Instant Tuning for a Manual Tuner

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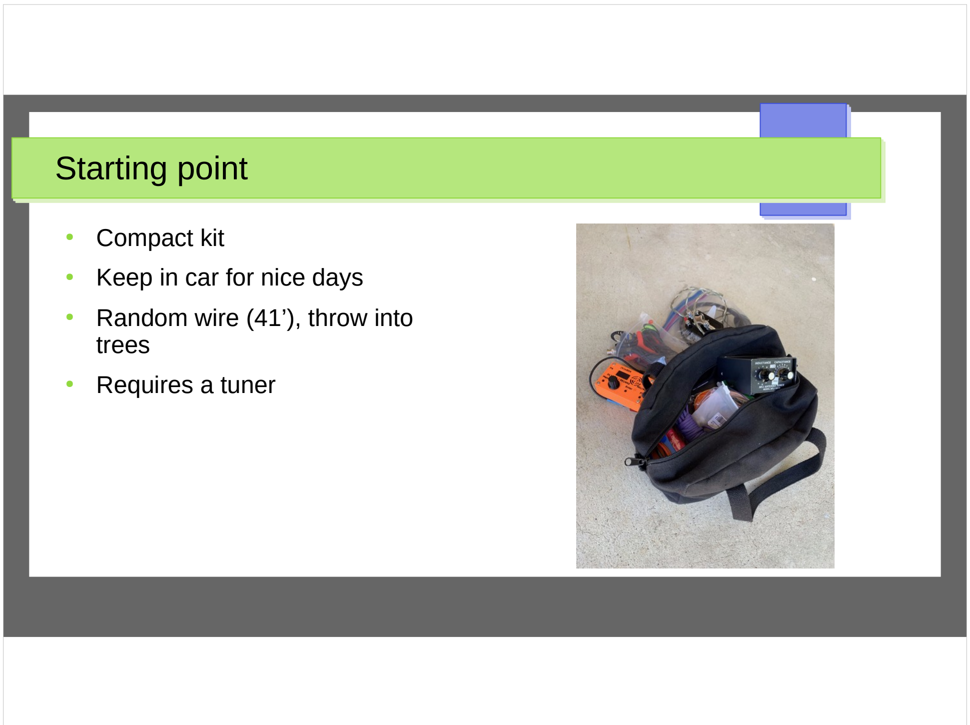
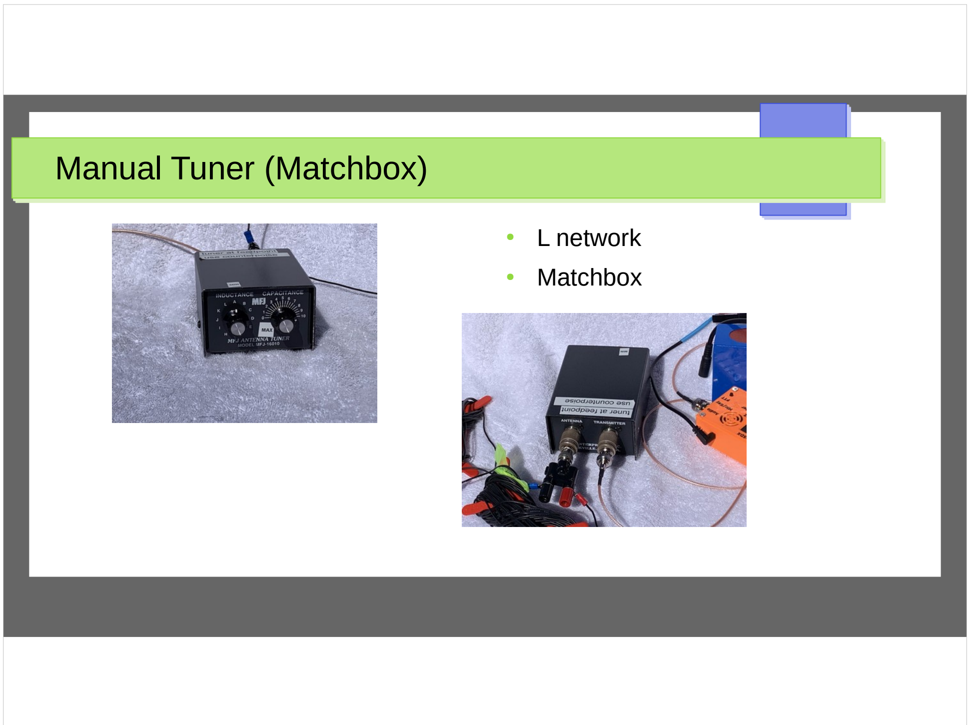
January 2025



- Have a compact kit, ATU a little big and heavy, needs power, cheap ones are wonky. Small manual preferred but tuning is a little tedious.
- Small autotuners exist
- Curiosity-- is there a different way to do it?



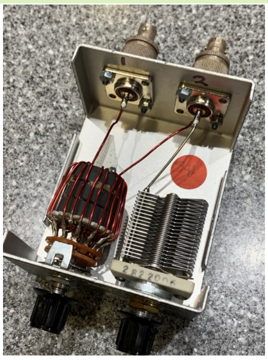
Tuner is compact. One variable capacitor, one inductor with multiple taps. L is in series, C is shunt

In principle will match anything as long as the ranges of values of C & L are large enough.

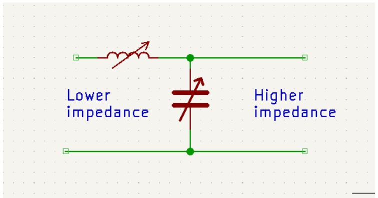
Sometimes you have to reverse the direction (just by reversing connections) depending on the antenna impedance. Namely whether the native antenna real part is above or below the frequency of interest

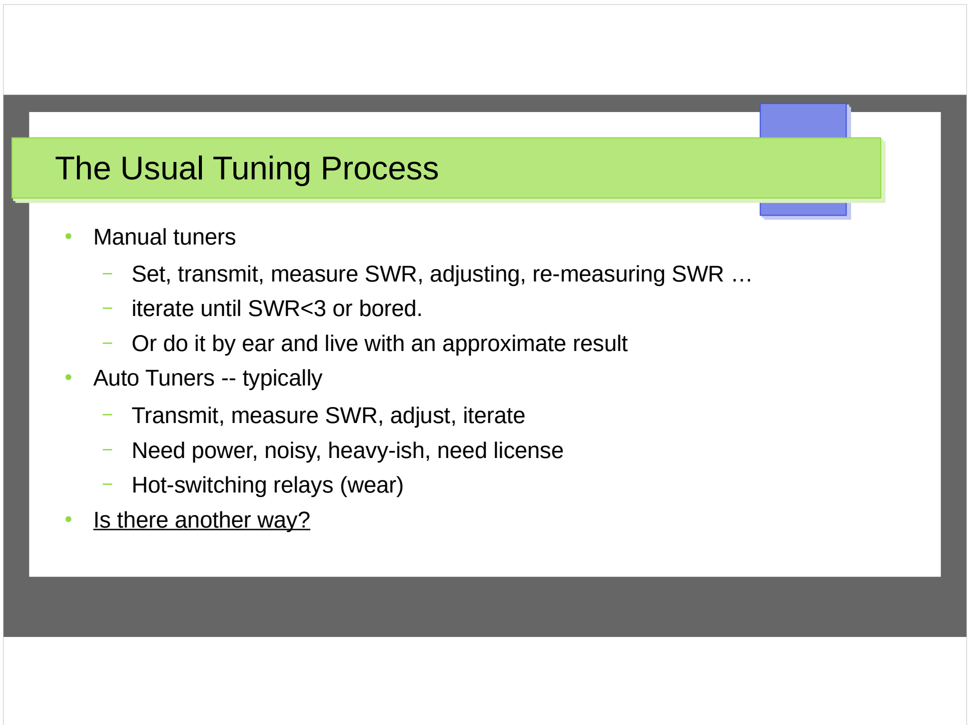
In principle one solution

Matchbox guts and schematic

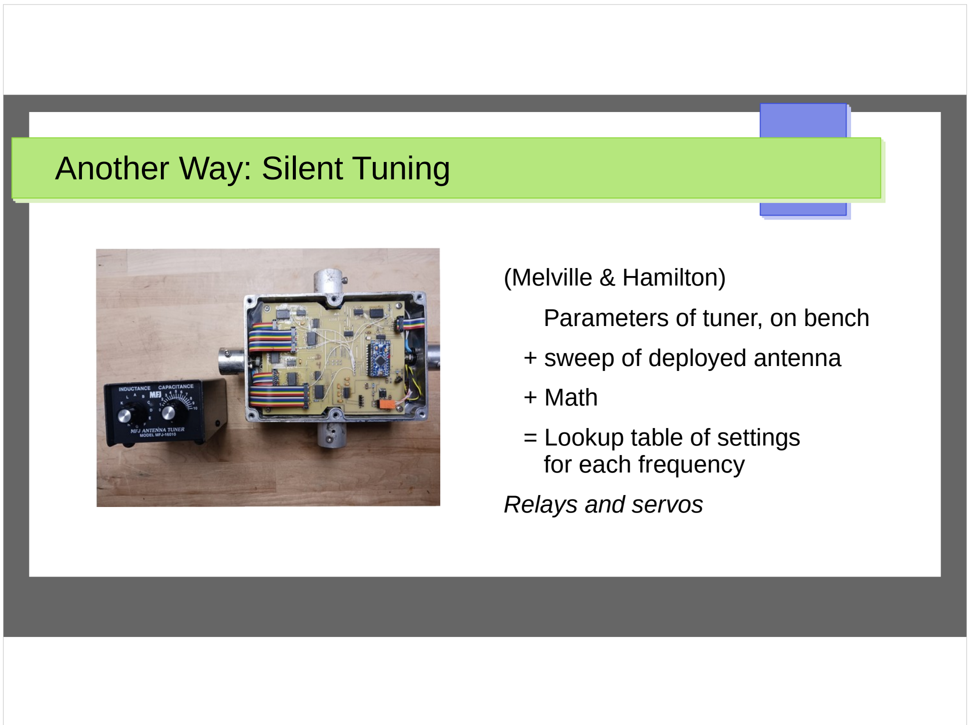


L Network



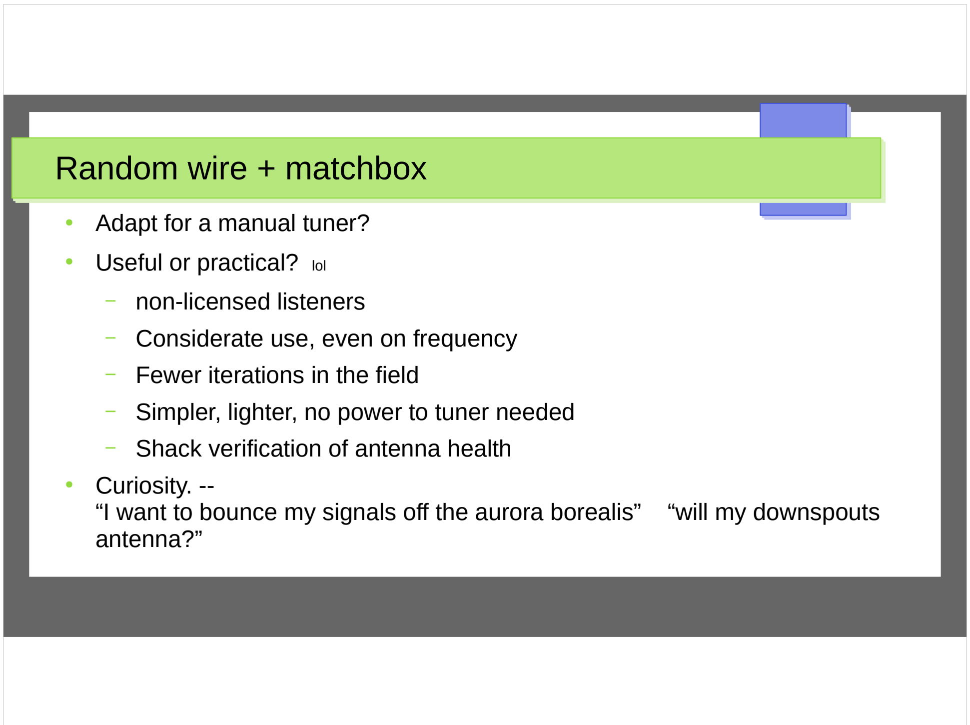


- Some nice little compact auto-tuners out there
- Auto Tuners typically work by transmitting, directly measuring SWR and searching.
  - Requires transmitting
  - Requires a powered tuner with relays etc
- Manual tuners work by setting, measuring SWR, adjusting, re-measuring SWR … iterate until SWR<3 or bored.   Or do it by ear and live with an approximate result.
- Melville and Hamilton took a different approach
  - Characterize the tuner and antenna
  - Calculate result
  - Remotely adjust tuner head with servos and relays

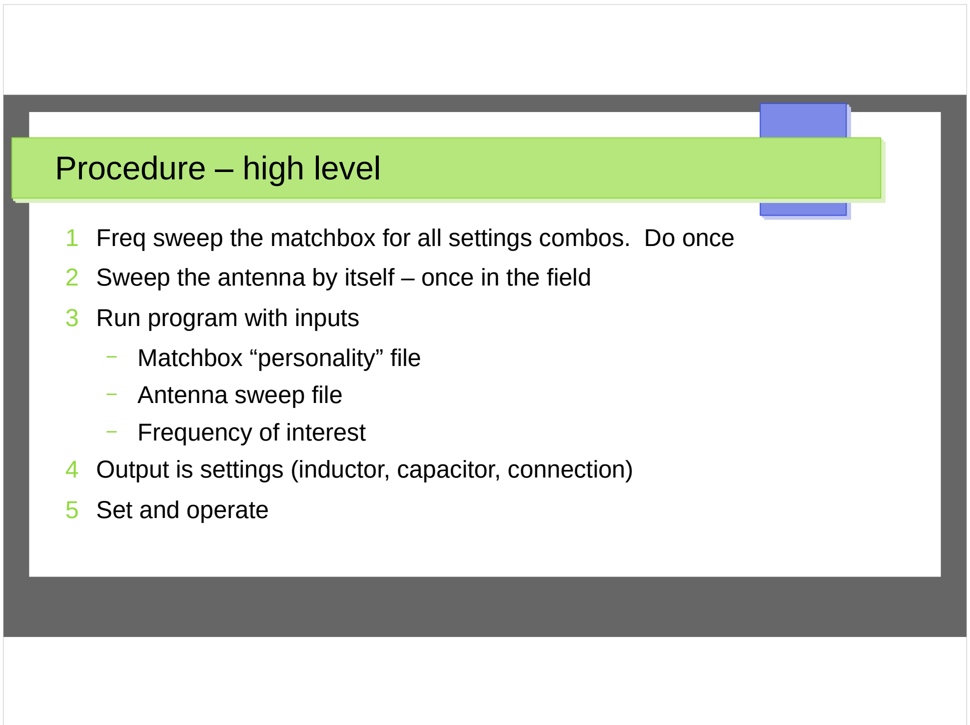


Relays and servos are needed for automation, but what if I’m willing to make the indicated adjustments by hand?

I could eliminate
- electromechanical complexity
- Weight
- Power requirement



No goofier than many other questions we ask as hams



Matchbox personality file: S11, S12, S21, S22 sweep from .8 MHz to 32 MHz

Note: S12 = S21 for an L-network (or any reciprocal network) – thanks to Paul AA6PZ for pointing this out.

Sweep the antenna in the field, as many points as you like, record S11

This is a summary of the procedural steps. Now let’s see details about how it’s actually done:

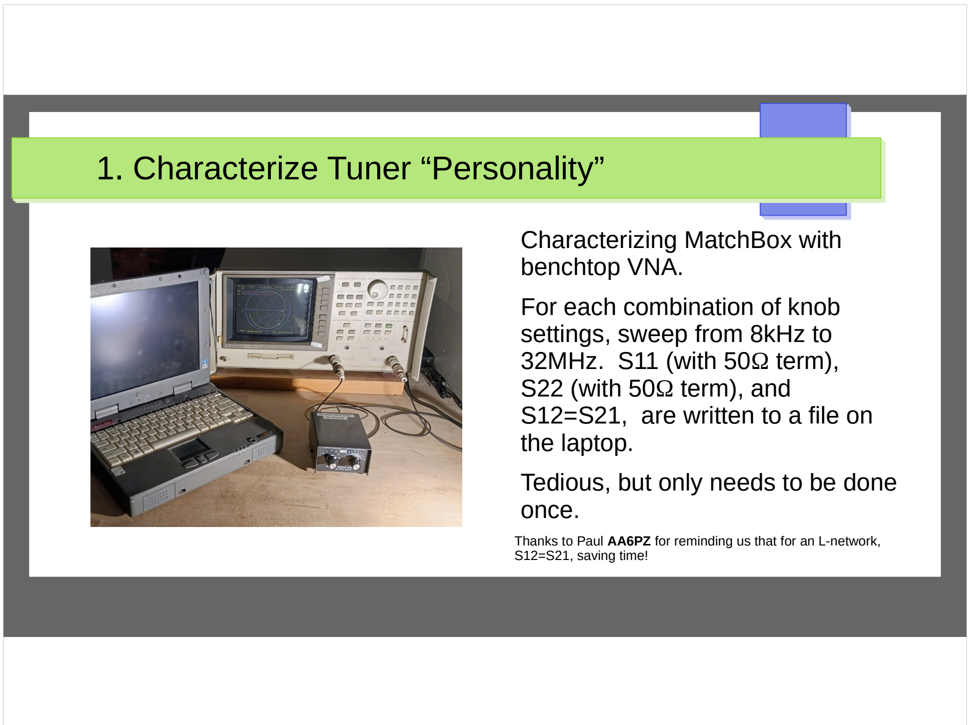
Example: Random Wire Antenna (with counterpoise)

- 41 foot (12.5 m) “random” (nonresonant) wire with counterpoise
- BNC to binding post / banana plug adaptor
- Arborist’s bag and line for getting end up in a tree

Out of the lab, into the field, example antenna

The other BNC connector here goes to the radio

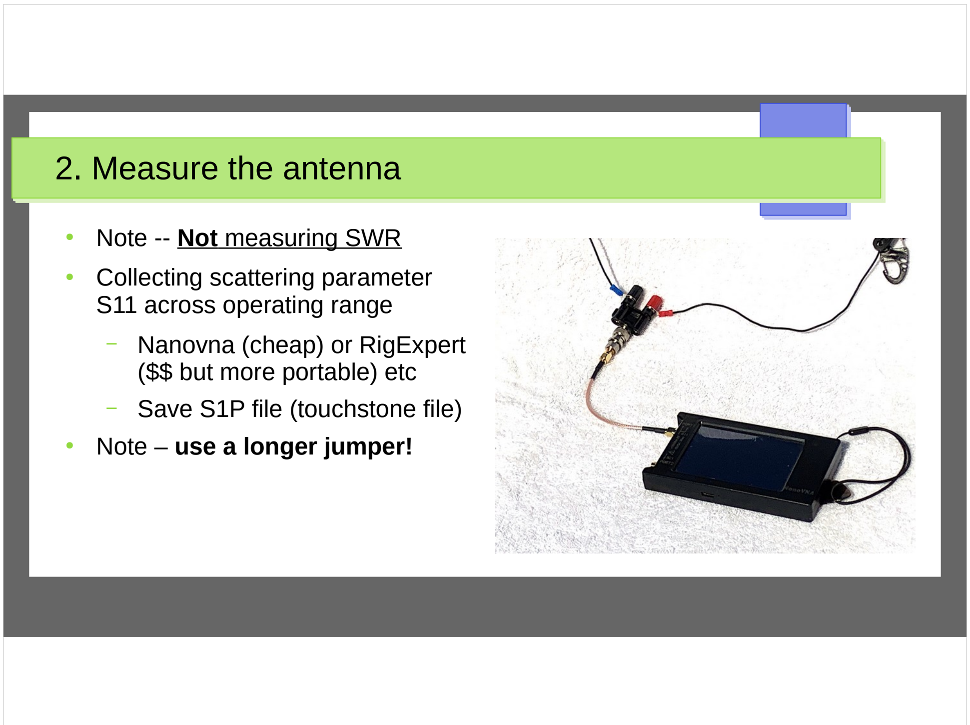
Just FYI what it looks like deployed



HP 8753D lab VNA, fyi

Re measuring S21 & S12: Should have thought about it first. Facepalm.

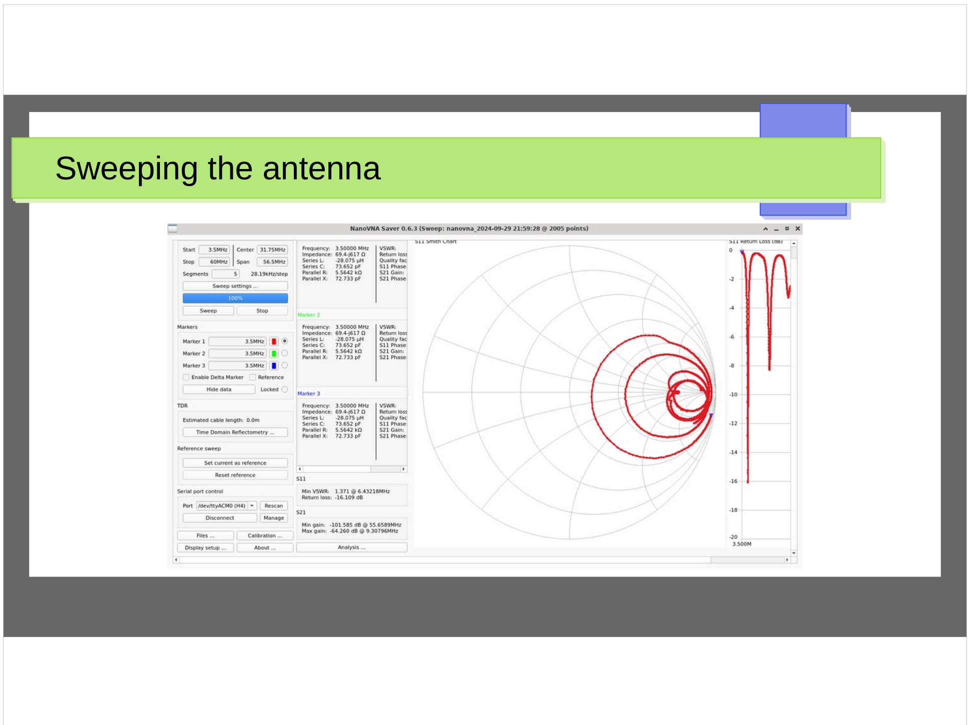
"There is no expedient to which a man will not resort to avoid the real labor of thinking" - posted around the lab by Thomas Edison, originally Sir Joshua Reynolds



When the jumper is this short, your presence interferes with measurements.   Use a longer jumper for sweeping the antenna.

(Foreshadowing a virtue of instant tuning – the tuner settings can be calculated without your body being near the tuner, which in my experience can significantly affect impedances)

Reminder about calibration: calibrate with standards at the end of the jumper (ie the end that will be connected to the antenna)



- NanoVNASaver
- Set Start and Stop frequencies
- Set “number of segments” high enough to get small enough steps (better resolution). 5 is probably excessive
- Click on “Files” and “save 1-port file” S1P file
- Touchstone file (a text file with descriptive header)

Explanation of the format of the matchbox "personality" file:

Each combination of settings is preceded by its own # format header
Each line corresponds to a frequency -- 801 of them in HZ 8e5 to 32e6 inclusive
The first 801 lines are S11 for that set of frequencies
The next 801 lines are S21 for the same set of frequencies
The third set are S12… [note – this is redundant with S21]
The fourth set are S22 …

Format of the antenna sweep file (Touchstone standard):

format header
Frequency (Hz)   S11 real part   S11 imaginary part

3. Run the program

#compile once

gcc -o qsy qsy.c -lm

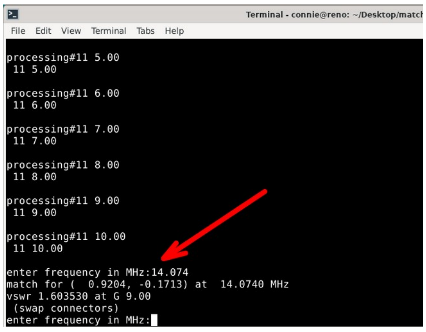
#run in the field-- interactive

./qsy matchbox_fullsweep antenna.s1p

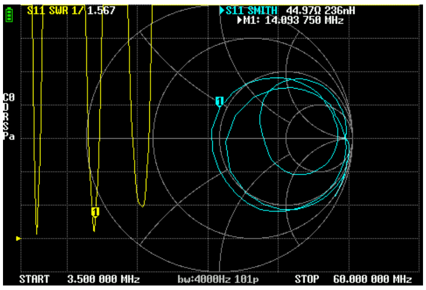
Enter 14.074 MHz at the prompt

→ **Set to G 9**

(Program simply calculates all SWRs, then does a search)



It works



#run in the field-- interactive

./qsy matchbox_fullsweep antenna.s1p

Enter 14.074 MHz

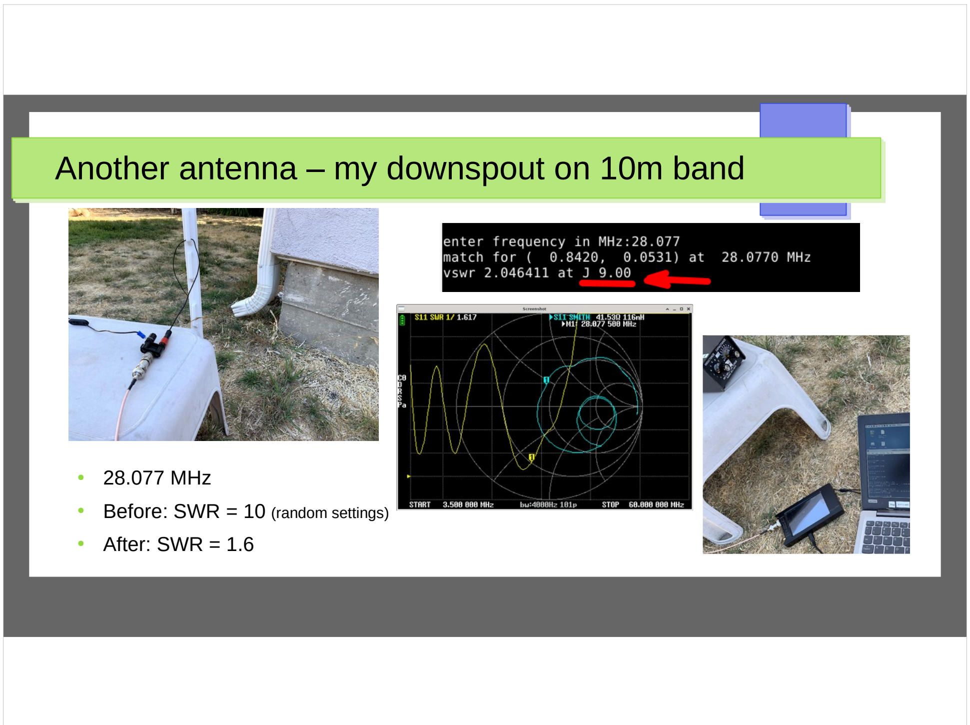
→ **Set to G 9**

SWR ≈ 1.5

(Nanovna only 401 pts. 14.093 closest)

Great for a “random wire”

Pretty near the minimum.   Resolution

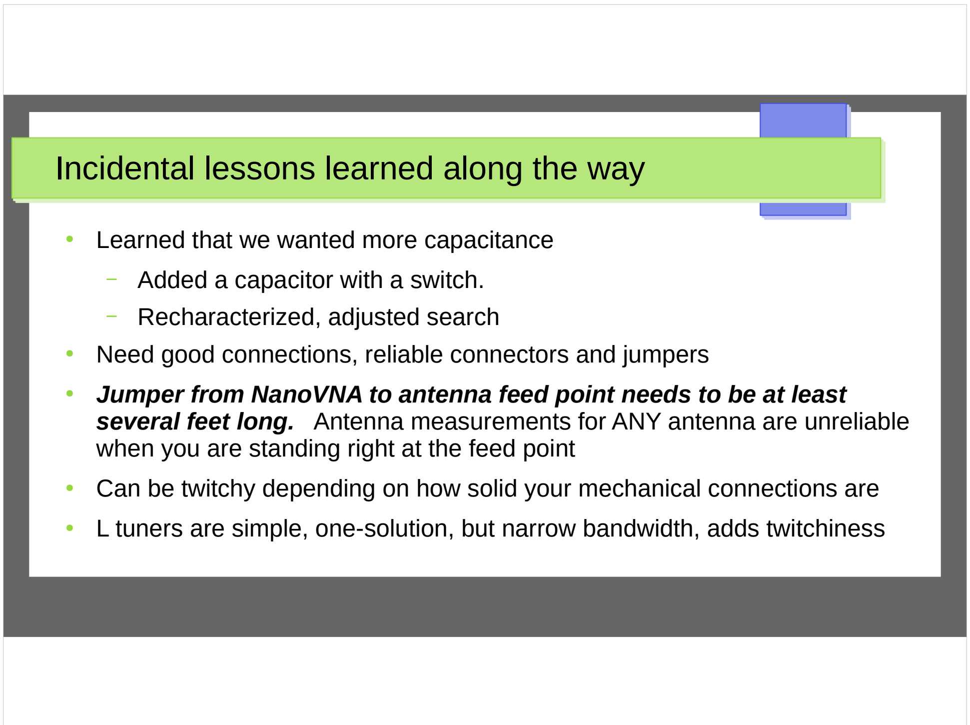


Side note: my downspout and gutters are around 1.5:1 on the 20m band without a tuner so didn't demo there. But it's a good problem to have! I have worked the middle of the country on phone on this downspout with 10 Watts on 20m and no tuner

Lessons learned:

MUST take antenna measurements with at least several feet of jumper. DO NOT be right next to the antenna when you measure it. This goes for ALL antennas. Standing near it with your VNA guarantees messed-up measurements

Re NanoVNA + freeware on computer: great little instrument, but you do get what you pay for. Setup occasionally locks up when alternating screenshots and measurements



Calibrate the VNA at the end of the jumper!

Remember when sweeping the tuner, that when taking S11 & S22 other port has to be terminated with 50Ω (Z_0)

Self-resonance “fences”

Things to do next

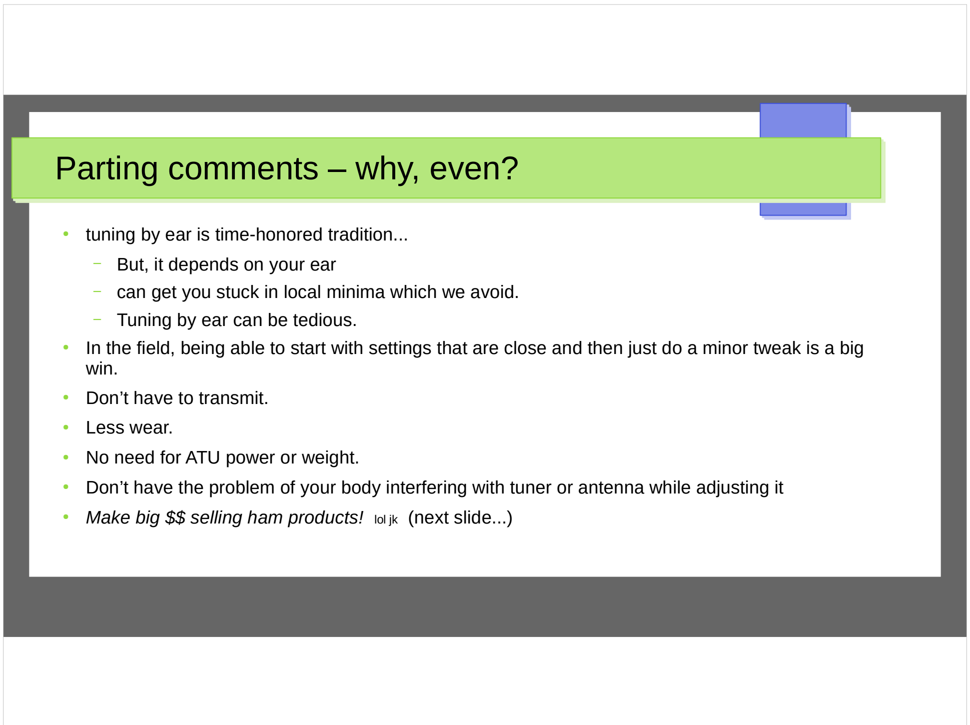
- **Nomogram** or booklet? Ie, no compute in the field? (cf aviation)
- Ideal wire length for a given tuner – modelling, or measuring
- Put everything in a single box: autotuner that incorporates a VNA/measure S11 plus small compute. Or modular kit.
- Put all the compute on your phone – phone will run c or python.
  - Connect phone to VNA, VNA to antenna
  - Run program, set tuner, win contests!
- Create tuner personality file from component values
- Other tuners – eg Z-match – Aaron **AK6IM** is trying this

If you have more than 2 knobs, creating the personality file by direct measurement is unsustainable. Prefer to do it analytically with component values

Since S21=S12 we can reduce # measurements taken and update the code accordingly

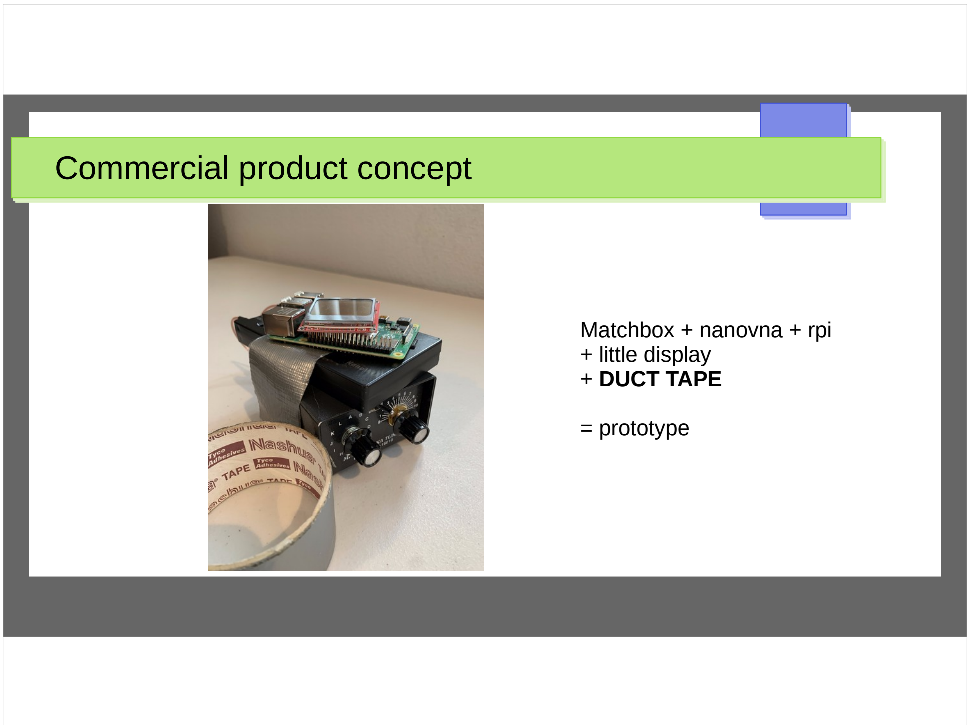
Python port – look at scikit-rf (thanks Aaron AK6IM)

Nomograms – thanks Ben KN6UBF for pointing out the importance of nomogram and slide rule type calculators historically in aviation



One problem with manual tuners is if the antenna is nearby the tuner, your body will interact and then when you step away it detunes.   Can be very frustrating.

Being able to take antenna scan and do the calculations remotely, then go straight to the right settings, avoids that frustration.



VNA and compute are small and cheap. Why not duct-tape them together, display the settings for the user?

But seriously, instead of a bunch of relays and electromechanical iterative search, put in the guts of a nanoVNA and compute with a small display telling the user what settings to pick. Skip the electromechanicals for weight, space, cost, and tinkerability.

Add servos and relays, and we’ve circled back to Melville and Hamilton.

Why even…? ...Ultimately:

Because we're hams, and we like to tinker! -- that's one of the reasons the amateur bands even exist

Thanks and have fun!

GE es 73 de W6EFI

Appendix 1: L-Match Tuner

- Capacitor and inductor, one in series and one in parallel with antenna
- Which way depends on whether the antenna R is high or low.
- That’s why you sometimes reverse the connections.
- In theory should always be able to get a match (limited by cpt values)
- Orientation determines hi-pass or lo-pass

Format of the matchbox “personality” file

- S11, S12, S21, S22 values over freq range of interest
- Each combination of settings is preceded by its own # format header
- Each line corresponds to a frequency -- 801 of them in Hz: 800kHz to 32MHz inclusive
- The first 801 lines are S11 for that set of frequencies
- The next 801 lines are S21 for the same set of frequencies
- The third set are S12 …   (Note: S12 = S21 so this is redundant)
- The fourth set are S22 ...

Appendix 3: qsy.c algorithm summary

- Read matchbox “personality” file (S11, S12, S21, S22 for freq range)
- Read antenna sweep file (S11 for freq range)
- Read input frequency
- Do some interpolation for frequency
- Iterate over all combinations of L & C settings and antenna connected to each port
- Calculate resultant input reflection coefficient and SWR, save them all in a table
- Search table for lowest SWR
- Print those settings, may include direction to reverse the ports

Appendix 4: Calculation notes

Reflection coefficient Γ

$$\Gamma = \frac{V_r}{V_f}.$$

or

$$\Gamma = \frac{Z_L - Z_o}{Z_L + Z_o}$$

$$\mathbf{SWR} = \frac{|V_{\max}|}{|V_{\min}|} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

$$|\Gamma| = \frac{\mathbf{SWR}-1}{\mathbf{SWR}+1}$$

Z_L: load impedance
Z_o: characteristic impedance of feedline
V_r: reflected voltage
V_f: forward voltage

At the input port, the VSWR (s_{in}) is given by

$$s_{\text{in}} = \frac{1+|S_{11}|}{1-|S_{11}|}$$

At the output port, the VSWR (s_{out}) is given by

$$s_{\text{out}} = \frac{1+|S_{22}|}{1-|S_{22}|}$$

S_{11} is the input port voltage reflection coefficient
S_{12} is the reverse voltage gain
S_{21} is the forward voltage gain
S_{22} is the output port voltage reflection coefficient.

Now connect a load (antenna) having Γ_L (S_{11ant}) to the output port.

Input reflection coefficient with the output termination arbitrary and $Z_s = Z_0$.

$$s'_{11} = \frac{b_1}{a_1} = \frac{s_{11}(1-s_{22}\Gamma_L)+s_{21}s_{12}\Gamma_L}{1-s_{22}\Gamma_L}$$
$$= s_{11} + \frac{s_{21}s_{12}\Gamma_L}{1-s_{22}\Gamma_L}$$

SWR looking into the tuner with the antenna attached

$$SWR_{\text{tuner with ant}} = \frac{1+|S'_{11}|}{1-|S'_{11}|}$$

Appendix 5: S12 = S21 for L networks

- **S_{11}**:

$$S_{11} = \frac{Z_1 - Z_0}{Z_1 + Z_0}$$

- **S_{22}**:

$$S_{22} = \frac{Z_2 - Z_0}{Z_2 + Z_0}$$

- **$S_{21} = S_{12}$**:

$$S_{21} = S_{12} = \frac{2Z_0}{Z_1 + Z_2 + 2Z_0} = \frac{2Z_0}{j\omega L + \frac{1}{j\omega C} + 2Z_0}$$

These equations express the S-parameters in terms of the inductance L, capacitance C, and the reference impedance Z_0.

References

Silent tuning

- R. Melville and S. Hamilton, "Silent Tuning: Matching a transmitter to an antenna without emitting a signal," MILCOM 2021 - 2021 IEEE Military Communications Conference (MILCOM), San Diego, CA, USA, 2021, pp. 808-812, doi: 10.1109/MILCOM52596.2021.9653009.

Antennas and tuners

- ARRL, *The ARRL Antenna Book* (24th ed)
- Krischke, J., DJ0TR, *Rothammel's Antenna Book*

Scattering parameters, reflection coefficients

- https://en.wikipedia.org/wiki/Scattering_parameters
- https://people.engr.tamu.edu/spalermo/ecen689/sparam_agilent_tutorial.pdf

Resources

- Matchbox personality files (for MFJ 16010 manual tuner)
- Code (yet to be posted – contact presenter)
- Latest presentation
-
- Will be posted to https://github.com/conniest/InstantTuning
-

Author Biographies

Connie Stillinger, PhD., W6EFI Connie was originally licensed in the 1970's as WN2EFI -- passed the 5 wpm code test -- but it lapsed before even making it into the callbook. About two years ago she rediscovered ham radio as a great way to make friends, hike around parks, and have fun tinkering together. She enjoys operating all modes on HF ranging from CW through Hellschreiber to SSTV.

Robert Melville, PhD., WB3EFT Bob worked at AT&T Bell Labs for 17 years in the areas of computer-aided design, numerical simulation of electronic circuits, and design and fabrication of RF integrated circuits. He has taught electrical engineering at Columbia University and served with the United States Antarctic Program at the Amundsen-Scott base at the South Pole doing engineering work in support of geophysics experiments. Bob is a Senior Member of the IEEE, who referees for Ieee-sponsored journals and conferences, and the Society for Industrial and Applied Mathematics. He co-organized a conference on numerical circuit simulation at Sandia National Labs and participated in the AT&T "Teachers and Technology" enrichment program for high-school math and science teachers.