Laboratory #6: Dipole and Monopole Antenna Design

I. OBJECTIVES

Design several lengths of dipole antennas. Design appropriate impedance matching networks for those antennas. The antennas will be fed by a BALUN (balanced-unbalanced transformer) for balanced excitation. The impedance matching network will be placed between the 50Ω source and the balun.

II. INTRODUCTION

A general purpose dipole antenna (long thin wire antenna) with height $h_1 = h_2 = L/2$, where L is the total length of the antenna is shown in Figure 1.

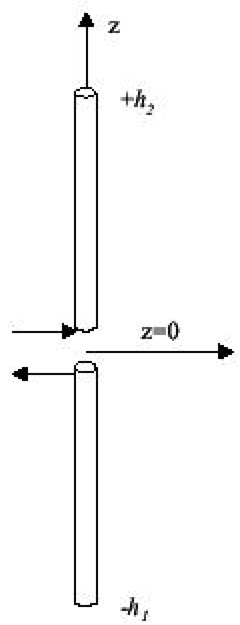


Figure 1. Thin Linear Antenna of Total Length $h_2 + h_1$

The dipole antenna is constructed with two thin linear elements that are symmetrically fed at the center by a balanced two-wire transmission line. The antennas may be of any length, but it is assumed that the current distribution is sinusoidal. Current-distribution measurements indicate that this is a good assumption provided that the antenna is thin: That is, when the conductor diameter is less than λ/100.

The current of the center fed antenna of length L at any point z on the antenna is:

$$I(z) = I_o \sin\left[\frac{2p}{l}\left(\frac{L}{2} - |z|\right)\right] \quad . \tag{1}$$

The far-field electric and magnetic field of a dipole antenna is determined by integrating the fields for an infinitesimal dipole of length *dz* at a distance *r* from the antenna

$$dE_\theta = \frac{jZ_o I_o \sin\theta \, dz}{2\pi r \lambda} \tag{2}$$

and $$dH_\phi = \frac{jI_o \sin\theta \, dz}{2\pi r \lambda} \quad . \tag{3}$$

The value of the magnitude for the magnetic field Hϕ for the entire length of the antenna is the integral Equation (3) over the length of the entire antenna:

$$dH_\phi = \int_{-L/2}^{L/2} dH_\phi \, . \tag{4}$$

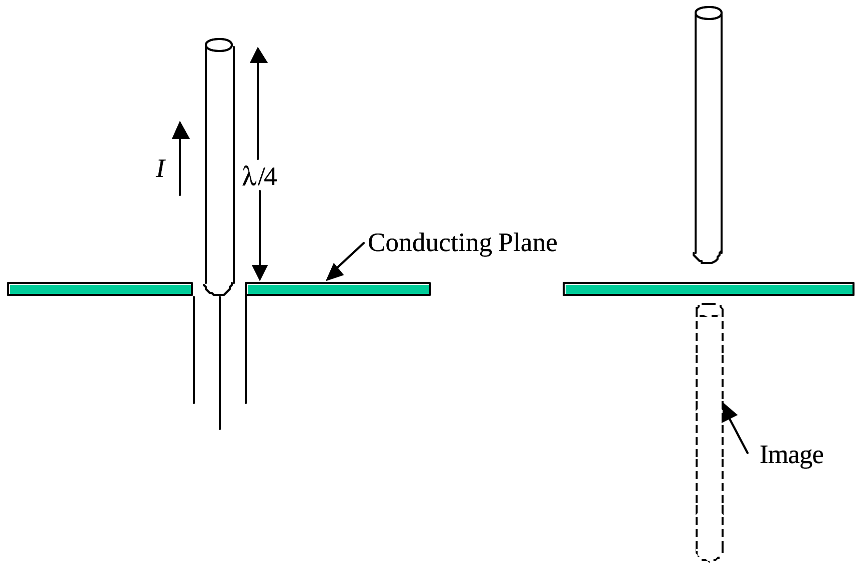
This yields the magnetic field for an arbitrary length dipole antennas in the far-field:

$$H_\phi = \frac{jI_o e^{-j\beta r} e^{j\omega t}}{2\pi r} \left\{ \frac{\cos\left[\frac{(\beta L \cos\theta)}{2}\right] - \cos\left(\frac{\beta L}{2}\right)}{\sin\theta} \right\} \quad . \tag{5}$$

The corresponding electric field for an arbitrary length dipole antennas in the far-field is:

$$E_\theta = \frac{jZ_o I_o e^{-j\beta r} e^{j\omega t}}{2\pi r} \left\{ \frac{\cos\left[\frac{(\beta L \cos\theta)}{2}\right] - \cos\left(\frac{\beta L}{2}\right)}{\sin\theta} \right\} \quad . \tag{6}$$

Single-ended sources may be used without baluns when monopole antennas are used. When placed over a conducting ground plane, a quarter-wave monopole antenna excited by a source at its base as shown in Figure 2 exhibits the same radiation pattern in the region above the ground as a half-wave dipole in free space. This is because, from image theory, the conducting plane can be replaced with the image of a λ/4 monopole. However, the monopole can only radiate above the ground plane. Therefore, the radiated power is limited to $0 \le \theta \le \pi/2$. Hence the λ/4 monopole radiates only half as much power as the dipole.



(a) (b)

Figure 2. (a) Quarter-Wave Monopole Antenna. (b) Equivalent Half-Wave Dipole Antenna

Note that the monopole antenna can accommodate single-ended signal feed.

A MathCAD routine for determining the radiation pattern (Electric Field) of a 3 meter dipole antenna operating at 100 MHz is shown below.

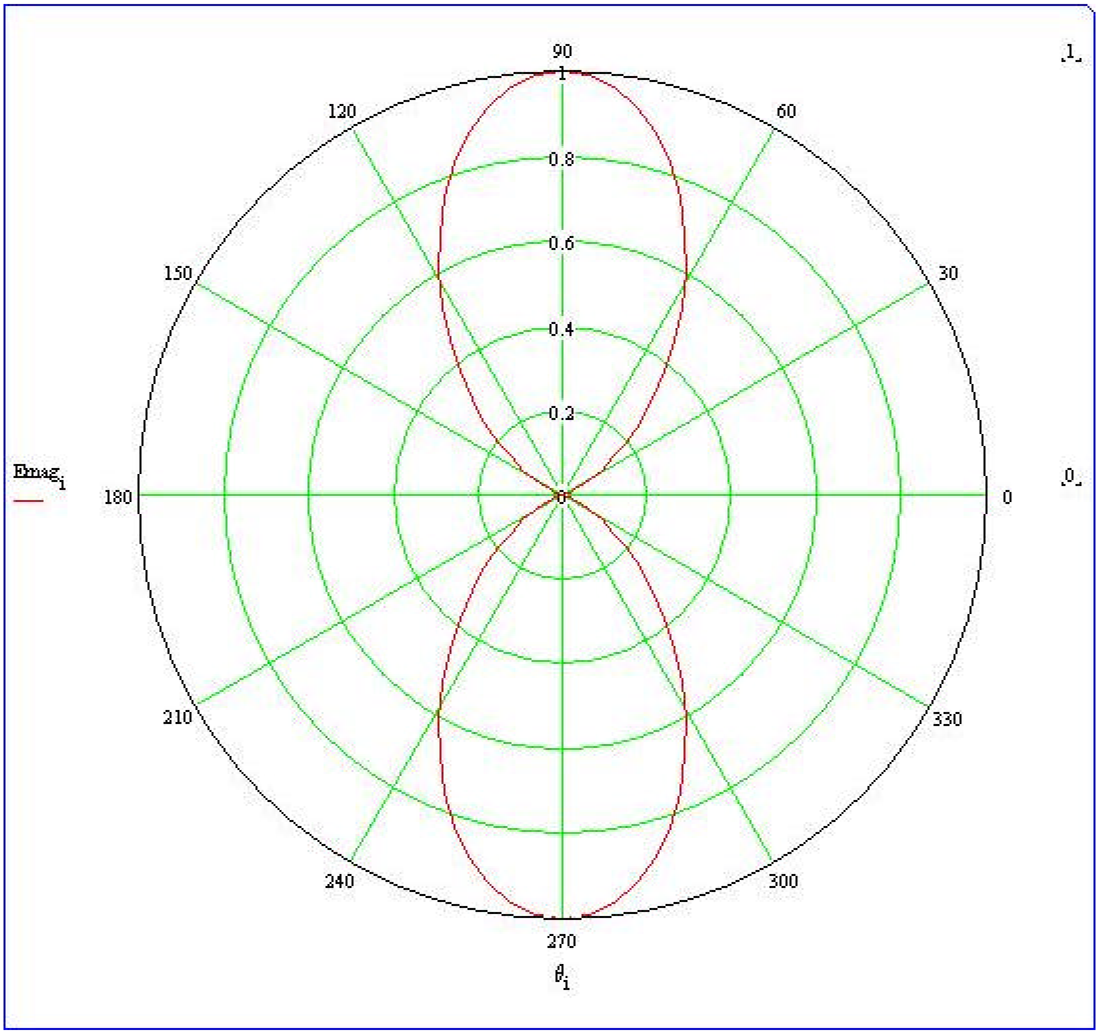
Linear antenna 3 meters long operating at 100 MHz.

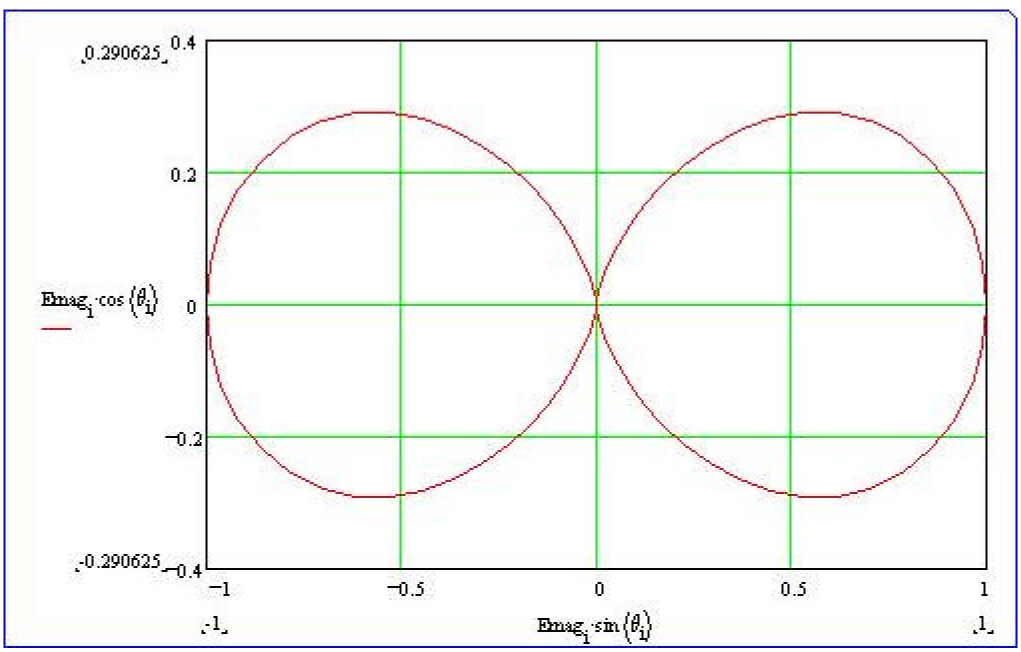
$i := 0..100$

$\theta_i := \frac{i \cdot 2 \cdot \pi}{100}$

$f := 100 \cdot 10^6$ Hz $\quad \lambda := \frac{3 \cdot 10^8}{f} \quad \beta := \frac{2 \cdot \pi}{\lambda} \quad l := 3.0$

$$Emag_i := \mathrm{if}\left[\sin(\theta_i) = 0, 0, \left|\frac{\cos\left(\frac{\beta \cdot l}{2} \cdot \cos(\theta_i)\right) - \cos\left(\frac{\beta \cdot l}{2}\right)}{2 \cdot \sin(\theta_i)}\right|\right]$$


90
60
30
0
330
300
270
240
210
180
150
120
1
0.8
0.6
0.4
0.2
0
Emag_i
θ_i
1
0


0.290625
0.4
0.2
0
−0.2
−0.290625
−0.4
Emag_i·cos(θ_i)
−1
−0.5
0
0.5
1
Emag_i·sin(θ_i)

To find the Radiation Resistance R_{rad} for a dipole antenna, we apply the average radiated power equation,

$$P = \frac{I_o^2 R_{rad}}{2}. \tag{7}$$

The power radiated is defined as

$$\begin{aligned} P &= \iint S_r ds \\ &= \iint \left(\frac{1}{2} Re\left\{ Z_o H_f H_f^{*} \right\} \right) ds \\ &= \iint \left(\frac{1}{2} \left| H_f \right|^2 \sqrt{\frac{m}{e}} \right) ds \\ &= \frac{1}{2}\sqrt{\frac{m}{e}} \int_0^{2p} \int_0^{p} \left| H_f \right|^2 r^2 \sin q \, dq \, df \end{aligned} \tag{8}$$

Simplified, radiation resistance for an arbitrary length dipole antenna is,

$$R_{rad} = \frac{Z_o}{p} \int_0^{p/2} \left\{ \frac{\cos\left[\frac{(b L \cos q)}{2} \right] - \cos\left(\frac{b L}{2} \right)}{\sin q} \right\}^2 \sin q \, dq \quad . \tag{9}$$

The radiation resistances for a common dipole antennas are:

Short Dipole:	$R_{rad} = 790\left(\frac{L}{l}\right)^2$
Half-Wave Dipole:	$R_{rad} = 73\ \Omega$
Quarter-Wave Monopole:	$R_{rad} = 36.5\ \Omega$

II. PROCEDURE

A. Design and plot the radiation pattern of a half-wave dipole antenna operating at 400 MHz.

Plot the radiation pattern for on MathCAD.

B. Design and analyze a quarter-wave dipole antenna operating at 400 MHz.

Plot the radiation pattern for a full-wave dipole antenna using MathCad. Determine the antenna's resistance.

C. *Design and analyze a quarter-wave monopole antenna operating at 400 MHz.*
Plot the radiation pattern for a full-wave dipole antenna using MathCad. Determine the antenna's resistance.

D. *Design impedance matching networks for the two antennas in Parts A, B, and C.*
Use both quarter-wave impedance transformers and single or double stub tuners.

E. *Compare the results*