EE354: Lab 9 – Introduction to Noisy Channels

Formal Report Required

Part 1: Noise in the Time Domain

NOTE: Before beginning, ensure that Channel 1 and Channel 2 of the Oscilloscope are configured for DC coupling, 50Ω Input Impedance.

For this part of the lab, you will need 2 Agilent 33220A Signal Generators, Three BNC cables, and one BNC "T" adapter.

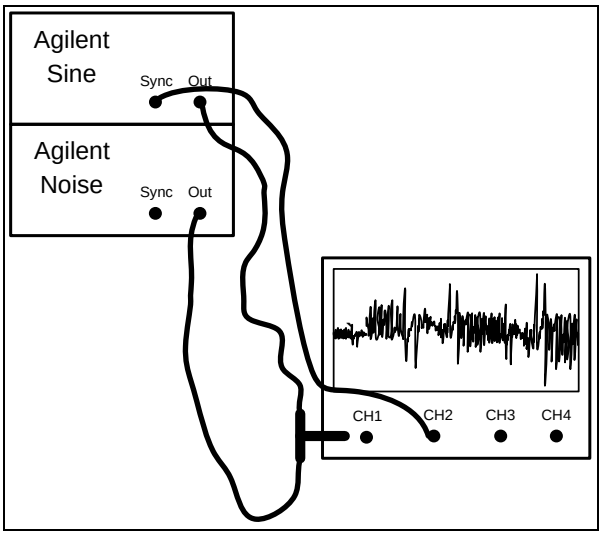

Figure 1: Measurement Setup Connections

1. Configure the first Agilent Signal Generator to produce a 2 MHz sine wave with an output power of +4 dBm.

2. Connect the output of the generator to one input of a BNC T adapter. Connect the output of a second Agilent Signal Generator to the other input of the BNC T, and connect the BNC T output to Channel 1 of the oscilloscope. Configure Channel 1 to have DC Coupling and a 50Ω input impedance.

3. Connect the Sync output of the first generator to Channel 2 of the oscilloscope. Configure the oscilloscope to trigger on Channel 2 and set the trigger level to 500 mV.

4. Configure the second generator to produce a noise waveform. On the front panel, select "Noise", then select "Amplitude" and set the amplitude to a power level of -30 dBm. Leave the output turned **OFF**. Before proceeding, verify that the 2 MHz sinusoidal signal appears on the oscilloscope screen.

5. Under the *Measure* → *Measure Setup* menu, configure the scope to measure the RMS voltage of Channel 1, by selecting the following:

- **P1:** RMS / C1 (RMS voltage for Channel 1)

NOTE: When using the RMS Measurement, make sure the scope displays a green check mark below the RMS value. This tells you that the measurement displayed is accurate.

Record the RMS voltage of the noise-free sinusoid: _____

Calculate the corresponding power in dBm: _____

6. Now, turn **ON** the output of the noise generator and observe the sinusoid. You should see an essentially noise-free waveform. Note that the amplitude may drop slightly (why does this happen? Think EE372 and provide an explanation in your report for extra credit).

7. Under the "Timebase" menu in the bottom right-hand corner of the screen, configure the scope to record 100,000 samples, and then adjust the horizontal menu until the sampling frequency is 100 MS/s. Your waveform will appear as a big yellow blob – this is normal. Save the Channel 1 waveform to a Matlab data file. Include a meaningful plot of your "noise-free" waveform with your report (see Lab 3 for instructions on loading the file into Matlab).

8. Adjust the timescale of the oscilloscope until you can once again distinguish the sinusoid. Vary the power level of the noise generator and observe the resulting sinusoid.

At which noise power level is it no longer possible to distinguish the sine wave shape (you're looking for just the shape, not an obliteration of the sine wave): _____

Save your "noisy sinusoid" waveform to a Matlab data file and include a *meaningful* plot of your waveform with your report.

9. Reset the output power level of the noise signal generator to -30 dBm. Turn **OFF** the output of the sinusoid generator.

10. Observe the measure RMS voltage for the noise signal on the oscilloscope and record the measured RMS voltage for the various levels of noise output power in Table 1 (You can get an accurate reading by pressing the "Stop" button, which will freeze the display). Provide a completed copy of the table with your report.

Table 1: Noise RMS Value

Noise Level (dBm)	Recorded RMS Value	Calculated Noise Power (dBm)	Theoretical SNR (dB)	Measured SNR (dB)
-30				
-25				
-20				
-15				
-10				
-5				
0				
5				
10				

Note: The *Theoretical SNR* is based on the theoretical power of the sinusoid (which you can calculate) and the theoretical noise power (column 1 in the table above). The *Measured SNR* is based on the measured power of the sinusoid (which you calculated in step 5) and the measured noise power, which you can calculate from the Recorded RMS value.

Note: The scope will then compute and display the measurement on the screen under the waveform, along with a green check-mark. The green check-mark means that the scope believes the measurement to be good quality and valid data; a red x-mark means that the measurement is of poor quality and possibly invalid. If you get a red check-mark, adjust the vertical scale so that the entire waveform is displayed on the screen.

10. Disconnect the noise generator from the BNC "T" adapter and connect it directly to Channel 1 of the oscilloscope. Set the noise generator output power to 0 dBm. Verify that the scope is configured to record at least 100,000 sample points. **Record the displayed noise waveform to a Matlab data file. Repeat this process for noise powers of +10 dBm and -10 dBm.**

11. Reconnect the noise generator to the BNC "T" adapter, and turn **ON** the output of the sinusoidal generator. Set the noise power to 0 dBm. Configure the oscilloscope to Average 11 waveforms together by going to: *Math* → *Math Setup* and selecting the following options:

- *Source1*: C1
- *Operator1*: Average
- Under the "Average" Tab on the lower right-hand part of the screen: *Sweeps*: 11.

Press the "Clear Sweeps" button to clear out the memory and restart the averaging process. Observe the noisy sinusoid. Increase the number of averages to 31, then 127, and finally 1009. What happens to the noisy sinusoid as you increase the number of averages? What can you conclude about the noise signal?

Note: In the bottom right-hand corner of the oscilloscope's screen, you will see a running count of the number of waveforms that have been included in the Average. Wait until the count reaches the number of averages you set, and then make the observation.

Part 2: Noise in the Frequency Domain

1. Connect the output from the BNC T to the Anritsu spectrum analyzer. Reset the noise generator output power level to -30 dBm, turn **OFF** its output, and turn **ON** the output of the sinusoidal signal generator (2 MHz sine wave with output power of +4 dBm). Reset the spectrum analyzer to the factory default settings.

Configure the Spectrum Analyzer to the following settings:

- Frequency Range: 500 kHz – 3.5 MHz
- Reference Level: +10 dBm
- Resolution Bandwidth: 30 kHz

Also, configure the spectrum analyzer to average traces by going to *BW/Sweep* → *More* → *Average* → *5*.

2. View the spectrum of the noise-free sinusoid. Use the markers to record the peak power of the sinusoid. This power level should match with the calculated/measured power in Part 1, Step 5**. Record a copy of the noise-free sinusoid spectrum and include it with your report.**

Measured power of the noise-free sinusoid: _____

3. Turn **ON** the noise generator. You should observe a slight increase in the overall noise level on the trace. Move the marker to a point far away from the peak of the sinusoidal signal (approximately 3 MHz is a good spot). You are observing a power level which corresponds to the Noise Spectral Density ($\frac{N_0}{2}$) integrated over the 30 kHz resolution bandwidth. To see the actual $\frac{N_0}{2}$, turn on the Noise Markers by going to *Marker* → *More* → *Noise Marker*.

On the bottom part of the screen, you should see a line that looks *similar to* the following:

M1: -71.22 dBm/Hz, 3.192 MHz

The first number represents the **Two Sided Noise Spectral Density** ($\frac{N_0}{2}$ in dBm/Hz) and the second provides the frequency at which the noise power was measured. Note that the value will be weaker by 3 dB. You can calculate the total noise power from the following equations:

$$\frac{N_0}{2} = 10^{\frac{p_{marker}}{10}} \quad [milliwatts / Hz]$$

$$p_{noise_{Total}} = 2\left(\frac{N_0}{2}\right) BW \quad [milliwatts]$$

Where BW is the bandwidth over which the noise power was <u>generated</u>. Note that the Agilent 33220A signal generator produces noise over a 9MHz bandwidth (if you zoom out on the spectrum analyzer, you can see the noise power fall off above 9 MHz). If calculated properly, the total noise power (in dBm!) should match very closely the power output setting on the signal generator.

Record a copy of the noisy sinusoid spectrum and include it with your report.

4. Using the spectrum analyzer, record the noise marker powers in the table below. For your report, provide the completed table in the results section.

Table 2: Noise Value in dB

Noise Level (dBm)	Recorded $\frac{N_0}{2}$ Value (dBm/Hz)	Calculated Total Noise Power (dBm)	Theoretical SNR (dB)	Measured SNR (dB)
-30				
-25				
-20				
-15				
-10				
-5				
0				
5				
10				

Note: The *Theoretical SNR* is based on the theoretical power of the sinusoid (which you can calculate) and the theoretical noise power (column 1 in the table above). The *Measured SNR* is based on the measured power of the sinusoid (which you measured in step 2) and the calculated Total Noise Power.

5. Record a copy of the noisy sinusoid with a noise power level of 0 dBm and include a copy of it in your report.

Part 3: Stochastic Properties of Noise

Note: Once you have recorded the three noise-only waveforms from Part 1, this part of the lab can be completed outside of the lab period.

1. Start Matlab and load your -10 dBm noise-only waveform.
NOTE THAT: Column 1 of the data will be the time samples and Column 2 of the data will be the corresponding amplitude values.

2. Use the `mean()` and `std()` commands to determine the mean and standard deviation of the amplitude values of the noise waveform. Record these values in the table below:

Table 3: Noise Statistics

Noise Level (dBm)	Mean Value (V)	Standard Deviation (V)	Calculated $\frac{N_0}{2}$ Value (dBm/Hz)	$\frac{N_0}{2}$ Value from Table 2 (dBm/Hz)
+10				
0				
-10				

3. Assuming that the noise signal is Gaussian, the noise spectral density (N_0) can be found from the standard deviation using the following equation:

$$\frac{N_0}{2} = \frac{\sigma^2}{2 \bullet BW_{Scope}}$$

Where BW_{Scope} is the bandwidth of the LeCroy oscilloscope. Use the above equation to calculate the $\frac{N_0}{2}$ value based on the statistics and compare it with the $\frac{N_0}{2}$ value that you will calculate for Table 3.

4. The following segment of Matlab code will allow you to compare the PDF of your recorded noise signal with an ideal Gaussian PDF. Run the code, comment on how accurately the Gaussian PDF models the probability density of the actual noise signal, and include a copy of the plot in your report.

```
n=length(data(:,2));

% Get histogram parameters

[N, x]=hist(data(:,2),20);  % Get histogram data
del_x = x(3)-x(2);      % Determine bin width
pdf_hist = N/n/del_x;   % get probability from histogram

% Generate Theoretical PDF
pdf = (1./sqrt(2*pi*sigma.^2))*exp(-(x-mean).^2./(2*sigma.^2));

plot(x,pdf,'k-')
hold on
plot(x,pdf_hist,'X')
```

<u>Answers to Lab Questions to be included in the Discussion of Results Section of the Report.</u>

Part 1, Step 8: At which noise level is it no longer possible to distinguish the sine wave shape?

Part 1, Step 9: Does the measured noise power match the noise power set on the noise generator? Does the measured SNR match the theoretical SNR? What SNR value corresponds to the noise power level where you were unable to observe the sine wave?

Part 1, Step 11: What happens to the noisy sinusoid as you increase the number of averages? What can you conclude about the noise signal?

Part 2, Step 3: Does the measured noise power match the noise power set on the noise generator? Does the measured SNR match the theoretical SNR? Do the measured SNR values from the spectrum analyzer match the measured SNR values from the oscilloscope? If any discrepancies exist, explain what's causing them.

Part 3, Step 5: How accurately does the Gaussian PDF model the actual recorded probability density of your recorded noise voltages?

<u>Figures to include in the Report</u>

Plot of noise-free sinusoid from Part 1, Step 7.
Plot of noisy sinusoid from Part 1, Step 9.
Completed Table from Part 2, Step 3.
Plot of noise-free sinusoidal spectrum from Part 2, Step 2.
Plot of noisy sinusoidal spectrum from Part 3, Step 3.
Completed Table from Part 3, Step 3.
Plots of theoretical and actual noise PDFs from Part 3, Step 5.