To automatically tune a Magnetic Loop Antenna

A stand-alone, fully automatic Magnetic Loop Antenna Controller

Presentation for West Island Amateur Radio Club (WIARC) 2015-01-19
and some updates 2015-03-01

Loftur E. Jónasson
TF3LJ & VE2LJX
A Magnetic Loop Transmitting antenna is:

- basically just a resonant circuit using an oversized inductor and an adjustable capacitor
- If the inductor has a circumference of much less than, say, 1/10th of a wavelength, then the efficiency of the antenna will be rather low
- If the inductor circumference approaches ¼ of a wavelength or more, then the antenna would more accurately be characterized as an electrical loop antenna, with characteristics similar to those of a dipole
Some defining characteristics of an efficient Magnetic Loop:

- Extremely high voltage across the Capacitor, easily over 5kV when connected to a 100W transmitter
- Very high current in the main loop, tens of amperes
- A separate coupling loop is used for matching to 50 ohms
- The variable capacitor is tuned for resonance of the loop. Best to have a remotely controlled motor-tune
- The loop has a very high Q = very narrow bandwidth. Need to retune the antenna every few kHz
A couple of my own loops

One 6 foot diameter loop (24’ or 7.5m circumference), tunes 3.5 – 14.35 MHz
One 3 foot diameter loop (12’ or 3.8m circumference), tunes 10 – 29 MHz
A simple means to remotely tune a loop:

- Use a stepper Motor and some minimal control circuitry coupled to a remotely located Rotary Encoder

or

- Use a geared DC Motor with remotely located Up/Down buttons

Frustrating: Antenna has to be retuned every time the frequency is changed by a couple of kHz!!
Enter: The Automatic Magnetic Loop Controller

- Tunes the antenna in real time, tracking every movement of the Transceiver VFO, using the Transceiver Serial (CAT) output
- Receives frequency information from the Transceiver and calculates an appropriate Capacitor position by extrapolating between stored frequency/position pairs
- Initial programming of the Controller is an easy Tune and Store operation, one frequency/position pair per 50 or 100 kHz. The Controller tunes in a linear fashion between the stored presets
But how about automatic tuning for best SWR?

Other similar controller projects have focused on SWR based auto-tuning

- Requires “Transmit to Tune” every time the frequency is changed.

This controller, by reading the frequency data from the transceiver – and by having the antenna characteristics stored in memory –

- Will retune the antenna automatically without needing to Transmit. Not really any need for SWR based auto-tuning

The latest version of the controller can also do SWR based auto-tuning

- This simplifies the initial calibration/store of memory positions and is useful for one-click recalibration
- It also facilitates use without frequency information input from the Transceiver
Transceivers that the controller can communicate with (as of 2015-02)

- Elecraft K3, KX3
- ICOM, all recent CI-V
- Kenwood TS-480, TS-590, TS-2000…
- Yaesu FT-100
- Yaesu FT-817, FT-847, FT857, FT-897
- Yaesu FT-450, FT-950, FT-2000, FTdx1200, FTdx3000…
- TenTec Argo V, Argo VI, Eagle, Omni VII… (two different protocols, have not been tested yet)
- Pseudo-VFO (for radios without serial control)
No common standard for Transceiver Serial wiring, signal levels, data rates and protocols

- Some use RS232, some use TTL, different connectors, usually two signal wires (& ground) for RXD and TXD, but sometimes only one signal wire...

- As per the diagrams to the left, I accommodate all the variants using different cables, all with a 3.5mm stereo connector at the controller side.
Controller building blocks

- Teensy 3.1, an Arduino near-clone (32 bit ARM Cortex M4 microcontroller running at 96 MHz) available for instance at [www.pjrc.com](http://www.pjrc.com), [www.sparkfun.com](http://www.sparkfun.com), or [www.robotshop.ca](http://www.robotshop.ca)

- Two Allegro A4975 Stepper controllers with associated current control circuitry

- Low Pass filters to choke any RF coming over the control cable

- Serial Port, RS232 and TTL levels compatible

- USB Port for programming and backup/restore of frequency/position memories

- 20x4 LCD, Rotary Encoder and Pushbuttons for control

- Expansion: SWR bridge for SWR assisted auto tune
Controller schematic
Inside my Prototype Controller
Here is a picture of the Controller assembled using a bit more professional looking PCB. I laid these out using KiCad and had a bunch of them fabricated.
A few words on the Arduino compatible Teensy 3.1 microcontroller

- 32 bit ARM Cortex M4 at 96 MHz. 64k RAM, 256k Flash
- Small platform, can be soldered or socketed as a DIL device onto a PCB
- Serial over USB and 2x RS232 or TTL level hardware serial
- 32 digital IO pins, 21 Analog inputs, 1 Analog output, I2C, I2S, etc…
An example of rapid prototyping using the Teensy 3.1:

USB connected 65 MHz frequency counter

A few lines of code:

```c
#include <FreqCount.h>

void setup() {
  Serial.begin(115200);
  FreqCount.begin(1000);
}

void loop() {
  if (FreqCount.available()) {
    unsigned long count = FreqCount.read();
    Serial.println(count);
  }
}
```

Some minimal Hardware:

OK – the Magnetic Loop Controller Firmware is probably at over 7500 lines of code by now 😊
To program frequency/position pairs into the controller:

- Tune the Transceiver to a desired frequency, say 14.000 MHz. By turning the Encoder, tune the Antenna for maximum noise, then dip SWR. Store position.

- Tune the transceiver to another frequency, say 14.200 MHz. By turning the Encoder, tune the Antenna for maximum noise, then dip SWR. Store position.

- Add as many memories as desired, in any order.

- From now on, the Controller will tune linearly between the stored positions.
Example of stored frequency/position pairs

This graph shows the frequency/position pairs stored for my 6 foot diameter antenna, between 3.500 and 14.350 MHz.
To derive a Capacitor Position from a Frequency (LCD Screen Capture)

Calculated Position based on stored Frq/Pos pairs above and below the current Frequency of the Radio

Tuned Position or Actual capacitor position is the Calculated Position + or – an offset adjustable with the Encoder or Up/Down buttons. This is used to fine tune antenna, and to tune when no valid frequency.

Tuned frequency of the antenna, based on the Tuned Position

Radio: 7.037.800 Hz
Tuned: 7.037.974 Hz
StepP: 5.811 5.812
Range: 8 Motor: Off
Encoder and Push switches

**Up/Down switches:**
Fine tune Capacitor, using Backlash/Slop compensation, if enabled.
If no frequency information from Radio (manual mode), then step up/down between Memory Presets.

**Encoder:** Tune Capacitor, and navigate Setup Menu

**Menu/Enact button** has several functions:
- Outside of Setup Menu:
  - Short push to recalibrate (stepper pos = calculated pos)
  - Long push to enter Setup Menu
- Inside of Setup Menu:
  - Navigate with Encoder and Short push to confirm selection

**SWR Tune** and **SWR Autotune:** See description on a later slide
Special case scenarios (1)
Endstop or no Endstop

1. **Soft End Stops.** Vacuum variable capacitor, no end-stop switches. Here one has to take care that the stepper motor is just powerful enough to turn the capacitor but not excessively more so. Stepper current is adjustable (RV2). The Up/Down switches will not work beyond the lowest/highest stored frequency/position and the Radio cannot tune the capacitor beyond the lowest/highest stored position. To go beyond an already "proven" range, one needs to turn the capacitor by turning the Encoder, and store new frequency/positions to extend the range.

2. **Hard End Stops.** Vacuum variable, end-stop switches. All as 1) except no software "intelligence" to inhibit use of Up/Down buttons or Radio to tune beyond an already "proven range".

3. **No End Stops.** Butterfly capacitor. Otherwise same as 2).
Special case scenarios (2)
Backlash or Slop compensation

When adjusting the capacitor with a sub-degree precision, any backlash or slop in the coupling mechanism will cause huge inaccuracies depending on whether the capacitor is being tuned in an upward or a downward direction. To battle this, a backlash compensation function can be enabled.

The backlash function works in the following manner:

- When the controller receives frequency information from the Radio which is lower than the most recent previous frequency information, then it does:
  - Tune down to the new position
  - Tune further down by a set angle and then finally tune back up by the same angle.

- A harmless but weird looking side effect of the backlash compensation function is that whenever you tune the VFO down in a slow manner the backlash will be triggered every time new frequency information is received from the Radio. This looks a bit disturbing, but it actually works very well.

With the backlash compensation function enabled and when using the Down Switch to fine tune for resonance, this is best done with short pulsing of the Switch.
Most things are configurable through a set of menus

- Enter with a long push of Menu/Enact button
- Navigate with Encoder
- Select with short push
Using the Microcontroller USB port as a second serial port

- Pass-through mode for computer control of Radio
  - Use with logger software or Ham Radio Deluxe…

- Alternately, USB commands for:
  - Backup/Restore of frequency/position memories
  - Power and SWR poll by computer
  - Debug serial connection to Radio
  - …
SWR Auto Tune

- Blazing fast, same speed as normal tune.

- Includes a Dual Bargraph Power and SWR meter - a subset of the one described here:

  https://sites.google.com/site/lofturj/power-and-swr-meter
SWR Auto Tune

Three basic tune modes:

- **Hunt mode**: (push SWR Tune, or automatic) Hunts for SWR dip within a range of a few hundred steps to each side of current position

- **Tune UP**: (push SWR Tune and UP button) Tunes upward until endstop or SWR dip is found

- **Tune DOWN**: (push SWR Tune and DOWN button) Tunes downward until endstop or SWR dip is found

If no solution found, then return to start position
SWR Auto Tune

Two additional Push switches:

- **SWR Tune:**
  If no RF Power detected, then:
  1) Read Mode of Transceiver
  2) Read Power setting of Transceiver,
  3) switch to AM Mode and set Power to minimum
  4) Transmit On
  5) SWR Tune and report success or fail on LCD
  6) Switch back to Receive, restore previous Mode and Power settings of Radio

  If RF Power detected, then:
  - SWR Tune and report success or fail on LCD, no need to control Radio.

The **SWR Tune** button works in Hunt mode by default, if **UP** or **DOWN** buttons also pushed, then UP or DOWN mode.

- **SWR Autotune Mode On/Off:** If on, then automatically initiate SWR Tune (Hunt) if SWR above acceptable level. Will give up if 3 consecutive failures
SWR Auto Tune

While moving the stepper, a running sum is made of the square of each of the 32 last SWR measurements. As per diagram:

Average for 2 is lower than for 1
Average for 3 is lower than for 2
Average for 4 is lower than for 3
Average for 5 is **higher** than for 4 – We have passed the **best SWR** dip

If the SWR 17 steps earlier (midpoint: \(32/2 + 1 = 17\)) was better than minimum acceptable SWR – then we have found best SWR – Move back to midpoint.

If backlash comp, then an additional move back and forth

The tuning sequence only takes a couple of seconds 😊
SWR Auto Tune

Hardware addition is a Tandem Match coupler. Here is a popular $9 kit which can be modified for 100W and fast response SWR metering:

http://kitsandparts.com/bridge.php

A picture of the kit, as shown on Kits and Parts website:

This is how you would modify it for 100W and fast response:

If R15, R16 on the Controller PCB selected as 18k each; and R17, R18 selected as 22k each, then this meter will work up to 200W
SWR Auto Tune

Another alternative is a double modified Bruene bridge, works between 1.8 and 50 MHz, 0.2 and 200W

If R15, R16 on the Controller PCB selected as 18k each; and R17, R18 selected as 68k each, then this meter will work up to 200W
Project information is in the public domain

- Everything is documented here:
  https://sites.google.com/site/lofturj/to-automatically-tune-a-magnetic-loop-antenna

- Project is licensed under the GNU General Public License.
- Includes fully documented source code
- Bill of materials and building instructions
- Etch mask for homebrewing your own PCB
- Ready made PCBs available for $20 (incl shipping)
Useful references

A few informative Links on Magnetic Loop Transmitting Antennas (selected at random, there is a lot of good stuff out there)


- [http://www.66pacific.com/calculators/small_tx_loop_calc.aspx](http://www.66pacific.com/calculators/small_tx_loop_calc.aspx)  A nice online magnetic loop calculator

- [www.w1hkj.com/magloop/magloop.xls](http://www.w1hkj.com/magloop/magloop.xls)  This is the best magnetic loop calculator I have found, written by AA5TB. This latest version is enhanced by W1HKJ to accommodate different shapes of loops

- [http://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm](http://www.nonstopsystems.com/radio/frank_radio_antenna_magloop.htm)  A comprehensive practical write-up by N4SPP

In case it comes back (link wasn’t working when I checked last time) here is one of the more comprehensive write-ups I have found on how to homebrew simple but efficient magnetic loops using plumbers grade copper pipes:  [http://www.standpipe.com/w2bri/](http://www.standpipe.com/w2bri/)