ECE 495 – Electromagnetic Warfare and Survivability

Block 1: Radar Fundamentals
Lesson 6: Antenna Patterns and Beamforming

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Where We Left Off

L5 gave us the range-Doppler map.

But the radar only sees energy that comes through its antenna. The antenna's *pattern* decides what enters the receiver and from where.

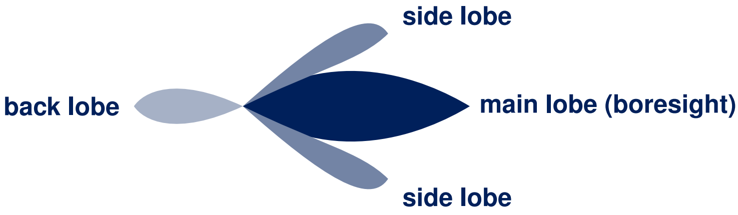
Today: pattern anatomy, the polar plot convention, beamforming, and ESAs — and why side lobes are the back door for EW.

Lesson Objectives

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

- Identify the **main lobe, side lobes, and back lobes** in a pattern
- Read a **polar plot** and extract HPBW and SLL
- Use the gain / aperture / beamwidth rule of thumb to size an antenna
- Explain how an **ESA** steers a beam and what that buys an EW operator

Anatomy of an Antenna Pattern



- **Main lobe** — where the radar wants to look
- **Side lobes** — unintended sensitivity off boresight; the EW back door
- **Back lobe** — look the other way; rarely big but always there

The Polar Plot

Patterns are drawn in polar coordinates with gain (dB) versus angle.

- **HPBW** — half-power beamwidth, where gain drops 3 dB below peak
- **SLL** — side-lobe level, peak side lobe relative to the main lobe (dB, negative)
- Uniform illumination $\Rightarrow$ first SLL ≈ -13.2 dB; tapering trades SLL for HPBW
- Two cuts (azimuth and elevation) describe a 3D pattern

The pattern is where the radar lives — and where it leaks.

Gain, Aperture, Beamwidth Revisited

For an aperture of size D:

$$\theta_{\text{HPBW}} \approx \frac{70\,\lambda}{D}\ \text{(deg)}, \qquad G \approx \frac{30{,}000}{\theta_{\text{az}} \cdot \theta_{\text{el}}}$$

X-band example ($\lambda = 3$ cm), 0.5×0.5 m antenna:

- $\theta_{\text{HPBW}} \approx 4.2^\circ$ in each plane
- $G \approx 30000/(4.2 \cdot 4.2) \approx 1700 \Rightarrow 32$ dBi
- Tighter beam means more gain — and less coverage per scan position

Beamforming Basics

Replace the dish with N small radiators (an array). Each element transmits the same signal with a programmed phase ϕ_n.

$$\Delta\phi = \frac{2\pi}{\lambda}\, d\, \sin\theta_s$$

- Constructive interference at the steering angle $\theta_s \Rightarrow$ main lobe points there
- Beam steered **electronically** — no moving parts
- More elements $\Rightarrow$ narrower beam and lower side lobes (with tapering)
- Space them too far apart and the pattern **aliases** — **grating lobes**, full-strength copies pointing where you did not ask: $d \leq \lambda/(1 + |\sin\theta_0|)$

Electronically Scanned Arrays (ESA / AESA)

ESA $=$ beam steered by phase shifters. AESA $=$ active ESA, each element has its own Tx/Rx module.

- **Microsecond beam pointing** — track many targets, interleave search and track in one dwell
- **Graceful degradation** — a few failed modules cost a few percent gain, not the radar
- **Multi-beam** — different waveforms in different directions at the same time
- HPBW broadens as $1/\cos\theta_s$ when steered far off boresight — physics still wins

Modern fire control radars and most new IADS surveillance are AESA.

Why Patterns Matter for EW

- **Side-lobe leak** — a jammer not on boresight still enters through side lobes
  - EP response: side-lobe cancellation, side-lobe blanker, low-SLL antennas
- **Main-beam pointing** — knowing where the threat is looking tells you what it is doing
- **ESA agility** — compresses the threat's kill chain; harder to deceive with classical techniques
- **Polarization purity** — cross-pol leakage shows up in patterns and matters for LO

Side lobes are the back door for EW.

Today's Interactive Demo: Array Factor and Steering

Today's interactive demo.

- Build the array factor for an N-element linear array
- Plot in polar (dB) and measure HPBW from the curve
- Steer the beam to $0°$, $30°$, $60°$ and watch HPBW broaden
- Mark the first side-lobe level and confirm the -13.2 dB rule

Companion script: `L6_ArrayFactorAndSteering.m`

For self-study: the book companion has a 1D / 2D interactive phased-array simulator.

In L7 we put these patterns inside an IADS and watch each radar do its job.

Quick Exercise / Type-along: Walk the Grating Lobe

Eight elements, wide spacing. Type it, run it — then change `th0` to `30` and run it again.

```
N = 8;  dlam = 0.9;  th0 = 0;          % elements, d/lambda, steer (deg)
th = -90:0.25:90;                      % look angles (deg)
n  = (0:N-1).';                        % element index, as a column
beta = -2*pi*dlam*sind(th0);           % programmed phase per element
AF = sum(exp(1j*n*(2*pi*dlam*sind(th) + beta)), 1)/N;
plot(th, 20*log10(max(abs(AF),1e-3)), 'LineWidth',1.5);
hold on;  grid on;  ylim([-40 0]);
xlabel('theta (deg)');  ylabel('|AF| (dB)');
fprintf('theta0=%2d | beta=%7.1f deg/elem | limit %.2f | used %.2f\n', ...
        th0, rad2deg(beta), 1/(1+abs(sind(th0))), dlam);
```

1. Full-strength lobes at $\theta_0 = 0$? At $\theta_0 = 30^\circ$?
2. The spacing never changed. What did?

Wrap-Up

Key ideas:

- Patterns have main, side, and back lobes; side lobes are the EW back door
- HPBW $\propto \lambda/D$; gain $\propto$ aperture $/\lambda^2$
- ESA / AESA $=$ microsecond beam steering, multi-beam, graceful degradation

Next lesson:

- **L7: Threat radar taxonomy in an IADS** — EW, ACQ, HF, GCI, TTR, AI, TIR
- Pre-flight quiz for L7 due before class