# ANTENNA SYNTHESIS

ECE 516E – ANTENNA & RADIOWAVE PROPAGATION

Monday, January 18, 2026

# WHAT IS ANTENNA SYNTHESIS?

1. **Antenna synthesis** is the process of designing an antenna to produce a specific radiation pattern that meets predefined specifications.
2. **Unlike antenna analysis** (determining pattern from structure), synthesis works backward from desired pattern to antenna structure.
3. **Goal:** Determine antenna configuration from desired radiation pattern

Synthesis: Desired Pattern → Antenna Configuration

Analysis: Antenna Configuration → Radiation Pattern

# CHALLENGES OF ANTENNA SYNTHESIS

**Antenna Synthesis** is more challenging than analysis because:

1. **Multiple antenna configurations** can produce similar patterns
2. **Practical constraints** (size, feeding, mutual coupling) limit solutions
3. **Mathematically**, it's often an ill-posed problem with **no unique solution**
4. **Synthesis methods typically involve optimization** to find the "best" solution given constraints.

# COMPARISON ANTENNA ANALYSIS Vs SYNTHESIS

| ASPECT | ANALYSIS | SYNTHESIS |
|---|---|---|
| **Goal** | Find pattern from known structure | Find structure from desired pattern |
| **Problem Type** | Forward/direct problem | Inverse problem |
| **Solution Uniqueness** | Unique solution (typically) | Multiple possible solutions |
| **Mathematical Approach** | Integration of known currents | Optimization, approximation |
| **Difficulty** | Generally straightforward | Often ill-posed, requires constraints |

**In practice, antenna design often involves iterative cycles of synthesis and analysis until requirements are met.**

# DESIRED RADIATION PATTERN
## Specifying Performance Requirements

Before synthesis can begin, we must define the desired radiation pattern characteristics:

1. **Main lobe characteristics:** Direction, beamwidth, gain
2. **Sidelobe requirements:** Maximum allowable sidelobe level (SLL)
3. **Null positions:** Directions where radiation should be minimized
4. **Polarization:** Linear, circular, or elliptical
5. **Bandwidth:** Frequency range over which performance must be maintained
6. **Physical constraints:** Size, weight, feeding complexity

**Trade-offs are inevitable:** narrower beamwidths typically mean larger antennas, lower sidelobes reduce gain, etc.

| System Parameters | Specifications |
|---|---|
| Operating Frequency | 5.3 GHz (C-band) |
| Bandwidth | 80 MHz |
| Polarization | $VV$ |
| Antenna Gain | 15 dBi |
| Platform Height, $h$ | 1000 m |
| Incident Angle | 25° |
| Azimuth Beamwidth | 4° |
| Elevation Beamwidth | 40° |

# ANTENNA SYNTHESIS METHODS OVERVIEW
## Classical and Modern Approaches

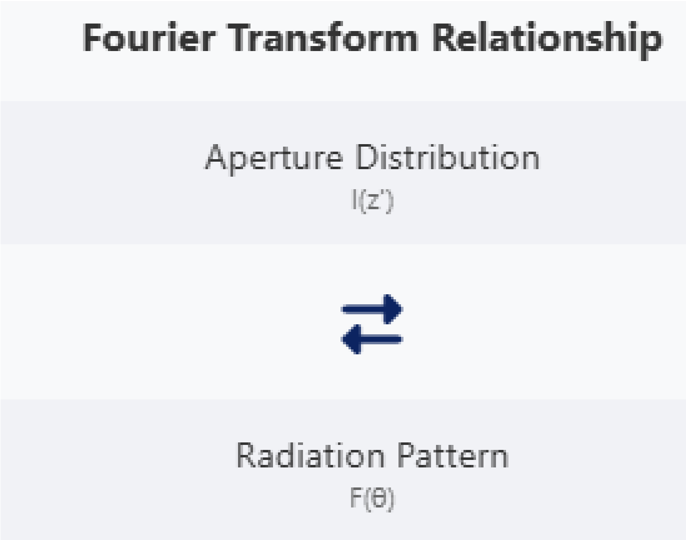
**Various methods have been developed for antenna synthesis**, each with strengths and limitations:

1. **Fourier Transform Method:** Relates aperture distribution to pattern via Fourier transform
2. **Woodward-Lawson Method:** Samples desired pattern at discrete points
3. **Schelkunoff Polynomial Method:** Represents array factor as polynomial
4. **Dolph-Chebyshev Method:** Optimizes sidelobe level for given beamwidth
5. **Taylor Distribution:** Creates patterns with decaying sidelobes
6. **Modern Optimization:** Genetic algorithms, neural networks, convex optimization

# CRITERIA FOR SELECTING ANALYSIS METHODS

| METHOD | BEST FOR | COMPLEXITY |
|---|---|---|
| Fourier Transform | Continuous apertures | Low |
| Woodward-Lawson | Pattern sampling | Low-Medium |
| Dolph-Chebyshev | Uniform sidelobes | Medium |
| Taylor Distribution | Decaying sidelobes | Medium |
| Modern Optimization | Complex constraints | High |

# FOURIER TRANSFORM METHOD
## Aperture-Pattern Duality




1. The Fourier transform relationship between aperture distribution and far-field pattern is fundamental to antenna theory:

$$SF(\theta) = \int_{-l/2}^{l/2} I(z')e^{jkz'\cos\theta}dz'$$

   where SF(θ) is the space factor and I(z') is the current distribution along the antenna of length L.

2. For synthesis, we take the inverse Fourier transform of the desired pattern:

$$I(z') = (1/2\pi) \int_{-\infty}^{\infty} SF(\theta)e^{-jkz'\cos\theta}d\theta$$

Further Reading: [Balanis - Antenna Theory and Design.pdf]() (Page 393)

# FOURIER TRANSFORM METHOD
# Laboratory Session

1. **Learning Objectives**
   - Understand the **fundamental relationship between aperture distribution and far-field radiation pattern** via Fourier Transform
   - Learn to **synthesize desired antenna patterns using Fourier Transform Method**
   - **Apply sampling techniques** to convert continuous source distributions to discrete array excitations
   - **Analyze trade-offs** between desired pattern and practical implementation constraints
   - **Compare theoretical patterns with synthesized approximations**
   - **Develop skills** in array factor calculation and pattern visualization.

**2. Website:**

https://ece516e.elimu.com/Laboratory/Antennas/Synthesis/Antena_Sythesis_Fourier_Lab(2).html

# WOODWARD-LAWSON METHOD
## Pattern Sampling Technique

1. **Woodward-Lawson method samples the desired pattern** at specific angles and constructs the aperture distribution as a sum of orthogonal beams:

$$I(z') = \sum_{m--m}^{M} a_m e^{-j\beta z' \cos \theta_m}$$

   where $\theta_m$ are sampling angles, and $a_m$ are samples of the desired pattern at those angles.

2. **Key features:**
   - Pattern is exactly reproduced at sampling points
   - Between samples, pattern approximates desired pattern
   - Simple and intuitive for array antennas
   - Results in uniform array spacing

Further Reading: Balanis - Antenna Theory and Design.pdf (Page 399)

# WOODWARD-LAWSON METHOD
# Laboratory Session

1. **Learning Objectives**
   - **Understand the Woodward-Lawson sampling method** for antenna pattern synthesis
   - **Learn to decompose desired patterns** into orthogonal uniform-array beams
   - **Apply pattern sampling techniques** to determine array excitation coefficients
   - **Analyze the relationship between sample points and array parameters** (N, d, λ)
   - **Evaluate pattern accuracy and limitations** of the sampling approach
   - **Compare Woodward-Lawson with Fourier Transform** methods.

**2. Website:**

https://ece516e.elimu.com/Laboratory/Antennas/Synthesis/Antena_Sythesis_Wood_Lab(2).html

# APPLICATIONS OF ANTENNA SYNTHESIS
## Real-World Implementations

Antenna synthesis techniques are critical in many modern systems:

1. **Radar Systems:** Low sidelobes to avoid clutter, shaped beams for ground mapping
2. **Satellite Communications:** Contoured beams matching coverage areas, high directivity
3. **Cellular Networks:** Sector antennas with specific beamwidths, downtilt
4. **Radio Astronomy:** Very low sidelobes to detect weak signals
5. **Electronic Warfare:** Null steering to suppress jammers
6. **5G/6G Systems:** Massive MIMO with beamforming for capacity enhancement

# MODERN SYNTHESIS TECHNIQUES
## Beyond Classical Methods

**Modern computational methods enable synthesis for complex constraints:**

1. **Genetic Algorithms:** Evolve solutions through selection, crossover, mutation
2. **Particle Swarm Optimization:** Swarm intelligence to explore solution space
3. **Neural Networks:** Learn mapping from patterns to antenna configurations
4. **Convex Optimization:** Formulate as convex problem for guaranteed optimality
5. **Machine Learning:** Pattern recognition to suggest initial designs

**Advantages:**

- Can handle non-linear constraints, multiple objectives, complex geometries.

**Disadvantages:**

- Computationally intensive, may not guarantee global optimum.

# CHALLENGES IN ANTENNA SYNTHESIS
## Practical Limitations and Trade-offs

**Real-world antenna synthesis faces several challenges:**

1. **Mutual Coupling:** Interaction between elements distorts the pattern
2. **Fabrication Tolerances:** Manufacturing errors degrade performance
3. **Feeding Network Complexity:** Complex distributions require intricate feeds
4. **Bandwidth Limitations:** Synthesized patterns often narrowband
5. **Non-linear Effects:** Active elements introduce distortion
6. **Multi-objective Optimization:** Conflicting requirements (beamwidth vs. sidelobes)

# CONCLUSION

**Antenna synthesis is a fundamental aspect of modern antenna engineering:**

1. Synthesis is the inverse of analysis: pattern → antenna structure
2. Multiple methods exist, each with strengths and limitations
3. Classical methods (Fourier, Woodward-Lawson, Dolph-Chebyshev, Taylor) provide foundational approaches
4. Modern optimization techniques handle complex, multi-constraint problems
5. Practical implementation requires considering mutual coupling, bandwidth, and fabrication limits
6. Antenna synthesis enables advanced systems in communications, radar, and sensing