

# GNU Radio Lab 2: Noise, SNR, and Signal Quality

## EE 451: Communications Systems

Name: \_\_\_\_\_ Date: \_\_\_\_\_

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### Objectives

1. Understand noise characteristics in communication systems
  2. Measure and calculate Signal-to-Noise Ratio (SNR)
  3. Observe the effect of noise on signal quality
  4. Implement noise addition and filtering in GNU Radio
  5. Relate SNR to practical communication performance
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### Equipment Required

- Computer with GNU Radio Companion installed
  - RTL-SDR USB dongle (for Part 4)
  - Antenna
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## Part 1: Gaussian Noise Characteristics (20 points)

### Task 1.1: Generate and Visualize AWGN

Create a flowgraph to generate and analyze Additive White Gaussian Noise (AWGN):

1. Add **Noise Source** block
  - Type: Gaussian
  - Amplitude: 1.0
2. Add visualization blocks:
  - **QT GUI Time Sink**
  - **QT GUI Frequency Sink**
  - **QT GUI Histogram Sink**
3. Set sample rate to 32000 Hz

**Screenshot 1.1:** Your noise generation flowgraph.

*[Insert screenshot]*

**Screenshot 1.2:** Time domain view of Gaussian noise.

*[Insert screenshot]*

**Screenshot 1.3:** Frequency spectrum of white noise (should be flat).

*[Insert screenshot]*

**Screenshot 1.4:** Histogram showing Gaussian distribution.

*[Insert screenshot]*

### Question 1.1 (10 points)

- Why is the frequency spectrum of “white” noise flat?
- What is the relationship between the noise amplitude setting and the noise power (variance)?
- From your histogram, estimate the standard deviation of the noise. How does this compare to the amplitude setting?

#### Your Answer:

*[Write your answer here]*

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## Part 2: Signal-to-Noise Ratio Measurement (30 points)

### Task 2.1: Create Signal + Noise System

Build a flowgraph with:

- Signal Source** (sine wave)
  - Frequency: 1000 Hz
  - Amplitude: 1.0
  - Sample Rate: 32000
- Noise Source** (Gaussian)
  - Amplitude: Variable (start at 0.1)
- Add** block to combine signal and noise
- Visualization:
  - QT GUI Time Sink (show both clean and noisy signals)
  - QT GUI Frequency Sink
- Add **QT GUI Range** slider to control noise amplitude (0.01 to 2.0)

**Screenshot 2.1:** Flowgraph with signal, noise, and variable control.

*[Insert screenshot]*

### Task 2.2: Measure SNR at Different Noise Levels

For each noise amplitude setting, measure: - Signal power from the spectrum display - Noise power from the spectrum display (noise floor) - Calculate SNR in dB

#### SNR Measurement Table:

Noise Amplitude	Signal Power (dB)	Noise Floor (dB)	SNR (dB)	Signal Quality
0.1				
0.3				
0.5				
1.0				
2.0				

### Task 2.3: Visual Comparison

**Screenshot 2.3a:** Time domain at high SNR (noise amplitude = 0.1).

*[Insert screenshot]*

**Screenshot 2.3b:** Time domain at low SNR (noise amplitude = 1.0).

*[Insert screenshot]*

### Question 2.1 (10 points)

- At what SNR does the sine wave become difficult to identify visually in the time domain?
- Even when the sine wave is hidden in noise visually, can you still see it in the frequency domain? Why?
- If signal amplitude is 1.0 and noise amplitude is 0.5, calculate the expected SNR in dB.

**Your Answer:**

*[Write your answer here]*

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## Part 3: Filtering to Improve SNR (25 points)

### Task 3.1: Add Low-Pass Filter

Modify your flowgraph to include filtering:

- Add **Low Pass Filter** after the Add block
  - Cutoff Frequency: 1500 Hz
  - Transition Width: 500 Hz
- Display both filtered and unfiltered signals

**Screenshot 3.1:** Flowgraph with filter added.

*[Insert screenshot]*

### Task 3.2: Measure SNR Improvement

Compare SNR before and after filtering:

Noise Amplitude	SNR Before Filter (dB)	SNR After Filter (dB)	Improvement (dB)
0.5			
1.0			

**Screenshot 3.2:** Spectrum comparison before/after filtering.

*[Insert screenshot]*

### Task 3.3: Experiment with Filter Bandwidth

Try different filter cutoff frequencies:

Cutoff Frequency	SNR (dB)	Signal Distortion?
5000 Hz		
2000 Hz		
1500 Hz		
1100 Hz		
1000 Hz		

#### Question 3.1 (15 points)

- Why does a narrower filter bandwidth improve SNR?
- What happens to the signal when the filter bandwidth is too narrow (e.g., below the signal frequency)?
- In practice, why can't we always use the narrowest possible filter?
- The noise power in a bandwidth  $B$  is  $N = N_{\text{noise}} \times B$ . If you halve the filter bandwidth, how much does the SNR improve (in dB)?

**Your Answer:**

*[Write your answer here]*

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### Part 4: Real-World SNR with RTL-SDR (25 points)

#### Task 4.1: Measure FM Station SNR

- Build FM receiver flowgraph (from Lab 1)
- Tune to a strong local FM station
- Tune to a weak/distant FM station
- Compare signal quality

**Screenshot 4.1a:** Spectrum of strong FM station.

*[Insert screenshot]*

**Screenshot 4.1b:** Spectrum of weak FM station.

*[Insert screenshot]*

#### Task 4.2: Estimate SNR from Spectrum

For each station:

Station	Freq (MHz)	Peak Power (dB)	Noise Floor (dB)	Est. SNR (dB)	Audio Quality
Strong					

Station	Freq (MHz)	Peak Power (dB)	Noise Floor (dB)	Est. SNR (dB)	Audio Quality
Weak					

### Task 4.3: Effect of Antenna Position

1. Move antenna to different positions
2. Observe SNR changes

#### Observations:

*[Describe how antenna position affects signal quality]*

### Question 4.1 (10 points)

- a) What causes the noise floor in the RTL-SDR receiver?
- b) Why does the FM signal “capture” effect mean that only the strongest signal is heard when two stations are close in frequency?
- c) FM is often described as having a “threshold effect.” What happens when SNR drops below about 10-12 dB?

#### Your Answer:

*[Write your answer here]*

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## Part 5: Noise Figure and System SNR (Bonus - 10 points)

### Background

The noise figure (NF) describes how much noise a component adds:

$$NF = 10 \log_{10} \left( \frac{SNR_{in}}{SNR_{out}} \right)$$

For cascaded stages (Friis formula):

$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \dots$$

### Question 5.1 (Bonus)

A receiver has these stages: - LNA: Gain = 20 dB, NF = 1.5 dB - Mixer: Gain = -6 dB (loss), NF = 8 dB - IF Amp: Gain = 30 dB, NF = 3 dB

- a) Calculate the total system noise figure.
- b) Why is the first stage (LNA) noise figure most critical?
- c) If the RTL-SDR has NF 4-6 dB, would adding a low-noise amplifier (LNA) with NF = 1 dB and G = 20 dB at the antenna improve performance? By how much?

## Your Answer:

*[Write your answer here]*

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## Lab Summary

### Key Concepts

1. **AWGN:** Gaussian amplitude distribution, flat (white) frequency spectrum
2. **SNR:**  $\text{SNR(dB)} = 10 \cdot \log_{10} (P_{\text{signal}}/P_{\text{noise}})$
3. **Filtering:** Narrower bandwidth reduces noise power
4. **Trade-off:** Bandwidth vs. SNR vs. data rate
5. **Noise Figure:** Describes noise added by receiver components

### Important Formulas

- $\text{SNR (dB)} = \text{Signal Power (dB)} - \text{Noise Power (dB)}$
- $\text{Noise Power} = kTB$  (thermal noise)
- $\text{Filter SNR improvement} = 10 \cdot \log_{10} (BW_{\text{old}}/BW_{\text{new}})$  dB

### Practical Insights

- First stage gain and NF are most important
  - Filtering helps but can't recover information lost to noise
  - Real systems have multiple noise sources
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### Submission Checklist

- ☐ All screenshots inserted
- ☐ All measurement tables completed
- ☐ All questions answered
- ☐ Flowgraph files (.grc) attached

**Files to Submit:** 1. This completed worksheet (PDF) 2. noise\_analysis.grc 3. snr\_measurement.grc 4. filter\_comparison.grc

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*Submit to Brightspace by due date.*