

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

EE 451: Communications Systems

Name: _____ Date: _____

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]

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]

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]

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]

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]

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)
- $\text{Filter SNR improvement} = 10 \cdot \log_{10} (BW_{\text{old}}/BW_{\text{new}}) \text{ dB}$

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

Submit to Brightspace by due date.