

ECE 764 Lab 2 - Antennas and Propagation

Due Wednesday, Feb 27, 2019 at actual COB (5pm)

Overview

In this lab, we will build simple halfwave dipole antennas and use them in several experiments to learn about:

- Design and construction techniques
- Loading effects of antennas on sources (impedance)
- Antenna/feedline-system reflection coefficient, return-loss, and SWR
- Electric field strength versus distance
- Polarization
- Antenna directivity and patterns
- Radio wave reflections and standing waves
- EM simulations with EZNEC

Lab Partners and Writeups

For this lab you should work in 2-persons teams. As before, this will prove necessary in taking the measurements. Unlike the previous lab however, you should split the workload in the writeup making it a true team effort. Each person should document about half the required experiments (the first half or the second half). The person doing the first half should also do a one page intro to the entire lab. The person doing the second half is responsible for the final conclusions section at the end. On the cover page and in the writeup, be clear on who did what portion(s)

In your report, you should document the experiment setups, the measurements, and the calculations. As before, include a narrative that describes the goal, the procedures used, problems you encountered (plus the resolution if any) in each part. Also include observations you made about how the theory compared with experimental results - especially in the conclusions. As before, grades will be based on the Completeness, Correctness, and overall Quality (CCQ) of your results and writeups.

Frequencies of Operation and Warnings

In this lab, you and your lab partner will each build an antenna, but you should use the same frequency. The choices include the 462-467 MHz UHF band of the Family Radio Service (FRS), the 902-928 MHz ISM band used by the digital radios, or the DECT6.0 1.92 - 1.93 Ghz band used by the cordless phones. Thus, your team must decide whether you want to target 467 MHz, 915 MHz, or 1.93 GHz in designing, building, and testing your antennas. Note that the HF CB and the VHF MURS bands are not included since the wavelengths associated with 27 MHz and 150 MHz are too large for use in the lab experiments we will be performing.

Pictures

Photos are strongly encouraged to *help* document what you did (remember - a picture is worth 1000 words, saving you some writing and me some reading ;-) It's also more clear in many cases.

Procedures

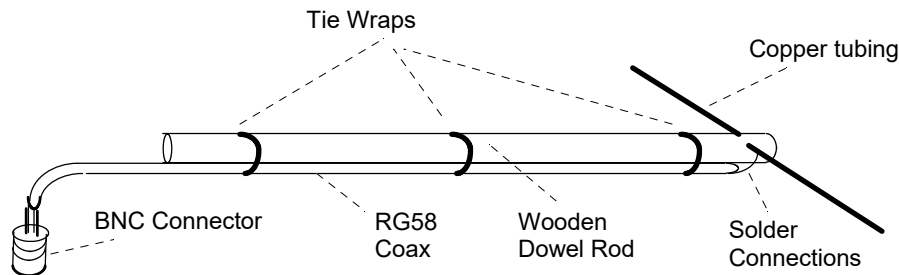
1 Antenna Design

Calculate the length of a half-wave dipole at the operating frequency selected above. For a real $\lambda/2$ dipole (one for which Z is purely resistive), the physical length should be about 2% to 5% *less* than the length calculated using the velocity of light, depending on the diameter of the antenna elements. This is due to an effective slowing of the wave in the presence of the wire structure and to capacitance present at the tip of the antenna. The exact percentage depends on the ratio of the rod/wire thickness to its length and other factors such as the feedpoint dimensions. For this design, use 3%. But ...

In determining the precise length of your antenna elements, be sure to account for the length of the exposed coax braid and center lead where they separate from each other and connect to the antenna elements at the “feedpoint” since these segments will become part of the radiating structure (see drawing below). Also, make sure the wooden rod and coax are perpendicular to the antenna and long enough that the antenna elements will not couple excessively to the test equipment you drive it from. See the figure below. (Generally, one or two wavelengths should be OK, but make the coax long enough to get the antenna away from stuff in the lab and see footnote below about the use of baluns in some antennas).

2 Construction

Construct your antenna using the materials and tools provided in the lab. ***USE SAFETY GLASSES*** when appropriate (e.g. Drilling). In your writeup be sure to sketch an assembly drawing showing how your antenna was constructed. A rough drawing of a recommended construction technique is shown below¹. ***Yours should be more detailed. Carefully show the feedpoint and dimensions in your diagram.***



3 Antenna Impedance Estimation

To learn about antenna impedance and to check for major errors in antenna construction *before* progressing through all the measurements below, let's look at how our antenna loads a signal generator source. For this we will use an HP8656 RF signal generator, an RF voltmeter (the HP8505 vector voltmeter), and a 10:1 RF probe. **Do the following for both antennas, since you'll need both in the subsequent measurements !**

¹ Note that we really should use a “balun” between the end of the coax and the antenna to make the antenna pattern closer to ideal. Without it, the fields from the center-conductor will couple to the coax shield outer surface (undesired) as well as to the other element (desired). For simplicity, we will try to get away without a balun. Hence, impedances and patterns may be a little off from theory. You will investigate that issue using the EZNEC simulator at the end of the lab.

Setup the RF generator for the frequency you have chosen and set its output voltage to a moderately large (e.g. 0.25V). Then measure the open-circuit voltage out of the generator using the vector voltmeter (VVM) with one of the brown 10:1 RF probes (**DO NOT USE a 10:1 oscilloscope probe!!**). To do the measurement, **gently** place the probe tip into the center of the generator's BNC RF output connector while holding the ground-pin of the probe tip against the BNC connector shell.

Note that the RF probe contains an internal 450 Ohm series resistor. When connected to an RF test instrument such as the VVM with a 50 Ohm input impedance, the probe scales the voltage it is seeing by $50/(50+450) = 1/10$. This is done so that it can present a relatively light load ($450+50 = 500$ Ohms) to the circuit being measured. Thus, the measured voltage should be *approximately* 1/10th of the unloaded voltage from the generator. Verify that this is the case after reading and understanding this additional issue/complication:

IMPORTANT: *The RF generator has a Thevenin output impedance of 50 Ohms and the displayed voltage is the value that would be presented to a "matched load" of 50 Ohms - NOT necessarily the value at the output.* For example, if left open-circuited, the actual output voltage will be two times the displayed value.

In your writeup, show a schematic diagram representing the generator with a Thevenin source (with 50 Ohm source resistance), and the probe and VVM as discussed above. Compare the calculated value you should see with the value you measured. It should be reasonably close. What does reasonably close mean? How much error would you expect if both the signal generator and VVM could each have errors of up to 0.5 to 1 dB - which is a reasonable assumption for moderate cost test RF equipment.

Next, place a BNC "T" connector onto the generator's output connector ***with one side of the T connected to your antenna*** and the other open to allow checking the (loaded) voltage with the probe as above. Measure and record this *loaded* voltage (with the antenna connected).

Assuming your half-wave dipole antenna is "resonant" (so that it's impedance is a purely real "radiation resistance"), ***sketch another schematic diagram representing the equivalent circuit for the antenna plus probe both connected to the generator.*** Use your measurements to calculate the antenna's radiation resistance (under the assumption it is real-valued). How does it compare to the expected value? If it is not exactly equal to the value you expect from a half-wave dipole antenna, do not worry. We don't have a balun and the coax modifies the impedance somewhat from that of an ideal dipole. **HOWEVER** - if it is wildly off, re-read the above and make sure you accounted for all the factors of 2, 10, etc. If it is still widely off (more than 50% or so), check for shorts or opens in your coax connector, etc and ask for help.

Finally, try measuring the impedance at the antenna "feedpoint" (at the location where the metal rods are mounted to the wooden rod). This measurement may be closer to the predicted value for a 73 Ohm load. Is it? Remember that this is not a great dipole since we do not have a balun, so don't expect perfect results here either. We will learn to deal with these issues and learn how to make more precise (and full complex impedance) measurements later this semester...

4 Reflection Coefficient, Return Loss, and SWR

An issue related to the impedance measurement made above is how well your antenna matches the so-called "characteristic impedance" of the transmission line (coax) used to "feed" it. As we discussed, if the antenna impedance does not match that value, the signal that travels down the transmission line (coax) to the antenna will be partially reflected back toward the source and less signal will be radiated.

Reflection Coefficient (Γ), return loss (RL) and Standing Wave Ratio (SWR) are three common measures of how good the match is. They can be found by inserting a "directional coupler" into the transmission line feeding the antenna. The directional coupler allows independently measuring the voltage wave traveling toward (or "incident" on) the antenna (V_{inc}), and the "reflected" voltage wave (V_{refl}) coming back from the antenna toward the signal generator.

Reflection coefficient is defined as:

$$\Gamma = \frac{V_{refl}}{V_{inc}}$$

To measure this quantity, use the bench where the directional coupler is set up and connected to the two channels of the VVM. Make sure the signal generator used on this bench is set to output a reasonably good level (e.g. 0.25V) at your antenna's design frequency. Connect your antenna down-stream of the directional couplers. The VVM should then allow you to read V_{inc} and V_{refl} if you enable both the A and B channels. (Actually it reads attenuated versions of V_{inc} and V_{refl} , but since gamma is the ratio of the two, the coupling coefficient will divide-out).

Take measurements of the (attenuated) V_{inc} and V_{refl} values from 50% to 200% of your center frequency and record your results in a table. Take closer spaced measurements near the expected region of resonance (e.g. every 1%). Then compute gamma and add it to the table in the 4th column. Plot gamma over the 50% to 200% frequency range.

Two additional related measures of antenna impedance matching are return loss (RL) and standing-wave-ratio (SWR). Both return loss and SWR can now be found from the gamma values measured above. As discussed in class, the formulas for return loss (in dB) and SWR are

$$RL = -20 \log|\Gamma| \quad \text{and} \quad SWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

Augment your table above by computing these at each frequency and adding them in columns 5 and 6. Then plot them, either on the same graph as you plotted gamma or on new graphs - whatever provides a better view of results for the reader.

The reflection coefficient gamma should be small (e.g. < 0.3) near the design frequency of your antenna and should increase as you deviate from that frequency. Correspondingly, Return Loss should be large (e.g. $> 10\text{dB}$) and decrease at other frequencies. SWR should be small (e.g. < 2) at the center frequency and increase at other frequencies. Any of these plots can be used for a "quick-look" at how well an antenna is operating and what its center frequency and bandwidth are.

5 Field Strength versus Distance Measurements

Connect a long piece of coax to the signal generator and add a female-female coax adapter at the end to join the long coax to your antenna's coax connector. (You should delete the T connector now) Set the frequency to the value used in designing your antenna and the amplitude to **0.25 V** as before.

Next, connect your partner's antenna to the HP8505 RF "Vector Voltmeter" (VVM). With this receiving antenna connected, the VVM will read the RMS voltage of *any* reasonably large incoming signal between 0.1 and 2000 MHz (provided no-one else in the room is transmitting too!).

Note that the meter presents a 50 Ohm load to the receiving antenna, so that the voltage displayed will be less than the antenna's open circuit voltage computed from $V = E L_{\text{eff}}$. Compute how much less using the voltage divider equation, assuming the antenna is an ideal half-wavelength dipole.

IMPORTANT

For the following measurements, it is very important to try to keep the path between and around the antennas clear of anything that can interact with it. (Metal objects for sure, but also yourself, tables, chairs, floor, ceiling, etc.) Use sufficiently long coax to get away from these objects !

Orient your antennas for maximum reception (“co-pole” orientation and at the same height) and record the received RMS voltage for antenna separations ranging from $\frac{1}{4}$ wavelength to 2 wavelengths in $\frac{1}{4}$ wavelength (or less) steps. A yardstick and tape-measure is available in the lab. It is probably best to use ones that are not metallic ! (why?) Show a diagram and/or photo of where your antennas were and how they were oriented in your notebook writeup.

To calculate expected received voltages, you will need to compute the transmitted power from $V_{\text{ANT}}^2/R_{\text{ANT}}$ and then find the power density at a given distance using the theory from class. Then find the corresponding E-field magnitude, open circuit received voltage, and loaded received voltage at each distance, (taking into account the adjustment factors having to do with impedances discussed above).

Detail your analysis and show your measured and calculated values in tabular form in your notebook. Then plot your measured and calculated data on a semi-log graph (log scaling on the distance axis) .

Use a single graph with two curves on it for easier comparison. Comment on differences between calculated values and those measured. If they do not agree, explain the most likely cause(s).

6 Polarization

Repeat experiment 5 above for cases of horizontal (“cross-pole”) and slant 45° polarizations². Keep the receive antenna vertical and hold the transmit antenna at the specified angles **making sure you understand what axis to rotate it on!** Show a diagram and/or photo of how your antennas are oriented in your notebook writeup, together with the respective tables and graphs.

7 E-Plane Pattern

To estimate the antenna pattern, you can take field-strength measurements with your transmit antenna held at a fixed distance of approximately 1 wavelength from the receive antenna (so it is approximately in the “far field”). Rotate the transmit antenna from a broadside orientation to an “end-fire” orientation (with respect to the receiving antenna) in 10° steps, recording the received voltage at each angle to allow one quadrant of the antenna pattern to be found. Don't confuse this with the rotations done above...

Using this data and the symmetry of the problem, plot the pattern on a polar plot (with 90° defined as broadside). **Show your pattern** in terms of *relative* gain in dB ($20\log|V(\theta)/V(\text{broadside})|$) over a range of 0 to -20 dB and **find the 3dB beamwidth**.

² To find the expected values, you should not need to extensively recalculate here. Just scale the calculated E-field values from step 5. For the cross-pole case, the answer should be easy! For the case of slant-45 polarization, note that a field with a 45° tilt can be resolved into the sum of a vertical and a horizontal polarized field and use this to scale your previous values.

WARNING: You may want to do the polar plot by hand, since some software (e.g. Matlab) does not work with negative numbers well in this format without considerable coercion.

8 Radio Wave Reflection, Standing Waves, and Wavelength

In this step, you will be performing a modified version of an experiment done by Hertz in the late 19th century to demonstrate the existence of the radio waves predicted mathematically by Maxwell. This involves reflecting the waves from a metal surface and measuring the distance between the peaks and nulls of the resulting “standing waves” in order to estimate the wavelength.

Position your antennas in a co-pole orientation as in step 5, with a separation of 1 or 2 wavelengths (***and as clear of other metal stuff in the lab as possible!***). Next, position a large metal plate just *behind* your receive antenna -- on the side opposite the transmit antenna. This will cause the plate to reflect the transmitted wavefront and send it back toward the receive antenna (with an inversion), creating constructive and destructive interference between it and the direct-path wave, as we have discussed.

Move the plate to vary the distance between it and your receive antenna, *while keeping the distance and orientation between TX and RX antennas constant.* This should cause the interference to vary between destructive and constructive. Record the received signal strength for antenna-to-plate separations from 1/10th wavelength to 1 wavelength in 1/10th (or finer) wavelength increments. Plot the result using a linear distance axis and **explain the curve.** *Where should the peaks and nulls be and why?*

Based on your measurements, estimate the wavelength of the radio wave. How well does it agree with theory? Elaborate. What level of error might you expect based on your setup and procedures ?

9 Antenna Simulation

Finally, download and use the EZNEC 6.0 program to simulate your antenna. As a minimum, simulate and document the following. (you may wish to start with the provided dipole in the program examples, but modify it to match your antenna dimensions):

- Antenna Currents. This will also show your antenna geometry. Be sure to scale so the current shape is visible.
- Driving point impedance at operating frequency (See Src Dat tab)
- Antenna E-plane pattern and associated gain in dBi
- SWR versus frequency from 50% to 200% of center

Repeat the above after modifying your antenna model (editing the Wires table) to model the effects of the feedline coax. Add a 2 lambda length wire perpendicular to your antenna and joined at about 1/20th lambda or less away from the center. See how it changes your antenna’s behavior. What effect does it have on the driving point impedance and on the pattern?

Summary

At the end of your team’s writeup, provide a brief summary of what you learned in the lab. Which measurements agreed well with theory and which did not? Suggest possible reasons. Also, comment on how useful you thought the lab was and suggest ways the lab experience could be improved (doesn't get you any real brownie points - but may help future students ;-)