A Freeware-Based Antenna Simulation Exercise

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Abstract

Although several excellent microcomputer-based antenna simulation programs exist, the prohibitive cost and restricted availability of these programs severely limits their application in teaching-oriented settings. While freeware simulators lack the capabilities required for serious research, they can be quite useful for reinforcing basic concepts and introducing antenna simulation. One such program, MMANA, offers an intuitive user interface, an extensive collection of sample input files, and a surprising list of features. A laboratory exercise incorporating MMANA has proven to be an effective component of the undergraduate Wireless Communications course at Southern Polytechnic State University. This exercise introduces MMANA via a brief tutorial, and then guides students to observe the impact of element height and length on the pattern, gain, and impedance of an antenna. This paper briefly describes MMANA, it details the simulation exercise that was written to use MMANA, and it displays the results that are obtained by completing the exercise.

The MMANA Simulation Program

MMANA [1] is an acronym for the **M**akoto **M**ori **An**tenna **A**nalysis Program, named for its author. MMANA provides an intuitive graphical user interface supported by the MININEC simulation engine. MININEC is a reduced-functionality microcomputer version of its big brother, the Numerical Electromagnetic Code (NEC). MININEC's primary shortcoming is its inability to deal with closely spaced conductors, or with conductors in close proximity to ground. MININEC is, however, quite capable of providing an effective introduction to basic antenna simulation.

Figure I shows the MMANA **Compute** Screen while Figure II shows its **Far Field Plot** Screen. While MMANA's target is Amateur Radio enthusiasts, the program itself is general-purpose. The current version installs with 224 sample files that encompass a wide variety of antenna types. MMANA's ease-of-use, zero cost, small size, and fast execution make it extremely attractive and accessible to students for home use.

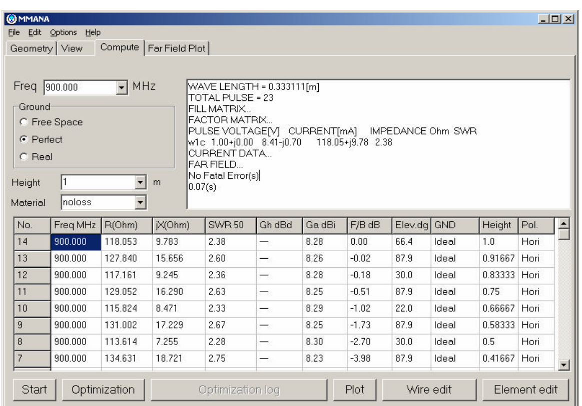

Figure I: MMANA Compute Screen

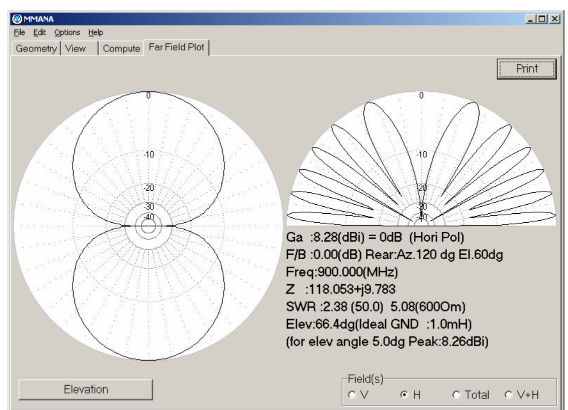

Figure II: MMANA Far Field Plot Screen

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The Antenna Simulation Exercise

Overview

The following exercise provides an MMANA tutorial as an introduction to antenna simulation. It progresses into the simulation of a dipole antenna under various conditions that demonstrate the effects of antenna height and element length on pattern shape, gain, and impedance. Words or phrases shown in **bold** refer to tabs, headings, blanks, and boxes associated with the program. "Click" refers to a left mouse-click unless stated otherwise.

Procedure I: Introduction

1. Start MMANA. Note that the program presents the user with a spreadsheet for entering element geometries.

2. Click the **View** tab to observe the orientation of the coordinate axes. Horizontal elements should be entered such that they lie in the xy plane (i.e., Z1 = Z2) and are parallel to the y-axis (i.e., individual elements have X1 = X2).

3. Click the **Geometry** tab to return to the spreadsheet screen.

4. Click the **Name** blank, then type "Horizontal Dipole (*Your Name*)". Note: replace *Your Name* with your own.

5. Click the **Freq** box, then type 900 to change the frequency to 900 MHz.

6. The next line contains four blanks associated with the element segmentation parameters (e.g., DM1). Use the default values for these parameters.

7. Leave the **Keep connected** box unchecked.

8. The spreadsheet heading line identifies the element coordinates (**X1**, **Y1**, **Z1**, **X2**, **Y2**, **Z2**), the element radius (**R**), and the number of segments (**Seg.**) used for modeling the element. Note that the default unit for coordinates is meters and the default unit for radius is millimeters.

9. Click the **lambda** box to change the coordinate and radius units to wavelengths. Observe the changes that occur on the spreadsheet heading line.

10. Click the cell in the **Y1** Column of the **next** row. Type -0.25 <Enter>. These steps insert the value thus entered into Row **1**.

11. Click the cell in the **Y2** Column of Row **1**. Type 0.25 <Enter>.

12. Click the cell in the **R** Column of Row **1**. Type 0.000001 <Enter>. Steps 10 - 12 create a thin element on the y-axis that is one-half wavelength in length and centered at the origin.

13. Click the cell in the **Seg.** Column of Row **1**. Type -1 <Enter> to instruct MMANA to use automatic segmentation with tapered segment sizes. This type of segmentation produces an efficient, accurate model that is appropriate for most antenna geometries.

14. Click the **View** tab. The element defined in steps 10 - 13 appears as a small dot at the origin.

15. Click **Full view** to select an appropriate zoom factor. The dipole should now be visible as a dark line symmetrically oriented along the y-axis.

16. Click the **Segments** box to display the element segmentation scheme. Note the tapering. Re-click the **Segments** box to hide the segmentation.

17. Place the cursor over the element, then right-click. Select **Move/Add source to**, then select **center of wire**. A red circle should now appear in the center of the element indicating the presence of a feedpoint.

18. Click the **Geometry** tab, and then observe the information about **Source 1** in the lower left quadrant of the screen. Note the presence of the **Voltage** and **Phase dg** cells. These cells are used to set the relative amplitude and phasing (degrees) of multiple sources in a driven array.

19. Click the **Compute** tab. Note that the operating wavelength appears in the upper right pane.

20. Click **Free Space** if it is not already selected.

21. Click **Start** to initiate the simulation process. Note the series of status messages in the upper right pane of the screen. The simulation is complete when the execution time appears at the bottom of this pane.

22. Note the values displayed in the results pane in the lower half of the screen. This pane sequentially numbers successive simulations and tabulates their results to facilitate analysis of the impact of revisions. Table I interprets the headings for this pane.

23. Note the excellent agreement between the simulation results for radiation resistance and gain, and their respective theoretical values (73Ω and 2.15 dBi).

24. Click the **View** tab. Note that a plot of antenna current has been added to this figure. Click-and-drag the **Zoom currents** [not **Zoom**] control to maximize the on-screen display of the current.

Table I: Interpretation of the Headings Used in the Results Pan*e*

Heading	Meaning
No.	The sequence number that identifies a particular simulation.
Freq MHz	The simulation frequency in MHz.
R (Ohm)	The real part of the radiation resistance.
jX (Ohm)	The imaginary part of the radiation resistance.
SWR 50	The SWR when connected to a 50Ω transmission line.
Gh dbd	The gain in dBd.
Ga dbi	The gain in dBi.
F/B db	The front-to-back ratio in dB.
Elev. dg	The elevation angle (degrees) of the main lobe.
GND	The type of ground used in the simulation.
Height	The height of the antenna above ground (if used).
Pol.	The dominant polarization of the antenna.

Current plots with serious discontinuities usually indicate the presence of a modeling problem—either the segmentation parameters need to be revised to improve the model, or the element geometry is such that MININEC cannot perform an accurate simulation. MININEC has difficulty with elements that are too close together, and it also has difficulty with elements that are too close to ground.

25. Click the **Far Field Plot** tab. Note that the azimuthal-plane pattern appears on the left of the screen while the elevation-plane pattern appears on the right. Also note that most of the parameters tabulated on the **Compute** screen are duplicated on the **Far Field Plot** screen.

26. Click the **Geometry** tab, then uncheck the **lambda** box to prepare for changing the element radius to a more realistic value (0.000001λ = 333nm!). Click the radius box for Element **1**, then type 6.35.

27. Click the **Compute** tab, click **Start**, and then note the ease with which the results of the most recent simulation (Row **2**) can be compared with the results of the previous simulation (Row **1**).

Procedure II: Height Effects

1. Complete the second column of Table II by computing the height in meters for each height in wavelengths.

2. Click **Perfect**, click the **height** blank, type 0.08333, and then click **Start**. These steps simulate the performance of the previously defined dipole at a height of 0.08333m above a perfectly conducting ground plane.

3. Record **Ga** in the G_{max} column of Table II, then click the **Far Field Plot** tab to observe the resulting patterns. Use the elevation-plane pattern to observe the gain at an elevation angle of 5°. To determine the exact value of this gain, click **Elevation**, type 5 <Enter>, then note the result labeled **for elev angle 5.0dg Peak.** Record this value in the $G_{5°}$ column of Table II.

4. Click **Compute**, then repeat Steps 2 and 3 as needed to complete Table II. Pay special attention to the changes (if any) that occur in the elevation-plane pattern as the dipole height is increased.

5. When finished, click the **Compute** tab, then use <Alt><Print Scrn> to take a screen shot of your results. Open the Paint program (but do not close MMANA), paste your screen shot into Paint, and then print a hardcopy (or save a graphics file) for inclusion in your report.

Table II: Gain as a Function of Height

Height (λ)	Height (m)	G_{max} (dBi)	$G_{5°}$ (dBi)
0.25	0.08333		
0.50			
0.75			
1.00			
1.25			
1.50			
1.75			
2.00			
2.25			
2.50			
2.75			
3.00			

Procedure III: Length Effects

1. Return to MMANA.

2. Click **Element edit**, click the **lambda** box, click the **Widt** cell of Element **1**, type 0.1, then click **OK.** These steps reduce the dipole length to 0.1 wavelength.

3. Click **Free Space** to remove the ground plane that was added in Procedure II, and then click **Start**.

4. Record your results in the 0.1λ row of Table III: **Ga** in the Gain Column, **R** in the Resistance column, and **X** in the Reactance column.

Table III: Gain, Resistance, and Reactance as a Function of Dipole Length in Free Space

Length (λ)	Gain (dBi)	Resistance (Ω)	Reactance (Ω)	Length (λ)	Gain (dBi)	Resistance (Ω)	Reactance (Ω)
0.1				0.7			
0.2				0.8			
0.3				0.9			
0.4				1.0			
0.5				1.1			
0.6				1.2			

5. Click the **Far Field Plot** tab to observe the pattern in the azimuthal plane.

6. Click the **Compute** tab, and then repeat steps 2 - 5 as necessary to complete Table III. Closely monitor the azimuthal-plane pattern for changes.

7. When finished, take a screen shot of your **Compute** screen. Use Paint to prepare a hardcopy (or save a graphics file) for inclusion in your report.

Analysis

1. Plot the **Gain at Five Degrees of Elevation versus Height** (wavelengths) using the data in Table II. Note that this gain exhibits a definite trend as the height above ground is increased. Identify this trend, and describe the elevation pattern behavior that produces it.

2. Plot the **Gain versus Dipole Length** using the data in Table III. Note that this gain also exhibits a definite trend, at least to a point. Identify this trend, and describe the azimuthal pattern behavior that limits the extent of it.

3. Plot the **Resistance versus Dipole Length** and the **Reactance versus Dipole Length** (separate plots) using the data in Table III. Use these figures and your knowledge of coaxial cable impedances to explain the popularity of "half-wave" dipoles.

The Simulation Exercise Results

Procedure II investigated the relationship between the gain of a dipole and its height above a perfectly conducting ground plane. Specifically, the maximum gain and the gain at a 5° elevation angle were sought as antenna height was increased from 0.25 wavelength to 3.0 wavelengths.

Table IV summarizes the values obtained in Procedure II. The corresponding plot of **Gain at Five Degrees of Elevation versus Height** appears in Figure III.

Table IV: Gain as a Function of Height

Height (λ)	Height (m)	G_{max} (dBi)	$G_{5°}$ (dBi)
0.25	0.08333	7.58	-9.72
0.50	0.16667	8.53	-2.83
0.75	0.25000	8.15	0.18
1.00	0.33333	8.34	2.68
1.25	0.41667	8.23	4.25
1.50	0.50000	8.30	5.60
1.75	0.58333	8.25	6.51
2.00	0.66667	8.29	7.27
2.25	0.75000	8.25	7.75
2.50	0.83333	8.28	8.11
2.75	0.91667	8.26	8.24
3.00	1.00000	8.28	8.26

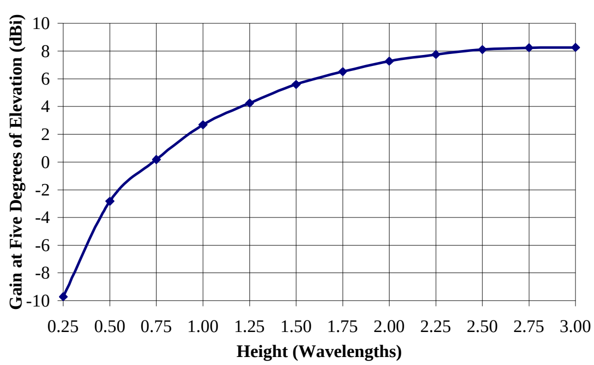

Figure III: Gain at Five Degrees of Elevation versus Height

Figure III demonstrates the impact of antenna height on its effective gain at low elevation angles. A comparison of the gain columns in Table IV reveals that the *Gain at 5° Elevation* approaches the *Maximum Gain* as the height of the antenna is increased (at least within the range of heights considered in the exercise).

Procedure III investigated the dependence of gain and feedpoint impedance on the length of a dipole. Table V summarizes the expected results for Procedure III. Figures IV, V, and VI present the corresponding plots of **Gain versus Dipole Length**, **Resistance versus Dipole Length**, and **Reactance versus Dipole Length**, respectively.

Table V: Gain, Resistance, and Reactance as a Function of Dipole Length in Free Space

Length (λ)	Gain (dBi)	Resistance (Ω)	Reactance (Ω)	Length (λ)	Gain (dBi)	Resistance (Ω)	Reactance (Ω)
0.1	1.77	1.224	-177.389	0.7	2.81	259.629	-179.938
0.2	1.81	6.692	-140.975	0.8	3.19	166.892	-234.501
0.3	1.92	18.466	-86.719	0.9	3.63	102.358	-221.661
0.4	2.06	48.185	-33.514	1.0	4.12	66.729	-193.831
0.5	2.25	122.608	12.597	1.1	4.52	47.239	-162.542
0.6	2.50	250.360	-28.953	1.2	4.46	38.862	-127.928

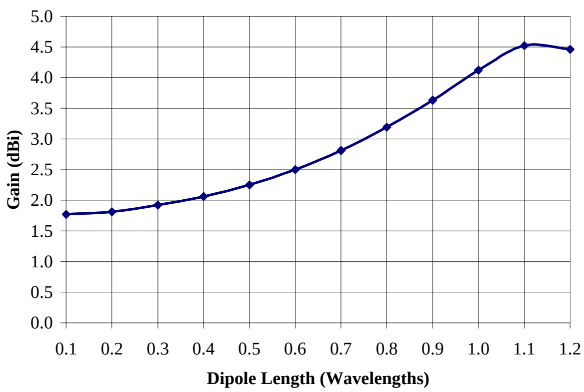

Figure IV: Gain versus Dipole Length

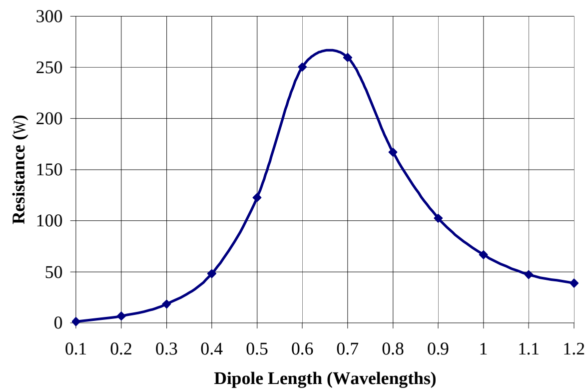

Figure V: Resistance versus Dipole Length

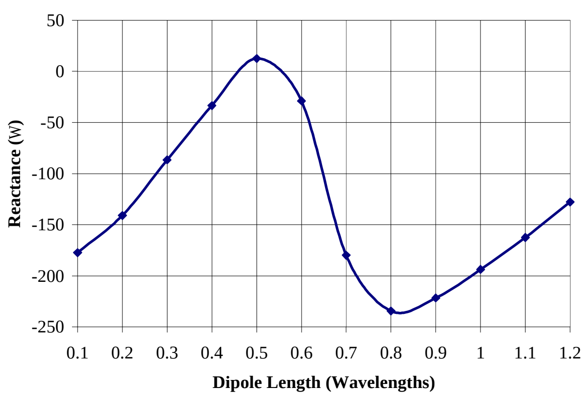

Figure VI: Reactance versus Dipole Length

Figure IV reveals that dipole gain increases with length at lengths less than about 1.1 wavelengths. Observation of the azimuthal-plane pattern adds insight to the reversal of this apparent trend: at lengths above 1.1 wavelengths, the pattern's dominant main lobe fragments into minor lobes. The pattern becomes less concentrated, so the gain falls.

Figure V relates dipole length to radiation resistance, while Figure VI relates dipole length to feedpoint reactance. Note, using Figure VI, the resonance that occurs at slightly less than one-half wavelength. Figure V indicates that the corresponding radiation resistance is about 75Ω. "Half-wave" dipoles are popular because they are relatively easy to match to standard 50Ω or 75Ω coaxial cables.

Conclusions

MMANA provides a great opportunity for budget-conscious departments to incorporate a powerful antenna simulation tool into their curriculums. Its ease of use, attractive display, fast execution, and zero cost make it suitable for classroom demonstrations, laboratory activities, and homework assignments. It sparks student interest, makes antenna concepts more tangible, and improves comprehension. Since MMANA tabulates the results of successive simulations, students can use it to explore antenna behavior in a practical way that both supplements and extends the information conveyed by the tables and diagrams in their textbooks. Students can install MMANA at home and/or at work; easy access to the program encourages its use and simplifies its usage in distance-learning applications. MMANA also demonstrates basic capabilities common to other antenna-simulation programs, which prepares students for future efforts with more powerful tools. Thus, MMANA offers numerous enticements toward its application in the academic realm.

While MMANA is an outstanding product as it stands, several limitations and potential improvements are worthy of note. MMANA inherits the limitations of MININEC, the simulation engine it shares with several commercial products. Limitations related to minimum element spacing and ground proximity have already been discussed. From a practical standpoint, MININEC is also limited to wire antenna applications. While other types of antennas can be simulated through Herculean efforts to construct wire models for solid surfaces, the time required by such efforts renders them to be impractical. As for potential improvements, MMANA would benefit from the addition of a three-dimensional pattern-plotting capability, and from an option to save pattern graphics in a standard image format.

An antenna simulation exercise has been written to tap some of the potential that MMANA offers. This exercise integrates a stand-alone program tutorial with a thought-provoking study of basic antenna characteristics. Expected results and relevant observations follow the exercise, both to assist its evaluation, and to support its use. Additional exercises could be written to exploit the specialized features of MMANA that were not demonstrated in this basic exercise. Potential topics for such exercises include parasitic arrays, driven arrays, impedance matching, and antenna optimization.

References

1. MMANA is available for downloading at http://www.qsl.net/mmhamsoft/.

2. Balanis, Constantine A. (1997) *Antenna Theory: Analysis and Design*, John Wiley & Sons, New York, NY.

3. Kraus, John D. (2002) *Antennas For All Applications*, McGraw-Hill, New York, NY.

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