

# Magnetic Loop Antenna for 80-20 mtr

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text highlighted in yellow is still scratchpad/notes.

- Click [here](#) to contact Frank N4SPP

## INTRODUCTION

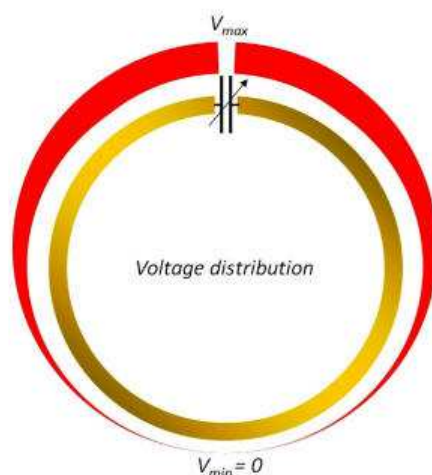
I wanted a **small transmitting loop** (STL) antenna that covers at least the 80 and 40 meter bands. Why?

1. I want to do 80 mtrs DX, but I have no room for a decent 80 m wire-antenna. I have had success with short, loaded vertical antennas with a single elevated radial (much better than a bunch of radials on or in the ground), see here and here. But I cannot install those permanently at my QTH.
2. Below 10 MHz, our apartment building generates a massive amount of QRM (S9++), probably due to the huge, dirty switched power supply of the central ventilation system. An STL tends to be less sensitive to picking up electrical noise in the near-field ( $< 1 \lambda$ ), which is why this type of antenna is also referred to a "magnetic loop antenna".
3. STLs have a radiation pattern with directivity. They are also small enough to rotate with a small motor, or TV-antenna rotor.
4. Less conspicuous (to my friends of the home-owners association "police") than a wire antenna strung along the outside of the building.
5. Don't want to have to mess with radials, counterpoises, RF-grounds, etc. Loops are inherently symmetrical, like dipoles.
6. Can be installed close to the ground (vertically oriented), without significantly losing efficiency. Yes, higher is better.

A loop is generally considered "small", if its circumference is less than 10% of the operating wavelength. In my case "small" would be a circumference of less than 8 mtrs, e.g., a circular loop with a diameter less than 2.5 mtrs ( $\approx 8.2$  ft).

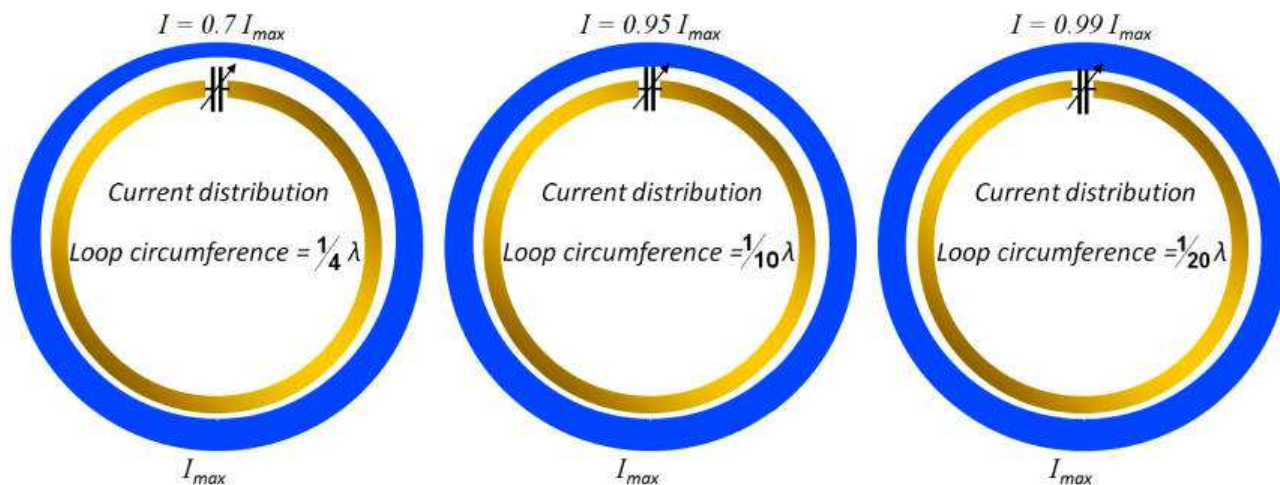
To be more precise, it is a **small resonant loop**. To obtain resonance, we need to combine inductive and capacitive reactance. The loop is the equivalent of a single winding of a coil, so it has a self-inductance. Resonance is obtained by connecting a capacitor across the ends of the opened loop. The capacitance has to be appropriate for the desired resonance frequency, as in all (parallel) resonant circuits. Note that the loop-winding not only has inductance, but also stray capacitance. So, even without the additional capacitor, the loop has a resonance frequency. It is the maximum resonance frequency that can be obtained with the loop.

One important aspect to keep in mind, is the voltage and the current distribution along the loop - at resonance. As shown in the figure below, the voltage is highest at the capacitor, and zero at the point diametrically opposed (in a perfectly symmetrical loop + capacitor + capacitor connections). In some coupling methods, the braid of the coax feedline is actually connected to that neutral point.



The current is highest at the point opposite the capacitor. and lowest at the capacitor. Ben Edginton, G0CWT, has nicely

illustrated this with a video clip on [his website](#). Note that the minimum current is not zero! Unlike the voltage distribution, the current distribution depends on the size of the loop (circumference), as a fraction of the wavelength. For a small transmitting loop (circumference  $< 0.1 \lambda$ ), the current distribution is nearly constant around the loop. Both the voltage and the current distribution are symmetrical.



Clearly, the impedance (ratio of voltage and current) also varies around the loop; from highest at the capacitor, to lowest at the opposite point. So, for instance, there are two 50 ohm points, offset from the point opposite the capacitor (one on each side). This is used coupling methods such as Gamma Match and Delta Match.

Just to get a feel, I have calculated the characteristics for a loop with a circumference of 5 m (that is: 1.6 m diameter,  $\approx 5.2$  ft), made of copper tubing with a 16 mm outside diameter. This is a standard item at the local building supply store (straight or rolled up):

Resonance frequency	Capacitance	Efficiency	Bandwidth	Capacitor voltage	Q
3350 kHz	503 pF (max)	4 %	3.6 kHz	2.9 kV	931
3580 kHz	440 pF	5 %	3.8 kHz	3.1 kV	953
7040 kHz	104 pF	36 %	7.8 kHz	4.2 kV	905
14800 kHz	14 pF (min)	88 %	61 kHz	3.1 kV	241

*Calculated antenna characteristics for the given copper loop (KI6GD calculator)*

Resonance frequency	Capacitance	Efficiency	Bandwidth	Capacitor voltage	Q
3300 kHz	500 pF (max)	4 %	3.6 kHz	3.0 kV	986
3580 kHz	424 pF	5 %	3.5 kHz	3.3 kV	1015
7040 kHz	110 pF	36 %	7.3 kHz	4.5 kV	963
14800 kHz	14 pF (min)	88 %	58 kHz	3.3 kV	256

*Calculated antenna characteristics for the given copper loop (AA5TB calculator)*

The tables show that the calculated / predicted efficiency for 80 mtrs is rather low (no surprise), but my other antennas for 80 mtr are (very) short verticals. I do not know what their efficiency is, but I am sure that it is very low as well. In the end, what counts is performance at my location, for the available space, for the prevailing conditions (proximity to the building, QRM levels, etc), and with respect to other antennas that I can install there.

The tables also show that this loop should be tunable from 80-20 mtrs with a 15-500 pF variable capacitor.

I have not looked into the assumptions that the calculators make, regarding installation height (free space?), coupling method, etc. As in all high-Q resonant circuits, calculated and actual performance is highly dependent on the losses in all components (loop, capacitor) and all interconnections. Losses in the single-digit milli-ohm range may be significant! In general, doubling the diameter of the tubing will reduce the (inductor) losses by 50%.

Mike Underhill, G3LHZ, has a very controversial view on the efficiency estimates obtained with traditional models. I recommend reading this:

- "Small Loop Antenna Efficiency", May 2006
- "All sorts of small antennas – they are better than you think – heuristics shows why!", February 2008

The tables above are for a circular loop. The values for an octagonal loop are very similar: for the same circumference, an octagon has nearly the same area as a circle. For those who like (or need) formulas, this is shown below.

For a **circle** with radius  $R$  and diameter  $D$ :

$$\text{Circumference} = 2 \cdot \pi \cdot R = \pi \cdot D$$

$$\text{Area} = \pi \cdot R^2 = \frac{\pi}{4} \cdot D^2$$

For an **octagon** with side  $L$ :

$$\text{Circumference} = 8 \cdot L$$

$$\text{Area} = (2 + \sqrt{2}) \cdot L^2$$

After some basic manipulations, we can derive that for equal circumferences:

$$\text{Area}_{\text{circle}} = \frac{16}{\pi \cdot (2 + \sqrt{2})} \cdot \text{Area}_{\text{octagon}} \approx 1.055 \cdot \text{Area}_{\text{octagon}} \quad \text{q.e.d.}$$

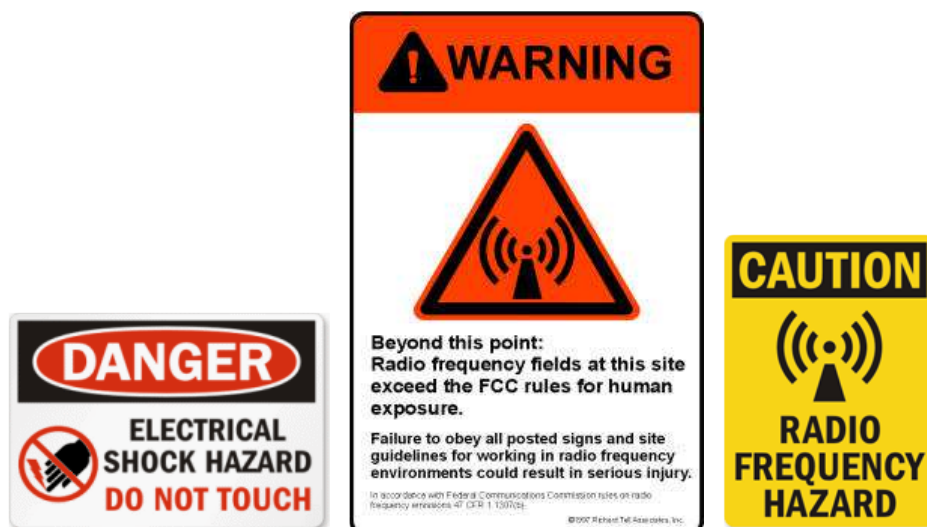
The height of an octagon (i.e., distance between parallel sides, not the largest distance between corners of the octagon):

$$H = (1 + \sqrt{2}) \cdot L \approx 2.4 \cdot L$$

Note that if you make an octagon with eight sections of length  $L$ , you will require elbow pieces to join these sections. This increases  $H$ . In my case by 5-6 cm ( $\pm 2$ ”).

## WARNING

A tuned loop can exhibit several hundred volts when operating at QRP power levels (5-10 W). At higher RF levels, **several thousand** volts will be present at resonance! Exercise caution when building and using this antenna. Build and operate this antenna at your own risk.



***Do not get anywhere near the antenna when transmitting!  
Do not let any animals (or people that you care about) get near the antenna when transmitting!  
It is very dangerous to touch the loop conductor during transmissions. RF burns do not heal well!***

## THE TUNING CAPACITOR

A loop with a fixed-value capacitor is resonant at a single, fixed frequency. A well-constructed small loop antenna) has a bandwidth that requires re-tuning when changing frequency across a band. Note that the resonance frequency will vary noticeably with temperature (sunshine/weather, heating due to losses, ...).

To be able to make the loop resonant

Standard options for variable tuning capacitors are:

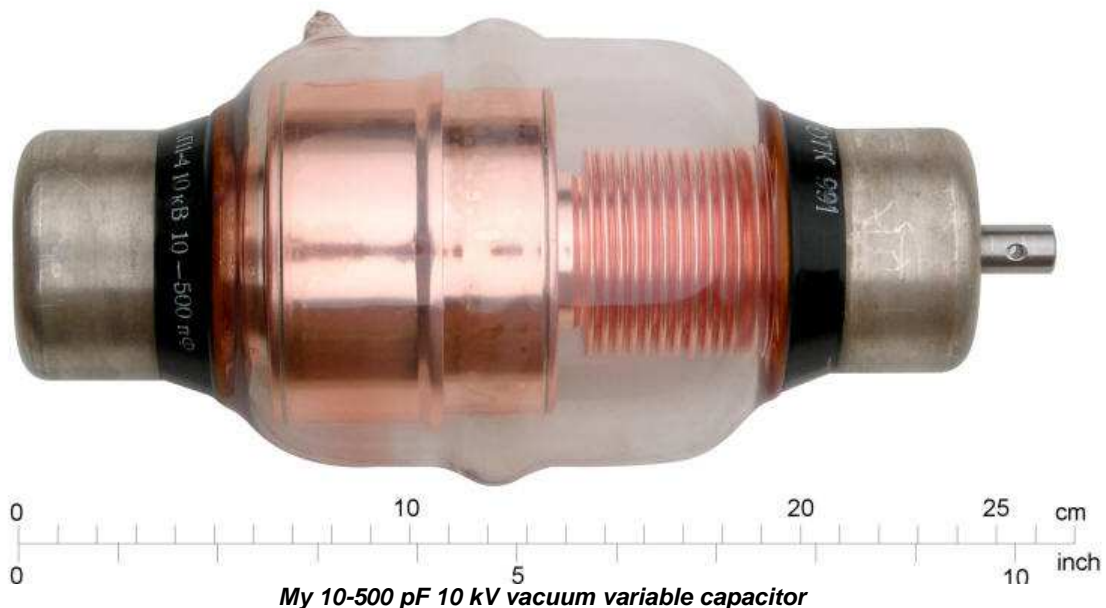
- rotary variable air-gap capacitors
- vacuum variable
- capacitors.air variable capacitor: consists of stack(s) of stator (stationary) plates, and stack(s) of rotor plates that intermesh with the stator.
  - dielectric strength: 0.8 kV / mm (at 20 deg C, standard humidity)
  - "bread slicer" (e.g., tuning cap from an old AM radio). The shaft of these capacitors cannot be turned freely
  - type split-stator (no wiper contacts) vs butterfly style. Do not use varco where one set of plates is connected via a rotary joint + wiper contact. can use, if dual capacitor, hooked up such that no current through the wiper contact.
  - butterfly
  - air as dielectric: need at least 1mm spacing between the plates per kV; With 1 kV for 20 , 100 W operating power, may get 4-5 kV across the cap
- vacuum variable capacitor.
  - vacuum dielectric: xx mm per kV

Consideration: if & how intend to motorize the varicap. Without position control, you need a cap that does not have end-stops. I.e., entire capacitance range in 1 turn, and cap can be turned endlessly.

Note: a commercial air variable capacitor for 15-500 pF and 5-10 kV is not necessarily smaller or less expensive than an equivalent vacuum variable capacitor!

I purchased a Russian-made capacitor at the 2010 Ham Radio fair in Friedrichshafen/Germany. It is marked "10 kB 10-500  $\pi\Phi$ " in other words: "10 kV,10-500 pF". I measured 15-510 pF with an LCR-meter. Cost me €80 ( $\approx$  100 \$US, mid 2010 exchange rate).

A vacuum variable capacitor uses two sets of plates. Each set is made from a number of concentric cylinders that can be slid in or out of an opposing set of cylinders (sleeve and plunger). Spacing between opposing cylinders is several mm. These plates are then sealed inside of a non-conductive envelope such as glass or ceramic, and placed under a high vacuum. The movable part (plunger) is mounted on top of a flexible metal membrane (harmonica-style bellows). The membrane seals and maintains the vacuum. A screw shaft is attached to the plunger, when the shaft is turned, the plunger moves in or out of the sleeve and the value of the capacitor changes. The vacuum dielectric significantly increases the voltage rating of the capacitor.



Also did a quick test to verify integrity of the vacuum: put the cap in the refrigerator for about an hour. Should be no formation of condensation on the inside of the glass when in the fridge or after taking it back out (on outside is OK). Size: see scale in the picture above. Weight is a hefty 2140 gr ( $\approx$  4  $\frac{3}{4}$  lbs). It takes 36 turns to go from minimum to maximum capacitance, or vice versa. I.e.,  $\approx$ 14 pF per turn - assuming a linear relationship between capacitance value and shaft revolutions (not necessarily a valid assumption!).

The highest resonance frequency of the loop is determined by the minimum capacitance, and, conversely, the lowest resonance frequency by the maximum capacitance value.

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## COUPLING THE LOOP TO THE FEED-LINE

The loop antenna will be connected to my transceiver via a coax feed-line. This means that the coax needs to be coupled

to the loop, and the coupling must be wide-band enough to cover the tuning range of my antenna (80-20 mtrs, 3.5-14.5 MHz). As with other types of antennas, there are several ways to do this. Most commonly used are:

- Un-shielded coupling loop
- Shielded coupling loop ("Faraday Loop")
- Gamma Match
- Ferrite transformer coupling

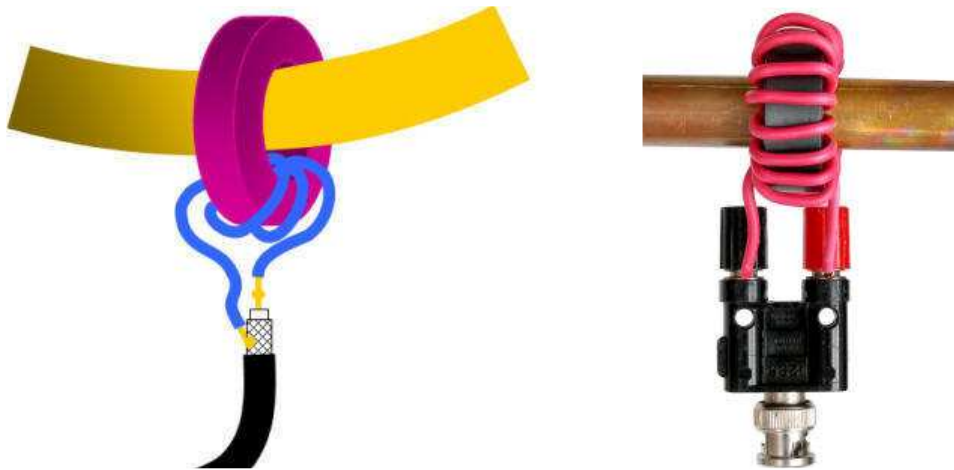
I determined SWR and other curves for several of these coupling methods. They are presented [at the end of this section](#).

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Let's start with the **ferrite transformer coupling**, as it is very easy and there are no adjustments or other manipulations required! It consists of a toroidal transformer that comprises a ferrite core, a single primary winding (the main loop), and a number of windings of insulated wire on the secondary side. The coax connects to the latter. As with the other coupling methods, it is installed on the main loop, at the point opposite the tuning capacitor.

This coupling method only has two simple variables: the type of ferrite material, and the number of secondary windings. Obviously the ferrite core must be large enough to fit over the tube that makes up the main loop (and elbow joints, if any), and accommodate the required number of secondary windings.

As it is a 1: $N$  transformer,  $N$  has to be chosen such that  $50 / N^2 =$  impedance of the loop at the point where the transformer is installed on the loop (assuming 100% efficiency = 0% losses). Conversely, once the  $N$  has been found that provides correct impedance match to the coax, then we know the impedance of the loop at that point.



**Coupling with a ferrite core toroidal transformer - multiple secondary windings**

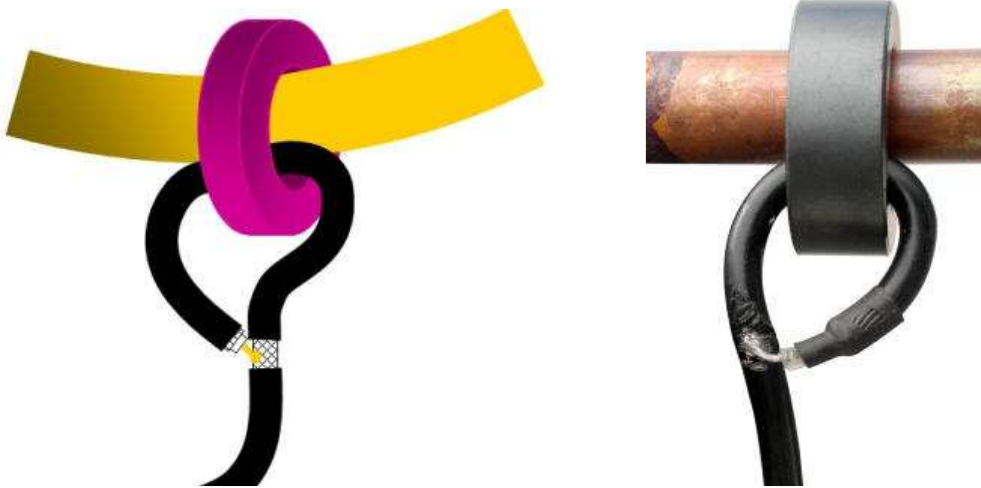
As I have several FT-140-43 ferrite cores in stock, this is what I used. These core are made of type 43 material, have an outer diameter (OD) of 1.40" and an inner diameter of 0.9" ( $\approx 23$  mm). This is large enough to slide over a tube with 16 mm (5/8") OD, and still add about 16 windings of insulated heavy installation wire of  $1.5 \text{ mm}^2$  (AWG 14-16). The next size up is FT-240, which has a one inch larger OD (2.40") and a  $\frac{1}{2}$ " larger ID (1.4",  $\approx 35$  mm).

I have used heavy duty installation wire ( $1.5 \text{ mm}^2$ , AWG 14-16) for the secondary windings. Of course, the wire need not be heavier gauge than the center-conductor of the coax. The windings are spread out evenly around the core.

The *RJLOOP1* calculator by G4FGQ predicts that my loop would require 24 secondary windings at 3.5 MHz, and 8 at 14.230 MHz - for a ferrite core of "suitable grade". K3JLS uses 3 windings of 14 AWG enameled wire on an FT-240-43 core for his 40-20m loop. AA5TB used 2 windings on his 30m loop.

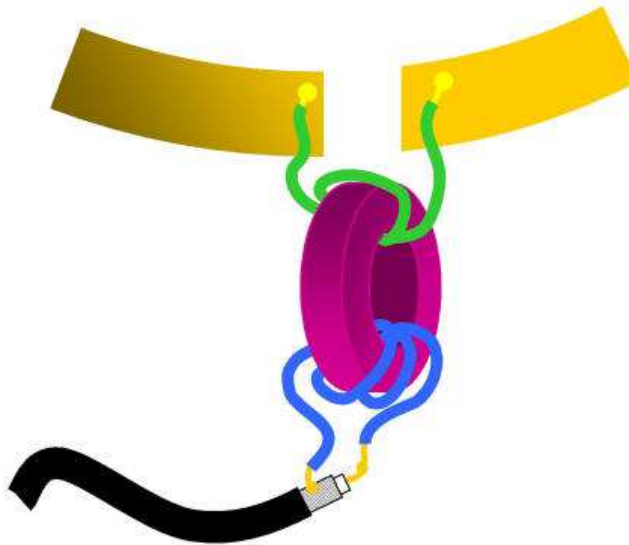
Some people recommend using type 61 ferrite (or N100 NiZnFe). I happen to have two FT-140-61 cores, and gave it a try. I tried 1-14 windings, and could not get better than  $\text{SWR} = 10$  at any frequency. Maybe my cores are not 61, or the one I used has an internal fracture, or... I don't know... Others suggest using type 31 material. It is a MnZn mix that supposedly behaves like type 43 at HF, but "better" below 5 MHz. I have not (yet) tried this.

Some folks use 1 winding of coax as secondary winding. That is, a 1:1 transformer. This puts the 50 ohm impedance of the coax feed line in series with the very small loop impedance. This results in significant mismatch and/or losses. I tried this, and found a nice low SWR over the *entire* frequency range of interest, but a bandwidth that was *at least* an order of magnitude larger than when using multiple wire windings.



*Coupling with a ferrite core toroidal transformer - coax loop as secondary winding*

Another variation on the toroidal transformer coupling is using a small number of primary windings, instead of just a single one. This requires the loop to be opened and the primary windings to be connected across the gap. I have no experience with this, nor references regarding its performance.



*Coupling with a ferrite core toroidal transformer - main loop split*

The second category of coupling methods uses an inductive coupling loop. There is no physical connection between the main loop and the coupling loop. However, if the coupling loop is placed at the center of the main loop, directly opposite the tuning capacitor, then the shield of the coax to the coupling loop may be connected to the main loop at that point.

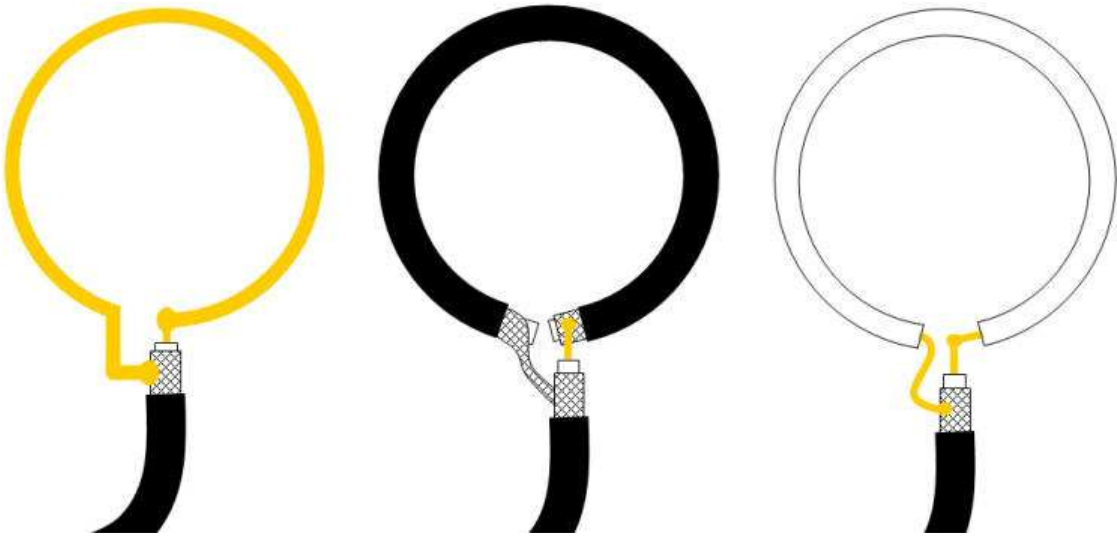
The first type of inductive coupling loop is the simple **un-shielded loop**. The conductor that makes up the loop, has to be stiff / rigid enough to retain its shape. Commonly used are:

- heavy gauge wire or small diameter copper tubing; the conductor need not be heavier gauge than the center-conductor of the feed-line coax. However, heavier conductor will help retain shape of loop, and make it self-supporting. I have used "extra heavy" single-strand installation wire of 2.5 mm<sup>2</sup>.
- the braid of a coax (the center conductor is not used), and
- the center conductor of coax, with outer insulation and braid fully removed. The dielectric material of the coax is kept, and provides rigidity.

The main loop and the coupling loop form a loosely coupled transformer. The turns ratio is fixed, but there are several coupling loop parameters that affect the coupling:

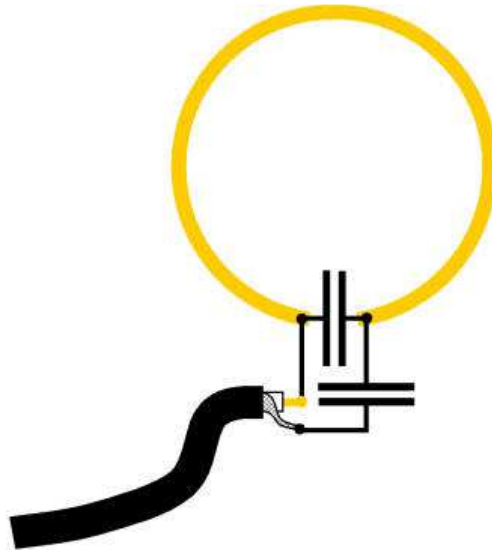
- the **size** of the loop. Its standard diameter is 1/5 that of the main loop. However, I have seen designs with 1/3 to 1/8 the diameter of the main loop.
- the **shape** of the loop. The standard shape is circular. Obviously, like the main loop, other shapes can be used (square, octagonal, ..). To obtain the desired coupling, the coupling loop can be squashed or stretched into a vertical oval or egg-shape. This changes the aperture of the loop (area of the "opening"), as well as the distance to the main loop.
- **placement** along the main loop. Standard is opposite the tuning capacitor. However, to adjust the coupling, it can be moved off-center, along the main loop.
- **proximity** to the main loop. Normally, the coupling loop is placed with its bottom (where the coax is connected)

- close to the bottom of the main loop.
- **alignment** with the main loop. That is: whether the plane of the coupling loop coincides with that of the main loop. The coupling with the main loop can be varied by turning the coupling loop about its vertical axis (from where the coax is connected to the point at the top of the loop), such that it sticks through the main loop. Instead of turning, it can also be bent.
- the **gauge** of the conductor - as with all coils / inductors.



**Un-shielded coupling loop**  
(solid wire, braid of coax, center-conductor of coax)

These coupling loops are basically un-tuned. Some people add tuning and loading capacitors to the coupling loop, though I am not sure that wide-band matching can be obtained this way...

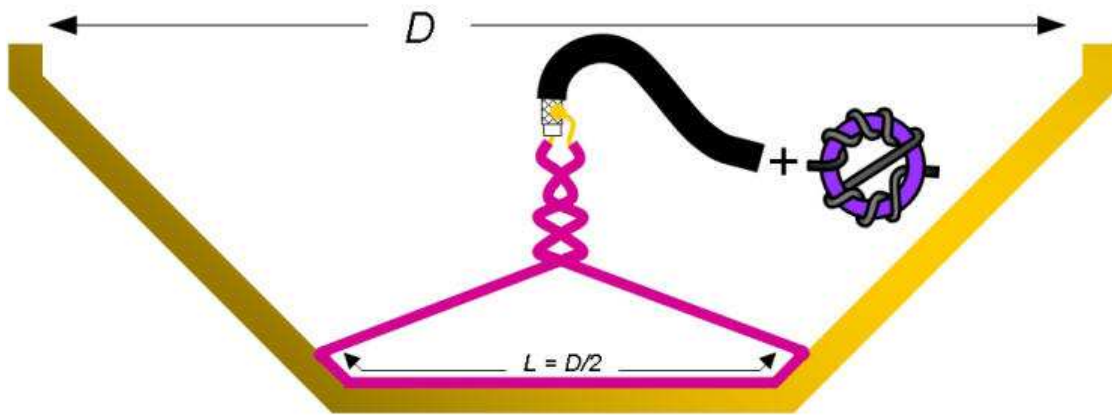


**Un-shielded coupling loop with tuning & loading capacitors**

An other variation on the wire loop is what I call the "clothes hanger" coupling loop. It consists of insulated wire (e.g., installation wire, or even heavy enameled copper wire). The overall wire length is a little over the diameter of the main loop. The coupling loop is symmetrically placed onto (and affixed to) the main loop over a distance equal to  $\frac{1}{2}$  the main loop's diameter (i.e.,  $\approx \frac{1}{6}$  the loop's circumference). Rather than connecting the coax at the bottom, it is connected at the top of the feed loop. I.e., an upside-down wire loop.

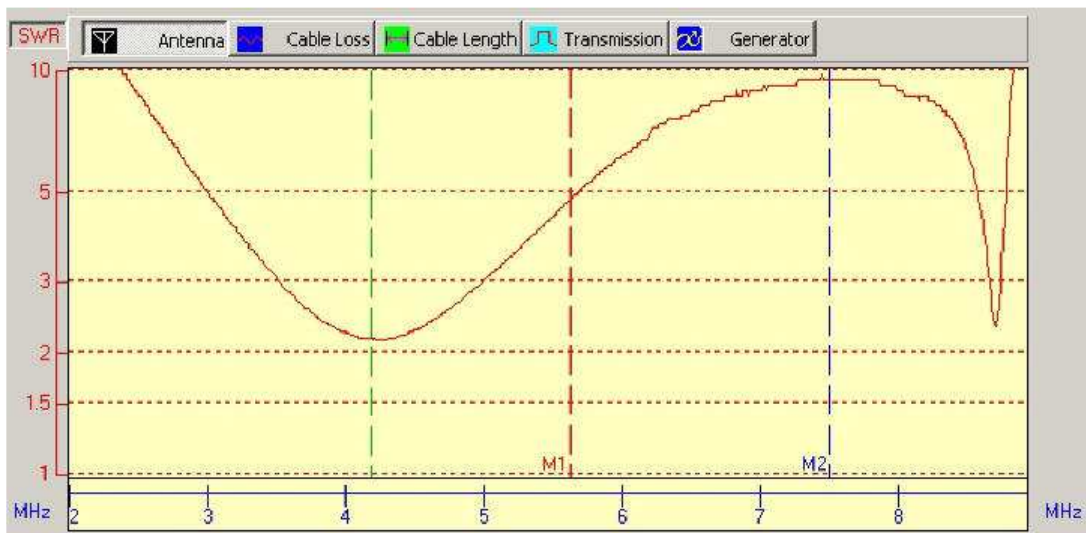
The wire ends are folded towards each other, joined and twisted over a distance of about 10-12 cm (4-5"; not critical), and connected to the coax (with a current choke "balun" near the coupling). It looks like a clothes hanger without the hook... The point where the wire ends are twisted, is moved up or down, to obtain the desired matching.

This is similar to the triangular feed-loop of my (mono-band) spiral loop antennas, where the coupling loop has a circumference that is  $\frac{1}{8}$  that of the spirally-wound  $\frac{1}{4}\lambda$  main loop.



*"Clothes hanger" un-shielded coupling loop with current choke "balun"*

I tried this coupling loop first with  $L = D$ , instead of  $L = D / 2$  (don't ask me why). The resonance frequency varies quite a bit when the connection to the coax is moved up and down. SWR was relatively flat, but had an odd "double dip" for resonance frequencies around 4 MHz. This threw me off for a while. The smallest bandwidth that I found was around 200 kHz, at 8200 kHz. That is, an order of magnitude more than what I measured for coupling with a ferrite ring (see further below). When I reduced the size of the coupling loop to  $L = D / 2$ , SWR was below 1.2 over a significant frequency range, but again, the lowest bandwidth was about 200 kHz.

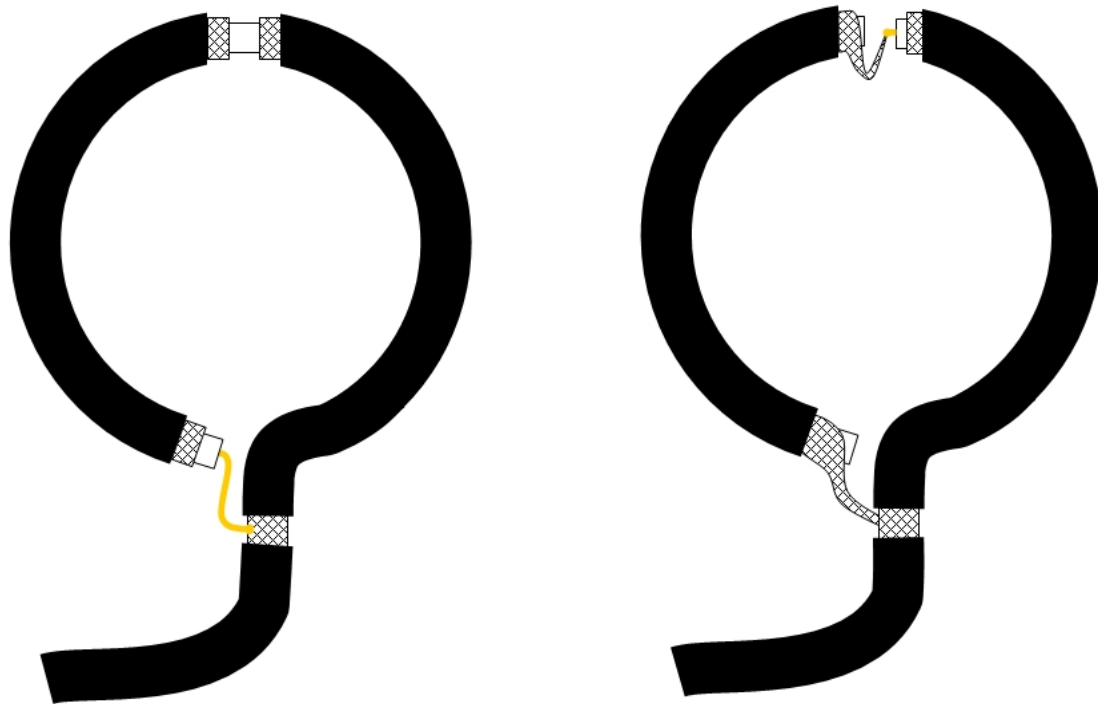


*"double dip" SWR curve*

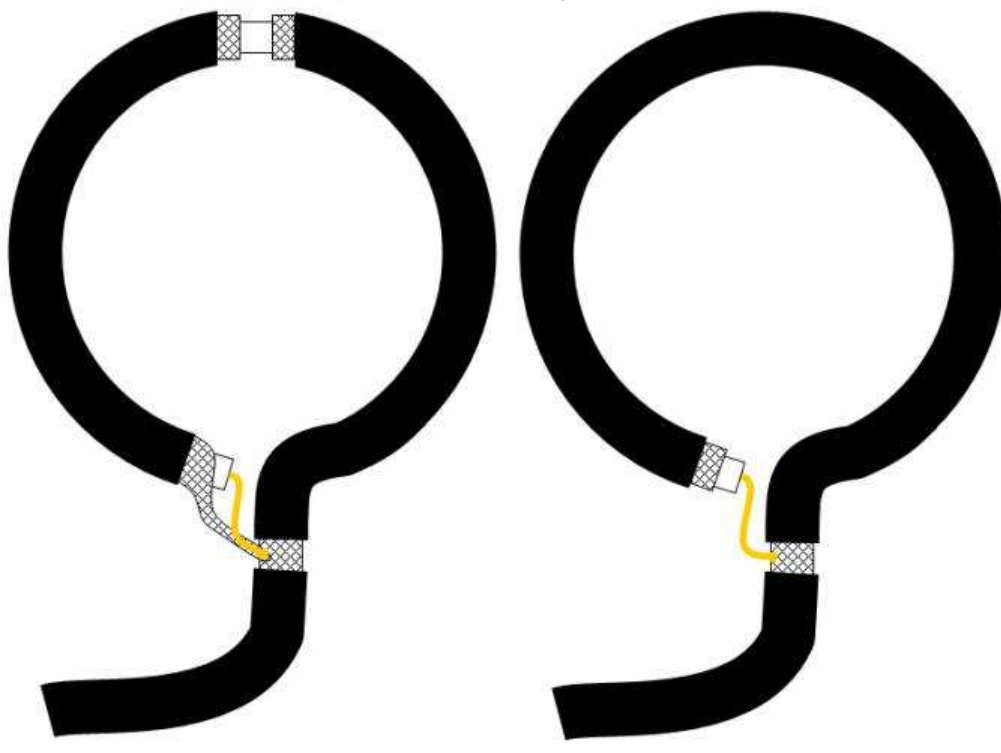
The second type of inductive coupling loop is the **shielded loop**, often referred to as "**Faraday Loop**".

- 1/5 - 1/6 the size of the main loop.
- split (interrupt braid) at top vs center conductor to braid at loop starting point vs braid-to-center-conductor at top
- as with wire loop: center, off-center, squashed/egg-shaped such that more/less follows main loop
- variation: braid also connected to loop center
- It has been customary to partially screen this loop by stripping the braid only half way around it and joining braid to central conductor at the top of the loop- leaving half the small loop as a single conductor to join the braid of the feeder.
- no convincing evidence that this "shielding" makes a significant difference w.r.t. un-shielded coupling loops. Some people feel that this offers better screening from "electrostatic" noise. Apparently, the same reasoning does not apply to the main loop, for reasons that escape me...
- My conclusion: the primary difference between the various forms of shielded and un-shielded coupling loops, is the resonance frequency of the coupling loop by itself.



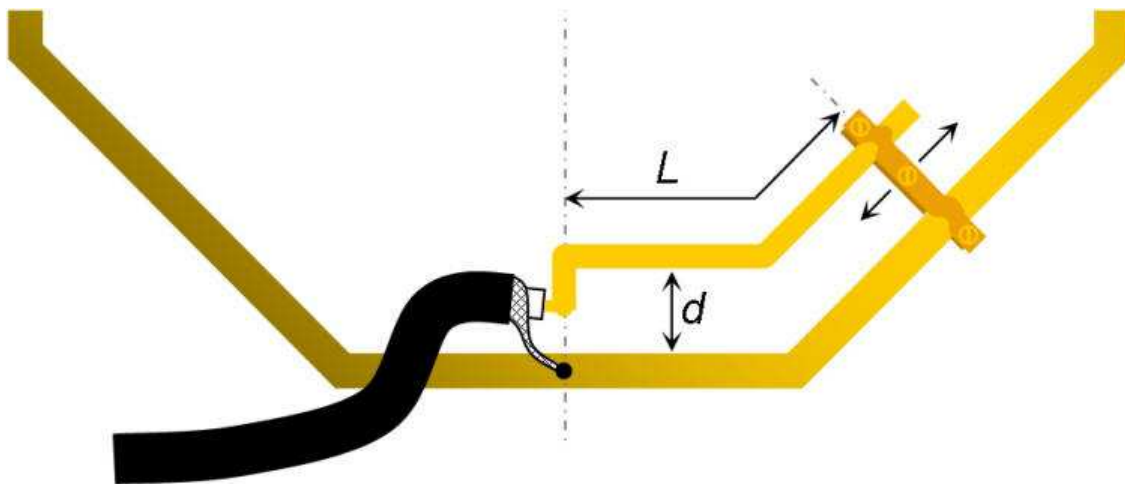


*"Faraday" shielded coupling loop - variations*



The **Gamma Match** is an auto-transformer type coupling, that steps up the antenna impedance to match that of the unbalanced feed-line. Basically:

- the braid of the coax is connected to the neutral point of the radiating element. Here: the center point of the loop, opposite the tuning capacitor.
- the center conductor of the coax is connected via a bar or tube (the Gamma "Rod") to a point on the loop where the voltage/current ratio matches the 50 ohm impedance of the coax.



**Gamma Match (without series-capacitor)**

Actually, this is only part of a *true* Gamma Match. The latter has a (sometimes variable) capacitor in series with the Gamma "Rod", to compensate the inductance of the Gamma Rod. Without the capacitor, the coupling can be multi-band, but the missing compensation capacitance implies slight de-tuning of the loop.

Once correctly set, the Gamma Match works over a wide frequency range (reportedly as much as 10:1, if antenna installed sufficiently clear (15-20 ft, 5-6 m) from any objects and at least 1/2 loop diameter above ground).

All variations of the Gamma Match are asymmetrical, as readily seen in the diagram above. This somewhat skews the radiation pattern causing a front-to-back ratio, favoring the direction of the of the gamma match mount.

Instructions for adjusting/tuning a Gamma Match are deceptively simple:

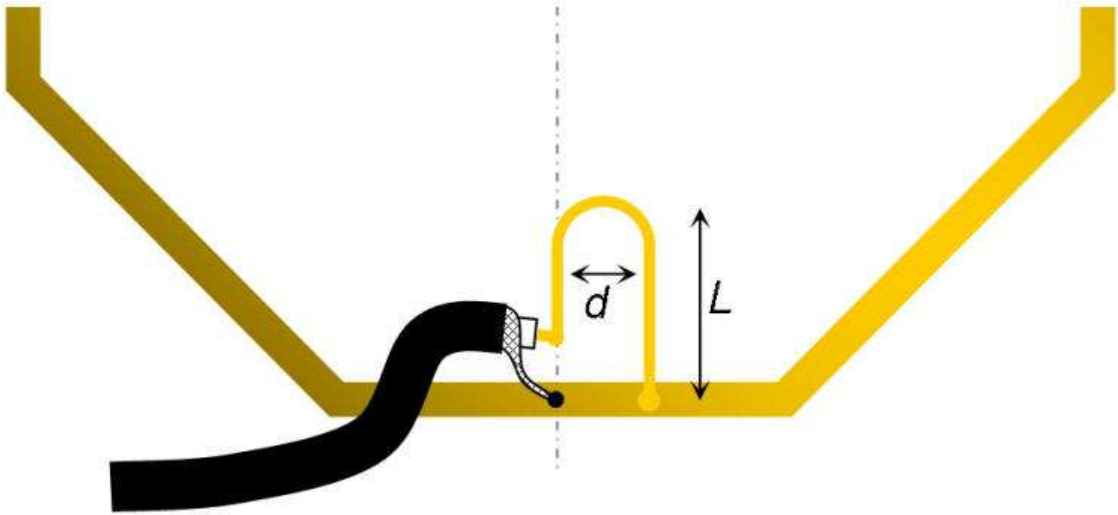
*"change the size, shape, material, position with respect to the main loop, and the tap point of the Gamma "Rod" along the loop, until the desired impedance matching is obtained"*

This is not all that surprising, as the position tap point depends on characteristics of the Match (length of the Gamma Rod/bar/wire, diameter of the gamma rod, shape of the loop formed by the rod and the main loop, center-to-center spacing between the Gamma Rod and Radiating Antenna Element, etc.; see ref. 6, 7), as well as the main loop and its construction. In general, the lower the Q of the loop is (e.g., due to losses in solder joints), the farther away from the neutral point the tap point will be. Also: the higher the Q, the more sensitive the position of the tap point will be: moving the tap just a couple of mm ( $\approx 1/8"$ ) may make quite a difference!

This basically means that finding the "sweet spot" for the tap point is pretty much 100% empirical. This is why there appear to be as many settings as there are antennas, and settings vary widely. Here are some examples that I have collected from designs posted on the internet (only very few indicate sufficient details to reconstruct the actual design):

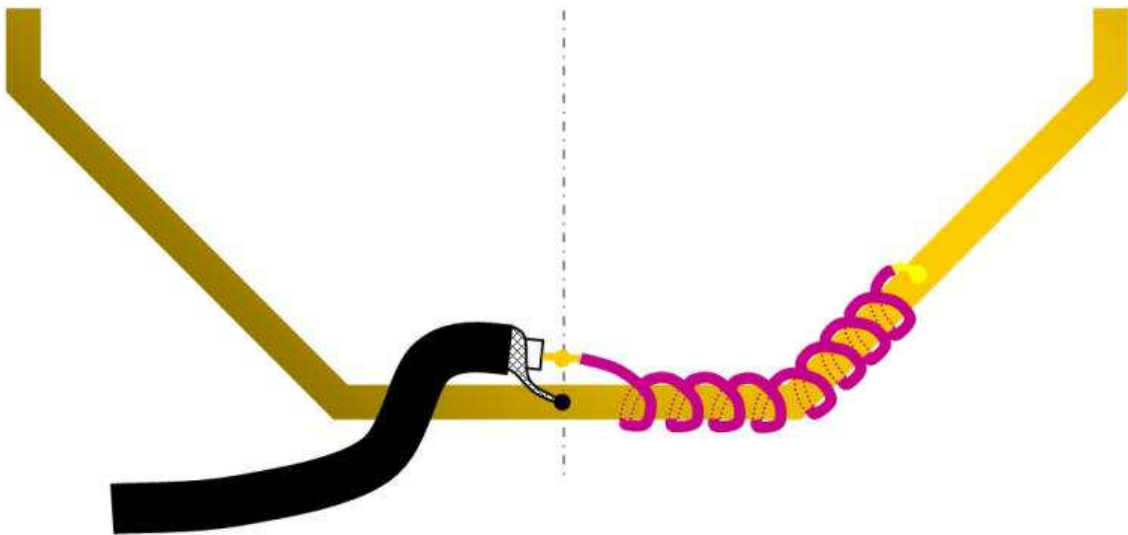
- some literature suggests the tap point at "main loop circumference / 10" from the center point, and the rod at a distance of "main loop circumference / 200".
- tap point at "main loop circumference / 15.8" from center point; rod is 1/4" diam. copper tube, 2 3/8" (6 cm) distance from main (diam. 3 1/2 ft); started half-way up the loop (i.e., 1/4 circumference from center bottom), final tap at 8 3/8" ( $\approx 21$  cm).
- tap point at "main loop circumference / 10" from center point; rod at distance of  $0.5\% \lambda$
- tap point at "main loop circumference / 10" from center point; rod at distance of 20 cm (8") from main loop.
- tap point at "main loop circumference / 8" from center point
- tap point at "main loop circumference / 11.4" from center point (21" vs 533mm); rod at distance of 7.6 cm (3") from loop
- tap point at "main loop circumference / 7" from center point; rod is 12" of 1/8" wire, spaced 1" from main loop of 5/16" copper tubing
- tap point at "main loop circumference / 4.3" from center point ; rod is 91 cm, curved & parallel to main loop.
- tap point at "main loop circumference / 10" from center point; rod is 12", parallel to main loop at 1" distance
- tap point at ("main loop circumference / 4" from center point; rod is 9"
- loop diameter 1 meter, rod length 31 cm, rod spacing 11 cm
- loop circumference 20 ft (6m), rod length 21" (53 cm), rod spacing 3" (7.6 cm); 80-40m loop.
- loop circumference 2.4m (8 ft), rod length 23 cm (10"); 20m loop.
- loop circumference 4m (13 ft), tap point at 86 cm from the neutral point, rod of 8 mm  $\varnothing$  copper tubing, parallel to main loop at 8 cm (3 1/4") distance.

The Gamma Match itself can also be considered as a kind of loop. If the end of tap point is chosen relatively close to center point (where the coax braid is attached) but we retain the size (area) of the loop, we end up with the Hairpin Match (a.k.a. Beta Match).



*The Hairpin Match (Beta-Match)*

An other variation is the "Twisted" Gamma Match (a.k.a. "Mu-Gamma" or "G3LHZ-Gamma", ref. 8, 9). I have no suggestions regarding the total length of the wire, and pitch of the windings.



*The "twisted" Gamma Match*

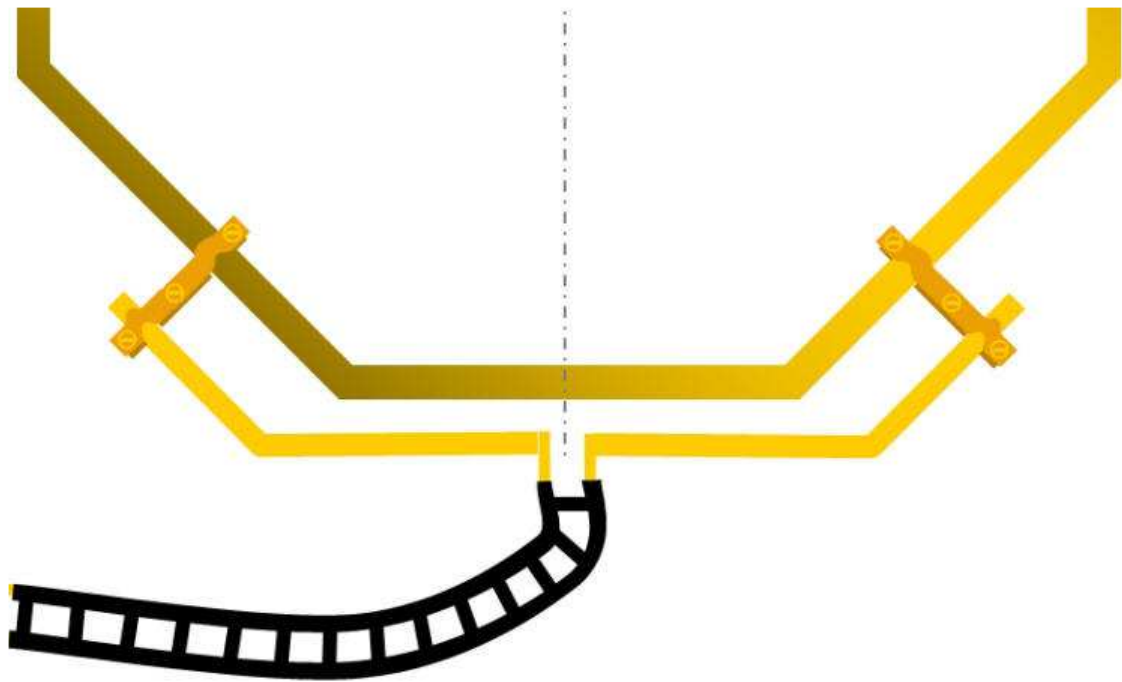


*For Gamma Match: BNC chassis connector fits perfectly into 10 mm OD end of a T-piece*

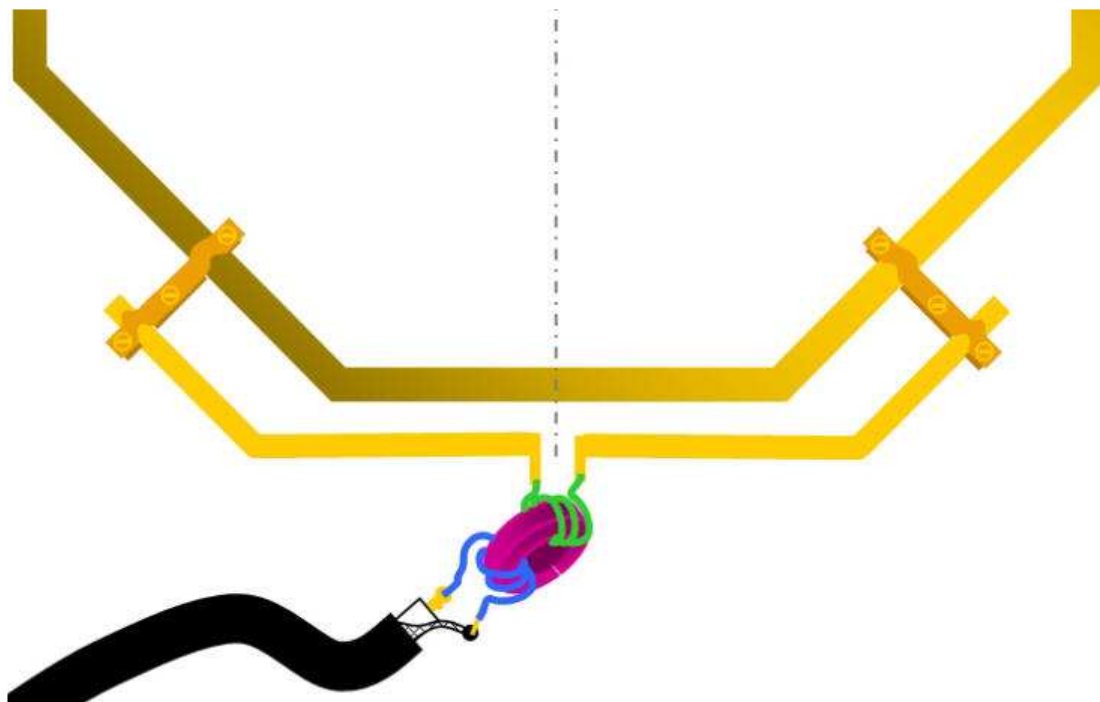
- Decided to insert T-piece, even if not using it for a Gamma Match.1 copper T-piece, 16 ID / 10 OD / 16 OD (to serve as starting point of a Gamma Match). BNC female chassis-mount connector. 1 m of thick solid copper wire (e.g., 3 mm)

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INSERT DIAGRAM  
*Delta-Match*



*T-Match*



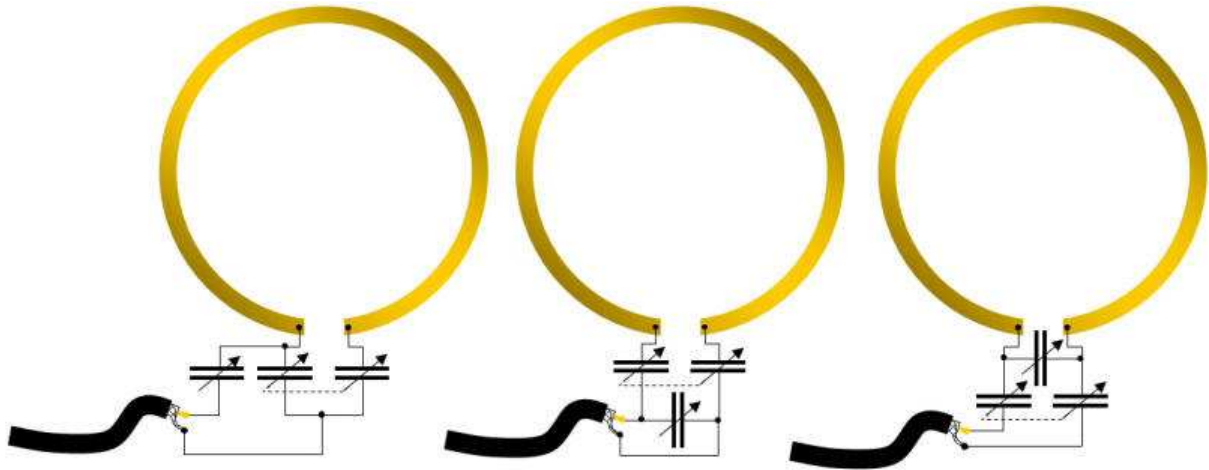
*T-Match with balun*

Symmetrical feed line: shunt matching: Delta Match + ladder line: not considered here. The delta match uses a section of 2-wire transmission line with gradually increasing separation to match a 2-wire line to an antenna. Two advantages of the delta match is the simplicity of its construction and its ability to match a wide range of impedances. Two major disadvantages are: generally, the length and amount of separation increase must be determined experimentally for a specific antenna and feed line, and the delta match section radiates some RF, changing the radiation pattern of the antenna. A variation of the delta match that is widely used for VHF/UHF Yagi antennas is the T-match: The T-match, unlike the delta match, does not radiate, but this advantage is offset by the need to adjust the overall length of the antenna slightly, as well as the T-match separation and length, to get a proper match. In general, lengths A, B and C must be determined by experiment.

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#### CAPACITIVE COUPLING

So far: inductive coupling. In duality, can also make capacitive coupling.



*Capacitive couplings (center: "Army Loop", a.k.a. "Patterson Loop")*

Army/Patterson Loop: has tuner at the antenna. Dual-gang capacitor across gap in loop - tunes resonance freq; the cap in series with the coax is for impedance matching. There are also capacitive methods to couple to the main loop.

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*I know that the above listing of coupling methods is not exhaustive. However, it sufficiently covers all standard and practical methods.*

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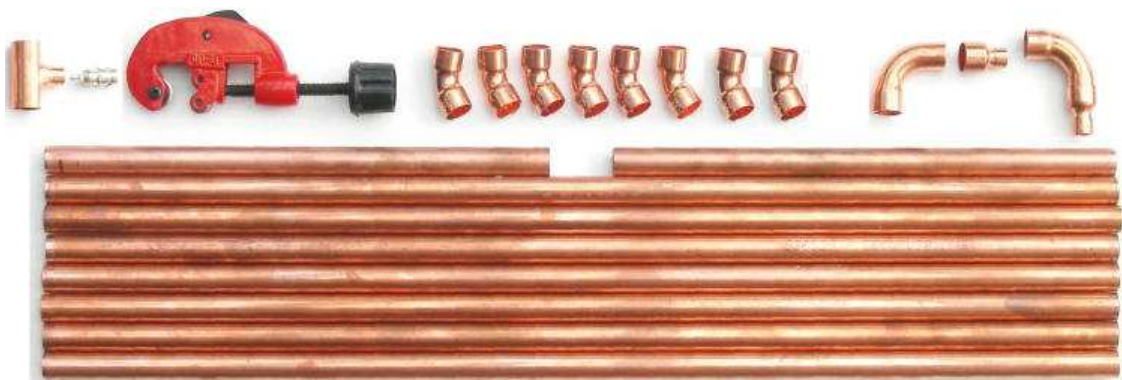
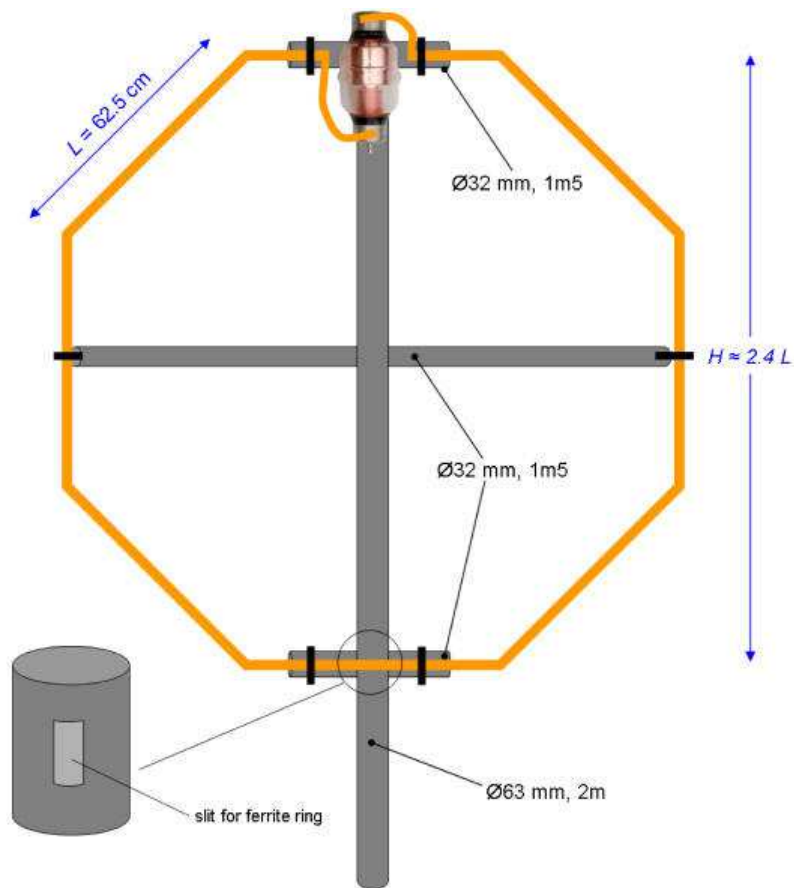
## CONSTRUCTION OF MY FIRST LOOP ANTENNA - 2010

- Shape: square, octagonal, round: latter has largest possible surface area for the (fixed) circumference.
- Importance of keeping loop loss resistance to an absolute minimum, as the radiation resistance is very low. How achieve this, for the capacitor and the tube ends? Solder / weld / large surface compressed joints,... Braze vs solder?
- Support structure.
- Permanently install TL tube or neon glowbug on structure.

The industry standard is to refer to the O.D. when talking about TUBE and the I.D. when referring to PIPE.

First thought I'd use a 5 m roll of soft copper tubing. This annealed (re-cooked) copper is not malleable by hand, and hard to make a nice round shape by hand - I do not have access to a professional tube bending machine. So I changed my mind and decided to go for an octagonal loop.

[The surface area of a circular loop is only about 5% larger than that of an octagon with the same circumference.](#)



*Copper tubing pieces and tube cutting tool*

**For the loop:**

- 7 sections of copper tubing, each 62.5 cm (24.6") in length, 16 mm outer diameter (OD).
- 2 sections of copper tubing, each 29 cm (11.4") in length, 16 mm outer diameter.
- 8 copper elbow pieces, 45°, female-to-female, 16 mm
- 2 copper elbow pieces, 90°, female-to-male, 16 mm
- 2 copper reduction pieces, 16 mm inner diameter (ID) to 10 mm OD (to connect tube to braid to capacitor)
- 1 copper T-piece, 2 x 16 mm ID, 1x 10 mm ID, (for Gamma Match coupling)

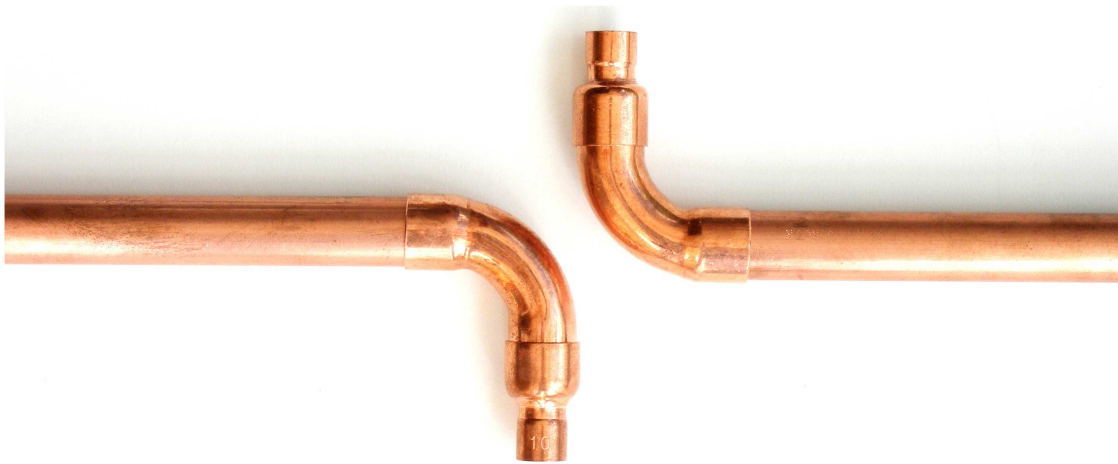
The required 5 m copper tubing (16 mm OD, ≈ 5/8 inch = 19 mm) cost me €24 (≈ 30 \$US, mid 2010 exchange rate). This is readily available from DIY centers). This length will give a loop height of about 1.5 m (≈ 5 ft).

**For the PVC structure:**

- 2 m PVC tubing with 63 mm diameter (≈ 2½")
- 1 m PVC tubing with 32 mm diameter (≈ 1¼")

**For connecting the capacitor to the loop:**

- 2 stainless steel hose clamps (**UK**: jubilee clips)
- 2 x 25 cm (10") thick & wide copper braid (also available from automotive supply store, as ground strap for car batteries), silver-plated 2-layer braid from RG-214 coax, or heavy multi-strand copper wire (e.g., AWG #4)



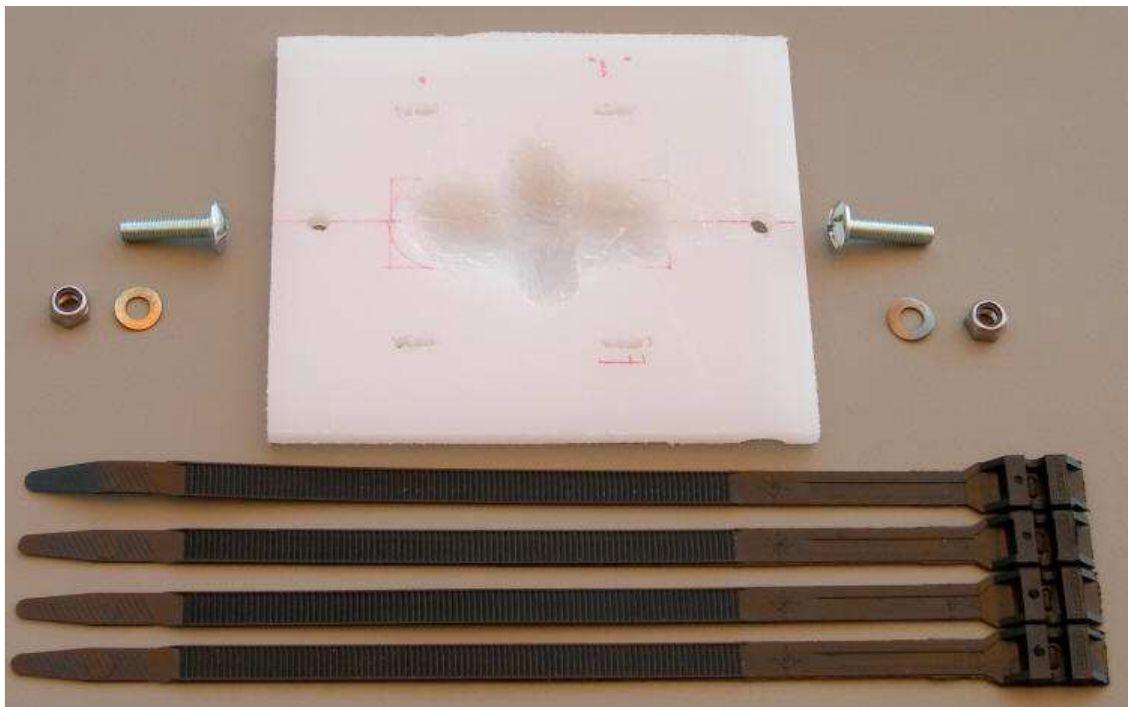
**Terminating of the ends of the loop - connection to the capacitor**  
(*"spark" gap between elbow pieces must have at least the same voltage rating as the capacitor: here: 10 kV*)



**Heavy multi-strand wire and hose clamps for connecting to the capacitor**

**For mounting the capacitor:**

- 8 mm thick polyethylene cutting board (from the kitchen). SIZE
- 2 xx bolts, M6 x ??
- 2 self-locking nuts, M6
- 4 large tywraps . Size? Black (better UV)



*Parts of the capacitor installation bracket*

**Tools:**

- Blow torch (high temp --> propane, acetylene - preferred); the simple one I used supposedly produces 1750 °C ( 3200 °F)
- Silver solder (plumbers solder)
- Flux (borax flux powder + water, or non-acid liquid or paste flux)
- Piece of sandpaper or steel wool



*Soldering tools: blowtorch, two kinds of silver solder (flux not shown)*

This is the most expensive antenna I have ever built!

**15-oct-2010:** a befriended plumber soldered the antenna together for me (thank you Bruno!!!!). He used a professional acetylene torch and brass & copper soldering rods. No flux or other stuff. The household blowtorches do not have the required temperature to do the soldering job in a reasonable amount of time (or at all). I use stainless steel hose clamps to connect to the capacitor. Heavy-duty multi-strand copper wire was soldered to the hose clamps and to the tips of the loop. The copper wire also helps keep the capacitor in place.





**A pipe/tube bending tool**  
(F: pince à cintrer)

**NOTE:** the circumference of the constructed loop (5m copper tubing) turned out to be 5m12 + 45 cm capacitor connection leads.

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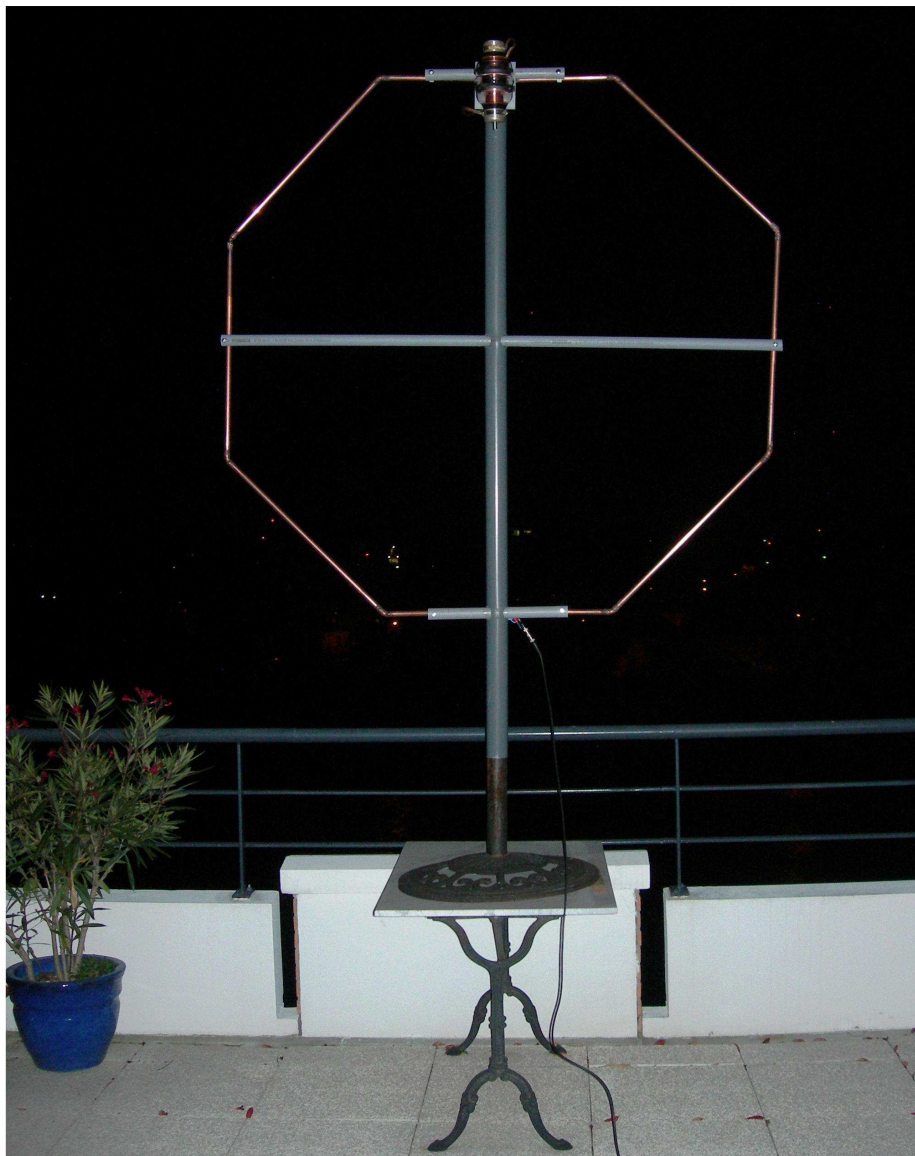




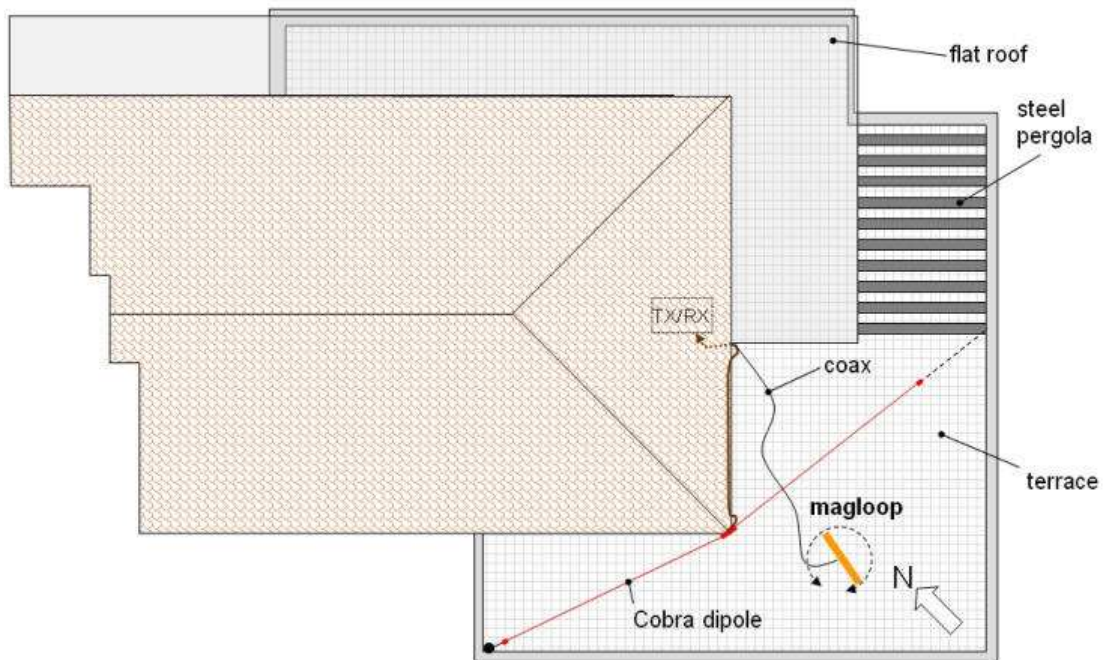
*Examples of commercially available capacitor mounting brackets*

**UPDATE 24-Feb-2012:** one and a half year after construction, I have used a professional milliohm meter (HP 4328A) to measure the DC-resistance of the copper parts of my loop (i.e., octagon + wires to the clamps): 3.2 milliohm. I also measured the resistance of a brand new round loop - without solder joints: also 3.2 milliohms. My joints are pretty good! However: I measured a DC-resistance of over 4 milliohm between the copper wires and the stainless steel clamps (i.e., 2 x 4 milliohms total). This kills the efficiency of the antenna - which I had already noticed over time. Must use a different method in my next design!





- add close up photos of parts of PVC structure (tubing, clips)
- photo of complete antenna, erected in umbrella stand, w/o motor drive
  - photo of complete antenna, erected, with motor drive
    - photo with weatherizing



**Location of the magloop on the terrace of my apartment**

This "beast" weighs in at 7.1 kg (15.8 lbs) without the motor.

**20-Oct-2010:** My first try was with an improvised coupling at the bottom-center of the loop: an T140-43 ferrite ring with 9 windings of heavy-duty installation wire. Reduction from 9 to 4 turns did improve the SWR at 3 MHz (from 8:1 to 5.6:1 and to 6.3:1 @ 3.6 MHz). Did not check bandwidth.

**23-Oct-2010:** gave the ferrite ring one more try today. Increased the number of windings to 14 of heavy-duty solid installation wire (1.5 mm<sup>2</sup>). Could not fit more windings on the toroid, with the copper pipe also passing through it (FT140 cores have an OD of 1.40" and 0.9" ID). With 14 windings I got a much more workable result: SWR of 1.9:1 around 3600 kHz, 1.3:1 around 5800, 1.6:1 around 7040, 3.4:1 around 10100, and over 10:1 at 14 MHz.

I sent some test signals on 7050 kHz around 18:00 local time. The Web-SDR in The Netherlands (about 1000 km from my QTH) showed good signals, and about 2 S-points reduction when I turned the antenna 90 degrees (broadside to the receiver site). This sounds reasonable for my installation situation: the idealized radiation pattern diagrams that most people use, is easily affected by nearby conductive or dielectric objects - this makes the nulls less deep.

I am pleased! However, it looks like coupling with a ferrite core is not broad-band enough: I need a good SWR over at least a 4:1 frequency range. Some literature suggests using ferrite material 61 instead of 43; however, 61 material is intended for use at higher frequencies - that is not what I want! And I should get a bigger ferrite ring (FT240 instead of FT140, i.e., 1 inch larger diameter: 2.4" OD, 1.4" ID).

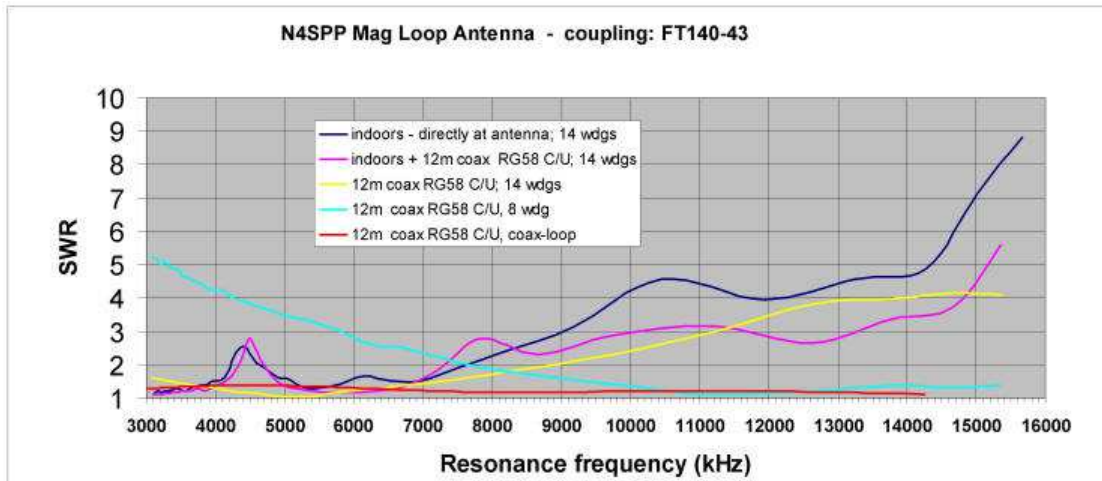
Adding a current choke "balun" does reduce SWR slightly (1.37 --> 1.3) --> this implies a slight asymmetry in antenna system, probably due to environment/location, or maybe the way in which the feed line coax was routed away from the antenna. Changed to 14 wdg's!

All measurements of SWR and phase angle were done with my *miniVNA* HF/VHF antenna analyzer.



**miniVNA - a tiny antenna analyzer for 0.1-180 MHz, with USB connection to a PC**  
(the latest version of the miniVNA has a built-in Bluetooth interface and battery)

The diagram below shows the SWR vs resonance frequency curves for several numbers of secondary windings, with and without 12 mtrs of RG58 coax, and installation indoors vs. outdoors. The antenna is placed 80 cm (2½ ft) off the floor.

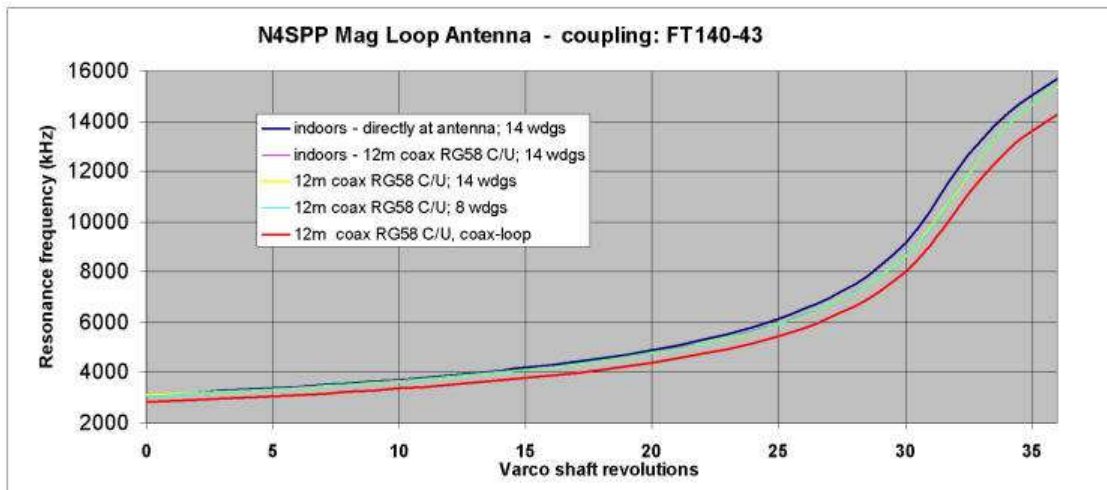


The above plots suggest that:

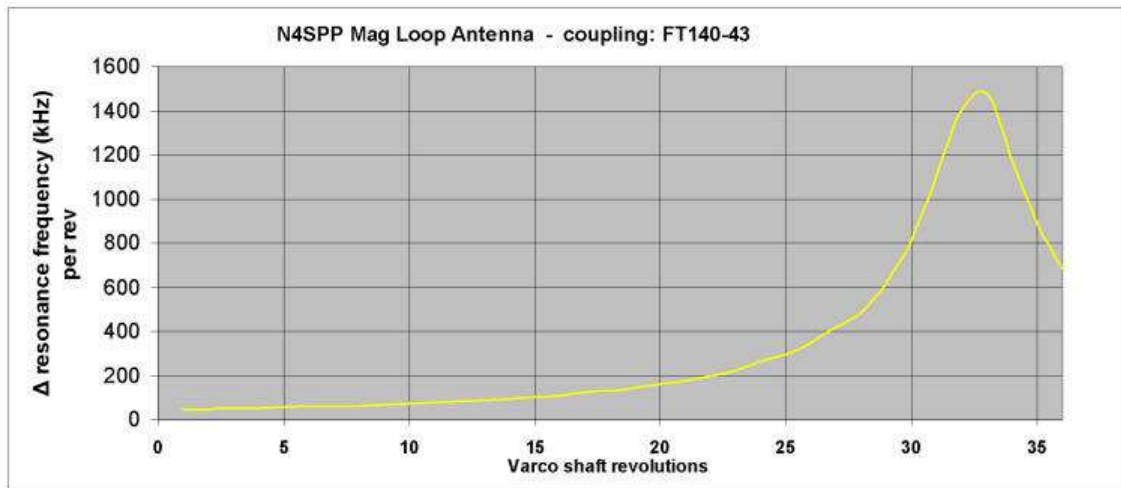
- windings of installation wire on a ferrite ring (material type 43) provide workable (SWR < 2) matching over a 3:1 frequency range. However, I need 4:1
- reducing the number of secondary windings shifts the SWR curve to the right; with 12 or 13 windings, I may get SWR < 2 for 80-30 mtrs.
- using a small coax loop on the ferrite ring might be the way to go, based on the "good" SWR for the entire frequency range. However, with this coupling method, the SW=2 bandwidth of the antenna went up by at least an order of magnitude compared to using windings on the ferrite ring. With the latter, I determined a bandwidth of about 4.5 kHz on 80 mtrs, slightly higher than the 3.6 kHz predicted value (for free-space installation).

**NOTE:** SWR=2 bandwidth is relative to SWR = 1 at the resonance frequency. If the SWR is not 1:1 at resonance, then the SWR curve must be translated (shifted vertically) such that at resonance SWR =1, or the SWR=2 points must be shifted to SWR = (2+SWR<sub>res</sub>). If not, the bandwidth statement is meaningless. E.g., bandwidth would be undefined for a resonance SWR-curve that never dips below SWR=2. Bandwidth is determined by the -3 dB (with respect to resonance!) frequencies, at either side of the resonance frequency. I.e., relative and not an absolute SWR=2.

**UPDATE 15-March-2012:** I intend to change over to ferrite rings made of material type 31. This should be better for frequencies below 10 MHz than 43 material. The lowest cost source that I have found for FT240-31 rings (= Fair-Rite part number 2631803802) is Arrow: \$5.31 a piece (3/2012 pricing).



As the resonant loop is an LC-circuit, the resonance frequency varies with the square-root of the tuning capacitor's value. The plot below shows that towards minimum capacitance, the capacitance does not vary linearly with the capacitor's shaft position.

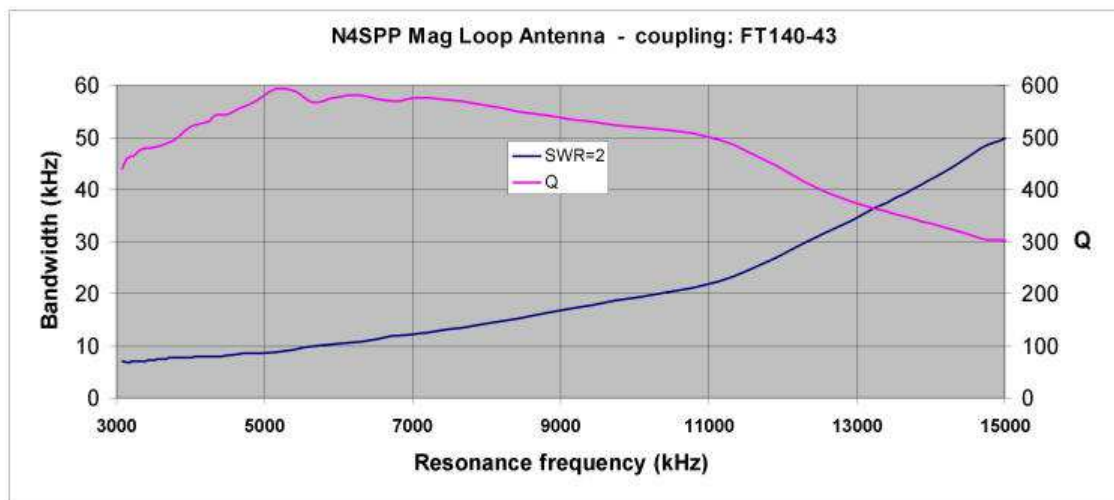


*Non-linear change in resonance frequency as function of the varco position  
(measured for coupling with FT140-43 core)*

The "Q" (Quality) factor depends inversely on the bandwidth. It is a measure for how lossy the resonant circuit is: peak energy stored in the circuit, divided by the average energy that is dissipated per cycle, in the circuit at resonance. This can be expressed as:

$$Q = \frac{f_{\text{resonance}}}{\text{bandwidth}}$$

where bandwidth is the difference between the SWR=2 frequencies on either side of the resonance frequency (referenced to SWR=1 at  $f_{\text{res}}$ ). The plot below shows both bandwidth and Q for the ferrite transformer coupling with 14 secondary windings. The bandwidth varies from 6.8 kHz around 3 MHz, to 50 kHz around 15 MHz. The associated Q varies from 450 to 300, with a maximum of 600 around 5 MHz.



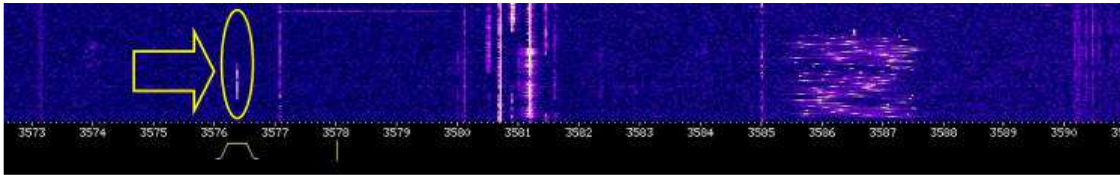
*Bandwidth and Q for coupling with an FT-140-43 core and 14 secondary windings*

## OPERATION AND PERFORMANCE OF MY FIRST ANTENNA

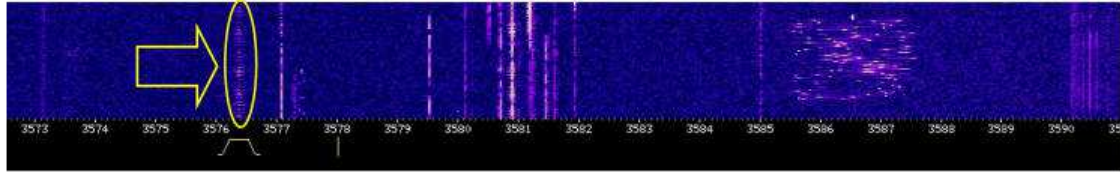
With maximum capacitance (500 pF), the resonance frequency is 3064 kHz, with minimum capacitance (15 pF) it is around 15.8 MHz. This range is larger than what the various calculators estimated - suits me fine! Note that the connections between the loop and the tuning capacitor do add to the size of the loop.

I first test-fired the antenna on 19 October 2010, around 3577 kHz in the 80 mtr band, at sunset (19:00 hrs). As usual, I used [the world's best Web-SDR](#) as a remote receiver. It is located some 1000 km (≈620 mi) to the north of my QTH in France. The antenna was fed via a ferrite ring coupling + 14 windings, as described further above; the residual SWR was easily eliminated with my ATU. As you can see below in the waterfall display of the Web-SDR, my signals are getting out there. The plane of the antenna was aligned to the north (i.e., the opening of the loop pointing east-west). Turning the antenna 90 degrees, made the S-meter of the Web-SDR go down about 2 S-points.





*My tuning signal (80 W) clearly visible in the waterfall display of the Web-SDR*

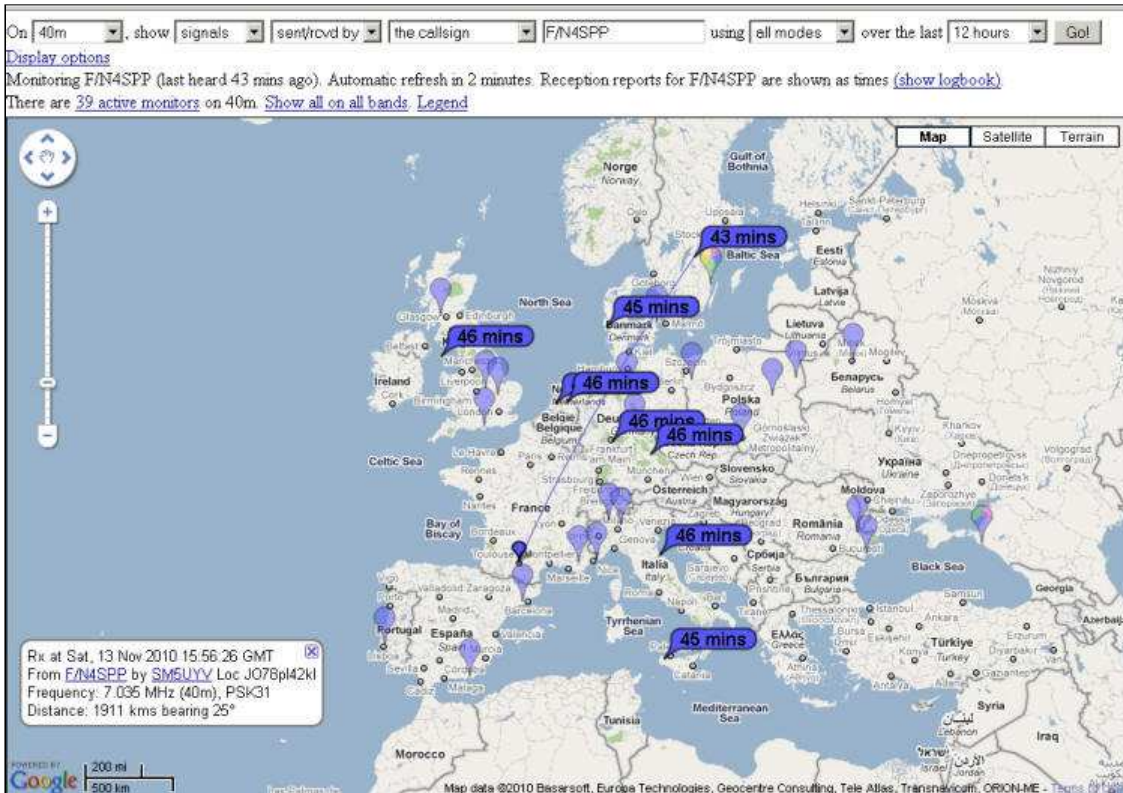


*Sending a series of "E" characters in Hellschreiber mode*

**31-Oct-2010:** 17:00-18:00 local time; 3579 kHz. Participated in Hell Net (1000 km).

**12-Nov-2010:** RX test on 7040 kHz, coax relay to quickly switch between loop and Cobra dipole; Loop several S-points stronger + noticeably quieter!

**13-Nov-2010:** 17:00 local time, 7036 kHz, PSK-31. Had an FB QSO with Rolf, DF7XH. With all my other antennas, I have only had marginal communication with Rolf - at best! This QSO was 59+ in both directions, with the loop pointing towards his QTH (about 750 km, bearing 50 deg). The screenshot below shows the location of PSK receiving stations that automatically reported receiving my signals. Coax coupling via 14 windings on ferrite ring; residual SWR of 1.3 easily eliminated with my ATU. I am quite pleased!



*Screenshot from PSK Reporter*

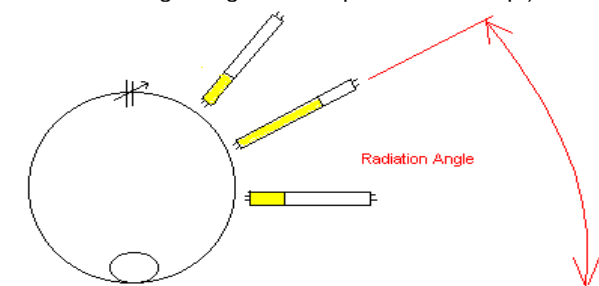
Note of 27 Nov: used the antenna for some tuning and RX tests today. When the sun came out, the resonance frequency started to drift. To be kept in mind when driving to pre-set positions...

- 80-40-30-20
- add plot of bandwidth vs frequency (+/- 45 deg phase angle bandwidth; cross-check against SWR=2 bandwidth with SWRres translated to 1:1)
- accuracy of remote tuning (freq --> swr)
- WebSDR
- contacts
- radiation pattern; nulls
- Add: video clip / screen capture of miniVNA plot + controller GUI, as cap is driven from from min to max
- miniVNA plots (toroid coupling, Gamma/Delta, at min and max capacitor value, at target frequencies)
- RX noise relative to my other antennas

- signal relative to my other antennas
- RX nulling
- TX to SDR

*Text + diagrams about radiation pattern + polarization*

theoretical radiation pattern (dependent on circumference as fraction of wavelength ? The doughnut shaped radiation pattern is in the plane of the loop with nulls at right angles to the plane of the loop.)



carrier with XX watt  
and add same with photos or video clip

- photo with TL tube (overlay of several pix at various angles)

Below are two short video clips of a demonstration by Mike Underhill, G3LHZ, of the field around a magnetic loop antenna.

- "Field around a loop", HFC2000
- "More field", HFC2000

## NEXT TIME....

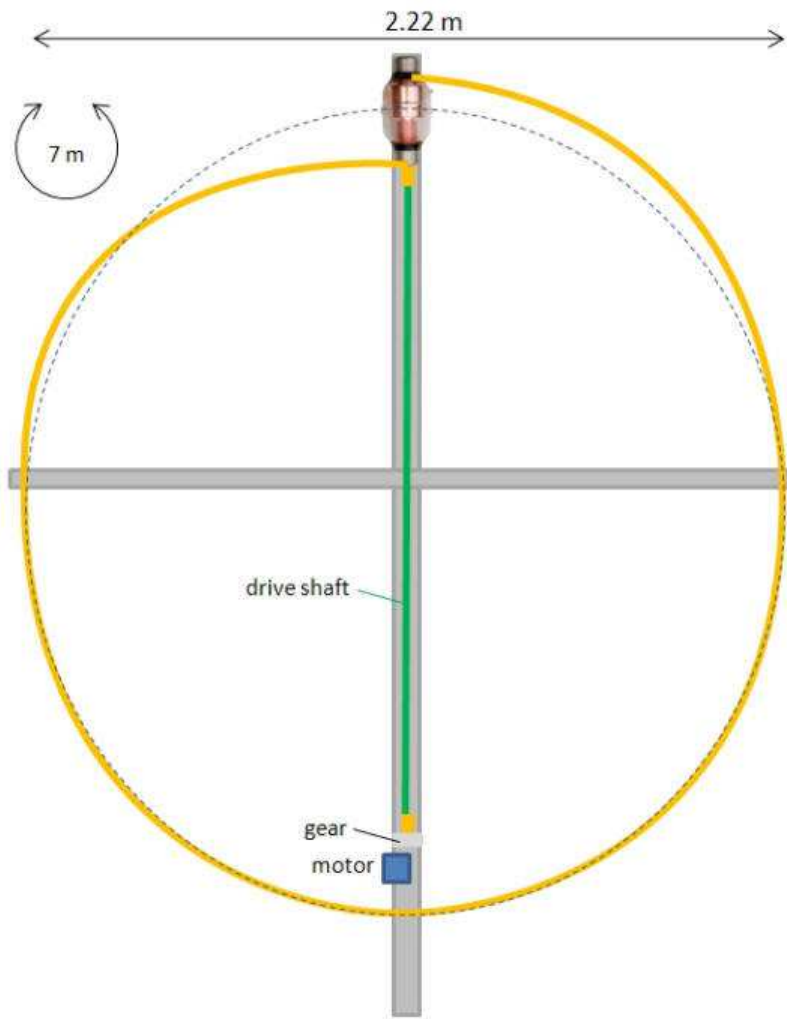
### If I had to do it all over again:

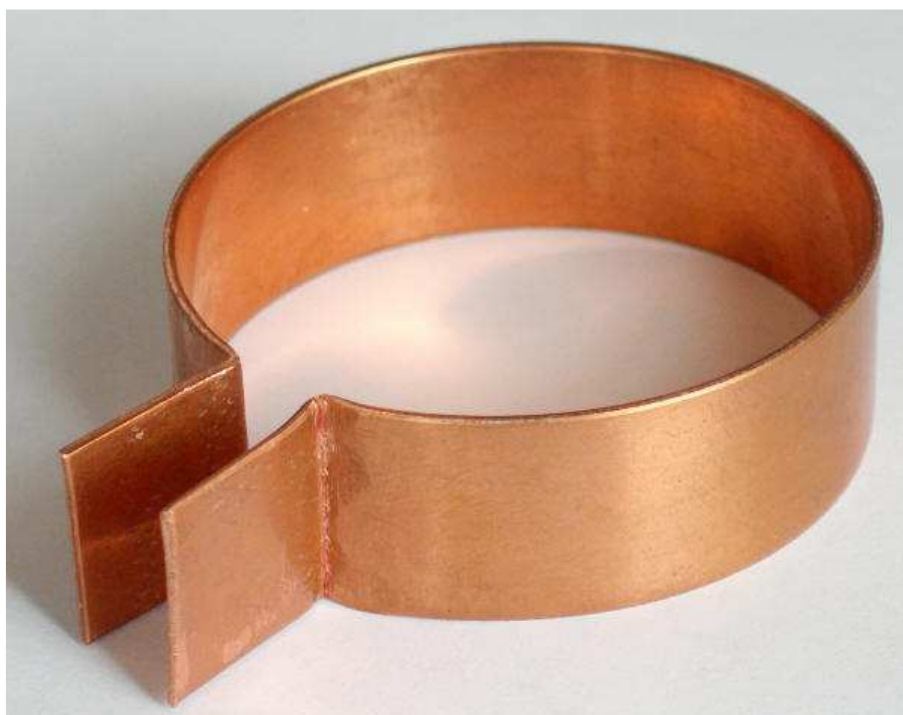
- Reduce the number of joints. Use a tube bending tool rather than cut the straight pipe into sections and solder a bunch of elbow pieces. It looks cleaner, each joint potentially adds highly undesirable series resistance to the loop, and someone has to solder each joint... Note that a proper tube bending tool stretches the tube during the bending process. This is done to avoid crimping / rippling of the tube.
- Use a different method to connect the ends of the copper tube to the vacuum capacitor.
  - after about a year and half after construction, the total DC-resistance of the copper part of the loop has not changed (still at 3.2 milliohm), but the resistance between the copper wire and the stainless steel hose clamps had increased to a little over 4 milliohms - per clamp! This kills the efficiency (as mag loop calculators will quickly show).
- If optimal efficiency in the 80m band is of prime interest, use a loop with at least 2 m diameter. This will cover 80-30m. However, 2 m diameter implies 6.3 m length (20.6 ft). Not available in the local do-it-yourself store. Increasing the loop-circumference from 5 m to 7 m will double the area of the loop, and more than double the efficiency of the antenna on 80m!
- Clearly, I will have to replace the stainless steel clamps to hook up the capacitor. I am planning to make clamps out of soft copper strip, about 2-3 cm wide ( $\approx 1$ " ) and 2-3 mm thick ( $\approx 0.1$ " ). I have toyed with the idea of silver plating the copper (using [this recipe](#) by ON7LR), but based on a discussion (half way down on [this page](#)) by David, G3YNH, I may skip that...
- Use a stepper motor with enough torque to meet the requirements of the capacitor (turn over all positions, stall at end-stop), without the need for gearing. Probably a modern bipolar or hybrid stepper motor; Phidgets also has a single-motor controller card for bipolar steppers (model 1063); it allows setting of a current limit (= torque).
- I liked using the Phidgets card and programming the controller in LabView. However, if you don't have LabView, it is a bit difficult to get my software up & running.
- I intend to change over to ferrite rings made of material type 31. This should be better than #43 material for frequencies below 10 MHz. The lowest cost source that I have found for FT240-31 rings (= [Fair-Rite part number 2631803802](#)) is [Arrow](#): \$5.31 a piece (March 2012 pricing).

## CONSTRUCTION OF MY SECOND LOOP ANTENNA - FALL/WINTER 2012

### SEPTEMBER 2012: IN PROGRESS

My first mag loop antenna has a circumference of about 5 mtrs ( $\approx 16\frac{1}{2}$  ft) - a standard length of copper tubing in the local Do-It-Yourself stores. I am extending this by 2x 1 mtr to 7 mtr ( $\approx 23$  ft; standard length of a roll in the US is 20 ft - perfect). So the diameter of the loop will be about 2.2 mtr ( $\approx 7.3$  ft). Don't make the mistake to assemble a loop of this size inside the house: it probably will not fit through a regular door. Don't paint yourself into a corner, hihi.

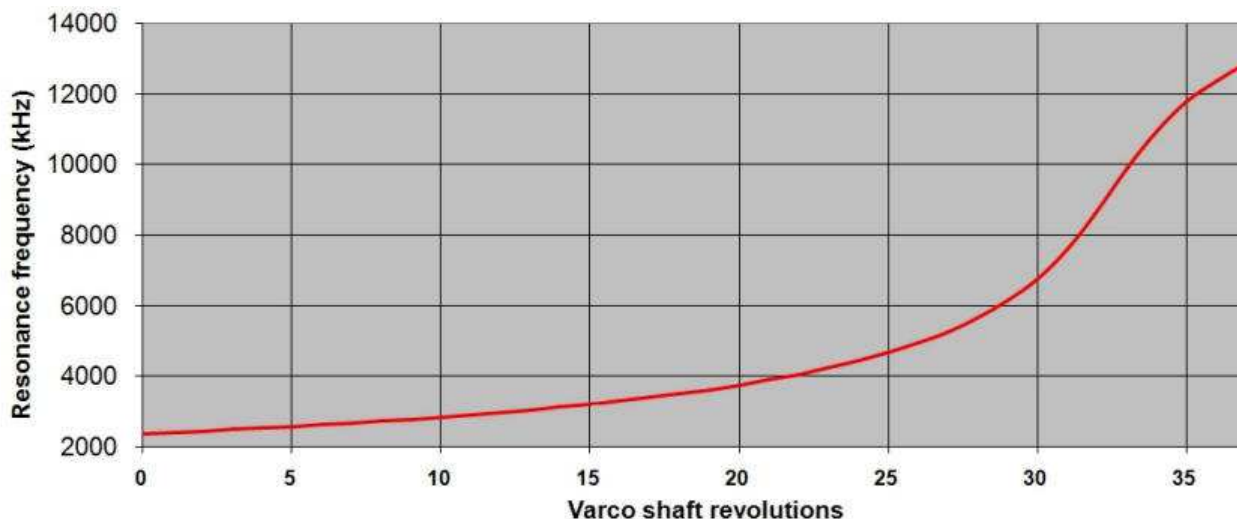
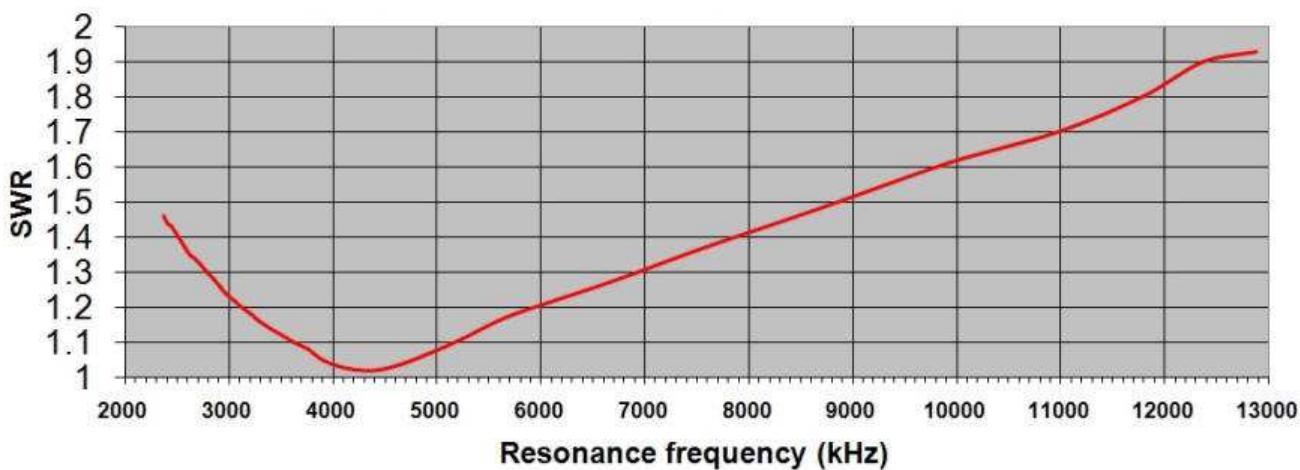
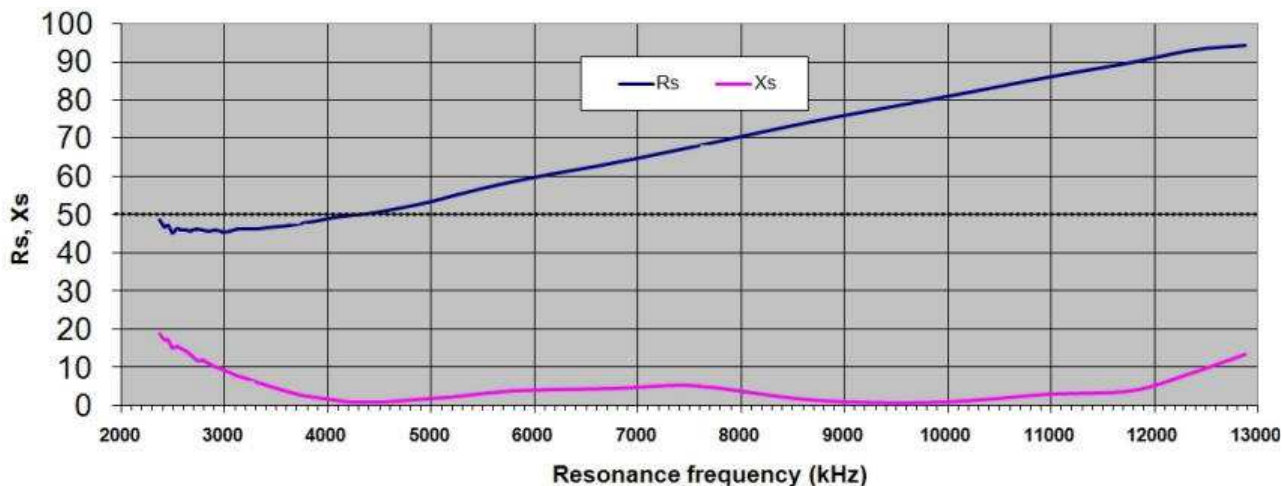




*Capacitor clamp/bracket - made of a strip of 1x20 mm soft copper*

**January 2013: preliminary measurements.** I did some quick measurements with my miniVNA analyzer. As outlined under "next time" above, I used an FT-240-31 ferrite ring for coupling. The first measurement, with a single secondary winding (just a wire stuck once through the ring) showed an impedance of about 10-12 ohms. So, to get the 1:4

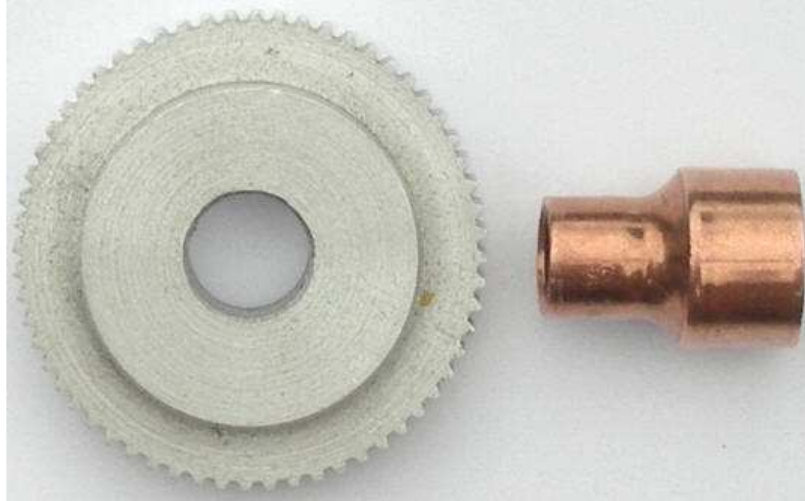
transformation ratio required to get close to 50 ohms, I needed 2 secondary windings. I added a 1:1 current choke right at the coupling. I took one sets of measurements, 1 for each turn of the varco shaft. Results are shown below. It does confirm the suitability of -31 ferrite material for the lower frequencies.



I will move the motor away from the capacitor, to the "neutral" point opposite the capacitor. This requires a long, torsionally-stiff drive shaft. I found very stiff green plastic rods of 1.8 m (6 ft) length and 16mm diameter in the gardening section of the local do-it-yourself store (thanks for the idea Mark, KF7KIN). **Be careful:** some of these green garden rods are just plastic-coated metal tubes or rods. It is not easy to tell! I ended up with a 1.8 m section of 16mm PVC electrical conduit. It is flexible, but torsionally stiff.

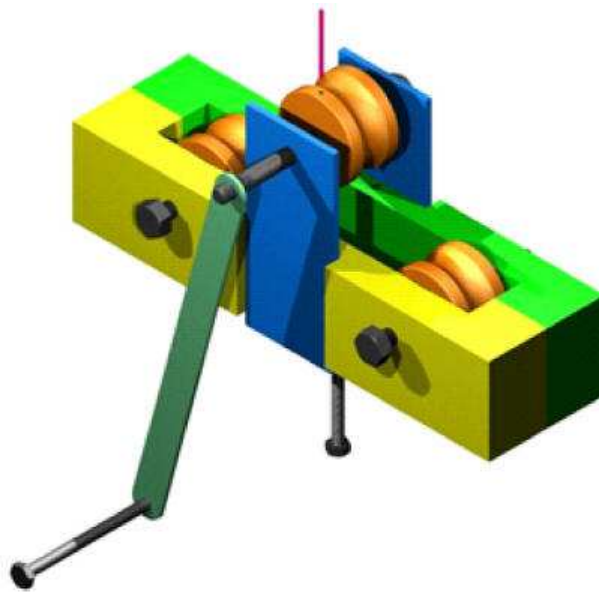
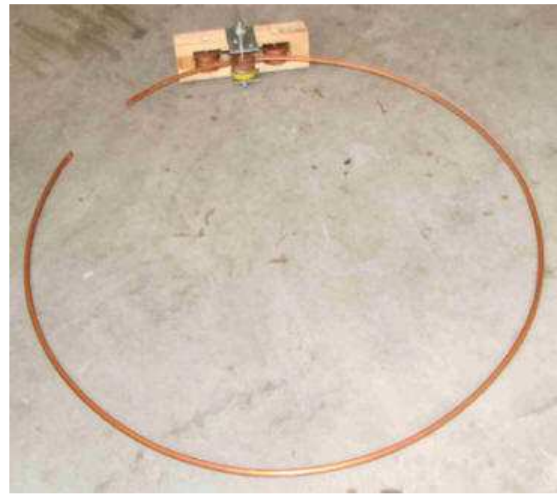
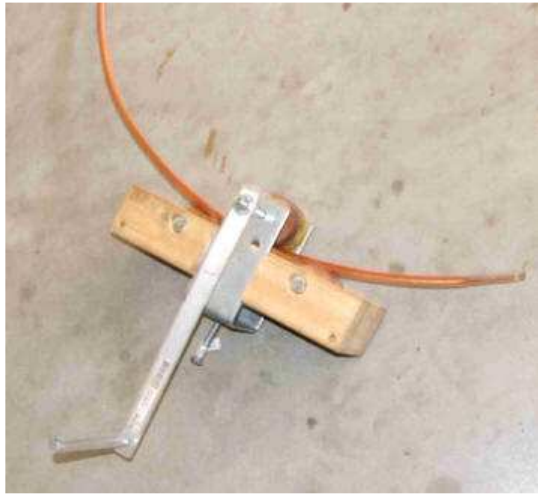
The bore of my large gearwheel is 12 mm, as is the diameter of the capacitor-shaft. Adapting the 16 mm rod to the 12 mm bore (inner diameter) is easy, with a 16-to-10 mm copper adapter piece. It has 1 wall-thickness of 1mm, so  $10+1+1=12$  mm outer diameter. I pressed it in with the bench vise. Adapting the 16 mm rod to the 12 mm outer-diameter of the capacitor shaft is equally simple, with a 16-to-12 mm adapter piece. The store didn't have that one in stock, so I used a 3

adapters: 16-to-10 & 10-10 (female-female) & 10-to-12. I will install a ball bearing with 16mm bore on the rod, close to the motor.



Roger Dunn (VK4ZL) sent me a well-illustrated description of a tube roller that he built with material from the do-it-yourself store. It makes very nice round tube out of straight tubes. It is adjustable for tube diameters of 12-25mm ( $\frac{1}{2}$  -1").

- ["Tube roller"](#), by Roger Dunn (VK4ZL), September 2011, 2 pp. - used with permission.



Twan van Gestel (PA0KV) also made his own tube roller. He used it to make a perfect loop with a 4 meter diameter ( $\approx 13$  ft) out of 22 mm ( $\approx 1$ " ) copper tubing. The loop, including the motor drive and Gamma-Match coupling, is described on the ham radio page of [his website](#).



*Tube roller made by Twan, PA0KV  
(photos used with permission)*

For a quite different approach - using wide copper band wrapped around a PVC frame, instead of copper tubing - check this:

- ["Helically Loaded Magnetic Loop Antenna"](#), by Richard Fusinski (K8NDS)





Or use a Slinky coil:

- [Slinky Loop aerial](#) by Tom Haylock (M0ZSA)

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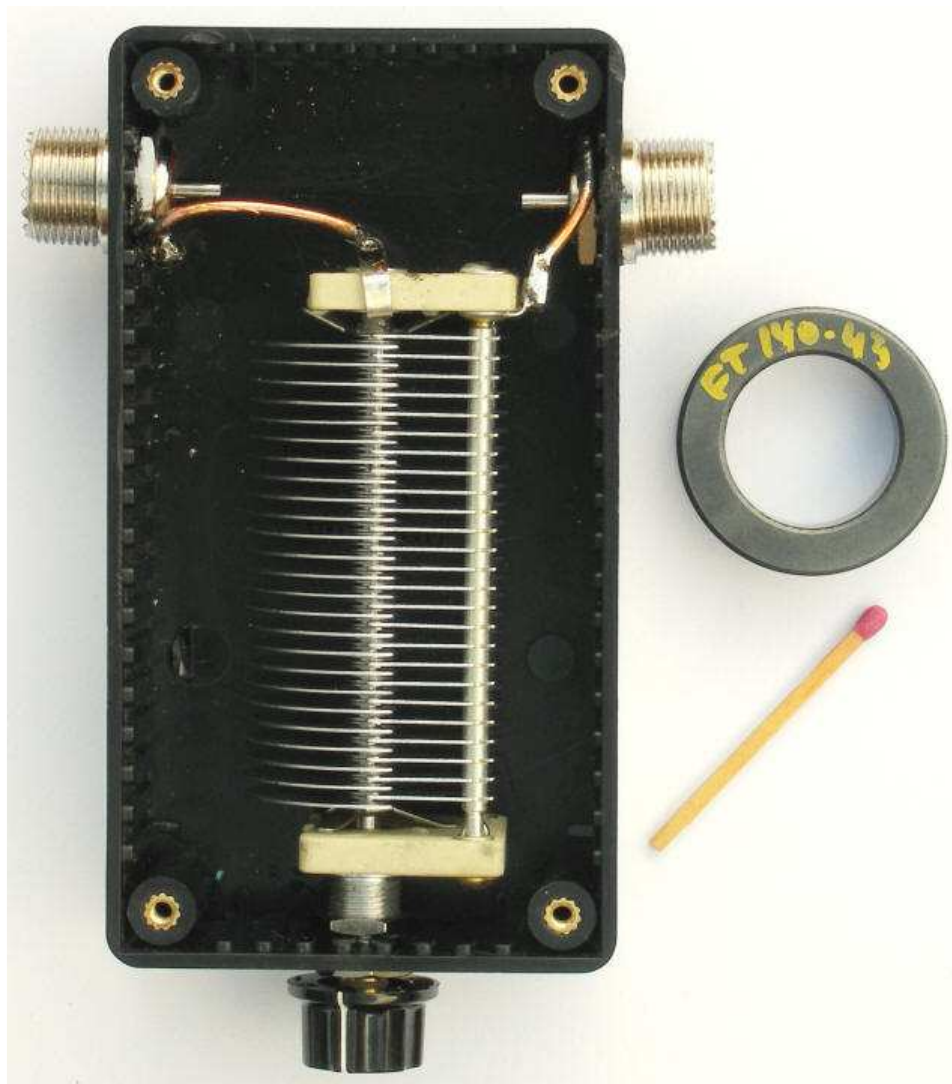
### CONSTRUCTION OF MY PORTABLE LOOP ANTENNA - *FUTURE PROJECT*

Mid-2012 I acquired a portable QRP rig: a Yeasu FT-817ND (HF + 2m + 70cm). So now I need a portable loop (40-20 or 40-10). I'll be making one out of heavy/rigid coax (1 cm Ø) and a diameter of 1 m (3.3 ft). Such loops are available commercially for several hundred euros/dollars. You can make one yourself for a fraction of that price.

- 3.3 m (≈10.5 ft) rigid coax (at least 10 mm diameter) for the main loop, e.g. LRM-400; loop diameter: 1 meter (3.4 ft)
- 2 PL-259 plugs, at the ends of that coax
- 2 SO-239 chassis jacks (short-circuit the braid and the center conductor, connect to capacitor)
- at each end of the coax, the braid and the center conductor are interconnected (in the plug and/or in the jack)
- air-gap variable capacitor, ca. 10-300 pF. I will first try with a [10-208 pF capacitor from MFJ](#) (\$24 + S&H, mid-2012 pricing). Rotation of this capacitor's shaft is not limited. Should be OK for 40-20m.
- small ABS-plastic project box (not metal!); mine measures 11x6x3 cm.
- Coupling: an FT140-43 ferrite ring (the inner diameter is large enough to fit over both coax and the PL259 plug)
- PVC tube, in sections
- small down-geared motor (salvaged from a jackscrew window opener)



*The MFJ air variable capacitor*



*The assembled tuning box and the T-140-43 ferrite ring*

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## MY MOTOR DRIVE FOR THE VARIABLE CAPACITOR

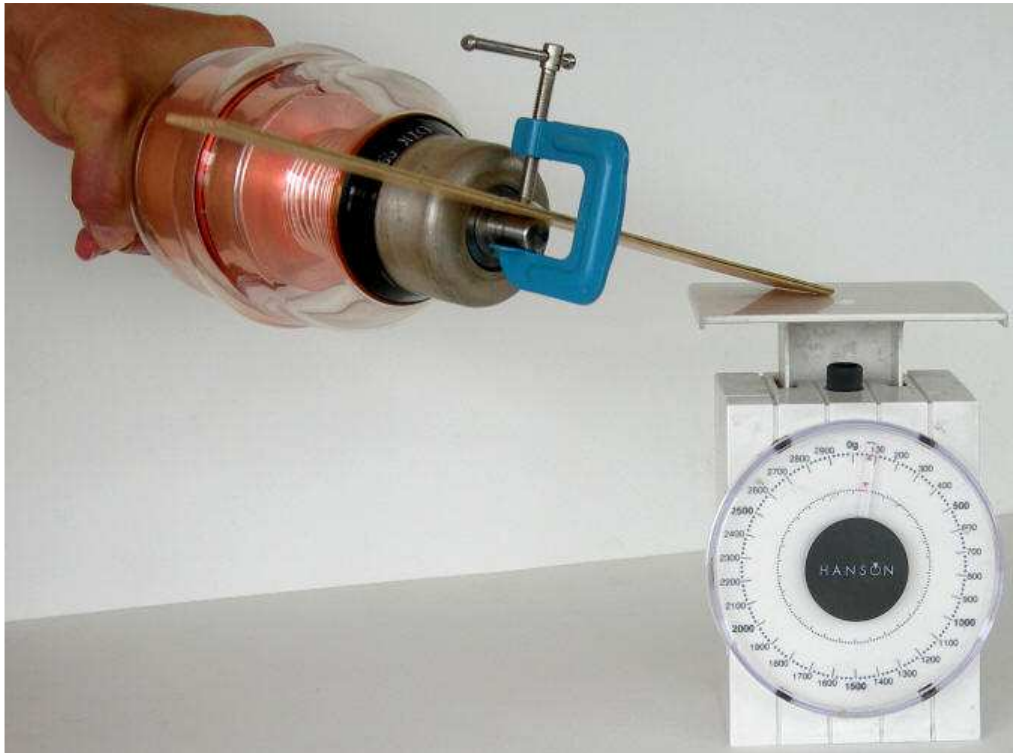
This type of antenna has relatively small bandwidth, see plot above. Also, temperature variations (e.g., sun hitting the loop and capacitor) change the resonance frequency noticeable. Given the field strengths, you do not want the antenna anywhere near you when transmitting - besides, physical presence near the antenna de-tunes it. Manually tuning the loop antenna is a real hassle: you have to run back & forth between the transmitter (or antenna analyzer) and the antenna. This may be OK during initial check-outs of the antenna, but not for normal operation:

**A small transmitting loop antenna requires a remote-control motor drive for the tuning capacitor.**

---

The first design parameter for the motor-drive is the **torque required** to overcome the stiction (static friction) and turn the shaft of the variable capacitor. This drives the size of the motor and reduction gear (if required). Variable vacuum capacitors have a torque value that depends on the position of the capacitor (mid-range vs close to the end-stops), and the direction (towards or away from an end-stop). I do not have the data sheet of my Russian capacitor. To get an order-of-magnitude idea, I checked the values for a comparable capacitor (25-500 pF, 10 kV test, 9 inch length) on [the Jennings website](#): 6 inch-pound (in.lb) or  $6 \times 0.113 \approx 0.68 \text{ Nm} = 68 \text{ Ncm}$ .

I then decided to measure it myself ("trust, but verify!"). This is actually quite easy to do! I clamped a standard 30 cm (1 ft) ruler onto the shaft of the capacitor with a small C-clamp. Pushing slowly down onto a kitchen scale until the shaft barely turns, and read the "weight". *Voilà*. See photo below. The force was applied to the shaft with half of the ruler, i.e., an arm of 15 cm.



*Determining the torque values of my capacitor*

Here are the results:

- Depending on the turn direction, I measured about 80 to 100 gr at positions up to mid range (starting at minimum capacitance). So, the applied torque was  $(0.1 \text{ kg} \times 9.8) \times 0.15 \text{ m} \approx 0.15 \text{ N.m} = 15 \text{ N.cm} (\approx 21 \text{ oz.in})$
- Somewhere mid-range, it became harder to turn the shaft, and I needed to apply about 140 gr, i.e.,  $20.6 \text{ N.cm} (\approx 29 \text{ oz.in})$
- I needed about 300 gr to get completely to the opposite end (maximum capacitance), i.e.,  $44.1 \text{ N.cm} (\approx 63 \text{ oz.in})$
- I cranked it up to 1000 gr without breaking anything, i.e.,  $150 \text{ N.cm} (\approx 208 \text{ oz.in})$

There are numerous on-line calculators for converting torque values between various units, e.g., [here](#), [here](#), and [here](#).

I decided to *not* measure the torque required to go *beyond* the end-stops of the capacitor, hihi. However, it would be nice if the stalling torque of the motor-drive were less than this unknown value, so I could dispense with end-stop protection.

The second important design parameter is the **angular resolution of the motor-drive**. The loop antenna has a large Q, or - equivalently - a very narrow bandwidth. The motor-drive must be able to make angular displacements that are small enough, such that the associated capacitance change does not change the resonance frequency more than a fraction of the bandwidth. Otherwise it will be next to impossible to tune the resonance frequency close enough to the desired operating frequency. The calculated bandwidth for my antenna is 3.8 kHz on 3580 kHz, and 61 kHz at the high end of the 20 m band. Assuming that the capacitance changes linearly with rotation of the capacitor's shaft, we get  $500 \text{ pF} / (22 \text{ turns} \times 360^\circ \text{ per turn}) \approx 0.06 \text{ pF} / \text{degree}$ . I have not (yet) verified the validity of this assumption...

Plugging in various resonance frequency values into the AA5TB spreadsheet (assuming no additional loss resistance), I obtained the following estimates:

Around maximum capacitance:

- resonance frequency is in middle of the 80 m band.
- bandwidth is about 3.5 kHz
- resonance frequency changes about  $4.2 \text{ kHz} / \text{pF}$  (i.e.,  $0.24 \text{ pF} / \text{kHz}$ )

Around minimum capacitance:

- resonance frequency is at the high end of in the 20 m band.
- bandwidth is about 52 kHz
- resonance frequency changes about  $275 \text{ kHz} / \text{pF}$  (i.e.,  $0.0036 \text{ pF} / \text{kHz}$ )

Clearly, variation around the minimum capacitance is the critical case!

Let's assume that accurate tuning requires changing the resonance frequency with a resolution that is better than 20% of the bandwidth. The above data implies a required resolution of better than  $20\% \times 52 = 10.4 \text{ kHz}$ , i.e.,  $10.4 / 275 = 0.038 \text{ pF}$ !

Based on the 0.06 pF / degree change in capacitance as estimated (assumed) above, I need an angular positioning resolution of better than  $0.038 / 0.06 = 0.63$  degree.

Note: the actual bandwidth of my antenna system is actually larger than the predicted/calculated bandwidth. I measured 4.5 kHz in the 80 mtr band, slightly higher than the 3.6 kHz predicted value (for free-space installation). This implies only a slight relaxation of the angular resolution requirement.

---

A secondary design parameter is the **drive speed**. We don't want to wait an hour for the capacitor position to move from min to max value, and vice versa. My capacitor requires 36 turns for this min-max range, which should cover the 80-20 m bands. If I could live with 1 minute, that would be 36 rpm at the capacitor shaft = 0.6 rps.

---

Now we can choose a **motor and associated drive electronics**.

There are two basic options:

- stepper motor (with gearing, if necessary for torque and/or position resolution),
- DC motor with gearing + position feedback (unless you just want to move the motor while observing the SWR or antenna impedance and don't care about the motor position). The DC motor has to be a brushless type, otherwise the brushes will generate electrical noise when tuning the antenna in receive mode.

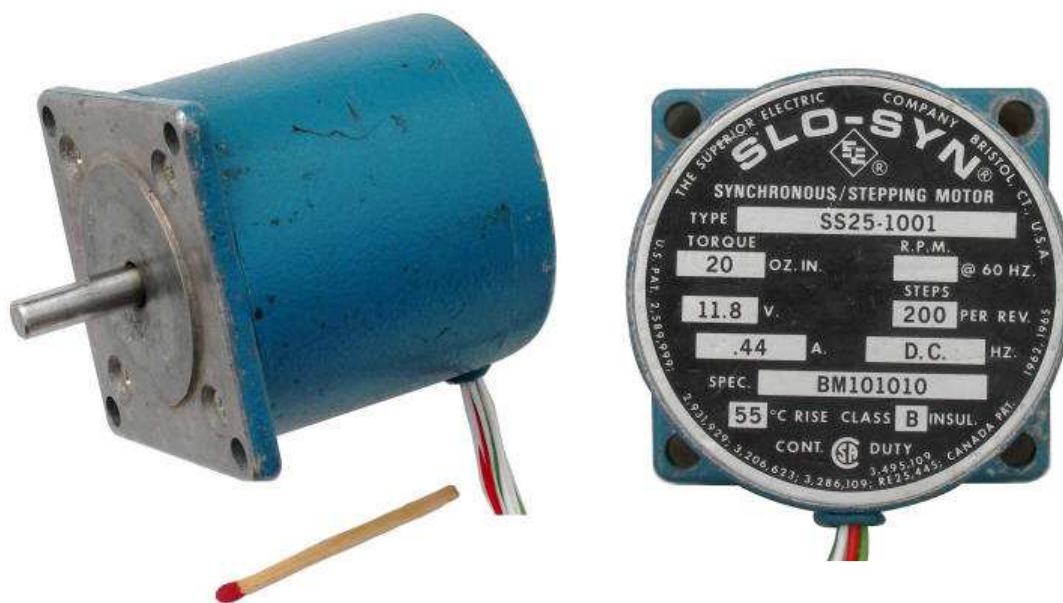
Note that if you are using an air variable capacitor instead of a vacuum capacitor, .. But such capacitors go through their capacitance range in a single revolution of the capacitor shaft. For multi-band tuning (large capacitor value), this implies a positioning resolution that is at least an order of magnitude better than what is needed for a multi-turn (10-40 turns) vacuum variable capacitor.

The stepper motor approach his more accurate than the analog motor, for the following reasons:

- \* Predictable and more accurate control,
- \* No 'drifting' in the presence of RF when finally tuned, and
- \* Higher torque for moving 'heavier' capacitors.
- \* without position feedback and some controller sophistication, this type of drives tends to overshoot target positions.
- \* barbeque spit motor (normally comes with a gear); motor from electrical screwdriver + gear.

Positioning accuracy and torque requirements are easily met with a stepper-motor: they have a specified torque and step size. Stepper control electronics often have half-stepping capability (though this typically reduces available torque by about 30%). Common step sizes are 1.2, 1.8, 3.6, 7.5, and 15 degrees. I.e., 300, 200, 100, 48, and 24 steps per revolution, respectively. Smaller step sizes do exist, e.g., 0.9 and even 0.36 deg, but at a cost...

One of my colleagues donated a stepper motor (Thank you Helmut!). It is a Slo-Syn SS25-1001. This is a 5-wire brushless permanent magnet inductor motor that can be operated as a constant-speed AC synchronous motor, or as a 1.8° uni-polar DC stepper motor.



*The Slo-Syn SS25-1001 motor*

"SS25" stands for "Standard Slo-Syn" with 25 oz.in (17.7 N.cm) torque at 72 rpm (120 Vac, 60 Hz). However, as a stepper motor, it has different torque ratings:

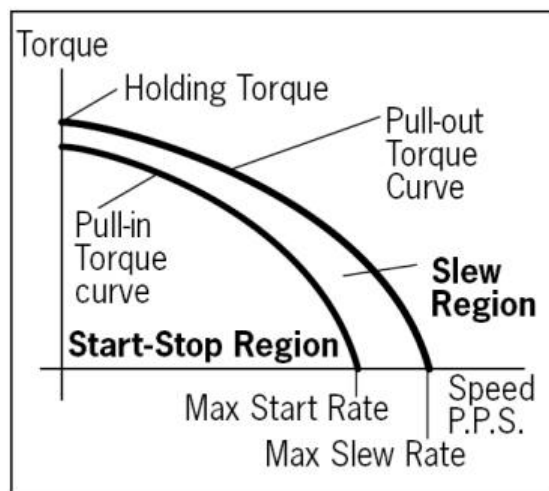
MOTOR TYPE	MINIMUM HOLDING TORQUE				TYPICAL RESIDUAL TORQUE OZ-IN (Ncm)	MAX. RADIAL FORCE LB (N)	MAX. AXIAL FORCE LB (N)	NEMA FRAME SIZE	NET WEIGHT	
	ONE WINDING ON OZ-IN (Ncm)	TWO WINDINGS ON OZ-IN (Ncm)	CURRENT PER WINDING (AMPERES)	DC VOLTS PER WINDING					LB	kg
	SS25	30 (21.2)	40 (28.2)	0.07					80	1 (0.7)

*Specification of the SS25 stepper motor*

There are several kinds of torque to consider:

- **holding torque** (a.k.a. **break-away** torque): the amount of torque required to break the shaft away from its holding position, with motor at standstill and coil(s) energized with rated current & voltage.
- **pull-in torque**: max torque at a given speed, for stopping/reversing without losing sync.
- **pull-out torque**: max torque at a given speed, without losing sync or stalling.
- **residual torque** (a.k.a. **detent** torque): torque produced by the motor's permanent magnets, when no coils are energized.

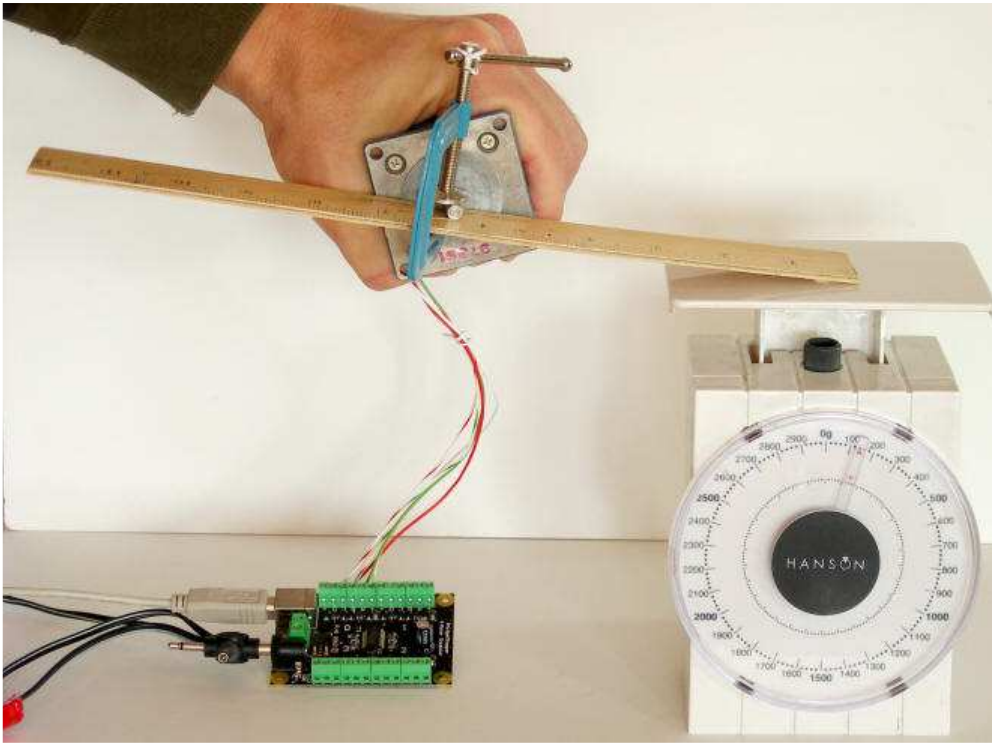
The holding torque and residual torque are not interesting for my application, as the motor will not be holding a load. Of interest are the pull-in and pull-out torque, typically provided as a torque vs. speed curve. The curves are highly dependent on the type of motor driver used.



*Typical shape of the torque curves*

I do not have the torque curves for this motor, but typically it appears to be about a factor three smaller than the holding torque. That would imply a torque of about 10 oz.in (7 N.cm). Less than half of what I need! On top of that, the Phidgets card uses half-stepping: the drive alternates between two phases energized and a single phase energized. This provides smoother motion and doubles the angular resolution from 1.8° to 0.9°. However, the motor also typically produces about 30% less torque (at the 1/2 step positions between full step positions). Maybe I will only get about 7 oz.in (5 N.cm)! This means I will probably need a 4:1 gear ratio between the motor and the shaft of the variable capacitor...

So why not determine the *actual* torque, the same way I measured the *required* torque. With the motor energized, just make the "arm" push down on the scale until the motor turns.

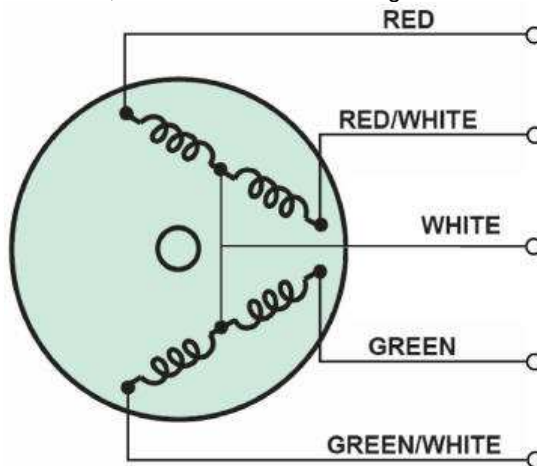


*Determining the break-away torque value of my SS25 motor*

With this simplistic kitchen scale method, I measured a break-away torque of approximately  $140 \text{ grams} \times 15 \text{ cm} = 2100 \text{ g.cm} = 20.6 \text{ N.cm} = 29.2 \text{ oz.in.}$  Almost exactly as specified! The same value is obtained by fixing the motor in place, and commanding it to turn, one step (or 1/2-step) at a time until it "pops". This very easy to do with the controller software I wrote (see further below).

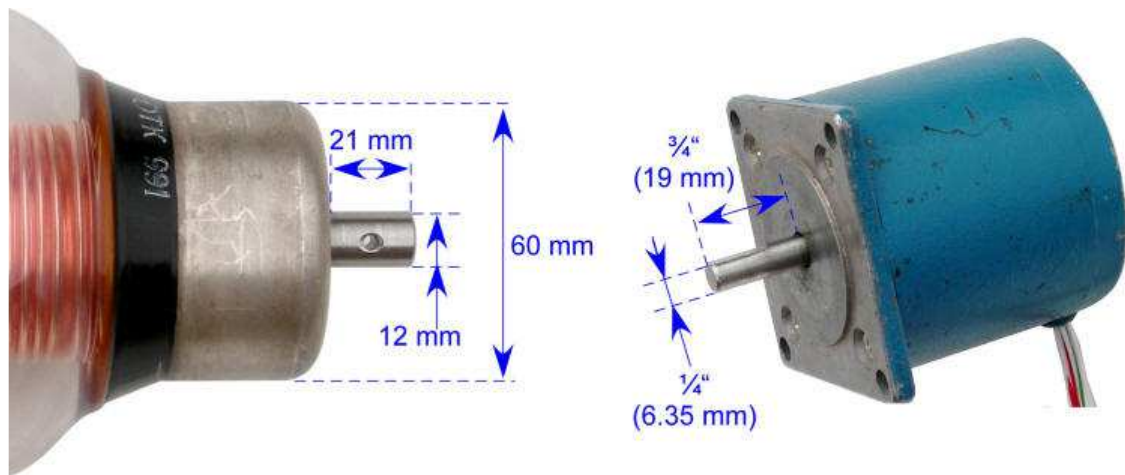
Keep in mind that I need at least  $44 \text{ N.cm}$  ( $\approx 65 \text{ oz.in.}$ ). So I have to add down-gearing of at least 3:1.

The SS25 is a 5-wire device. It has a common wire (white) and four coil wires (green, green/white, red, red/white, for coil 1-4). This corresponds to the connections "+", and A-B-C-D on the Phidgets motor controller card that I use.



*Wiring of the SS25*

Now we can choose a **mechanical coupling** of the motor to the shaft of the antenna's variable capacitor.



*Shaft dimensions of my capacitor and motor*

**IMPORTANT:** you need **non-conductive** material or rod to couple the motor to the capacitor. The capacitor shaft is not insulated from the capacitor itself. Hence, it is at the same potential as the capacitor (up to several kV at resonance). You don't want the capacitor voltage on the motor (or its wiring)! Standard options are using a non-conductive (plastic, ceramic) driveshaft, or a belt drive. The shaft and housing of the motor, and any metal gear wheels attached to it, must remain at a safe distance (at least 1 cm (1/2") from the shaft and connections of the capacitor.

I would have preferred a straight, rigid shaft-to-shaft coupling. But as determined above, my motor doesn't generate enough torque for 1:1 coupling: I need down-gearing of at least 3:1. The easiest way to do this, is with pulleys (cog wheels) and a timing belt.

A timing belt (a.k.a. toothed, notch, cog, synchronous belt; *D*: Zahnriemen, *F*: courroie dentée) has teeth that fit into a matching toothed pulley. When correctly tensioned, there is no slippage: motor and load remain "synchronized". Timing belts need the least tension of all belts, and are among the most efficient (though no issue at very low speeds of a few RPM). Standard belts are fiberglass reinforced neoprene or polyester-urethane (PU). There are several standard belt profiles, but this is not critical in our low speed, low torque application. The basic choice was between a simple T (trapezoidal) profile with 2.5 mm pitch and 6 mm width, vs. 5 mm pitch and 10 mm width.



*Standard metric belt profiles (left to right: T, AT, HDT)  
(similar British/Imperial profiles are L, H, XL, MXL)*

There is a finite choice of standard pulleys. The standard number of "teeth" is typically 10-20, 22, 25, 28, 36, 40, 48, 60, 72, or 84. The diameter of the pulley is determined by this number, and the pitch (distance between the centers of adjacent teeth) of the belt. It is recommended that at least one of the two pulleys has flanges, to avoid the belt from running off the pulleys when the input and output shaft of the gear are not properly aligned. Standard materials are aluminium and plastic (typ. acetal resin). Pulleys for a T5 belt are significantly larger than for a T2.5 belt. Pulleys have standard bore sizes.



*Plastic flanged pulley*

**Considerations:**

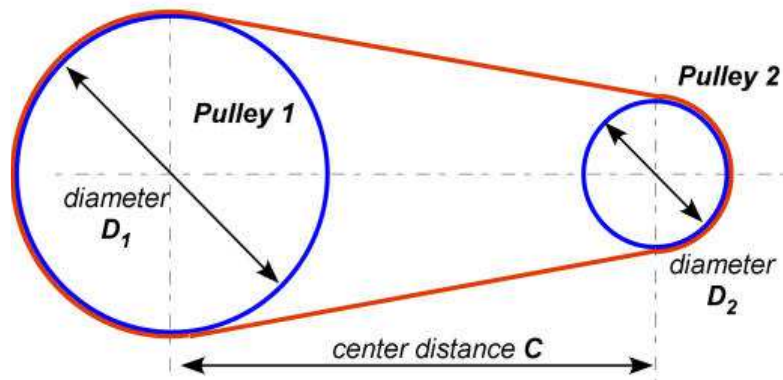
- I did not want the pulley on the capacitor shaft to be larger than the end-connector of the capacitor (60 mm diameter).
- I want to be able to create a 3:1, 4:1 or 5:1 gear ratio.
- the diameter of the hub of the pulleys has to be large enough to increase the bore (with a drill press!) to the

- respective shaft size, and still have at least 2 mm hub thickness left.
- the height of the hub has to be enough to allow drilling a radial hole, thread it, and use a set-screw (grub screw) to fix the pulley onto (or through) the shaft.

I settled for a T2.5 x 6mm belt, a 60 teeth pulley (48 mm diam.) for the capacitor shaft, and a 15 teeth pulley for the motor. I.e., a 4:1 ratio (I also got a 10 teeth pulley, just in case I needed 5:1 gearing, but did not need it).

Now we need to figure out the length of the belt with the formula below (it is a very close approximation, as it neglects the fact that the belt does not touch the pulley over half its circumference, unless the pulleys have the same size):

$$\begin{aligned}
 L &= (\frac{1}{2} \times \text{circumference of pulley 1}) + (\frac{1}{2} \times \text{circumference of pulley 2}) + 2 \times \sqrt{\left(\frac{D_1 - D_2}{2}\right)^2 + C^2} \\
 &= \frac{\pi}{2} \times (D_1 + D_2) + 2 \times \sqrt{\left(\frac{D_1 - D_2}{2}\right)^2 + C^2} \\
 &\approx \frac{\pi}{2} \times (D_1 + D_2) + 2 \times C
 \end{aligned}$$



For the diameter of the selected pulleys, and a minimum of 2 cm spacing between the pulleys, I ended up with a standard belt with a 200 mm (8") overall length (80 teeth). I.e., T2.5 x 6 x 200 belt.

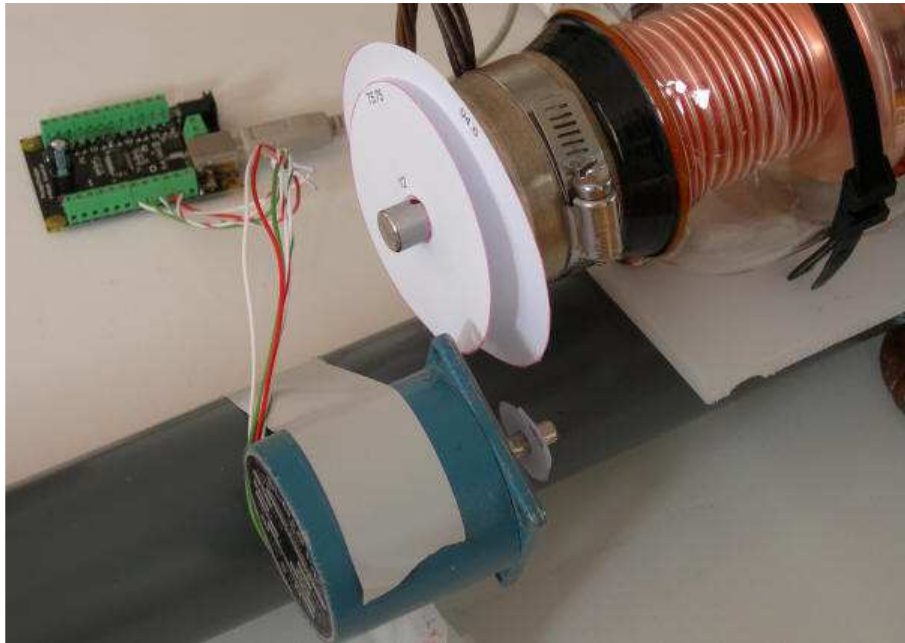
Timing belt on-line calculator based on distance between shaft centerlines, size of pulleys, ..

- <http://www.sdp-si.com/Cd/default.htm> (calculates resulting distance between centers):
- <http://www.roadlessgear.com/html/techarticles/beltlength/index.php3>
- [http://smarthost.maedler.de/maedlertools/maedler\\_en.html](http://smarthost.maedler.de/maedlertools/maedler_en.html)

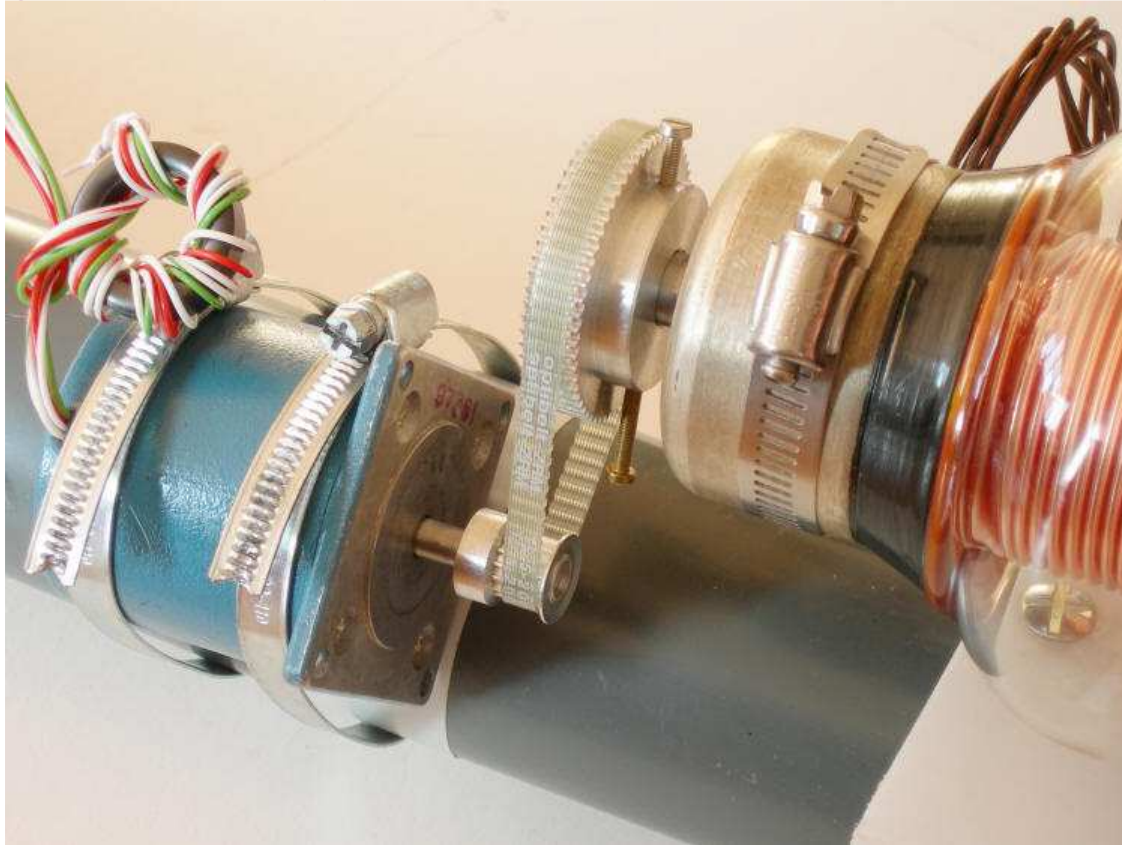
Here are some suppliers of belts, pulleys and couplers (*note*: I do not endorse companies):

- [Mädler](#): belts, pulleys, couplings (metric & non-metric)
- [Stock Drive Products / Sterling Instruments](#): belts & pulleys
- [McMaster-Carr](#): belts & pulleys
- [Servo City](#): gears, couplers
- [Huco](#): timing belt pulleys (non-metric)
- [The Robot Market Place](#): belts & pulleys (non-metric)
- [Spielwaren Modelleisenbahn Direktversand \(SMDV\)](#): belts & pulleys (metric)
- [Zahnriemen24](#): belts & pulleys (metric & non-metric)
- [Small Parts](#): gears, pulleys, belts, couplings (non-metric)





*Using various paper disk "pulleys" on the motor and capacitor shaft to check dimensions and clearances*

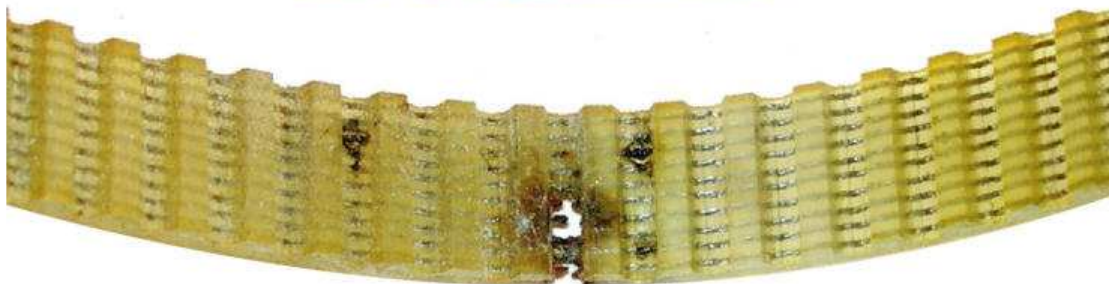


*The pulleys and belt installed on the motor and capacitor  
(note the ferrite toroid with 5 windings of the motor wiring)*

I installed the motor onto the antenna mast with two hose clamps (a.k.a. radiator clamps; **UK**: "jubilee clips", whatever...).



**POSTSCRIPT:** I have to revise my choice of belt material! The original belt was reinforced with embedded steel tension cords. As you can see in the photos below, this caused arcing between the belt and the pulley of the motor. Luckily, no damage was done to the controller card or transceiver. Must use polyurethane or neoprene belts that are reinforced with fiberglass, polyester, or polyurethane cords. E.g., Optibelt Alpha Power.



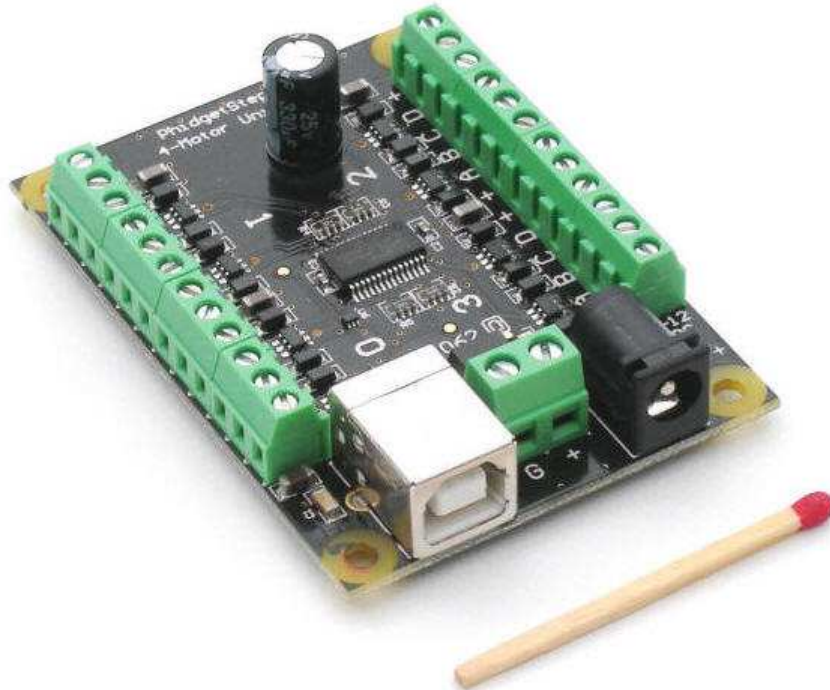
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## MOTOR CONTROLLER HARDWARE

We have a motor, now we need to control it. I prefer to control the motor from my PC, rather than having a separate control box. This means that the controller hardware must have an interface to the PC. Standard options are an RS232 interface via a COM port, or - more modern - a USB interface. My PC only has one COM port, and that one is already used for the PTT-interface from the PC to my transceiver. Yes, I could add a USB-serial interface. But if I go USB, I might as well skip the RS232.

The main choice to make now, is "make" vs. "buy". Yes, there are many stepper-motor controller hardware designs floating around in cyberspace. Few have a USB interface. I determined that piecing a design together, building and debugging it, was too much of a hassle. Instead, I searched for a relatively inexpensive off-the-shelf USB solution. I

decided to go with a [Phidgets 1062](#) controller card. It handles up to 4 **unipolar** stepper motors simultaneously (e.g., an antenna rotor as well). It is almost "plug-and-play", via USB. This controller card is really tiny: 5 x 6.3 cm (2 x 2½ ")! And: it is rated for 1 amp per winding, without a heatsink! I bought mine at [Sawtus Shop](#) (they had the best price I could find at the time (mid- 2010): \$66 plus S&H). It does come with some rudimentary software, to check out the card and the motor.



*Phidgets 1062 USB controller card for up to 4 unipolar stepper motors*

**IMPORTANT:** the unipolar Phidgets card (model 1062) does not support speeds above 383 half-steps per sec! That is, about 2 rpm with a 1.8 deg stepper motor (200 full steps/rev).

**NOTE:** Phidgets also sells a controller card (model 1063) for a single bipolar motor. As the name suggest, control of bi-polar stepper motors involves changing the polarity of the applied voltage across the motor windings. This makes bipolar controller hardware inherently more complicated (typically H-bridges instead of simple transistor switches). Yes, unipolar motors are old-fashioned and generally produce less torque than bipolar/hybrid steppers. The latter can also be micro-stepped, whereas half-stepping appears to be the limit for unipolar motors. The bipolar controller card supports much higher speeds, and also has 4 discrete/digital inputs.

The instruction set of the Phidgets 1063 card is a super-set of the 1062's instruction set. I.e., the 1063 has all functionality of the 1052 - and some additional functions. E.g., limiting the motor current (= torque). This means that [the control software that I developed for the 1062](#) will also work with the 1063. Leslie, EI5GJB, has confirmed this recently (November 2011) and is quite pleased!

The Phidgets cards needs to be connected to the PC via a standard USB printer cable (supplied with the card). My motor happens to be a 5-wire motor (some unipolar stepper motors have more wires), so I need to run a cable with at least 5 conductors from the card to the motor. Some options are:

- standard Cat 5 (category 5) cable; this is for 10/100 Mbs Ethernet communication - no need to go for Cat5e or Cat6 cable (100/1000). This is an 8-conductor cable, usually 4 twisted-pairs. There are UTP (unshielded twisted pairs) and STP (shielded) cables. STP is recommended for the application at hand.
- 5 conductor thermostat cable,
- 5 or 7 conductor antenna rotor cable,
- 6 or 8-wire phone cable.

The advantage of an 8-conductor cable is that this leaves 3 conductors to accommodate a sensor at the motor drive, e.g., a potentiometer or end-stop switch. Of course, it can also accommodate an 8-wire stepper motor. As I had several long Cat5 cables laying around, I settled for one of 15 mtrs (50 ft). With two mating RJ45 chassis connectors (8P8C modular jacks), I'm in business.

The controller card takes its power from the USB port, but only for the control electronics - not to power the motor! The latter power must be supplied separately to the card: either via a standard barrel connector, or hardwired to a terminal block. My motor uses 12 volt DC. I use the barrel connector and a 12 V / 750 mA "wall wart" power supply, or a sealed 12 V / 4 Ah motor cycle battery.

**UPDATE - January 2013:** an other controller hardware option is the "[Stepper-Bee](#)" card. It comes with more useful demo software than Phidgets.

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## RFI PROTECTION

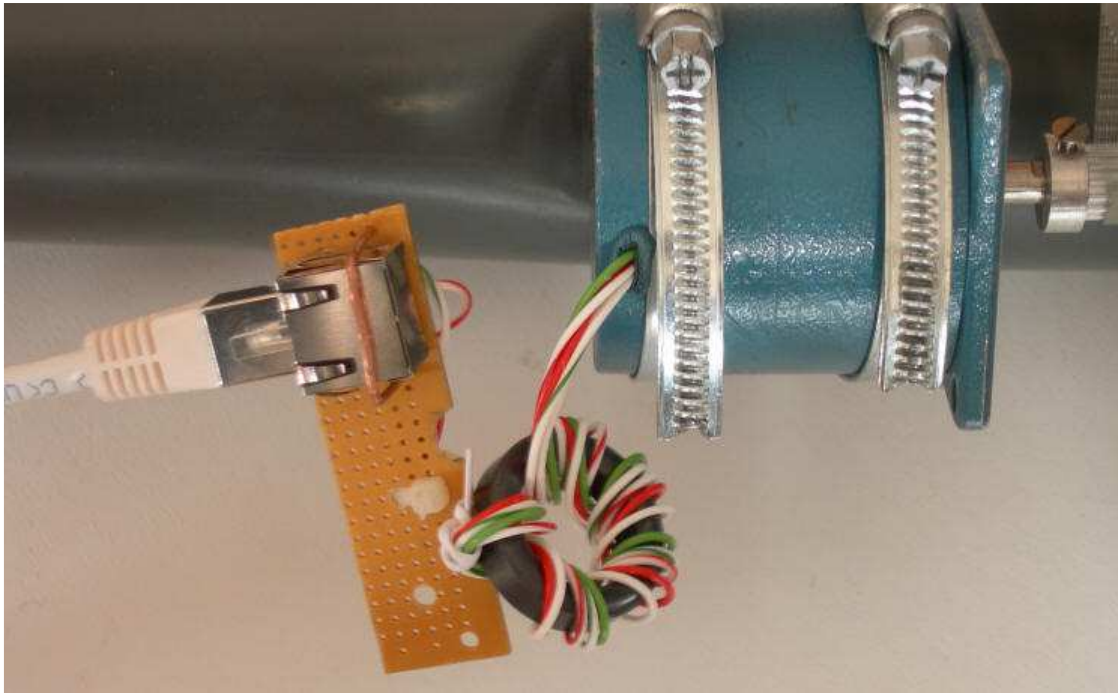
**VERY IMPORTANT.** As noted in [the warning section above](#), the antenna generates strong a RF field when at resonance - enough to light up a fluorescent light tube, with just a couple of watts transmit power. You do not want to get this RF into the controller card and do damage to it, or into the PC connected to it.

As for most of my HF-chokes, I use FT140-43 ferrite rings. One is placed at the controller card, between the RJ45 connector and the card. I use a short section of Cat 5 cable between the connector and the card. This cable is wound 5 times through the ferrite ring.



*The ferrite choke at the card end of the CAT5 cable to the motor*

I have placed a second choke at the motor end of the Ethernet cable: between the RJ45 connector and the motor. The motor wires are wound 5 times through the ferrite ring.



*The ferrite choke at the motor end of the CAT5 cable from the controller card*

According to various loop antenna calculators, the highest capacitor voltage for my size antenna, occurs for a resonance frequency around 7 MHz. Running 100 W into the antenna - with the controller card operational - did not cause any damage or abnormal behavior.

Tuning motor control cables should be run symmetrically with respect to the two halves of a loop and be choked with RF chokes immediately outside the loop area.

Options for end protection of cap: calibration / ref. position switch, spindle plus limit switches. Not needed, if motor torque sufficient to turn the cap shaft, but not break the cap.

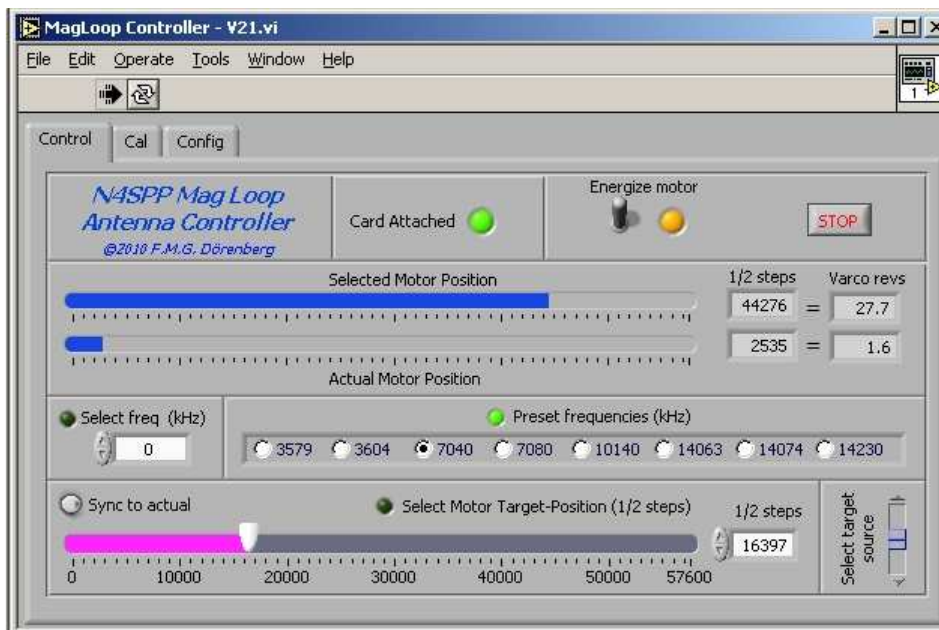
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## **MOTOR CONTROLLER SOFTWARE**

Obviously, the Phidgets motor controller card needs to be controlled from my PC. This requires the user (me) to somehow create software. The [Phidgets website](#) provides a library of *dll* and API files, and some simplistic code samples and low level suggestions on how to control the card via Visual Basic, C/C++, LabView, MatLab, Java, etc.

I decided to go with LabView, because I have access to it, and it is graphically oriented (both design and the controller). It has taken me over a week of spare time to learn "LabView 8 Pro" well enough to make quite a decent controller with a nice Graphical User Interface (GUI) - in my humble opinion. My GUI has three tabs: "Control", "Cal", and "Config".

Next time around, I may have a go at Visual Basic. The development tools are basically free, whereas LabView is prohibitively expensive for private use. And unlike LabView, no enormous Real Time Operating System needs to be installed (I think).



*The "Control" tab of the GUI of my varco motor-drive control software*

The "**Control**" tab provides the GUI for the following functionality:

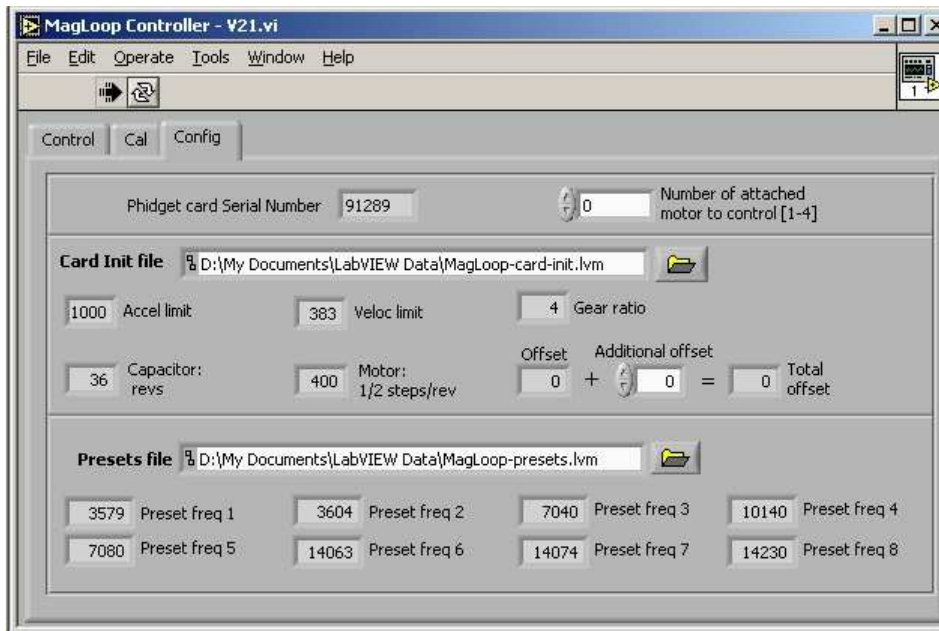
- indication of whether the software has established contact with the Phidgets card,
- a toggle switch for commanding the Phidgets card to energize the motor. Default is de-energized. A LED indicates energization status feedback from the card. Note that the card does not know whether a motor is actually attached or electrical power is available, so this (and of other parameters such as speed and position) is only a feedback of the *commanded* state.
- there are three ways to enter the desired motor position. A 3-position slide switch (lower right-hand corner) is used to select which one of these three (a small LED lights up next to the selected source):
  - type-in the desired antenna frequency (plus "enter" on your keyboard), with incremental up/down buttons (+/- 1 KHz),
  - radio-buttons for eight preset (and configurable) frequencies,
  - a magenta slider (with incremental up/down buttons, +/- 1/2-step) to command motor position, rather than frequency. There is a push button next to this slider. When pushed, the slider position is synchronized to the actual motor position. This is useful when using a pre-set frequency, and needing to tune around this position.
- two blue sliders that indicate the selected motor position and the actual motor position. The associated numerical positions are expressed in both motor 1/2-steps, and revolutions of the tuning capacitor. The upper limit of all three control & indicator sliders is initialized based on the gear ratio and the number of 1/2 steps per motor rev. Note that the actual motor position is *not* measured - the controller card just keeps track of how many steps it commanded with respect to the initialization position.
- a "stop" button, that halts execution of the control software and commands the controller card to de-energize the motor.

If a desired frequency is selected (numerical entry or preset), then the software interpolates the antenna's calibration data to calculate the corresponding motor position. This interpolation scheme, and assigning the labels of the radio buttons based values read from a file, was the trickiest part of the software design! Note that the calibration data is only valid at a certain temperature and position or the antenna. E.g., if the data was obtained with a cold antenna, and the sun (or QRO operation) heats it up, then the actual resonance frequency will drift.

When turning a vacuum capacitor, there is no need to apply holding torque when not moving (unlike other applications). Hence, there is no need to keep motor energized while at rest. However, no harm is done when the motor is kept energized, and turning the energization on & off for each movement makes the controller software more complex. Also, when the motor is re-energized, it may jump a step. So: my controller software keeps the motor energized (with manual override).

Upon start-up, the controller reads-in three tiny text files:

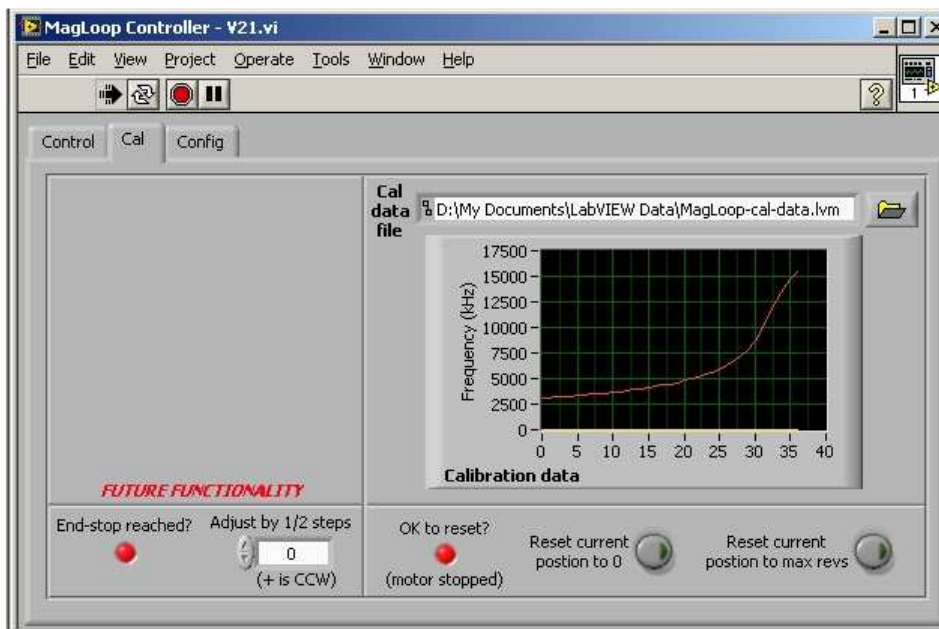
- initialization settings for the Phidgets card and the controller: acceleration limit, velocity limit (1/2-steps/sec), the number of 1/2-steps per revolution of the motor, gear ratio between the motor and the tuning capacitor, offset (1/2-steps), number of capacitor revs for end-to-end travel,
- preset frequencies of my choice, and
- calibration data (resonance frequency of the antenna, measured for each full revolution of the capacitor shaft). Obviously, the calibration data from *my* antenna will not be correct for someone else's antenna (or my own antenna at a different location).



The "Config" tab of the GUI of my varco motor-drive control software

The "Config" tab provides the GUI for the following functionality:

- indication of the serial number read from the Phidgets card,
- setting of which motor to command (the Phidgets 1062 card handles four motors; default is 0). Note: this *not* the number of motors that are attached to the card.
- location of the initialization data for the card and the controller. The file location has a default, but a browser button can be used to locate the file.
- a numerical entry (with incremental up/down buttons) for modifying the offset. I added this feature, to be able to adjust the applied offset (from the init file) when (re)starting the software, without having to modify the initialization data file. This allows to adjust for imprecise positioning at the reference position.
- indication of the eight preset frequencies read from the presets data file. The file location has a default, but a browser button can be used to locate the file.



The "Cal" tab of the GUI of my varco motor-drive control software

The "Cal(ibration)" tab provides the GUI for the following functionality:

- a plot of the calibration data. The file location has a default, but a browser button can be used to locate the file.
- two push-buttons, for resetting the card's internal "current position" either to zero or to max position (the motor's 1/2-steps per rev, times the number of revs of the capacitor). This feature is used when the motor is positioned at the known reference position ("end stop"). The LED next to the button indicates whether it is OK to push the button (OK = when the motor is not moving).
- A block for future functionality: detection of arriving at the end-stop (signaled via a serial COM-port, or better yet: serial-USB adapter). This will be used in combination with the "reset position to zero" function.

LabView uses a graphical "block diagram" editor to create the desired functionality and GUI.

- The graphical design of V21 of my controller is [here](#) (the image has enough resolution for zooming-in on the details).
- The actual LabView "virtual instrument" design file (.vi) is [here](#).
- LabView "Pro" supports creating a LabView-independent .exe file. The zipped executable package is [here](#).
  - This .exe application can run without the Labview development environment (i.e., you don't need the costly LabView suite), but it *does* require the LabView Run-Time Engine (RTE) Version 8.0. This is available for free - for all standard operating systems - from the [National Instruments website](#). It appears that using RTE version higher than 8.0 causes problems...
  - Of course you must install the drivers that came with the Phidgets card (or download from [www.phidgets.com](#)).
- The zipped package of the three data files that I use (initialization, presets, calibration data) is [here](#). Changes to these files must be made with an ASCII-editor such as Notepad or Wordpad - do not use a word-processor such as Microsoft Word!

As the my motor plus 4:12 gearing does not have enough torque to damage the varco, I do not need an end-stop sensor. However, I am considering adding a USB ADC-card and simple SWR measurement (tap into my manual antenna tuner with SWR meter) or impedance measurement (Wheatstone bridge), and fully automate the tuning!

As noted further above, my control software can also be used with the Phidgets 1063 controller for a single bipolar stepper motor. The 1063 is based on 1/16 steps, whereas the 1062 is based on 1/2 steps. When using my software with a 1063 card, the *MagLoop-card-init.lvm* file must be edited accordingly (again, only with a simple ASCII text editor, not MS Word or similar).

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## WEATHERIZING

- weather (rain etc) affects the resonance frequency (temp does as well, by the way). Unprotected capacitor: may reduce high voltage blocking.
- steel wool + clear coat the copper - not really required for weatherizing, but I like the shiny look.
- capacitor + motor drive: tupperware® type box; some folks manage to house the motor + cap large diam PVC tube , or even the mast of the antenna.
- toroid windings to coax: solder + liquid electrical tape
- insulate with brush-on Liquid Electrical Tape or Dipt®.



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## REFERENCES

- **Ref. 1:** "Small, high-efficiency loop antennas", Ted Hart (W5QJR), QST, June 1986, pp. 33-36
- **Ref. 2:** "My Magnetic Loop Antenna", A. Krist (KR1ST), AntennaX, Issue No. 111, July 2006
- **Ref. 3:** "[An Overview of the Underestimated Magnetic Loop HF Antenna](#)", by Leigh Turner (VK5KLT), V1.1, 28 Nov 2010 (figures 4, 5, 9, 10, and 12 are from my website, with my permission)
- **Ref. 4:** "[The Midnight Loop - An Experimental Small Transmitting Loop ~ Theory & Practice ~](#)", by G. Heron,



- N2APB and J. Everhart, N2CX
  - **Ref. 5:** "Loop Antennas", Chapter 5 in "ARRL Antenna Handbook, 21st edition
  - **Ref. 6:** "[An examination of the Gamma Match](#)", D.J. Healy W3PG/W3HEC, QST, April 1969, pp. 12-15, 57
  - **Ref. 7:** "[What's with the Gamma Match Equations?](#)" (Gamma Match Equations and Associated Confusion), N6MW
  - **Ref. 8:** pp. 12, 13, 20 in "[Small Loop Antenna Efficiency](#)", Mike Underhill - G3LHZ, May 2006
  - **Ref. 9:** "The G3LHZ Twisted Gamma Match", p. 3 in "[Surrey radio Contact Club Newsletter](#)", no. 797, February 2009
  - **Ref. 10:** "Easy Step'n - An Introduction to Stepper Motors for the Experimenter", David Benson, Square 1 Electronics, 200 pp.
  - **Ref. 11:** "[G3LDO's experiences with a small transmitting loop antenna](#)", RADCOM, September 2010, pp. 34, 35
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#### LINKS:

- [Small Transmitting Loop Antennas](#) - by Steve, AA5TB
- [W2BRI's Magnetic Loops](#) (incl. ferrite toroids)
- [PA3CNJ Magnetic Loop](#)
- [KI6YFQ Small Magnetic Loop Transmitting Antenna](#)
- [KJ3JLS Automatic Magnetic Loop Antenna Controller](#)
- [K0BG Antenna controllers - RF protection](#)
- [calculators](#) (online, exe)

#### CALCULATORS:

- [AA5TB calculator](#) (Microsoft Excel file - if you don't have MS Excel on your PC, you can download the freeware viewer from Microsoft [here](#))
  - [KI6GD calculator](#)
  - [On-line loop calculator](#) (based on ARRL Antenna Handbook)
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