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

- 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?

# Manual Tuner (Matchbox)

- L network
- Matchbox

Problem & Inspiration: Silent Tuning

- Auto Tuners
  - Transmit, measure SWR, iterate
  - Need power, noisy, heavy-ish, need license
  - Hot-switching relays (wear)
- 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 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

Another Way: Silent Tuning
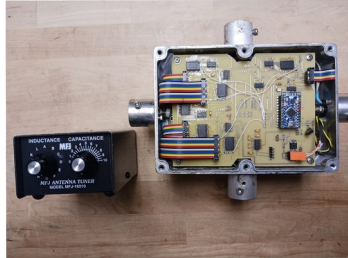
(Melville & Hamilton)

   Parameters of tuner, on bench

\+ sweep of deployed antenna

\+ Math

\= Lookup table of settings
for each frequency

Relays and servos

Relays and servos are needed for automation, but what if I'm willing to make adjustments by hand?   I could eliminate some electromechanical complexity.

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
  - 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 combo. Do once
2. Sweep the antenna – 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

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

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 how it's done:

1. Characterize Tuner
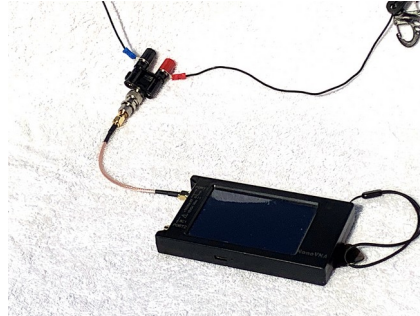
Characterizing MatchBox with benchtop VNA.

For each combination of knob settings, sweep from 8kHz to 32MHz. S11, S12, S21, S22 are written to a file on the laptop.

Tedious, but only needs to be done once.

HP 8753D lab VNA, fyi

2. Measure the antenna

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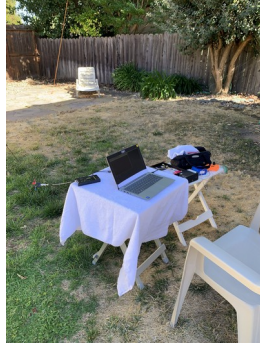 - Save S1P (touchstone file)
- Note – **use a longer jumper!**

When the jumper is this short, your presence interferes with measurments.
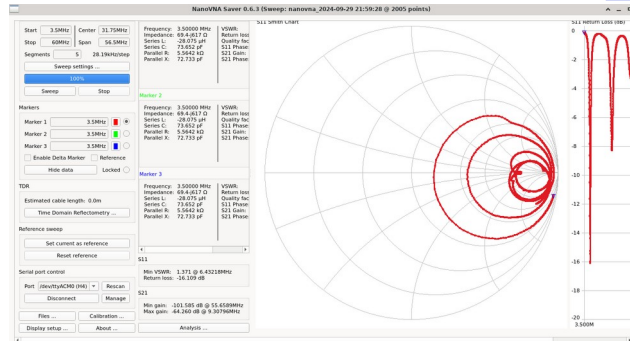
Wire Antenna

- 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

Sweeping the antenna

- NanoVNASaver
- Click on "Files" and "save 1-port file" S1P file
- Touchstone file

Files

- Tuner model file - ONCE

- Antenna sweep file

```
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?
```

```
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?
```
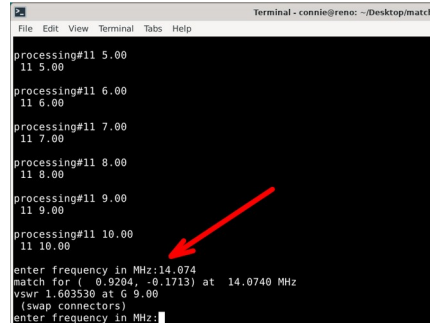
3. Run the program

#compile once

gcc -o qsy qsy.c -lm

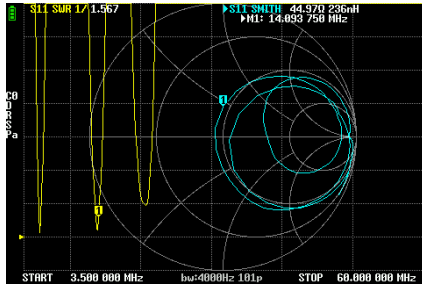#run in the field-- interactive

./qsy matchbox_fullsweep antenna.s1p

Enter 14.074 MHz

→ **Set to G 9**

It works

#run in the field-- interactive
./qsy matchbox_fullsweep antenna.s1p
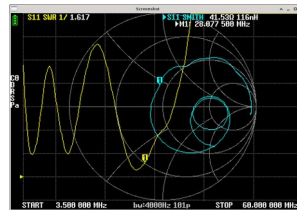
Enter 14.074 MHz
→ **Set to G 9**
SWR ≈ 1.5
(Nanovna only 401 pts. 14.093 closest)
Great for a "random wire"

Another antenna – my downspout

- 28.077 MHz
- Before: SWR = 10
- After: SWR = 1.6

Side note: my downspout and gutters are around 1.5:1 on the 20m band so not a good demo here. 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

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

Things to do next

- Nomogram or booklet?   Ie, no compute in the field?
- 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!
-

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 (next slide...)

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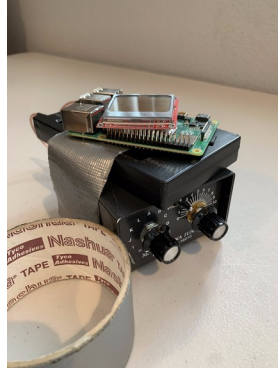
VNA and compute are small and cheap. Why not duct-tape them together, display the settings for the user?

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

Resources

- Matchbox sweep files (for MFJ 16010 manual tuner)
- Code (yet to be posted – contact presenter)
- https://github.com/conniest/InstantTuning
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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 ...
- The fourth set are S22 ...

Appendix 3: 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 (a la buffer amplifier)
- Search 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

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

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

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

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

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

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

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

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

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

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