# Computer Exercise 1

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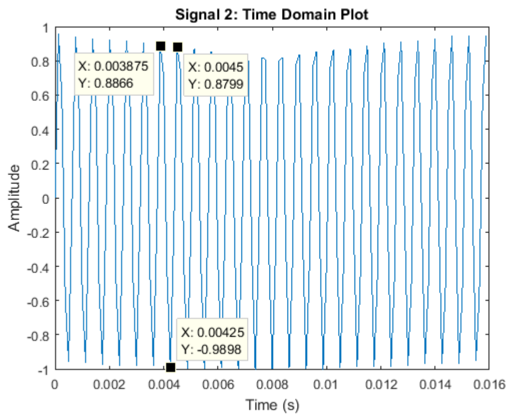


Fig. 1. Signal 2: Time Domain

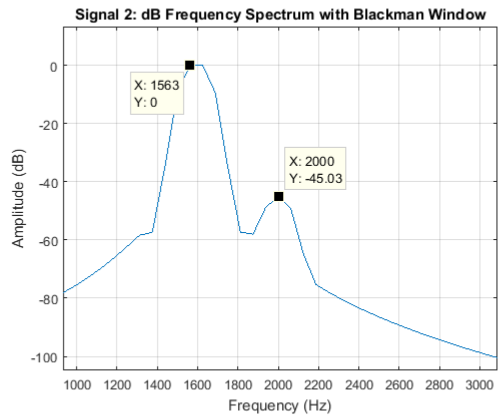


Fig. 2. Blackman Window, Low Resolution

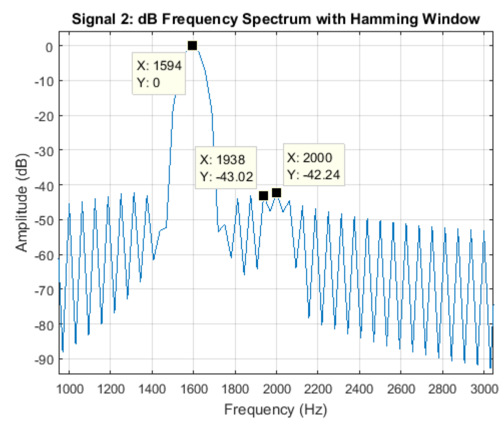


Fig. 3. Hamming Window

## I. Signal 2

Signal 2 was composed of 128 samples of a roughly sinusoidal waveform sampled at 8000 Hz. The signal is about 16 ms in duration. From the time domain waveform, Figure 1, one observe at least 2 component frequencies. The obvious frequency component is at about 1.6 kHz as determined by the distance between the peaks. The second component should account for the apparent oscillation of the waveform.

The waveform was first transformed to the frequency domain without padding. All waveforms were compared by transforming them with Rectangular, Bartlett, Hamming, von Hann, and Blackman windows then plotting the linear and decibel magnitudes of the FFT. The Blackman window, Figure 2, showed two peaks most prominently when plotted with a decibel magnitude, the largest at 1.563 kHz which aligns well with the time domain measurement, and one at 2 kHz. The Blackman window, however, has a fairly broad main lobe width at $0.09375\pi$ which translates to 375 Hz and can easily smear signals that are within 188 Hz.

### A. *Smearing Analysis*

Padding the windowed waveforms with 128 extra zeros, then rerunning the transform and plots, increased the relative frequency resolution from 62.5 to 31.25 Hz and better displayed the 2 kHz frequency peak across all the windows functions. The higher resolution also made possible smeared peaks more apparent. Figures 3 and 4 show the decibel magnitudes of signal 2 through the Blackman and Hamming windows respectively. The Hamming window, with a main lobe width of $0.0625\pi$ smearing signals within 125 Hz, shows three nearly equal peaks around 2 kHz, with a similar perturbation preset in the Blackman windowed waveform. Both the Blackman perturbation at 1.875 kHz and the Hamming perturbation at 1.938 kHz, are within smearing range for their respective windows. It is possible that these two perturbations represent a third signal around 1.9 kHz, but they could also represent side lobe interference from the 1.59 kHz with the signal at 2 kHz.

### B. *Side-Lobe Level Interference*

The possibility of side lobe interference in the Blackman window is fairly low. The side-lobe level between the main signal at 1.59 kHz and the secondary signal at 2 kHz is at $-67.1$ dB. This is far less than $-46.1$ dB attenuation between the main and secondary signals so side-lobe level interference is not a factor in displaying the 2 kHz signal. The magnitude possible tertiary signal at or around 1.875 kHz is $-59.12$ dB

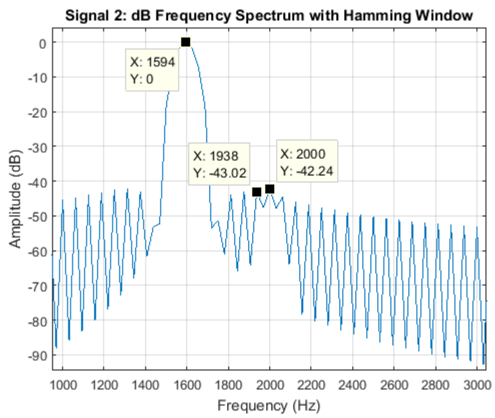


Fig. 4. Blackman Window, High Resolution

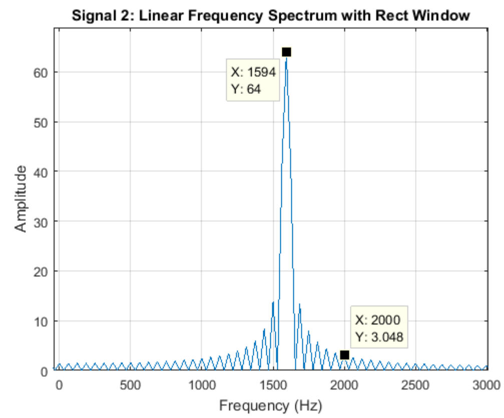


Fig. 5. Rectangular Window

and the side-lobe level at this distance from the 1.59 kHz peak is $-59.44$ dB. Given the similarity in attenuations, the perturbation at 1.875 kHz in the Blackman window is likely the side lobe from the main peak smearing with the secondary peak.

The frequency spectrum created by the Hamming window shows three peaks with the tallest centered at 2 kHz. With an amplitude of $-42.24$ dB, the amplitude of the secondary signal is only slightly greater than the side-lobe level of $-44$ dB. Furthermore, the possible tertiary peak at 1.938 kHz has a gain of $-43.02$ dB which is still greater than the side-lobe level of $-43.16$ dB at that distance from the main peak. Given that the secondary peak at 2 kHz is only slightly larger than the surrounding side-lobe levels, evidence for the existence of a 2 kHz signal comes from the two troughs on either side of the 2 kHz peak which fall on the theoretical 0 gain points on the Hamming window. The levels at these two frequency points do not match the attenuation experienced at similar 0 gain points in the waveform. The higher levels at these two troughs are likely due to smearing around the 2 kHz peak.

### C. Signal 2 Structure

The most present frequencies in Signal 2 is the main signal at or very near 1.59 kHz with a relative amplitude of about $\pm 0.9353$. This amplitude matches the initial time domain analysis which estimated the frequency at 1.6 kHz, and it is reasonable to assume that a slight bias from the secondary signal could draw the 1.59 kHz closer to 1.6 kHz. The secondary signal at or near 2 kHz has a relative amplitude of about 0.045, shown in Figure 5.

## II. Signal 3

Signal 3 shown in Figure 6, contains what appears to be 3 signals, broadly resembling an amplitude modulated wave. The first signal appears to be a carrier frequency distinguished by the most prominent peaks in the wave. The second signal appears as the envelope waveform shown by the peaks at 0 seconds and 0.0125 seconds. If this second signal is indeed a modulated signal, then one would expect to see 2 frequency peaks 80 Hz on either side of the carrier signal peak. A third

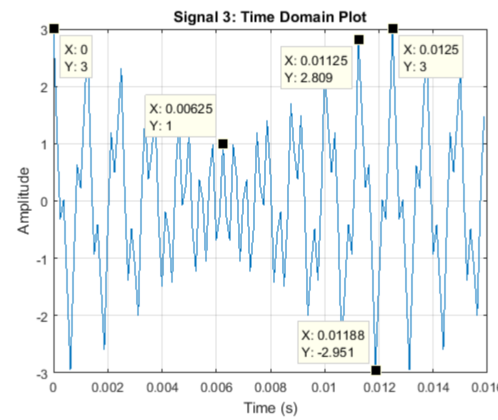


Fig. 6. Rectangular Window

signal, which is difficult to analyze in the time domain, appears as the small periodic perturbations in the waveform. The signal itself is 16 ms long.

From analysis of the time domain waveform, Figure 6, the signals should align with 800 Hz with a relative amplitude of $\pm 2.98$ and 80 Hz with a relative amplitude of 2. The third signal cannot be easily be described or estimated using the time domain plot.

### A. Smearing Analysis

Working under the theory that Signal 3 represents an amplitude modulated signal with 2 peaks within 80 Hz of a larger carrier peak the rectangular window, with a half main-lobe width of 62.5 Hz should provide the necessary resolution without smearing. Padding the signal to 2 and 3 times the original width prior to the applying the FFT, showed the same 3 peaks. The $3 \times 128$ length signal is shown in the analysis as the peaks are more present. The decibel amplitude plot of the rectangular window is shown in Figure 7.

Three peaks are evident in the plot of the rectangular windowed waveform. Two very close frequency peaks at 791.7 Hz and 895.7 Hz with fairly equal magnitude, then a third peak at 2.396 kHz which is slightly shorter than the two main peaks. For comparison, the Hamming and von Hann window plots data are show in Figures 8 and 9 respectively. The frequencies

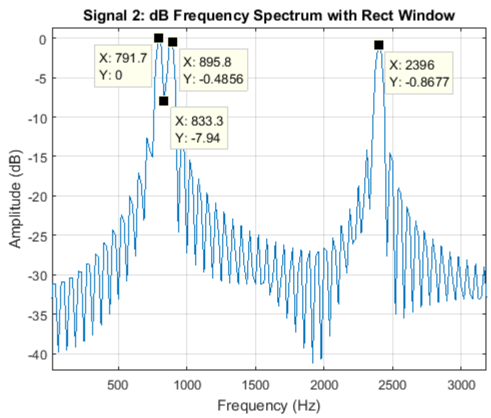


Fig. 7. Rectangular Window

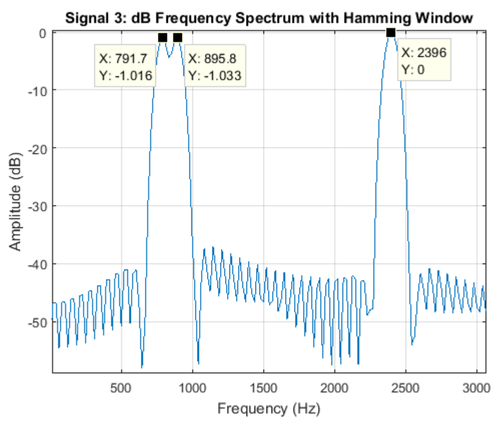


Fig. 8. Hamming Window

of the three peaks in the are consistent across all three plots, however, with main lobe widths of 375 Hz the trough between the two peaks is predictably higher in the Hamming and von Hann windows than that gained from through Rectangular window. Also the Hamming and von Hann windows show the 2.4 kHz peak of slightly greater amplitude, even though they generally have lower side-lobe levels.

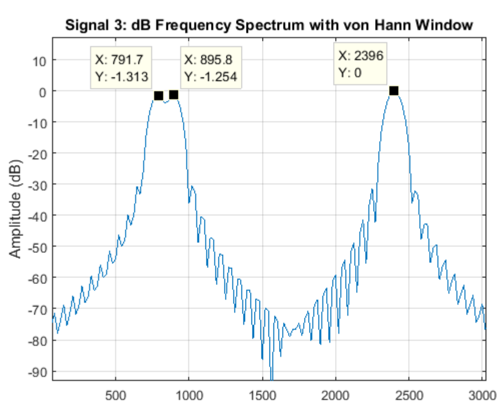


Fig. 9. Hamming Window

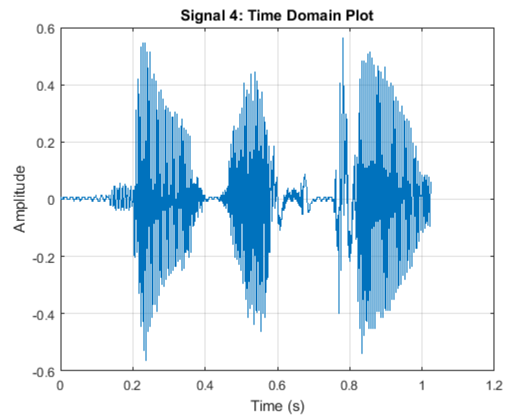


Fig. 10. Signal 4

### B. Side-Lobe Level Interference

Comparing Figure 7 with Figures 8 and 9 brings up a discrepancy in the respective amplitude of the frequency bins. While the von Hann and Hamming windows generally have lower side-lobe levels than the Rectangular window, both windows the 2.4 kHz peak higher than the two lower frequency peaks. Side-lobe level analysis should indicate which peak is really the highest.

The two peaks on the rectangular window are separated by 104 Hz corresponding to a side-lobe level of $-14.8$ dB which is insignificant relative to the level of the two peaks. For the 2.4 kHz peak, side-lobe levels are $-38.2$ dB relative to the 895 Hz signal and $-45.4$ relative to the 791 Hz signal, levels too low relative to the main lobe to be very significant in regards to side-lobe level interference.

Analyzing the Hamming window with regards to side lobe interference gives side lobe levels of $-54.8$ dB and $-61.9$ dB for the 791 Hz and 895 Hz signals respectively. These signals firmly rule out side-lobe level interference, however, because they are much less than the levels for the rectangular windows, the Hamming and von Hann windows probably give a better representation of the frequency magnitudes, even if they are all very close.

### C. Signal 3 Structure

In refutation of the AM signal hypothesis, Signal 3 in Figure 6 can be best represented as a simple addition of 3 sinusoidal frequencies of roughly equal magnitude at 791 Hz, 895 Hz, and 2.40 kHz.

## III. Signal 4

Signal 4 contains 8192 samples of a fairly complicated and heterogeneous waveform consisting of lasting a little over 1 second. The waveform consists of 3 main noise blocks roughly contained within times 0.1 and 0.4 seconds, 0.45 and 0.7 seconds, and 0.7 and 1 seconds. Figure 10 shows the overall time domain plot of the waveform.

A generalized frequency analysis was performed by dividing the waveform into 8 equally sized blocks, multiplying by a Blackman window, performing the FFT on each blocks,

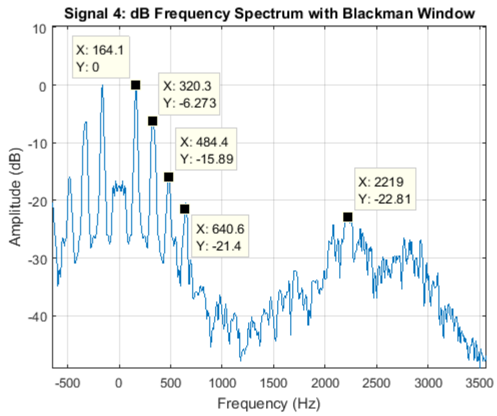


Fig. 11. Signal 4

then finally averaging the blocks to remove noise. The result is given in figure 11. The peaks of the frequency domain correspond to integer multiples of 160 Hz, with (roughly) exponentially decaying peaks. This pattern, albeit with substantial noise, is consistent with several harmonics of a single note, commonly associated with resonant sounds like musical instruments and the human voice box. The fundamental frequency of 160 Hz should roughly represent the average pitch of the signal.

The highly irregular nature of the signal combined with the resonance suggests a human source for the signal. Indeed listening to the signal as sound showed it as a voice saying the letters ”DSP”. Even though the signal well within the bandwidth of the human speaking range, the signal can still be understood.