Automatic Magnetic Loop Antenna Controller

- Under Construction -

1. Introduction

a) Initial Considerations

This controller has been designed to automate the control of magnetic loop antennas. The reader is encouraged to read through the information on this website to determine if he or she undertakes this project. There are several concerns you need to evaluate:

- The first has to do with possible adverse effects to people and animals caused by the RF fields generated by a magnetic loop antenna. RF exposure can be intense and possibly harmful in close proximity to these (and all) transmitting antennas. *Please check the FCC RF Exposure Guidelines and other web sources to help you make an informed decision about whether or not a magnetic loop antenna is right for you and for your family.*

- There is always the ***possibility of equipment damage***, especially when connecting something to equipment not expressly designed for it. *(Even connecting 'compatible' equipment items has been known to cause problems).* Today's electronic equipment is not 'cheap' and can be damaged in a number of ways, viz: by electro-static discharge, by lightning and by transmitting with no antenna attached, or into an antenna with a high SWR.

- The controller described herein attempts to facilitate the safe and automatic tuning of a mag loop antenna by reducing the output power to an acceptable level via ALC control so the RF output circuitry will not be damaged when the line SWR is highr. *The prototype version works perfectly well with my IC-746, and I believe that it will work just as well on other similar, mid-range radios.*

- But I cannot, and will not be responsible for any personal damage and / or damage to your equipment should you undertake this project**.**

b) Magnetic Loop Antenna Experiments

For several years now I have been experimenting with Magnetic Loop Antennas at this QTH. In the beginning, I tried octagonal 3/4" copper loops with homebrew ‘trombone’ capacitors wrapped in Teflon tape and driven by a surplus screwdriver motor. While they worked OK, they were a real nuisance to peak after QSY’ing.

After this, I built a similar loop that used an *MFJ butterfly capacitor*, driven by the very same motor that MFJ uses in their magloops. The motor was controlled by a microprocessor and an SWR bridge designed to automatically sense resonance. This semi-automated approach worked better, but experienced difficulty hitting the ‘sweet spot’ as the analog motor – controlled by a M/P generated PWM signal – would often drift past resonance, and the controller would keep hunting back and forth over it. *Operation was not always consistent.*

Finally, at the suggestion of **Byron – WA8LCZ –** I used a stepper motor in conjunction with the MFJ butterfly capacitor and programmed the controller to automatically hunt for resonance. The microprocessor driven controller – when activated – will perform the following steps:

- Apply ALC voltage to the transmitter to save the final amplifier transistors during tune up,
- Key the transmitter / transceiver in either the CW (key) or SSB (PTT) mode),
- Apply a 1Khz. tone to the microphone input to provide a signal source *(so there’s no need to switch modes while tuning),*
- Automatically rotate the capacitor to resonance, and then release the whole connection, with a resonant antenna, ready for use.

If desired, the capacitor can be rotated manually, at either slow or fast speed. Resonance will be noted by the marked increase in background noise.

The stepper motor approach has proven itself to be much more accurate than the analog motor, for the following reasons:

- Predictable and more accurate control,
- No brush generated noises when tuning in the receive mode,
- No 'drifting' in the presence of RF when finally tuned, and
- Higher torque for moving 'heavier' capacitors.

The ***current*** *design works* ***best*** *with* ***butterfly capacitors*** as it’s very difficult for the controller to determine in which direction to rotate the capacitor *unless the detected SWR happens to fall within the capture range of the Directional Coupler (described later)*. If the SWR is 4:1 or less, then the controller will move the stepper in one direction while noting any increase or decrease in SWR, adjusting accordingly. However, if the SWR is higher, then the controller will keep moving in the initial direction while ‘watching’ for a decrease in SWR. Once found, it will ‘zero in’.

With a butterfly capacitor (rotatable over 360 degrees), this is no problem. I’m still trying to develop an efficient remote phase detector to ‘tell’ the controller in which direction to move the capacitor. The best I can offer for those wishing to use a vacuum variable, for example, is a ‘limit switch’ type of sensor at the capacitor itself which, when activated, will alert the controller to change direction. The stepper motor design is more complex than conventional analog motors *(as used in the MFJ Magnetic Loop design and in homebrew loops)* where the end of tuning travel interrupts the current feeding the motor via the limit switch. This current ‘interruption’ followed by a polarity reversal will not work with a stepper motor as the controller needs to reverse the stepping sequence.

2. Purpose

This website will not go into any exhaustive details about how to build magnetic loop antennas as there are many excellent sites written by authors much more experienced than me. For anyone who is interested, however, I will briefly describe the magnetic loop I'm currently using with the intelligent controller should anyone care to replicate this design.

3. How The Controller Works - *View the Schematic Diagram*

The controller itself is driven by a *Motorola MC68HC908QY4* flash programmable microprocessor (M/P). The controller has been programmed to move the UNIPOLAR stepper motor in either the forward or reverse directions using the ***half-step*** mode. The simplicity of this approach is that no additional stepper motor interface chips *(aside from the 4 TIP-122's needed to drive the motor itself)* are required. All the "stepping' code is within the M/P.

However, one potential drawback is that the ***microstepping*** offered by the other more complex driving arrangements *(with special purpose chips and software overhead)* is ***not available*** in this design. Rather, the builder may have to use an external reduction gear at the capacitor itself to achieve the degree of resolution to automatically tune the loop close to 1:1 SWR. I used a reduction gear in my loop.

There are just 3 switches on the controller, and 2 (normally open) push buttons.

- The first DPDT switch (**ON / OFF**) turns on the power to the controller and to the stepper motor.
- The second SPST switch is the mode (**AUTO / MAN**), and the
- Third SPST switch controls the speed (**FAST / SLOW**) when in the **MAN** mode only. This switch has no function in the **AUTO** mode as the stepper ***motor speed*** and ***direction*** of rotation is controlled ***autonomously*** by the M/P.
- The **UP** and **DOWN** push buttons, when pressed in the **AUTO** mode will start a tuning cycle by keying the radio, etc. In the **MAN** mode, they simply rotate the motor.

On power up, the M/P initializes and goes to the WAIT mode. When in the **AUTO** mode and when either of the **UP** or **DOWN** Tune buttoms are pushed, the M/P will apply ALC voltage, activate the SSB tuning tone and then key the transmitter. If, after 250 ms, no RF is detected, the M/P will release everything.

If RF is detected, the M/P will examine the SWR provided by the external Directional Coupler or SWR Bridge. If the SWR is 4:1 or less, the M/P will step the motor along for a couple of steps and then re-examine the SWR. If found to be less, the M/P will keep moving the motor in the same direction, hunting for resonance. If the SWR has increased, the M/P will reverse the direction and keep hunting. A front panel LED shows motor direction.

When resonance has been found, the M/P will release. The user has an additional 2 seconds to use either the **UP** or **DOWN** buttons to fine tune the loop if the absolute 1:1 point has not been found. Sometimes this happens.

In the **MAN** mode, the M/P will work in either the **FAST** or **SLOW** modes. The **FAST** mode is useful in finding near resonance by listening to the receiver noise / or actual signal. ***In the FAST mode, the transmitter is not keyed.***

The **SLOW** mode is useful for fine tuning the transmitter as the M/P will first apply ALC, key the transmitter (etc) for as long as either the **UP** or **DOWN** buttons are depressed. So, for example, an amateur could use just the **MAN** mode to fine tune a mag loop antenna without resorting to the **AUTO** approach.

4. Construction of the Intelligent Controller - *Parts Inventory*

The ideal construction method is a printed circuit board (PCB). Thus far, I have designed a *PCB* (about 3.5 x 4 "), but have yet to submit it to the PCB manufacturing facility, mainly because:

- I'm personally happy with my '*breadboarded*' design, and because
- subsequent demand for any P/C boards is uncertain at this point.

> ***Please Note:*** *The breadboarded design picture shown on this website is more complex than necessary as the board mounted switches and the extra components are needed for the development phase and to program the M/P from a personal computer.*

If the amateur community expresses any interest in P/C boards, then I'll undertake its manufacturing so long as all of the per board manufacturing and shipping costs are covered. I've had boards made before for other projects and the per board cost usually came out in the $18 / $22 range.

a) Fully Automatic Operation - *Sensor Circuit Required*

For fully automatic operation, the SWR sensing is required. The primary benefit of remoting an SWR sensor from the controller itself is that, in addition to removing RF from the M/P, the interconnection coaxial cables (from the transmitter to the sensing device and from the sensing device to the loop itself can be placed on the floor, away from the equipment desk and connected to the controller with a shielded 2 conductor cable. The controller itself - while small - can be placed in a convenient space on the desk with the **UP / DOWN** push buttons mounted in a *small plastic enclosure* anywhere on the desk. Taking this one step further, the **AUTO / NORM** and **FAST / SLOW** switches could also be mounted in the same enclosure.

Two types of remote SWR sensors will work with the loop controller if automatic tuning is desired. The first is a directional coupler, and the second is a type of SWR Bridge. I have personally used both. The directional coupler was purchased from ***W8DIZ*** and modified with higher wattage 51 ohm resistors. It comes complete with a P/C board, requires no adjstments and is easily built / installed.

The SWR Bridge type uses a single bi-filar wound toroid, a variable capacitor and a handhul of parts, is constructed on a small piece of (Radio Shack) perf board and requires a single (null tune) adjustment.

b) Manual Operation

If only manual operation is required, then the remote directional coupler is not required. Furthermore, other features may be omitted, like the SSB transmit Tone, ALC provision, etc, etc by not installing the components shown on the functional schematic and in the 'Chinese menu' parts listing.

c) Breadboarding the Loop Controller Circuit

Any builder experienced in breadboarding construction techniques could whip up a suitable controller using the parts shown on the attachment *(some of which may readily be found in his / her junkbox).* I can provide a programmed M/P to complete the package.

5. Choice of a Suitable Stepper Motor

a) UNIPOLAR with a Small Step Size and (Possibly) a Reduction Gear

This is perhaps the most challenging part of the process. Ideally, you should look for a UNIPOLAR motor ***(BI-POLAR** will **NOT** work in this design)* with a small step size - say .9 degree. This means that the motor will have 360/.9 = 400 steps per revolution if used in the full step mode. If used in the half step mode, then each step will be .45 degree, and the motor will have 360/.45 = 800 steps per revolution.

When fine tuning a mag loop, you need the finest resolution possible to come close to a 1:1 SWR. While 800 steps per revolution might be enough for the tuning of a vacuum variable capacitor, I didn't think that it would be fine enough for a butterfly capacitor which goes from min to max capacity in 90 degrees, or in 200 steps in the half-step mode. So, when mounting the stepper motor on the capacitor, I interposed a 10:1 Jackson Brothers reduction drive and it works like a charm with my 20 foot, octagonal, .5 inch copper loop. I'll try to provide an XCEL spreadsheet to better describe these requirements.

b) Low Current Drive

When looking for stepper motors, I 'lucked out' when searching the All Electronics website. I found a NEMA 17 motor with a .9 degree full step that required just 450 ma per phase (you use both phases when half-stepping) - nicely satisfied by a 12 VDC supply. So, I use a 1 amp Radio Shack "wall wart" supply to power both the controller and the stepper motors together. In normal operation, neither the supply nor the TIP-122's get warm and no heat sinking is required. Later on you'll find some additional reading / research material on stepper motors.

6. Building the Magnetic Loop Antenna

Since every ham has his or her own construction methods, I'll show you 'mine' if you promise not to laugh (hihi).

a) Copper Loop Construction

First, I constructed an octagonal magnetic loop antenna using 20 feet of copper tubing and 8 - 45 degree elbows purchased at Home Depot. I cut the tubing into equal lengths, cleaned the joints and soldered it up. *Nothing really special here, right??*

Next, I mounted the stepper motor onto a *piece of spare aluminum* that I had from a small Radio Shack project box. I used 3 of these sheets, one to mount the motor itself, one to hold the reduction gear, and the last one to bolt the whole thing to the MFJ variable capacitor.

Here's how the capacitor assembly looks *all bolted together*.

Next, the 'whole thing' is placed within a 4" PVC drainpipe which will remder it waterproof when the top is placed on it, *as shown here.*

> ***Note:*** *There is a 4 inch cut in the top member of the octagon to allow connection to the variable capacitor.*

That's Home Depot 5 conductor thermostat cable hooked to the stepper motor. Finally, the capacitor assembly is mounted on the top of a PVC mast, and the top copper member is opened up so that each end of the loop may be connected to the top of the capacitor with heavy gauge wire. Not very pretty, but it is *waterproof and it does work well*.

b) Feeding The Loop - *A Toroid Seems Better*

For feeding the loop, I've used both wire and Faraday Loops. By adjusting the coupling loop, it's possible to get a very low SWR on several ham bands (e.g. 40, 30 and 20 meters with a 20 foot loop). Recently, I replaced the wire coupling loops with an FT 240-43 toroidal core. The toroid is placed one the lower leg of the loop, shimmed and centered in place with a short length of PVC pipe. The coax from the transmitter terminates in a 3 turn link (of #14 enameled wire) wound thru the toroid (see picture).

In my experience, this feeding method is preferable as the loop seems somewhat quieter in the receive mode and presents a very near 1:1 match without any manipulation *(as was common with the wire-type coupling loops)*.

7. Testing It Out - *Verify the Stepper Motor Operation First*

a) Identifying the Stepper Motor Leads

If you decide to 'encapsulate' your capacitor / reduction gear / stepper motor assembly in a waterproof container, verify its operation with your controller before enclosing it. Accordingly, connect it up to your controller, referring to the manufacturer's data (if any).

Your surplus UNIPOLAR stepper motor may have 5 leads, but will generally have 6 or even 8 wires. The wires for the 6 and 8 lead varieties exit the motor in either 3 or 4 lead 'bundles', respectively. UNIPOLAR steppers have 2 coils per stator pole.

- In the ***8 lead motor***, the two leads from the two coils from both stators emerge from the motor.
- In the ***6 lead motor***, the two coils on each stator pole are joined (opposite sense) together before they emerge from the motor.
- In the ***5 lead motor***, each of the two joined wires are themselves joined before they leave the motor.

Please check out the *following information* to determine how to connect the power, and the A, B, C and D leads to your magnetic loop controller. As long as you have correctly identified the power lead(s), and the respective stator pairs, the worst that can happen when they are connected to the controller is for the motor to 'quiver' when either the UP or Down buttons are depressed in the Manual mode.

Once you have the motor 'poled up' correctly, ensure that there is no binding of either the capacitor or the reduction gear (if used) when operating in the FAST mode.

b) Interfacing with the Stepper Motor

Connect the coax directly to your magnetic loop antenna. Do not connect the KEY / PTT, ALC or SSB tone leads at this point. Then, in any amateur segment for which your loop is designed to operate, peak up the received signal in the **MAN**ual mode, **FAST** speed by pushing either the **UP** or **DOWN** buttons. If you can, the motor is working properly. Verify that the REV LED changes state when the direction of rotation is changed.

Place the radio in the **CW** mode, reduce the RF power as low as it will go, switch the controller to the **SLOW** mode, depress your key and watch the SWR bridge as you hit either the **UP** or **DOWN** button to reduce the SWR to its lowest point. If you see a dip, but not close to 1:1 and if you're using a wire loop / Faraday Shield, remove the RF and adjust the position of the loop. Then, try it again. If your wire coupling loop is 1/5th the size of the main loop, you should be able to get very close to 1:1 by adjusting the coupling loop shape (i.e. 'squashing' it a bit from a circle to somewhat of an oval).

You may now consider your loop adjusted. If desired, you can use the controller as it is, in the purely manual mode - it works pretty well. You may also decide to activate the ALC and PTT / KEY circuits to save you the time and effort of changing modes / reducing power when tuning up the loop. But, if you want totally automatic operation, then you'll have to build a suitable RF sensing arrangement, as shown below.

c) Testing the CW Keying Interface

Connect the **KEY** leads from the controller to your radio. If you are using an external keyer**,** you may have to 'tap in' on the output side of the keyer.

Place the radio in the **CW** mode, reduce the RF power as low as it will go, switch the controller to the **MAN / SLOW** modes, depress either the **UP** or **DOWN** button and verify that the radio keys and outputs a low RF level. Release the button and verify that the radio stops transmitting, By watching the SWR meter, 'toggle' either the **UP** or **DOWN** button (as required) to achieve a low SWR and then release the button.

> ***Note:*** *If you use CW most often, if you don't mind adjusting the RF power, and if you don't need automatic operation, you're done!*

c) Testing the SSB PTT Interface

Connect the **KEY** leads from the controller to your radio. Using a *shielded cable*, connect the **TONE** lead (and ground) to the SSB mike input. Most of the newer radios provide a rear connection for this purpose and make these leads available in a DIN jack. If not, then you'll have to make the connection at the microphone plug. Place the radio in the SSB mode, ***switch any compression off***, and switch the controller into the **MAN / SLOW** modes.

Turn down your radio's RF power to its lowest level. Next, switch the controller to the **MAN / SLOW** modes, depress either the **UP** or **DOWN** button and verify that the radio keys the PTT function. Adjust the **SSB TONE LEVEL** control in the controller to produce a few watts of RF output with your mike gain set in the normal operating position, and verify that you can tune the loop through resonance. When done, release the button..

> ***Note:*** *you don't mind adjusting the RF power when tuning up, and if you don't need automatic operation, you're done!*

d) Testing the ALC Interface

Note: *This is an important test as connecting an improper ALC voltate to your radio may damage it.*

Don't connect the ALC lead to your radio yet. Remove the magnetic loop antenna and connect a dummy in its place. Set the CW mode. Set the controller to the **MAN / SLOW** modes, and connect your voltmeter to controller's ALC output lead and ground. ***Set the voltmeter to read a <u>negative</u> voltage***.

Hold down either the **UP** or **DOWN** button and check the negative voltage produced. Vary the **ALC LEVEL ADJ** control (R9) to both extremes, noting the maximum and minimum voltage levels. If the maximum negative ALC voltage produced exceeds what your radio can tolerate (check your owner's manual), then you'll have to change Zener diode D10 to a lesser value.........

If the ALC voltage level does not exceed the limit defined in your operator's manual, then power down both the radio and the loop controller, and connect the ALC line and ground to your radio. Power up the radio and then the loop controller. Be sure that the dummy load is still connected.

Put the radio in the CW mode, operate the **MAN / SLOW** switches on the controller, and depress either the **UP** or **DOWN** button while noting the RF power delivered to the dummy load. Turn up the power on the radio to max output and adjust R9 until the transmitter's power drops down to its lowest level, around 1 or 2 watts. Then, release the button.

If you do not see the need for automatic loop antenna tuning, and are content to tune the loop manually (in the **FAST** mode for maximum noise and then in the **SLOW** mode for fine SWR tuning), you are finished.

If not, move on to the next step which is connecting and aligning the remote directional coupler or SWR bridge.

9. Connecting and Aligning the SWR Sensor

Two types of RF sensing arrangements can be used, either a fixed-tuned ***Directional Coupler***, or a more conventional ***SWR Bridge*** type of arrangement, which requires a simple 'null' adjustment. These sensors will send low level DC (FWD and REV) signals to the loop controller board which, in turn, will compute the actual SWR and move the motor / capacitor to resonance.

a) Building, Adjusting and Using the Remote SWR Sensors

- Construct either unit from the *schematics shown* and mount it in a suitable enclosure. If building the W8DIZ coupler, replace the supplied 1/4 watt 51 ohm resistors with the 3 watt units shown in the parts list.   *You'll need the extra wattage to handle 100 watts out. Everything else should hold up, at least the components in mine do.* There's no need to install the variable trimming resistors; just be sure to place jumpers so that the DC signals arrive at the proper output point. *Alternatively, you may install the trimmers and place them in the position of least resistance to the output.*

- Identify the SO-239 connectors for the transmitter (**IN)** & for the antenna (**OUT**), and make the **FWD** and **REV** connections to the output 3 wire jack.

- Connect your transmitter (with an external SWR bridge, if required) to the **IN** jack and a 50 ohm dummy load to the **OUT** jack. Verify that you have continuity thru the coupler by transmitting at low power. (say, 10 watts).

- If you are building the SWR Bridge sensor, connect the voltmeter between **JP-8 (REV)** on the controller board and ground. Then, carefully adjust the null capacitor for as low a reading as possible. It should dip close to 0.0 volts (0.1 volt is OK).

- Next, connect your voltmeter between **JP-5 (FWD)** on the P/C board and ground.

- Gradually increase the output power to the 100 watt level. Check the remote sensor for any signs of overheating. Then, cut the power.

- Quickly key the transmitter again and adjust R2 (FWD) so that **JP-5** reads 4.0 volts. Once done, cut the power.

Swap the connections at the remote sensing device. The transmitter is now feeding the OUT jack and the dummy load is connected to the **IN** jack.

- Connect your voltmeter between **JP-8 (REV)** and ground.
- Quickly apply 100 watts of transmitter power and adjust **R5 (REV)** so that JP-8 reads exactly the same as the previous reading. Then cut the power.
- Restore the connections on the directional coupler to their original state.

10. Using the Automatic Mag Loop Controller

a) Automatic Tuning a Butterfly Capacitor

If you are using the controller with a butterfly antenna that's free to rotate 360 degrees, tuning up is very easy. Just push either the **UP** or the **DOWN** buttons with the controller in the **AUTO**matic mode and the tuner will do its thing, provided, of course, your antenna has been proven to resonate in the band you are using. When the controller stops tuning (and your radio returns to the receive mode), you have an additional 2 seconds to 'fine tune' your antenna with either the **UP** or the **DOWN** buttons. *If you wait longer than 2 seconds, the controller will go into another automatic cycle.*

b) Manual Tuning a Butterfly Capacitor

You can tune your loop in the **MAN**ual mode using either the **FAST** or **SLOW** buttons. Pressing the **FAST** button simply moves the stepper motor in the fast mode - without keying the transmitter. This is a useful way to peak your received signals while tuning around the band, while SWL'ing, etc.

The **MAN**ual **SLOW** mode will key the transmitter, apply **ALC**, generate an **SSB** tone, etc. and is useful for fine tuning your antenna to the point of the lowest SWR.

c) Automatic Tuning a Vacuum Variable or Similar Capacitor

....more to follow...

11. Interesting Magnetic Loop Antenna Websites and Related Articles

- *Small Transmitting Loop Antennas- Steve Yates - AA5TB*
- *W2BRI's Magnetic Loop Antenna Site - W2BRI*
- *PA3CQR 's Magnetic Loop Antennas*
- *Magnetic Loop Antenna Calculator*