

ECE 215/S – Principles of Electronic Cyber Warfare

Block 3: Communication Systems, Radar, and Electronic Warfare

Lesson 37: Electronic Warfare and Jamming

Department of Electrical and Computer Engineering
United States Air Force Academy

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Objective 3.9

I can analyze jamming scenarios using the Friis equation, RADAR equation, and SNR.

- Lesson 36 ended on a question: what happens when someone raises your noise floor **on purpose**? That is **jamming**, and it is today's lesson
- No new physics. Friis (Lesson 33), the radar range equation (Lesson 34), and the required SNR (Lesson 36), used together
- This is the **last new material before Quiz 10** (Objectives 3.5–3.9), due at Lesson 38

Where We Are Going

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

- Classify a spectrum activity as **ES**, **EP**, or **EA**
- Compute the SNR of a link **under jamming** and judge it against the SNR the receiver requires
- Simplify the jamming SNR to its essential terms
- Compute the SNR of a **jammed radar** and find its **burn-through range**
- Explain **low probability of intercept** and how spread spectrum defeats a jammer

Electronic Warfare: ES, EP, EA

Goal of EW: control the electromagnetic spectrum for our use and deny it to the adversary.

- **ES — Electromagnetic Support:** know what is emitting, where it is, and what it is. Radar warning receiver (RWR), ELINT
- **EP — Electromagnetic Protection:** make our own radios and radars hard to find and hard to jam. Frequency hopping, spread spectrum, emission control
- **EA — Electromagnetic Attack:** jam, deceive, or destroy threat sensors. Noise jamming, chaff, decoys, anti-radiation missiles

The order. Lesson 34: the listener has the advantage, because $1/R^2$ beats $1/R^4$.

- **ES first** — you cannot jam intelligently what you have not intercepted and characterized
- Then **EA** — put energy into the victim receiver's band so its SNR collapses
- **EP** the whole time — transmitting is what gives you away

"Electronic" is the legacy term; "Electromagnetic" is the current Joint term.

Jamming Is an SNR Problem

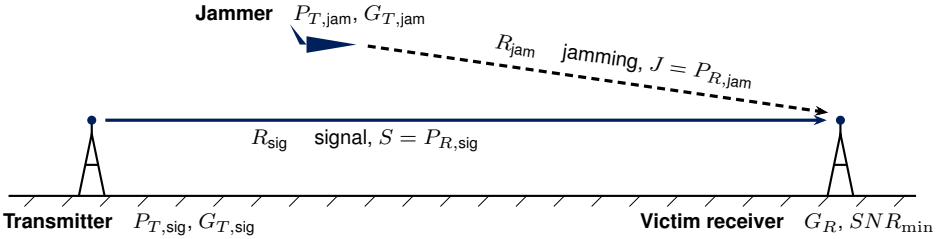
A jammer does not break the receiver. It **adds to the noise**.

A receiver works if and only if $\dfrac{S}{N+J} \geq SNR_{\min}$

- S: the wanted signal's received power. $N = k\,T_{\text{sys}}\,BW$: Lesson 36's thermal noise. J: the **jammer's received power**. $SNR_{\min}$: the receiver's one threshold, jammer on or off
- **Jammer off** ($J = 0$): Lesson 36's sensitivity, $P_{R,\min} = SNR_{\min}\,k\,T_{\text{sys}}\,BW$
- **Jammer on:** J swamps N — in today's example, 21.62 nW against 11.04 fW, about 2 million times larger. So drop N and compute S/J: the equation sheet's SNR_{comm} and SNR_{rad}
- $SNR_{\min}$ belongs to the **receiver's processing**: adding up pulses or de-spreading lets a receiver detect *below* the noise, with $SNR_{\min}$ far below 1. Without that, $SNR_{\min}$ is above 1

Vocabulary only, not assessed: EW references quote the jamming-to-signal ratio J/S; jamming works when $J/S > 1/SNR_{\min}$.

Communications Jamming



- Two **Friis** calculations into the **same receiver**: S over R_{sig}, and J over R_{jam}
- R_{jam} runs from the jammer to the **victim receiver** — never to the transmitter. A jammer apart from the link it attacks is a **stand-off** jammer
- Assumed: the receive antenna has the **same gain** G_R **toward both**, and the jammer is **on the victim's frequency**, inside its bandwidth

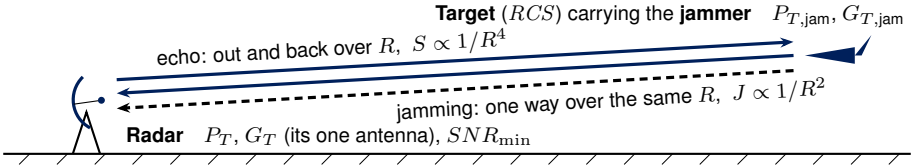
The Jamming SNR, Written Out

$$SNR_{\text{comm}} = \frac{P_{R,\text{sig}}}{P_{R,\text{jam}}} = \frac{\dfrac{P_{T,\text{sig}}\, G_{T,\text{sig}}\, G_R\, \lambda^2}{(4\pi R_{\text{sig}})^2}}{\dfrac{P_{T,\text{jam}}\, G_{T,\text{jam}}\, G_R\, \lambda^2}{(4\pi R_{\text{jam}})^2}} = \frac{P_{T,\text{sig}}\, G_{T,\text{sig}}\, R_{\text{jam}}^2}{P_{T,\text{jam}}\, G_{T,\text{jam}}\, R_{\text{sig}}^2}$$

G_R, λ^2, and $(4\pi)^2$ are in both and cancel. What is left is the **equation sheet's row**.

- The reading's R_{txrx} is R_{sig}, and its P_T, G_T, P_{jam}, G_{jam} drop the second subscript
- Gains are **linear ratios, no units**. The two ranges only need the **same** unit (1 mi = 1.61 km)
- **Range is the dominant lever.** A jammer twice as far away is four times less effective, so a **stand-in** jammer near the victim beats a distant one of the same power
- $G_{T,\text{jam}}$ counts only if the jammer is *pointed* at the victim. A receive antenna that nulls the jammer's bearing breaks the cancellation — and the jamming

Radar Jamming: The Jammer Rides on the Target



$$SNR_{\text{rad}} = \frac{P_{R,\text{rad}}}{P_{R,\text{jam}}} = \frac{\dfrac{P_T\, G_T^2\, (RCS)\, \lambda^2}{(4\pi)^3 R^4}}{\dfrac{P_{T,\text{jam}}\, G_{T,\text{jam}}\, G_T\, \lambda^2}{(4\pi R)^2}} = \frac{P_T\, G_T\, (RCS)}{P_{T,\text{jam}}\, G_{T,\text{jam}}\, 4\pi R^2}$$

the equation sheet's row

- Echo: the **radar range equation** (RCS is Lesson 34's σ). Jamming: **Friis** into the radar's antenna
- The jammer is *at the target's range* — **self-screening**, or an **escort** flying with it — so one R serves both paths. True stand-off radar jamming needs two ranges: outside this course

Burn-Through Range

$SNR_{\text{rad}} \propto 1/R^2$: far out the jamming wins, and as the target closes the echo gains on it. The **burn-through range** is where SNR_{rad} reaches the radar's $SNR_{\min}$:

$$R_{BT} = \sqrt{\frac{P_T\, G_T\, (RCS)}{P_{T,\textbf{jam}}\, G_{T,\textbf{jam}}\, 4\pi\, SNR_{\min}}}$$

in meters, since RCS is in m²

- **Two limits.** Jamming does not move the radar equation's detection range. It adds a second, tighter limit, the burn-through range: a jammed radar detects only **inside it**
- **Read it against the geometry.** A jammer at 30,000 ft is never closer than $30{,}000 \times 0.305 = 9{,}150$ m. If R_{BT} is less than that, the radar **never burns through**
- On the Lesson 37 page's EW Simulator, choose **ECE 215**: that page marks burn-through the same way, at $S/J = SNR_{\min}$

LPI and Other Countermeasures

Low probability of intercept (LPI) — the best defense is not being found:

- **Spread spectrum** — smear the signal across a very wide band so its power density drops below the noise floor. Only the intended receiver can de-spread it
- **Frequency hopping** — move the carrier many times per second on a pattern only the two ends know. A **chirp** sweeps it across the band instead
- **Power management** and **narrow beams** — radiate the least power, in the fewest directions, that closes the link

All of these make a signal hard to *find*. Spreading and hopping also make it hard to *jam*: the jammer must cover the whole band at once, which thins its power.

- **Other attacks: chaff**, **flares**, and **decoys** offer false targets; **anti-radiation missiles** (HARM) home on a radar's own emissions
- **The response:** frequency agility, sidelobe blanking, home-on-jam, or shutting down and moving

Method: The Jamming Problem

1. **Find the victim receiver** and its $SNR_{\min}$. Sketch the geometry, with every range drawn *into that receiver*
2. **Signal** S — Friis over R_{sig} for a link; the radar range equation over R for a radar
3. **Jamming** J — always Friis, over the jammer's own range to the victim
4. **Form** S/J — or go straight to the equation sheet: SNR_{comm} for a link, SNR_{rad} for a radar jammed from the target's range
5. **Decide.** At or above $SNR_{\min}$ the receiver still works; below it, it is jammed. For a burn-through range, set $SNR_{\text{rad}} = SNR_{\min}$ and solve for R
6. **Check:** J is far above $k\,T_{\text{sys}}\,BW$; meters wherever RCS appears; and the range makes sense against the geometry (line of sight, altitude)

Every range is measured into the victim receiver.

Worked Example

A threat air-defense site is cued over a radio **data link** and searches with its own **radar**. You jam both.

A. The data link — stand-off jamming

Transmitter	$P_{T,\text{sig}} = 1$ kW, $G_{T,\text{sig}} = 3$
	$R_{\text{sig}} = 80$ km, $f = 750$ MHz
Receiver	$G_R = 3$, $T_{\text{sys}} = 400$ K, $BW = 2$ MHz
	$SNR_{\min} = 0.06$ (it de-spreads)
Your jammer	$P_{T,\text{jam}} = 2$ kW, $G_{T,\text{jam}} = 20$
	$R_{\text{jam}} = 75$ km, on 750 MHz

B. The radar — self-screening jamming

Radar	$P_T = 250$ kW, $G_T = 2{,}000$
	$f = 3$ GHz, $SNR_{\min} = 2$
	$T_{\text{sys}} = 400$ K, $BW = 2$ MHz
Your aircraft	$RCS = 10$ m^2
Its jammer	$P_{T,\text{jam}} = 1$ W, $G_{T,\text{jam}} = 1$

1. **A:** Find S, J, and SNR_{comm} at the data-link receiver. Does the link survive your jamming?
2. **B:** You are 50 km from the radar. Find SNR_{rad}. Does the radar detect you?
3. **B:** Find the burn-through range
4. **B:** With your jammer off, how far out could this radar detect you?

Every gain is a linear ratio, and line of sight exists on every path.

Worked Example — Solution

A. Data link — victim: the site's receiver

$\lambda = c/f = (3 \times 10^8)/(750 \times 10^6) = 0.4$ m

$$S = \frac{(1000)(3)(3)(0.4)^2}{(4\pi \cdot 80{,}000)^2} = 1.425 \text{ nW}$$

$$J = \frac{(2000)(20)(3)(0.4)^2}{(4\pi \cdot 75{,}000)^2} = 21.62 \text{ nW}$$

$SNR_{\text{comm}} = 1.425/21.62 = 0.0659$. From the sheet, km over km:

$$SNR_{\text{comm}} = \frac{(1000)(3)(75)^2}{(2000)(20)(80)^2} = 0.0659$$

Decide: $0.0659 \geq 0.06$. The link **survives**, barely — your jamming is not effective from 75 km.

Check: $N = k\,T_{\text{sys}}\,BW$
$= (1.38 \times 10^{-23})(400)(2 \times 10^6) = 11.04$ fW $\ll J$.

B. Radar — victim: the radar (R in meters)

$$SNR_{\text{rad}} = \frac{(250{,}000)(2000)(10)}{(1)(1)(4\pi)(50{,}000)^2} = 0.159$$

$0.159 < 2$: at 50 km you are **not detected**.

$$R_{BT} = \sqrt{\frac{(250{,}000)(2000)(10)}{(1)(1)(4\pi)(2)}} = 14{,}100 \text{ m}$$

That is **14.1 km**. **Jammer off:** same N, so $P_{R,\min} = 2\,(11.04 \text{ fW}) = 22.08$ fW; $\lambda = 0.1$ m

$$R = \left[\frac{(250{,}000)(2000)^2(10)(0.1)^2}{(4\pi)^3\,(22.08 \times 10^{-15})}\right]^{1/4} = 219 \text{ km}$$

That is inside line of sight (394 km for a target at 30,000 ft). A 1 W jammer cuts 219 km to **14.1 km**.

Check: at 14.1 km, $J = 0.637$ nW $\gg N$.

Your Turn

Same site, same numbers as the worked example.

1. **Data link.** You close to $R_{\text{jam}} = 50$ km from the receiver. Find the new SNR_{comm}. Is the link jammed now?
2. By what factor did SNR_{comm} fall when you closed from 75 km to 50 km? What is the farthest R_{jam} from which your jamming works?
3. **Radar.** A stronger pod has $P_{T,\text{jam}} = 20$ W and $G_{T,\text{jam}} = 5$. Find the new burn-through range
4. You fly at 30,000 ft. Can the radar ever burn through the stronger pod?
5. Closing on the victim *helps* the data-link jammer but *hurts* the self-screening jammer. Why?

Wrap-Up

Key ideas:

- **ES** senses, **EA** attacks, **EP** protects — ES comes first, and **LPI** is EP: do not be found
- One rule, jammer on or off: $S/(N+J) \geq SNR_{\min}$. With a jammer on, N drops out
- A jammed link is SNR_{comm}; a radar whose target carries the jammer is SNR_{rad}. Both are on the equation sheet, and range rules both
- **Burn-through range** is where $SNR_{\text{rad}} = SNR_{\min}$. A jammed radar detects only inside it

Next:

- **Thanksgiving break**, 25–30 Nov. This was the **last new material before Quiz 10** (Objectives 3.5–3.9), due at **Lesson 38 (1/2 Dec)**
- **Lesson 38 — Project 3 Workday.** In teams of two, buy **one radar** on the EW Simulator's **ECE 215** page that meets **three requirements** within budget. The handout is on the Project 3 page; Gradescope opens over Thanksgiving