Post-Lab Report

ECEN 489 Lab 2 – Signal to Noise Ratio, Quantization

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GitHub Repository for Code:

<https://github.com/bdwade4/ECEN_489_Labs>

Introduction

Section 1: Signal to Noise Ratio

Part A:

In this instance, a the variance that was added to the signal is as follows and the code for creating the signal is included in the appendix. The entirety of this lab uses a 400 point DFT. The variance of the Gaussian noise was set to 8 uV^2 which resulted in an SNR of -50dB the majority of the time. This variation is due to the variation and randomness in the noise. It typically varies from -48 to -52 dB depending on the iteration. An example of the graph can be seen below. Note that this is a 400 point DFT, therefore, the SNR is 23dB above the noise floor (-73dB)

A graph with a blue line

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Figure 1: The Normalized PSD graph in dB with the values normalized to the fundamental signal

The calculated noise floor of this pictured signal with Gaussian noise was -72.9990879875 dB. With a DFT of 400 points,

The calculated noise variation required for an SNR of -50dB can be determined by the equation.

Given that the peak-peak voltage is 2V and the noise power is given, this is an approximately accurate Gaussian noise variation to ensure a -50dB SNR. Reversing the equation, the ideal power of the noise can be found as 5uV^2 which is very close to the calculated value.

As the power of a noisy signal is directly dependent on its variance and only its variance. Due to this, the exact same calculation can be run as was run in the Gaussian distribution.

Part B: The same simulations but run with various windows being applied.

The code used to implement these windows was inserted in the appendix. It can be noted that, with the current setup, the signals fall directly on a frequency bin of the DFT. Because of this, any spreading of the signal will likely raise the SNR. In nearly any ideal situation however, it would likely help the situation.

Additionally, the SNR was measured by taking the noise floor below 1.5MHz which eliminates any influence of the spread signal by the windows.

A graph with blue lines

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Figure 2: The same signal with a Blackman window applied to the signal.

In this instance, the Noise floor was measured as -73.1710725127462 dB. Because the same number of points were used for the system, this indicates an SNR of 50.1607 dB. The variance of this noise was decreased to 5 uV^2 to create this SNR. This exactly matches the theoretical value needed.

A graph of a signal

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Figure 3: The same signal with a Hanning window applied to the signal

In this instance, the Noise floor was measured as -73.90555563207748 dB which is nearly identical to the result of the Blackman window. The variance is unchanged from the previous window at 5 uV^2. This pushes the idea that many of the windows have similar performance.

A graph with blue lines

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Figure 4: The same signal with a Hamming window applied to the signal

In this instance, the Noise floor was measured as -73.75861311475154 dB which is nearly identical to the result of the Blackman and Hanning windows. The variance is unchanged from the previous window at 5 uV^2. Again, this has very similar performances to the other windows.

In conclusion, many of the windows have very similar performance. This is due to the fact that, with a DFT of 400 points, the noise floor was nearly identical at -73dB for each of the applied windows. This is with a Gaussian noise of 5uV^2 compared to the 8uV^2 noise variance without any of the filters.

The only reason that a narrow variance is needed was that the frequency is exactly on one of the DFT bins. In any other situation, the windows would have likely very much improved the performance.

Section 2: Quantization

Part A:

This 200MHz signal is sampled at 400MHz and quantized at 6 bits. The code for this is included in the appendix. This introduces some noise. The DFT of this signal and noise when pictured with a DFT of 30 points is pictured below.

A graph of a signal

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Figure 5: The PSD of the signal with a 30 point DFT

With this signal, the SNR is measured as -20.25990702044295 dB. There is a periodic effect on this signal as seen above. This is likely due to harmonics between the chosen signal and the sampling rate being exact multiples of each other. For curiosity sake, the DFT with the signal frequency adjusted to 200.1MHz is pictured below. This gives and SNR of -22.72701432769872 dB.

A graph with a line going up

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Figure 6: The PSD of the signal adjusted to 200.1MHz with a 30 point DFT

A graph of a signal

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Figure 7: The PSD of the signal at 200MHz with a 100 point DFT

With this signal, it has a SNR of -39.96136592107461 dB. However, it appears that the signal multiples are heavily being impacted by the harmonics of the signal.

From this, it can be concluded that, if the sampling frequency or the number of DFT periods is a multiple of the signal frequency, the DFT will be heavily impacted by the periodicity of the signal. If the frequencies can be as inharmonic as possible, the signal will be much more accurate. This is supported by the textbook equations and the equations presented in class.

Part B:

The easiest way to find an incommensurate sampling frequency is to follow the ratio below:

Because the input frequency is set at 200MHz and the DFT length is set at 100 points, the parameter that must be adjusted is the number of cycles “C” until the sampling rate is above the Nyquist rate. To make M and C incommensurate, the prime number 31 is chosen (as M is fixed at 100). This results in a sampling rate of 645.16MHz. The PSD of that is pictured below:

A graph of a normalized signal

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Figure 8: PSD of the signal sampled at 645 MHz with a 6-bit quantizer and a DFT of 100 samples

In this case, the SNR is calculated to be -33.33114812142718 dB. This is much better and a much clearer PSD. This new clarity is due to the incommensurate sampling frequency chosen between it and the input frequency.

Part C:

This same process is repeated with a 12-bit quantizer. The same input frequency of 200MHz and sampling frequency of 645.161MHz is used to ensure that the two frequencies are incommensurate.

A graph of a normalized signal

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Figure 9: PSD of the signal sampled with a 12-bit quantizer at 645MHz

In this case, the SNR is calculated as -44.84854413303562 dB. The actual SNR of the signal is slightly improved, but the signal itself is much clearer. This is due to the quantization error being greatly reduced. The spread of the signal is likely due to the quantized signal not being exactly on a signal bin.

In this case, the SNR is about 6N, but with heavy approximations. With a 6-bit quantizer, the SNR is about -33dB (from ideally 36dB), but with the 12-bit quantizer, the SNR was -44dB. This was far away from the ideal SNR of -72dB. So this may hold up, but it doesn’t in this specific situation.

Part D: The signal will be re-sampled with a Hamming window with 6- and 12-bit quantizer.

A graph of a normalized fft of signal

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Figure 10: PSD of the signal with a Hanning window sampled with a 6-bit quantizer at 645 MHz

In this case, the SNR is calculated as -52.920719456166374 dB. This is a massive improvement due to the processing window. It effectively spreads the signal and decreases the error from quantization. With this non-ideal situation, the positive effects of the Hanning window can much more easily be seen. This gave a nearly 20dB improvement in the SNR

A graph of a normalized signal

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Figure 11: PSD of the signal with a Hanning window sampled with a 12-bit quantizer at 645 MHz

In this instance, the SNR is calculated as -95.76499393769099 dB. This further reinforces the effectiveness of the Hanning window. This is a further nearly 50dB improvement from before the window was applied.

Overall, the Hanning window further introduced nulls on the harmonic frequencies of each discrete sample. This reduced the spread of the peak of the primary frequency on the DFT. This much more clearly showed the fundamental signal and showed a clear noise floor. The clarity of the noise floor is another great improvement and benefit of adding the Hanning window.

Part E:

A graph showing a normalized fft of signal

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Figure 12: PSD of the signal sampled with a 6-bit quantizer and no window applied

In this instance, an SNR of -36.39411456939579 dB was applied, but it took a Gaussian noise signal with a variation of 100uV^2 in order to do this. This is a very substantial noise signal.

-36.28093783521043

A graph showing a normalized ftt of signal

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Figure 13: PSD of the signal sampled with a 12-bit quantizer and no window applied

In this instance, an SNR of -36.28093783521043 dB was applied, but it took a Gaussian noise signal with a variation of 100uV^2 in order to do this. This is a very substantial noise signal. With the same noise signal as the 6-bit quantized signa, there was an approximate 0.2 dB improvement in SNR. This is very minor and the Gaussian noise is much more substantial than the Quantization noise in this case. This is the reason for such a small decrease

A graph showing a normalized signal

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Figure 14: PSD of the signal sampled with a 6-bit quantizer and a Hanning window applied

In this instance, an SNR of -38.28047089865 dB was applied, but it took a Gaussian noise signal with a variation of 50uV^2 in order to do this. This is a very substantial noise signal, but it is reduced from the past samples. This shows that, with noise added, the SNR is made worse by the Hanning window.

A graph showing a normalized ftt of signal

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Figure 15: PSD of the signal sampled with a 12-bit quantizer and a Hanning window applied

In this instance, an SNR of -37.26197504492513 dB was applied, but it took a Gaussian noise signal with a variation of 50uV^2 in order to do this. This is a very substantial noise signal, but it is reduced from the past samples – particularly those without the Hanning window. Again, this is a slight improvement from the 6-bit quantization under the same circumstances due to the decrease in quantization noise.

Overall, in this instance, the quantization noise is incredibly small when compared to the introduced Gaussian noise. Due to this, there is not a lot of change when the quantization bits are increased from 6 to 12 bits. In addition to this, the Hanning window also decreases the SNR of the measured signal. This could be due to how the increase in spread interacts with the introduced Gaussian noise which could make it more prevalent.

Section 3: AD2 Sampling

Note: The values of the FFT were imported into Excel to calculate the SNR and the ENOB. This was done by taking the average value of the noise floor up to 1.8MHz which will discount the fundamental signal

A screen shot of a graph

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Figure 16: PSD of the signal sampled without the 741 op

In this figure, the SNR can be seen to be 92.92989789 dB. This is due to the remarkable clean signal and effective sampling of the op amp. Due to the ENOB equation, the ENOB can be calculated from the SNDR as 15.14450131 bits.

A screen shot of a graph

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Figure 17: PSD of the Signal Sampled through the 741 op-amp without noise added – this accounts for the slew rate error of the op amp

The same is done for this figure with an SNR of 60.69458215 dB and an ENOB of 9.7897977 bits. The reason that the measured SNR doesn’t match the pictured line was that the maximum amplitude of the fundamental signal pictured here was -35.60311439 dB. This was largely due to the slew rate limitations of the op-amp and served to decrease the fundamental signal compared to the DC signal.

A screen shot of a graph

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Figure 18: Output of the noisy amplifier in the time domain with 100MHz, 50mV noise

A screen shot of a computer

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Figure 19: PSD of the output of the noisy amplifier

In this instance, similar to before, the gain of the fundamental frequency compared to the DC is reduced. This results in an SNR of 58.71780208 dB which results in an ENOB of 9.461428917 bits.

The noise results in a reduction of 1.9767 dB to the SNR. This is largely minimal and results in a reduction of the ENOB by 0.326 bits.

Appendix:

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Code 1: The code used for generating the sinewave with added gaussian noise

A computer screen shot of a program

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Code 2: The code used to apply the various filtering windows for part 1b. This is used for each of the three filtering windows

A computer screen shot of a code

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Code 3: The function used to quantize the value. Given that the value is centered around zero, the value is multiplied by 2^5 and then rounded to the nearest one before being decimated again.