Small Form Factor Ionosonde Antenna Development

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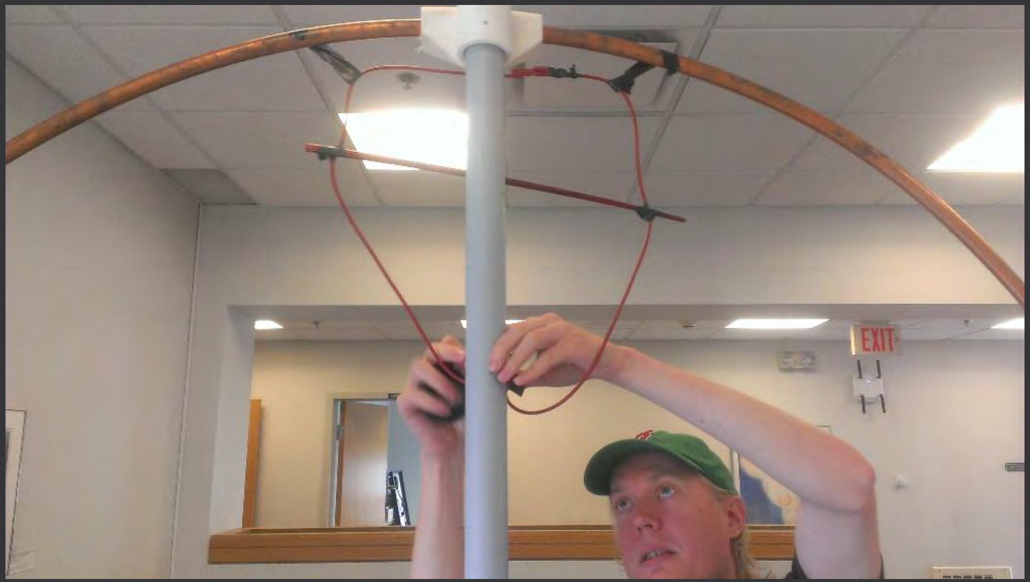
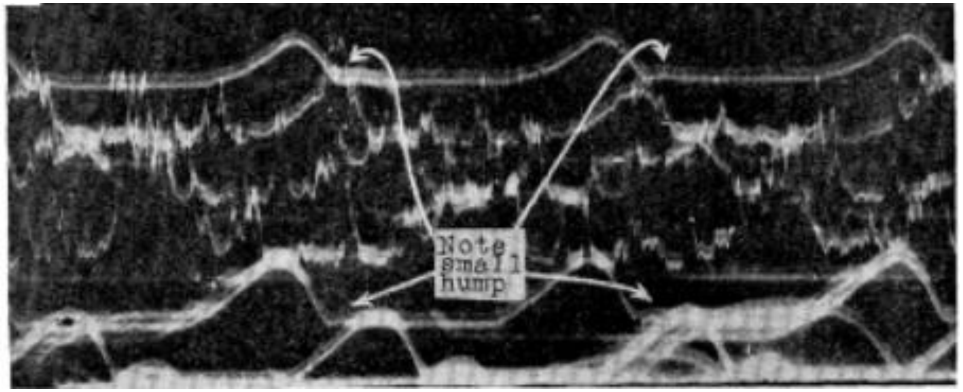
Alternatively,
Jury-Rigging 101: A Juha Approach

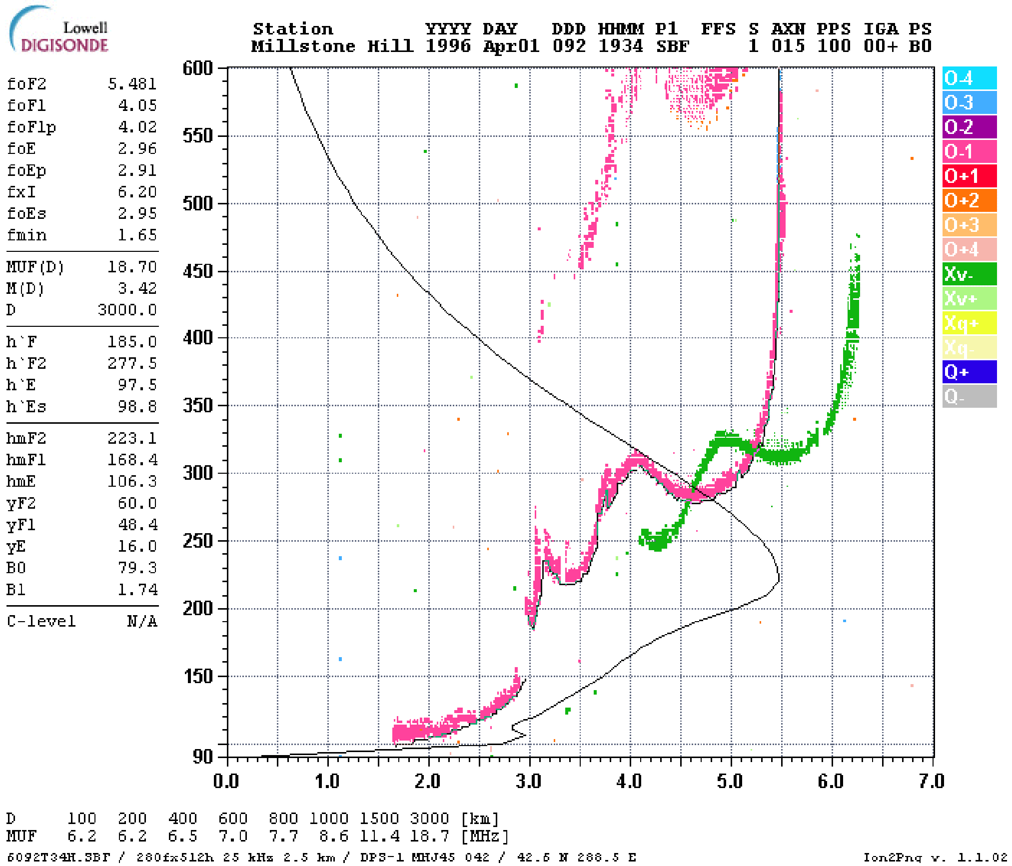


Ionosonde History



Breit G, Tuve M A. A test of the existence of the conducting layer. Phys Rev, 1926, 28: 554–575

- Bottom-side ionosphere typically spans 100-400km
  - Ionized by solar radiation
  - Influences radio propagation
- Gregory Breit and Merle Tuve first confirmed the ionosphere's existence in 1926
  - Using a 5KW transmitter
  - Looked at transmitted and received
  waveforms with oscilloscope for bumps
- Today we sound at various frequencies
  - View height as a function of frequency
  - Can fit to achieve electron density profile
  - Look at overall structure



Ionosonde Basics

- Used to probe the ionosphere
  - Typical frequencies: .5-16 (vertical), 8-40MHz (oblique)
    - Depends on what you want to study
- Current antennas → large, unwieldy, and expensive
  - Limits usage in dense networks
  - Millstone delta loop ionosonde ~$100k
  - ~100m in each dimension
- Goal:
  - Want to build a small, cheap antenna to probe ionosphere

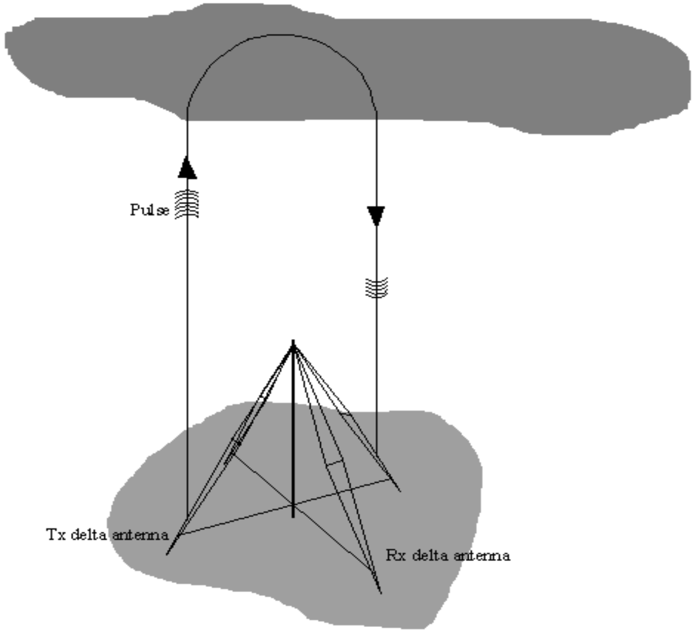
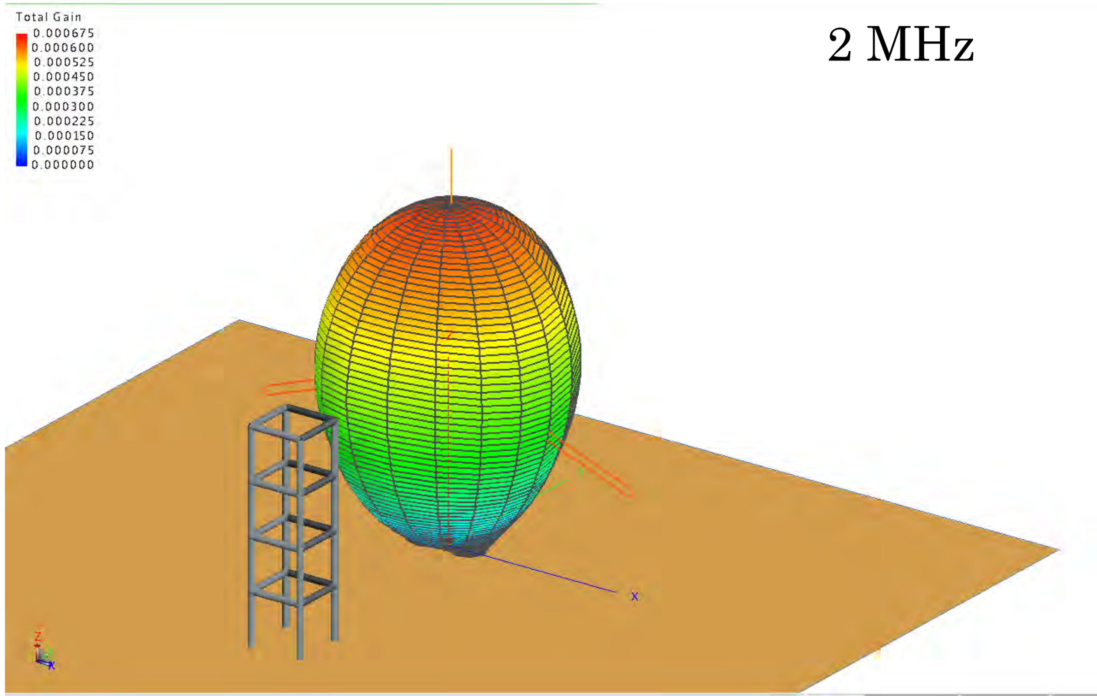
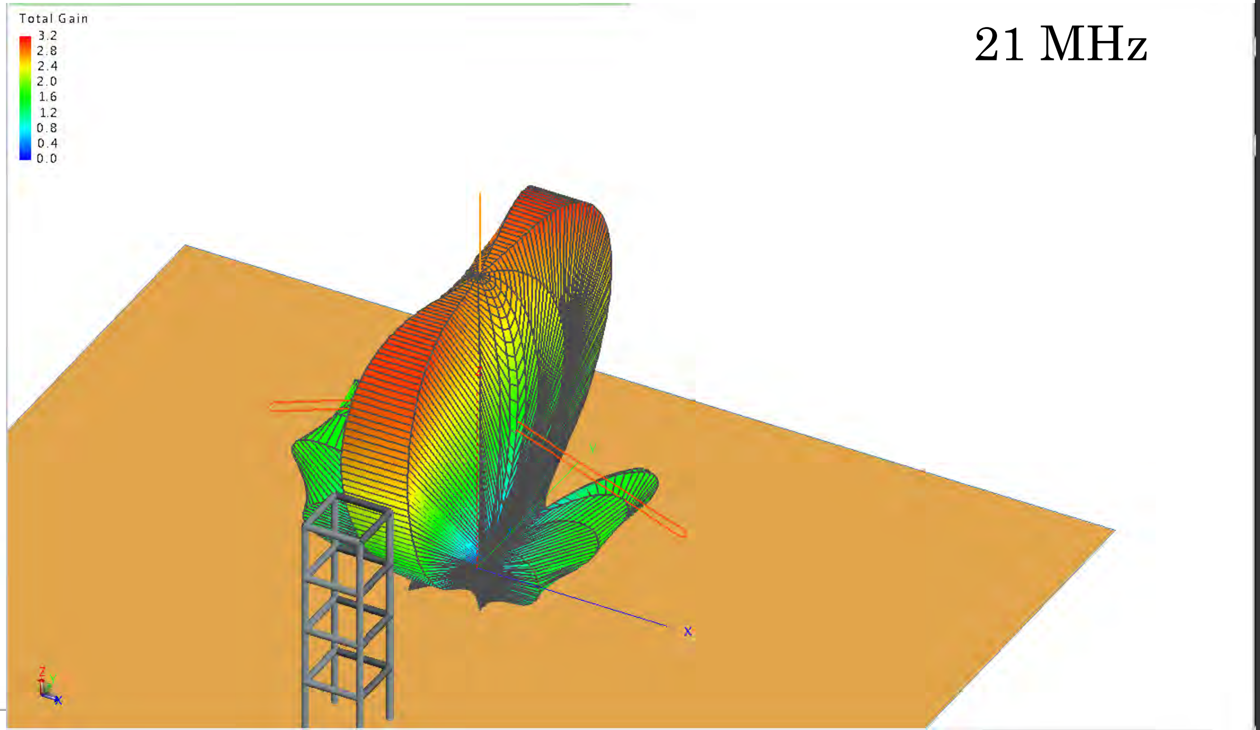


Image Credit: http://www.radtelnetwork.com.au/propagation/HFpropagation_files/img003.gif

Inverted Vee Folded Dipole

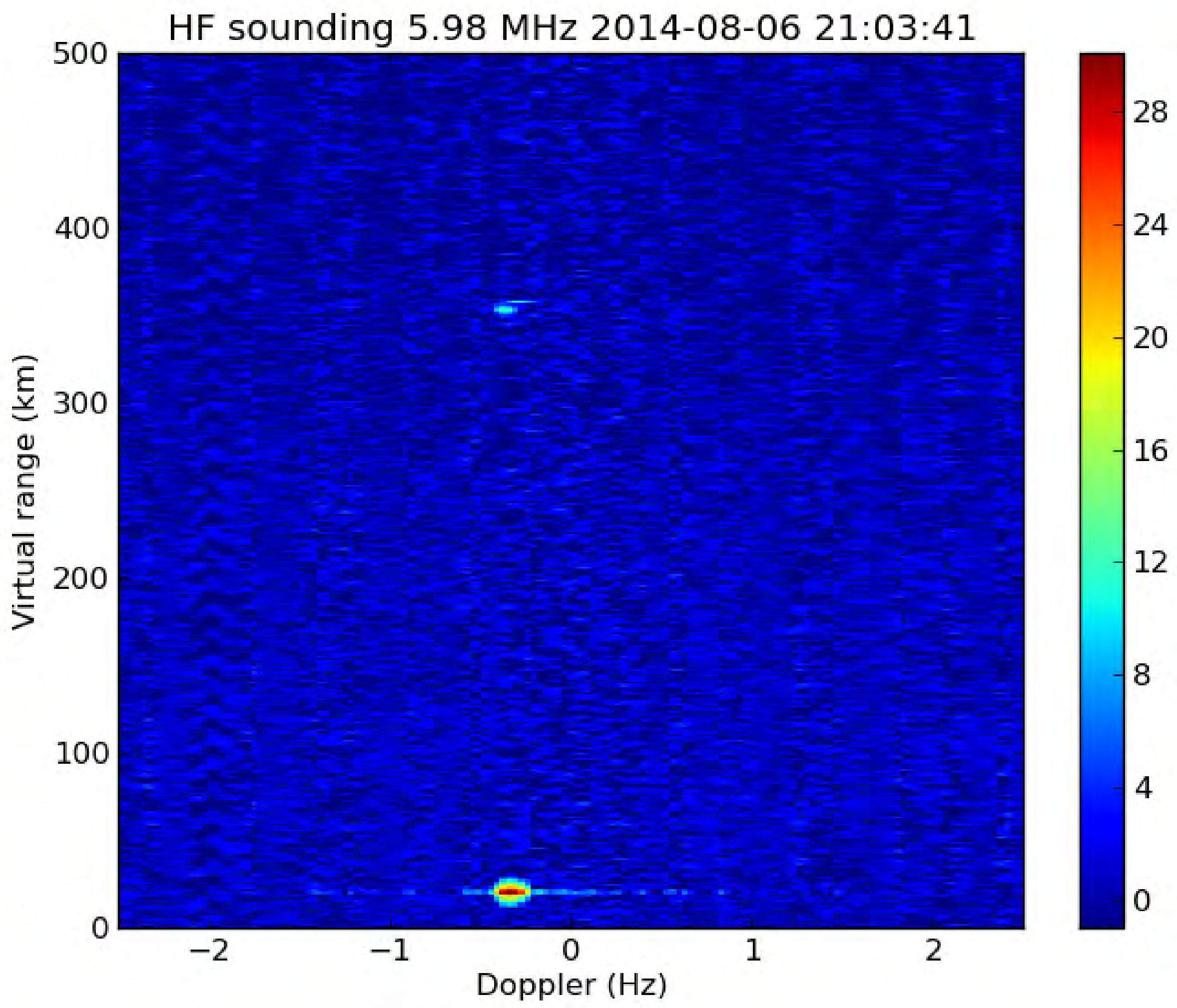
- Off the shelf resistively-loaded folded vee antenna
  - Good for the range of 2-30MHz, both receive and transmit
  - Still fairly large, 30ft either arm





Inverted Vee Ionosphere

- Can see consistent echo at ~350km



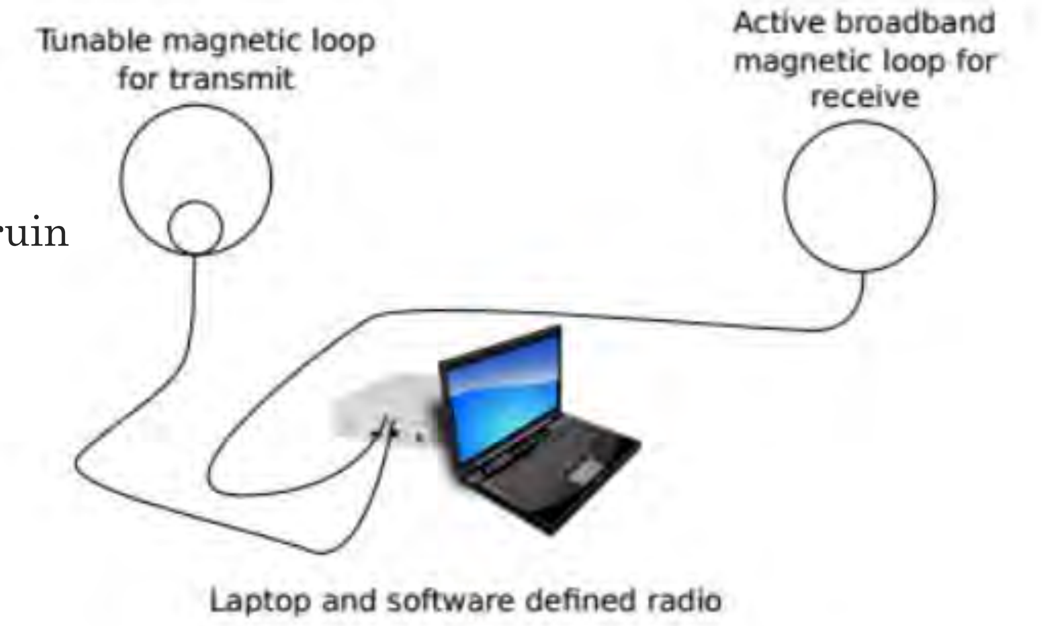
Small Magnetic Loop Antenna

Pros:

- Small size
- Radiation present at all elevation angles
- Circles are the coolest of the shapes

Cons:

- Low radiation resistance, small losses can ruin radiation efficiency
- Very narrow bandwidth - Not resonant at a broad range of frequencies
  - Use a variable capacitor to tune the antenna to multiple frequencies



http://www.kr1st.com/Images/loop.jpg

Antenna Parameter Development

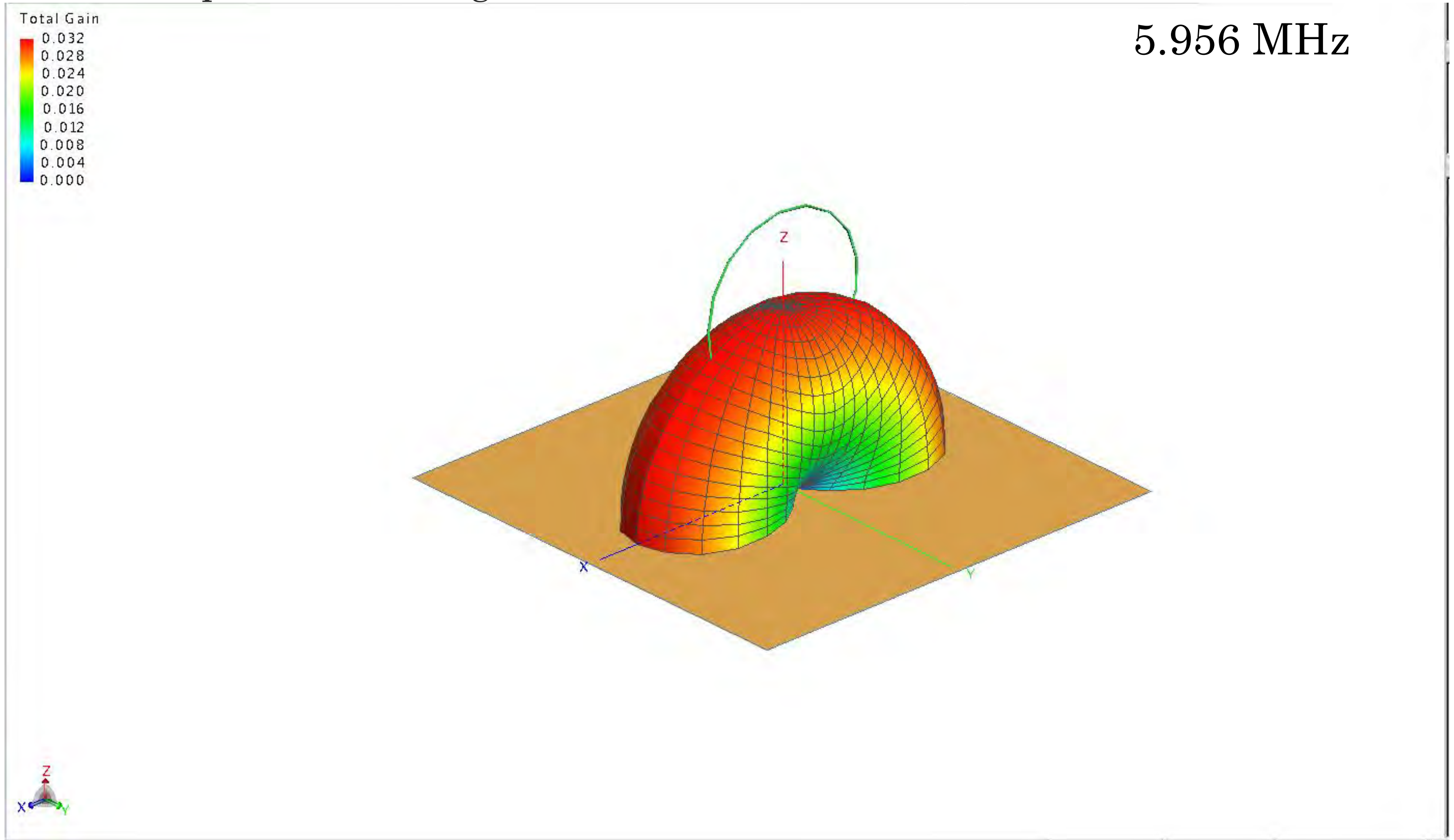
- Focus on the 2-14MHz band centered at 5.956MHz
  - Plasma Frequency: $f_N = \frac{1}{2\pi}\sqrt{\frac{Ne^2}{\varepsilon_0 m_e}}$ → ~ 10^{10} - 10^{12} e^-/m^3
    - Good for E and F regions

- Small antenna constrained by Chu-Harrington limit: $Q = \frac{1}{k^3r^3} + \frac{1}{kr}, \ k = \frac{2\pi}{\lambda}$
  - Bandwidth $= \frac{f}{Q}$
  - Diameter of loop $< \frac{\lambda}{10}$
    - For our range, 149.93m > λ > 21.42m

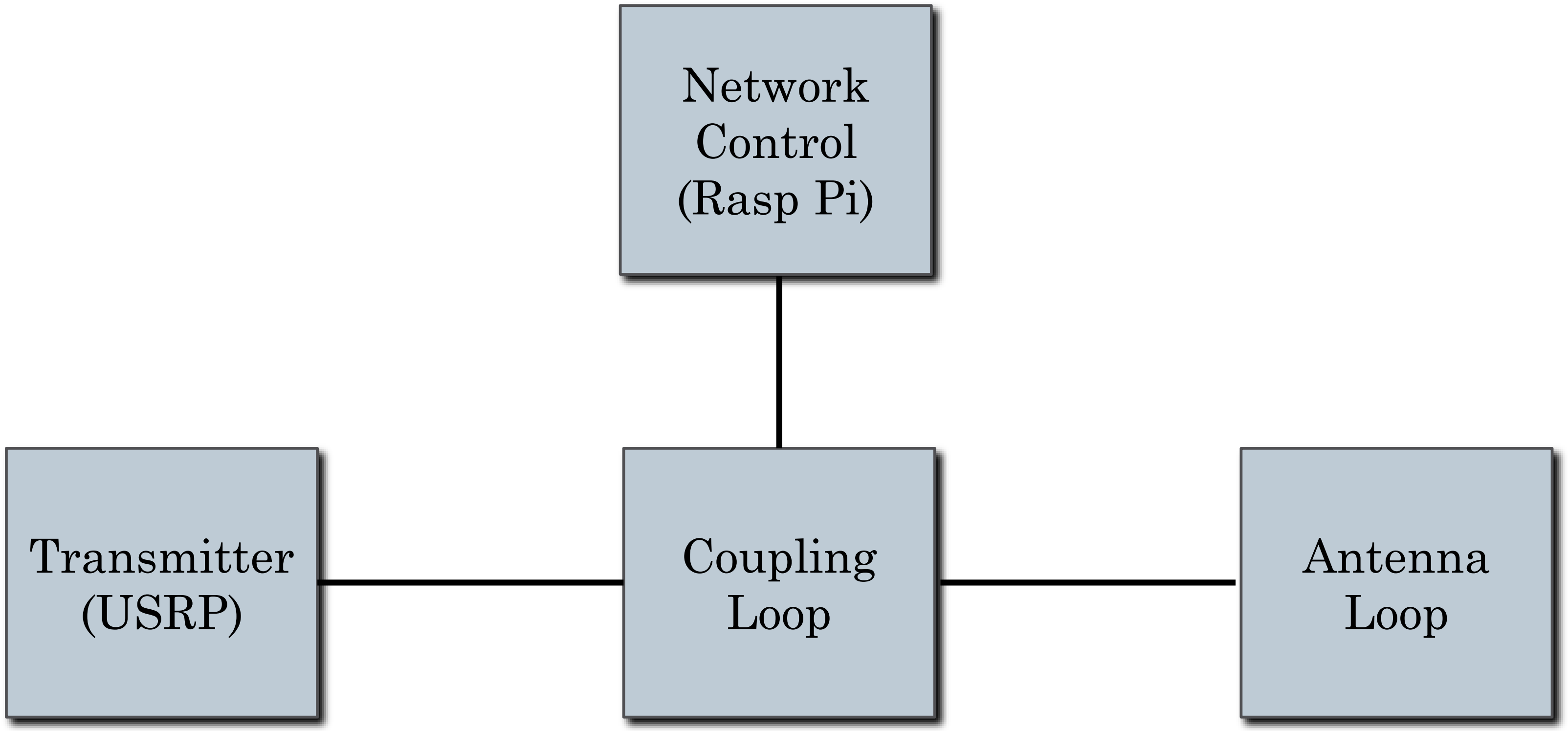
- We need to estimate how much power we should put into the loop antenna: ~ 100 W, assuming ~ -20 dB efficiency.
  - $\eta = \frac{R_R}{R_R + R_L}$
    - R_R – Radiation Resistance, R_L – Loss Resistance

FEKO (**FE**ldberechnung für **K**örper mit beliebiger **O**berfläche) Modeling

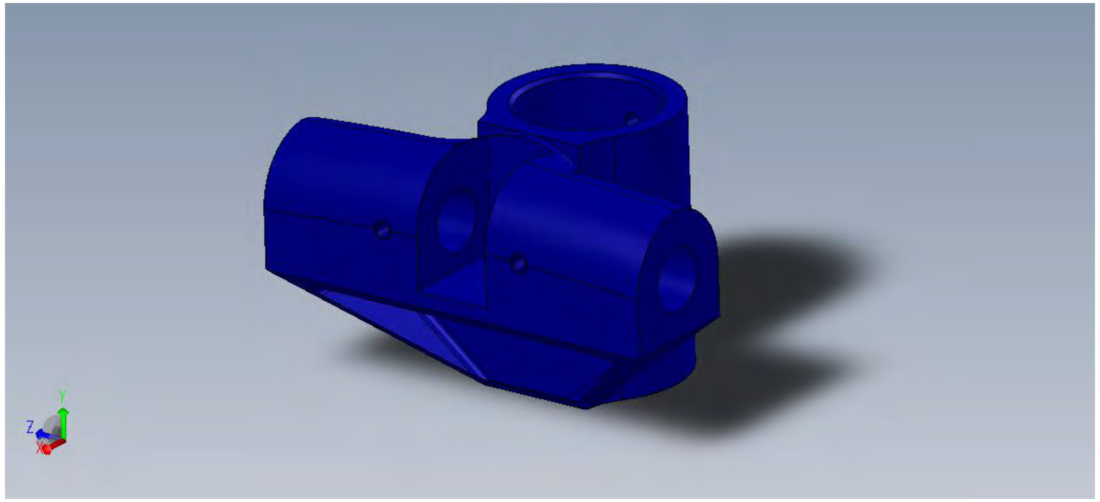
- Wanted a model to compare to physical antenna
  - Proved helpful in modeling environmental effects



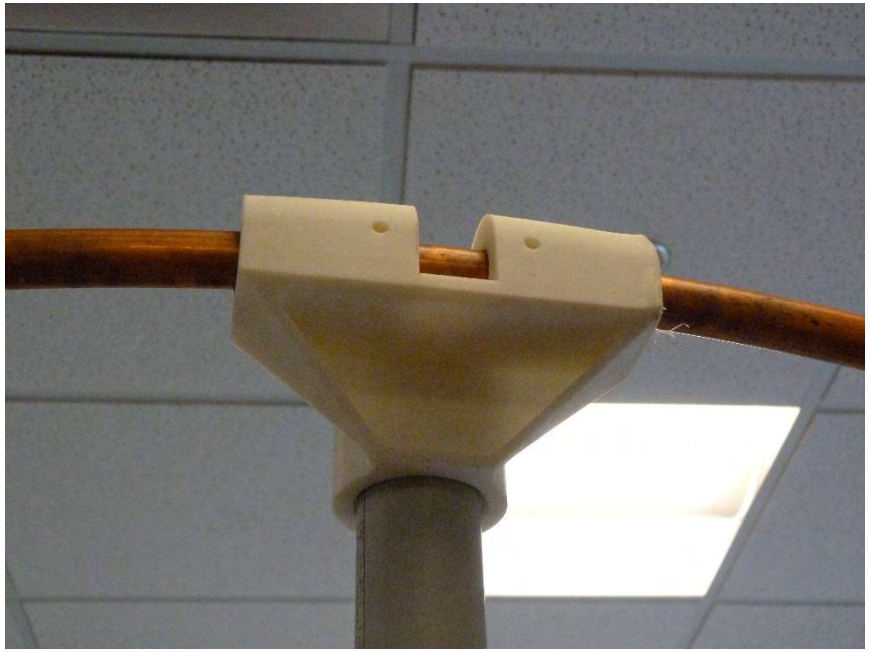
Simplified Overall Block Diagram

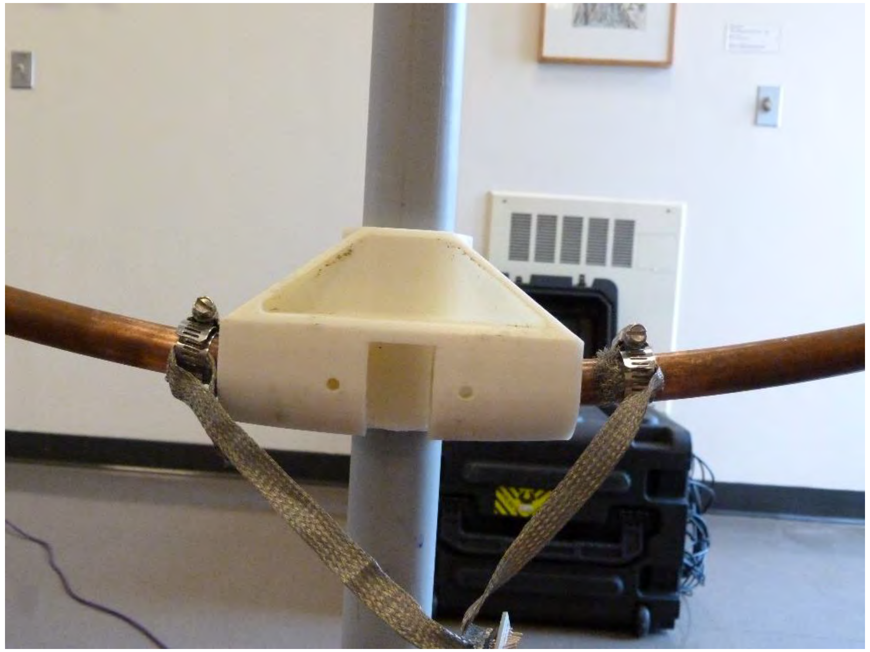


Construction



- Loop made from 5/8” copper pipe
  - → found it lying around
- 3D printed brackets to mount loop to central PVC support



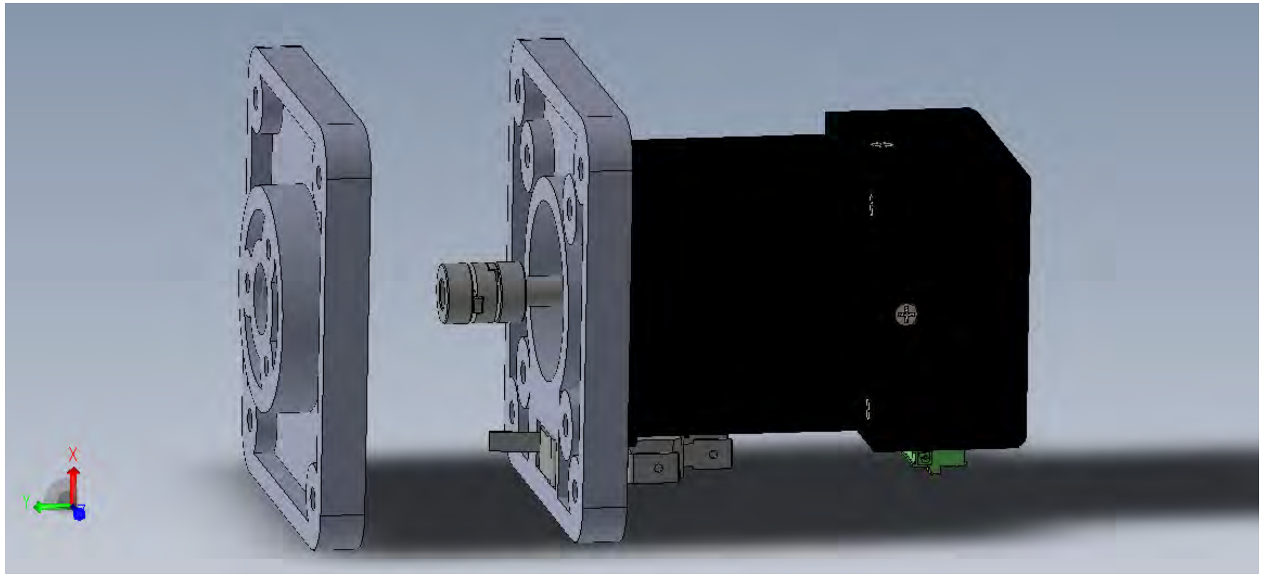


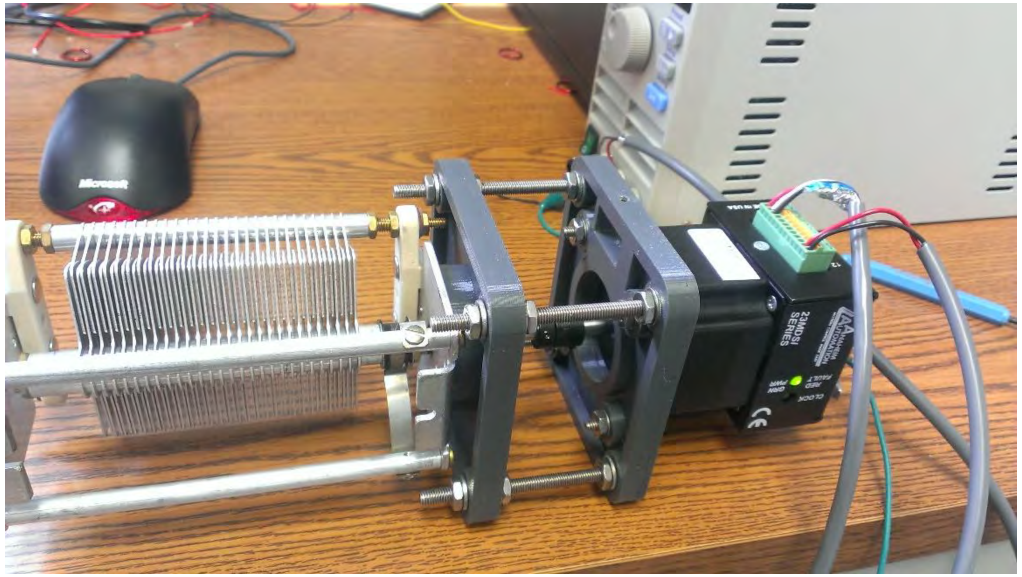
Coupling

- Original transformer windings had too much parasitic capacitance
- Switched to very simple coupling loop

Variable Capacitor and Stepper

- .225° resolution stepper motor
- 20-1000pF variable capacitor
- Limit switch to home/provide consistency





Computer

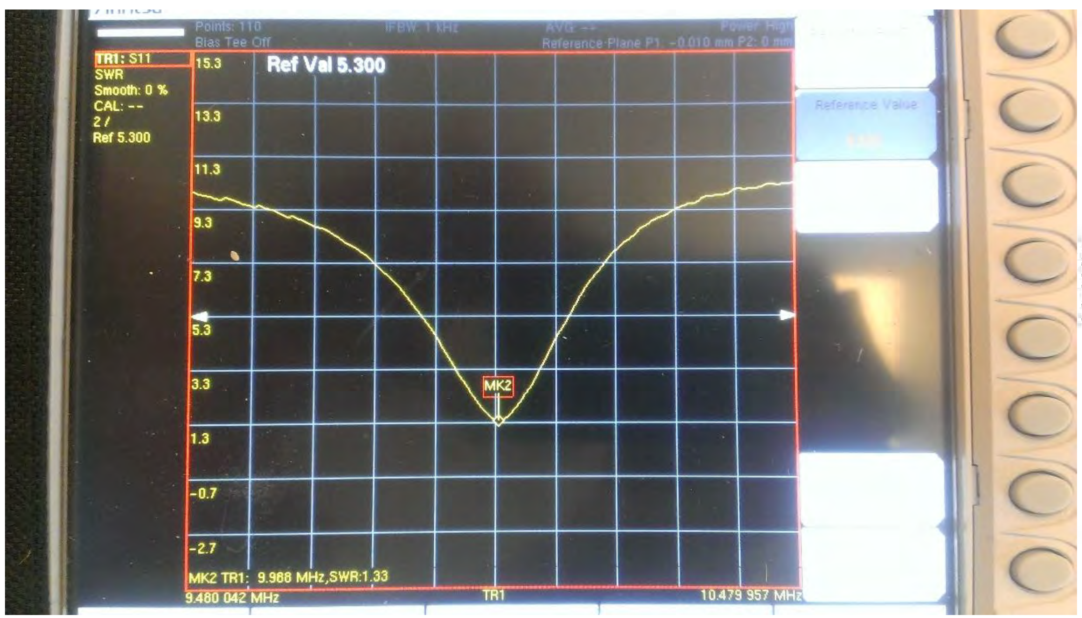
- Raspberry Pi: small low cost highly flexible computer
  - Control the stepper motor using serial commands sent via python script

- Can be accessed over the network remotely

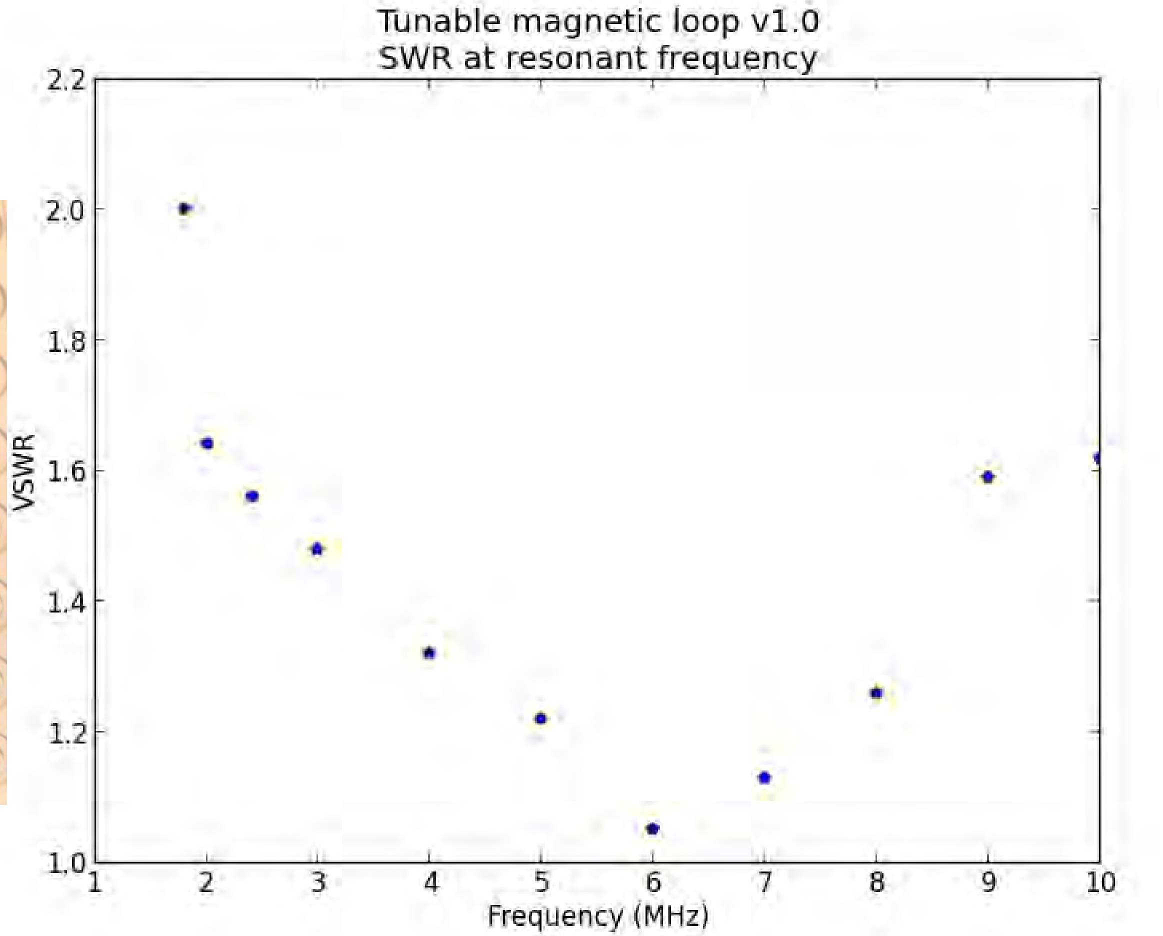
Results: VSWR

- Measured VSWR using network analyzer to measure S11
  - VSWR is a ratio of maximum and minimum voltage
  - 1 is preferable

VSWR

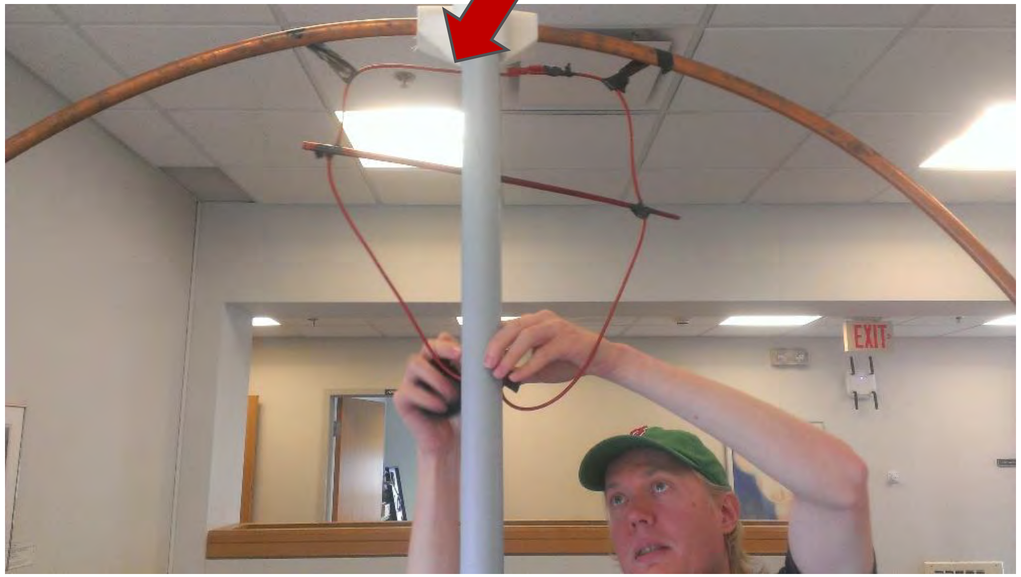


Frequency (MHz)



Artfully crafted
pickup loop

Results: -3 dB Bandwidth



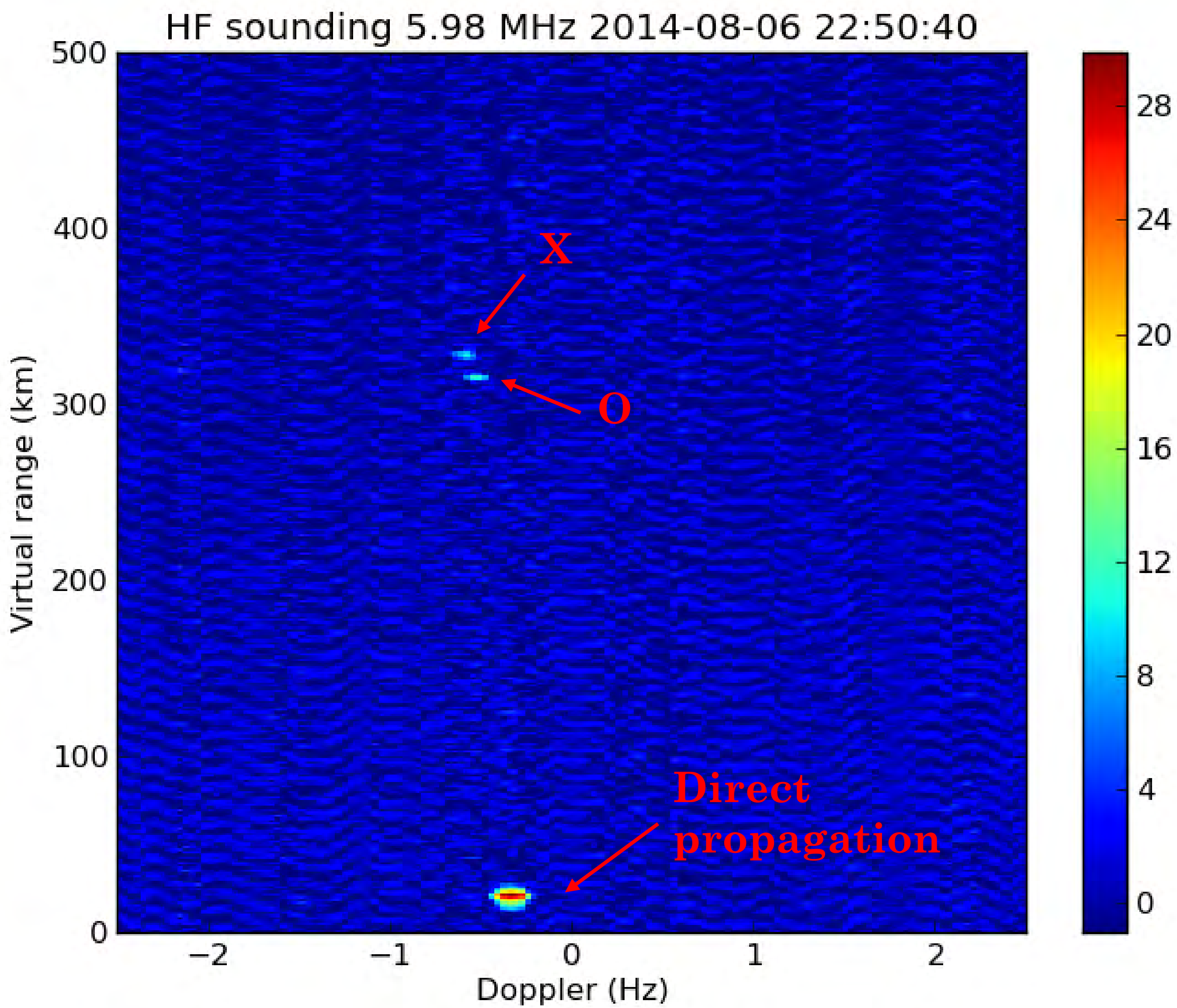
- Found using a pickup loop and a network analyzer using the S21 measurement

- 2MHz → ~110KHz of bandwidth
- 10MHz → ~182 KHz of bandwidth

- Increases with frequency
  - Should increase due to skin effect: losses increase as a function of frequency
    - Losses increase bandwidth of resonance

Results

- Transmitted with 1W
  - Radiated ~10mW
- Nice X and O mode trace



Overall

- Folded Dipole works pretty well
  - Frequency range 2-30 MHz with < 2 VSWR
  - ~$3000 off-the-shelf, but large (including computer, amps, receive antenna, etc)
    - Antenna itself $150
- Small loop antenna also works, but needs active tuning element due to high Q
  - Frequency range 2-14 MHz with < 2 VSWR
  - ~$3000 (including computer, amps, receive antenna, etc)
    - Antenna itself $600

Future Work

- Increase output power → loop has ~20dB loss
  - So can safely output 100W to reach our 1W max
  - Tried this, power supplies started making disconcerting noises
    - Do it right next time
- Make the antenna smaller → 1m diam.
  - Should make antenna capable of higher frequencies, limits lower frequencies
- Transmit *and* receive with the same antenna
  - Few modifications, e.g. add a balun to feed
- Acquire exotic animals, set loop on fire, start circus

Acknowledgements

- Juha Vierinen – You know, mentoring and all. Showing me how to break out of jail. Likewise, helping me get unstuck from that security gate.
- Will Rogers – For aiding in the construction of our antenna. For stymieing our jury-rigging urges.
- Chris Beaudoin – For helping me fight with FEKO and Ltspice modeling
- Frank Lind – For making sure we constructed our antenna somewhat professionally. For yelling at MiniCircuits
- Chris Eckert – For designing and printing our 3D parts. Also for fantastic mechanical engineering advice
- Jason Soohoo and Tim Morin – For acquiescing in my relentless requests for various items
- Mark Jerome and lots of other people who deserve more credit than this slide is capable of.