



## ECE 516E – ANTENNA & RADIOWAVE PROPAGATION

### STUDY GUIDE: DESIGN OF DIPOLE ANTENNAS

---

#### 1. OBJECTIVE

The primary goal is to design a resonant antenna that efficiently transfers power from a transmitter (or to a receiver) at a specific frequency or over a desired bandwidth, with a specified radiation pattern and input impedance.

#### 2. KEY DESIGN PARAMETERS & EQUATIONS

##### 2.1. Resonance and Physical Length

- The *electrical length* determines resonance, not the physical length.
- **Free-Space Wavelength:**  $\lambda = c / f$ 
  - $c$  = speed of light ( $3 \times 10^8$  m/s)
  - $f$  = operating frequency (Hz)
- **Initial Length Calculation:**
  - **Half-Wave Dipole:**  $L \approx \lambda / 2$
  - In practice, due to **end effects** (capacitance at the ends), the physical length is approximately 5% shorter:  
 $L$  (meters)  $\approx 143 / f$  (MHz) or more precisely  $L \approx 0.48 \times \lambda$
- **Final length tuning** is almost always required and is done by carefully trimming the ends while measuring the impedance or VSWR.

##### 2.2. Input Impedance ( $Z_{in}$ )

- **Theoretical Ideal:** At resonance, for an infinitely thin half-wave dipole in free space:

$$Z_{in} \approx 73 + j0 \Omega$$

- **Practical Reality:** Impedance is affected by:
  1. **Conductor Diameter:** Thicker elements have lower Q and broader bandwidth, slightly reducing the resonant length.
  2. **Proximity to Ground:** Antennas near a ground plane see a reduced impedance (can be as low as  $\sim 35$ - $40 \Omega$  for  $\lambda/4$  height).
  3. **Other Objects:** Metal structures, trees, and buildings can detune the antenna and alter its impedance.

##### 2.3. Bandwidth

- Defined as the frequency range over which the **Voltage Standing Wave Ratio (VSWR)** is  $\leq 2:1$  (equivalent to a return loss  $\leq -9.54$  dB or  $|S_{11}| \leq \sim 0.33$ ).
- **Bandwidth  $\propto$  (Conductor Diameter / Length)**
  - A "fatter" dipole has a wider bandwidth. This is why many commercial dipoles use aluminum tubing instead of thin wire.

#### 2.4. Radiation Pattern

- The classic "doughnut" shape.
- **E-plane:** The plane containing the antenna's axis. Pattern is a figure-8 with nulls off the ends.
- **H-plane:** The plane perpendicular to the antenna's axis. Pattern is omnidirectional (a circle).
- **Gain:** A half-wave dipole has a **directivity of 2.15 dBi** (decibels relative to an isotropic radiator).

### 3. THE DESIGN PROCESS: A STEP-BY-STEP GUIDE

#### Step 1: Define Specifications

- **Centre Frequency ( $f_0$ ):** e.g., 145 MHz for a 2m amateur radio band.
- **Desired Bandwidth ( $\Delta f$ ):** e.g., 5 MHz.
- **Target Impedance ( $Z_{\text{target}}$ ):** Almost always 50  $\Omega$  to match standard coaxial cable.

#### Step 2: Calculate Initial Dimensions

- $\lambda = c / f_0 = 300 / f_0(\text{MHz})$  (approx. in meters)
- Initial Length (L) =  $0.48 \times \lambda$  (for a half-wave dipole)
- Choose a **conductor diameter**. A thicker diameter increases bandwidth. A common rule of thumb is to use a diameter between 1/1000 and 1/100 of the length.

#### Step 3: Choose a Feeding Method (Critical Step)

- **Problem:** Coaxial cable is an *unbalanced* transmission line, while a dipole is a *balanced* antenna. Feeding it directly with coax will cause current to flow on the outside of the cable shield (**common-mode current**), distorting the radiation pattern and making the antenna sensitive to its environment.
- **Solution: Use a Balun (BALanced to UNbalanced transformer).**
  - **Function:** Presents a high impedance to common-mode currents, forcing the antenna to operate in a balanced mode.
  - **Types:**

1. **Choke Balun:** (Most common) A coil of the feedline that presents a high impedance to RF current on the outside of the shield. Simple and effective.
2. **Transformer Balun:** (e.g., 1:1 or 4:1) Can also provide impedance transformation.

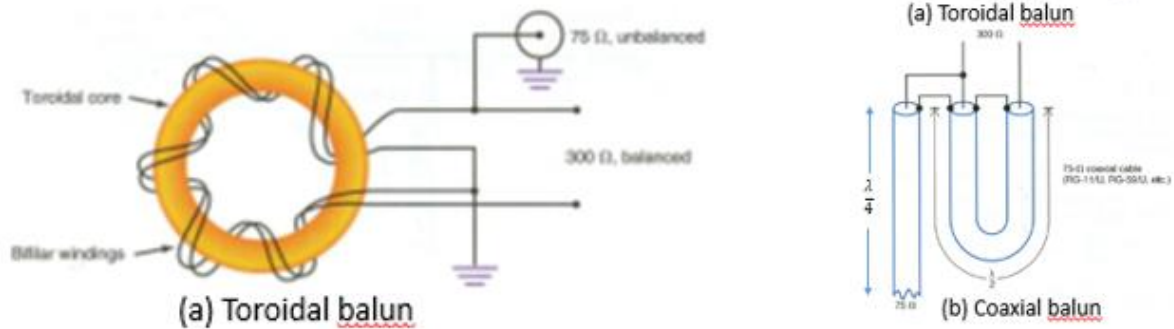


Figure x. Types of Baluns

#### Step 4: Model and Predict Performance

- Use antenna simulation software (**NEC-based tools like EZNEC or 4NEC2**) to model the design with its environment (ground type, support mast).
- Simulate and observe: input impedance, VSWR vs. frequency, and radiation pattern.

#### Step 5: Build, Measure, and Trim

1. **Build** the antenna slightly longer than your calculated length.
2. **Measure** the VSWR across the band using a **Vector Network Analyzer (VNA)** or antenna analyzer.
3. **Trim** the ends symmetrically in small increments (e.g., 1 cm at a time).
4. Re-measure after each trim. Stop when the resonant frequency (point of lowest VSWR) is at your desired  $f_0$ .

## 4. COMMON DIPOLE VARIATIONS & THEIR DESIGN

### 4.1. Folded Dipole

- **Design:** Two parallel dipoles connected at the ends.
- **Key Feature: Impedance is multiplied by  $\sim 4x$ .**
  - A half-wave folded dipole has  $Z_{in} \approx 300 \Omega$ .
- **Use:** Excellent for matching to  $300 \Omega$  twin-lead cable. Often used as the driven element in Yagi-Uda antennas.

### 4.2. Off-Center Fed (OCF) Dipole

- **Design:** Fed at a point that is not the center (e.g.,  $1/3$  of the way from one end).

- **Key Feature:** Creates a complex impedance transformation, allowing for **multi-band operation** with a single wire.
- **Design Challenge:** Requires a robust impedance matching unit (e.g., a 4:1 or 6:1 balun).

### 4.3. Inverted-V Dipole

- **Design:** A center-fed dipole where the ends are lowered to form a "V" shape.
- **Key Feature:** The apex angle affects impedance. A common apex angle of 90-120° gives  $Z_{in} \approx 50 \Omega$ , eliminating the need for a perfect impedance-matching balun.
- **Advantage:** Only requires one tall central support mast.

## 5. PRACTICAL CONSTRUCTION TIPS

1. **Materials:** Use low-loss, weather-resistant materials. Copper wire, aluminum tubing, and UV-stable plastics are common.
2. **Insulators:** Use strong, non-conductive insulators at the ends and feed point to maintain structural integrity and electrical isolation.
3. **Waterproofing:** Protect the feed point and balun from moisture, which can detune the antenna and cause losses.

## 6. VERIFICATION AND TESTING

1. **VSWR/Return Loss:** Measure across the band to verify bandwidth and resonance.
2. **Radiation Pattern:** Verify with field strength measurements at different angles (requires an open field and a distant transmitter/receiver).
3. **Impedance:** Use a VNA to measure the complex impedance ( $R + jX$ ) at the design frequency.

## 7. Essential Formulas Quick Reference

PARAMETER	FORMULA	NOTES
Wavelength	$\lambda = c / f$	$c = 3e8 \text{ m/s}$
Dipole Length	$L \approx 0.48 * \lambda$	Start longer and trim to tune
Directivity	$D = 2.15 \text{ dBi}$	Gain = D * Efficiency
Free-space $Z_{in}$	$\sim 73 \Omega$	For infinitesimally thin $\lambda/2$ dipole
Folded Dipole $Z_{in}$	$\sim 300 \Omega$	Approx. 4x standard dipole

This guide provides the foundational knowledge to move from theory to a functional, designed antenna. The most critical lesson is that antenna design is an iterative process of **model, build, measure, and refine**.

