
# ECE 495 – Electromagnetic Warfare and Survivability

## Block 2: RF Electronic Warfare

## Lesson 14: Triangulation and Fusion

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# Where We Left Off

L13 turned a measured phase into a **bearing**. But one bearing is a *line* — the emitter is somewhere along it, near or far, we cannot tell.

Cross a second bearing from a second receiver and the lines meet. That intersection is a **fix**.

**Today:** crossing bearings into a position, fusing more than two, and the full chain from antenna to track.

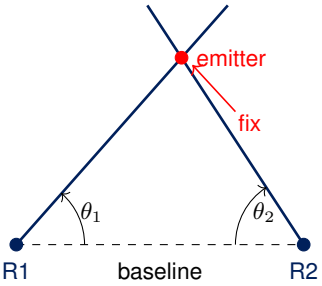
# Lesson Objectives

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

- **Triangulate** an emitter by crossing two lines of position
- Explain how **crossing geometry**, not receiver quality, sets the fix error
- Describe **multi-receiver fusion** and why more bearings help
- Trace the full **RWR processing chain** from intercept to track

# From Bearing to Fix

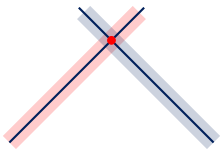
Each receiver gives a **line of position** (LOP) — the emitter lies somewhere along its bearing. Two LOPs cross at the fix.



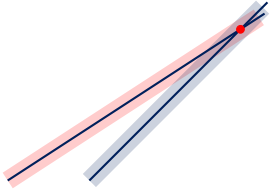

Two receivers, two bearings, one point — if the geometry cooperates.

# The Cut: Geometry Sets the Error

Each bearing carries a noise band. The fix lives where the two bands overlap — and that overlap depends on the **crossing ("cut") angle**.



cut $\approx 90^\circ$: tight



shallow cut: smeared

A $90^\circ$ cut gives a near-circular fix; a shallow cut stretches the error **along range**. Collinear emitter and receivers — a *seam* — has no cut at all.

# More Receivers: Least-Squares Fusion

With three or more bearings, the lines almost never meet at a single point — noise pulls them apart.

- The problem is now **overdetermined**: more equations than unknowns
- Solve for the position that best fits *all* bearings — a **least-squares** fix
- Each added receiver brings **redundancy** and, if well placed, a better cut
- A bad bearing stands out as a large residual — you can spot and down-weight it

**Two bearings give a fix. More bearings give a fix you can trust.**

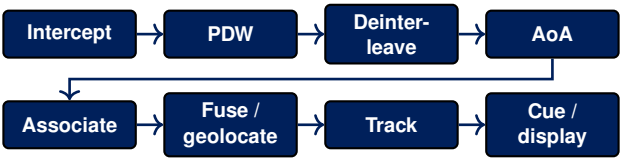
# Networked ESM in Practice

Crossing bearings across *platforms* is how standoff geolocation works:

- Separated receivers — wingmen, ships, ground sites — share PDWs over a data link
- All measurements must be **registered**: common time and common grid
- A wide baseline holds a usable, non-collapsing cut at long range — the B-21 standoff case
- Fused bearings can locate an emitter that no single receiver could place

This is the bridge from *warning* (where is it, roughly) to *targeting* (where is it, precisely).

# The RWR Processing Chain, End to End




- L12 built the top row — intercept to per-pulse AoA on *one* receiver
- L13–L14 add the bottom row — across receivers, into a located, tracked threat

# Association: The Step Before You Can Cross

Two receivers each report a bearing. Crossing them assumes they heard the *same* emitter. In a dense scene, that is a real question.

- Match candidate emitters across receivers on **frequency, PRI, and PW** first
- Only after they associate can their bearings be crossed into a fix
- Cross two *different* emitters and you invent a **ghost** — a fix on nothing

*Geolocation is only as good as the association feeding it.*

# Today's Interactive Demo: Cross the Bearings

Today's interactive demo.

- Two receivers, one emitter; each bearing carries $2^\circ$ of noise
- Cross the two lines for a single fix — then run it 2,000 times
- Move the emitter downrange and watch the *same* receivers do far worse

*Companion script:* `L14_TwoReceiverCrossFix.m`

*The receivers never change — only the geometry does. That is the whole lesson.*

# Quick Exercise / Type-along: Fix the Geometry

Two receivers sit 8 km apart on an east–west line. Reason about each case:

1. An emitter sits due north, abeam the pair. Good cut or bad?
2. The same emitter is now 40 km north. What happens, and which way?
3. The emitter drifts onto the receivers' east–west line. What breaks?
4. You may reposition *one* receiver. Where do you put it, and why?

# Wrap-Up

Key ideas:

- One bearing is a line; two crossing bearings are a fix
- The **cut angle** sets the error — shallow geometry smears it along range
- More receivers turn the fix into a least-squares solution you can trust
- Association comes first — cross the wrong pair and you get a ghost

Next lesson:

- **L15: Electromagnetic Protect** — LPI radar, agility, side-lobe cancellation
- Pre-flight quiz for L15 due before class