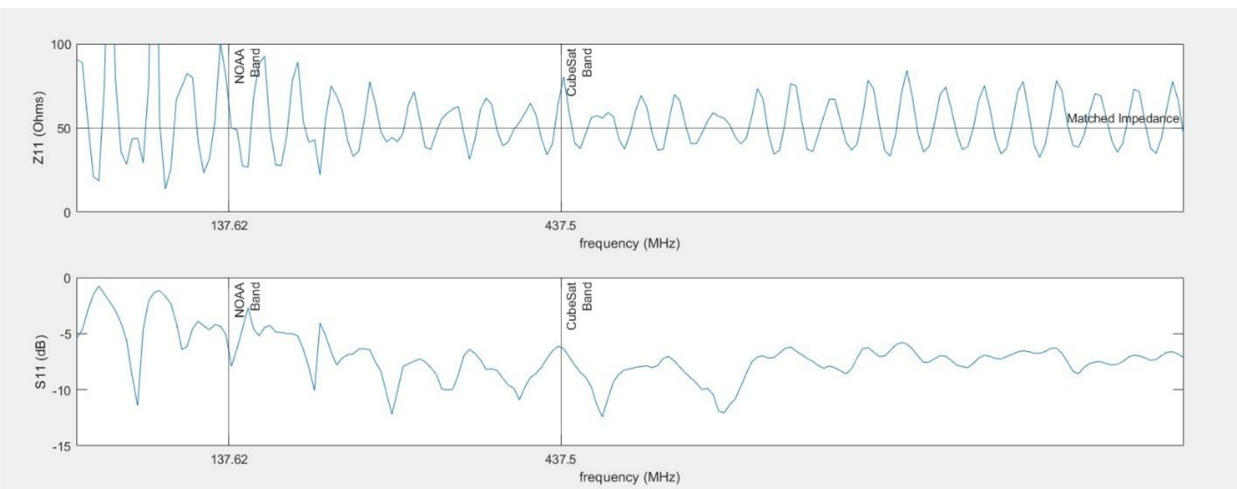
Antenna Testing with a Vector Network Analyzer (VNA)

The frequency band the ground station will be transmitting and receiving in is the 420 to 450 MHz Amateur band, as per the FCC frequency allocation chart[1]. The purchased Yagi-Uda antenna gives a very large and loose bandwidth from 110 to 1300 MHz, and only gives detailed values for 300 MHz. Thus, it is necessary to understand the limitations of the antenna at the band we are interested in by using a VNA.

S-Parameters of the Antenna

For our purposes, the VNA is useful for determining the scattering parameters (S-Parameters) of RF components, such as amplifiers, filters, and for this test, the antenna. For a two-port device, four s-parameters can be measured, but for an antenna, the most interesting one is S11, which can be thought of as how much of the incoming signal is being reflected.

S-parameters are complex-valued but are more intuitively described in their magnitude in decibels. Ideally, we would like absolutely no reflection, i.e. S11 equal to zero, or in dB, negative infinity. Of course, this isn't achievable in real life, but we must try to do the best we can. By convention, the antenna is designed to have an impedance of 50 ohms, which must be matched will all other cascaded devices for maximum power transfer. So, when given a reference of 50 ohms, we can use the MATLAB function s2z to convert the collected s-parameters to impedances to show on a graph over frequency.



Above is the graph of impedances, or Z11, and below that is the graph of the s-parameters, or S11. A horizontal line has been placed on the Z11 graph to indicate where the antenna is properly matched to 50 ohms. The vertical lines indicate the bands of interest, one being the frequency band of the Sentinel or NOAA weather satellites, and the other being the band that many other CubeSats transmit in, being an Amateur band.

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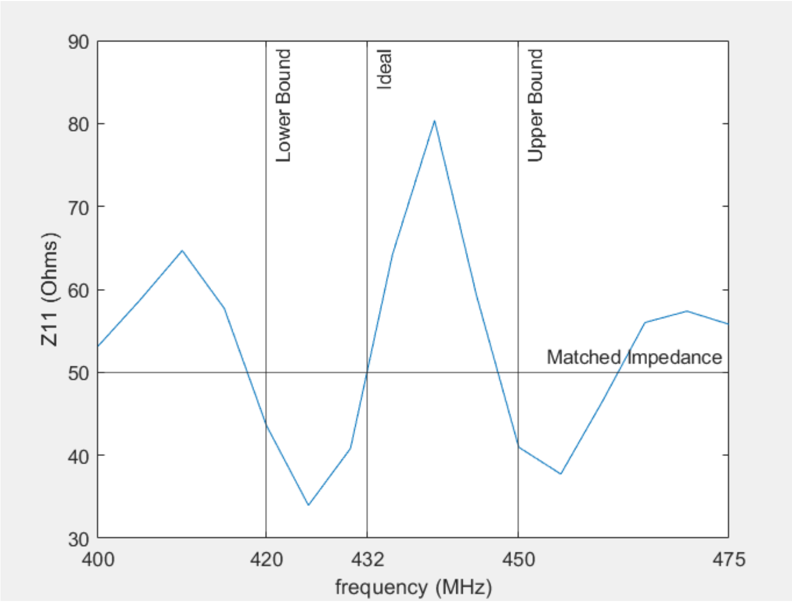
[1] https://www.ntia.doc.gov/files/ntia/publications/2003-allochrt.pdf

Bands of Interest

Other very small available bands exist at lower frequencies, such as 144 to 148 MHz and 216 to 220 MHz, but at the moment, our equipment is best rated for the available UHF band. These are all visible on the FCC frequency allocation chart.



Zooming in to the CubeSat band, we can pick a frequency that most closely matches the 50-ohm standard our equipment is set for.

The bounds represent the bandwidth that is allocated for Amateur radio. The vertical line labelled "Ideal" is the position where Z11 equals 50 ohms in magnitude, and it is the position closer to the center, giving a little more room. The slightly wobbly poles of the antenna make this a slightly unpredictable value, but each pole of the antenna corresponds to a different frequency, so this crossing is guaranteed in a small range of 432 MHz.

Fun Things

While conducting the experiment, I observed that as I ran my hand up and down the length of the antenna, a wave would flow through the graph on the VNA in a predictable manner. In a similar vein to the FM radio reception, our bodies act as natural capacitors which can interfere with RF signals.

Because the length of the poles is in descending order to the tip of the antenna, the tip corresponds to the reception of a higher frequency. So, as my hand hovered from the large base of the antenna to the tip, a wave could be seen traveling from left to right on the graph, up the frequency domain. Seeing this in action was very exciting!

Written by Jay Williams, March 21st, 2024

MATLAB Code:

```
%% data input

T = readtable("S11-032124-RI.CSV", "VariableNamingRule", "preserve");
T = T(3:end, :);
T = renamevars(T, ["# Channel 1", "Var2", "Var3"], ["f", "R", "I"]);
D = table2array(T);

freq = D(:,1);
S11 = D(:,2) + 1j* D(:,3);

%% processing

Z11 = reshape(s2z(S11, 50), [201 1]);
mag = abs(Z11);
phase = angle(Z11);

%% figures

NOAA = 137.62;
CubeSat = 437.5;

figure

subplot(3,1,1);
plot(freq/1e6, mag);
xline(CubeSat, '-', {"CubeSat","Band"});
xline(NOAA, '-', {"NOAA","Band"});
yline(50, '-', {"Matched Impedance"})
xticks([NOAA, CubeSat])
yticks([0 50 100])
ylim([0 100])
ylabel("Z11 (Ohms)")
xlabel("frequency (MHz)")

subplot(3,1,2);
plot(freq/1e6, 10*log10(abs(S11)));
xline(CubeSat, '-', {"CubeSat","Band"});
xline(NOAA, '-', {"NOAA","Band"});
xticks([NOAA, CubeSat])
ylabel("S11 (dB)")
xlabel("frequency (MHz)")

subplot(3,1,3);
plot(freq/1e6, unwrap(180*phase/pi));
xline(CubeSat, '-', {"CubeSat","Band"});
xline(NOAA, '-', {"NOAA","Band"});
xticks([NOAA, CubeSat])
ylabel("Phase (Degrees)")
xlabel("frequency (MHz)")

figure
plot(freq/1e6, mag);
xlim([400,475])
xline(420, '-', {"Lower Bound"});
xline(450, '-', {"Upper Bound"});
xline(432, '-', {"Ideal"});
yline(50, '-', {"Matched Impedance"})
xticks([400 420 432 450 475])
ylabel("Z11 (Ohms)")
xlabel("frequency (MHz)")
```