Experiment 2 - Noise

INTRODUCTION

In his *The Art of War*, Sun Tzu advises the reader to know his or her enemy. In the field of communications there are a number of enemies, but they all serve one master – noise. Noise limits what information can be sent, how far it can be sent and how fast. If there was no noise, it would be possible to receive any signal at any time, no matter how weakly or far away it was sent. It would merely be a question of applying sufficient amplification to bring the signal up to a useful level.

Noise can enter the link through a number of sources. Perhaps the most ubiquitous is thermal or Johnson noise. Every passive component or any conductor with resistance produces a noise power proportional to its temperature and the bandwidth being used or observed.   This noise may be also expressed as a power spectral density, that is the amount of noise power per hertz of bandwidth, $\frac{N_o}{2}$, where $N_o = kT,\ k = 1.38 \times 10^{-23},\ T = \ temperature\ (Kelvin)$

This corresponds to a noise spectral density of $4\text{x}10^{-21}$ Watts/Hertz at 290 K. Such a low power may not seem like much, but it is more than enough to disturb long distance communications.

This noise has a Gaussian distribution with a variance of σ^2 and a mean of zero. The variance is the power in a one ohm load and is dependent on the bandwidth, as will be reviewed below in the pre lab. Thermal noise is 'white', that is, its power spectral density does not change with frequency. This is valid up to about 80 GHz. Above there, quantum effects take over.

In addition, active components, such as transistors, diodes and vacuum tubes produce additional noise which cannot be characterized by any simple equation, but is usually measured for the particular device.

Other sources of noise enter the signal when it is traveling through the channel. Wireless channels are prone to atmospheric noise, usually from lightning at HF and from extraterrestrial sources, such as the sun and our galaxy, at higher frequencies. While other sources – typically manmade – can also interfere with a signal, they are classed as interference and not noise. In different circuits at different frequencies, it is important to know which source of noise is dominant.

Despite the seemingly insidious and pervasive character of noise, this enemy has readily definable characteristics which offer the communications engineer ways of dealing with it. This experiment is to review and test those characteristics and explore how they can be simulated in Simulink.

PRE LAB

1. Review the following important relationships and definitions for noise:

a. The power spectral density (PSD) or G(f) of Gaussian, white noise is given as $\frac{N_o}{2}$ W/Hz.

b. The noise power in any limited bandwidth, B, is $2B[G(f)]$. Note the factor of 2. This is because the spectral density is defined for positive and negative frequencies.

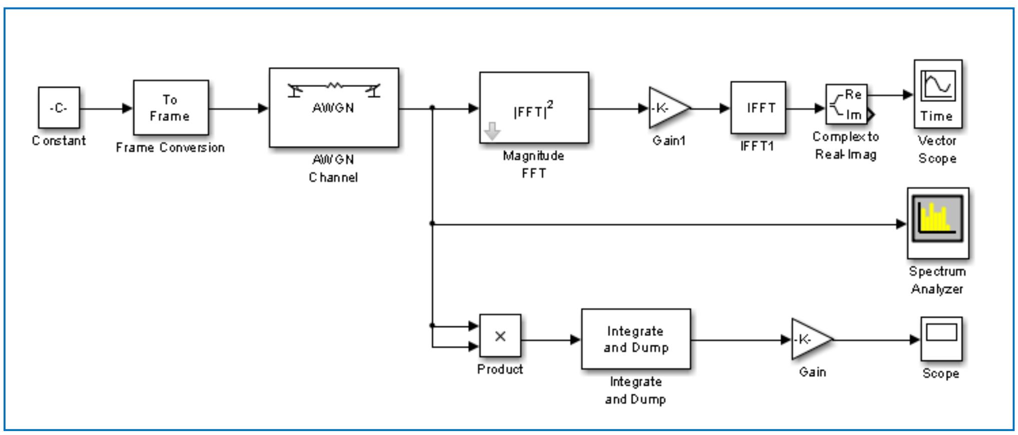
c. The noise power in a one ohm load is also the variance of the noise, σ^2. This is related to the PSD of the noise by $\sigma^2 = BN_o$.

d. In a sampled system, the maximum bandwidth is given by the Nyquist relation of $B = \frac{\text{sampling rate}}{2}$.

2. Given a sampling rate of 100000 samples/sec, a symbol power of 1 W, a symbol duration of 2 ms, and a desired E_b/N_o of 10 dB, what variance would you specify for the additive, white Gaussian noise? What would bethe power spectral density of this noise , $(N_o/2)$?

PROCEDURE

1. Construct the simulation shown below in Simulink.



2. Configure the simulation blocks as follows:

Constant:	Constant value: zeros(1,1024) Check Interpret vectors as 1-D Sample time: 1024/10000
AWGN Channel:	E_b/N_o: 10 dB Symbol Period: 200/10000
Magnitude FFT:	Output: Magnitude squared FFT Length: 1024
Gain (both):	Gain: 1/(1024*10000)

IFFT:	Check Divide output by FFT length Uncheck inherit FFT length from input dimensions FFT Length: 1024
Vector Scope:	Time Display span: 11 frames Axis Properties > Vertical Axis Minimum Y Limit -5 e-4 Maximum Y Limit 15 e-4
Scope:	Right click and bring up axes properties. Set the limits to the same values as the vector scope.
Spectrum Analyzer:	Main options > Type: Power Density Trace options > Units: dBW/Hz Trace options > Averages: 11
Integrate and Dump:	Integration Period: 1024

Leave all other parameters as default. Run the simulation for 0.1024 seconds, observe the outputs of the various scopes and verify that the outputs of each leg show the power spectral density of the noise. Compare these results with the results expected from the pre lab.

The simulation is set up as to investigate the noise generated by the AWGN block in Simulink. A sequence of zeros is the input to the block. The output of the AWGN block is sent to three different subsystems which are designed to yield the power spectral density of the noise.

The top subsystem, consisting of the Magnitude-squared FFT block and IFFT block is modeling the expression for finding the autocorrelation of a random function:

$$R_n(\tau) = F^{-1}\{G_n(f)\} = F^{-1}\{\lim_{T\to\infty} \frac{1}{T} |X_n(f)|^2\}$$

Notice that $X_n(f)$is the *continuous* time Fourier Transform. We are approximating this by using the *discrete* Fast Fourier Transform (FFT) block in Simulink. Therefore the equation is modified:

$$R_n(\tau) \cong F^{-1}\{\frac{1}{T} |F_n(f)\Delta t|^2\}$$

Where T is the length of the FFT in time and Δt is the sampling period. Since the lab is just not quite long enough to observe the noise signal for an infinite length of time, the length of time is truncated to 1024 samples, chosen since it is a power of 2. The Gain1 block

following the FFT block represents the $\frac{\Delta t^2}{T}$ factor that needs to be applied so that the model yields the approximation of $R_n(\tau)$.
The output of this subsystem is the autocorrelation function, which is a function of time having a value of $N_o/2$ at τ=0 and is zero elsewhere. This function repeats every 1024 samples.

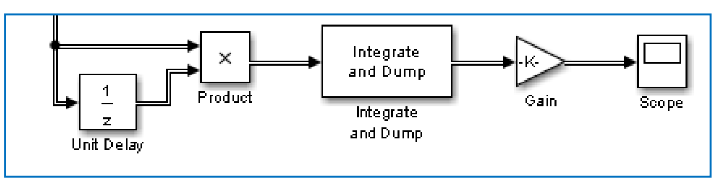
In the middle section, the Spectrum Analyzer is set up to display the power spectral density function. The power at any given frequency is expressed in units of dB watts per hertz. Zoom in and record the value at 0 kHz.

The bottom leg is a straight forward application of the average power, averaged over 1024 samples. The AWGN Channel output is squared and integrated over a period of 1024 samples. The Gain block divides this by 1024, yielding the average. The Gain block also divides the Integrate and Dump output by the bandwidth to give the power spectral density. This output is updated every 1024 samples. The output of this leg equals the value of the autocorrelation function with τ = 0.

3. Using the value calculated from the pre lab, reconfigure the AWGN Channel by setting the Mode parameter to Variance from mask and enter the variance. Run the simulation again and verify that outputs are unchanged.

4. The value of 1024 samples was chosen arbitrarily in all of these cases. Longer periods of observation will yield results with a smaller variation. Reprogram the system to integrate or calculate for periods of 256 and 2048. Be sure to change the simulation run time to keep the number of observation periods equal to 10. Observe and record the variation in each of the outputs, especially the top and bottom legs. In other words, in the top leg, a series of ten pulses will be displayed. Note the values of each pulse amplitude. Calculate their average value and then calculate the variance or average deviation of each pulse from this average value. In the bottom leg, there will be a series of ten levels shown on the scope. Again, calculate their average value and the variance of the pulses from the average.

5. Modify the system to insert a unit delay in one of the lines to the product block in the bottom leg as shown below.

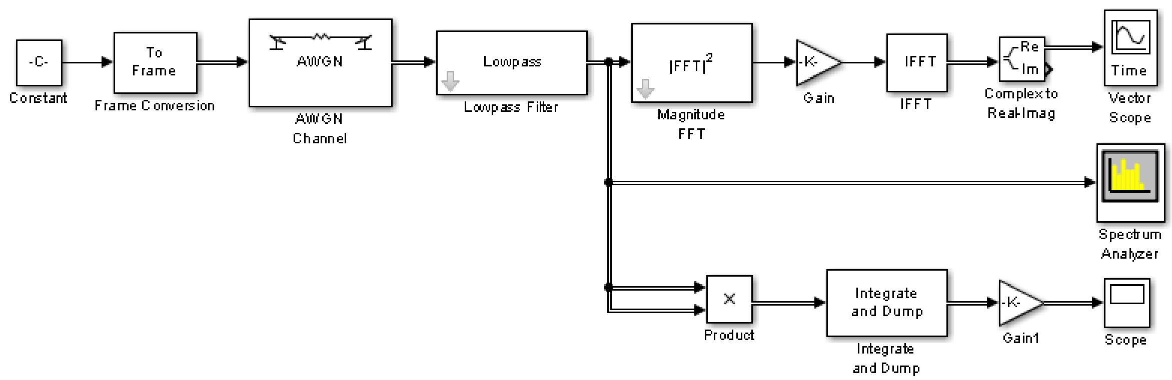


Set the input processing as frame based for the Unit Delay. This changes to bottom leg to calculate the autocorrelation function for $\tau = T_s$, one sample period. The equation for this is:

$$R(\tau) = \int_{-\infty}^{\infty} x(t)x(t+\tau)dt$$

Again, we are approximating this over a finite period of time. Set the integration period to 1024 samples and adjust the Gain block accordingly. Run the simulation for .1024 s and observe the Scope. What is the mean of the ten values that appear on the scope? What do you expect the mean to be if the AWGN block noise is truly random?

6. Modify the system to include a low pass filter, as shown below. Remove the unit delay block.



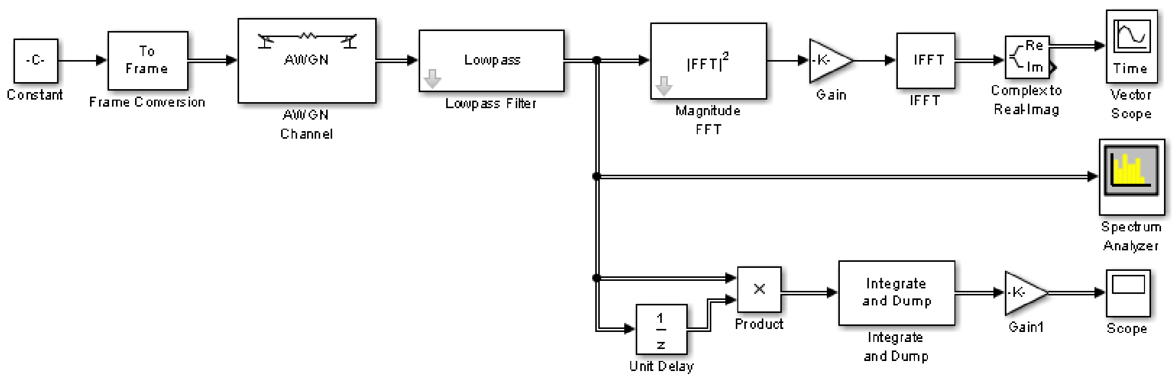
Configure the Lowpass Filter to be a FIR filter with minimum order. Enter the sample frequency and set the Fpass = 10000 Hz and Fstop =11000 Hz. Leave Apass at 1 and Astop at 60, their defaults. Calculate the double sided, -3dB bandwidth of this filter and change the value of the Gain block in the bottom leg accordingly. You can find the -3dB point in the filter response by double clicking on the lowpass filter block and clicking on View Filter Response in the dialog box.

7. Run the simulation for .1024 s and observe the outputs of the various scopes. Notice that the Vector Scope displays shorter and slightly wider pulses. Zoom in on the pulse near the 10 ms mark in the simulation. What is the shape of the pulse now? Record the time position and value of the peak. Record the locations of the first zero crossings. How do these compare with the bandwidth of the filter and the autocorrelation function for bandwidth limited noise? Notice the peak of the pulse is smaller. How does this relate to the fact that the noise without the filter was a *power* signal and with the filter it is an *energy* signal? Use the definition of the autocorrelation function for each type of signal in your answer.

Notice the Spectrum Analyzer still shows a flat noise spectrum out to the plus and minus Fpass frequencies at the same level as before. Is the power spectral density for frequencies below Fpass the same? Zoom in and record the value of the Spectrum scope at 0 kHz.

Notice the average level of the scope in the bottom leg is unchanged. Remember we adjusted the level of the Gain block to account for the change in bandwidth. Return the Gain block value to its original value and run the simulation again. How does the new average value for this scope compare with the peak of the Vector scope?

8. Insert the unit delay block as shown below. Run the simulation again. Record the average value of the Scope in the bottom leg. How does this compare with the values of the Vector scope 0.01 ms to the right and left of the peak near 10 ms?



THOUGHTS FOR CONCLUSION

1. How does the fact that we are limiting our observations to finite amounts of time affect the observations in this experiment?
2. What can we say in general about measurements of noise parameters such as variance and power spectral density?
3. Passing white noise through a low pass filter reduces the amount of energy in the noise. What else does it do?
4. In steps 2 and 7, you recorded the value displayed on the spectrum scope at 0 kHz. This corresponds to the DC component on the noise, which is also the mean value of the noise voltage. The mean value of white, Gaussian noise is 0. Why are these values not 0?

As always, do not limit your conclusions to these questions.