Course notes, module 8, week 44

Radio antennas

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1 Agenda

1. Presentation of module 7 lab exercises
2. Presentation of the HealthDrone project
3. Intro to module 9-12
4. Module theory
5. Exercises

2 Module theory

This module deals with constructing and testing radio antennas. Specifically we will construct a dipole antenna with a resonating frequency of 434 MHz, which is the default settings center frequency of our MRO telemetry radio modems used for the UAS C2 link.

2.1 Dipole antenna

The dipole antenna is the most fundamental physical antenna consisting of two (di) radials (poles) and with an electrical length of $1/2\lambda$ at the resonnating frequency.

The propagation pattern of the dipole antenna is depicted in figure 1. The corresponding gain in the direction with the highest response (perpendicular to the center of the antenna) is 2.15 dBi[1].

Figure 2 shows a sketch of a dipole constructed using wire soldered directly to a coax cable. This is a simple and practical method to construct a dipole antenna and it works surprisingly well.

The physical length of the antenna will be somewhat shorter than $1/2\lambda$. The actual length depends on the thickness of the conductor, any insulation at the ends and also any interaction with ground or nearby conductors will influence the length. When constructing an antenna, you will therefore have to tune the antenna by adjusting the length of the radials.

2.2 SWR

A much used indication of how well an antenna is working at a given frequency is the Standing Wave Ratio or SWR. To understand SWR we will define the power transmitted by the antenna (p_t) as the power forwarded from the radio transmitter to the antenna (p_f) minus the power reflected by the antenna back into the radio transmitter (p_r).

$$p_t = p_f - p_r \tag{1}$$

[1] i.e. a gain of 2.15 dB with reference to the theoretical isotropic point antenna.

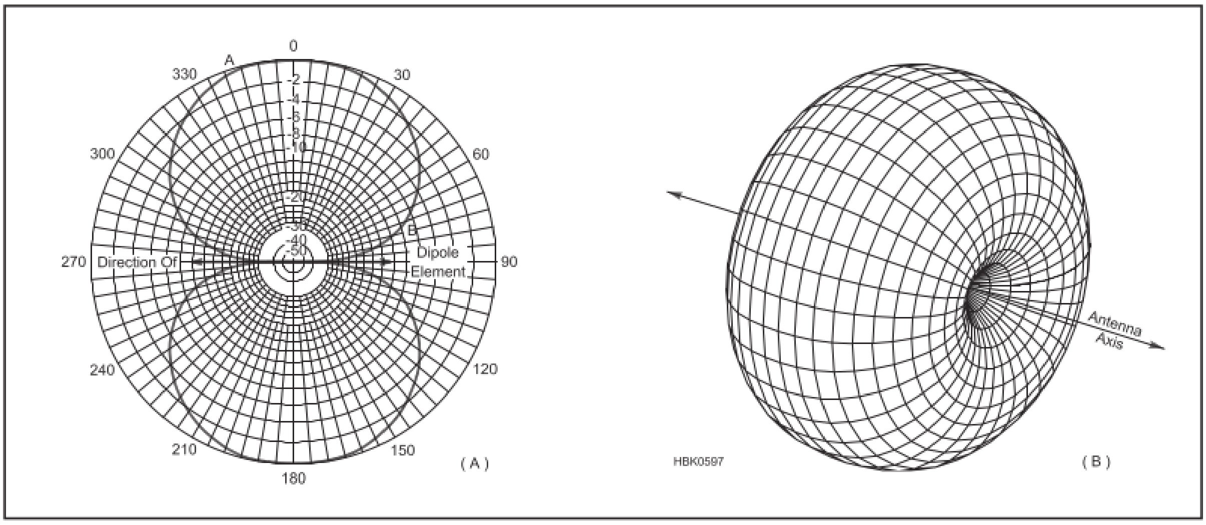

Figure 1: *Response of a dipole antenna in free space. Source: The ARRL Handbook for radio communications 2017.*

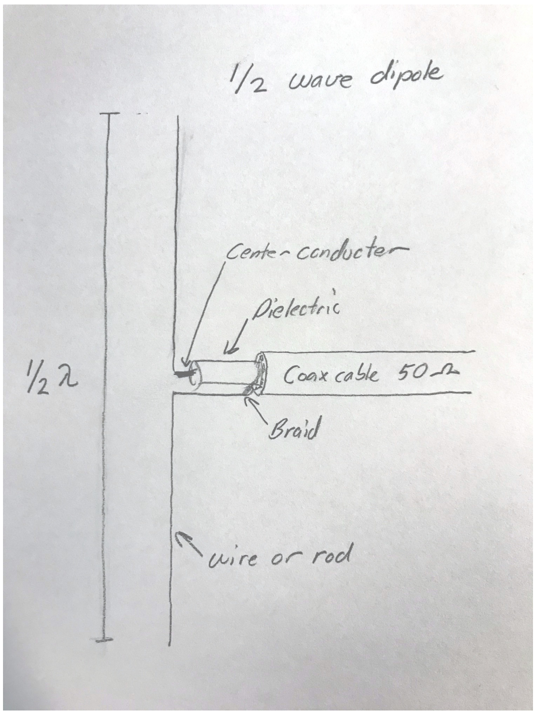

Figure 2: *Sketch of a dipole antenna soldered directly to a coax cable.*

Theoretically if the antenna is perfectly matched i.e. the characteristic impedance of the transmission line and the impedance of the antenna are equal, then all the power forwarded through the transmission line p_f is transmitted by the antenna p_t and $(p_r = 0)$.

In practice this is not the case, and thus some reflected power p_r travels back to the radio transmitter through the transmission line. This creates interference with the power forwarded in the transmission line p_f and establishes standing waves of AC voltage along the transmission line. The more reflected power, the higher the difference between the minimum voltage V_{min} and maximum voltage V_{max} of the waves:

$$\begin{aligned} V_{max} &= V_f + V_r && (2) \\ V_{min} &= V_f - V_r && (3) \end{aligned}$$

We define The Voltage Standing Wave Ratio (VSWR) as:

$$\begin{aligned} VSWR &= \frac{V_{max}}{V_{min}} && (4) \\ &= \frac{V_f + V_r}{V_f - V_r} && (5) \\ &= \frac{1 + \frac{V_r}{V_f}}{1 - \frac{V_r}{V_f}} && (6) \\ & && (7) \end{aligned}$$

The forwarded power p_f and reflected power p_r are proportional to the square of the voltages and SWR may therefore be expressed as:

$$SWR = \frac{1 + \sqrt{P_r/P_f}}{1 - \sqrt{P_r/P_f}} \tag{8}$$

As an example assume that a transmitter is forwarding 4W to the antenna and that the antenna is perfectly matched, so that 0W is reflected:

$$SWR = \frac{1 + \sqrt{0/4}}{1 - \sqrt{0/4}} = 1 \tag{9}$$

Which is denoted as a SWR 1:1

Now assume a transmitter is forwarding 4W to the antenna and 1W is reflected. We then have:

$$SWR = \frac{1 + \sqrt{1/4}}{1 - \sqrt{1/4}} = \frac{1 + 0.5}{1 - 0.5} = 3 \tag{10}$$

Which is denoted as a SWR 1:3

Now similarly assume a transmitter is forwarding 4W to the antenna and 0.16W is reflected. We then have:

$$SWR = \frac{1 + \sqrt{0.16/4}}{1 - \sqrt{0.16/4}} = \frac{1 + 0.2}{1 - 0.2} = 1.5 \tag{11}$$

In practice a SWR of 1:1.5 and below is considered a well matched antenna with a negliable *return loss* i.e. reflected power p_r. If the SWR is 1:3 or above, the power loss (p_r) is noticable and something should be done to lower the SWR.

Now if you followed carefully the radio theory class, you would instantly consider to calculate the loss in dB to see how a poorly matched antenna would influence the radio link budget...

For the SWR 1:3 case the return loss r_l would be:

$$r_l = 10 * log(\frac{p_t}{p_f}) = 10 * log(\frac{3}{4}) \approx -1.25\ dB \tag{12}$$

Considering the magnitudes of other gains and losses expressed in dB in a radio link budget, this is almost negliable, however there is one critical effect of reflecting power back into the transmitter: The output power amplifier in a transmitter is typically unable to absorb the reflected power. Thus if the transmitter senses reflected power p_r, it instantly reduces the forwarded power p_f to protect the power amplifier circuit. At high SWR's this leads to a significant reduction of the forwarded power which causes a much higher loss.

If you wish to have a deeper understanding of SWR, I recommend reading this document available in the course materials:
`Understanding_Standing_Wave_Ratios.pdf`

3 Exercises

3.1 Antenna construction

In this exercise we will construct a dipole antenna resonnating at 434 MHz. Use the supplied antenna cable which has a connector in one end which will fit your telemetry modem.

Before you begin a few words of caution: Please don't shorten the antenna cable, the length will come in handy at a later stage to you and also means that we can reuse the cable for the next students. Please don't make any hard bends or flatten the antenna cable anywhere. This means less power transmitted to the antenna.

Remove the insulation so that you are able to solder one wire to the center conductor and one wire to the braid. The best way to remove the insulation is to carefully cut halfway through the insulation material with a knife while slowly rotating the cable and then removing it with your nails. You only need to remove 5-7mm of the black insulation. Then push the braid back and similarly remove 3-4 mm of the white dielectricum to expose the center conductor.

From standard electrical wire cut two radials of length slightly longer than $1/4\ \lambda$. Since we are dealing with low power transmissions only, you can also use the thinner electronic signal cable. Keep in mind that the formula for calculating the wavelength λ is:

$$f * \lambda = \nu \tag{13}$$

Where ν is the propagation velocity which in vacuum equals to the speed of light $C = 3 * 10^8 m/s$.

Solder the radials onto the antenna cable and mount the dipole onto the round log as in figure 3. Please keep the ends free of electrical tape as you will need to cut from both ends of the wire to tune the antenna.

Please include a photo of how your antenna looks at this point in your report,

3.2 Antenna tuning

Now it is time do measure the resonnating frequency f_r of the antenna and then trim the lengths of the radials to obtain a $f_r = 434\ MHz$.

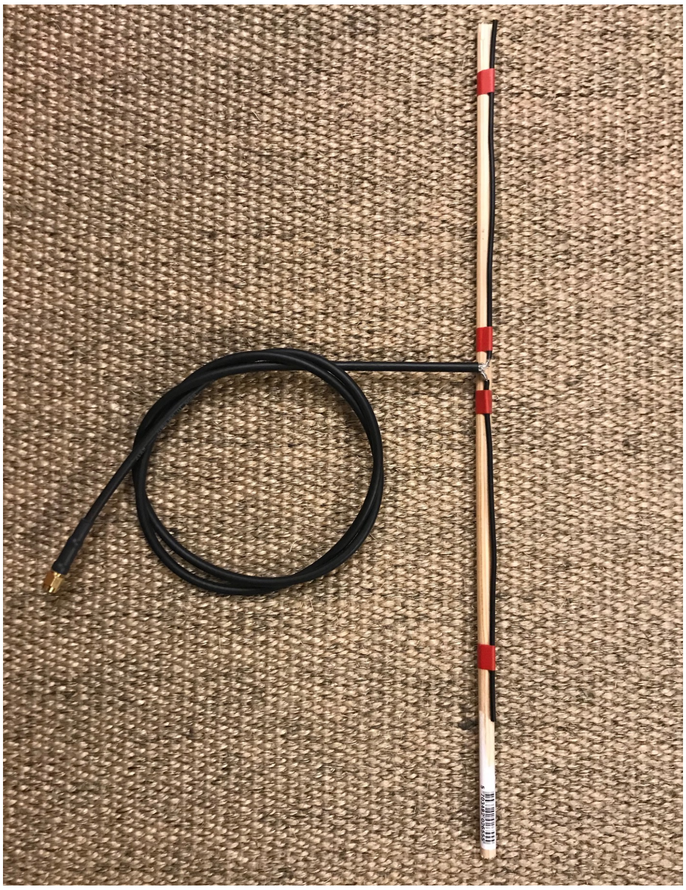

Figure 3: *The constructed dipole antenna.*

We measure this using the RigExpert antenna analyzer. The use is quite simple, however please keep in mind that the RigExpert is both a delicate and expensive measurement unit, so please handle with great care.

1. Turn on the RigExpert
2. Press 2 and set the center frequency to $0\ 434\ 000$
3. Press 3 and set the range. We begin by setting a huge range to see where the antenna is resonating, then gradually we limit the range to see the details. Start by setting it to $200\ 000$ corresponding to +/- 100 MHz. from the center frequency i.e. 334 to 534 MHz.
4. Now whenever you press 4, the RigExpert will scan the SWR over the defined frequency spectrum. While doing so please ensure that the antennas near field is disturbed as little as possible. In practice grab the antenna cable at least half a meter from the antenna, stretch your arm and let the antenna hang freely away from you, office chairs and any other nearby obstacles.
5. Please remember to take photos of relevant SWR scans to document your progress in your report.

Since your radials are most likely longer than needed, the resonnating frequency f_r will be lower than 434 MHz. My first scan looked like figure 4.

Now it is time to iteratively cut small pieces of wire off each radial and then rescan the SWR. Start by cutting a couple of mm's each time while ensuring that both radials have the same length. Then as you get closer to $f_r = 434\ MHz$ cut less and less each time, down to less than half a mm and only from one radial at the time until you end up with something like in figure 5. If you miss it, try soldering new radials and start over again. It may take some practice.

When you are done, you should now have a functional dipole antenna resonnating at $f_r = 434\ MHz$. We often use dipole antennas constructed just like this for drone communications and they work well.

Please include a photo of how your antenna looks at this point in your report.

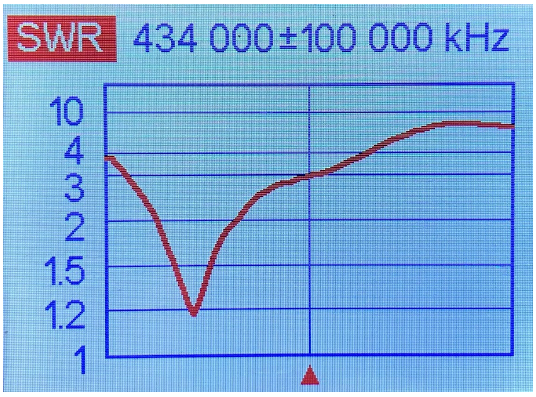

Figure 4: *First SWR scan using the RigExpert. Please notice that the scan range here is +/- 100 MHz*

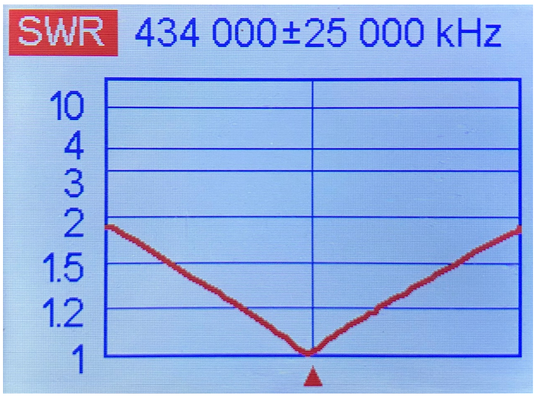

Figure 5: *Final SWR scan using the RigExpert. Please notice that the scan range here is +/- 25 MHz*

3.3 Antenna near field obstacles

Now that you have a functional antenna, it is time to experiment with obstacles in the antenna's near field.

Start by placing your hand gradually closer to the antenna by holding the antenna cable less than half a meter from the antenna. What happens to the SWR response? What about the antennas center frequency?

Then introduce various conducting 'obstacles' at various distances from the antenna.

What happens?

At which angles are the antenna most sensitive to near field obstacles?

3.4 Range test

It is now time to field test your antenna. We do this using the C2 link and standard antennas that you have already been issued and worked with.

Outdoor within line of sight you establish a radio link at a testing distance of about 100 meter or more. The parking space or the round football field next to the TEK building might be good places.

We do not yet have a ROS2 solution for monitoring RSSI as this is not yet implemented in the mavros package. You will therefore need to use ROS1.

To be able to monitor the Received Signal Strength Indicator (RSSI) using ROS1 you must follow the guide from module 6 at:

https://kjen.dk/go/idt/confluence/

Go to *MAVLink LoRa Communication (ROS1)*, then at step 8 where you run the show_pos.py script, there is also at show_rssi.py which will show both the RSSI and remote RSSI (received by the drone).

Vary the distance this way: use two persons standing next to each other, one with the Pixhawk flight controller and one with the laptop. Then walk away to increase the distance until you have reached the testing distance. You should underway on the laptop be able to monitor a decrease in RSSI and remote RSSI corresponding to the increasing distance. If you do not see a decrease, you need to configure the power output of both modems to less than the default 20 dBm and redo this.

Then while standing still at the testing distance try to replace the stock plastic antenna at the laptop with your newly constructed dipole antenna. What happens to the remote RSSI? Hopefully you will see an increase. How much?

Please include a picture of the test scenario (where the antennas are etc.) in your report.