FFT Laboratory Experiment 5
A Comparison of FFT Window Functions

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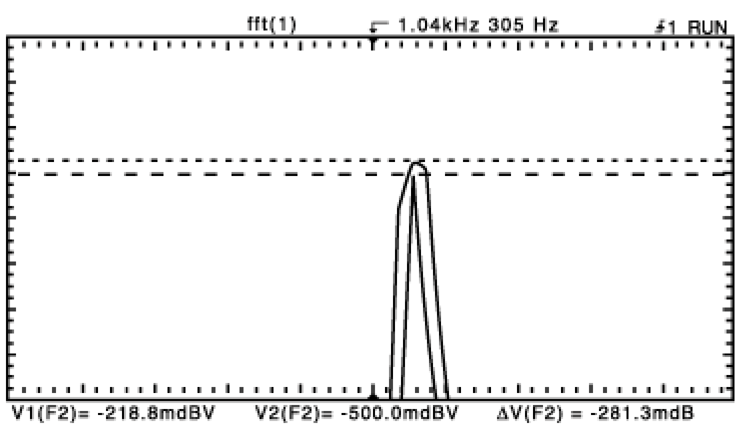
Purpose:
In this brief experiment the Hanning, rectangular and FlatTop windows are used to analyze the frequency content of simple signals. The experiment compares the spectral resolution and spectral amplitude measurement capabilities of these windows.

Procedure:
1. Connect and display a 1 *V* (RMS) sinusoid with a fundamental frequency of 1 *k*Hz. This experiment will involve measuring the absolute amplitude of the sinusoid in the frequency domain. For this reason, the 1 *V* (RMS) setting should be as accurate as possible. To quickly read the RMS value, press the *VOLTS* key on the oscilloscope and read the RMS value.

2. Turn on the FFT display and turn off the time-domain display on channel 1. Use the settings shown in Figure 6.1 to isolate the fundamental frequency of the sinusoid. Since the absolute amplitude scale of the FFT is in *dBV*, which is referenced to a 1 *V* (RMS) sinusoid, the theoretical peak amplitude of a "perfect" sinusoid should be 0 *dBV.* Use the Hanning, rectangular and FlatTop windows to measure the amplitude peak. Which of the three windows produces the best amplitude estimate?

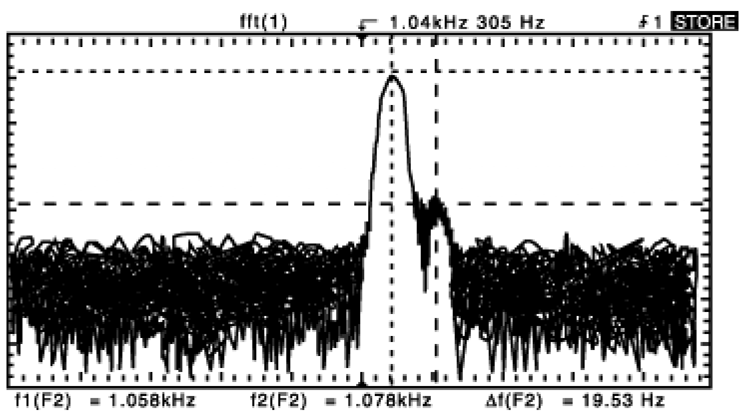
3. For the next portion of this experiment, connect the simple circuit from the previous experiment shown in Figure 5. 1. Select v_1 to be a 3.5 *V* (peak-to-peak), 1 *k*Hz sinusoid. Select v_2 to have a frequency which is roughly 20 Hz greater than that of v_l , and attenuate the amplitude of v_2 by approximately 30 *dB.* Use the settings shown in Figures 6.1, 6.2 and 6.3 to demonstrate the frequency resolution properties of each of the three windows. A sequence of overlapping FFT traces is displayed by using the *Auto-store* feature of the oscilloscope. Notice that by displaying several overlapping FFT traces, it is possible to clearly identify both harmonic components. Also notice that the Hanning window is the most effective in identifying the low energy frequency component.



Function 2: Menu		
Effective Sampling Rate	Units/div	Ref Level
5.000 kSa/s	1.0 dB	2.500 dBV
FFT Menu		
Center Freq.	Freq. Span	Window
1.040 kHz	305.2 Hz	Hanning, FlatTop

Figure 6.1

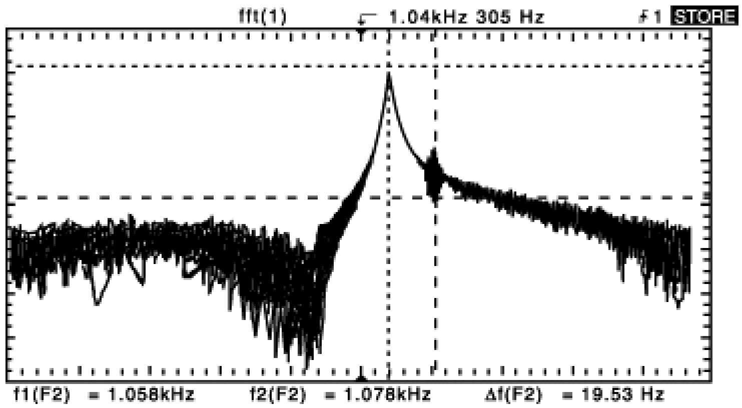
The 1024 point DFT (Magnitude) of a 1 *V* (RMS) sinusoid with a fundamental frequency of 1 *k*Hz. The FFT Menu settings were selected to isolate the peak FFT amplitude. In this figure, the *Trace* features of the oscilloscope were used to simultaneously display the results of the Hanning and FlatTop windows.



Function 2: Menu		
Effective Sampling Rate	Units/div	Ref Level
5 kSa/s	10.00 dB	10.00 dBV
FFT Menu		
Center Freq.	Freq. Span	Window
1.045 kHz	305.2 kHz	Hanning

Figure 6.2

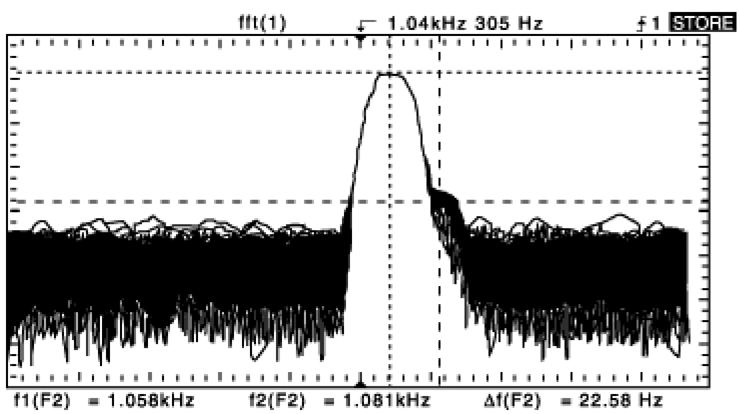
The 1024 point DFT (Magnitude) of a sum of two sinusoids using a Hanning window. The two components are spaced approximately 20 Hz apart and the low frequency sinusoid is attenuated by approximately 30 *dB*. The *Auto-store* feature of the oscilloscope was used to display a sequence of overlapping FFT traces.



Function 2: Menu		
Effective Sampling Rate	Units/div	Ref Level
5 kSa/s	10.00 dB	10.00 dBV
FFT Menu		
Center Freq.	Freq. Span	Window
1.045 kHz	305.2 kHz	Rectangular

Figure 6.3

Same as figure 6.2, but using a rectangular window.



Function 2: Menu		
Effective Sampling Rate	Units/div	Ref Level
5 kSa/s	10.00 dB	10.00 dBV
FFT Menu		
Center Freq.	Freq. Span	Window
1.045 kHz	305.2 kHz	FlatTop

Figure 6.4

Same as figure 6.2, but using a FlatTop window.

Questions:

1. Rank the three windows used in this experiment in terms of their effectiveness in accurately measuring spectral amplitudes.

2. Rank the three windows used in this experiment in terms of their ability to resolve closely spaced frequency components.

3. Periodogram averaging is a common DSP technique used in spectral analysis. A periodogram is obtained by squaring the FFT (magnitude) of a time-windowed portion of the input signal. Discuss the relationship between periodogram averaging and the displays obtained in Figures 6.2-6.4.

Conclusions:

1. An FFT analyzer is capable of resolving relatively closely spaced frequency components, even when one component is attenuated.

2. By using the *Auto-Store* feature of the oscilloscope, it is possible to use “visual" averaging to mitigate the effects of noise and sampling jitter.

3. The Hanning window is the most effective window for resolving the frequency location of closely spaced sinusoids, whereas the FlatTop window is the most effective window for performing amplitude measurements.

4. The RMS value of the waveform is not the same as the value of the main lobe. The RMS value is affected by the main lobe, all harmonic content, and the internal noise of the oscilloscope.

References

1. Alan V. Oppenheim and Alan S. Willsky with Ian T. Young, *Signals and Systems.* Prentice Hall, Englewood Cliffs, New Jersey, 1983.

2. John G. Proakis and Dimitris G. Manolakis, *Introduction to Digital Signal Processing,* Macmillian Publishing Co., New York, 1988.

3. Alan V. Oppenheim and Ronald W. Schafer, *Discrete-Time Signal Processing.* Prentice Hall, Englewood Cliffs, New Jersey, 1989.

Answers to Questions

1. The best window choice is the FlatTop, followed by the Hanning, followed by the rectangular.

2. The best window choice is Hanning, followed by the FlatTop, followed by the rectangular.

3. Figures 6.2-6.4 can be viewed as a form of "visual averaging." By displaying several traces, the effects of noise are, in a sense, "averaged out" leaving a more accurate view of the signal spectrum.