Analysis of a Vertical Half-Wavelength Dipole Antenna in the 40 Meter Band

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INTRODUCTION

DIPOLES are a common antenna design renowned for their simplicity, robustness and high efficiency. While although dipoles are used across a wide number of frequencies, they enjoy significant popularity for HF (frequencies from 3 to 30 MHz),where both omnidirectional transmission and reception are required. Many useful equations appearing in the report come from a combination of lecture [1] and the class textbook [2].

I. IMPEDANCE VARIATION VS FREQUENCY

Sampling data from between 6.3 MHz and 7.7 MHz, the length of the dipole was set to be 48.457% of wavelength λ in order to acheive resonance. Resonance is defined by the Antenna Impedance shown in Equation (1):

$$Z_A = R_A + jX_A[\Omega] \tag{1}$$

Where if the reactance $X_A = 0$, the antenna becomes resonant. This meant that instead of the dipole being 20 meters long, it would be in total only 19.38 meters long. This would be about 30.86 cm removed on each side of the dipole.

A. Demonstration of Resonance

By decreasing the length of the antenna, the radiation resistance was lowered such that $X_A = 0$ when the frequency is 7 Mhz. This is shown in Figure 1, where the dotted line represents the reactance X_A and the solid line is the radiation resistance R_A. Since we are working under ideal free-space condtions, there are no losses on the antenna, that is, $R_A = R_r$. Using FEKO, this value was found to be $R_r \approx 75.65\Omega$. An approximation is available to confirm the analysis conducted by FEKO. This is provided by Rutledge [2], where a dipole is expected to have R_r around 73Ω.

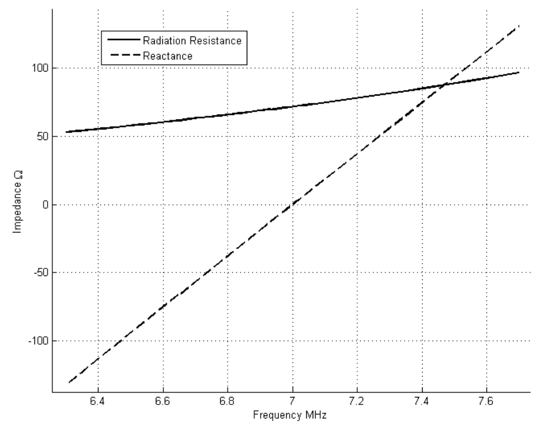

Fig. 1. Impedance versus frequency

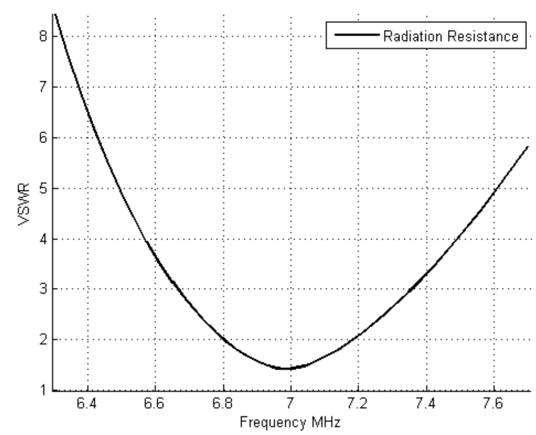

Fig. 2. VSWR versus frequency

II. VSWR VS FREQUENCY

A good way to tell if an antenna is well-matched at a given frequency is to calculate its Voltage Standing Wave Ratio. This can be calculated by Equation(2):

$$\text{VSWR} = \left(\frac{1+|\Gamma|}{1-|\Gamma|}\right) \quad \text{VSWR} \in (1, \infty) \tag{2}$$

$$\Gamma = \left(\frac{V_{Reflected}}{V_{Incoming}}\right) = \left(\frac{Z_A - Z_0}{Z_A + Z_0}\right) \quad \Gamma \in (0, 1)$$

Given that our reference impedance Z_0 was 50Ω, our VSWR was found to be 1.433 at 7MHz. This can be observed as the minimum in the plot of VSWR against frequency shown in Figure 2.

III. RETURN LOSS VS FREQUENCY

Another way of describing the efficiency of an antenna is with Return loss. Return Loss is defined using the magnitude of the Reflection Coefficient Γ in the following form:

$$RL = -20log|\Gamma|\text{dB} \tag{3}$$

In Figure 3, it can be seen that as the frequency approaches 7MHz, the value of the return loss reaches near -15dB. This is a desirable (albeit non-ideal) value where little power is lost by returning to the transceiver.

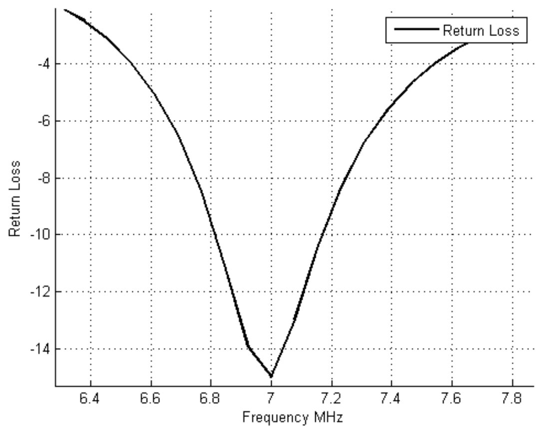

Fig. 3. Return Loss versus Frequency

IV. Radiation Pattern

A. Gain and Directivity

The gain of the dipole is represented in dB as the polar plot of the $\vec{E}$ Field in Figure 4 generated by FEKO.

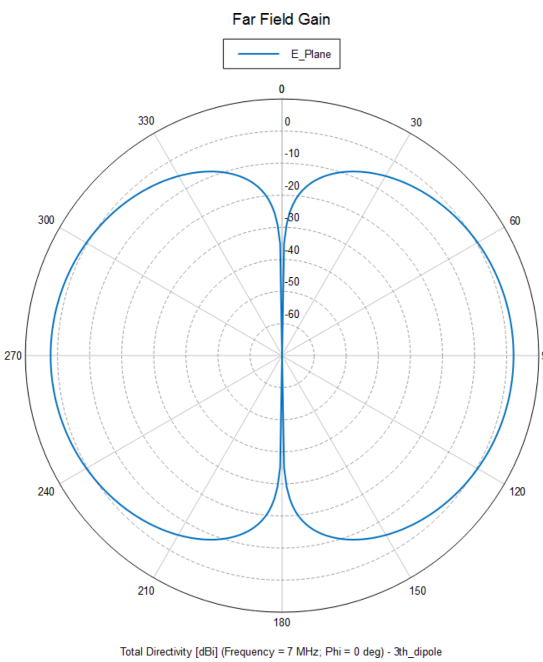

Fig. 4. Dipole Gain

The directivity of a dipole radiation pattern is omnidirectional, with a null at the point where $\theta = 0°$. This is more readily seen in the full 3D far field plot in Figure 5. When $\theta = 90°$, the gain is at its peak value. The $\vec{H}$ field is normal to the dipole and is perfectly circular. This simplifies analysis, as any slice of the $\vec{E}$ field is equivalent to any other slice.

B. 3dB beamwidth

The 3dB beamwidth, or, the angle where most of the power is transmitted was found using FEKO, and the plot is in Figure 6.

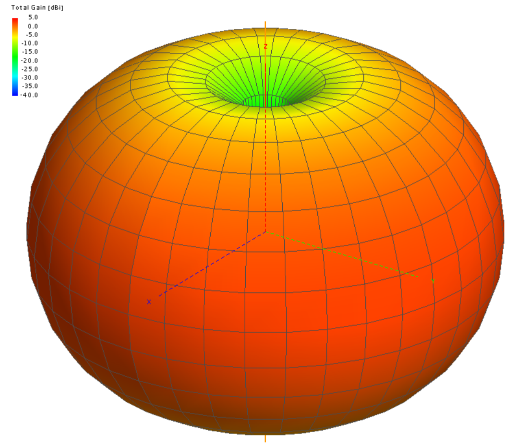

Fig. 5. Dipole Radiation Pattern in 3D

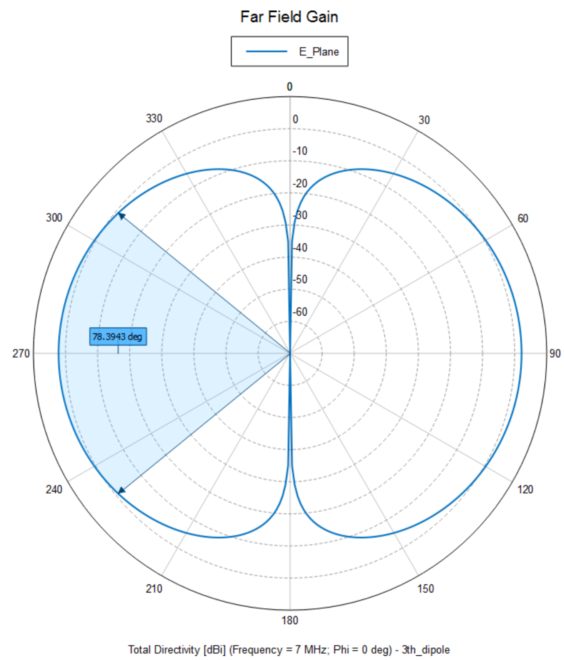

Fig. 6. Dipole 3dB Beamwidth

V. Antenna Polarization

The polarization of a dipole is straightforward to determine; vertical dipoles are vertically polarized and horizontal dipoles are horizontally polarized. Revisiting Figure 6, it is easily seen that a vertically polarized dipole will be largely restricted to groundwave communication, since most of the antenna power is concentrated parallel to the ground. If skywave communication is desired, the dipole may be angled or bent to accomodate better communication; doing this will allow the antenna's power to be directed at an angle towards the ionosphere where skywave communication can occur.

VI. Effects of Real Grounds

A. Relative Permitivity and Conductivity in Boulder, Colorado

Using material published by the American Radio Relay League, the estimated ground conductivity in Boulder, Colorado was found to be 15 mS/m [3], which is consistent with the description of rocky soil and mountainous terrain. A more specific region was selected as the effective ground conductivity varied noticeably across the state from 2-15 mS/m. The relative permitivity ϵ_r for the region that describes Boulder varies between 12-14. As a result, ϵ_r for Boulder was assumed to be 13.

1) Effects on Gain: After modeling the ground plane in FEKO, a change in the Gain was observed as shown in Figure 7. Here, it can be seen that the point where the transmission power is greatest is directed upwards such that $\theta_{Ground} < \theta_{Ideal}$.

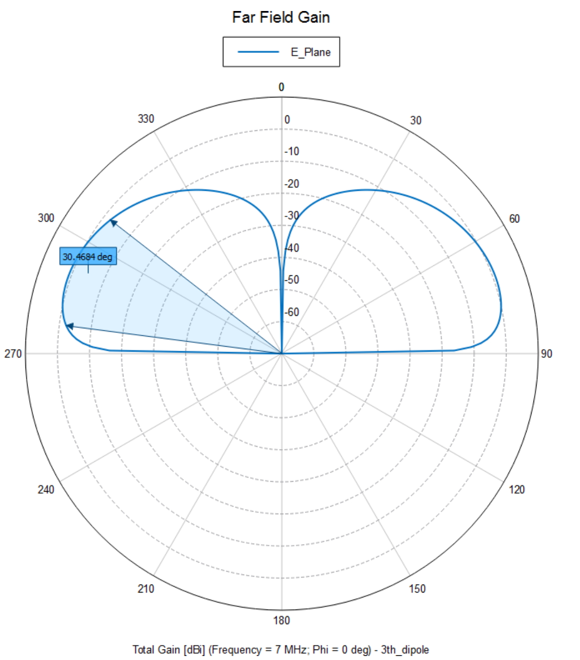

Fig. 7. $\vec{E}$ field plot and 3dB beamwidth considering ground effects

2) Effects on Efficiency: The change in Efficiency was the most significant change after applying the ground. Using the Equation (4), the efficiency was found:

$$\eta_A = P_{Rad}(1 - L_M)^2 \tag{4}$$

Where η_A is the radiation efficiency, P_{Rad} is the total radiated power and L_M is the mismatch loss. All of these quantities can be calculated using FEKO. At the 7MHz point, the efficiency with the ground was found to be 80.38%, in contrast to the 92.3% efficiency in free space.

3) Effects on Impedance: After adding in the ground, the antenna's resonance changed from 7 MHz to about 6.9 MHz, as seen in Figure 8.

4) Effects on Radiation Pattern: Having a ground plane under the antenna is akin to having a somewhat reflective surface under a tubular flourescent lamp; RF energy that is reflected from the surface of the ground interferes with the waves that would otherwise travel straight, causing an overall change in the shape of the $\vec{E}$ field shown in Figure 7. The 3D pattern is shown in Figure 9. Interestingly, this makes the antenna somewhat safer to be around as, instead of having

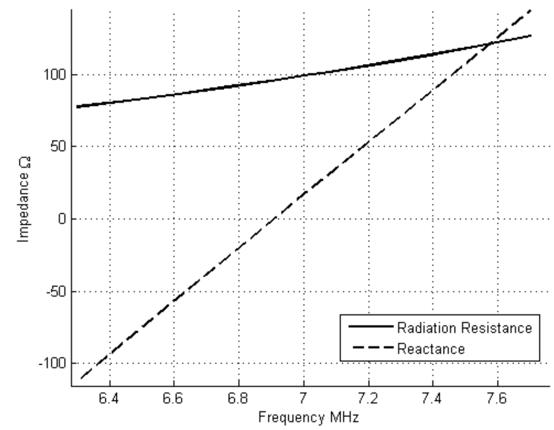

Fig. 8. Impedance versus frequency accounding for ground effects

the full force of the transceiver be directly across from the antenna, most of the power is instead directed upwards.

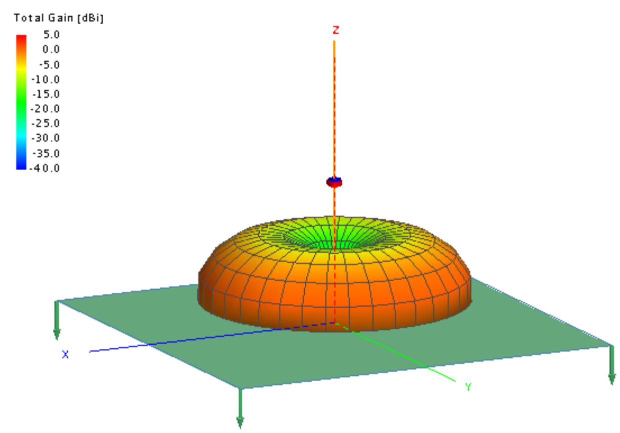

Fig. 9. $\vec{E}$ field plot considering a ground and 3dB beamwidth

VII. Effects of Real Antenna Materials

Taking into account real matallic materials for antenna construction, two factors need to be considered; the material itself and the diameter of the wire.

A. Material and Diameter

A better conductor is preferable for the reduction of losses. As a result, it seems most prudent to use Copper, which is an excellent conductor with a conductivity $\sigma = 59.6 * 10^6$S/m [4]. For diamater, it appears that 14 AWG is a desirable wire thickness for its durability (with a breaking strength rated at 550lbs from some manufacturers)[5]

B. Effects

Compared to the ideal antenna in free space, the more realistic antenna had the following differences at 7Mhz.Afterwards, the length of the dipole was adjusted such that X_A would be near zero again, and measurements were listed as the *Adjusted* entry in the following table. The new length was 48.4% of λ.

Property	*Ideal*	*Practical*	*Adjusted*
VSWR	1.43	1.94	1.93
R_A	75.7Ω	97.1Ω	96.8Ω
X_A	0Ω	1.93Ω	-43.5mΩ
Efficiency	92.93%	29.36%	29.53%

VIII. Practical Mounting of the Antenna

For the HF vertical dipole antenna, a reasonable and practical method of mounting the antenna involves the use of guy wires. This is done by having a trio of wires evenly spaced radially about the tower connecting to bases prevening wind from causing to buckle. On taller towers, there are several segments of guy wires. Following advice from the ARRL, guy wire segments should not be seperated more than 35 feet (10.67 meters), and all guy wires should connect to a common base roughly 60%-80% of the tower length out from the base of the antenna. [3]

Therefore, for a $\frac{\lambda}{2}$ dipole antenna for $\lambda = 40$m, there should be a total of at least two guy wire segments; the first segment connecting at 10.67m with a length of 21.3 meters to a base firmly anchored in the ground roughly 14m out. The second set should be at or near the top of the antenna at 20m and have a length near 24m.

IX. Loss in a Real Coaxial Cable

Using an RG-8/U coaxial cable, the required specifications were identified from a datasheet [7]. Using Equation (5) [6] the properties of the coaxial cable can be analyzed.

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\epsilon}}ln\frac{D}{d} \approx \frac{139\Omega}{\sqrt{\epsilon_r}}log\left(\frac{D}{d}\right) \tag{5}$$

Where ϵ_r can be solved as being 1.25. Next, using Equation (6), the loss in terms of dB/m can be found.

$$\alpha_L \approx 92.0216\sqrt{\epsilon_r}tan(\delta) \cdot f \tag{6}$$

Where $f = 7$MHz and $tan(\delta) \approx 5 \cdot 10^{-10}$, so the loss in dB/meter at 7 MHz is about 0.38db/m, so with 20 meters, the total loss is approximately .56dB.

X. Antennas for Purchase

Now turning to real manufactured antennas, the following were investigated.

A. Radiowavz 40-DP11

Contacting the Colorado Ham Radio Outlet (HRO), I was recommended to get the Radiowavz 40-DP11 40M Dipole Antenna with a Balun built in. It also uses 14 AWG wire as in my modeling of a realistic antenna. The antenna kit itself would require that the antenna be fed through segments of plastic or narrow PVC pipe in order to be set vertically.[8] Cost: $47.99

B. Alpha-Delta DX40

These more expensive 40-meter dipole kits include built-in Surge Suppression, 50 ft of nylon support wire and use 12 AWG wire. However, the product website seems to suggest that its antennas are generally to be used with a horizontal polarization. However, similar to the Radiowavz dipole, the DX40 could also be strung up vertically, albeit the provided nylon support cord would not be strong or abundant enough for setting up guy segments.[9] Cost: $62.95

C. Comparison

Property	*40-DP11*	*DX40*
Cost	$47.99	$62.95
Wire	12 AWG	14 AWG

Unfortunately, the website for the Radiowavz antenna was temporarily down, preventing a more comprehensive comparison between the antennas.

References

[1] D. Filipovic, *Antenna Introduction*, March 2013

[2] D. Rutledge, *The Electronics of Radio*, Cambridge, England: Cambridge, 1999. ch.15, sec.9, pp.291-292.

[3] G. Hall, J.W. Healy, J. Almeida, et al. *The ARRL Antenna Book*, 15th ed. Newington, CT: ARRL, 1988.

[4] C.R. Hammond *Handbook of Chemistry and Physics*, 81st ed. Boca Raton, FL: CRC Press, 2005.

[5] *Antenna Wire*, [Online]. Available:http://www.thewireman.com/antennap.html

[6] W.C. Elmore *Physics of Waves*, 2nd ed. Mineola, NY: Dover Pubn, 1985.

[7] Belden, "Detailed Specifications & Technical Data of Coax Cable", RG-8/U Type Coax Datasheet, May. 2012

[8] *Radiowavz 40-DP11*, [Online]. Available:http://www.hamradio.com/detail.cfm?pid=H0-008392

[9] *Alpha-Delta DX40*, [Online]. Available:http://www.hamradio.com/detail.cfm?pid=H0-005115