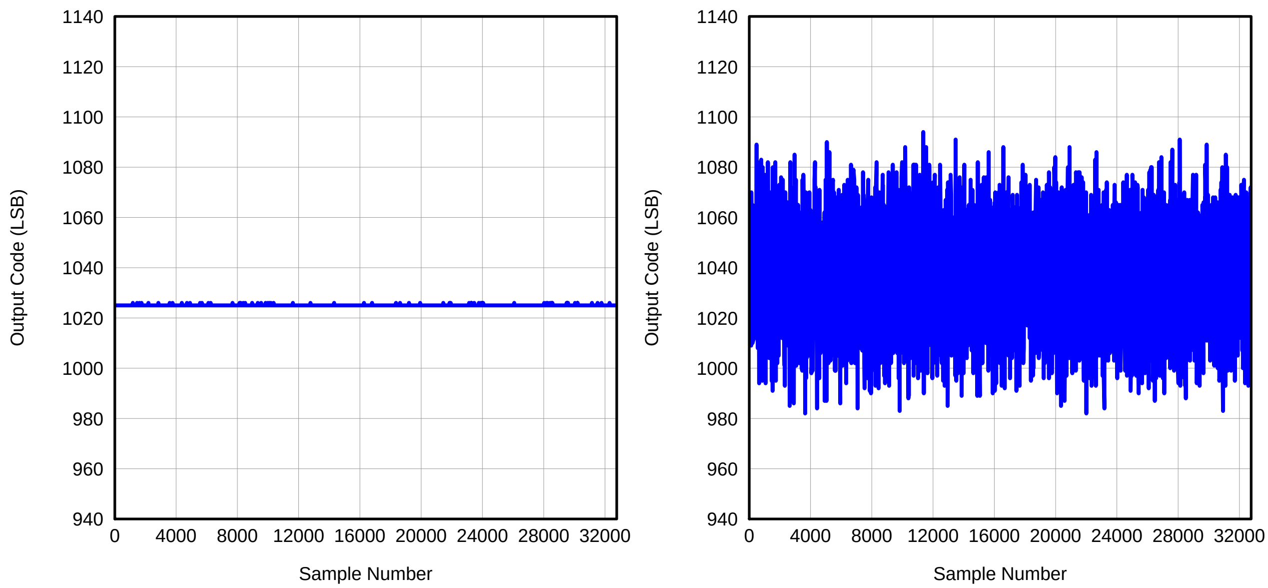

Figure 3. Time Domain Data With SNRBoost^{3G} Disabled and Enabled (With No Input Signal)

The increased noise results in loss of coherency. The FFT spectrum of this data has a noise floor that is not uniformly flat and changes from one capture to the next.

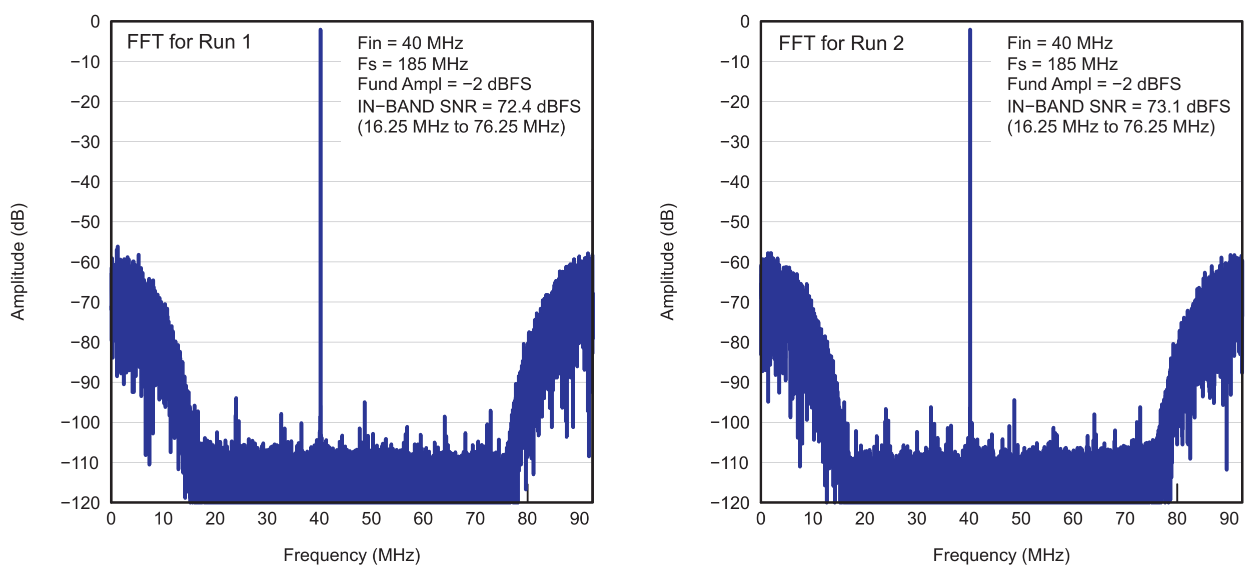

Figure 4. Unstable Spectrum With SNRBoost^{3G} Enabled

3 Using Windowing

Windowing can be used to overcome the loss in coherency. Any of the common window functions (Hanning, Hamming, Blackman-Harris, etc.) can be applied to the ADC output data. The resulting signal is now coherent with a stable noise floor in the FFT spectrum.

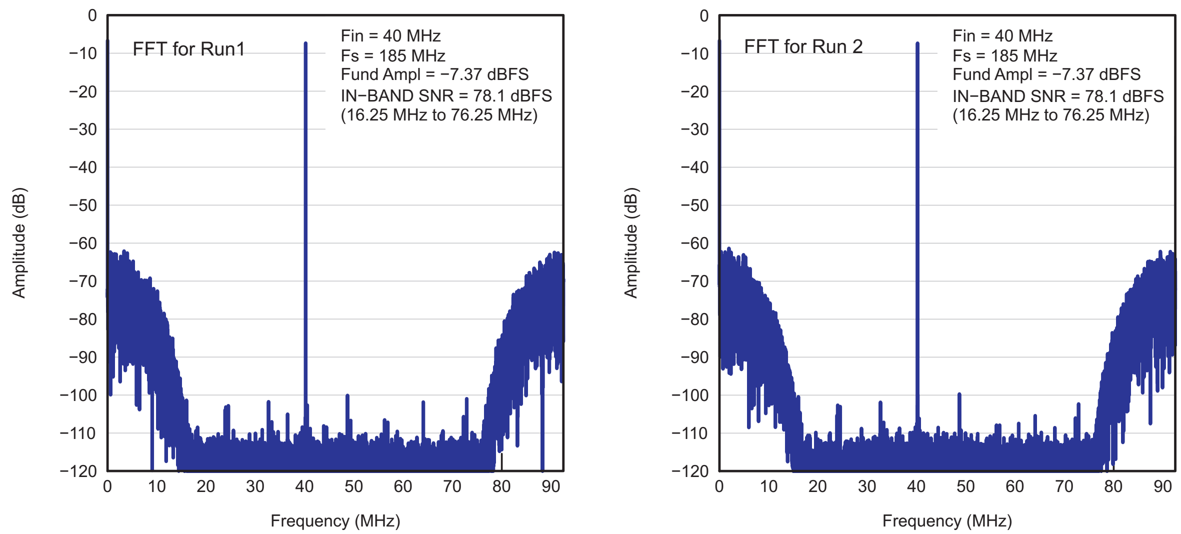

Figure 5. Stable Spectrum With SNRBoost^{3G} Enabled and After Windowing

The windowing has one side effect: the amplitude of all the frequency bins in the spectrum are reported smaller than their actual values. For a narrow-band signal, the fundamental signal and the rest of the spectrum are modified by different amounts as shown in Table 1.

Table 1. Effect of Windowing

Window Function	Delta SNR (dB)	Delta Signal Amplitude (dB)
Hamming	4.01	5.35
Hanning	4.26	6.02
Blackman Harris	5.88	8.90

Use Table 1 to determine the SNR and signal amplitude of the original signal without windowing as follows:

SNR (*pre-windowing*) = SNR (*post-windowing*) – Delta SNR

Signal Amplitude (*pre-windowing*) = Signal Amplitude (*post-windowing*) + Delta Signal Amplitude where SNR and Signal Amplitude are reported in dBFS values.

In this way, the correct SNR of the signal with SNRBoost^{3G} enabled can be determined.

3.1 Example

With the preceding method, the improvement in SNR using SNRBoost^{3G} technology in the ADS58C48 can be determined.

Consider a case where the sample clock is 184.32 MSPS and the input signal bandwidth is 60 MHz centered at 46 MHz. With SNRBoost^{3G} disabled, the in-band SNR reported is 68.6 dBFS. After the SNRBoost^{3G} technology is turned on, a *Hamming window* is applied to the ADC output data. The spectrum of the windowed signal reports an in-band SNR of 78.1 dBFS.

Using Table 1, find the in-band SNR (*pre windowing*) with SNRBoost^{3G} ON:

= 78.1 dBFS – 4.01 dB
= 74.09 dBFS

This means that the SNRBoost^{3G} technology resulted in an in-band SNR improvement:

= SNR (*pre-windowing*) with SNRBoost^{3G} on – SNR with SNRBoost^{3G} off
= 74.01 dBFS – 68.6 dBFS
= 5.49 dB within the band of 60 MHz.

Appendix A Theory

The aim of this section is to determine the change in spectral power after windowing. To find this, a single tone input signal is used that is coherent and has known power. The input signal is then multiplied by the window function. The difference in the power of the tone between the input signal and the windowed signal gives the desired result.

Consider two N-point sequences V(n) and W(n), that represent the ADC output data and the window function sequence, respectively.

$$V(n) = A \cos\left(\frac{2\pi}{N} k\, n + \theta\right) \tag{1}$$

$$W(n) = m_1 + m_2 \cos\left(\frac{2\pi}{N - 1} w\, n\right) \tag{2}$$

For simplicity of analysis, the ADC output sequence is assumed to be a single tone with all other tones having zero power. Because the spectrum from N/2 to N–1 is a mirror image of the spectrum from 0 to N/2–1, the spectrum is represented only in the range 0 to N/2–1, after adjusting the power of each tone.

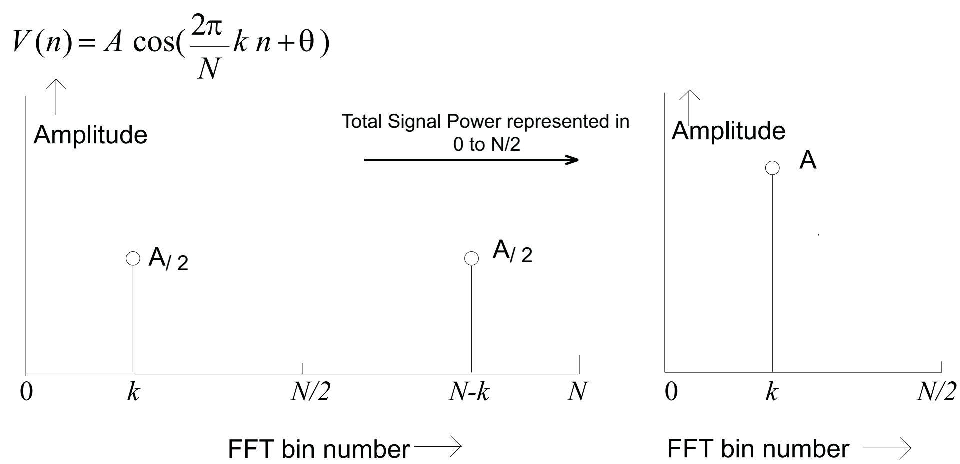

Figure 6. Spectrum of ADC Output Sequence

Similarly, the spectrum of the window function is shown in Figure 7.

$$W(n) = m_1 + m_2 \cos(\frac{2\pi}{N-1} wn)$$

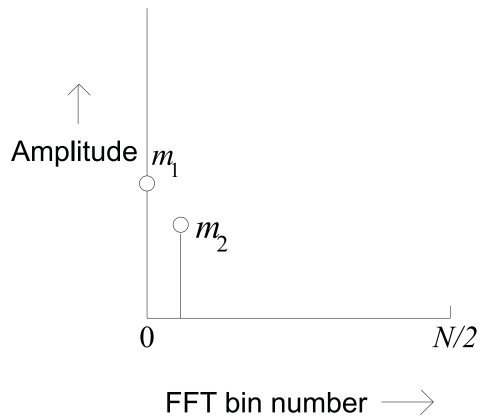

Figure 7. Spectrum of Window Function

Windowing involves multiplication of the ADC output sequence by the window function.

So,

$$\begin{aligned} V_o(n) &= V(n)\, W(n) \\ &\approx A \cos\left(\frac{2\pi}{N} kn + \theta\right) \quad \left(m_1 + m_2 \cos\left(\frac{2\pi}{N} wn\right)\right) \\ &= m_1\, A\cos\left(\frac{2\pi}{N} kn + \theta\right) + \frac{m_2\, A}{2} \cos\left(\frac{2\pi}{N}(k - w)n + \theta\right) + \frac{m_2\, A}{2} \cos\left(\frac{2\pi}{N}(k + w)n + \theta\right) \end{aligned} \quad (3)$$

The spectrum of the signal after windowing is shown in Figure 8.

$$v_o(n) = W(n)\ v(n)$$

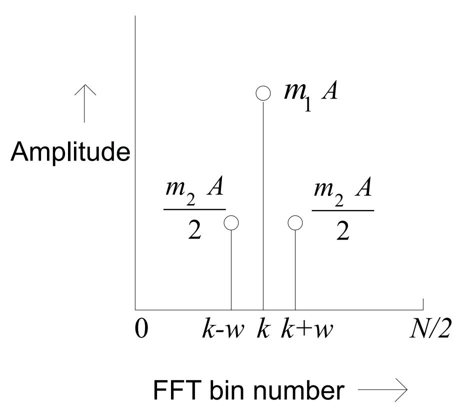

Figure 8. Spectrum of Signal After Windowing

Note that each tone with bin number 'k' in the input signal spreads into three tones.

- One main tone (at bin k) having amplitude m_1A and
- Two side tones (at bins k ± w) having amplitudes m_2A / 2.

The change in signal amplitude of the main tone is due to windowing = 20 log (m_1)

Note that it is assumed that the input signal has zero amplitude noise components. With non-zero noise components, the input signal can be represented as:

$$V(n) = A\cos\left(\frac{2\pi}{N}kn + \theta\right) + \sum_{r=0}^{N-1} B_r \cos\left(\frac{2\pi}{N}rn + \phi_r\right) \tag{4}$$

Similar to the signal tone, each noise component is also spread into three tones having

$$\text{amplitudes } m_1B_r \text{ and } \frac{m_2 B_r}{2} \tag{5}$$

The total power of all noise components after windowing is

$$= m_1^2 \sum_{r=0}^{N-1} B_r^2 + \frac{m_2^2}{4} \sum_{r=0}^{N-1} B_r^2 + \frac{m_2^2}{4} \sum_{r=0}^{N-1} B_r^2$$

$$= \left(m_1^2 + \frac{m_2^2}{2}\right) \sum_{r=0}^{N-1} B_r^2 \tag{6}$$

Because $\sum_{r=0}^{N-1} B_r^2$ represents the noise power of the ADC output sequence, Equation 6 can be re-written as:

$$\text{Noise power after windowing} = \left(m_1^2 + \frac{m_2^2}{2}\right) \times \text{ADC output noise power.} \tag{7}$$

$$\text{So, the change in the SNR after windowing} = 10\log\left(m_1^2 + \frac{m_2^2}{2}\right) \tag{8}$$

Table 2 lists the changes in signal amplitude and SNR after windowing for some common window functions.

Table 2. Window Functions

Window Function	m1	m2	w	Delta SNR (dB)	Delta Signal Amplitude (dB)
Hamming	0.54	–0.46	1	4.01	5.35
Hanning	0.5	–0.5	1	4.26	6.02