High Frequency Magnetic Loop Antenna Auto-Tuner for Amateur Radio

Southdown Amateur Radio Society

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October 4 2024

Biography

Gregory Raven, first licensed novice WD5HUV in 1978.

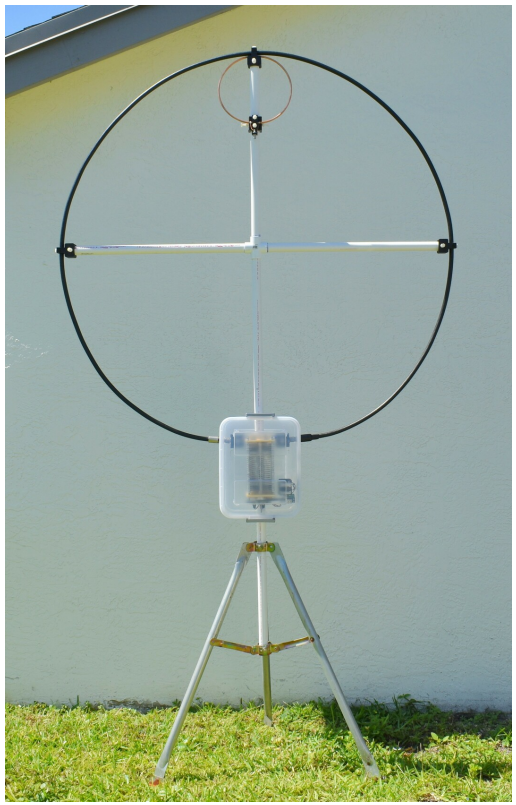
KF5N since 1980.

38 Year retired Motorolan, entire career designing Two-way FM Radios. Mostly interested in Ham Radio experimenting and science. Residing in Florida, all of my antennas have been blown down by hurricanes or struck by lightning.

NOT a professionally trained digital hardware engineer! I am a very "Analog-RF" engineer. Eventually I decided learning digital was a good idea, and I attended the TAPR conference in Maryland in 2011. Slowly going up the learning curve since then ...

The "Magnetic Loop Antenna"

The "Magnetic Loop Antenna" (MLA) is an alternative to a dipole or vertical antenna for the high frequency amateur radio bands. MLAs are a popular amateur radio construction project, and there are a few MLAs commercially available.



Pros and Cons of Magnetic Loop Antennas

The primary advantage of a MLA is that it is relatively small and portable compared to other antennas. You can easily pick it up and move it around. This is really great for situations where a permanently mounted outdoor antenna is not possible. Some ops even use them indoors!

MLAs make amateur radio possible in circumstances which would otherwise prohibit operation on the HF bands.

But there are cons too:

- Very narrow bandwidth.
- Low efficiency which translates into less radiated power.
- Some sort of tuning mechanism is required. In this case, a moderately complex controller unit.

Building a Loop Antenna and Controller Prototype

"Microcontroller Projects for Amateur Radio" by Jack Purdum W8TEE and Albert Peter AC8GY contains two chapters on what they call the "Double-Double Mag Loop". One chapter covers the mechanical details of the antenna, and the next covers the controller.

The “Blue Pill” Device is no fun!

The Microcontroller Projects book loop controller uses a “Blue Pill” microcontroller board.

This “Blue Pill” controller board comes in a lot of variants. There are “official” and clones. Some will work, and some will not. Do you know which ones will work and which ones will not? Only by trying them!

Also needed is a bunch of support software and also a “dongle” (clone? Yes!) to code upload. This all works in Arduino, but the configuration is a headache.

But there was something new on the horizon ...

The Raspberry Pi Pico is a lot of fun!

The "Raspberry Pi Pico" appeared about the same time I was working with the original project. This device solves a lot of problems! It has all of the capabilities of the Blue Pill and more. The documentation and "Software Development Kit" (SDK) are superb. The programming interface connects into the GPIO of a Raspberry Pi single-board-computer (SBC). So with this new device, I was off to the races re-developing the loop controller with the Pi Pico.

Most importantly of all, the Pi Pico includes a debugger! This was essential in development of the software. Pi Pico 2 was recently released:

`https://www.raspberrypi.com/products/raspberry-pi-pico-2/`

Block Diagram of a Radio and Loop Antenna

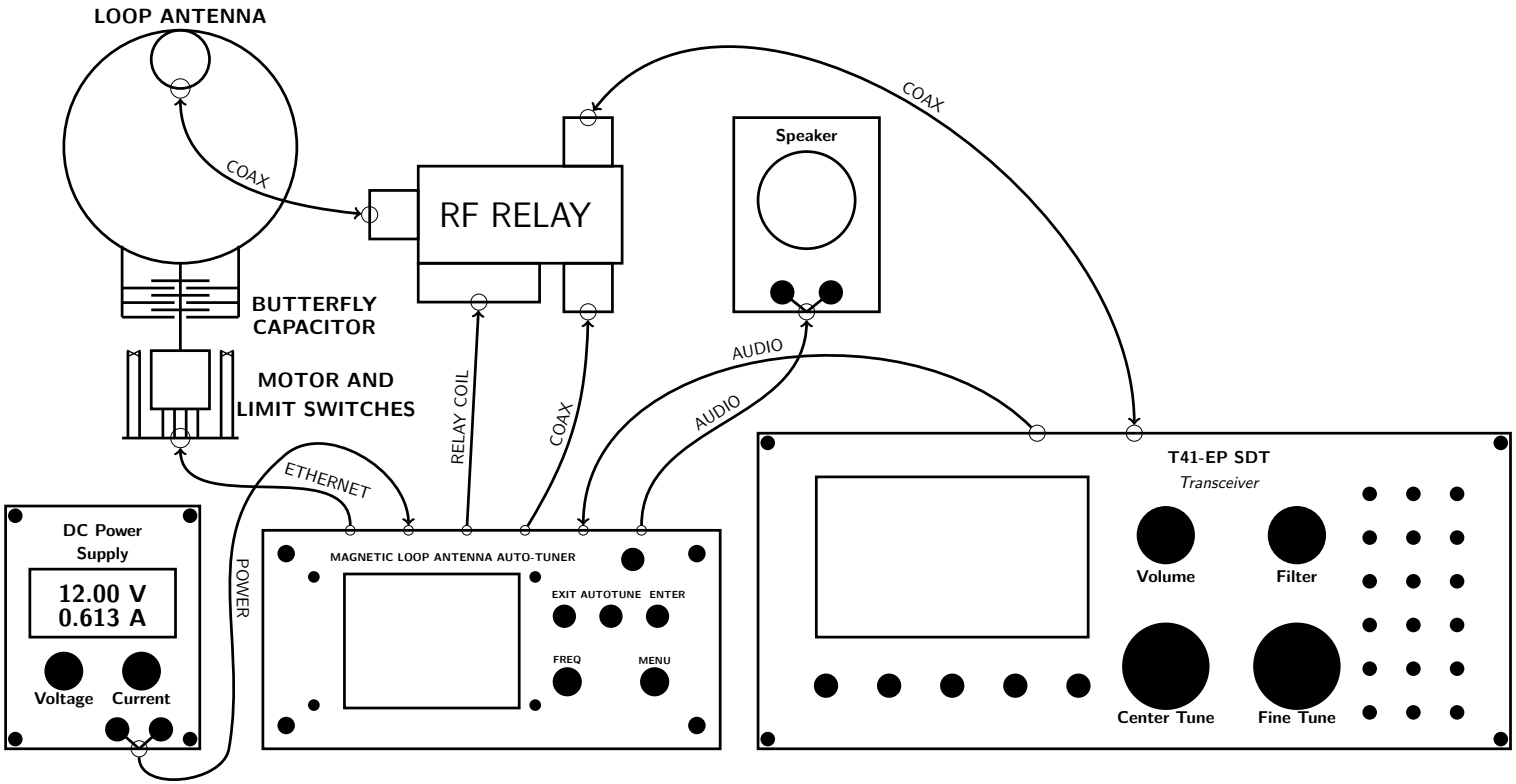


Figure: **An Amateur Radio Station using the Loop Antenna Controller**

This is an Electro-Mechanical Project!

The Pi Pico based controller is the easy part!

If you want to build a successful MLA, there must be a lot of attention to the mechanics of the antenna. What are the reasons for this?

- The antenna is a high-Q narrow bandwidth tuned circuit.
- The frequency change per angular rotation of the capacitor is very high, especially on the highest band.
- "Backlash" must be minimized, or the lowest possible SWR setting will never be achieved.
- The antenna is "calibrated" via stepper motor steps, and returning to any given step must be repeatable.

Borrowing from Another Technology: 3D Printers

We can borrow from another technology and get the precision repeatability we need! Thankfully 3D printing technology gives us the parts and technology to make an inexpensive home-brew MLA a real possibility.

What components are these?

- 0.9 degree stepper motors and sturdy mounting brackets.
- Toothed belts and pulleys. 3:1 reduction, so $0.9/3 = 0.3$ degree angular rotation.
- Calibration and limit switches.
- Sophisticated stepper driver modules like the TMC2225.

Pulley and Belt

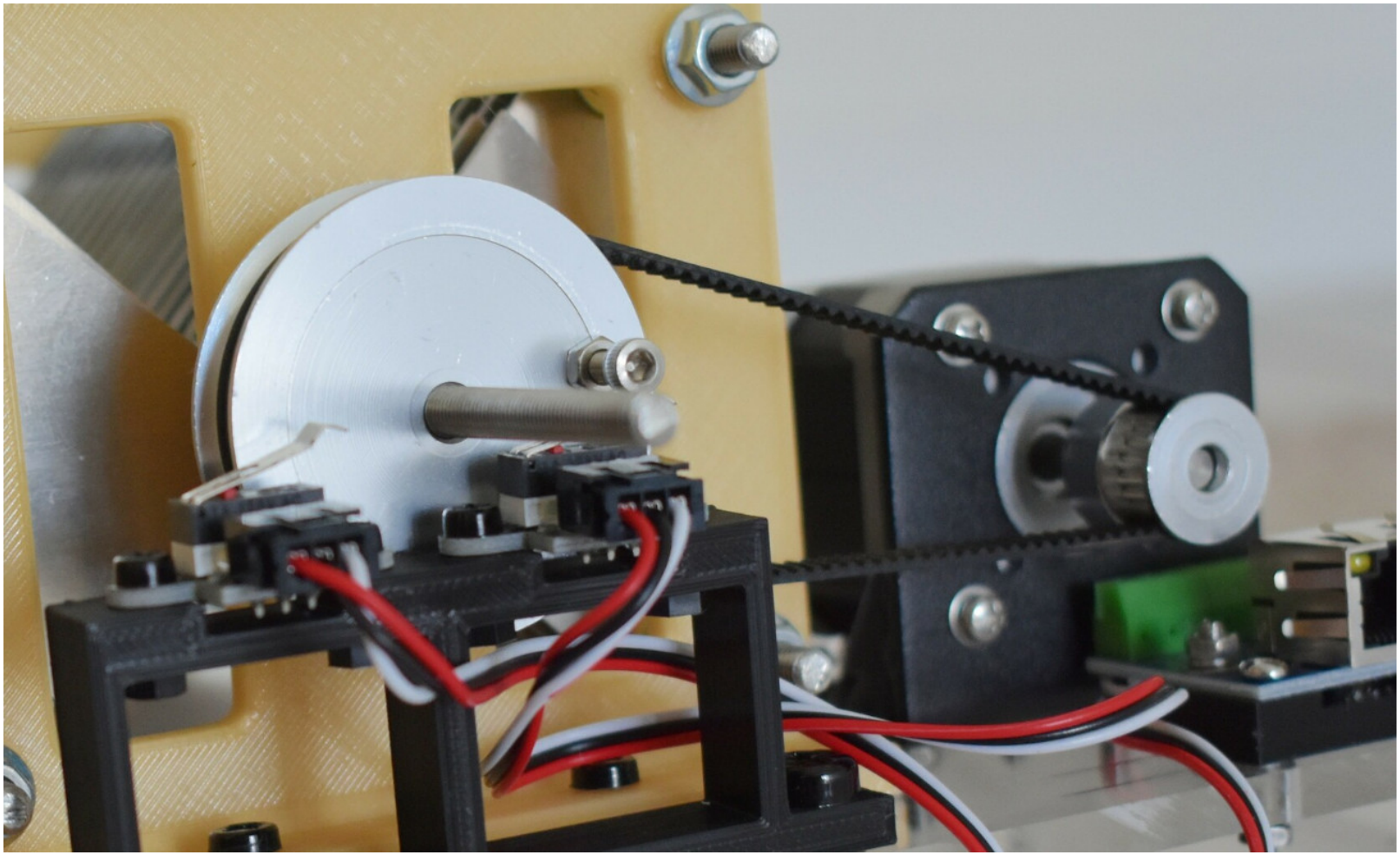


Figure: **3D Printer Technology**

TMC Series of Stepper Motor Controllers

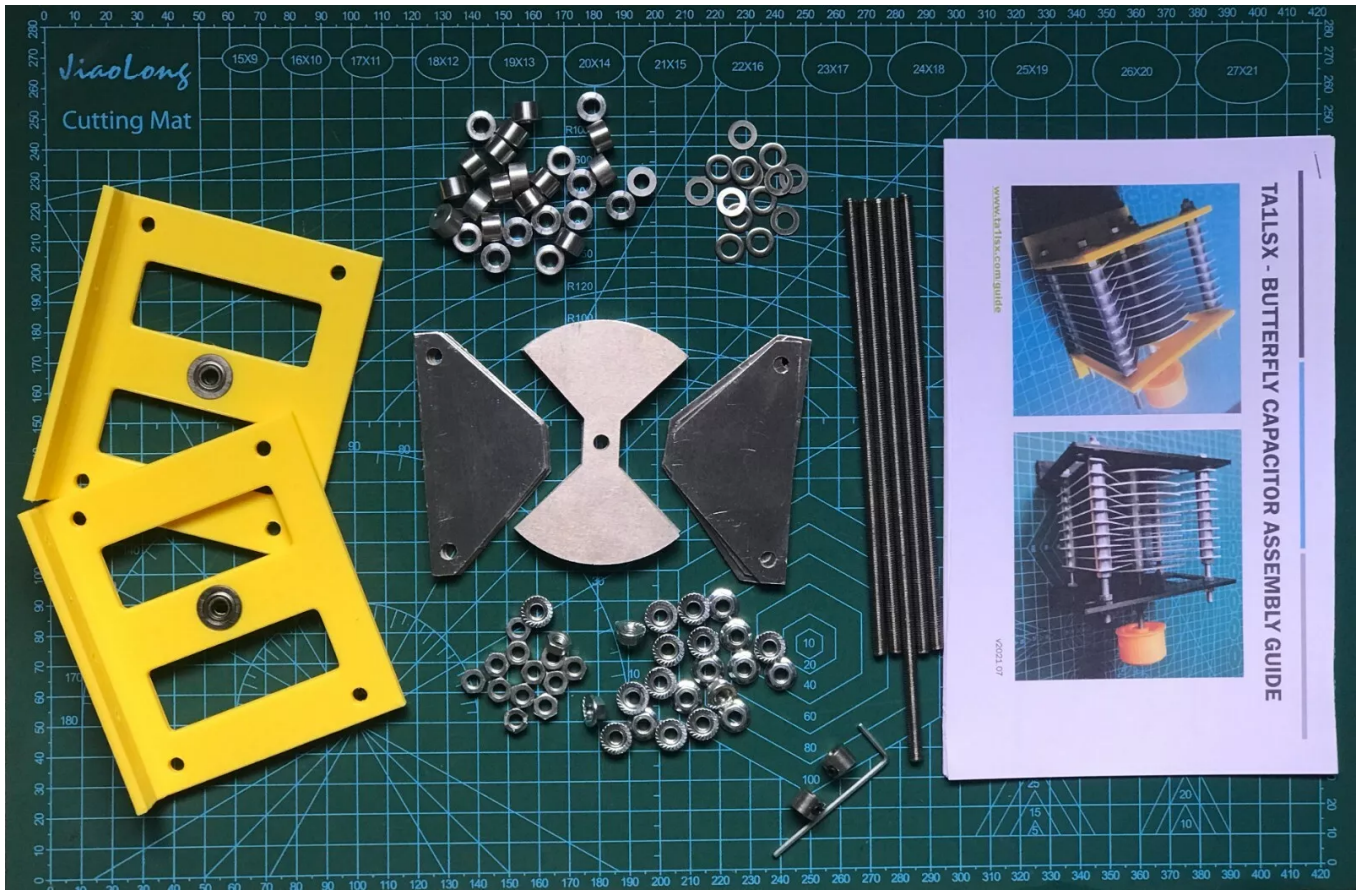
The TMC stepper motor controllers are very sophisticated. Incorporating this technology into the controller was a huge leap forward! The ability to get fine control over the motor is greatly enhanced. Also, due to the way the controller drives the motor, RF interference during antenna tuning is greatly reduced.

The particular device used in the TMC2225, which is controlled via a UART from the Pi Pico. This does add complexity to the software. But it is very well worth it!

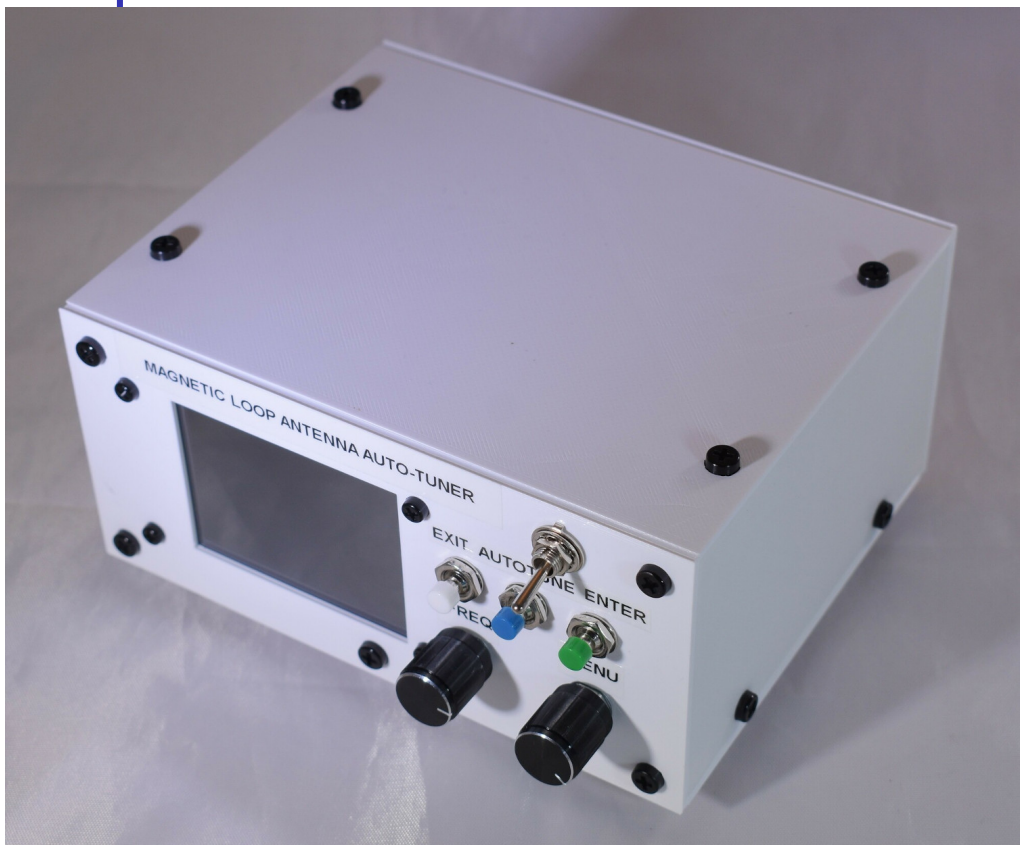
eBay Variable Capacitor Kit

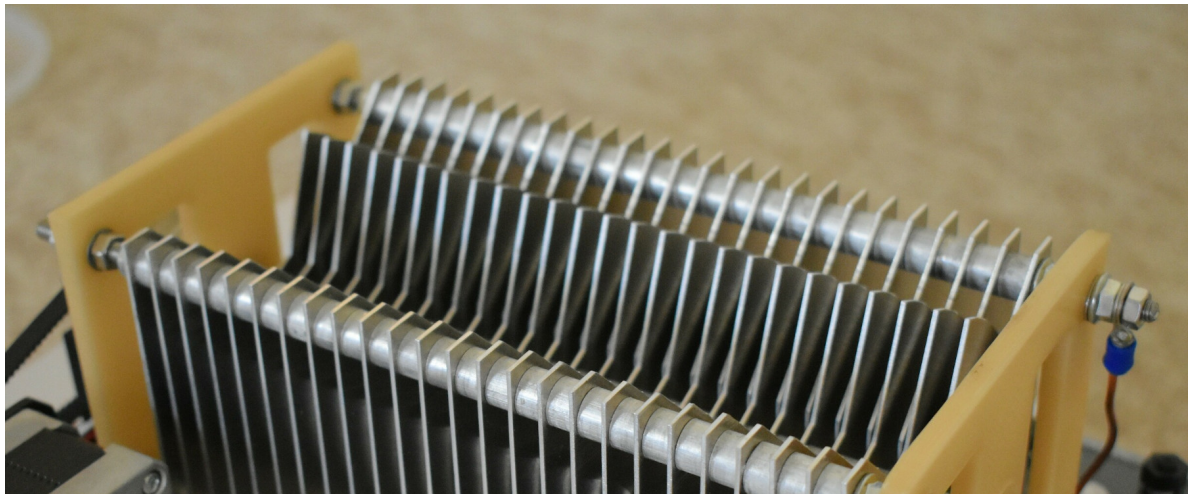
This is the variable capacitor kit used in my loop antenna:

`https://www.ebay.com/itm/165378860136`



eBay Variable Capacitor Kit



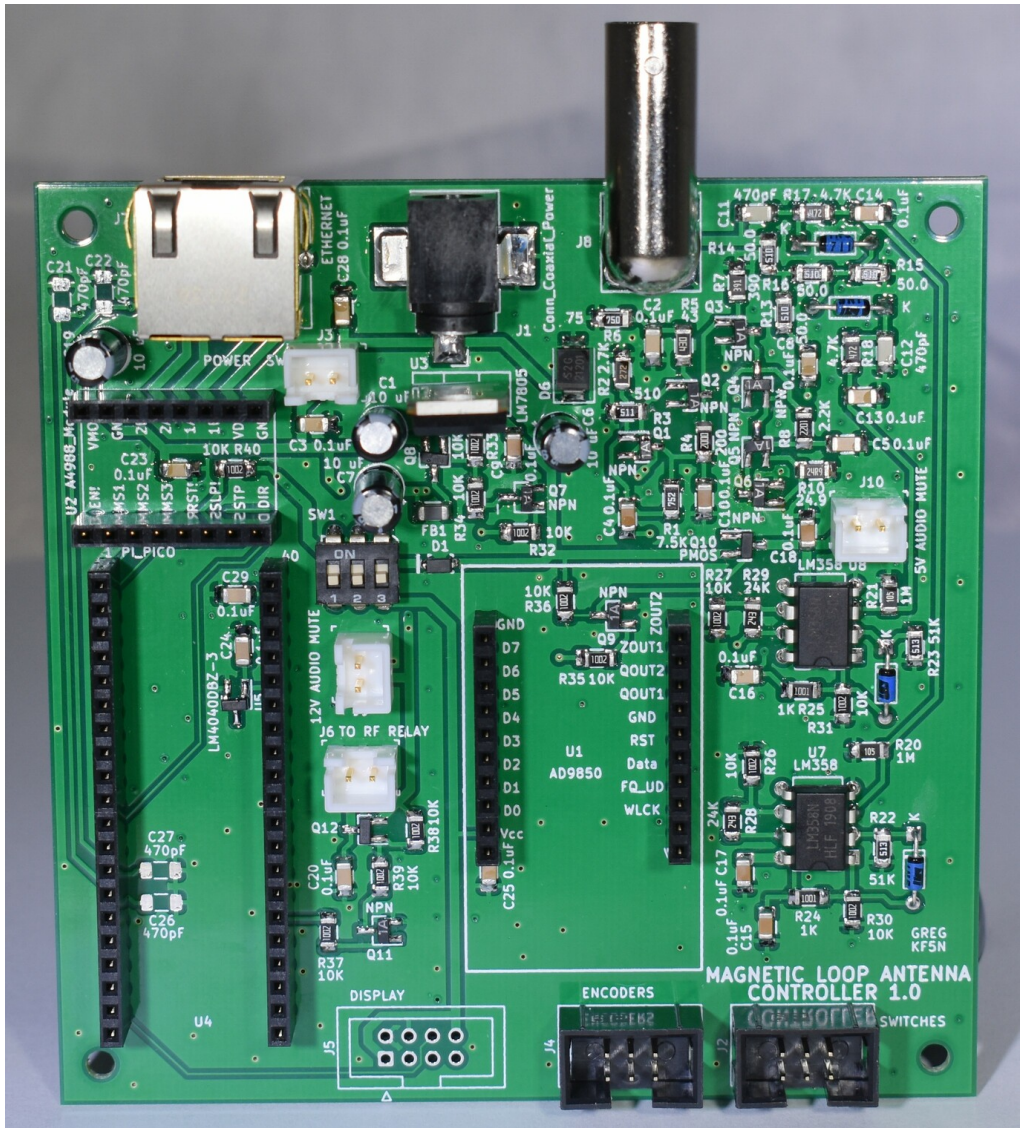


The Controller

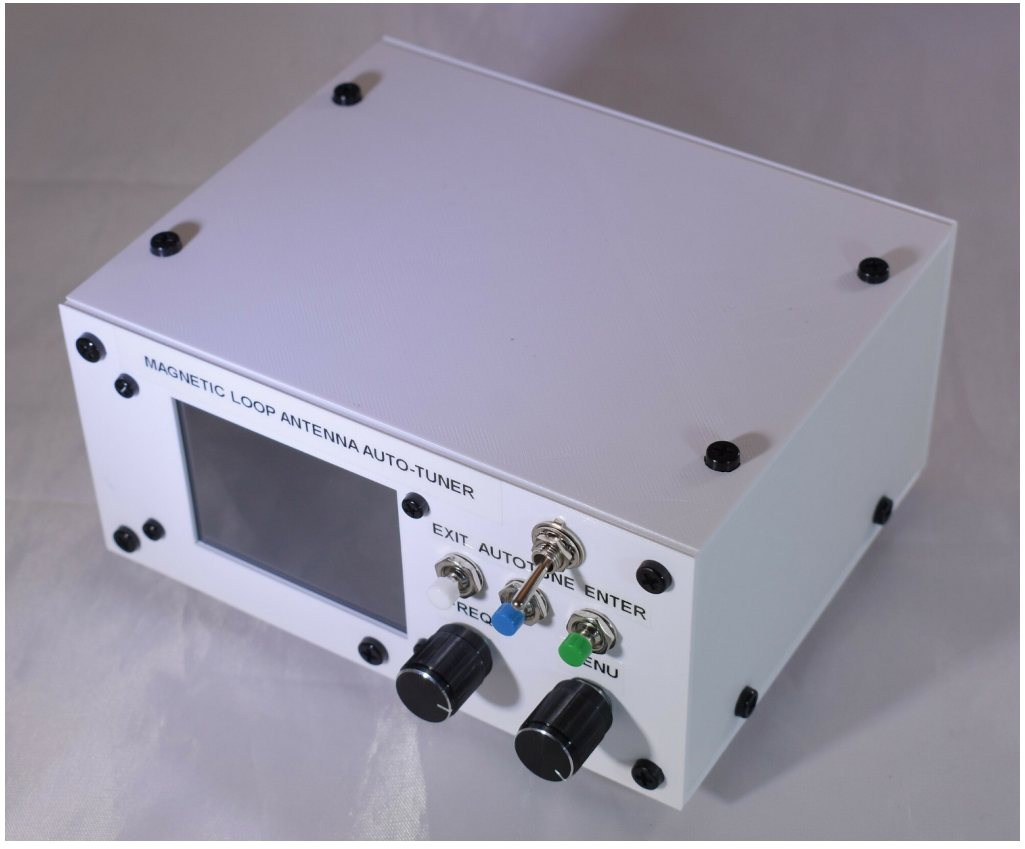
The controller is “stand-alone”. It operates 100% independently of the radio. The user interface is designed to be simple to use, but flexible enough for a typical use cases.

Figure: **Loop Controller**

The Controller PCB



3D Printed Enclosure



What connects to the antenna?

There are two cables between the controller and the antenna:

- 50 ohm coaxial cable.
- CAT-6 or equivalent LAN cable, preferably outdoor rated.

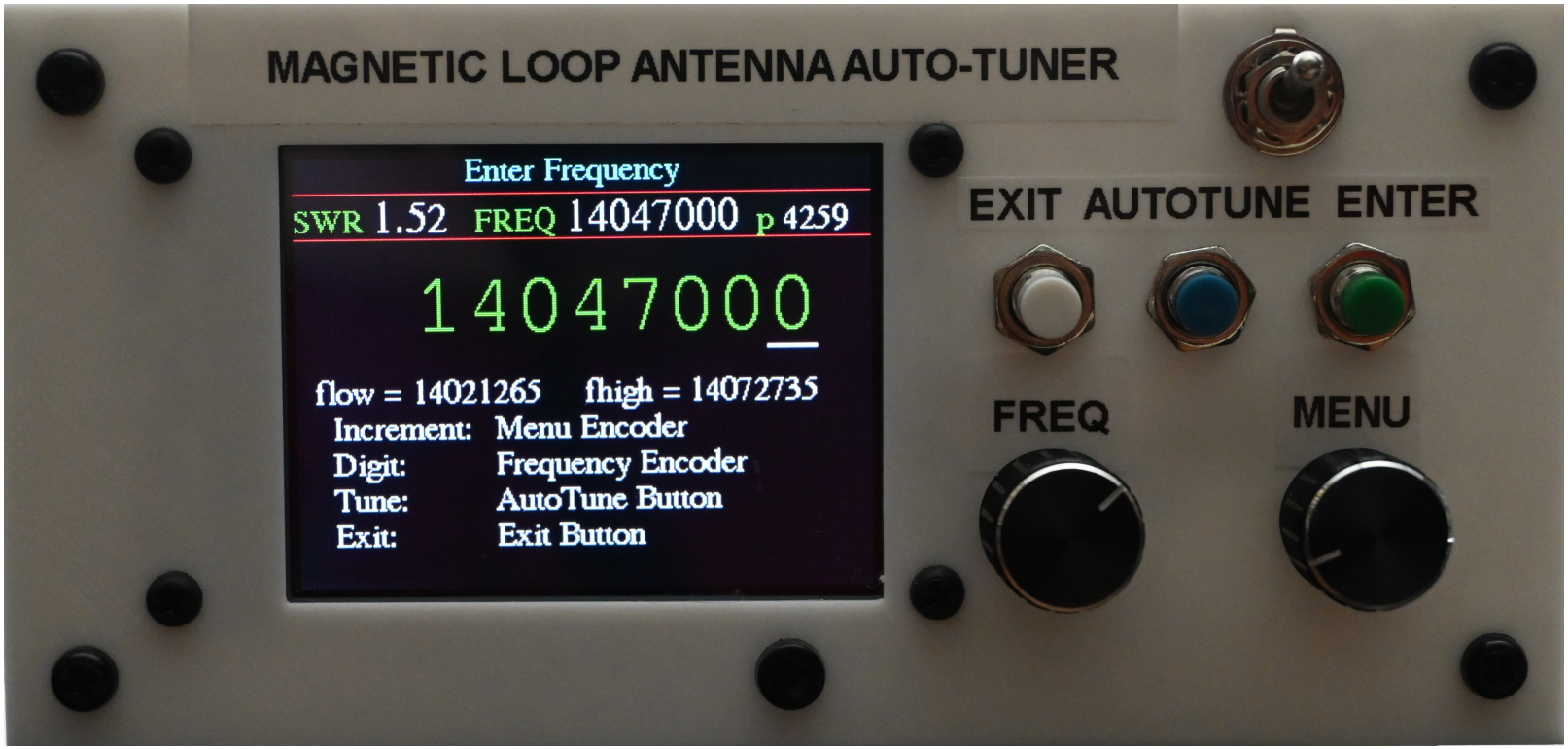
The CAT-6 LAN cable carriers the four wires required by the stepper motor, grounds, and two more wires for the calibration and limit switches.

CAT-6 LAN cable is critical because it is shielded!

RF Relay

As mentioned before, the controller is completely independent. This is unlike other loop controllers which require a transmitter to generate a tuning signal. The controller has a DDS which generates the tuning signal. Thus, an external relay is required to connect/disconnect the controller and radio. The controller has a relay output connector which provides the switching function. When this relay is de-energized, the radio is connected to the antenna.

Main Controller Function

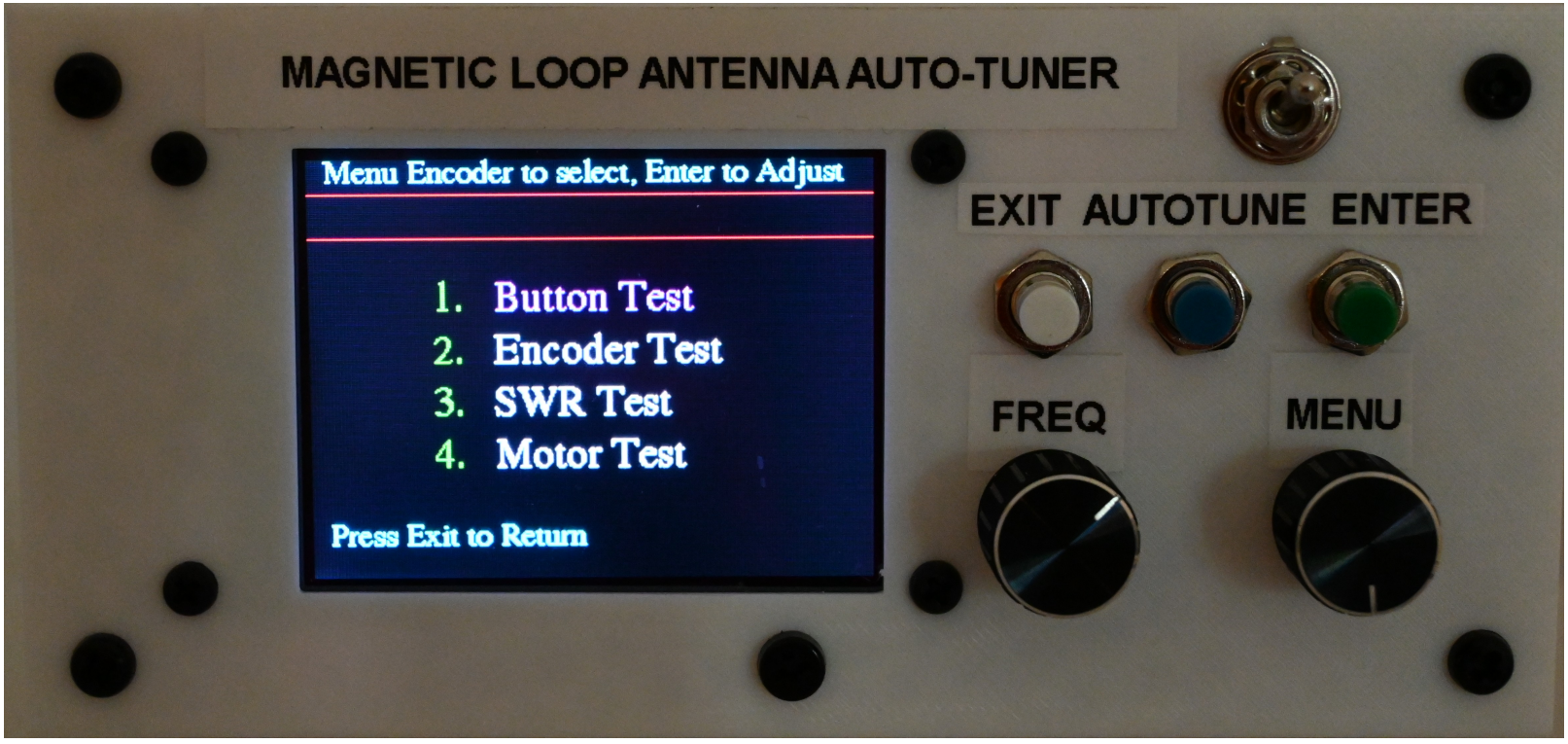


Functions of the Controller

The controller has several test functions for the initial power-up:

- Button test.
- Encoder test.
- SWR test.
- Motor test.

Functions of the Controller



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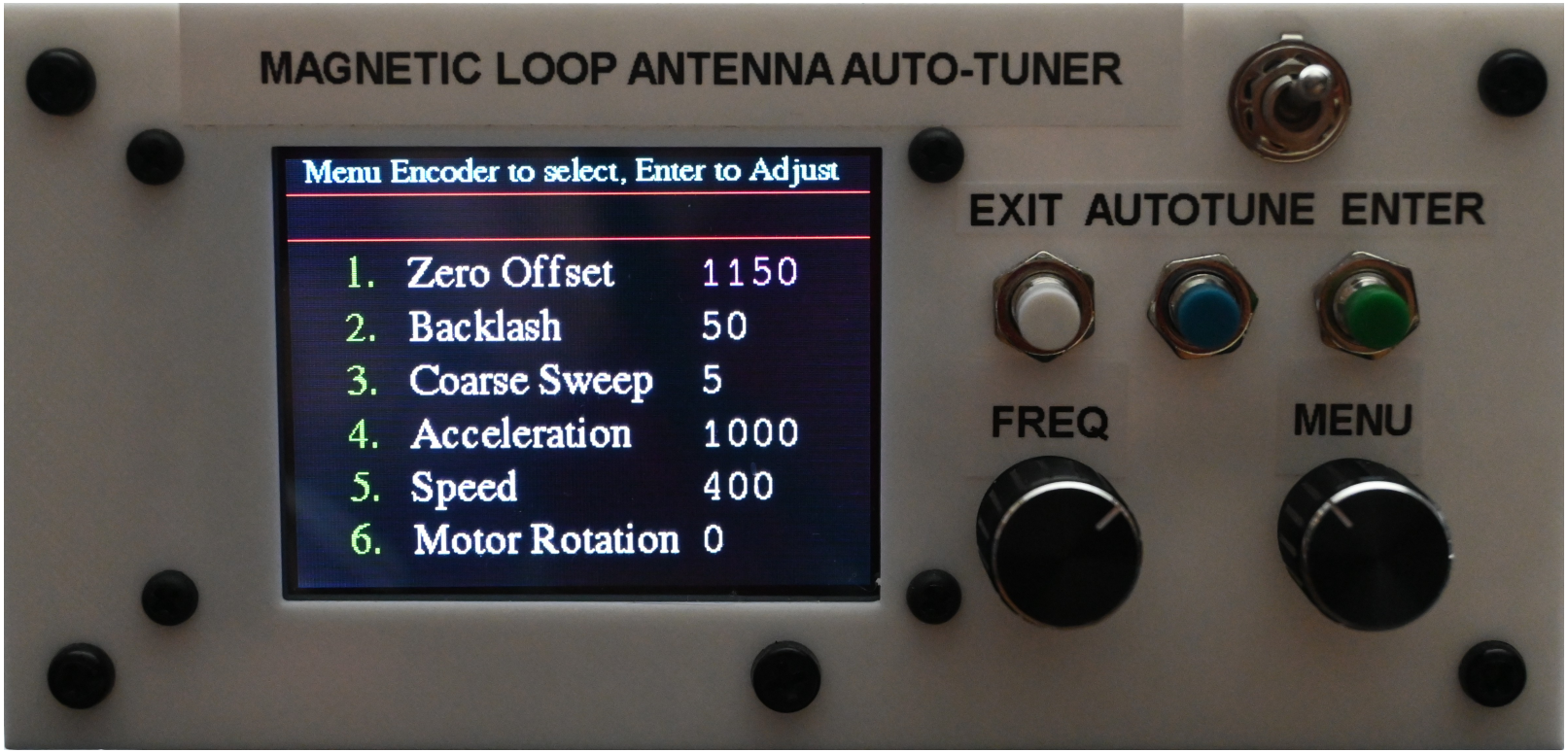
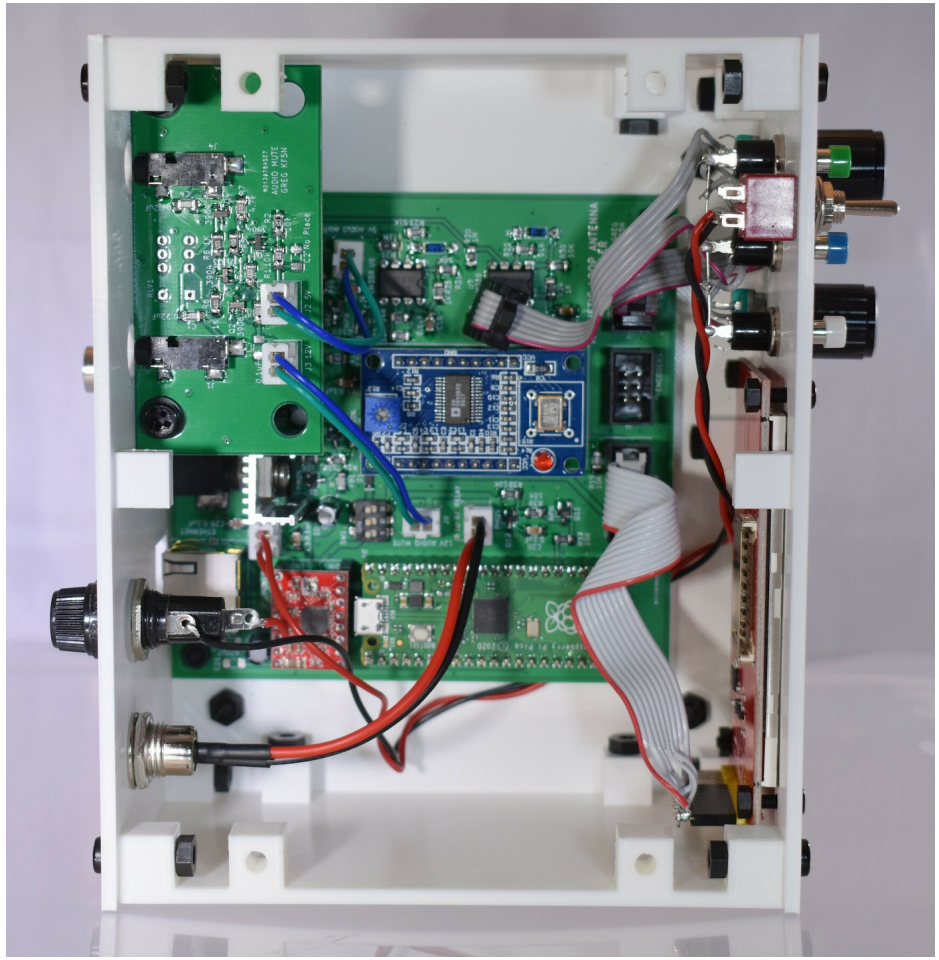


Audio Mute Board

An optional feature which mutes the audio during Auto-tune.



URLs of Github Repositories

This takes you to the PDF documentation file. This is where you should start:

`https://github.com/Greg-R/magloop_pico_project/blob/master/magloop_pico_book.pdf`

The primary project repository:

`https://github.com/Greg-R/magloop_pico_project`

The primary project repository contains submodules. Antenna components:

`https://github.com/Greg-R/magloop_pico_antenna2`

Pi Pico SDK code:

`https://github.com/Greg-R/magloop_pico_code_2`

URLs of Github Repositories

Pi Pico Arduino code:

`https://github.com/Greg-R/magloop_pico_arduino`

The PCB:

`https://github.com/Greg-R/magloop_pico_pcb_2`

3D printed enclosure:

`https://github.com/Greg-R/magloop_pico_enclosure`

Audio mute PCB:

`https://github.com/Greg-R/magloop_pico_audiomute`