Hideo Okawara's
Mixed Signal Lecture Series

DSP-Based Testing – Fundamentals 31
Window in Spectrum Analyses vs. Window in FIR Generation

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Preface to the Series

ADC and DAC are the most typical mixed signal devices. In mixed signal testing, analog stimulus signal is generated by an arbitrary waveform generator (AWG) which employs a D/A converter inside, and analog signal is measured by a digitizer or a sampler which employs an A/D converter inside. The stimulus signal is created with mathematical method, and the measured signal is processed with mathematical method, extracting various parameters. It is based on digital signal processing (DSP) so that our test methodologies are often called DSP-based testing.

Test/application engineers in the mixed signal field should have thorough knowledge about DSP-based testing. FFT (Fast Fourier Transform) is the most powerful tool here. This corner will deliver a series of fundamental knowledge of DSP-based testing, especially FFT and its related topics. It will help test/application engineers comprehend what the DSP-based testing is and assorted techniques.

Editor's Note

For other articles in this series, please visit the Verigy web site at www.verigy.com/go/gosemi.

Preface

Window applications were already discussed in the previous Lecture Series of "Windowing"[1] and "FIR (Finite Impulse Response) Filtering."[2] Author learned from communication with a local application engineer that the article about FIR filtering might give confusion between windowing and filtering, because both topics relate to spectrum analyses. So it is a good opportunity to review windowing and FIR filtering in order to refresh readers' memories.

Blackman-Harris Window Function

There are many window functions available. Hanning and Flat-top are the most useful functions in our test arena so that they are already discussed very much. Here in this article the Blackman-Harris window is taken as an example. This function is defined as follows.

$$w(k) = a_o - a_1 \cos\left(\frac{2\pi k}{N}\right) + a_2 \cos\left(\frac{4\pi k}{N}\right) - a_3 \cos\left(\frac{6\pi k}{N}\right) \quad (1)$$

where a_o=0.35875, a_1=0.48829, a_2=0.14128 and a_3=0.01168.

This function looks as the curve that Figure 1 illustrates, where the data size (N) is 1024. The both ends converge on zero, which is very important characteristic for our applications.

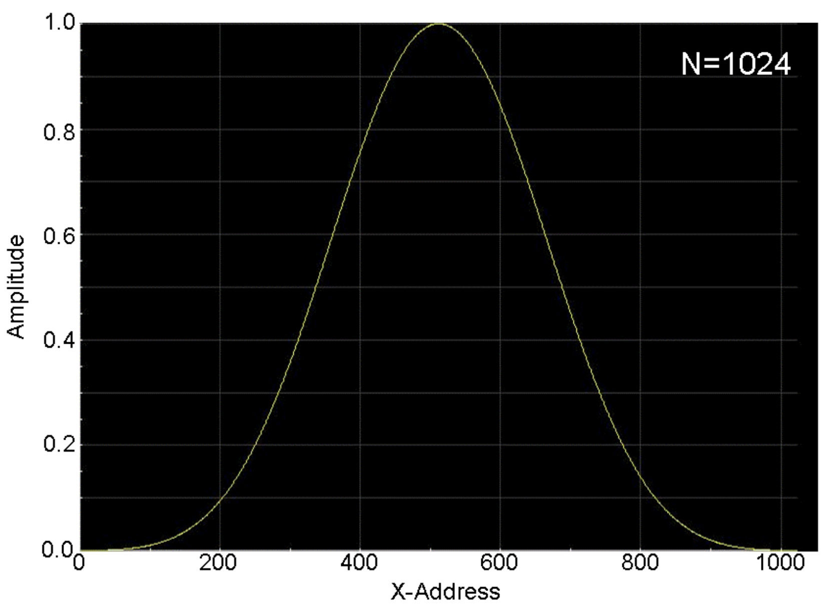

Figure 1 Blackman-Harris Window Curve (Array Size=1024)

[1] Hideo Okawara's Lecture Series "DSP Based Testing – Fundamentals 11 Windowing"
[2] Hideo Okawara's Lecture Series "DSP Based Testing – Fundamentals 14 FIR Filter"

Window Application for Spectrum Analysis

Figure 2 shows the sinusoidal waveforms. The yellow line is a 1V sinusoid containing 51.4 cycles with 1024 sampling points in the unit test period (UTP). It is intentionally captured fractional cycles. The cyan colored curve shows the Blackman-Harris window applied waveform. The original waveform has the level of 0.7071Vrms, but the window weighted waveform is reduced to 0.3591Vrms.

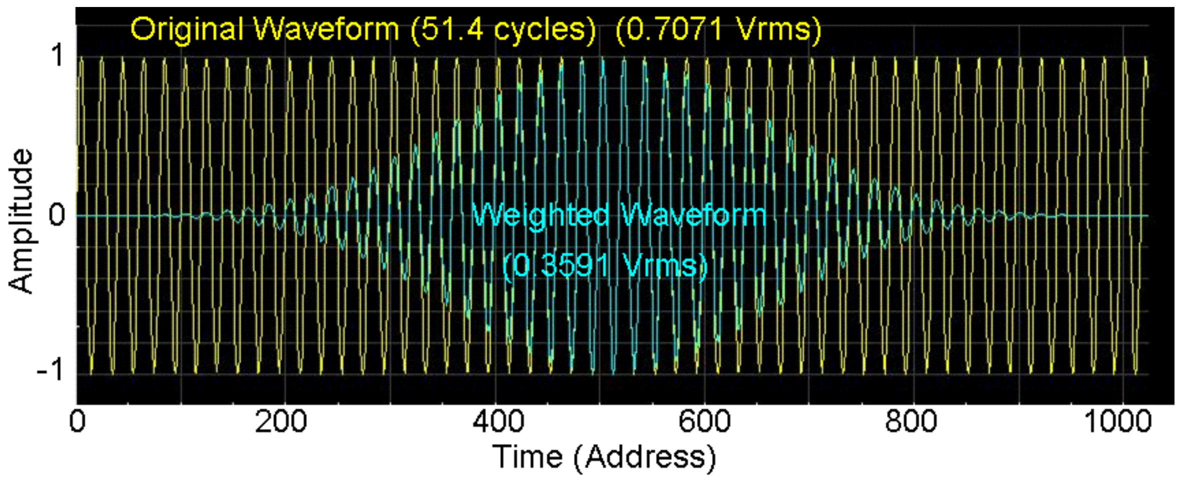

Figure 2 51.4-Cycle Sampled Waveform

When applying FFT to the waveforms in Figure 2, the frequency spectra appear as Figure 3 shows. Since the original waveform is 51.4 cycles captured in the UTP so that the end point of the yellow sinusoid cannot be connected smoothly to the starting point in Figure 2. There is a discrepancy between the end and the start points so that the frequency spectrum looks severely smeared as the yellow spectrum in Figure 3. On the other hand, the Blackman-Harris window applied waveform shows much better outlook of spectrum. You can recognize the harmonics and the noise floor level in this spectrum. Because of the windowing, the both ends of the waveform converge to zero so that the discrepancy disappears. This is the advantage of the windowing in the spectrum analysis.

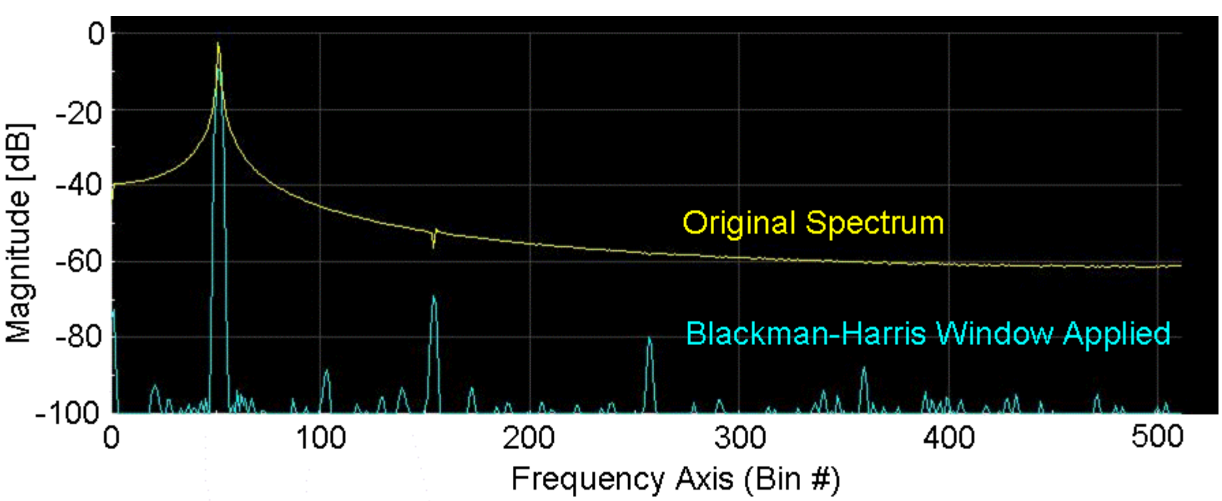

Figure 3 FFT Spectra of Waveforms in Figure 2

However, as you can see, the original waveform is deformed by the window function. The original signal has the level of 0.7071Vrms but the modified signal has 0.3591Vrms. The total power is reduced significantly. The yellow line in Figure 4 illustrates the original signal spectrum if it would not be weighted by the window. Parameters such as the signal level and the signal to noise ratio cannot be calculated, because the signal power is already modified and the magnitude of every weighted line is reduced from the original level by several deci-bells. However, you could estimate the harmonics distortion and might find spurious signals under this condition.

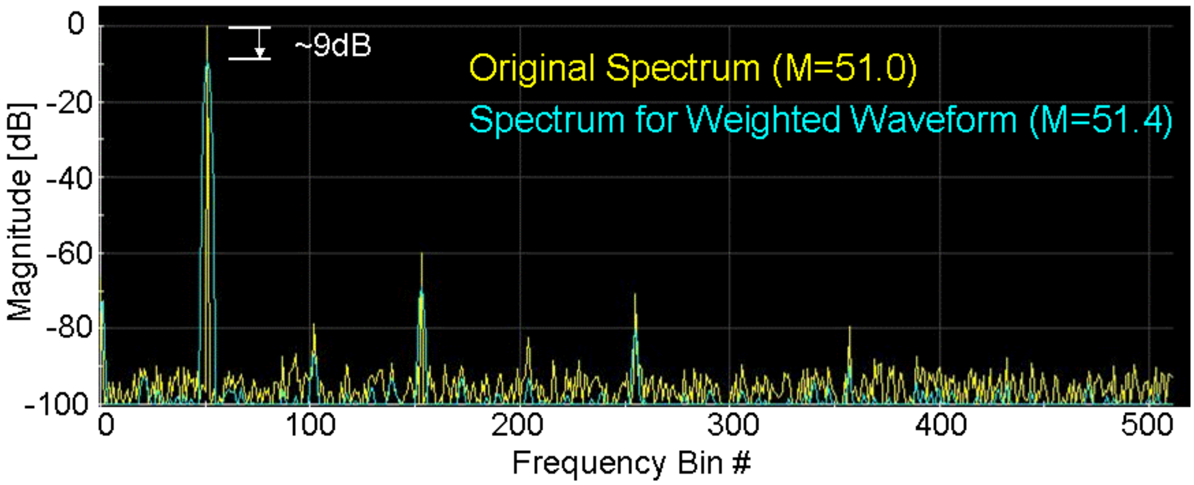

Figure 4 Effect of Window Weighting in Spectrum

When window weighting is employed for the frequency spectrum analysis, it can improve the spectrum smearing caused by the fractional number of signal cycles in the UTP. However windowing in measurement is always a kind of workaround. You should build up a test plan to be able to capture strictly integer number of cycles of the test signal.

Window Application for FIR Generation

Another window application is FIR generation. When an FIR curve is created for convolution that is filtering in the time domain, windowing is necessary for improving the rejection characteristics. Figure 5 illustrates FIR curves generated. The FIR length is 128. The yellow line is generated as a brick-wall low pass response by using IFFT. You can see the both ends of the FIR do not converge to zero, which actually gives a severe impact to the rejection performance of the FIR filtering. The cyan line shows the Blackman-Harris weighted FIR, whose terminals converge to zero.

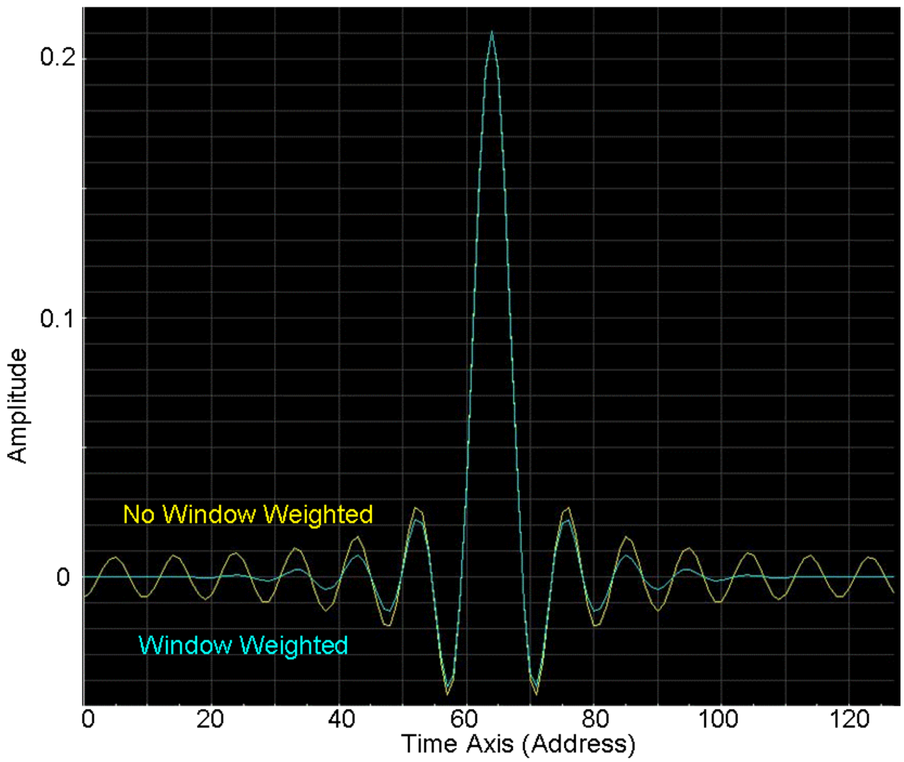

Figure 5 FIR Characteristics

When performing convolution with the FIR curves in Figure 5, the low pass filter characteristics are illustrated in Figure 6. When using the no windowed FIR, the LPF response has poor rejection as -20dB to -40dB from the pass-band flat (grey line). On the other hand, when using the window weighted FIR, the LPF has excellent rejection better than -100dB from the pass-band. So the FIR data should be weighted by an appropriate window function.

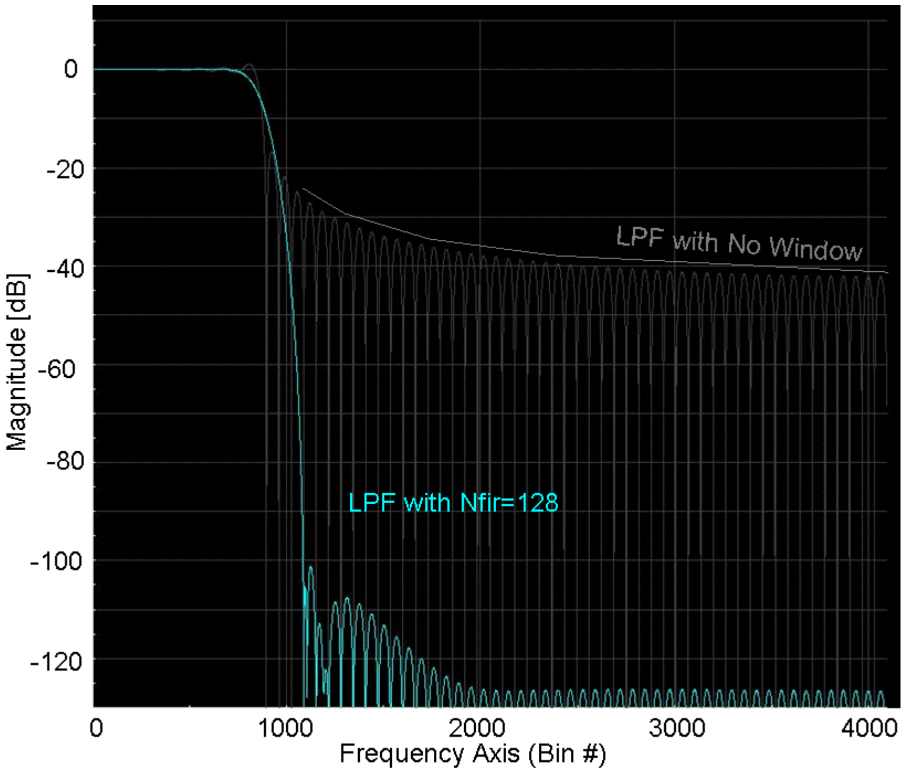

Figure 6 Low Pass Filter Frequency Responses

Conclusion

Windowing to a waveform for spectrum analyses is a workaround processing for coping with fractional number of signal cycles. It can improve spectrum smearing, but it has nothing to do with filtering. The original waveform is deformed by the window so that you cannot calculate the signal level or the S/N. You can estimate the harmonics distortion and the spurious level. You should keep in mind it is a workaround at first.

Windowing in an FIR generation is about improving the rejection performance of its digital filter functionality. This is strongly recommended processing when creating an FIR curve for digital filtering.

Appendix

In precision audio and telephone device testing, special weighting functions may be applied in the spectrum analyses. It is a traditional practice. “A-weighting” is often employed in precision audio, and either “psophometric” or “C-message” is applied in telephone audio. The API DSP_ASSIGN_FILTER() generates the three weighting functions automatically.[3]

This weighting is confusional with the windowing for spectrum analyses discussed above. This weighting (A-weighting, psophometric or C-message) is a kind of filtering performed in the frequency spectrum domain. The filter shape is generated by using DSP_ASSIGN_FILTER(), or you can generate whatever you like by yourself. The filter shape is passed to an FFT API such as DSP_SPECTRUM() as a parameter.

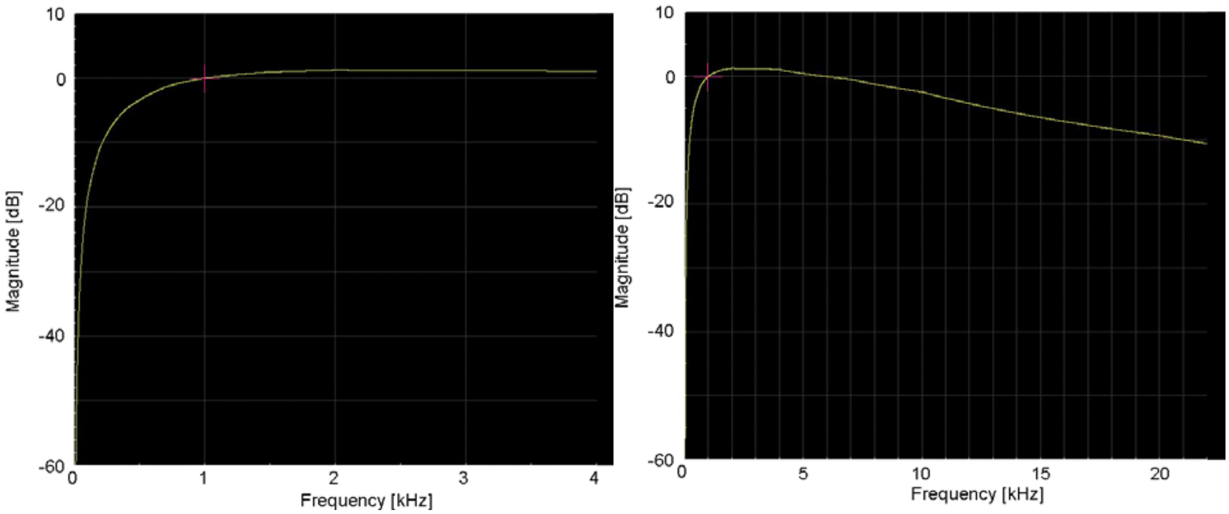

Figure A-1 A-weighting Characteristic (DC to 4kHz, DC to 22kHz)

Figure A-1 shows the A-weighting that DSP_ASSIGN_FILTER() generates. It is normalized at 1kHz. Figure A-2 shows how the A-weighting works for the 1kHz signal spectrum. The red is the original spectrum, and the yellow is the A-weighting applied spectrum.

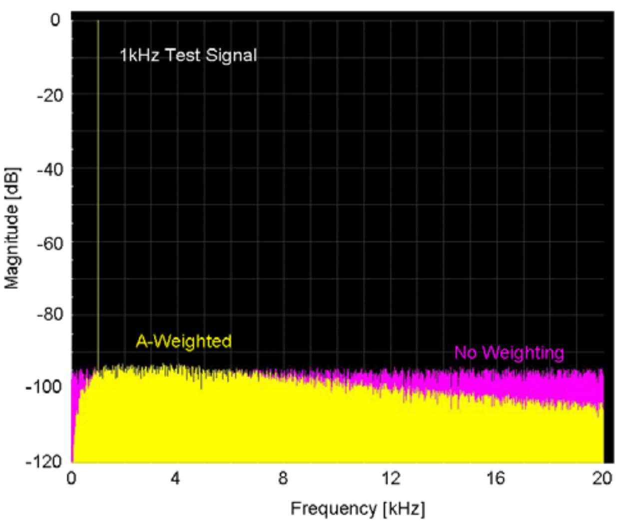

Figure A-2 A-weighted Spectrum (Yellow)

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[3] Hideo Okawara’s Lecture Series “DSP Based Testing – Fundamentals 6 Spectrum Analysis -- FFT”