

ECE 215/S – Principles of Electronic Cyber Warfare

Block 3: Communication Systems, Radar, and Electronic Warfare

Lesson 32: Line of Sight and Wireless Channels

Department of Electrical and Computer Engineering
United States Air Force Academy

Fall 2026

Objective 3.4

I can calculate the maximum line-of-sight (LOS) distance between two terrestrial objects.

- Antennas (Lesson 31) told you how the signal leaves. Today: **how far it can reach**
- LOS combines with Friis at Lesson 33 to answer “can these two radios actually talk?”
- Assessed on **Quiz 9** (Objectives 3.3–3.5), due at Lesson 35
- **Quiz 8** (Objectives 3.1–3.2) is due tonight

Where We Are Going

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

- Name the **four wireless propagation methods** and the bands each one works in (context only — not assessed)
- Match a mission to the right **propagation mode** (context only — not assessed)
- Compute the **maximum LOS distance** for one or two elevated antennas, in miles and in kilometers
- Explain why LOS is the mode that matters for modern military communications

Channels: Wired and Wireless

Guided (wired)

- Copper cable
- Fiber optics
- Waveguides

High capacity, secure, and immune to jamming — but you have to lay it, and it does not move.

Unguided (wireless) — our concern

- Surface / ground wave
- Sky wave
- Forward scatter
- **Line of sight**

Mobile and flexible — and everything an adversary can hear or jam.

Frequency, not preference, decides which wireless mode you get.

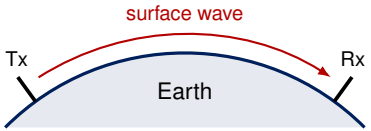
Context only: the propagation modes are not assessed. Objective 3.4 is the line-of-sight range.

Surface Waves

Context only — not assessed

The wave **"hugs"** the Earth's surface, following its curvature by diffraction.

- Works at **VLF, LF and MF** — a carrier $f_c \lesssim 3$ MHz — and fades as the frequency rises
- Range well beyond the horizon
- Commonly used for **AM broadcast radio**, which sits in MF
- Also submarine communications at VLF, where low frequency penetrates seawater

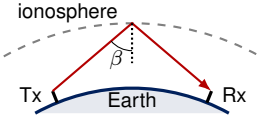


The wave follows the curve, so the receiver can be beyond the transmitter's horizon.

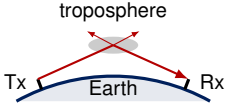
Long wavelengths bend around obstacles. Short ones do not — which is the whole story of this lesson.

Sky Waves and Forward Scatter

Context only — not assessed



Larger β, a more grazing ray: better bounce, longer hop



Most of the power scatters elsewhere

	Sky wave	Forward scatter (troposcatter)
How	The signal **bounces off the ionosphere**, at angle of incidence β, and comes back down far away	The signal strikes **discontinuities in the troposphere** and scatters in all directions; a small fraction lands at a distant receiver
Bands	**HF** (carrier $f_c \lesssim 30$ MHz)	**VHF, UHF and SHF** (from about 50 MHz up)
Use	Long-haul radio broadcast and **over-the-horizon radar (OTHR)**	**Beyond-line-of-sight** range without a satellite — which is why it is still fielded today
Catch	Depends on the ionosphere, so it varies with time of day and solar activity	Very inefficient: it trades power for range, so it takes big transmitters and big dishes

Line of Sight

- **All** electromagnetic signals propagate by LOS — every band, without exception
- The **geometric** limit is that the transmitter and receiver must *see* each other: distance is bounded by the **curvature of the Earth**. (Power is the other limit: Lesson 33)
- Common uses: satellite communications, cell phones, secure military links such as BFT2 and Link 16, and essentially all radar

LOS is the default. Everything else is a workaround for not having it.

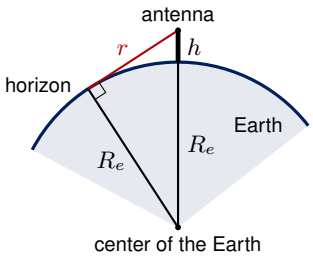
Choosing a Channel

Context only — not assessed

Mode	Bands	Range	Typical use
Surface wave	VLF, LF, MF ($\lesssim$3 MHz)	Beyond horizon	AM broadcast, submarine
Sky wave	HF ($\lesssim$30 MHz)	Long hops	Long-haul radio, OTHR
Forward scatter	VHF, UHF, SHF ($\gtrsim$50 MHz)	Beyond horizon	Troposcatter links
Line of sight	All	To the horizon	Satcom, Link 16, radar

- **Low frequency** buys range and obstacle penetration, but very little bandwidth
- **High frequency** buys bandwidth and antenna gain, but demands line of sight
- **Match the mission:** a message to a submerged submarine? A 5 MHz broadcast across an ocean? Link 16 between two fighters?

The LOS Distance Equation



Not to scale: h is exaggerated

The sight line from height h grazes the Earth at the **horizon**, at a right angle to the radius R_e. With $h \ll R_e$:

$$R_e^2 + r^2 = (R_e + h)^2 \implies r = \sqrt{2R_e h + h^2} \approx \sqrt{2R_e\, h}$$

The atmosphere bends radio waves slightly downward, so we use the **4/3 Earth radius** model — 3960 miles becomes 5280 miles. A mile is also 5280 feet, so the units collapse:

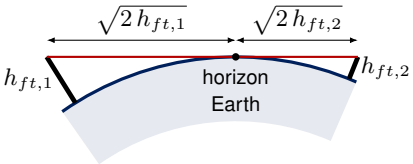
$$r = \sqrt{2h} \quad \text{— } h \text{ in feet, } r \text{ in statute miles}$$

An *improper* equation — the units do not balance — but it is right, and it is fast.

Two Elevated Antennas

When *both* ends are elevated, each one reaches its own horizon and the ranges add:

$$R_{LOS,mi} = \sqrt{2\,h_{ft,1}} + \sqrt{2\,h_{ft,2}}$$



Not to scale: heights are exaggerated

- This is the **equation sheet's row**; its subscripts are the units. With one end **on the surface**, $h = 0$ there and it reduces to $r = \sqrt{2h}$
- Height helps only as a **square root**: four times the altitude, twice the range — you cannot get there by raising a tower, which is why airborne relays and satellites exist
- **Conversions**, also on the sheet: 1 ft = 0.305 m, 1 mi = 1.61 km (**statute** miles)

Method: Line-of-Sight Range

1. **Sketch the two ends** and write each antenna's height above the surface between them
2. **Heights to feet.** A height in meters: divide by 0.305 m/ft
3. **One horizon distance per end:** $\sqrt{2\,h_{ft}}$, in miles. An end **on the surface** contributes 0
4. **Add them:** $R_{LOS,mi} = \sqrt{2\,h_{ft,1}} + \sqrt{2\,h_{ft,2}}$, in statute miles
5. **Kilometers, if asked:** multiply the miles by 1.61 km/mi
6. **Check:** heights went in as feet and miles came out; an aircraft's horizon is tens to hundreds of miles away; raising either end never shortens the range

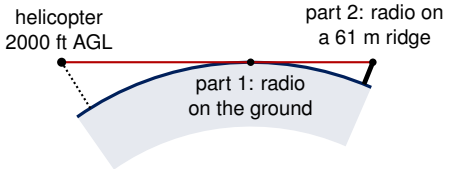
Equation sheet, Conversions row: 1 mi = 1.61 km 1 ft = 0.305 m (use only these)

Worked Example

A CSAR helicopter is searching for a downed airman from **2000 feet AGL**. Assume flat terrain.

1. The airman's survival radio is at **ground level**. How close must the helicopter get before the two have line of sight — in miles and in kilometers?
2. The airman climbs to a ridge **61 m** above the terrain. What is the maximum LOS range now?

Work it before the next slide.



Not to scale: heights are exaggerated

Worked Example — Solution

Part 1 — radio on the ground

1–2. Heights, in feet: $h_{ft,1} = 2000$ for the helicopter; $h_{ft,2} = 0$, an end on the surface

3–4. Horizon distances, added

$$R_{LOS,mi} = \sqrt{2(2000)} + 0 = 63.25 \text{ mi}$$

5. Kilometers

$$63.25 \text{ mi} \times 1.61 \text{ km/mi} = 101.8 \text{ km}$$

Part 2 — radio on the 61 m ridge

2. Height to feet:
$h_{ft,2} = 61 \text{ m} \div 0.305 \text{ m/ft} = 200 \text{ ft}$

3–4. Horizon distances, added

$$R_{LOS,mi} = \sqrt{2(2000)} + \sqrt{2(200)} = 63.25 + 20.00 = 83.25 \text{ mi}$$

5. Kilometers: $83.25 \times 1.61 = 134.0$ km

6. Check: a ridge one-tenth the helicopter's height still adds 20 miles — range goes as $\sqrt{h}$

Answer: contact within about **63 miles** (102 km) of an airman on the ground, or **83 miles** (134 km) of one on the ridge.

Your Turn

An E-3 AWACS orbits at **30,000 feet**. It needs to maintain a Link 16 connection with a fighter at **25,000 feet**.

1. What is the maximum separation at which they can hold line of sight — in miles and in kilometers?
2. A ground station's antenna is **30.5 m** above the ground. How far can the AWACS be from it?
3. To *double* the AWACS-to-ground range, what altitude would the ground antenna need?
4. What does your answer to 3 say about the value of altitude?

Wrap-Up

Key ideas:

- Four wireless modes: **surface wave**, **sky wave**, **forward scatter**, **line of sight** — frequency decides which you get (context only — not assessed)
- **LOS works in every band** and is what modern military communications rely on
- $R_{LOS,mi} = \sqrt{2\,h_{ft,1}} + \sqrt{2\,h_{ft,2}}$ — feet in, statute miles out; an end on the surface adds 0
- Range grows only as $\sqrt{h}$ — altitude has diminishing returns
- The sheet's conversions: meters $\div\ 0.305$ gives feet; miles $\times\ 1.61$ gives kilometers

Next lesson:

- **Lesson 33 — Objective 3.5: The Friis Equation.** Line of sight is necessary, not sufficient — you also need enough power. Friis is metric, so bring today's range in km
- **Quiz 8** (Objectives 3.1–3.2) is due tonight