Instant Tuning for a Manual Tuner

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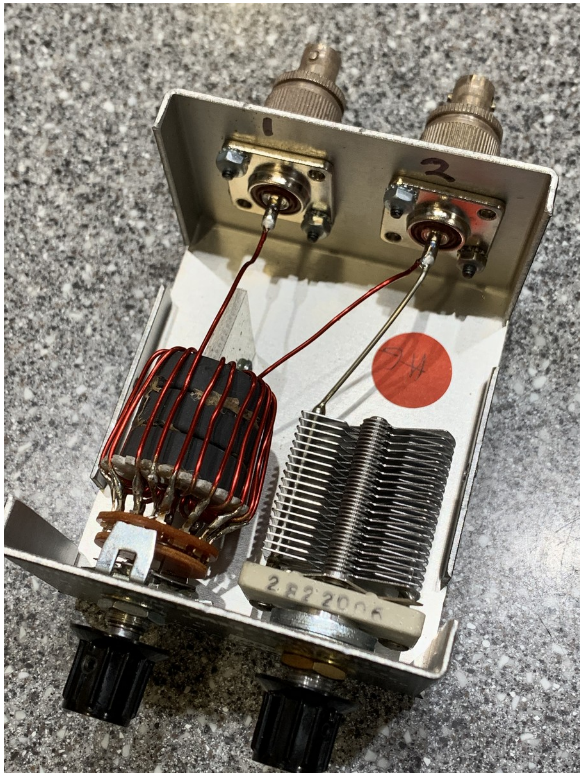
Starting point

- Compact kit
- Keep in car for nice days
- Random wire (41’), throw into trees
- Requires a tuner

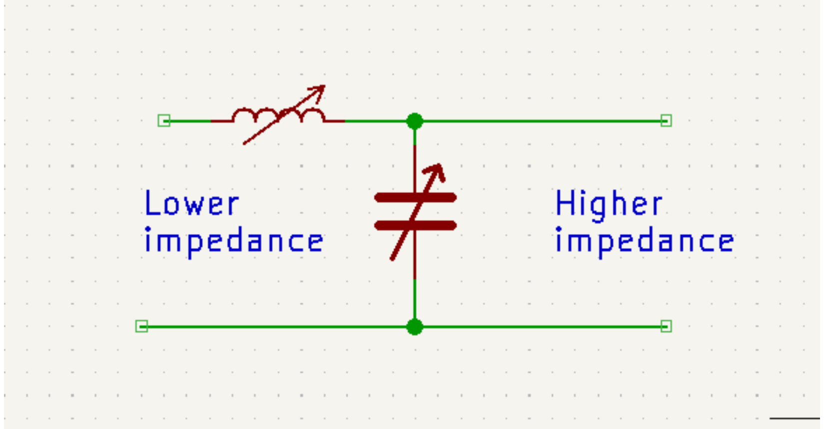
Manual Tuner (Matchbox)

- L network
- Matchbox

Matchbox guts and schematic



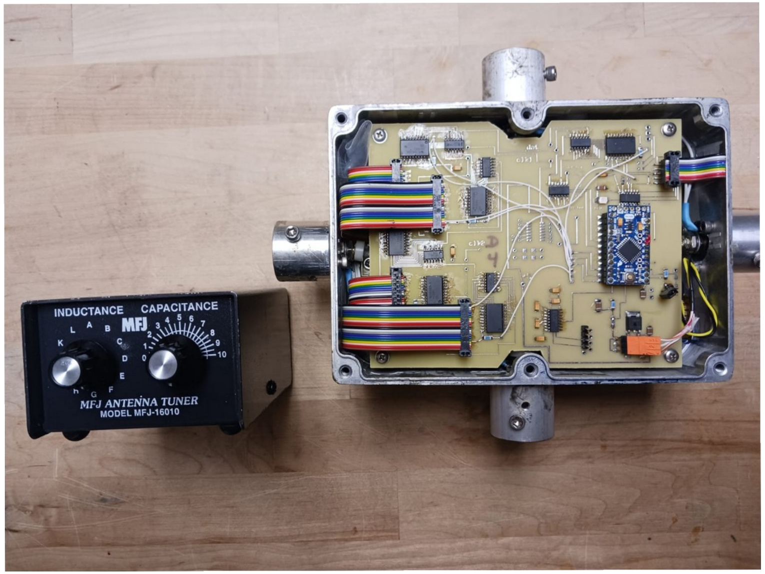
L Network



The Usual Tuning Process

- Manual tuners
  - Set, transmit, measure SWR, adjusting, re-measuring SWR …
  - iterate until SWR<3 or bored.
  - Or do it by ear and live with an approximate result
- Auto Tuners -- typically
  - Transmit, measure SWR, adjust, iterate
  - Need power, noisy, heavy-ish, need license
  - Hot-switching relays (wear)
- <u>Is there another way?</u>

Another Way: Silent Tuning



(Melville & Hamilton)

Parameters of tuner, on bench

+ sweep of deployed antenna

+ Math

= Lookup table of settings
for each frequency

Relays and servos

Random wire + matchbox

- Adapt for a manual tuner?
- Useful or practical? lol
  - non-licensed listeners
  - Considerate use, even on frequency
  - Fewer iterations in the field
  - Simpler, lighter, no power to tuner needed
  - Shack verification of antenna health
- Curiosity. --
  “I want to bounce my signals off the aurora borealis” “will my downspouts antenna?”

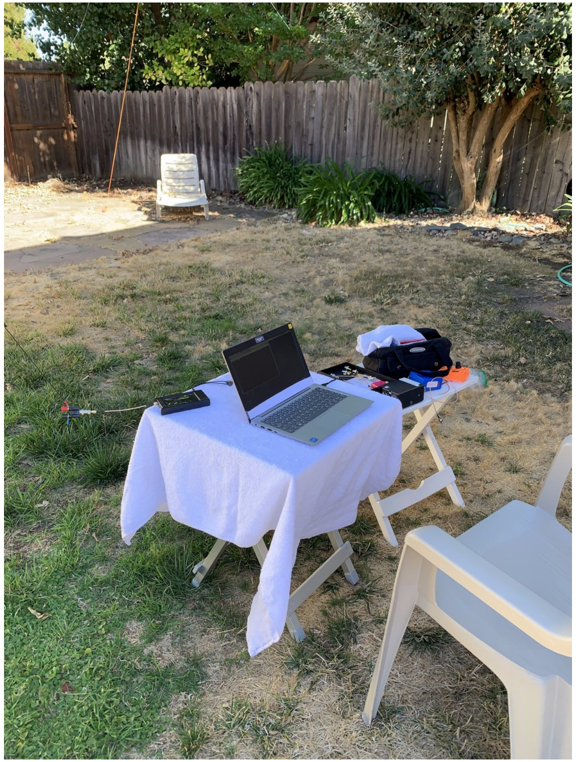
Procedure – high level

1. Freq sweep the matchbox for all settings combos. Do once
2. Sweep the antenna by itself – once in the field
3. Run program with inputs
   - Matchbox “personality” file
   - Antenna sweep file
   - Frequency of interest
4. Output is settings (inductor, capacitor, connection)
5. Set and operate

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

Field Station



1. Characterize Tuner "Personality"

Characterizing MatchBox with benchtop VNA.

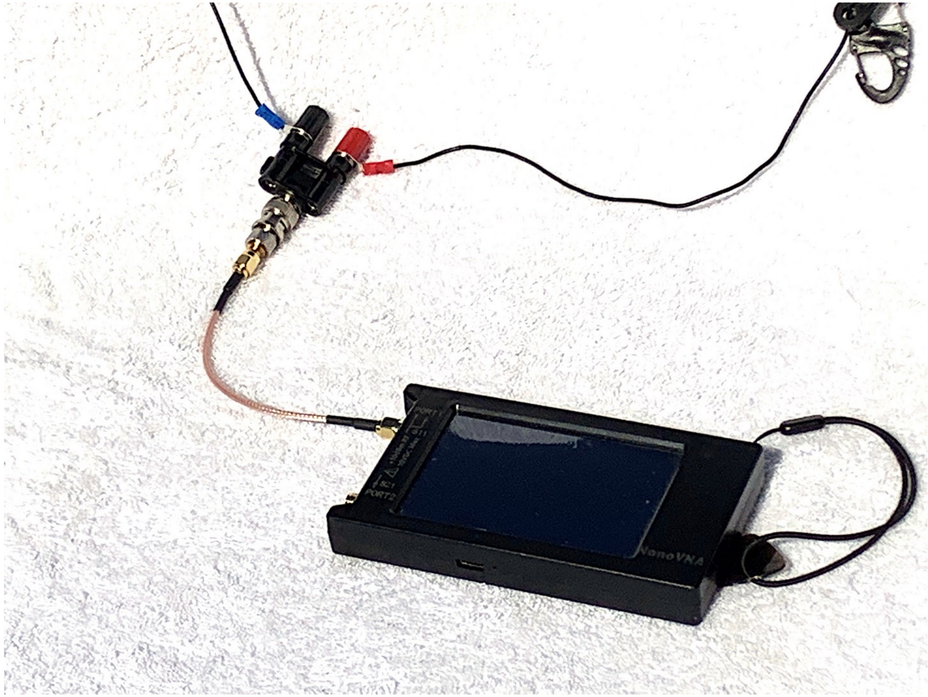
For each combination of knob settings, sweep from 8kHz to 32MHz. S11 (with 50Ω term), S22 (with 50Ω term), and S12=S21, are written to a file on the laptop.

Tedious, but only needs to be done once.

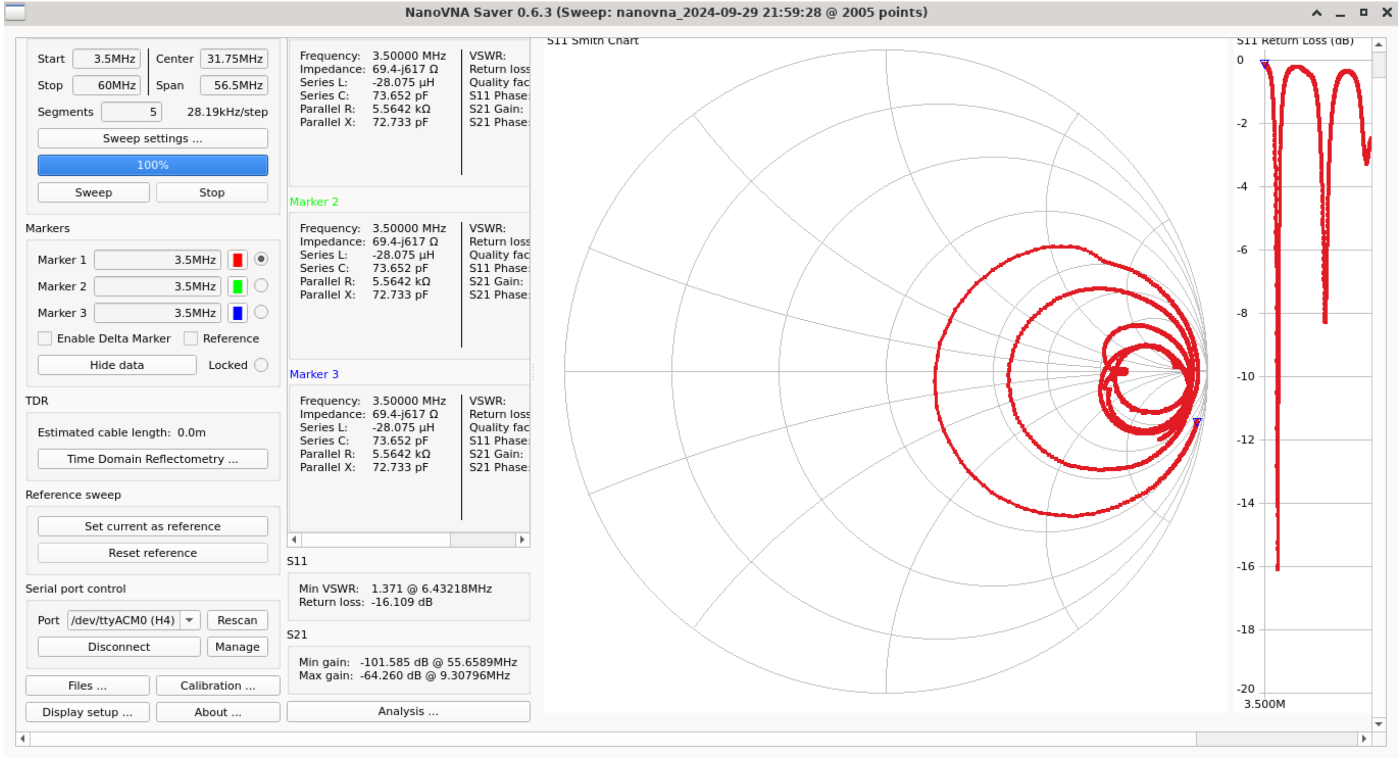
Thanks to Paul **AA6PZ** for reminding us that for an L-network, S12=S21, saving time!

2. Measure the antenna

- Note -- **Not** <u>measuring SWR</u>
- Collecting scattering parameter S11 across operating range
  - Nanovna (cheap) or RigExpert ($$ but more portable) etc
  - Save S1P file (touchstone file)
- Note – **use a longer jumper!**



Sweeping the antenna



Files

- Tuner personality file - ONCE

```
W6EFI QRZ? head matchbox_fullsweep
#00 0.00
-1.668930e-04 -1.217937e-02
-7.677078e-05 -1.293850e-02
-1.177788e-04 -1.350069e-02
-1.630783e-04 -1.414919e-02
-2.527237e-04 -1.474953e-02
-2.560616e-04 -1.530743e-02
-3.376007e-04 -1.588726e-02
-4.663467e-04 -1.651096e-02
-5.102158e-04 -1.709843e-02
W6EFI QRZ?
```

- Antenna sweep file

```
W6EFI QRZ? head antenna-sweep.s1p
# HZ S RI R 50
3500000 0.968524288 -0.16958
3528194 0.968009984 -0.171774128
3556388 0.967150592 -0.17366896
3584582 0.966259072 -0.175629824
3612776 0.965635776 -0.178835568
3640970 0.965098112 -0.1806528
3669164 0.96412768 -0.183494512
3697358 0.962757184 -0.185992
3725552 0.962109056 -0.188524432
W6EFI QRZ?
```

3. Run the program

#compile once

gcc -o qsy qsy.c -lm

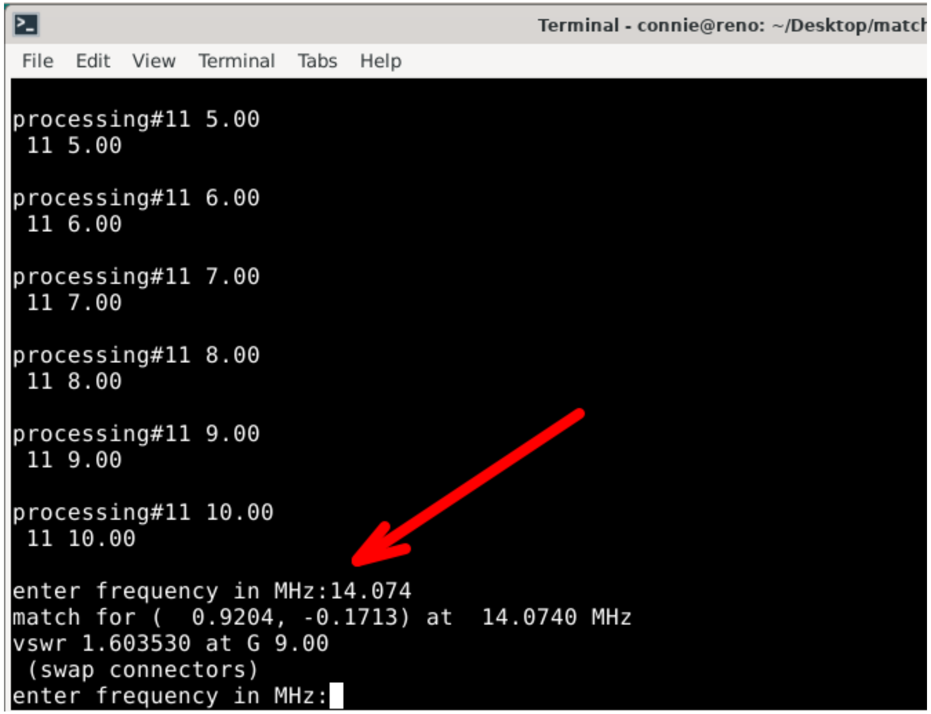
#run in the field-- interactive

./qsy matchbox_fullsweep antenna.s1p

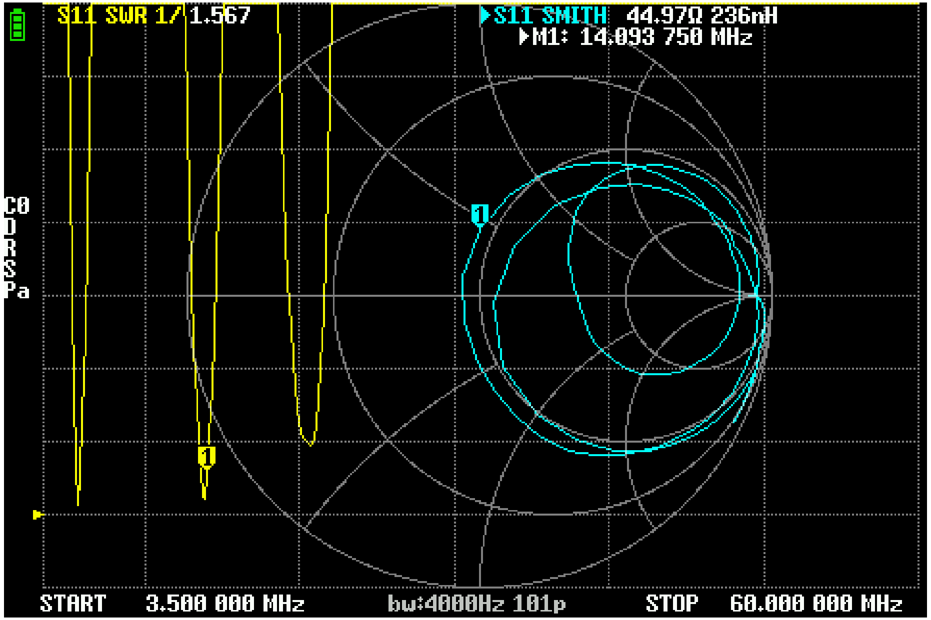
Enter 14.074 MHz at the prompt

→ **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

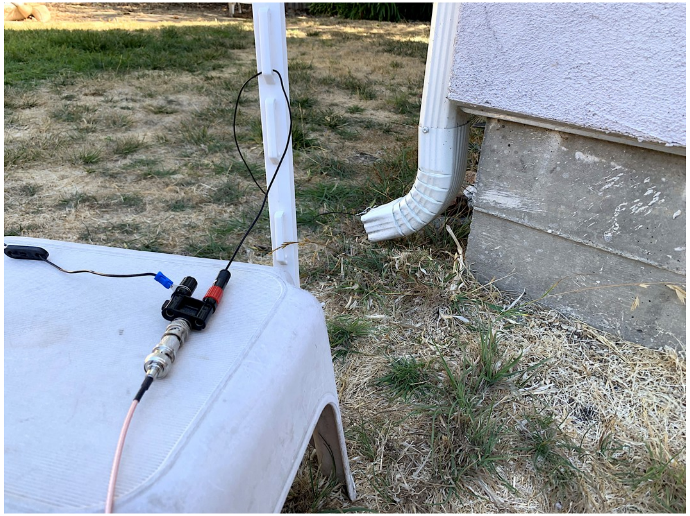
→ **Set to G 9**

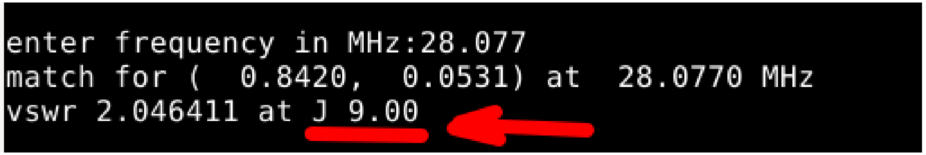
SWR ≈ 1.5

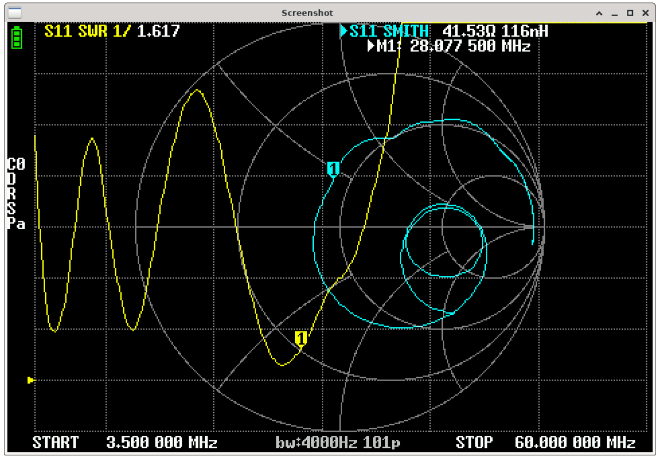
(Nanovna only 401 pts. 14.093 closest)

Great for a “random wire”

Another antenna – my downspout on 10m band







- 28.077 MHz
- Before: SWR = 10 (random settings)
- After: SWR = 1.6

Incidental lessons learned along the way

- Learned that we wanted more capacitance
  - Added a capacitor with a switch.
  - Recharacterized, adjusted search
- Need good connections, reliable connectors and jumpers
- ***Jumper from NanoVNA to antenna feed point needs to be at least several feet long.*** Antenna measurements for ANY antenna are unreliable when you are standing right at the feed point
- Can be twitchy depending on how solid your mechanical connections are
- L tuners are simple, one-solution, but narrow bandwidth, adds twitchiness

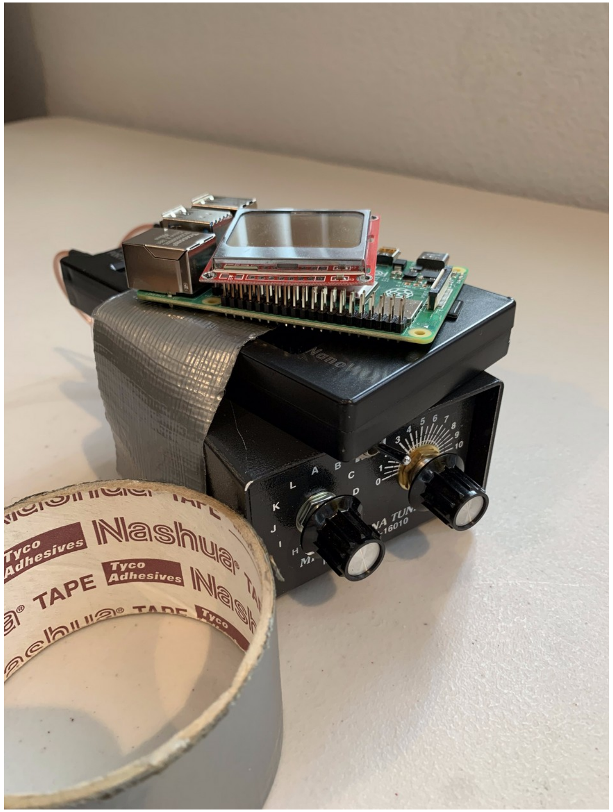
Things to do next

- **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

Parting comments – why, even?

- tuning by ear is time-honored tradition...
  - But, it depends on your ear
  - can get you stuck in local minima which we avoid.
  - Tuning by ear can be tedious.
- In the field, being able to start with settings that are close and then just do a minor tweak is a big win.
- Don’t have to transmit.
- Less wear.
- No need for ATU power or weight.
- *Make big $$ selling ham products!* lol jk (next slide...)

Commercial product concept



Matchbox + nanovna + rpi
+ little display
+ **DUCT TAPE**

= prototype

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 $\boldsymbol{\Gamma}$

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

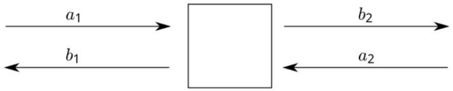
or

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

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

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

Z_L: load impedance
Z_0: 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 $\boldsymbol{\Gamma}_L$ (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.