

ECE 215/S – Principles of Electronic Cyber Warfare

Block 3: Communication Systems, Radar, and Electronic Warfare

Lesson 36: Signal-to-Noise Ratio

Department of Electrical and Computer Engineering
United States Air Force Academy

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Objective 3.8

I can calculate signal-to-noise ratio (SNR) and determine the effects on wireless communications.

- Lessons 33 and 34 each handed you a sensitivity $P_{R,\min}$. Today we find out where that number *comes from*
- Lesson 35 said a shorter pulse makes a weaker echo and costs detection range. Today's **noise floor** is the reason
- SNR is also the foundation of jamming — which is Lesson 37
- Assessed on **Quiz 10** along with Objectives 3.5, 3.6, 3.7, and 3.9

Where We Are Going

By the end of this lesson, you will be able to:

- Explain where **noise** comes from and what sets the noise floor
- Compute **noise power** from system temperature and bandwidth
- Compute **SNR** for a communications link and for a radar link
- Decide whether a link closes or a radar detects, by comparing SNR with the receiver's **minimum SNR**
- Work backward from that minimum SNR to a **minimum detectable signal**

Where Noise Comes From

Thermal noise is not interference from someone else. It is there when **nobody** else transmits.

- **Thermal noise** — every conductor above absolute zero has charge carriers in random motion. That motion is a tiny random voltage
- **Receiver noise** — the amplifiers and other electronics in your own receiver add their own
- **Sky and ground noise** — the antenna collects thermal radiation from whatever it points at

You cannot turn noise off. You can make the signal bigger, the bandwidth narrower, or the receiver colder. Lesson 37 adds a hostile transmitter on top of this floor.

SNR Defined

$$SNR = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

- In plain terms: *how loud you are talking* divided by *how loud everyone else is talking*
- It is a **ratio** of two powers — dimensionless. In dB, $SNR_{\text{dB}} = 10\log_{10}(SNR)$: power ratios use $10\log_{10}$, and the sheet's $20\log_{10}$ row is Lesson 17's voltage-gain form
- Every receiver has a **minimum SNR** it needs, written $SNR_{\min}$ — its "required SNR." Below it the link fails, even when the signal is above the noise. $SNR > 1$ is **not** the test
- $SNR < 1$ means only that the signal is below the noise *as received*. $SNR_{\min}$ belongs to the receiver's processing: one that integrates many pulses, or de-spreads a spread-spectrum signal, can work with $SNR_{\min}$ far below 1. One without that processing gain needs $SNR_{\min}$ above 1

Noise Power

Thermal noise power depends on two things you control and one you do not:

$$P_{\text{noise}} = k\,T_{\text{sys}}\,BW$$

k	Boltzmann's constant, 1.38×10^{-23} J/K — not the prefix kilo
T_{sys}	system noise temperature (K) — receiver quality and what the antenna looks at
BW	the receiver's bandwidth (Hz), matched to the signal (Lessons 15, 29); for a simple pulse radar, $BW \approx 1/\tau$ (Lesson 35)

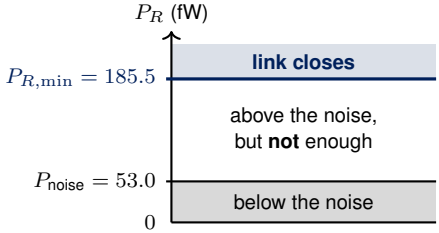
- Units: $(\text{J/K})(\text{K})(\text{Hz}) = \text{J/s} = \text{W}$. At 310 K and 10 MHz: $(1.38 \times 10^{-23})(310)(10 \times 10^{6}) = 4.28 \times 10^{-14}$ W $= 42.8$ fW — femto (f) is 10^{-15}
- **Narrower bandwidth means less noise**, so receivers filter down to just the signal. **Colder receivers hear better**, so radio astronomy cools its receivers

Minimum Detectable Signal

Set $SNR = SNR_{\min}$ in $SNR = P_R/(k\,T_{\text{sys}}\,BW)$ and solve for the received power:

$$P_{R,\min} = SNR_{\min} \cdot k\,T_{\text{sys}}\,BW$$

- This is the **sensitivity** ("minimum detectable signal") that Lessons 33 and 34 handed you. It belongs to **your receiver and its bandwidth**, not to the transmitter
- One test, two forms: $SNR \geq SNR_{\min}$ exactly when $P_R \geq P_{R,\min}$
- Example: $SNR_{\min} = 3.5$, 320 K, 12 MHz. Then $P_{\text{noise}} = 53.0$ fW, so $P_{R,\min} = 3.5\,(53.0) = 185.5$ fW



SNR in a Communications Link

Combine Friis with the noise floor:

$$SNR = \frac{P_R}{k\,T_{\text{sys}}\,BW} = \frac{1}{k\,T_{\text{sys}}\,BW} \cdot \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2}$$

- Everything that helped P_R in Lesson 33 helps SNR the same way. The gains are linear ratios with no units, as they were there
- And now you have a **second** lever: reduce BW
- Doubling range quarters the SNR. Halving the bandwidth doubles it

A lower data rate needs less bandwidth, which is why low-data-rate links reach so much farther at the same power.

SNR in a Radar Link

Same idea, but the signal comes from the *radar* range equation:

$$SNR = \frac{P_R}{k\,T_{\text{sys}}\,BW} = \frac{1}{k\,T_{\text{sys}}\,BW} \cdot \frac{P_T G^2 \sigma \lambda^2}{(4\pi)^3 R^4}$$

- The equation sheet writes RCS for σ and G_T^2 for G^2 — one antenna, used twice
- The R^4 carries straight through — radar SNR collapses *very* fast with range
- It detects when $SNR \geq SNR_{\min}$, so $P_{R,\min} = SNR_{\min}\,k\,T_{\text{sys}}\,BW$ here too
- Reducing σ attacks the numerator — why low observability works against detection

One threshold. A jammer (Lesson 37) adds its power to the noise, and the same $SNR_{\min}$ still decides: detect when $P_R/(P_{\text{noise}} + P_{R,\text{jam}}) \geq SNR_{\min}$. Today $P_{R,\text{jam}} = 0$.

Method: Deciding Whether a Link Closes

1. **Read the problem** — comms or radar? A verdict at one range, or a maximum range?
2. **Line of sight** (Lesson 32): $R_{LOS,mi} = \sqrt{2h_{\text{ft},1}} + \sqrt{2h_{\text{ft},2}}$, $\times 1.61$ for km. No LOS, no link
3. **Noise floor**: $P_{\text{noise}} = k\,T_{\text{sys}}\,BW$
4. **Received signal**: P_R from Friis (Lesson 33) or from the radar range equation (Lesson 34)
5. **Decide**: $SNR = P_R / P_{\text{noise}}$. The link closes — the radar detects — when $SNR \geq SNR_{\min}$. Max range: solve at $P_R = P_{R,\min} = SNR_{\min}\,P_{\text{noise}}$, then keep the **smaller** of that and LOS
6. **Check**: $P_R \geq P_{R,\min}$ gives the same verdict, and SNR has no units

A received power means nothing alone: compare it to the noise, or to a sensitivity that already contains the noise.

Worked Example

A relay aircraft at **20,000 ft** sends data to a ground station whose antenna is **50 ft** above the ground, **200 km** away. The gains are linear ratios with no units.

P_T	2 W	f	1.5 GHz	T_{sys}	400 K
G_T	1.64 (a dipole)	R	200 km	BW	5 MHz
G_R	10			$SNR_{\min}$	4

1. Is there line of sight?
2. What are the noise power and the received signal power at the ground station?
3. What is the SNR, and does the link close?
4. What is the receiver's sensitivity $P_{R,\min}$, and what is the link's maximum range?

Worked Example — Solution

1. Line of sight (Method step 2)

$$R_{LOS,mi} = \sqrt{2(20{,}000)} + \sqrt{2(50)} = 210 \text{ mi}$$

$210 \times 1.61 = 338$ km, and the link is 200 km: **yes**.

2. Noise floor, then received signal (steps 3–4)

$$P_{\text{noise}} = (1.38 \times 10^{-23})(400)(5 \times 10^{6}) = 27.6 \text{ fW}$$

With $\lambda = c/f = 0.2$ m, Friis gives

$$P_R = \frac{(2)(1.64)(10)(0.2)^2}{(4\pi \cdot 200{,}000)^2} = \frac{1.312}{6.317 \times 10^{12}}$$

$$P_R = 2.077 \times 10^{-13} \text{ W} = 207.7 \text{ fW}$$

3. Decide (step 5)

$$SNR = \frac{207.7 \text{ fW}}{27.6 \text{ fW}} = 7.53 \quad (8.8 \text{ dB})$$

$7.53 \geq 4$, so **the link closes**.

4. Sensitivity and maximum range

$$P_{R,\min} = 4\,(27.6 \text{ fW}) = 110.4 \text{ fW}$$

Check: $207.7 \geq 110.4$ fW, the same verdict.

$$R = \frac{\lambda}{4\pi}\sqrt{\frac{P_T G_T G_R}{P_{R,\min}}} = 274 \text{ km}$$

That is inside the 338 km horizon, so **power binds**: the link reaches 274 km.

Your Turn

A datalink receiver has $T_{\text{sys}} = 290$ K and needs $SNR_{\min} = 10$ to close.

1. With $BW = 5$ MHz, what is the noise power and the sensitivity $P_{R,\min}$?
2. The signal arrives at 150 fW. What is the SNR, and does the link close?
3. The link is redesigned for a lower data rate, dropping BW to 500 kHz. What is the new $P_{R,\min}$, and does 150 fW close the link now?
4. By what factor does the maximum communication range improve? (Recall $P_R \propto 1/R^2$)
5. Why does a radar gain much less from the same change?

Wrap-Up

Key ideas:

- Noise is thermal and unavoidable: $P_{\text{noise}} = k\,T_{\text{sys}}\,BW$
- $SNR = P_{\text{signal}}/P_{\text{noise}}$. A link closes — a radar detects — when $SNR \geq SNR_{\min}$
- **Sensitivity** $P_{R,\min} = SNR_{\min} \times k\,T_{\text{sys}}\,BW$ — where Lessons 33 and 34 got their $P_{R,\min}$
- **Narrower bandwidth means less noise** — a lever the transmitter does not have

Next lesson:

- **Lesson 37 — Objective 3.9: Electronic Warfare and Jamming.** What happens when someone raises your noise floor *on purpose*
- **Quiz 10** (Objectives 3.5–3.9) is due at Lesson 38