Course notes, module 7

Drone radio antennas

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1 Agenda

1. Reflections on mid-term evaluation
2. Presentation of module 6 exercise
3. Quick intro to module 9-12 exercises (Oscar)
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.

We will then compare the gain of your dipole antenna with the gain of the antennas provided with the telemetry radio modules for the drone.

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).

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

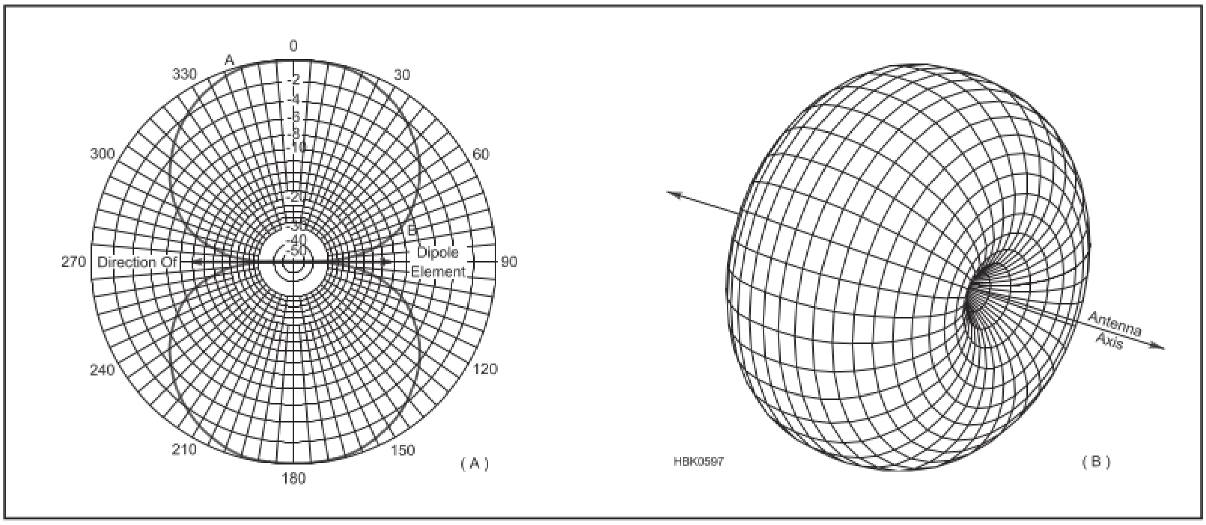

Figure 1: *Response of a dipole antenna in free space. Source: The ARRL Handbook for radio communications 2017.*

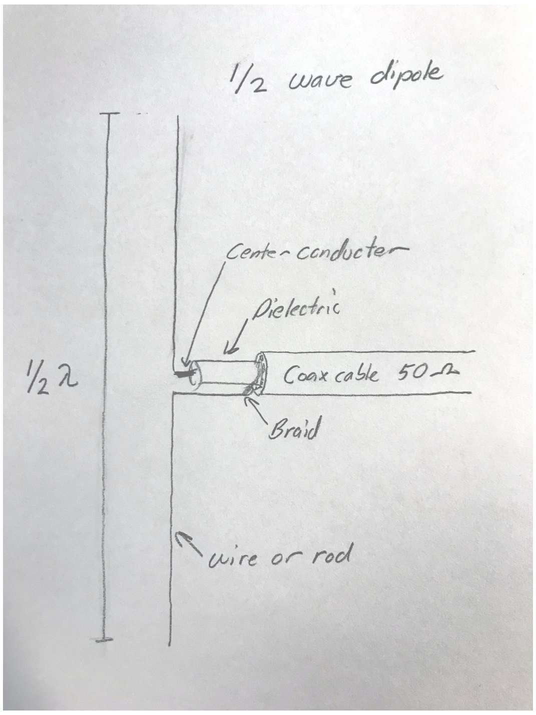

Figure 2: *Sketch of a dipole antenna soldered directly to a coax cable.*

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

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:

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

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

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

The forwarded power p_f and reflected power p_r are proportional to the square of the voltages because:

$$P = U\,I \tag{8}$$

For sinusoidal signals, this power is often expressed as the time-averaged power, and for an ideal transmission line with a characteristic impedance Z_0, the voltage and current are related by:

$$I = \frac{U}{Z_0} \tag{9}$$

Thus:

$$P = U\,\frac{U}{Z_0} = \frac{U^2}{Z_0} \tag{10}$$

Based on this, the SWR may therefore be expressed with respect to the power as:

$$SWR = \frac{1 + \sqrt{P_r/P_f}}{1 - \sqrt{P_r/P_f}} \tag{11}$$

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:

$$SWR = \frac{1+\sqrt{0/4}}{1-\sqrt{0/4}} = 1 \tag{12}$$

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:

$$SWR = \frac{1+\sqrt{1/4}}{1-\sqrt{1/4}} = \frac{1+0.5}{1-0.5} = 3 \tag{13}$$

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:

$$SWR = \frac{1+\sqrt{0.16/4}}{1-\sqrt{0.16/4}} = \frac{1+0.2}{1-0.2} = 1.5 \tag{14}$$

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:

$$r_l = 10 * log(\frac{p_t}{p_f}) = 10 * log(\frac{3}{4}) \approx -1.25\ dB \tag{15}$$

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

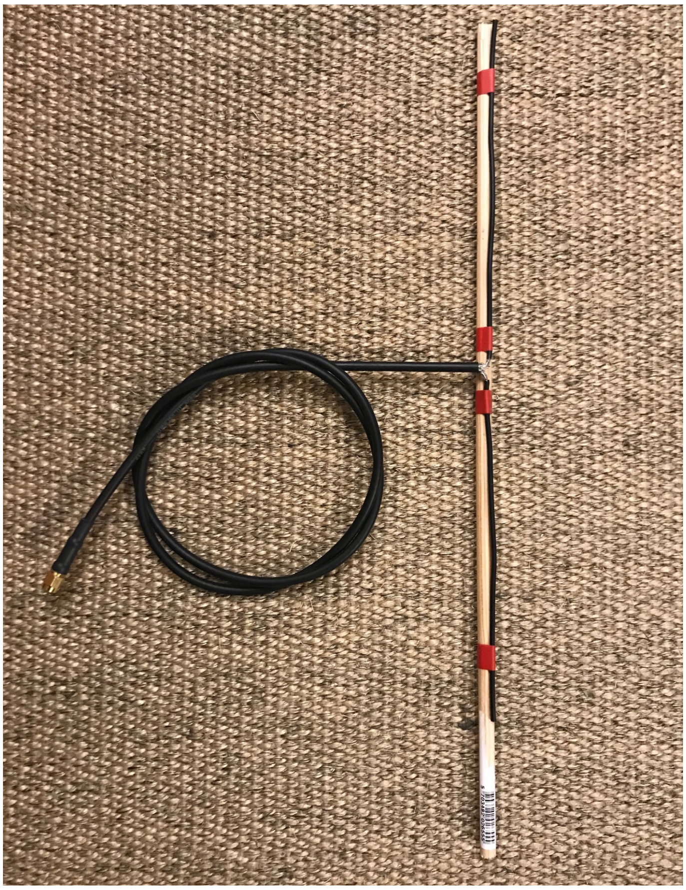

Figure 3: *The constructed dipole antenna.*

the antenna. A good rule of thumb is to never bend antenna cable more than it would be if bent around a soda can.

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:

$$f * \lambda = \nu \tag{16}$$

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 $f_r = 434\ MHz$.

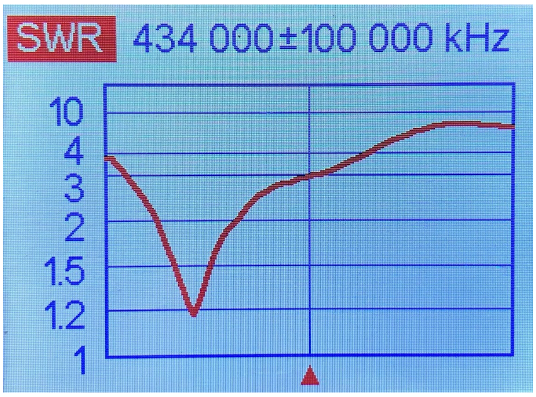

Figure 4: *First SWR scan using the RigExpert. Please notice that the scan range here is +/- 100 MHz*

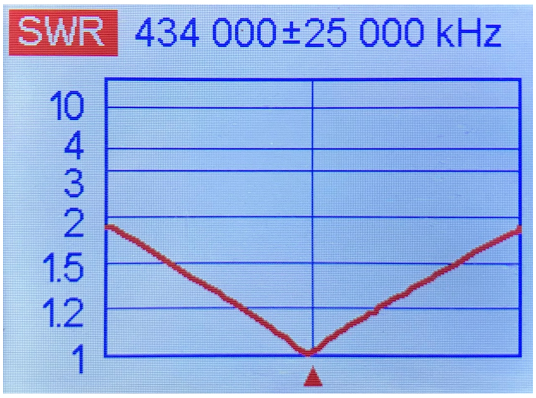

Figure 5: *Final SWR scan using the RigExpert. Please notice that the scan range here is +/- 25 MHz*

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 furom 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.

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 telemetry modems and the standard antennas that you have already been issued and worked with.

First we will create ROS2 nodes for logging position as well as the Radio Signal Strength Indicator (RSSI) of both telemetry modems. The purpose is to make a graph of these RSSI's as a function of the distance between them.

To do this you can use the `get_global_pos.py` that you have been issued at a previous module for logging the position. In order to log the RSSI's you should create a copy of the `get_global_pos.py` and call it e.g. `get_radio_rssi.py` Then modify this file to subscribe to the topic:

`/mavros/radio_status`

This topic contains `rssi_dbm` and `remrssi_dbm` You might also want to log noise, remnoise and rxerrors which also give valuable information about the radio link quality.

Having the ability to log the GNSS position, RSSI's and ideally also the other variables mentioned above, it is now it is time to test your antenna outdoor. Find a good place where you can vary the distance between the two antennas from 0 meter to as far as possible without having obstacles in between. The road next to the parking spaces in front of the TEK building or the football fields starting with the round football field next to the TEK building might be good places.

Divide your team into two: one subteam being the drone (flightcontroller, GNSS, telemetry modem, power source) and another subteam with the ground station (ROS2 laptop with telemetry modem).

We will start by creating a set of reference data. Make sure the issued small antennas are installed on both modems and the two subteams stand next to each other. Start your ROS2 logging node on the ground station laptop, check that the GNSS publishes positions and then the subteam with the flight controller starts walking away from the ground station. Stop when the ground station is no longer receiving any data.

Now replace the small antenna on the ground station with your own antenna and repeat this process.

For both datasets make a graph of the RSSI and remote RSSI in dB as a function of the drone distance from the ground station measured using the GNSS data. Keep in mind that you started next to each other, so the first recorded positions will be the position of the ground station.

You should see a fairly significant increase in gain and thus a longer range when using your own antenna, as this is a full dipole well tuned to the frequency used.

If you have problems getting the two modems with antennas far enough away from each other to observe that the communication breaks down, you need to configure the power output of both modems to less than the default 20 dBm and redo the tests.

In the report please include a picture of the test scenario (where the antennas are etc.) and the graphs from the outdoor tests. How much higher gain does your antenna have compared to the issued antennas?