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VOR & VOR Tracking.

A complete, ground-up guide to VHF Omnidirectional Range navigation: theory, equipment, radial tracking, cross-fixing, chart reading, and practical scenarios, with practice questions to check your understanding.

Written by pilots, for people learning to fly.
Flightline Studios

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CHAPTER 01

What Is a VOR, and Why It Still Matters

VOR stands for VHF Omnidirectional Range. It's a ground-based radio navigation aid that tells an aircraft its bearing to or from a fixed station, and it has quietly underpinned civil aviation navigation since the 1940s.

Strip away the acronym and a VOR does one job: it lets an airplane, anywhere within range and line of sight, determine which of 360 possible directions it lies from the station. No distance, no altitude, just a bearing, accurate to about a degree. Combine that bearing with a second one from another station, or with a distance from a co-located DME, and you have an actual position. Combine a whole chain of VORs and you have the backbone of the airway system that has guided airliners, cargo flights, and student pilots for eighty years.

A short history

Before VOR, the standard en-route aid was the four-course radio range (sometimes called the Adcock range), which broadcast Morse-coded "A" and "N" signals that overlapped into a steady tone along exactly four fixed courses, and nothing usable in between. Pilots flew by listening for that tone and correcting when it broke down into dits or dahs. It worked, but it only gave you four lines in the sky.

VOR, standardized after World War II and built out across the United States through the 1950s and 60s, solved that limitation: instead of four fixed courses, it broadcasts continuously variable bearing information, any of 360 courses, to a precision of about a degree. It was a dramatic leap in navigational flexibility for its era, and it became the foundation of the Victor airway system that still appears on charts today.

Where VOR sits today

GPS has taken over as the primary means of en-route and approach navigation for most operators, but VOR hasn't gone away, for a few concrete reasons:

- **It's a non-satellite backup.** The FAA maintains a deliberately thinned-out but still-functioning VOR network, the Minimum Operational Network, or MON, specifically so aircraft can still navigate if GPS is degraded or unavailable over a wide area.
- **It's still charted and still flyable.** Victor airways, VOR approaches, and VOR-defined holding patterns are all still active in the National Airspace System.
- **It's still required knowledge.** Every private and instrument pilot curriculum, and every corresponding checkride, still tests VOR theory and radial tracking, both because it's operationally relevant and because understanding phase-comparison navigation builds real navigational judgment that GPS doesn't force you to develop, since GPS hands you the answer already computed.

> **KEY IDEA**
>
> A VOR gives you **bearing only**, one of 360 radiating lines from the station. Everything else in this guide explains how that one piece of information gets generated, displayed, and turned into something useful.

The rest of this guide builds from that single idea: first how the station physically produces a bearing signal, then how your instruments display it, then how you fly with it: intercepting, tracking, cross-fixing, and reading it correctly under pressure.

CHAPTER 02

The Physics: How a VOR Produces a Radial

A VOR ground station broadcasts two signals on the same VHF carrier frequency and compares them. The difference between them is the bearing.

Two signals, one carrier

The station transmits:

- **A reference phase signal.** A 30 Hz signal broadcast identically, in every direction, at the same time. Every receiver around the station, no matter where it sits, receives this signal with the same phase.
- **A variable phase signal.** Also 30 Hz, but produced by an antenna pattern that effectively sweeps around the station, 30 times per second. Where a receiver sits around the compass determines how far behind, in phase, the variable signal arrives relative to the reference signal.

By definition, the two signals are exactly in phase at magnetic north, the 360° radial. Moving clockwise around the station, the variable signal's phase lag increases in lockstep with the angle: 90° of phase lag at the 090 radial, 180° at the 180 radial, and so on, all the way around. An aircraft's VOR receiver measures that phase difference electronically and reports it directly as the radial.

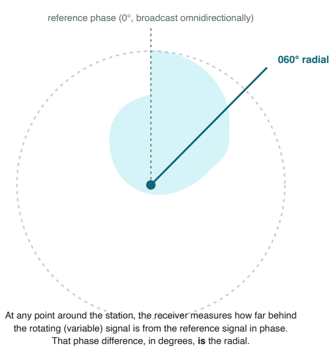


Figure 2.1: Reference phase (omnidirectional) versus the rotating variable-phase pattern. The phase lag measured at any point equals that point's radial.

Conventional VOR versus Doppler VOR

A conventional VOR (CVOR) produces the rotating variable signal with a directional antenna pattern that mechanically or electrically rotates. It's simple and effective, but it's also sensitive to siting: nearby terrain, buildings, or even large aircraft on the ramp can reflect the VHF signal and distort the pattern the receiver sees, producing small bearing errors.

A Doppler VOR (DVOR) solves this differently. Instead of one rotating antenna, it uses a ring of fixed antennas switched on in rapid sequence, which electronically simulates rotation using the Doppler effect. DVORs are considerably more resistant to siting errors, which is why you'll find them at VOR sites in mountainous or otherwise reflection-prone terrain. From the cockpit, a DVOR and a CVOR behave identically: the receiver, the CDI, and the radials all work exactly the same way. The difference is purely in how the ground station generates the signal.

> **WHY THIS MATTERS TO A PILOT**
>
> You never need to do this phase-comparison math yourself, the receiver does it. But understanding *that* a radial is a phase difference, not an arbitrary line someone drew on a chart, explains why VOR bearings are so consistent, why terrain can occasionally distort them, and why the whole system fails gracefully (a weak or noisy signal) instead of lying to you outright.

CHAPTER 03

Types of VOR Facilities

Not every VOR symbol on a chart represents the same equipment. Several variants exist, and knowing which one you're tuned into tells you what information you can get from it.

FACILITY	PROVIDES	NOTES
VOR	Bearing only	The baseline facility. No distance information.
VOR/DME	Bearing + distance	A VOR co-located with Distance Measuring Equipment. Bearing and distance together give you a fix from a single station.
VORTAC	Bearing + distance	A VOR co-located with a full military TACAN. Civil aircraft use the VOR for bearing and the TACAN's distance-measuring function, which is the same DME service; military aircraft can use TACAN's own bearing and distance channel directly.
TVOR (Terminal VOR)	Bearing only, shorter range	Lower-powered, intended for terminal-area use rather than long-range en-route navigation. Typically reliable to roughly 25 nautical miles.
VOT (VOR Test Facility)	A single simulated radial	Not a navigation aid at all. A ground facility (or function of one) that transmits a signal simulating the 360° radial in every direction, solely so pilots can check receiver accuracy. Covered in Chapter 11.

From the pilot's seat, the practical difference between a plain VOR and a VOR/DME or VORTAC is simple: if DME is available, you get a distance readout alongside your bearing, and a single station gives you a real position fix (bearing + distance) without needing to cross-reference a second VOR. Most VORs charted along major airways today are VOR/DME or VORTAC facilities for exactly this reason.

HOW TO TELL WHICH YOU HAVE

Sectional and en-route charts mark the facility type with a distinct symbol around the compass rose, and print the facility name and any co-located services in the identification box. Chapter 10 covers reading these symbols in detail, with the full set shown side by side.

CHAPTER 04

Understanding Radials

A radial is a magnetic bearing measured **from** the VOR station, outward. Every VOR broadcasts 360 of them, one in every direction, like spokes on a wheel.

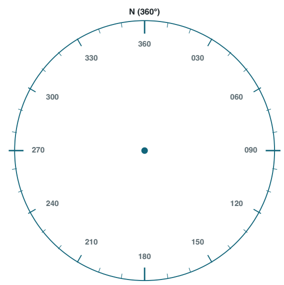


Figure 4.1: A VOR's 360 radials, numbered clockwise from magnetic north.

The rule that matters most

Radials are always numbered **from the station, outward**, never toward it. If you're physically positioned along the line labeled 045°, you are "on the 045 radial," regardless of which direction your nose is pointed. Whether you're flying away from the station (outbound) or toward it (inbound), the radial identifying that line never changes.

What changes is your heading and how you describe your direction of travel:

- Flying **outbound** on the 045 radial, in still air, you'd fly a heading of roughly 045°.
- Flying **inbound** toward the station along that same line, you'd fly the reciprocal heading, roughly 225°. Pilots commonly describe this as "inbound on the 045 radial," even though the heading flown is 225°. The radial names the line, not your direction on it.

> **MAGNETIC, NOT TRUE**
>
> Radials are referenced to **magnetic** north at the station, not true north, and each VOR's alignment already accounts for the local magnetic variation at its site when it's calibrated. You don't need to apply any variation correction yourself when working with radials; the station has already done it.

This 360-spoke wheel is also what gets printed on aeronautical charts: the circular compass rose you see around a VOR symbol on a sectional is a direct representation of these radials, oriented to magnetic north exactly as the station broadcasts them. Chapter 10 looks at that chart symbol directly, along with the other symbols in the VOR family.

CHAPTER 05

The Airborne Equipment

The station broadcasts a bearing. The cockpit equipment turns that broadcast into something you can act on, with three parts working together: the receiver, the OBS, and the CDI.

The VOR receiver

The receiver is tuned to the station's assigned frequency, somewhere in the VHF navigation band between 108.00 and 117.95 MHz. Internally, it demodulates both the reference and variable signals described in Chapter 2 and computes the phase difference between them: the radial the aircraft currently sits on. That raw number then drives everything else in the instrument.

The OBS, Omni Bearing Selector

The OBS is the rotatable knob (and the compass-card dial it turns) that lets *you* select a desired course: the radial, or its reciprocal, that you want to fly. Turning the OBS doesn't change anything about the signal coming from the station; it only changes what course the instrument is comparing your position against, and therefore how the needle and flag respond.

The CDI, Course Deviation Indicator

The CDI is the needle. It swings left or right of center to show how far off the selected course you currently are. On a real instrument, the course arrow at the top of the dial and the needle itself are both fixed relative to the case; what rotates when you turn the OBS knob is the numbered card underneath, so the selected course number always appears at the top. Most analog CDIs use a five-dot scale, and on a standard VOR receiver each dot typically represents about 2° of angular deviation from the course, with full-scale deflection representing roughly 10 to 12°.

The TO/FROM indicator

A small triangular flag (or equivalent glass-cockpit annunciation) tells you whether flying the selected course would take you **TO** the station or **FROM** it. This matters more than it sounds like it should: the CDI's left/right deviation only makes sense once you know whether you're oriented toward or away from the station on that course, and misreading this flag is the single biggest source of the "reverse sensing" confusion covered in the next chapter.

An **OFF** flag (or a blank display) appears when the signal is too weak or unreliable to trust: out of range, the station is off the air, or there's a receiver problem. Never treat CDI or TO/FROM indications as valid while the OFF flag is showing.

> **GLASS COCKPITS**
>
> Modern integrated displays typically present this same information on a Horizontal Situation Indicator (HSI), which combines the CDI course needle with a rotating heading card so your selected course and your actual heading are shown on the same instrument. The underlying VOR information, radial, deviation, TO/FROM, is identical; only the presentation changes.

CHAPTER 06

Reading the CDI

Four things, read together, tell you everything the instrument knows: the course you've selected, the needle's deflection, the TO/FROM flag, and whether you're headed in a direction that makes the first three meaningful.

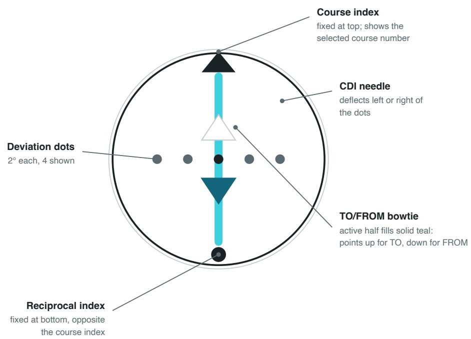


Figure 6.1: Anatomy of a VOR/OBS indicator. The course and reciprocal indices never move; only the needle position and the TO/FROM bowtie change as the aircraft moves.

> **READING THE BOWTIE**
>
> The TO/FROM indicator is two triangle outlines stacked in the middle of the dial, a bowtie. Only one half ever fills in solid: the upper triangle, pointing up toward the course index, fills for TO; the lower triangle, pointing down toward the reciprocal index, fills for FROM. Both halves stay visible as thin outlines even when hollow, so you can always see the shape, not just a flag that vanishes.

Figure 6.2: Four CDI readings, all with course 360 selected. Only the aircraft's actual radial changes between them.

All four examples above have the same course, 360, selected on the OBS. What changes is the aircraft's actual radial. Sitting exactly on the 360 radial with the course set to 360 gives a centered needle and the FROM triangle filled, since flying 360 from there leads away from the station. Sitting on the reciprocal, radial 180, with the same course selected gives a centered needle and the TO triangle filled instead, since flying 360 from there leads toward the station. Move slightly off either of those lines, to radial 010 or radial 350, and the needle deflects toward whichever side will bring you back to course if you follow it: left on 010, right on 350.

The basic procedure

1. Tune and positively identify the station (Chapter 11, never skip this).

2. Rotate the OBS until the CDI needle centers, or dial in the specific course you intend to fly.
3. Read the TO/FROM flag to know whether that course leads toward or away from the station.
4. Read the needle's deflection to see how far off that course you currently are, left or right.

Reverse sensing

The CDI's left/right logic only works intuitively when the heading you're flying roughly agrees with the course you've selected on the OBS. If you select a course but fly a heading closer to its *reciprocal*, nose pointed roughly opposite the selected course, the needle still deflects correctly by the underlying geometry, but it stops matching your instinct for which way to turn: it can appear to deflect toward the side you'd need to turn away from, if you're reading it as though your heading matched the course. This is called reverse sensing, and it's disorienting precisely because the instrument still looks normal; nothing tells you outright that your heading and your selected course are mismatched.

> **COMMON TRAP**
>
> Reverse sensing usually happens when a pilot sets the OBS to the *radial they're crossing* rather than the *course they intend to fly*. The fix is procedural, not mechanical: always set the OBS to the course you want to be flying, and always sanity-check the TO/FROM flag against your direction of travel before turning based on the needle.

> **PRACTICAL CHECK**
>
> Before trusting a deflected needle, ask: "Given my current heading, does the TO/FROM flag make sense?" If you're heading roughly toward the station and the flag says FROM, or the reverse, stop and re-set the OBS before making any turn based on the needle.

CHAPTER 07

Tracking a Radial

Getting established on a desired radial, and staying there despite wind, is the actual flying skill VOR navigation is built around. It comes down to two techniques: intercepting, and then holding.

Intercepting

If you're not currently on the radial you want, you need a heading that closes the distance to it at a reasonable angle, an intercept heading. A shallow intercept (20 to 30°) closes gradually and is easy to roll out of smoothly; a steep intercept (60 to 90°) gets you established quickly but requires a more decisive turn onto course. A 30 to 45° intercept is a comfortable default for most situations.

As you fly the intercept heading, watch the CDI needle move steadily toward center. That motion confirms the intercept is working. As the needle nears center, begin rolling out of the intercept heading toward the course heading itself, timing the turn so you arrive wings-level right as the needle centers, not after it's already passed through center.

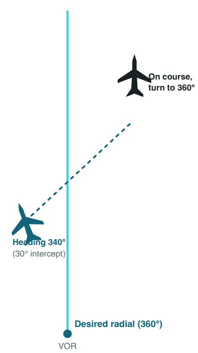


Figure 7.1: Flying a 30° intercept to establish on the 360° radial outbound, then turning on course as the CDI centers.

Holding the radial: wind correction

The moment you roll out on the course heading, wind will usually start pushing you off it again. The needle will begin a slow, steady drift away from center even though your heading hasn't changed. That drift is wind, not error, and the fix is a wind correction angle (WCA): a small heading adjustment turned into the wind, just enough to cancel the drift and hold the needle centered.

In practice, pilots find this angle by **bracketing**: apply a small correction (5° is a common starting point), watch how the needle responds over the next minute or two, then refine. If the needle still drifts the same direction, add more correction. If it now drifts the other way, you've overcorrected, so split the difference. Repeat until the needle holds steady. That tells you you've found a wind correction angle that matches the actual wind.

> **COMMON TRAP**
>
> Chasing the needle, making a big heading change every time it twitches, almost always makes tracking worse, not better, because it never gives you time to see whether a correction worked before the next one overrides it. Make a correction, then wait and watch before adjusting again.

> **TIP**
>
> Once you find a wind correction angle that holds the needle steady, that same angle will keep working as long as the wind doesn't change, so stop hunting once you find it. Small, patient corrections beat large, frequent ones.

CHAPTER 08

Station Passage and the Cone of Confusion

Fly directly over, or nearly over, a VOR station, and your instruments will briefly go strange: the needle wanders, the TO/FROM flag flickers, sometimes even flags OFF. This is normal, expected, and useful.

Why it happens

A VOR's ground antenna radiates its signal outward and slightly upward, but its vertical coverage pattern is weak almost directly overhead, like an inverted cone standing on top of the station where the signal geometry that makes bearing measurement reliable breaks down. Fly into that cone and the phase comparison the receiver depends on becomes unstable, so the CDI swings and the TO/FROM flag loses confidence, sometimes flipping to OFF entirely.

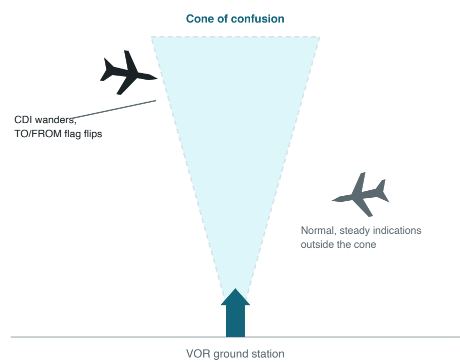


Figure 8.1: The cone of confusion sits directly above the station. Indications settle back to normal once you're through it.

Why it's useful

Because this wandering happens in a predictable, small zone directly over the station, pilots use it deliberately as confirmation of **station passage**, positive proof you've flown directly over (or very nearly over) the VOR. That matters for sequencing airway legs, timing procedures, and confirming position on a route defined as "direct to the station, then outbound on radial X." The needle settling back down and the TO/FROM flag flipping to the opposite sense (TO becomes FROM, or the reverse) tells you you're now on the other side.

The size of the cone isn't fixed; it scales with altitude. Fly directly over a VOR at 2,000 feet and you'll pass through the erratic zone quickly. Fly over the same station at 25,000 feet and the cone is much wider, so the period of unreliable indications lasts noticeably longer.

> **NOT A MALFUNCTION**
>
> A wandering needle and a flickering flag directly over a station is expected behavior, not a sign of equipment failure. If the same wandering happens well away from the station, that's a different story: see Chapter 12 for real error sources.

CHAPTER 09

Determining Your Position: The Two-VOR Cross-Fix

A single radial only tells you that you're somewhere along one line, not where on that line. To pin down an actual position, you need a second piece of information that crosses it.

The idea

Tune a VOR, center the CDI, and note the radial you're on. That's one line, extending outward from that station in one direction. On its own, it tells you nothing about your position along that line. But tune a *second* VOR, center its CDI, and note that radial too, a second line, from a different station. Your aircraft has to be sitting on both lines at once, so your position is wherever they cross.

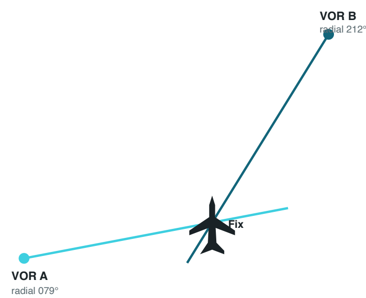


Figure 9.1: Radial 079° from VOR A and radial 212° from VOR B cross at a single point, the aircraft's position.

Picking good stations

Not every pair of VORs makes an equally good fix. What matters is the **angle of cut**, the angle at which the two radial lines cross. A cut close to 90° gives a sharp, well-defined intersection; a shallow cut, where the two lines are nearly parallel, makes the intersection mushy and much more sensitive to small needle-reading errors. As a practical guideline, look for two stations whose radials to your approximate position differ by somewhere between 30° and 150°, with something close to 90° being ideal.

> **TIP**
>
> On paper, pilots historically drew both radial lines directly on a chart and read the fix at their intersection. Whether you're doing this by hand for practice or watching a flight computer do the same calculation instantly, the underlying geometry, and the value of a good angle of cut, never changes.

This same principle extends beyond two VORs. A single VOR/DME or VORTAC gives you a fix on its own, because the DME distance functions as the "second line," in that case a circle of constant distance around the station, intersecting your one radial at a single point. A VOR radial crossed with a known time-and-groundspeed estimate can serve the same role in basic dead reckoning.

CHAPTER 10

VOR Airways and Chart Symbols

VOR stations aren't just standalone navigation points. Chained together, they form the low-altitude airway system that's been printed on charts for decades.

Victor airways

A Victor airway is a defined route, built along a specific radial (or sequence of radials) connecting one VOR to the next, generally used below 18,000 feet. They're labeled with a "V" followed by a number, V23, V495, and so on, and drawn as lines directly on sectional and en-route low-altitude charts, connecting VOR symbols in a chain across the country. Above 18,000 feet, the equivalent high-altitude structure historically used Jet routes ("J" airways), themselves largely VOR-based, though increasingly supplemented by satellite-based RNAV routes.

Flying a Victor airway is, at its core, just radial tracking strung end to end: fly outbound from one VOR on the airway's defined radial, and at some point, usually defined by a crossing radial, a DME distance, or station passage of the next VOR itself, transition to tracking inbound (or outbound on a new radial) to the following station.

The VOR symbol family

Every VOR-type facility is drawn inside the same circular compass rose, oriented to magnetic north. What changes between facility types is the small symbol at the center of that rose:

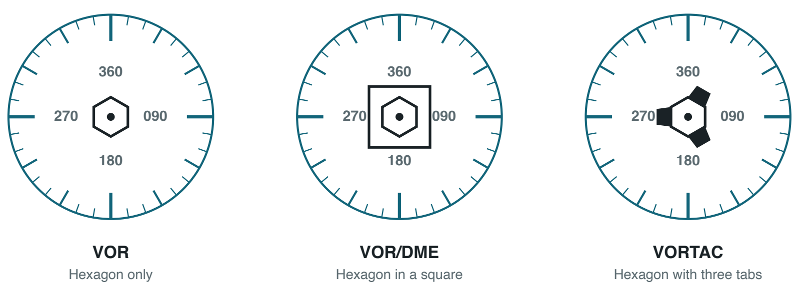


Figure 10.1: The three VOR-family chart symbols. A plain VOR is a hexagon alone; a VOR/DME adds a surrounding square; a VORTAC adds three tabs to alternating sides of the hexagon instead.

A TVOR uses the same plain hexagon as a standard VOR; there's no separate glyph for it. What marks a TVOR is usually a smaller or truncated compass rose on the chart, reflecting its shorter range, along with the facility name and remarks printed in the identification box. Frequency, three-letter identifier, and station name are printed next to every VOR-family symbol regardless of type.

> **READING TIP**
>
> When you're first learning to read charts, find a VOR symbol and rotate your mental frame so "up" on the compass rose lines up with true north on the chart, adjusted for that station's magnetic variation. It becomes automatic quickly, but it's worth doing deliberately a few times early on.

CHAPTER 11

Tuning and Identifying a VOR

A frequency alone doesn't guarantee you're receiving the station you think you are. Positive identification is a required step, not a formality.

Positive identification

Every operating VOR continuously transmits a unique identifier, typically a three-letter Morse code sequence, and many stations also broadcast a synthesized voice identification instead of or alongside the Morse code. Charts print each station's identifier both as letters and as its Morse dot-dash pattern next to the frequency box, so you can confirm you're hearing the right station without needing to have Morse code memorized.

This matters because a frequency alone isn't proof of anything: you could have mistyped it, the station could be undergoing maintenance, or it could be off the air. When a VOR is out of service or its signal isn't reliable enough to trust, its identifier is either removed from the broadcast entirely or replaced with a distinct maintenance code, either way a clear signal that the station shouldn't be used for navigation until you've confirmed otherwise.

COMMON TRAP

Tuning a frequency and trusting the needle immediately, without listening for the identifier first, is one of the easiest ways to navigate confidently off a station you're not receiving. Always identify before you rely on the indication.

Checking receiver accuracy

Because IFR flight can depend on VOR accuracy, 14 CFR 91.171 requires pilots operating under instrument flight rules to check their VOR receiver within the preceding 30 days, within defined tolerances. Four methods are approved:

- **VOT (VOR Test Facility):** a ground facility (or a function added to certain airport VORs) that transmits a signal simulating the 360° radial in every direction. Tuned in on the ground, a correctly functioning receiver should show 0° deviation with a FROM indication on a course of 360°, or a TO indication on 180°, within a tolerance of ±4°.
- **Certified ground checkpoint:** a designated spot on an airport surface with a known, published bearing to a specific VOR, allowing a similar check without a dedicated VOT. Same tolerance as a VOT: ±4°.
- **Airborne checkpoint:** a designated point or airway segment with a published bearing, checked in flight rather than on the ground. Because it's harder to hold position precisely in the air, the tolerance is looser: ±6°.
- **Dual VOR cross-check:** with two independent VOR receivers on board, tune both to the same station and compare their readings against each other; they must agree within ±4° of one another.

These checks, and their results (date, place or bearing error, and the method used), are required to be logged for aircraft used in IFR operations under VOR navigation.

TIP

Even outside of any regulatory requirement, running a VOT check is a good habit any time you have doubts about receiver accuracy. It takes under a minute and immediately tells you whether the problem is the ground station, your tuning, or the receiver itself.

CHAPTER 12

Accuracy, Errors, and Limitations

VOR is remarkably reliable, but it isn't perfect, and it isn't unlimited in range. Knowing where the real limits are keeps you from either over-trusting it or dismissing useful indications as errors.

Line of sight

VOR operates in the VHF band, and VHF signals travel in a straight line; they don't bend around the earth's curvature or reliably penetrate terrain. That means usable range depends heavily on altitude: the higher you fly, the farther over the horizon you can receive a usable signal. As a rough rule of thumb, VHF line-of-sight range in nautical miles is approximately **1.23 times the square root of your altitude in feet** above the station's elevation. At 5,000 feet that's roughly 87 nautical miles; at 20,000 feet, roughly 174 nautical miles, figures that broadly match published VOR service volume charts.

Terrain and reflection errors

Mountains, ridgelines, large buildings, and even nearby aircraft can reflect a VOR's VHF signal, and a receiver picking up both the direct signal and a reflected, out-of-phase version of it can show small, sometimes fluctuating bearing errors, often called scalloping or bending. This is precisely the problem Doppler VOR (Chapter 2) was designed to reduce, which is why you'll find DVOR facilities concentrated at sites with challenging terrain.

System accuracy

A properly functioning VOR ground station is held to tight design tolerances, on the order of ±1° at the station itself. Add ordinary airborne receiver tolerance and typical flight-technical error (how precisely a pilot holds the needle centered), and the commonly quoted overall system accuracy in practical use is within a few degrees. It's precise enough for reliable airway navigation and instrument approaches, but it's not GPS-level precision, and it was never designed to be.

SOURCE	TYPICAL EFFECT
Line-of-sight range	No signal at all beyond the radio horizon for your altitude
Terrain / reflection ("scalloping")	Small, sometimes fluctuating bearing errors near affected sites
Cone of confusion	Temporary, expected instability directly over the station (see Chapter 8)
Station and receiver tolerance	A few degrees of routine bearing error under normal conditions
Interference (co-channel stations, electrical noise, static)	Erratic or unreliable indications, sometimes an OFF flag

KEY IDEA

A VOR gives you bearing only, never distance and never altitude, unless it's paired with DME. Knowing what the system was never designed to tell you is as important as knowing what it does.

CHAPTER 13

Worked Scenario: A Complete Cross-Country Leg

Theory earns its keep in the cockpit. Here's how everything in this guide comes together on a single, realistic leg.

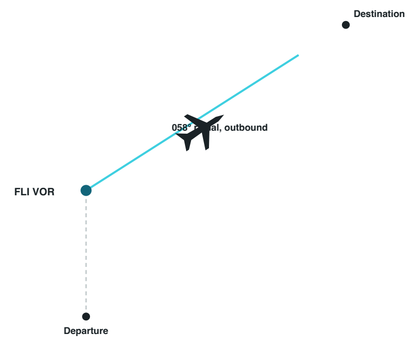


Figure 13.1: Departing near FLI VOR, tracking outbound on the 058° radial toward the destination.

The setup

You depart an airport a few miles south of FLI VOR. Your planned route takes you outbound from FLI on the 058° radial, and your destination lies roughly along that line, well within VOR range at your cruise altitude.

Step by step

1. **Tune and identify.** Before takeoff, or immediately after, tune FLI's frequency and confirm the Morse identifier against the chart. Don't trust the needle until you've done this.
2. **Set the course.** Rotate the OBS to 058°. Since you're departing south of the station and will be flying away from it, confirm the flag reads FROM once you're established; if it reads TO, you've got the reciprocal dialed in by mistake.
3. **Intercept.** Climbing out, the CDI shows you slightly east of the 058° radial. You turn to a heading of 030°, a comfortable intercept angle, and watch the needle walk steadily toward center.
4. **Establish on course.** As the needle nears center, you roll out on 058°, the course heading itself, timing the turn to arrive centered rather than overshooting through it.
5. **Hold the radial.** A few minutes later you notice a slow rightward drift, a crosswind from the north pushing you south of course. You apply a 6° wind correction angle, flying 052°, and after a couple of minutes the needle holds steady. You've found your WCA.
6. **Cross-check with a second VOR.** Partway along the leg, you tune a second station off to your right, center its CDI, and note the radial. Crossed with your known position along FLI's 058° radial, it confirms you're on track and roughly on schedule.
7. **Approaching the destination.** As you near the area, you switch your attention to the destination's own navigation aids or visual references for arrival, your VOR leg having done its job of getting you reliably from departure to destination.

> **THE TAKEAWAY**
>
> Nothing in this walkthrough is a special technique. It's just Chapters 5 through 9, applied in sequence: a small number of simple, repeatable steps that chain together into a complete cross-country leg.

CHAPTER 14

Common Mistakes and Practical Tips

Most VOR errors aren't equipment problems. They're the same handful of procedural slips, repeated. Here's what trips pilots up.

MISTAKE

Skipping station identification. Trusting a frequency without confirming the Morse or voice identifier means trusting a station you haven't verified. Make it a reflex, every time.

MISTAKE

Setting the OBS to the wrong course. Dialing in the radial you happen to be crossing, rather than the course you intend to fly, is the most common cause of reverse sensing (Chapter 6). Always set the OBS to your intended course.

MISTAKE

Chasing the needle. Large, frequent heading changes in response to every small needle movement almost always produce worse tracking than a smaller correction, held long enough to evaluate it (Chapter 7).

MISTAKE

Confusing "radial" with "course to." A radial is always measured outward from the station. Casually describing your position as "on the 270 course to the station" is a common source of 180° confusion. Say "inbound on the 090 radial" instead, and it's unambiguous.

MISTAKE

Mistaking the cone of confusion for a malfunction. A wandering needle directly over the station is expected. The same wandering well away from any station is a real problem worth investigating (Chapter 12).

MISTAKE

Skipping the receiver accuracy check. An out-of-tolerance receiver can look completely normal in flight while quietly feeding you a bearing error. Run a VOT or ground checkpoint check when you have doubts, and log it as required for IFR use (Chapter 11).

PRACTICAL TIP

Practice reading the CDI and TO/FROM flag on the ground, with the aircraft stationary and the OBS turned freely through different courses. Building an instant, reflexive read of the instrument on the ground makes it far easier to trust in flight, when you're also flying the airplane.

PRACTICAL TIP

When learning intercepts, exaggerate the angle at first. A steep, obvious intercept is easier to see working than a shallow one. Once the underlying picture clicks, dial the angle back down to something more efficient for actual cross-country flying.

Glossary

VOR
VHF Omnidirectional Range, a ground-based navigation aid broadcasting bearing information on any of 360 radials.

Radial
A magnetic bearing measured outward from a VOR station. One of 360, numbered 001 to 360.

Course
The specific bearing a pilot selects on the OBS to fly, which may or may not match the radial currently underneath the aircraft.

CDI (Course Deviation Indicator)
The needle showing how far left or right of the selected course the aircraft currently is.

OBS (Omni Bearing Selector)
The control used to select a desired course on a VOR instrument.

TO/FROM indicator
Shows whether the selected course, if flown, leads toward or away from the station.

Reverse sensing
CDI left/right indications that stop matching intuition, typically because the aircraft's heading is roughly opposite the selected course.

DME (Distance Measuring Equipment)
A system giving slant-range distance to a station, often co-located with a VOR.

VORTAC
A VOR co-located with a military TACAN, marked on charts by a hexagon with three tabs; civil aircraft use its VOR bearing and DME-equivalent distance.

TVOR (Terminal VOR)
A lower-power VOR intended for terminal-area rather than long-range en-route use. Uses the same plain hexagon symbol as a standard VOR.

VOT (VOR Test Facility)
A ground facility used solely to check VOR receiver accuracy, simulating the 360° radial in all directions.

Cone of confusion
The zone of unreliable indications directly above a VOR station, caused by weak overhead signal coverage.

Station passage
The moment an aircraft flies over (or nearly over) a VOR, confirmed by the CDI wandering and the TO/FROM flag flipping.

Victor airway
A defined low-altitude route built along VOR radials, labeled with a "V" and a number.

Wind correction angle (WCA)
A heading adjustment, into the wind, used to hold a desired course against drift.

Intercept angle
The angle between a current heading and a desired course, flown to close in on and establish on that course.

Fix
A known position, commonly determined by the intersection of two VOR radials, or one radial and a DME distance.

Magnetic variation
The angular difference between true north and magnetic north at a given location. VOR radials are already referenced to magnetic north at the station.

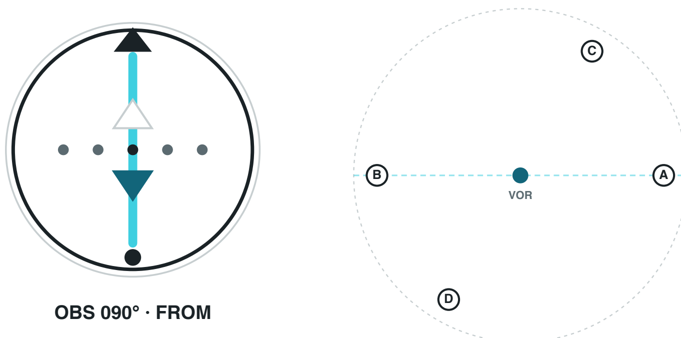
Line of sight
The direct, unobstructed path VHF signals require. VOR range is limited by the radio horizon, which increases with altitude.

MON (Minimum Operational Network)
A deliberately retained subset of VOR stations the FAA maintains as a non-satellite navigation backup.

Practice Questions

Seventeen questions covering everything in this guide, including two scenario problems that pair a CDI reading with a map. Answers and explanations follow on the next page.

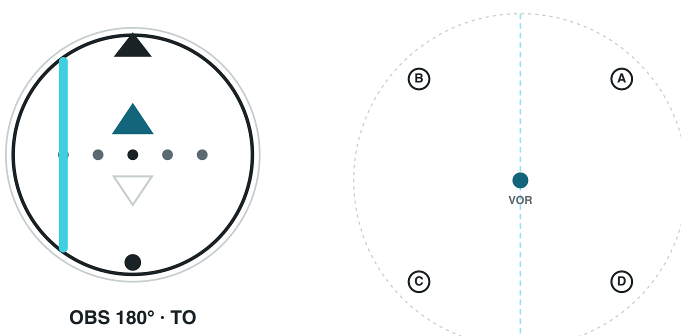
1. A VOR is shown below with four candidate aircraft positions, A through D. The CDI reading shown is what your instrument displays. Which point are you at?



OBS 090° · FROM

A. Point A
B. Point B
C. Point C
D. Point D

2. Same idea, different station and course. Given the CDI reading shown, which point are you at?



OBS 180° · TO

A. Point A
B. Point B
C. Point C
D. Point D

3. A VOR radial is always measured:

A. Toward the station
B. From the station, outward
C. Relative to true north
D. Relative to the aircraft's heading

4. The reference phase signal broadcast by a VOR is:

A. Directional, rotating at 1800 RPM
B. Broadcast identically in every direction
C. Only usable within the cone of confusion
D. Generated by the aircraft's own receiver

5. What does a phase difference of 90° between the reference and variable signals indicate?

A. The aircraft is on the 090 radial
B. The aircraft is directly over the station
C. The receiver requires a VOT check
D. The aircraft is out of range

6. Which facility provides both bearing and distance from a single station?

A. TVOR
B. VOT
C. VOR/DME
D. A plain VOR

7. On a sectional chart, a VOR/DME station is drawn as:

A. A hexagon alone
B. A hexagon inside a square
C. A hexagon with three tabs
D. A plain circle with no hexagon

8. A VOT is used to:

A. Extend a VOR's usable range
B. Check a VOR receiver's accuracy on the ground
C. Provide distance information
D. Broadcast weather information

9. On a standard 5-dot CDI, each dot typically represents approximately:

A. 1°
B. 2°
C. 5°
D. 10°

10. Reverse sensing most commonly occurs when:

A. The aircraft is inside the cone of confusion
B. The pilot flies a heading roughly opposite the selected OBS course
C. The station is a TVOR rather than a VORTAC
D. The aircraft is beyond the VOR's line-of-sight range

11. A wandering CDI needle and a flickering TO/FROM flag directly over a VOR station indicates:

A. A failed receiver
B. The cone of confusion, expected behavior near station passage
C. Reverse sensing
D. An out-of-tolerance VOT check

12. To determine an aircraft's exact position using two VORs, a pilot should look for stations whose radials cross at an angle close to:

A. 0°
B. 90°
C. 180°
D. It doesn't matter

13. A Victor airway is:

A. A satellite-based RNAV route
B. A high-altitude jet route above FL180
C. A defined low-altitude route built along VOR radials
D. A military-only navigation corridor

14. Approximately how far, in nautical miles, is the VHF line-of-sight range at 10,000 feet above a station's elevation? (Using range ≈ 1.23 × √altitude)

A. About 39 nm
B. About 87 nm
C. About 123 nm
D. About 174 nm

15. A Doppler VOR (DVOR) is typically installed instead of a conventional VOR at sites where:

A. Terrain or reflections are likely to cause siting errors
B. DME service is not required
C. The station only needs to serve as a VOT
D. Traffic volume is very low

16. An aircraft is established inbound on the 270 radial. Approximately what heading is it flying, in still air?

A. 270°
B. 180°
C. 090°
D. 360°

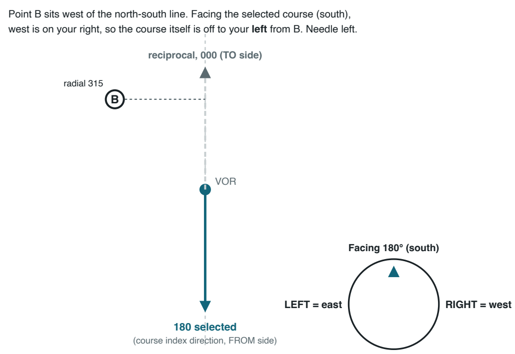
17. A pilot notices the CDI drifting steadily to one side despite holding a constant heading. The best response is to:

A. Ignore it, the drift will correct itself
B. Make a large, immediate heading change and hold it regardless of the result
C. Apply a small correction into the wind, then observe before adjusting further
D. Re-identify the station

Answer Key

1. A, Point A. Course 090 selected, centered needle, FROM flag. That combination only happens exactly on the 090 radial itself, due east of the station, which is point A. Point B (radial 270) would also center but show TO. Point C (radial 030) would show FROM but deflected right, not centered. Point D (radial 210) would show TO and deflected left. Every other point produces a visibly different CDI picture.

2. B, Point B. This is the case most likely to trip up the left/right reading, because the selected course is 180 (south), so the instrument's "up" doesn't match the map's "up." The needle's left/right always follows the selected course direction, not true north and not your actual heading, which is exactly what makes this one worth slowing down on.



Point A (045, northeast) is the mirror image of B: also TO, but deflects right. Points C (225) and D (135) are both south of the station, on the FROM side, so both read FROM no matter which way the needle leans. Only point B matches both the flag and the deflection direction shown.

3. B, from the station, outward. Radials are always named from the station's perspective, regardless of which direction the aircraft is flying along that line.

4. B, broadcast identically in every direction. It's the variable signal that's directional; the reference signal is omnidirectional by design.

5. A, the aircraft is on the 090 radial. Phase difference in degrees directly equals the radial.

6. C, VOR/DME. A VORTAC also qualifies, but VOR/DME is the more direct match; a plain VOR and a TVOR provide bearing only, and a VOT provides neither in normal navigation use.

7. B, a hexagon inside a square. A plain VOR is a hexagon alone, and a VORTAC uses a hexagon with three tabs on alternating sides.

8. B, check a VOR receiver's accuracy on the ground. A VOT simulates the 360° radial in all directions solely for this purpose.

9. B, 2°. With full-scale deflection representing roughly 10 to 12° on a standard receiver.

10. B, the pilot flies a heading roughly opposite the selected OBS course. This mismatch is what breaks the intuitive left/right reading.

11. B, the cone of confusion. Expected, temporary, and useful as confirmation of station passage.

12. B, 90°. A cut close to 90° gives the sharpest, most reliable intersection; shallow angles produce a mushy, error-prone fix.

13. C, a defined low-altitude route built along VOR radials. Generally used below 18,000 feet; jet routes are the high-altitude equivalent.

14. C, about 123 nm. $1.23 \times \sqrt{10{,}000} = 1.23 \times 100 = 123$ nm.

15. A, terrain or reflections are likely to cause siting errors. DVOR's electronically simulated rotation is considerably more resistant to these effects than a conventional rotating antenna.

16. C, 090°. Inbound on a radial means flying its reciprocal heading; the reciprocal of 270 is 090.

17. C, apply a small correction into the wind, then observe before adjusting further. This is the bracketing technique. Large or immediate corrections tend to overshoot, and re-identifying the station doesn't address a wind-drift problem.

That's the whole picture.

From phase comparison at the ground station to holding a wind correction angle on a real cross-country leg, VOR is a small set of simple ideas that chain together into a capable navigation system, one that's still worth understanding well, GPS or not.

This is the first release in an ongoing series of free aviation study material from Flightline Studios. More topics are on the way.

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