

ECE 215/S – Principles of Electronic Cyber Warfare

Block 3: Communication Systems, Radar, and Electronic Warfare

Lesson 31: Antennas

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Fall 2026

Objective 3.3

I can calculate the signal wavelength, antenna size, max antenna gain, and basic gain pattern for dipole, monopole, and parabolic dish antennas.

- Lessons 28–30 put a message on a carrier and took it back off — all on a wire. Today: how it gets **off the wire and into the air**
- Antenna gain feeds directly into the Friis equation (Lesson 33) and the radar range equation (Lesson 34)
- Assessed on **Quiz 9** (Objectives 3.3–3.5), due at Lesson 35

Where We Are Going

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

- Compute **wavelength** from frequency and size an antenna from it
- Explain what antenna **gain** means and why it is a ratio, not an amplifier
- Find the gain of a **half-wave dipole**, a **quarter-wave monopole**, and a **parabolic dish** — and size a dish for a gain you need
- Read a **gain pattern**, and explain what a **phased array** buys you

The RF Spectrum

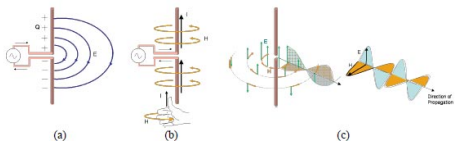
Band	Frequency	Wavelength	Typical use
VLF / LF	3–300 kHz	100 km–1 km	Submarine comms, navigation
MF	300 kHz–3 MHz	1 km–100 m	AM broadcast
HF	3–30 MHz	100–10 m	Over-the-horizon, long-haul radio
VHF	30–300 MHz	10–1 m	FM broadcast, air traffic
UHF	300 MHz–3 GHz	1 m–10 cm	Cell, GPS, Link 16
SHF	3–30 GHz	10–1 cm	Radar, satcom
EHF	30–300 GHz	1 cm–1 mm	Millimeter-wave radar

Frequency sets wavelength. Wavelength sets antenna size. There is no way around it.

How Antennas Work

An antenna converts a guided wave on a wire into a radiating wave in space — and back.

- **(a) Separation of charge** creates an electric field (**E-field**)
- **(b) Moving charge** creates a magnetic field (**H-field**)
- **(c) Drive the conductor with AC** and you get both, oscillating and perpendicular — a wave that travels outward, at right angles to both fields



Antennas are **reciprocal** — the same element transmits and receives with the same gain and pattern.

Wavelength Sets the Size

$$\lambda = c/f \quad \textbf{with} \quad c = 3 \times 10^8 \textbf{ m/s}$$

- An antenna radiates efficiently when its length is a **sensible fraction of a wavelength**. Too short and almost nothing radiates — the currents cancel
- Hence the high-frequency carrier of Lesson 28: a 3 kHz signal has $\lambda = 100$ km

Half-wave dipole — two $\lambda/4$ elements, fed in the middle: Length $= \lambda/2 = c/(2f)$

Quarter-wave monopole — one element over a ground plane, which mirrors it: Length $= \lambda/4 = c/(4f)$

Frequency	λ	**Dipole** $\lambda/2$	**Monopole** $\lambda/4$
100 MHz (FM)	3 m	1.5 m	0.75 m
1 GHz (cell)	30 cm	15 cm	7.5 cm
10 GHz (X-band)	3 cm	1.5 cm	0.75 cm

Row 1: $\lambda = 3 \times 10^8/(100 \times 10^6) = 3$ m. Its 0.75 m monopole is the whip on a vehicle.

Antenna Gain

Gain G compares the power an antenna sends in a direction with what an *isotropic* point source would send there. Quoted as one number, it means the **best** direction.

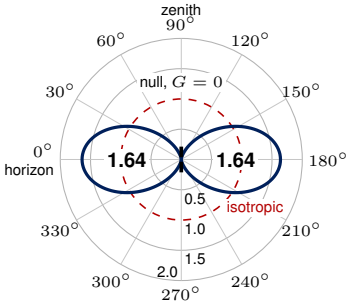
- An antenna does not create power — it **redistributes** it. Gain in one direction is paid for by a null somewhere else
- Isotropic reference: $G = 1$ in every direction. Real antennas have $G > 1$ in some directions and $G = 0$ (a **null**) in others. G is a **linear ratio with no units**
- **The equation sheet's two "Ideal" rows:** half-wave dipole $G = 1.64$; quarter-wave monopole $G = 3.28$ — twice that, because its power fills only half the space
- Data sheets often quote gain in dBi, $10 \log_{10} G$ (so 1.64 is 2.15 dBi) — a *power* ratio. The sheet's $G_{dB} = 20 \log_{10}$ row is the voltage-gain form from Lesson 17

Gain is focus, not amplification. Narrower beam means higher gain.

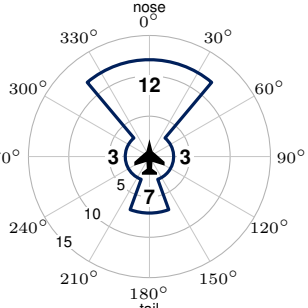
Reading a Gain Pattern

A **gain pattern** is a polar plot. The **angle** is the direction you look from the antenna; the **distance from the center** is the gain in that direction — a linear ratio, read off the labeled rings.

Side view: ideal half-wave dipole



Top view: an aircraft antenna



1. Find $0°$ — the plot names it

2. Find the direction to the **other end of the link**

3. Read the gain there. The bold number is that lobe's gain

Dipole: toward the horizon, $G = 1.64$. Straight up, $G = 0$

Aircraft: a wingman off the right wing is at $90°$. Toward $90°$ the gain is **3**, not the 12 on the nose

Omnidirectional is not isotropic: from above, this dipole's pattern is a circle, yet $G = 1.64$, not 1.

Parabolic Dish Antennas

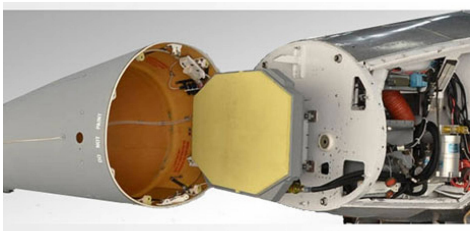


A dish reflects energy from a feed at the focus into **one narrow beam** along its axis.

$$G = \frac{(2\pi r)^2}{\lambda^2}\,\eta$$

- r — dish **radius**; η — aperture efficiency (typically 0.5–0.7), not Lesson 30's modulation efficiency
- The equation sheet writes it $G_{dish} = (2\pi r_{dish}/\lambda)^2\,\eta$ — the same equation
- Gain scales as **radius squared** and as $1/\lambda^2$; gains of hundreds to thousands are routine

Phased Arrays



Replace the dish with **many small elements** and control the *phase* fed to each one.

- Elements interfere constructively in one direction and destructively elsewhere
- Changing the phases **steers the beam electronically** — no moving parts
- Steering happens in **microseconds** rather than seconds
- An **AESA** gives each element its own transmit/receive module, so the array can do several jobs at once

Method: Sizing an Antenna and Finding Its Gain

1. **Frequency to hertz, then the wavelength:** $\lambda = c/f$, in meters
2. **Name the antenna** and take its row on the equation sheet

Ideal dipole	Length $= \lambda/2$	$G = 1.64$
Ideal monopole	Length $= \lambda/4$	$G = 3.28$
Parabolic dish	$G_{dish} = (2\pi r_{dish}/\lambda)^2 \, \eta$	

3. **A dish uses the radius.** Given a diameter D, halve it first: $r_{dish} = D/2$
4. **Working backward** from a gain you need: $r_{dish} = \dfrac{\lambda}{2\pi}\sqrt{\dfrac{G_{dish}}{\eta}}$, then $D = 2\, r_{dish}$
5. **Check:** a dipole or monopole is a fraction of λ long; a dish many λ across has a gain in the hundreds or more; every G is a linear ratio with no units

Worked Example

An X-band radar operates at $f = 10$ GHz with a parabolic dish **1 m in diameter** and aperture efficiency $\eta = 0.6$.

Find:

1. The wavelength
2. The length and gain of an ideal half-wave dipole at this frequency
3. The gain of the dish
4. The dish diameter that would raise the gain to $20{,}000$

Work it before the next slide.

Follow the Method: wavelength, then the row, then the radius.

Every gain here is a linear ratio.

Worked Example — Solution

1. Wavelength

$$\lambda = \frac{3 \times 10^8}{10 \times 10^9} = 0.03 \text{ m}$$

2. Ideal dipole row: Length $= \lambda/2 = 1.5$ cm, and $G = 1.64$

3. Dish row, with the radius: $r_{dish} = D/2 = 0.5$ m

$$G_{dish} = \left(\frac{2\pi(0.5)}{0.03}\right)^2 (0.6)$$
$$= (104.72)^2(0.6) = 6580$$

4. Backward, for $G_{dish} = 20{,}000$

$$r_{dish} = \frac{0.03}{2\pi}\sqrt{\frac{20{,}000}{0.6}} = 0.8717 \text{ m}$$

$$D = 2\, r_{dish} = 1.74 \text{ m}$$

5. Check

- The 1 m dish is 33 wavelengths across, so a gain in the thousands is right — about $4000\times$ the dipole's
- Forward again: $(2\pi \cdot 0.8717/0.03)^2(0.6) = 20{,}000$ ✓

Your Turn

A satellite ground station transmits at $f = 4$ GHz using a parabolic dish of **diameter** 3 m with aperture efficiency 0.65.

1. Find the wavelength
2. Find the dish gain
3. How long would an ideal quarter-wave monopole be at this frequency, and what is its gain?
4. If the frequency doubled to 8 GHz with the same dish, what happens to the gain?
5. Back at 4 GHz: what dish diameter would give $G_{dish} = 25{,}000$?

Wrap-Up

Key ideas:

- $\lambda = c/f$, and antenna size follows wavelength: $\lambda/2$ dipole, $\lambda/4$ monopole
- **Gain is focus, not amplification** — a linear ratio. Ideal dipole $G = 1.64$; ideal monopole $G = 3.28$. Omnidirectional is not isotropic
- On a **gain pattern**, find $0°$, then read the gain toward the other end of the link
- Dish gain $G = (2\pi r)^2\eta/\lambda^2$ — r is the radius. Solve it backward for the size a gain needs
- **Phased arrays** steer electronically in microseconds, with no moving parts

Next lesson:

- **Lesson 32 — Objective 3.4: Line of Sight.** How far the signal can actually reach
- **Quiz 8** (Objectives 3.1–3.2) is due at Lesson 32