

SMALL "MAGNETIC" TRANSMITTING LOOP FOR 80-20 MTRS

Antennas

Magnetic Loops

Verticals

Dipoles
& doublets

Other

Accessories



This page provides a top-level description of Small Transmitting Loop (STL) antennas (a.k.a. "Magnetic Loop Antenna", MLA), and my two versions of such an antenna for 80 mtrs and up. My smaller 40-20 loop is described [here](#). My helically wound "Slinky" loop is described [here](#).

[\[Introduction\]](#) [\[Safety\]](#) [\[Tuning\]](#) [\[Tuning-capacitors\]](#)

[\[Coupling methods\]](#) [\[Some antenna simulation modeling\]](#)

[\[My first STL\]](#) [\[My second STL\]](#) [\[Placement of the antenna\]](#)

[\[Effects of corrosion\]](#)

[\[DC- & stepper-motor drives for the tuning capacitor\]](#)

[\[DC-motor drive - weather protection\]](#)

[\[DC-motor drive - remote control box\]](#)

[\[DC-motor drive for the coupling loop\]](#)

[\[Next project\]](#)

[\[References\]](#)

Latest page update: January-May 2021 (expanded the coupling loop motorization section with a linear actuator drive; added new motor drive weather-protection design; added Fig. 86B-86D, added section on modeling; expanded ref. 4B, added Figs: 86E-86G + text; expanded Fig. 15).

Previous page updates: December 2020 (expanded text around Fig. 24C, added Fig. 2B with text); June-August 2020 (expanded "Effects of corrosion" section, expanded "air variable capacitor in oil" paragraph); January-February 2020 (added Fig. 28A/B and 34A/B + text, Fig. 83B & text, Fig. 24F & text); December 2019 (added Fig 24C); August 2019 (expanded the shielded coupling loop section with Fig. 24D and text)

©1999-2021 F. Dörenberg, unless stated otherwise. All rights reserved worldwide. No part of this publication may be used without permission from the author.

INTRODUCTION

I wanted a **small transmitting loop** (STL) antenna that covers at least the 80 and 40 meter bands (preferable 80 - 20). Why?

I want to do 80 mtrs DX, but I have no room for a decent 80 m wire-antenna, nor would I be able to install such an antenna high enough above ground. I have had some success with short, loaded vertical antennas with a single elevated radial, see [here](#) and [here](#). But I cannot install those permanently at my QTH.

Below 10 MHz, our apartment building generates a large amount of "electro-smog" QRM. An STL tends to be less sensitive to picking up

electrical noise in the near-field ($< 1 \lambda$), which appears to be the reason why this type of antenna is also referred to as a "*magnetic loop antenna*".

STLs have a radiation pattern with directivity. They are also small enough to rotate with a small motor, or TV-antenna rotor.

They are less conspicuous (to my friends of the home-owners association "police") than a wire antenna that is strung along the outside of the building.

I don't want to have to mess with radials, counterpoises, RF-grounds, etc. Loops are inherently symmetrical, like dipoles.

Can be installed close to the ground (vertically oriented), without significantly losing efficiency. Yes, higher *is* better.

A loop antenna is generally considered "small", if its circumference is less than 10% of the operating wavelength. So in my case (for 80 mtrs), "small" would be a circumference of less than 8 mtrs, e.g., a circular loop with a diameter less than 2.5 mtrs (≈ 8.2 ft). To be more precise, we are talking about a small *resonant* loop. Note that a multi-band loop that is "small" in the lowest band, is not necessarily "small" in the higher bands (= higher frequency).

Clearly, as with all antennas, "radiation resistance" is very important parameter. As the graph below shows, the radiation resistance of an STL is very small - we are talking **milliohms** here! The radiated RF power is determined by the radiation resistance (ref. 2J), multiplied by the square of the circulating RF loop current. As the radiation resistance is very small, a large loop current is required to get practical levels of radiated power. This implies that all losses (e.g., capacitor losses, contact resistance due to loop construction, losses due to coupling with the environment), even if only a couple of milliohms, are important in STLs!

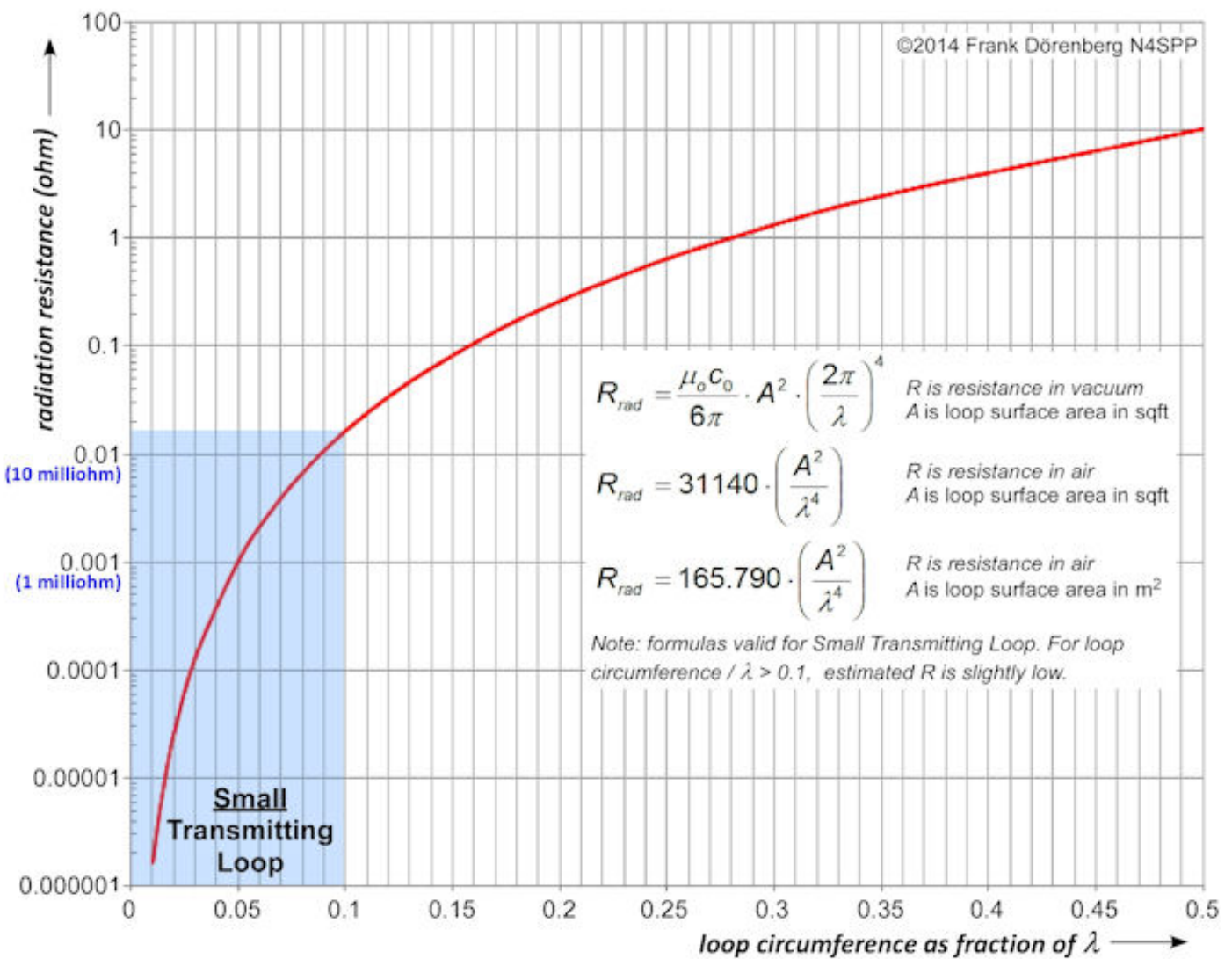


Fig. 1: Radiation resistance of a Small Transmitting Loop antenna

The radiation pattern of a Small Transmitting Loop antenna is shown below. The kidney-shape of the horizontal pattern (top view) becomes more pronounced (= deeper minimums) as the antenna circumference becomes a larger fraction of the wavelength. This is the case when operating a multi-band STL on the higher band(s). For large loops, the maximums of the horizontal pattern are actually in the directions *perpendicular* to the surface of the loop! See the "[Some antenna simulation modeling](#)" section for a more detailed analysis.



Fig. 2: approximate radiation pattern of a vertically oriented Small Transmitting Loop close to ground

(circumference = 0.15 λ , installed 0.08 λ above ground)

Due to the closed-loop shape, this type of antenna can be considered an extreme case of a "terminated folded dipole". A standard loop has a circular single-turn inductor. Of course, other shapes are possible: square, rectangular, octagonal, etc. There are variations such as multiple turns and configurations such as "figure-eight". As with dipoles, single-band directivity and gain can be increased by adding passive reflector and director loops, as in so-called multi-element "Yagi" beam antennas. This is all beyond the scope of this discussion.

Just to get a feel for some basic parameters, I have calculated the characteristics for a circular loop with a circumference of 5 m (diameter = 1.6 m, \approx 5.2 ft), made of copper tubing with a standard 16 mm outside diameter (5/8"). Input power is 100 watt (the limit of my transmitter).

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

Fig. 3: Calculated antenna characteristics for the given copper loop (KI6GD calculator, ref. 2A; no additional losses assumed in the calculation - note: read ref. 2F for caveats about loop antenna calculators!!!)

Resonance frequency	Efficiency	Bandwidth	Tuning capacitor	Capacitor voltage	Q
3300 kHz	4%	3.6 kHz	500 pF (max)	3.0 kV	986
3580 kHz	5%	3.8 kHz	424 pF	3.3 kV	1015
7040 kHz	36%	7.5 kHz	110 pF	4.5 kV	963
14800 kHz	88%	58 kHz	14 pF (min)	3.3 kV	256

Fig. 4: Calculated antenna characteristics for the given copper loop (AA5TB calculator, ref. 2B; no additional losses assumed in the calculation - note: read ref. 2F for caveats about calculators!)

If the input power is increased by a factor of N , then the maximum voltage across the capacitor is increased by a factor \sqrt{N} . E.g., doubling the power increases the capacitor voltage by ≈ 1.4 . Conversely, the voltage is reduced by a factor of 1.4 when the input power is reduced by a factor 2.

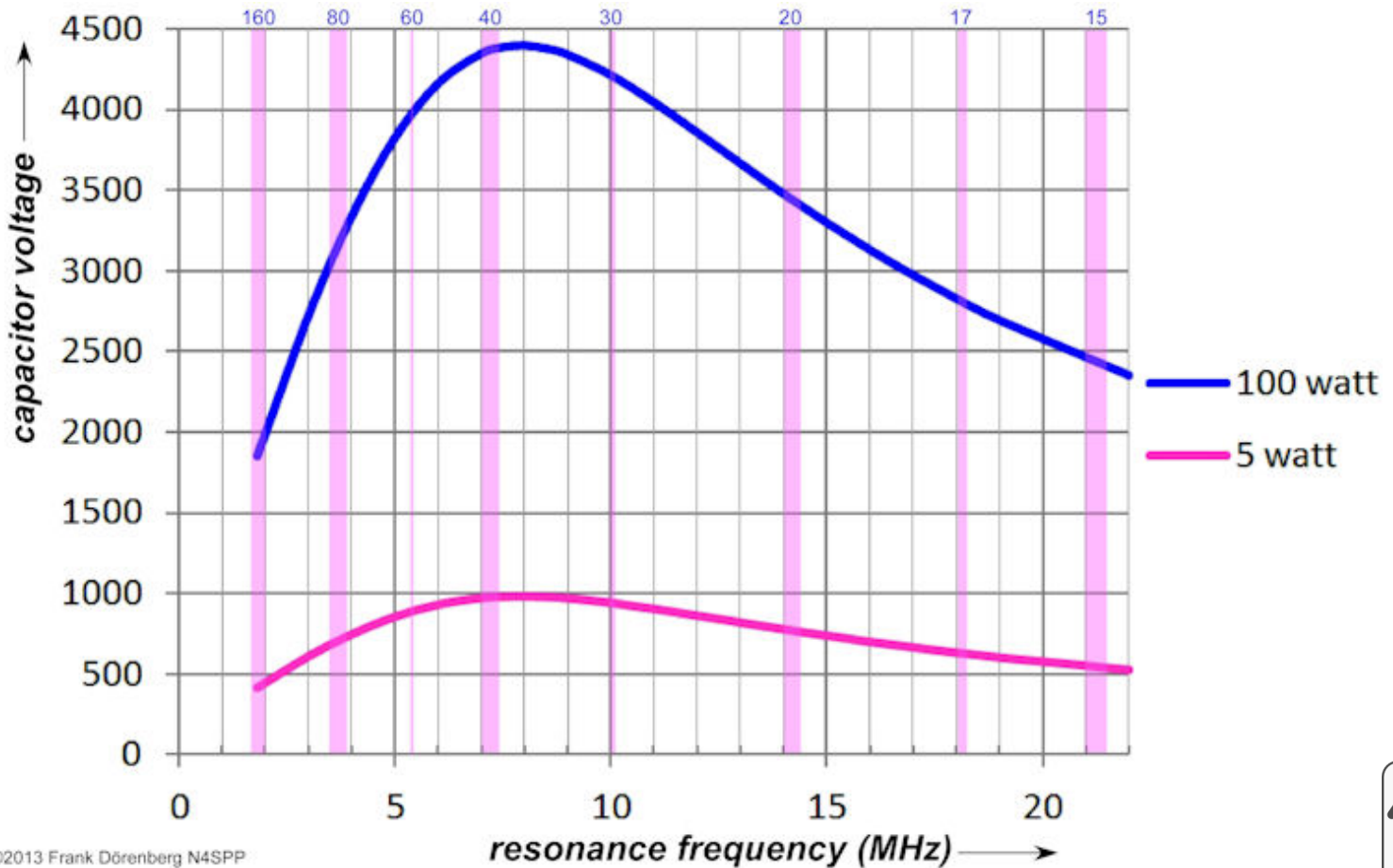


Fig. 5: Capacitor voltage as a function of frequency (1.6 mtr Ø loop made of 16 mm OD copper tubing)
(calculated with ref. 2B; assumes 5 milliohm loss resistance - note: read ref. 2F for caveats about calculators!)

"Efficiency" can be defined as "total power radiated by the antenna" divided by "net power accepted the antenna" [IEEE Std 145-2013 "Standard for Definitions of Terms for Antennas"]. The tables above 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. 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 (afford to) install there. The efficiency of STL antennas remains controversial (ref. 3).

As a rule of thumb, the optimum circumference of a multi-band STL is about 0.15λ of the lowest operating frequency. With an appropriate variable capacitor, the resonance frequency of an STL *can* be tuned over a frequency range that covers at least two octaves (= factor 4x). However, from an

antenna *efficiency* point of view, a factor of 2-3 is probably the practical limit. E.g., 80-40, 40-20, 30-10.

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 milli-ohm range may be significant! In general, increasing the diameter of the tubing will reduce the (inductor) losses - up to a point.

Instead of the standard tubular conductor, loops can be made of a wide, flat conductor strip such as copper "flashing" or foil. The strip can be straight (ref. 4), or helically wound (hence, helically loaded, ref. 5A/B). Of course, helical/spiral "hula hoop" antennas can also be made of a Slinky™ coil, [as I did late 2016](#). Ref 5C, 5F. Another option is a meandering or fractal loop circumference.



©Rich Fusinski K8NDS



©2010 Tom Haylock M0ZSA / RSGB

Figure 6A: Flat conductor loop (helically wound/loaded, shown without capacitor) and Slinky™ coil loop
(sources: ref. 5A/B and 5C)



Figure 6B: Flat conductor loop and meandering "fractal" loop
(source: ref. 4 and www.radioworld.co.uk)

Even on VHF (2 m band), the size of standard antennas such as HB9CV and Quads can still be sizeable or awkward for portable operation. VHF loops can be made with the same construction techniques as for HF. However, for the 2m band, a 0.1λ STL only takes an area of about 10x10 cm (4x4 inch). The main loop, and even the coupling loop, can be etched on a printed circuit board (PCB). This is what Thomas Schiller (DC7GB) did. Fixed capacitors can also be made of 2-sided PCB. However, Thomas' extensive experiments concluded that the dielectric properties of standard PCB material (e.g., FR4) varies too much (and on-linearly) with the main loop's E-field, even at low transmit power levels. At VHF, FR4 also has a large loss tangent δ . So he used a 4.7 pF 500V mica capacitor (yellow arrow in Fig. 7 below). That capacitance is too small to make variable for tuning. The latter is done by shaping a small (2-3 turn) coil (at the red arrow), placed in series with the coupling loop. A kit version is sold commercially, with a 1.6-8 pF trimmer capacitor (ref. 4B). Loop performance is supposedly close to that of a full-size dipole.

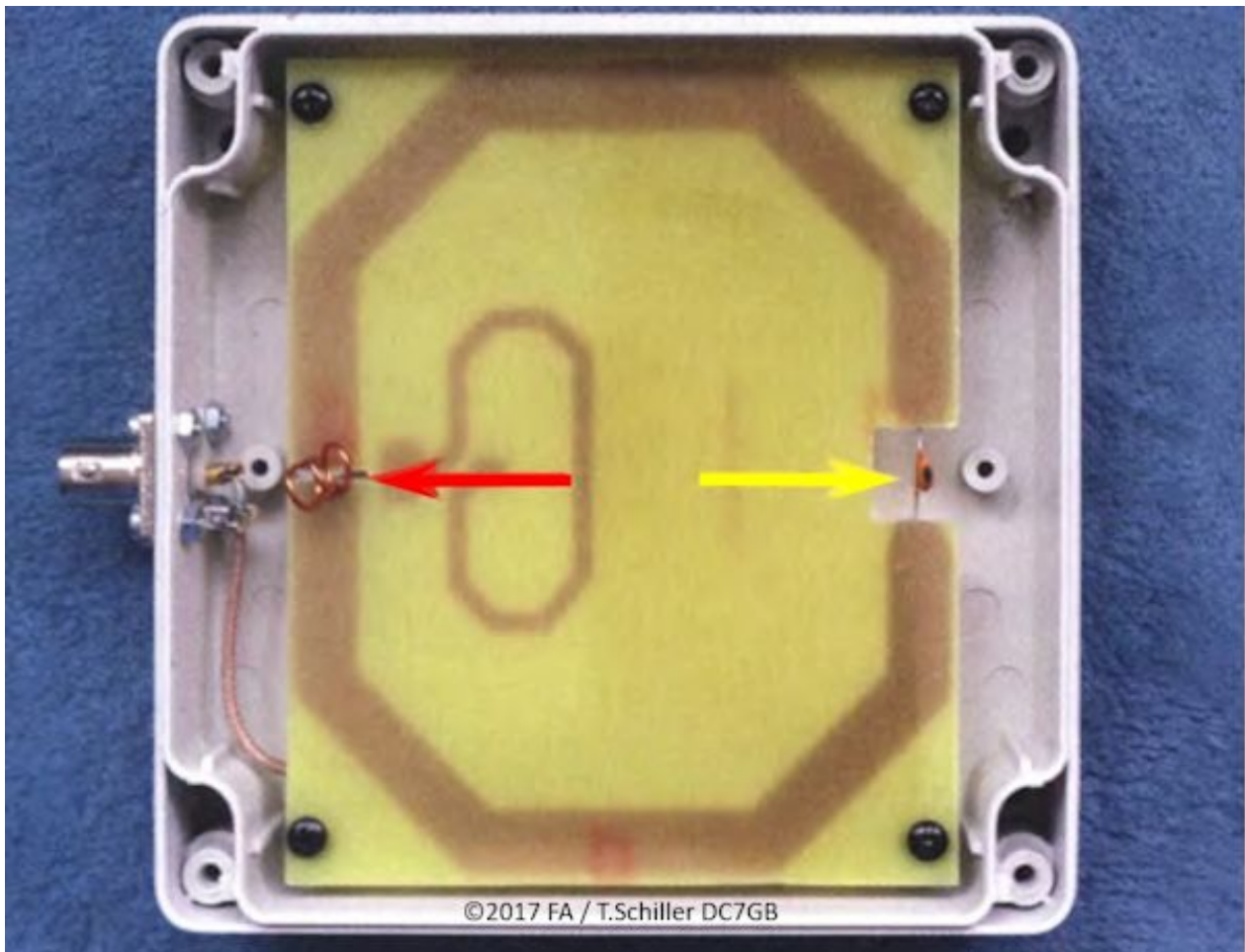
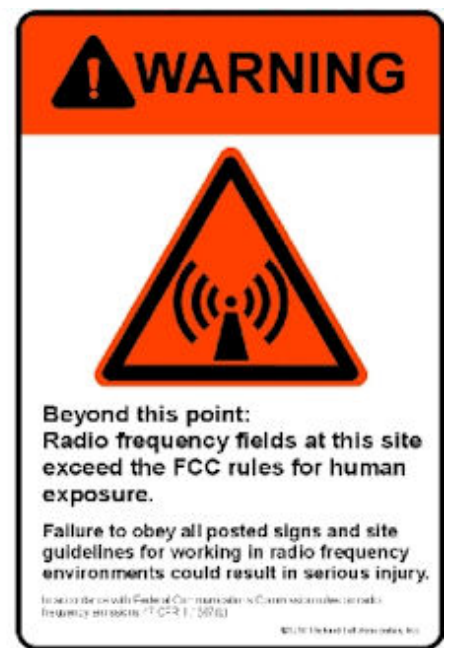


Figure 7: Printed circuit board loop for the 2m band
(source: ref. 4B; the PCB of the kit version measures 9x11 cm \approx 3.6x4.3 inch)

SAFETY

Figures 3-5 above show that there is a **very high voltage** across the capacitor at resonance, even at QRP levels! This is not only important when choosing a suitable capacitor, it is also a **SAFETY** issue! When transmitting, **NEVER** touch the capacitor or the loop, and do not let any other person or animal touch it! RF burns do not heal well!



Exposure to RF radiation is also a health hazard to humans and (other) animals! Legal limits and guidelines for such exposure generally vary by country. The table below shows the minimum estimated safe distance for various transmit power levels. Ref. 14A, 14B, 14C.

Average power (watt)	Freq band (m)	Loop size (diameter)	Estimated <i>controlled</i> compliance distance (aware users, e.g. radio operators)	Estimated <i>uncontrolled</i> compliance distance (general public)
5	40-10	small	4 ft = 1.2 m (FCC)	5.6 ft = 1.7 m(FCC)
10	40-10	small	4.9 ft = 1.5 m (FCC)	6.9 ft = 2.1 m (FCC)
	40-10	3.3 ft = 1 m	≤ 6.9 ft = 2.1 m (ICNIRP)	≤ 9.5 ft = 2.9 m (ICNIRP)
100	40-10	3.3 ft = 1 m	≤ 11.1 ft = 3.4 m (ICNIRP)	≤ 15.4 ft = 4.7 m (ICNIRP)
150	40-10	small	6.6-7.9 ft = 2-2.4 m (FCC)	9.2-13.8 ft = 2.8-4.2 m (FCC)
400	40-10	3.3 ft = 1 m	≤ 14.7 ft = 4.5 m (ICNIRP)	≤ 24 ft = 7.3 m (ICNIRP)
1500	80-10	3.3 ft = 1 m	9.9-19.4 ft = 3-5.9 m (FCC)	17.4-42.4 ft = 5.3-12.9 m (FCC)

Table 1: Estimated minimum safety distances for Small Transmitting Loop antennas

(sources: ref. 14A, 14B; distance is measured from the center of the loop)

TUNING THE LOOP'S RESONANCE FREQUENCY

The loop antenna is basically an LC-circuit that has to be tuned to resonance on the desired operating frequency. The loop by itself is an inductor that has the shape of a closed-loop. The generic formula for the resonance frequency of an LC-circuit is shown in Fig. 8 below. Note the duality of the "L" and the "C"

in this formula. Based on this, the resonance frequency can be changed in two basic ways:

by adding "C" to the circuit. This is typically done by opening the loop, and connecting a variable *capacitor* across the open ends of the loop. This is the standard way to "tune" the resonance frequency of a loop antenna.

by adding "L" to the circuit. This can be done by opening the loop, and connecting a variable *inductor* across the open ends of the loop. Continuously variable inductors with a large value range, a high power rating, and low loss are rare. Also, a fixed-value capacitor may also have to be added to the loop, based on the value range of the inductor. This is why there are very few practical examples. The only example known to me, is described in ref. 13A. It uses a ferrite rod that is inserted into a 2-turn coil. This tuning method is not discussed in the rest of this article.

The "L" of the loop can also be changed, by changing the size of the loop. However, this is not very a practical method for tuning the resonance frequency - other than for a single-frequency application.

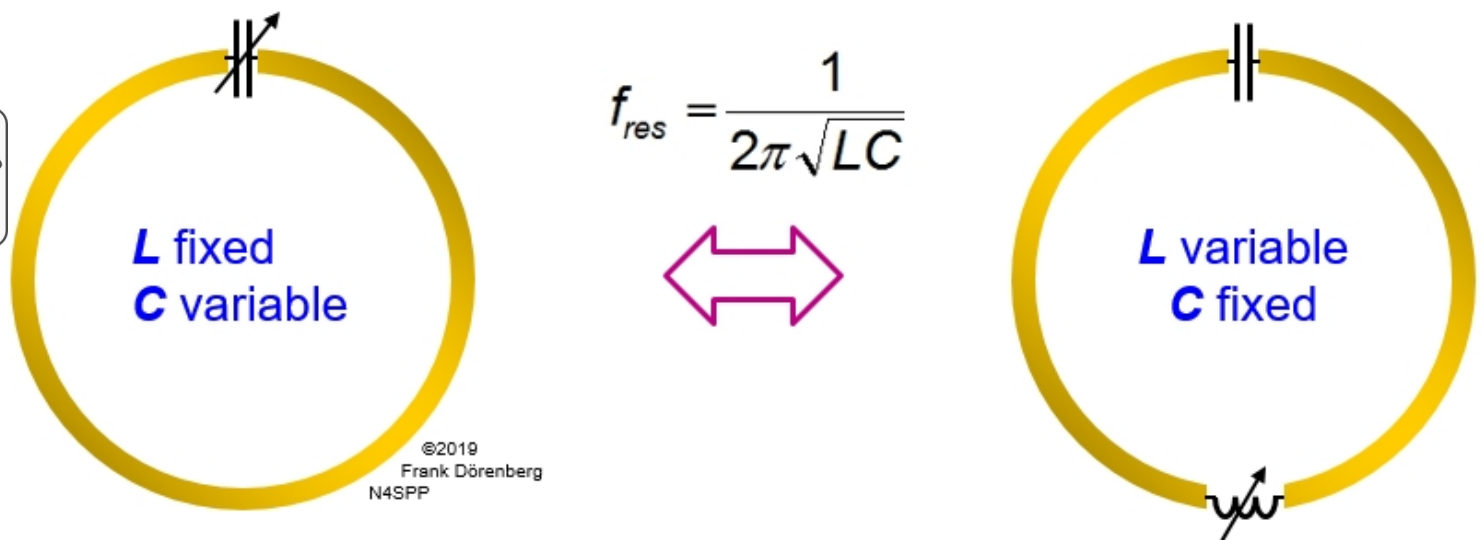


Figure 8: The duality of L and C in changing the loop's resonance frequency

Note that when "L" or "C" is *increased*, the loop's resonance frequency is always *reduced*. Also, the loop not only has inductance, but also stray (= parasitic) capacitance. This means that the loop has a self-resonance frequency, even without a tuning capacitor.

A simplified lumped-element diagram of a tunable LC-loop is shown below. The tuning capacitor is modeled as "non ideal", with equivalent series resistance (ESR) and inductance (ESL). Likewise, the loop's self-inductance includes loss resistance that represents skin-effect losses, construction losses (e.g., solder joints), etc. A "single-turn coil" loop is assumed, so no turn-to-turn

stray capacitance is modeled. The model does contain parasitic capacitance, to represent coupling to ground below the antenna and to nearby objects. The "radiation resistance" is a fictitious conceptual resistance that relates the power that is radiated *by* the antenna, to the current flowing *in* the antenna. So it is directly related to antenna efficiency. It can be modeled, but unfortunately, it cannot be measured directly.

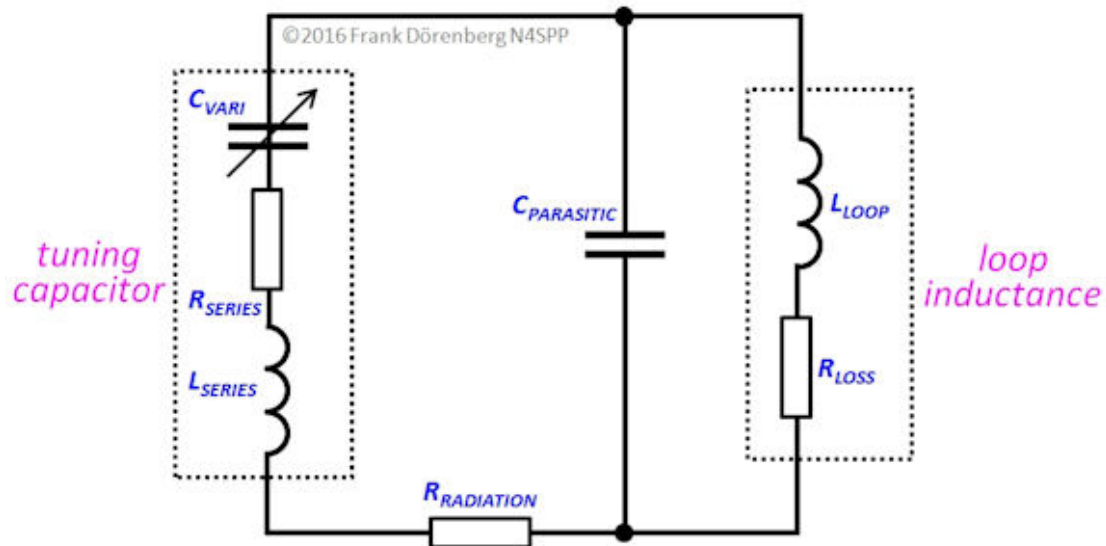


Fig. 9: Simplified equivalent lumped-element electrical circuit of an STL with tuning capacitor

(coupling to ground and objects near antenna is not shown; see Fig. 17 for tuning capacitor with dielectric other than air or vacuum)

"Tuning" the antenna is done by keying the transmitter (at low power setting) and observing the SWR-meter (or antenna-current meter) while adjusting the tuning capacitor. Alternatively, by tuning for maximum receiver noise level: there should be a sharp increase in the noise level when the antenna becomes tuned to the desired operating frequency.

An other 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 + environment). In some coupling methods, the braid (= shield) of the coax feedline is actually connected to that neutral point.

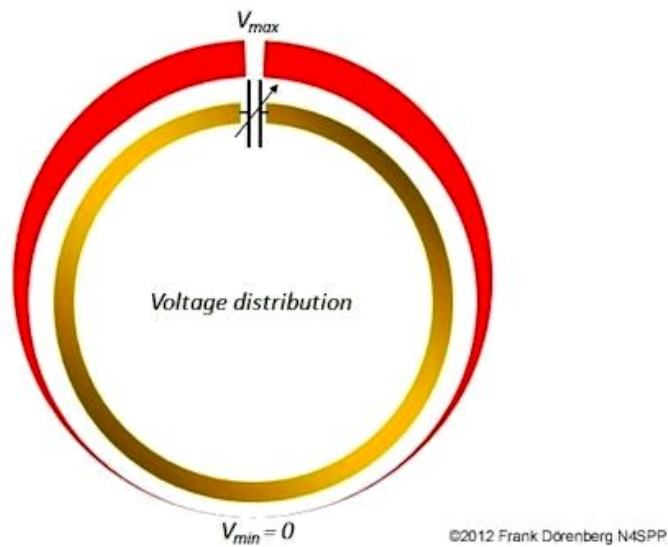


Figure 10A: Voltage distribution around a loop antenna

The current is highest at the point opposite the capacitor, and lowest *at* the capacitor. See ref. 1 for an illustration. 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 (uniform) around the loop. Both the voltage and the current distribution are symmetrical.

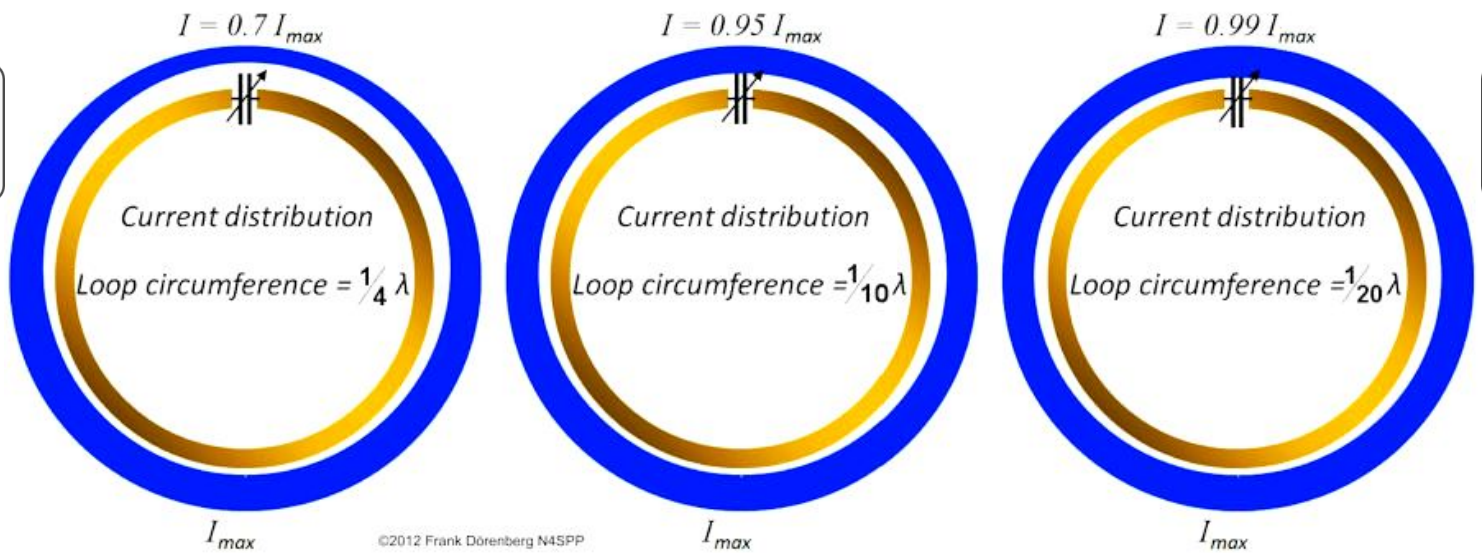


Figure 10B: Current distribution around a loop antenna
 (note: a circumference $> 0.1 \lambda$ is not "small")

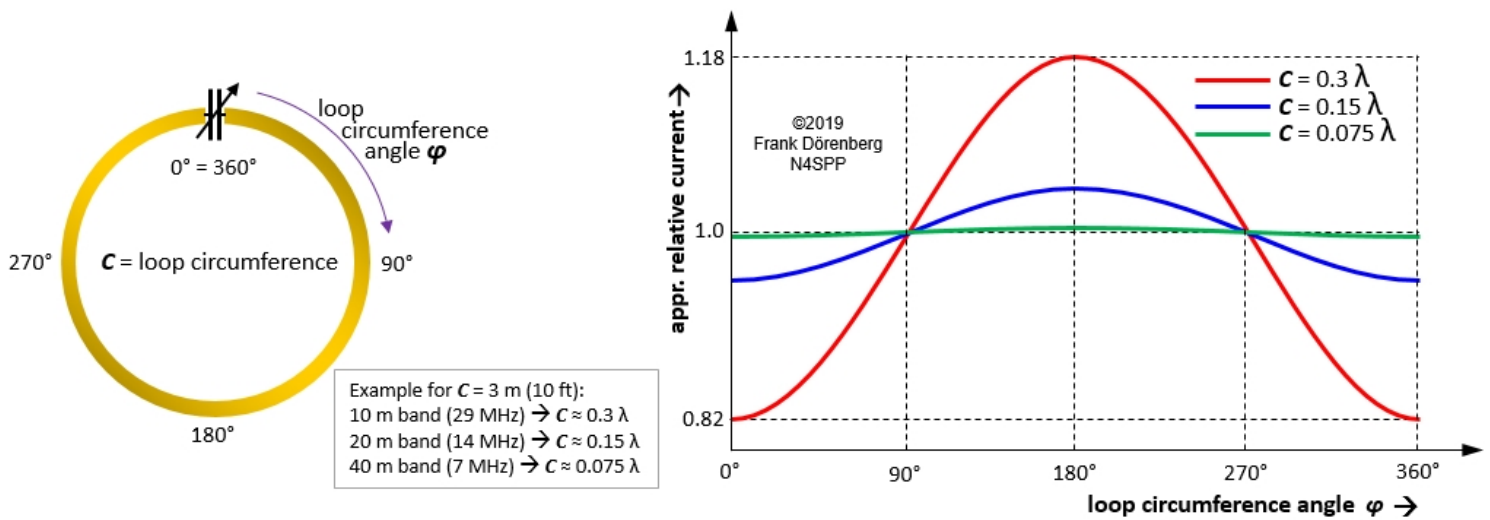


Figure 10C: first-order approximation of the amplitude of relative current around the loop - in free space
(source: adapted from ref. 8G)

The diagrams above shows that the largest current occurs at the point opposite the capacitor. This part of the antenna radiates the most. Some operators therefore install their loop with the capacitor at the bottom. Furthermore, placing the part with the highest voltage closest to the ground, increases losses due to parasitic capacitance to ground...

Based on the voltage and the current distributions, the impedance ($Z = V / I$) varies around the circumference of the loop. It is highest near the capacitor, and lowest at the point opposite the capacitor. E.g., there are two points, left and right of the neutral point opposite the capacitor, where the impedance is 50 ohm points with respect to that neutral point. This property is used in [coupling methods](#) such as Gamma Match and Delta Match.

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. Also, the resonance frequency will vary with temperature changes (sunshine/weather). In order to change the resonance frequency to the desired operating frequency, we need a *variable* capacitor.

The basic choice is between "air variable" capacitor and "vacuum variable" capacitor. Clean air has a dielectric strength of 0.8 kV per mm (at 20 °C and standard humidity). So, an "air variable capacitor" for 5 kV would need an air gap of 6.25 mm (1/4 inch) between the plates. High-vacuum has a dielectric strength at least 10x as high.

A typical air-variable capacitor is "rotary variable". It consists of a stack of stator plates (= stationary), and a stack of plates that are mounted on a rotor shaft. The rotor plates intermesh with the stator plates. Ideally, the rotor plate "vaness" are welded to the rotor shaft (rather than clamped) to reduce loss resistance. Connection to the rotor is either done via a sliding contact, and via a bearing to the frame of the capacitor. This always causes losses (series resistance)! Such moving contacts also tend to make tuning a bit "jumpy", cause receiver noise when changing rotor position, and limit transmit power during rotor movement. Such capacitors are generally to be avoided in "high Q" STL antennas. A discussion of losses in air variable capacitors is given in ref. 12M.

There are several basic types of air variable tuning capacitors:

Single-section: a single rotor-stator section.

Multi-section: basically two (or more) variable capacitors that are ganged (mounted side-by-side), with a single conductive rotor shaft. Hence, the rotor vanes of all capacitor sections are electrically connected. The losses of the wiper contact can be eliminated by putting two capacitor sections in series: the rotor contact is not used, only the two stator contacts. This doubles the voltage rating, but at the same time halves the total capacitance. However, note that parasitic capacitance of the capacitor is not cut in half, so neither is the smallest achievable capacitance!

Broadcast-band: typically used in early AM/FM receivers. The rotational range (rotor "swing") is limited, typically to around 140° . This mechanical limitation makes motorized tuning more complicated. Plate distance is small, so only suitable for low power (QRP) transmission. As the plates and spacing are small, the sections are separated by a shielding wall.

Split-stator: a 2-section arrangement in which the two sets of rotor plates are mounted on opposite sides of the rotor shaft. Likewise for the two sets of stator plates.

"Butterfly". The rotor vanes are typically shaped like a bow-tie ("butterfly wings"). There are two rotor/stator stacks. However, they not arranged side-by-side, but diametrically opposite of each other. Note that the full capacitance range is covered by 90° turn of the shaft. There is not always a rotor contact. The RF current passes through the two "wings" of each rotor plate, rather than through the rotor shaft. This reduces losses compared to split-stator and a regular 2-section capacitors.

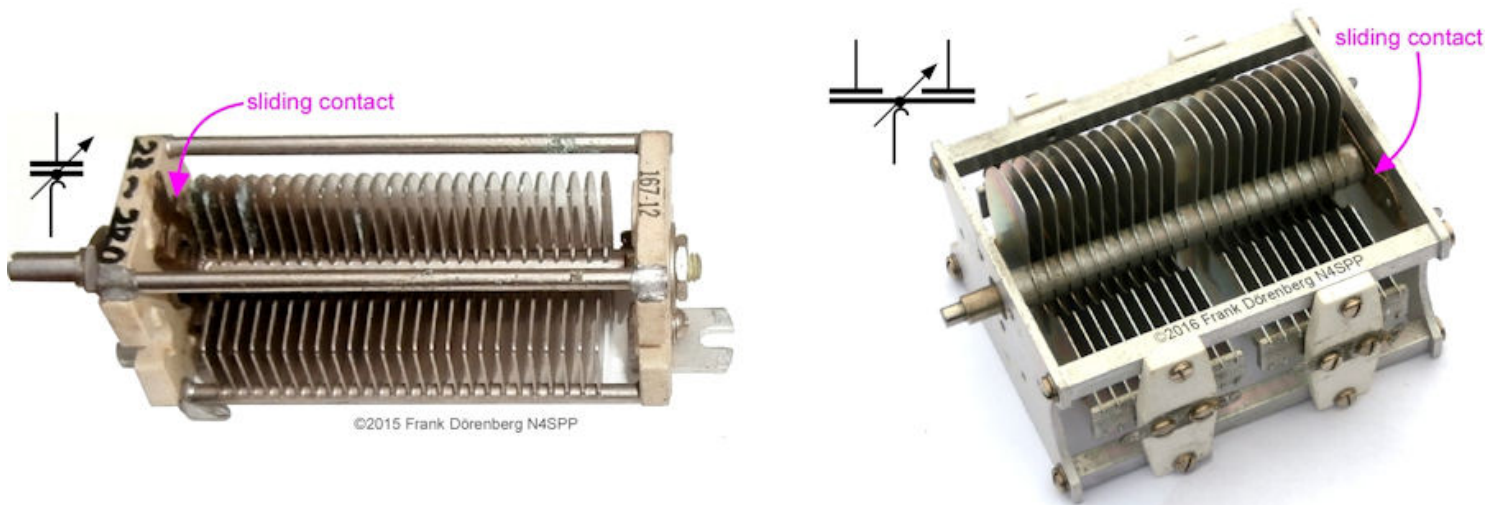


Figure 11: Single-section and dual-section capacitor

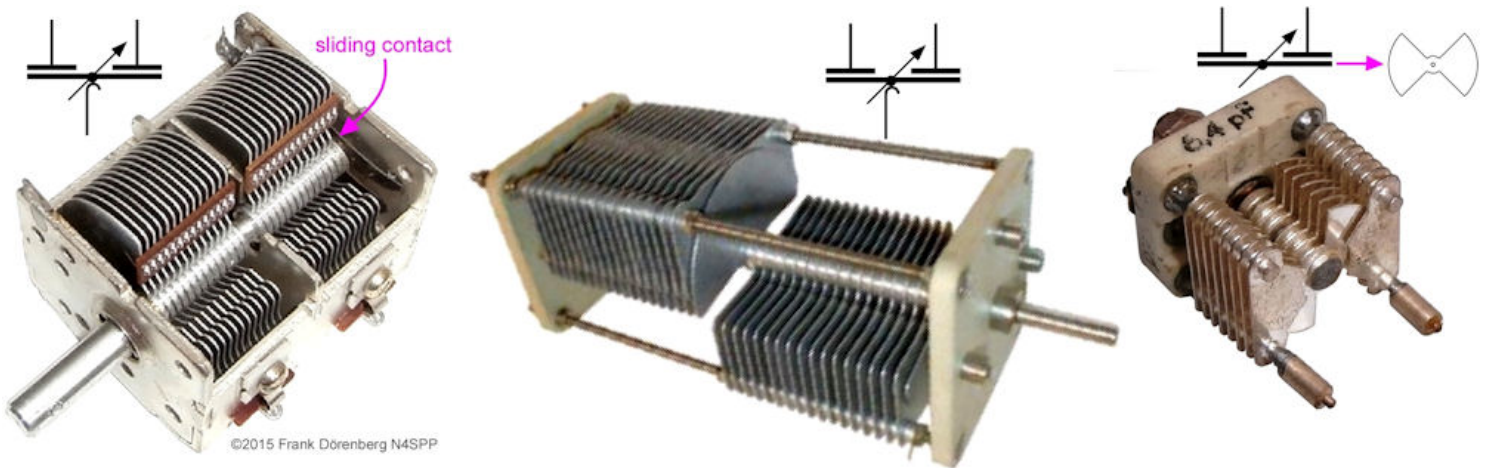


Figure 12: Broadcast receiver capacitor, split-stator capacitor, and butterfly trimmer

The dielectric *strength* (= voltage rating, breakdown voltage) of pure, clean, mineral oil is at least 10 kV/mm, as compared to 3 kV/mm for standard air. So, immersing an air variable capacitor in such oil more than triples the voltage rating (dielectric strength, breakdown voltage). Also, the dielectric *constant* (= relative permittivity) of oil is about 2, i.e., twice that of air. So an air-variable capacitor may be immersed in oil to double its capacitance. Of course, this also doubles the minimum capacitance of an air-variable capacitor, i.e., *reduces* the maximum tunable operating frequency of a loop by a factor of $\text{SQRT}(2) = 1.4$. Use an oil-tight non-metal container, and pure clean mineral oil (a.k.a. paraffin oil), synthetic motor oil, or similar. I.e., not transformer oil, which is expensive and often toxic. Make sure that the capacitor plates are completely immersed!

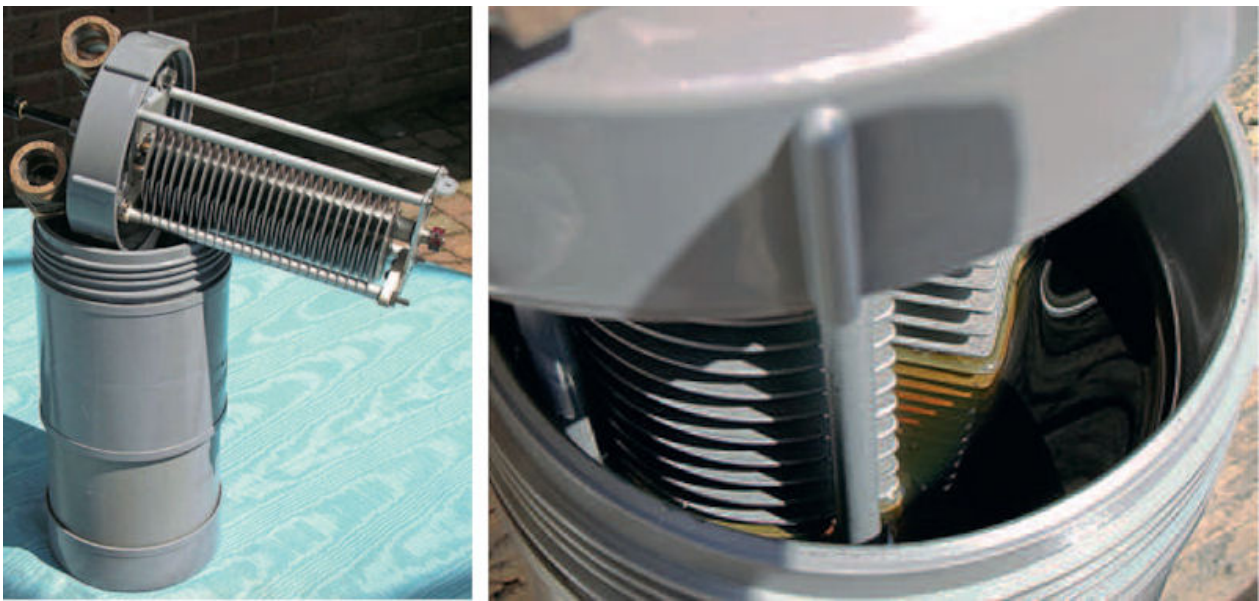


Figure 13: Air-variable capacitor immersed in oil - doubles capacitance and voltage rating
(source: ref. 12A)

Rather than meshing stacks of rotor and stator plates, a variable capacitor can also consist of "trombone-style" coaxial tubes: one tube is slid in and out of a slightly larger "stator" tube. This principle is also used in variable vacuum capacitors, see below.

On 15 June 1896, Nicola Tesla filed US Patent Nr. 567,818A (awarded three months later) for an "Electrical condenser", with increased efficiency that is obtained by "practically complete exclusion of air or gas from the dielectric". I.e., the vacuum capacitor! Nowadays, such capacitors typically use two sets of plates that are concentric thin-wall cylinders. In a vacuum *variable* capacitor, one of the two sets can be slid in or out of the opposing set of cylinders ("sleeve and plunger/piston"). The same concept is used in old fashioned air trimmer-capacitors that were made by Philips for several decades since the 1930s (a.k.a. "beehive" trimmer; German: "Tauchtrimmer"). Instead of intermeshing concentric cups, the electrodes may also consist of a continuous spiral (with a fixed pitch).



Figure 14: Philips tubular-piston "beehive" trimmer capacitors (5-30 pF, 0.3 mm plate distance)

(due to their shape, they are called "toltrimmers" in Philips-country (i.e., The Netherlands), meaning "spinning-top trimmer")

In the vacuum capacitor, spacing between opposing cylinders is several mm. The plates are sealed inside of a non-conductive envelope such as a glass or ceramic "bottle", 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, compared to an air-variable capacitor of the same dimensions and construction.

The tables in the previous section show that the assumed loop should be tunable from 80-20 mtrs with a 15-500 pF high-voltage variable capacitor. 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! In 2010, I purchased a Russian-made capacitor. It is marked "10 kV,10-500 pF". I measured 15-510 pF with a simple LCR-meter. This "bottle" is quite heavy: 2.2 kg (\approx 4.8 lbs). It takes 36 revs of the shaft to go from minimum to maximum capacitance. In 2021, I acquired a second vacuum capacitor, for some experiments. It is also Russian made and is marked "5 kV, 5-250 pF". It is significantly smaller and lighter: 730 grams (\approx 1.6 lbs).



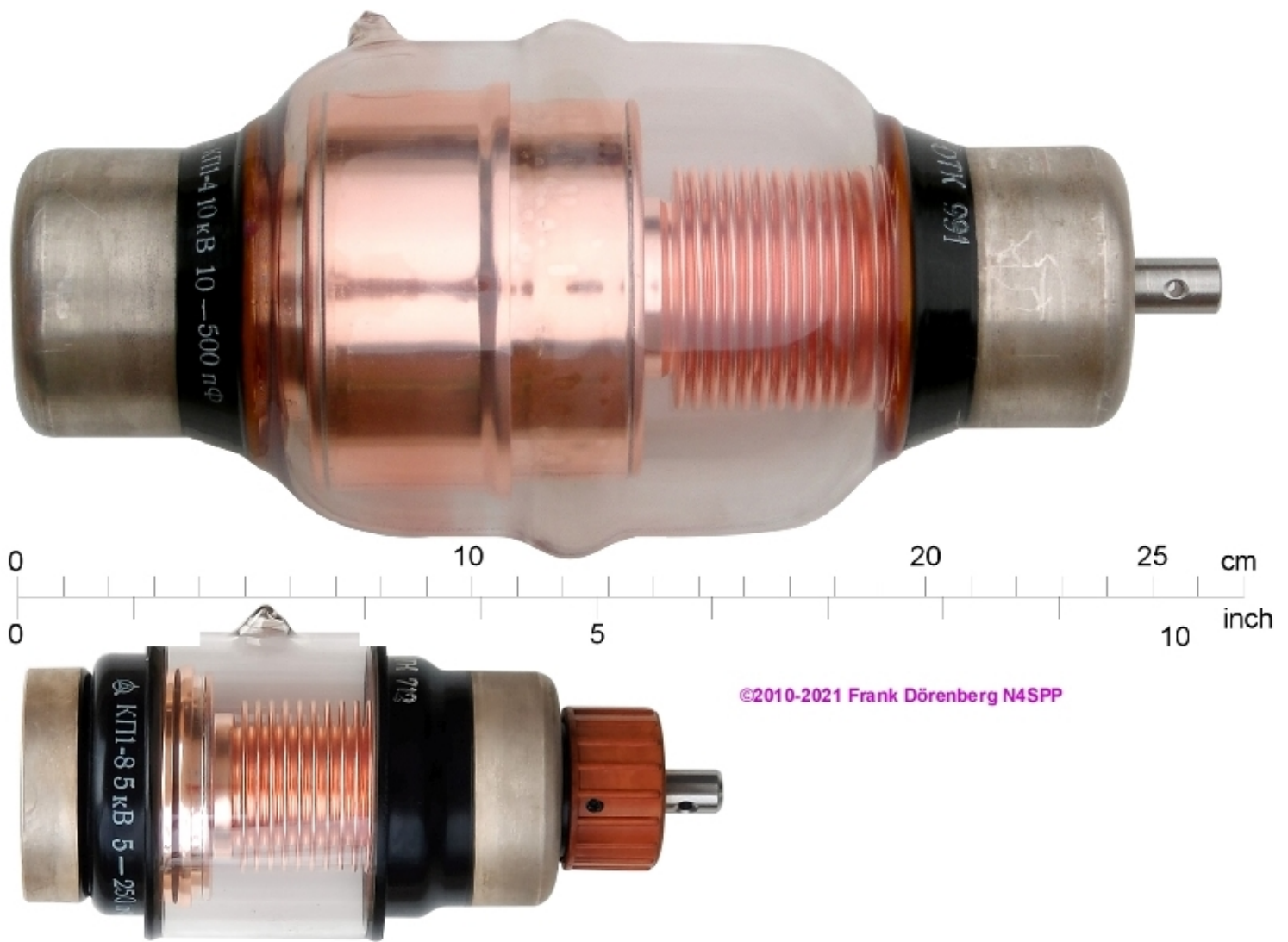


Figure 15: My vacuum capacitors

CAPACITOR RATINGS

Capacitors have two limits that are important in STLantenna applications:

Voltage rating, which is the dielectric breakdown voltage (with some margin).

Current rating, which is driven by losses that cause dissipation (= heating).

BREAKDOWN VOLTAGE. Dielectric strength is the maximum voltage that can be applied across a dielectric, without electrical breakdown occurring. Simply put, at the breakdown field strength, the dielectric becomes (locally) conductive: sufficient electrons are knocked out of the dielectric and/or electrode material, are sufficiently accelerated, and set free additional electrons via collisions. In capacitors with gaseous dielectric (such as air), the breakdown peak voltage as a function of plate spacing gas pressure is a non-linear relationship. It is critically affected by factors such as the geometry of the capacitor conductive parts, smoothness of edges, surface finish of the plates, ultraviolet illumination of the electrodes, etc. Breakdown results in a discharge,

and can be limited to a luminous corona glow (low-current, high-voltage) around plate edges, or take the form of a "spark" (high-current, low-voltage). It is modeled by *Paschen's law* and associated curves.

Note that dielectric strength of practical vacuum is not infinite! Even deep space is not a perfect absolute vacuum. Ref. 12K. In vacuum electronic components, the vacuum level is typically on the order of 10^{-7} Torricelli ≈ 0.0133 mPa. The breakdown field strength of air is often given as $V_S = 30$ kV/cm = 3 kV/mm = 3 MV/m. Note that this only applies for electrode (plate) spacing of about 2 cm = 20 mm! For smaller spacings, it is actually larger! E.g., for a spacing D around 1 mm, the following Townsend's formula is used in standard atmosphere: $V_S = (30 \times D + 1.35)$ kV, where D is spacing in cm. For 1 mm ($D = 0.1$ cm), this yields $V_S = 4.35$ kV, i.e., ca. 43 kV/cm = 4.3 kV/mm = 4.3 MV/m. The breakdown field strength of air is actually on the order of 2-5 MV/m. Note: if a vacuum capacitor is kept in storage for a long time, or is only exposed to low peak voltage levels for a long time, some gas may be released into the vacuum. This reduces the breakdown voltage below the capacitor's specified test voltage rating. The capacitor may have to be reconditioned (treated with an increasing DC voltage).

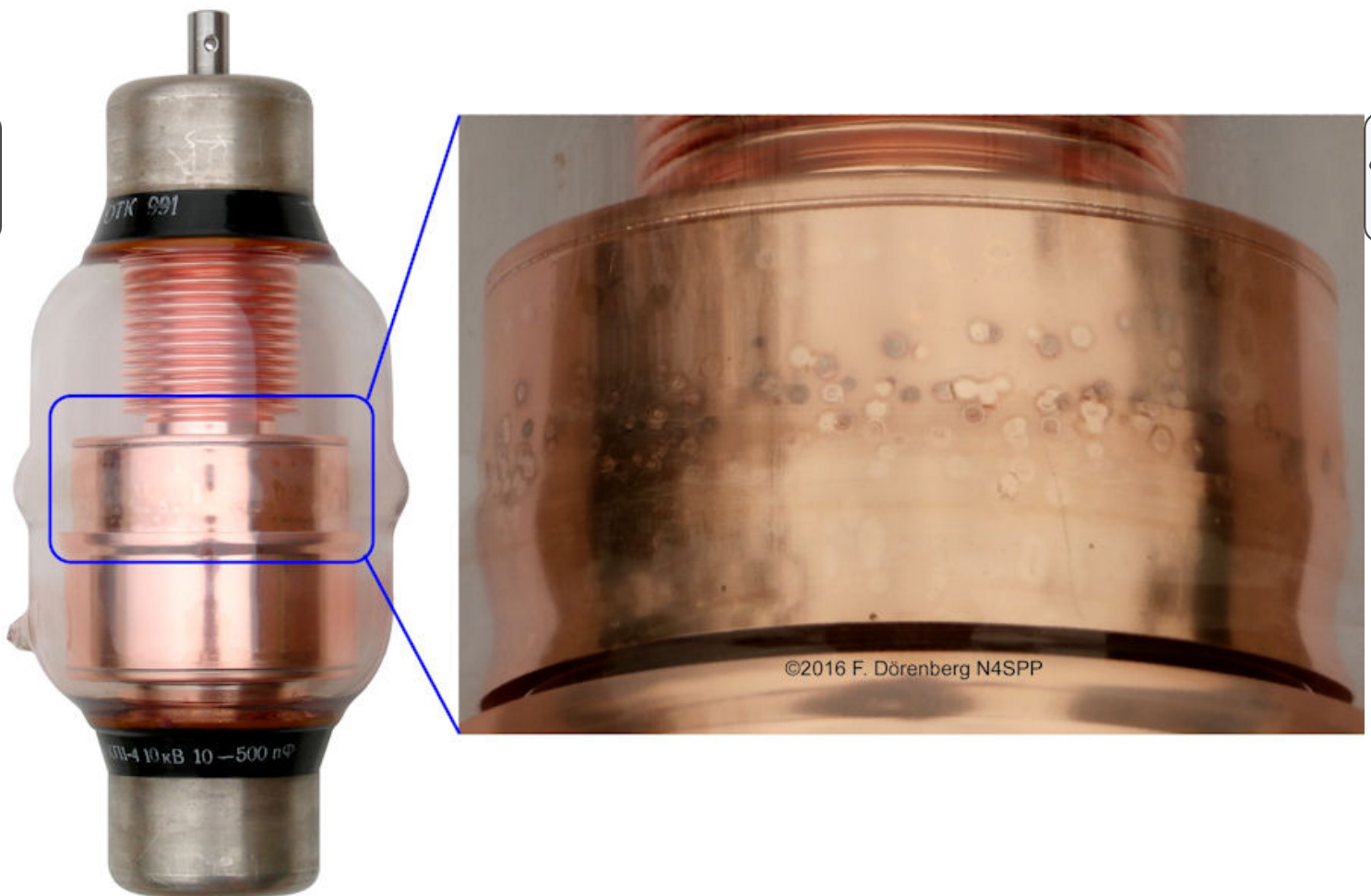


Figure 16: A vacuum capacitor with typical over-voltage arcing damage (the round damage spots are about 4 mm ($\approx 1/6$ inch) in diameter)

The following lumped-element equivalent circuit diagram shows that a practical capacitor is quite a bit more than just an ideal, pure capacitance:

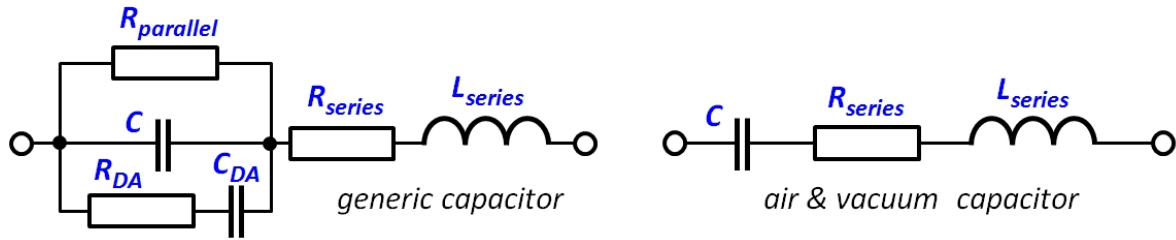


Figure 17: lumped-element equivalent circuit diagram of a capacitor

where

C = ideal, lossless capacitance

R_{series} = equivalent series resistance (ESR, loss)

L_{series} = equivalent series inductance (ESL)

$R_{parallel}$ = insulation resistance

R_{DA} = resistive component of the dielectric absorption

C_{DA} = capacitive component of the dielectric absorption

When transmitting, the loop's tuning capacitor will heat up due dissipation in the capacitor's loss resistances. The latter can be summed into the Equivalent Loss Resistance, ESR. The dissipated power is:

$$P_{diss} = I_{rms}^2 \cdot ESR = \frac{V_{rms}^2}{ESR}$$

ESR consists of metallic losses in the capacitor's electrodes and connecting leads, as well as dielectric losses. In a vacuum capacitor, the dielectric is "vacuum". Hence, the dielectric loss is negligible. At HF frequencies, the ESR of vacuum capacitors varies over a range of about 2 milliohms (at low HF frequencies) to about 20 milliohms (high HF). Ref.12G. The loss-resistance is primarily caused by the capacitor plates, the bellows and the structure that connects the movable electrode to its external mounting flange (in variable vacuum capacitors), and the transition between the rotor shaft and the rotor terminal (in air variable capacitor types, other than "butterfly" and "split-stator" with the stators interconnected). ESR is inversely related to the capacitor's (frequency dependent) Q. Manufacturers of vacuum capacitors typically provide a nomogram chart of max allowable I_{RMS} as a function of operating frequency at the specified peak operating voltage and max capacitance (= largest ESR). Ref. 12B shows the example of a particular vacuum capacitor with a temperature rise of about 40°C when operated at 6 MHz, 7.5 kV peak, and 10 amps RMS. Glass vacuum capacitors typ. have a max operating temperature around 90 °C (= 195 °F). Ceramic vacuum capacitors typically have a higher maximum: around 120°C (= 250°F).

Note that near resonance, a small transmitting loop may have a circulating RF current of several dozen Amps when transmitting at 100 W!

Some manufacturers of vacuum capacitors issue data sheets that include an RMS current rating graph. It typically shows a "continuous RMS current (amps) vs. frequency" curve for a fixed operating voltage (often the voltage rating). For *variable* vacuum capacitors, there may be two or more such curves, where the rating for lower capacitance values is lower than for higher capacitance values. The rating-curves normally increase (linearly on a logarithmic scale) with frequency, up to a certain frequency. For higher frequencies, convective heat-sinking capability becomes the limiting factor, and the curve(s) go down with frequency. The voltage rating is not frequency dependent.

Dielectric absorption is the effect by which a capacitor that has been charged for a long time, does not discharge completely when briefly discharged. In air capacitors and vacuum capacitors, this effect is typically too small to be measurable. The insulation resistance R_{parallel} accounts for leakage current through the dielectric. For variable vacuum capacitors, the latter is typically less than 10 microamps. This is extremely small, compared to the capacitor current when the loop is tuned to resonance.

The series self-inductance L_{series} of an air variable capacitor typically ranges from about 6 to 50 nH. For fixed vacuum capacitors, it ranges from about 2 to 10 nH. Variable vacuum capacitors have a bellows and a structure to connect the movable electrode to the external mounting flange. This increases the self-inductance to about 6 - 20 nH, and this inductance changes with the capacitance. The capacitor's self-resonance frequency that results from this series inductance, is normally well above HF.

EFFECTS OF TEMPERATURE, ATMOSPHERIC HUMIDITY & PRESSURE

(this section still needs some work...)

Have you ever noticed that the resonance frequency of your "Mag Loop" STL drifts when the capacitor's temperature changes? The temperature change may be due to loss-dissipation in the capacitor when transmitting, the sun shining on the capacitor, or change in ambient temperature. Likewise, have you noticed a frequency drift when the relative humidity of the air changes significantly (foggy weather, temperature near the dew point)? Or you have noticed a change in the maximum transmit power you can apply, before a luminous corona discharge appears at the capacitor plates, or arcing occurs?

There is surprisingly little literature (including university textbooks) that discusses the effects of parameters such as humidity, atmospheric pressure, and temperature on the performance of tuning capacitors. General literature often considers the effects as “minimal” or “negligible”, and uses simplistic, approximate models such as that of an ideal capacitor that consists of two flat parallel plates or concentric cylindrical plates:

$$C_{\text{parallel}} = \frac{\epsilon_r \epsilon_0 A}{d} \qquad C_{\text{concentric}} = \frac{\epsilon_r \epsilon_0 2\pi \cdot l}{\ln\left(\frac{r_1}{r_2}\right)}$$

where

C = capacitance in Farad

ϵ_0 = absolute permittivity of free space ("pure vacuum"); $\epsilon_0 = 8.85 \times 10^{-12}$

F/m

ϵ_r = relative permittivity of the dielectric (a.k.a. dielectric constant)

A = area of plate overlap in square meters ("active area")

d between plates in meters (= dielectric thickness)

l = length of overlap between the electrodes in meters

r_1 = inner radius of the outer electrode in meters

r_2 = outer radius of the inner electrode in meters

↑ These formulas ignore edge effects, and suggests that the capacitance C is a constant. However, the capacitance *does* change with temperature, as well as humidity and barometric pressure (air capacitors). Ref. 12B, 12C. ↑

TEMPERATURE. The capacitance of a decent “glass bottle” vacuum variable capacitor typically varies no more than about 100 ppm/°C = 0.01%/°C (ref. 12G). Ceramic vacuum capacitors only drift about half as much, but an air capacitor may drift three times as much. That’s still not much, right? Well, in a “low-Q” filter application this may well be the case. But in a well-constructed “high-Q” loop? Let’s take a marginal vacuum variable capacitor and assume a temperature increase of only 10 °C (= 18 °F). Worst-case (!), the capacitance will change by 10 x 0.01% = +0.1%. What does this mean for the resonance frequency of a loop antenna?

$$f_{\text{res}} = \frac{1}{2\pi\sqrt{LC_0}}$$

where L = loop inductance, and C_0 = capacitance of the tuning capacitor at a particular temperature T_0 . Note that, for the sake of simplicity, we are ignoring the stray (parasitic) capacitance of the loop inductance here. Based on the above formula, we can derive the change of the resonance frequency for a given shift in the capacitor temperature :

$$\Delta f_{res}(T_0 \rightarrow T_1) = f_{res}(T_0) \cdot \frac{1}{\sqrt{m} - 1}$$

where m = capacitance change-factor due to temperature change from T_0 to T_1 . Hence, $m = 1 + \text{drift percentage}$. For $\Delta T = +10^\circ\text{C}$, $m = 1 + 0.01\% = 1.01$. Hence:

$$\Delta f_{res}(\Delta T = +10^\circ\text{C}) = f_{res}(T_0) \cdot \left(\frac{1}{\sqrt{m}} - 1 \right) \approx f_{res}(T_0) \cdot 0.995$$

I.e., a change of -0.5%: temperature increase causes a frequency decrease. For instance, at 28 MHz, the resulting frequency drift would be $28 \text{ MHz} \times -0.005 = -14 \text{ kHz}$. At 3.6 MHz, the resulting frequency drift would be $3.6 \text{ MHz} \times -0.005 = -1.8 \text{ kHz}$. This much drift is quite noticeable! Note that there are even small hysteresis effects associated with large temperature changes (ref. 12C).

In the discussion above, we used the standard equation for the resonance frequency of an LC circuit and approximate models for capacitance. Per the resonance frequency equation, a relative change in C clearly has the same effect as the same relative change in L . The standard approximate model for an inductance coil is given below. Instead of the capacitor's permittivity ϵ of the medium between the plates, we now have the magnetic permeability μ of the medium inside the coil winding(s). For a cylindrical coil with N turns ($N = 1$ for a standard STL antenna), the inductance is approximately:

$$L = \frac{\mu_r \mu_0 N^2 A}{l}$$

where

L = inductance in Henry

μ_0 = absolute permeability of free space ("pure vacuum"); $\mu_0 = 4\pi \times 10^{-6}$ H/m

μ_r = relative permittivity of the dielectric

N = the number of turns of the coil-winding

A = area of plate overlap in square meters ("active area")

l = average length of the coil in meters (= dielectric thickness)

A standard "Mag Loop" STL antenna is a 1-turn air-core inductor. Like a capacitor's relative permittivity, a coil's relative permeability depends on the operating frequency, and the temperature, pressure, and humidity of the dielectric (= "air" for a loop antenna)!

Before I bought my used vacuum capacitor, did a quick test to verify integrity of the vacuum: I put the capacitor in the refrigerator for about an hour. There 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). If the vacuum seal is

compromised, the shiny copper will turn dull eventually. As heavy as the capacitor is, the glass is actually rather thin. I found this out when my first vacuum capacitor imploded when it rolled around on the tiles of my terrace floor.

HUMIDITY. Yes, the capacitance of vacuum capacitors is not affected by humidity: moisture can only affect the outside surface of such capacitors. But high ambient humidity may cause a small leakage current across the outside of the capacitor. However, for air capacitors, the capacitance change as a function of relative humidity of the air is actually so large, that such a capacitor can be used as a relative-humidity sensor (ref. 12D)! Note that air capacitors also exhibit small hysteresis effects associated with long exposure to high humidity (ref. 12F). Relative permittivity $\epsilon_r = 1$ for vacuum. Dry air has an $\epsilon_r \approx 1.0006$ (at standard temperature and pressure of 1 atm). This “constant” changes 2 ppm/°C for dry air, and 7 ppm/°C for moist air. Ref. 12H. Dry air has a relative permittivity $\mu_r \approx 1.000000037$. I’m still trying to dig up data on the relative permittivity of air as a function of temperature, humidity, and partial vacuum. With [my own helical loop antenna with air variable capacitor](#), I have observed a frequency drift of 0.5% (20 kHz around 3.6 MHz) when fog moved in, while temperature only changed 0.5 °C.

↑ COUPLING A LOOP TO THE FEEDLINE ↑

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. As with other types of antennas, there are several ways to do this:

[[Inductive coupling_\(coupling loop\)](#)] [[Capacitive coupling](#)]

[[Magnetic transformer coupling_\(ferrite ring\)](#)]

[[Auto-transformer coupling_\(Gamma Match, etc.\)](#)]

Note: this is only a overview of the most common methods. The list is not exhaustive.

INDUCTIVE COUPLING

The most common coupling method is using a small inductive coupling loop (a.k.a. matching loop). The main loop and the coupling loop form a (rather) loosely coupled transformer:

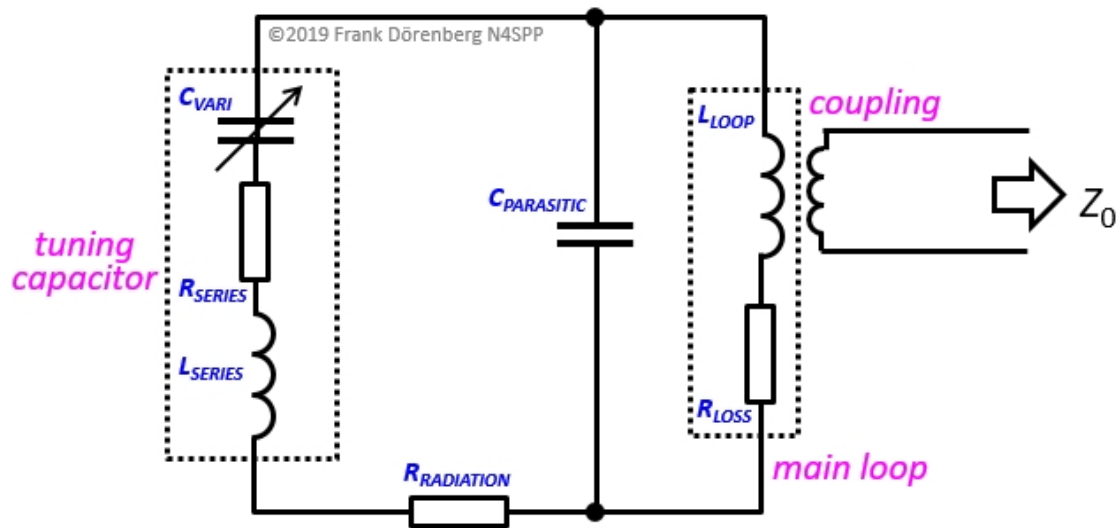


Fig. 18: Simplified equivalent lumped-element electrical circuit of an STL with inductive coupling
(coupling to ground and objects near antenna is not shown)

The turns ratio of this is inherently fixed (1:1), but there are several coupling loop parameters that affect the coupling:

The **size** of the coupling 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.

La **forma** del bucle. La forma estándar es circular. Obviamente, al igual que el bucle principal, se pueden utilizar otras formas (cuadradas, octogonales, ..). Para obtener el acoplamiento deseado, el lazo de acoplamiento se puede aplastar o estirar en un óvalo vertical o en forma de huevo. Esto cambia la apertura del bucle (área de la "apertura"), así como la distancia al bucle principal, consulte la Fig. 21 a continuación.

Colocación a lo largo del bucle principal. El estándar está opuesto al condensador de sintonización. Sin embargo, para ajustar el acoplamiento, se puede mover fuera del centro, a lo largo del bucle principal.

Proximidad al bucle principal. Normalmente, el bucle de acoplamiento se coloca frente al condensador de sintonización, cerca del bucle principal.

Alineación con el bucle principal. Es decir: si el plano del bucle de acoplamiento coincide con el del bucle principal. El acoplamiento con el bucle principal se puede variar girando el bucle de acoplamiento alrededor de su eje vertical (desde donde se conecta el cable coaxial al punto en la parte superior del bucle), de modo que se adhiera a través del bucle principal. En lugar de girar, también se puede doblar.

El **calibre** del conductor, como con todas las bobinas / inductores.

La **frecuencia** de funcionamiento / resonancia de la antena: al *augmentar la* frecuencia, el espaciado óptimo (en términos de ROE) entre el bucle de acoplamiento y el bucle principal *disminuye*.

Se hace una distinción entre bucles de acoplamiento "sin blindaje" y "blindados".

Los bucles de acoplamiento sin blindaje son muy simples:

Un cable de gran calibre o una tubería de cobre de pequeño diámetro; no es necesario que el conductor sea de calibre más pesado que el conductor central del cable coaxial de la línea de alimentación. Sin embargo, un conductor más pesado ayudará a retener la forma del bucle y lo hará autoportante.

He usado un cable de instalación de una sola hebra (sólido)

"extra pesado" de $2,5 \text{ mm}^2$, pero en estos días uso tubos de cobre blando estándar de aproximadamente 1/4 de pulgada (6,35 mm) de diámetro en mi bucle grande (consulte la Fig. 79 a continuación), y Fig. 139 y 140 para mi versión "nueva y muy mejorada"), y tubos de latón delgado (vea la [Fig. 9 de mi pequeño proyecto STL](#)). Esto es mecánicamente bastante estable.

Con un bucle de acoplamiento tan simple, obtengo muy buena ROE (mejor que 1.1) en un rango de frecuencia de al menos 1: 2.5.

El blindaje de una sección de cable coaxial. El conductor central se deja desconectado, o ambos extremos están conectados al blindaje.

El conductor central del cable coaxial, con el aislamiento exterior y la trenza completamente eliminados. El material dieléctrico del cable coaxial se mantiene y proporciona rigidez.

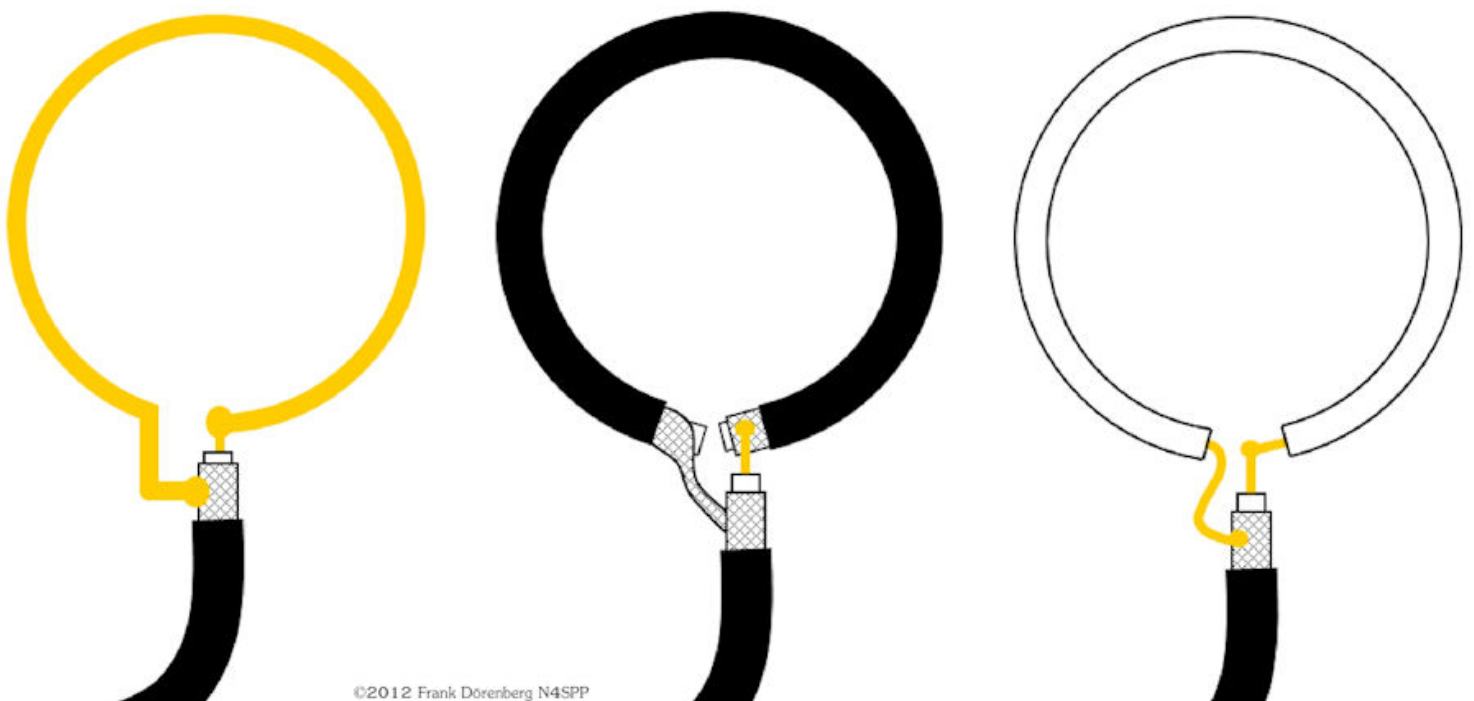


Figura 19: Bucles de acoplamiento sin blindaje
(alambre macizo, trenza de cable coaxial, conductor central de cable coaxial)

Una variación de esto es un "bucle de acoplamiento sintonizado", pero no parece ser popular:

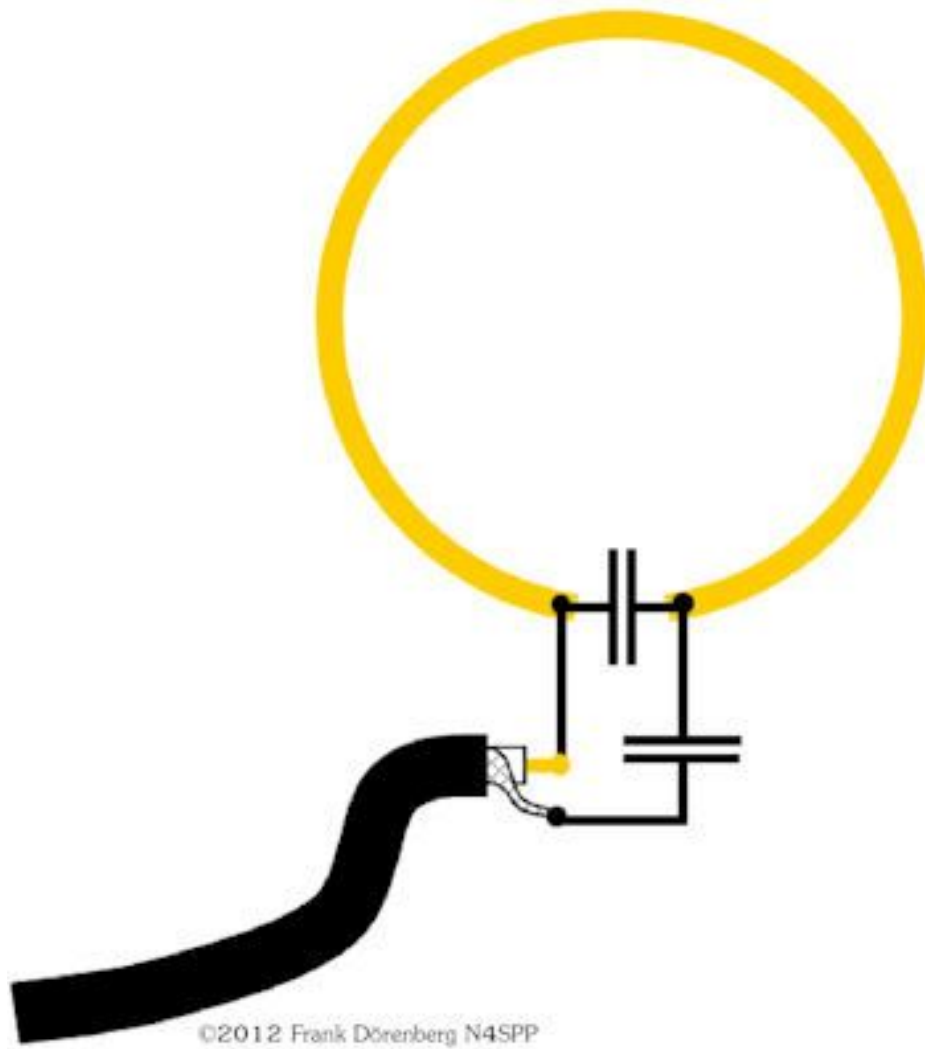


Figura 20: Bucle de acoplamiento sin blindaje con un condensador de sintonización y de carga

Tenga en cuenta que con el bucle de acoplamiento redondo estándar, el bucle principal y el bucle de acoplamiento están cerca uno del otro, pero solo en una pequeña parte de la circunferencia del bucle de acoplamiento. Dependiendo del tamaño del bucle de acoplamiento, a veces se puede obtener un mejor acoplamiento ("menor ROE") cuando el bucle de acoplamiento se estira o se comprime en una forma más ovalada:

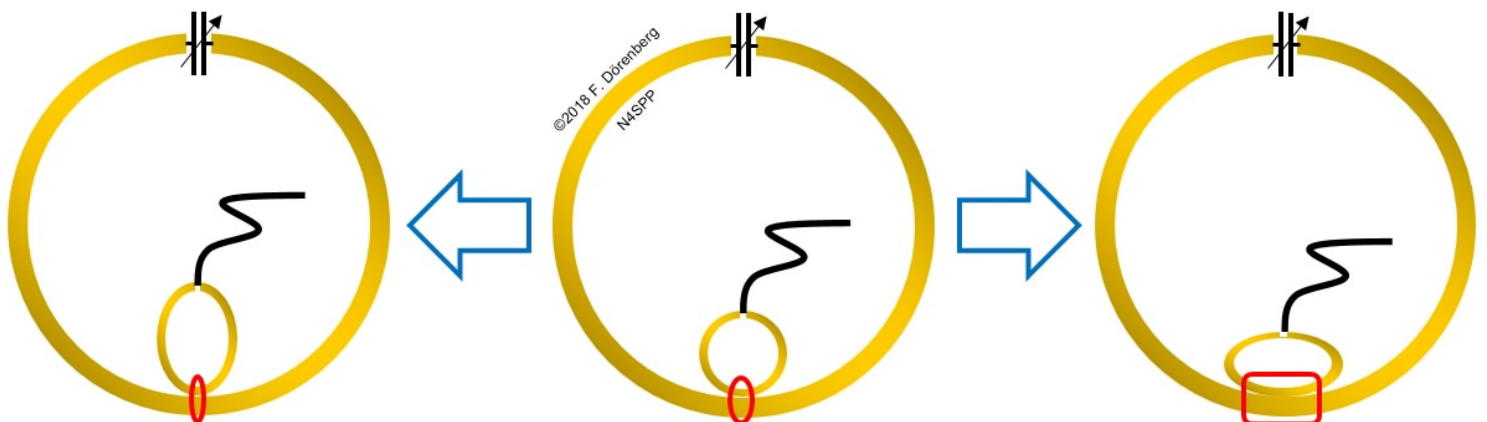


Fig.21: Estirar o comprimir un bucle de acoplamiento redondo para cambiar el acoplamiento con el bucle principal

Una variación de este método es lo que yo llamo el lazo de acoplamiento del "perchero". Consiste en alambre aislado (por ejemplo, alambre de instalación o incluso alambre de cobre esmaltado pesado). La longitud total del cable es un poco más que el diámetro del bucle principal. El bucle de acoplamiento se coloca simétricamente sobre (y se fija a) el bucle principal, a una distancia igual a la mitad del diámetro del bucle principal (es decir, $\approx 1/6$ de la circunferencia del bucle). En lugar de conectar el cable coaxial en la parte inferior, se conecta en la parte superior del bucle de alimentación. Es decir, un bucle de alambre al revés. Los extremos de los cables se doblan uno hacia el otro, se unen y se retuercen a una distancia de unos 10-12 cm (4-5 "; no es crítico) y se conectan al cable coaxial. Se coloca un estrangulador de corriente "cerca del acoplamiento. punto donde los extremos del cable se retuercen, se mueven hacia arriba o hacia abajo,

Solo he jugado brevemente con este método de acoplamiento. La frecuencia de resonancia de la antena variaba bastante cuando la conexión trenzada al cable coaxial se movía hacia arriba y hacia abajo. La ROE fue relativamente plana en un rango de frecuencia significativo, alrededor de 200 kHz, bastante más ancho que con un bucle de acoplamiento regular.

Esto es similar al bucle de alimentación triangular de [mis antenas de bucle en espiral \(monobanda\)](#), donde el bucle de acoplamiento tiene una circunferencia que es $1/8$ de la del bucle principal de $1/4 \lambda$ enrollado en espiral.

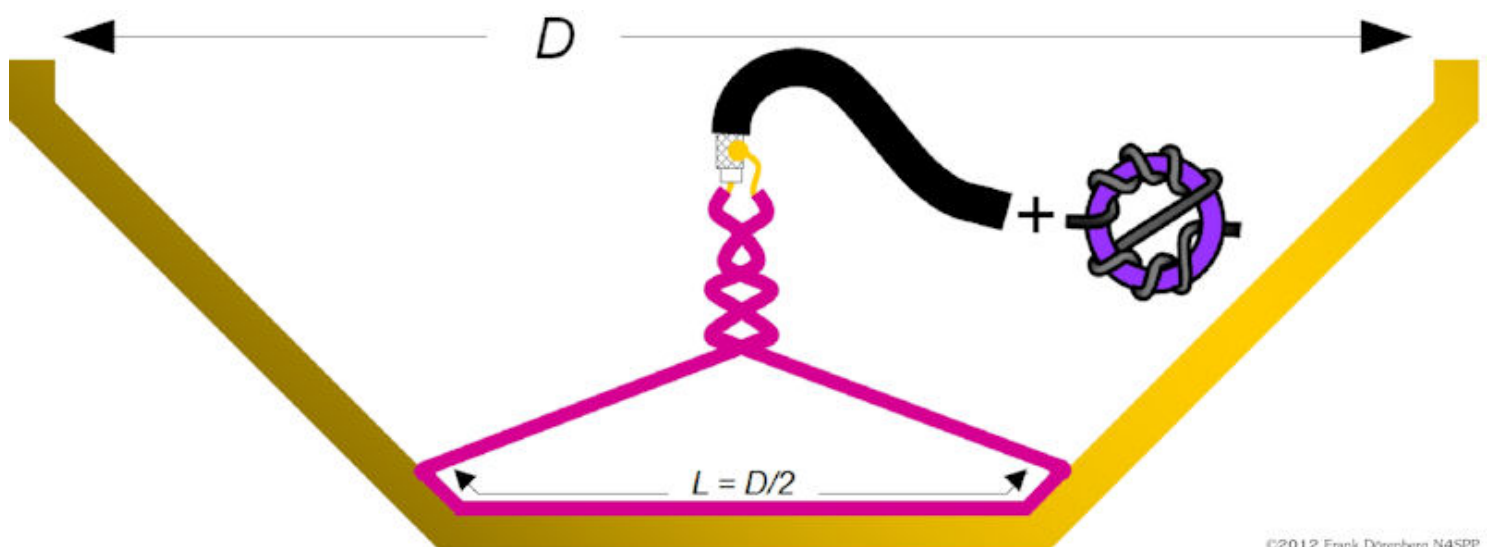


Figura 22: Bucle de acoplamiento "Perchero"

El acoplamiento entre el bucle de acoplamiento triangular y el bucle principal se puede hacer más estrecho, enrollando el cable aislado del bucle de acoplamiento alrededor del bucle principal, como lo ha hecho Jo Lourenço (CT1ECW) para su bucle de 7-21 MHz (ref. 6M) . Esto parece una

coincidencia delta "retorcida". La misma técnica se utiliza en la [combinación gamma "retorcida"](#) que se muestra más adelante. Tenga en cuenta que en la foto de abajo, la dirección de giro de la espiral cambia en el punto medio (es decir, donde la espiral pasa a través del "mástil" de madera). Esto puede ser contrario a la intuición, pero se basa en los experimentos de Jo ...

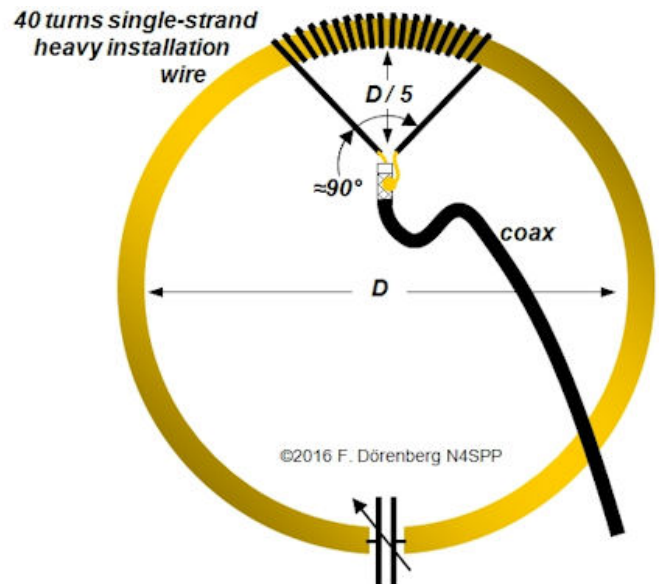


Figura 23: Acoplamiento en espiral
(foto: © Jo Lourenço (CT1ECW), usada con permiso)

El segundo tipo de bucle de acoplamiento inductivo es el bucle **blindado** (= apantallado), a menudo denominado "bucle de Faraday". Al igual que con el bucle de acoplamiento sin blindaje, el diámetro típico es 1/5 del del bucle principal (aunque algunas personas obtienen mejores resultados con un bucle de acoplamiento tan pequeño como 1/8 del tamaño del bucle principal). Para facilitar la construcción, este bucle de acoplamiento suele estar hecho de una sección de cable coaxial. En mi experiencia, es difícil hacer que un bucle coaxial de este tipo sea mecánicamente estable, especialmente con un cable coaxial delgado (RG58, RG8, ...) y una configuración "Faraday" (= trenzado coaxial interrumpido y conductor central).

Existe una serie de variaciones que difieren con respecto a:

- si la trenza coaxial (= blindaje) se interrumpe en el punto medio alrededor del bucle,
- si el conductor central se interrumpe en ese mismo punto,
- cómo se conectan la trenza y el conductor central en el punto de inicio del bucle.

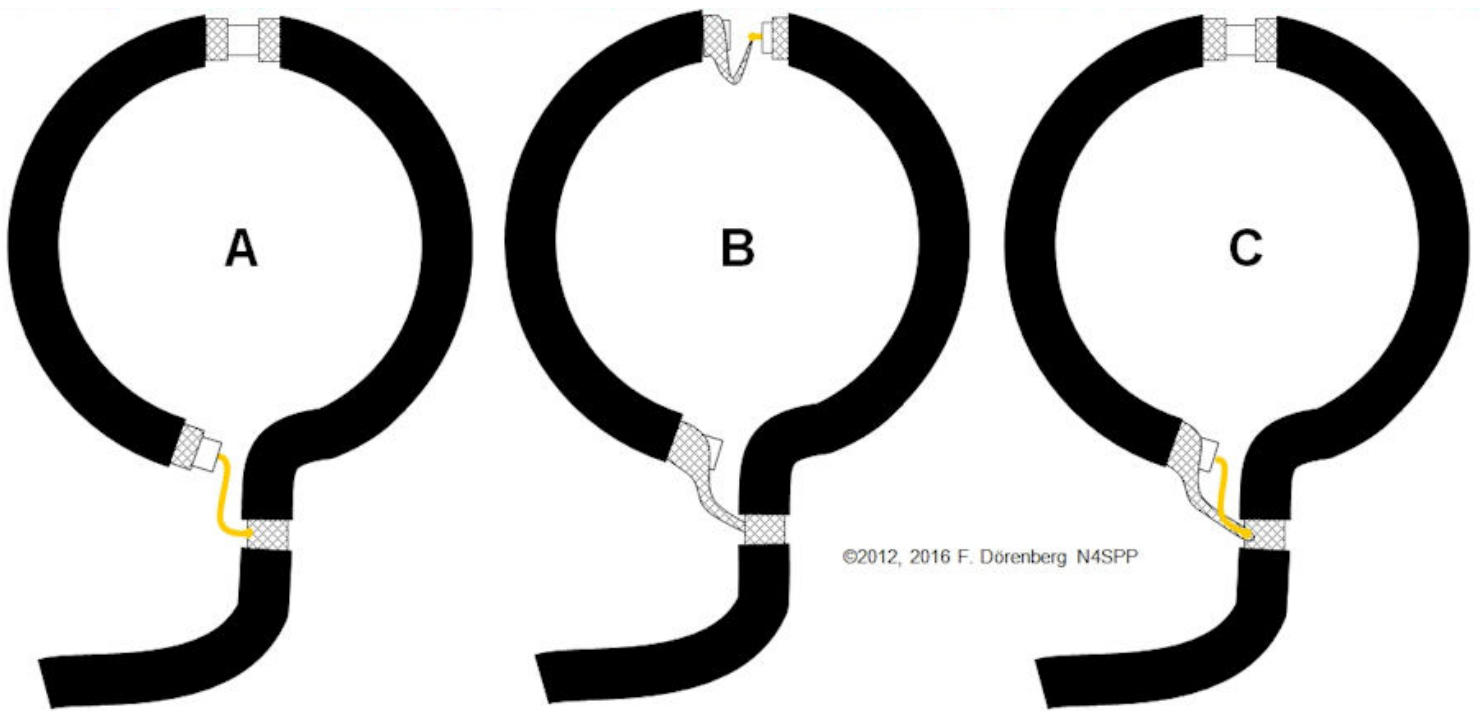


Figura 24A: Variaciones de los lazos de acoplamiento blindados

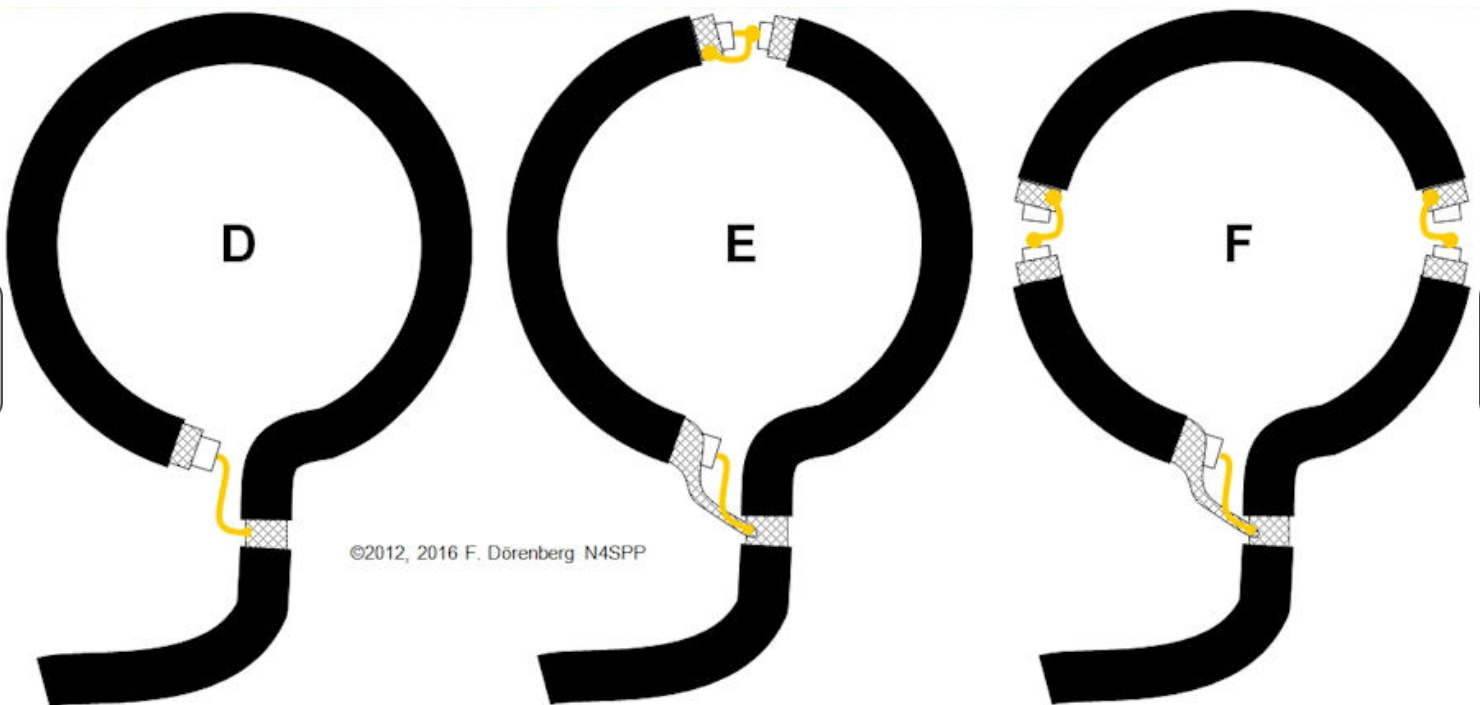


Figura 24B: Variaciones de los lazos de acoplamiento blindados (continuación)

Vamos a echar un vistazo más de cerca a la variación **D** . El escudo del bucle coaxial envuelve el flujo que es creado por la bobina de 1 vuelta formada por el conductor central de ese coaxial. Esto induce un voltaje a través del blindaje en bucle. El voltaje máximo ocurre en el punto donde termina el blindaje. En el punto medio del bucle coaxial (es decir, en la parte superior de ese bucle en el diagrama), está presente la mitad de este voltaje máximo. Por lo tanto, el bucle en su conjunto también tiene un $V_{\text{máx.}} / 2$ con respecto al suelo. Este bucle de acoplamiento genera un campo eléctrico que está principalmente polarizado verticalmente (asumiendo que el bucle de acoplamiento está

instalado verticalmente). Este está acoplado al blindaje de la línea de alimentación. A la inversa, este bucle "recibe" campos E polarizados verticalmente, incl. de la línea de alimentación (que puede llevar las perturbaciones que el transmisor pasa a tierra desde su fuente de alimentación y alimentación principal). Este problema se resuelve en la variación **B** (que en realidad es un bucle medio blindado). Aquí, la mitad izquierda y derecha del bucle de acoplamiento generan voltajes opuestos (= cancelando). En la *vertical* dirección, el promedio ahora es cero. Esto elimina la recepción y generación de campos E polarizados verticalmente. Claramente, todavía hay recepción y generación de campos E polarizados *horizontalmente*. En principio, *ambas* polarizaciones se pueden suprimir abriendo el lazo coaxial en la posición de las 3 en punto y en la de las 9 en punto, en lugar de solo en la posición de las 12 en punto. Ver variación **F**. Árbitro. 6R.

PRECAUCIÓN : la siguiente configuración puede ser fácil de construir, ¡pero NO funciona! No hay espacio en ninguna parte del escudo. ¡No se puede utilizar para generar o recibir un campo EM! Algunas antenas de bucle comercialmente vendidas parecen utilizar exactamente esta configuración de bucle de acoplamiento. Sin embargo, en una inspección minuciosa, se construyen según, por ejemplo, la configuración B de la figura 24A anterior. El espacio del blindaje, el cruce entre el blindaje coaxial y el conductor central y la abertura del conductor central están ocultos en la parte posterior de los conectores coaxiales. Este método de construcción debilita significativamente la rigidez coaxial en esos conectores. Es por eso que la entrada coaxial en los conectores generalmente se refuerza con engarzado, encapsulado y / o algún tipo de pegamento.

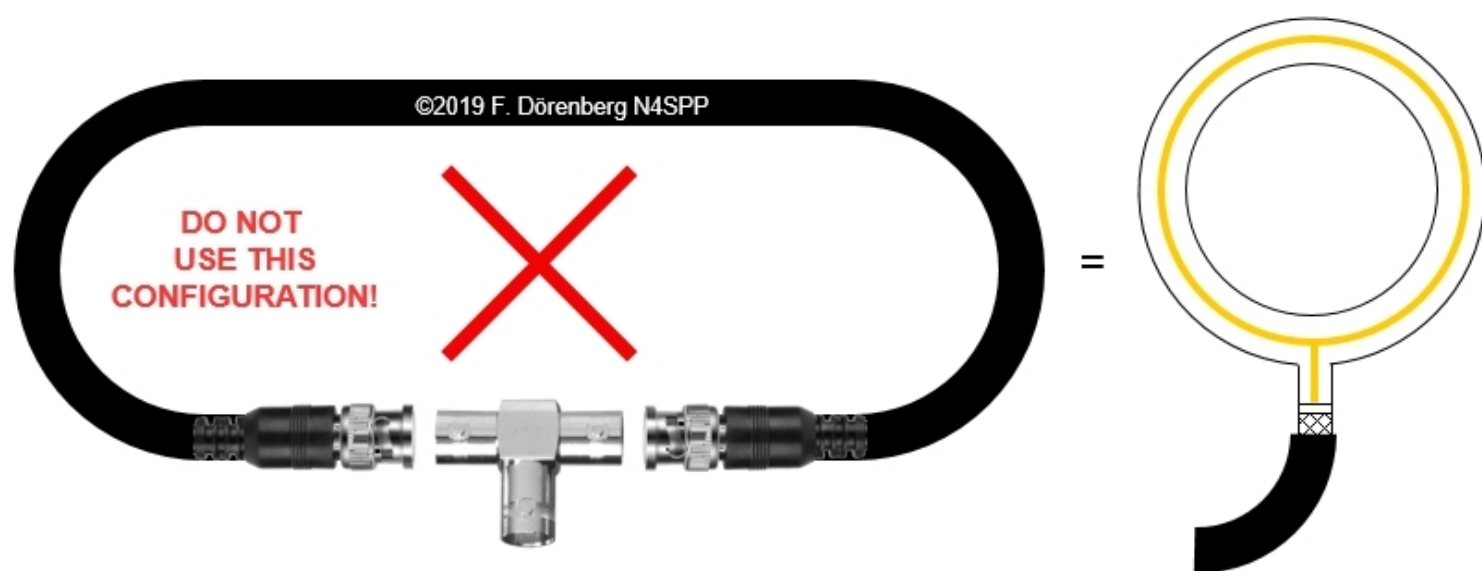


Figura 24C: ¡esta configuración no funciona!

Los siguientes dos bucles blindados están inherentemente equilibrados. Tenga en cuenta que los bucles de acoplamiento desequilibrados provocan un patrón

de radiación asimétrico del bucle principal, incluso si se colocan simétricamente con respecto a este último. La configuración **G** es otro "bucle dividido" convencional. En la configuración **H**, el conductor central del bucle de acoplamiento se cruza con el blindaje en el lado opuesto del espacio. Si se desplaza por uno de los hilos de conexión, es evidente que la señal pasa por el bucle de acoplamiento doble. Comience, por ejemplo, con el cable terminal rojo. Sígalo a través del primer cruce, luego alrededor del escudo, luego otro cruce y a través del cable azul hasta el segundo terminal. Esto se asemeja a

la denominada tira "Möbius". Lleva el nombre de la 19 siglo matemático alemán August Möbius (equivalentemente deletreado como "Moebius"). ¡Esta tira es una superficie con un solo lado! En su forma más simple, es una tira de material, uno de cuyos extremos se tuerce 180 grados y luego se une al extremo opuesto de la tira. El resultado es un bucle con un giro. Por tanto, la configuración de bucle **H** también se denomina "bucle de Möbius (tira)". Tenga en cuenta que la ruta de la señal de dos vueltas duplica el tiempo de retardo de la ruta (muy pequeño). Como un bucle de recepción, la tensión en los terminales es el doble del de configuración **G**. Ver ref. 15A-15G.

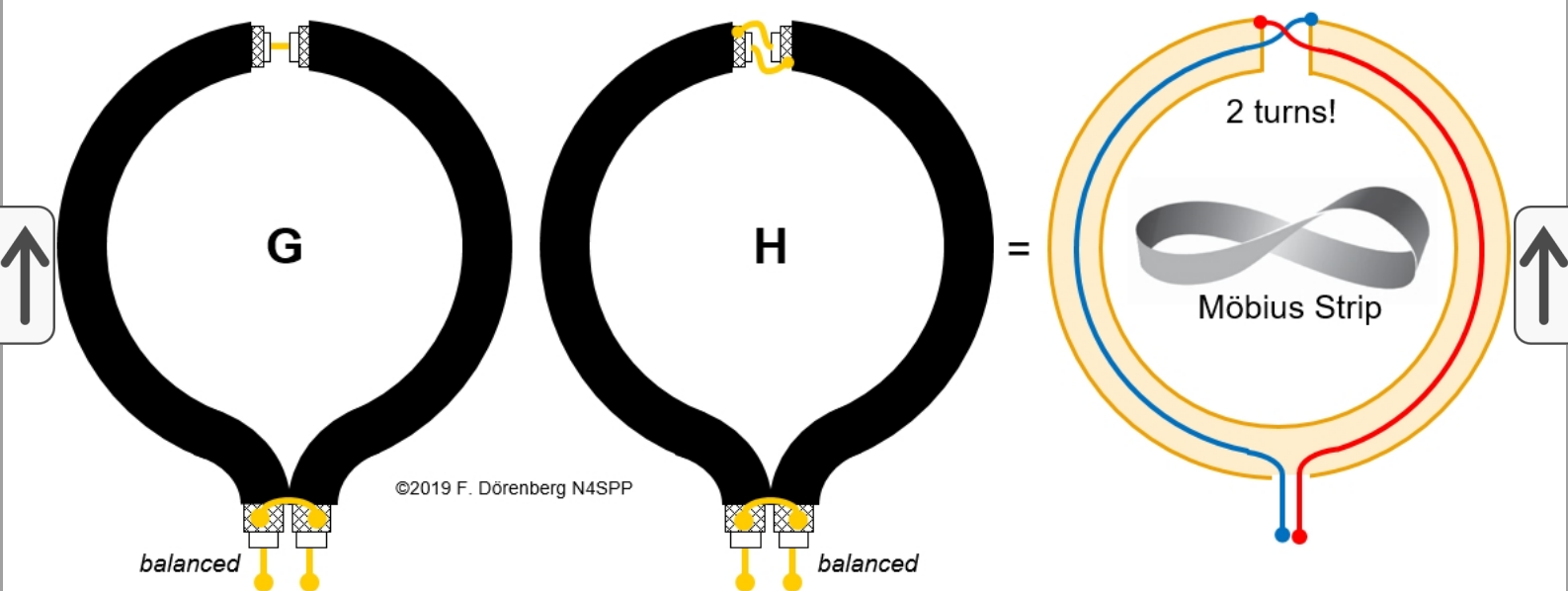


Figura 24D: Bucles de acoplamiento apantallados equilibrados

Para conectar los lazos de acoplamiento balanceados anteriores a una línea de alimentación coaxial, se debe usar un transformador balanceado a no balanceado (Bal-Un) 1: 1. El que se muestra en la Fig. 24D comprende 11 + 11 vueltas bifilares en un anillo de ferrita FT-240-43 (un FT-140-43 debe estar bien hasta 100 W más o menos, ¡una vez que el lazo principal esté sintonizado!). Utilicé un cable de ^{dos} conductores ^{de} $2 \times 0,75 \text{ mm}^2$ ($\approx 18 \text{ AWG}$) con un aislamiento relativamente delgado para maximizar el número de vueltas. El cable verde de la Fig. 24D conecta el blindaje del bucle de acoplamiento al blindaje del cable coaxial de la línea de alimentación.

Tenga en cuenta que un bucle de acoplamiento **no se** utiliza en ningún lugar cerca de su propia frecuencia de resonancia, que es mucho más alta que la frecuencia de resonancia máxima (= operativa) del bucle principal. Debido a su configuración particular, la frecuencia de resonancia de un bucle de Möbius es la mitad que la de un bucle convencional del mismo tamaño. En un STL, esto es irrelevante.

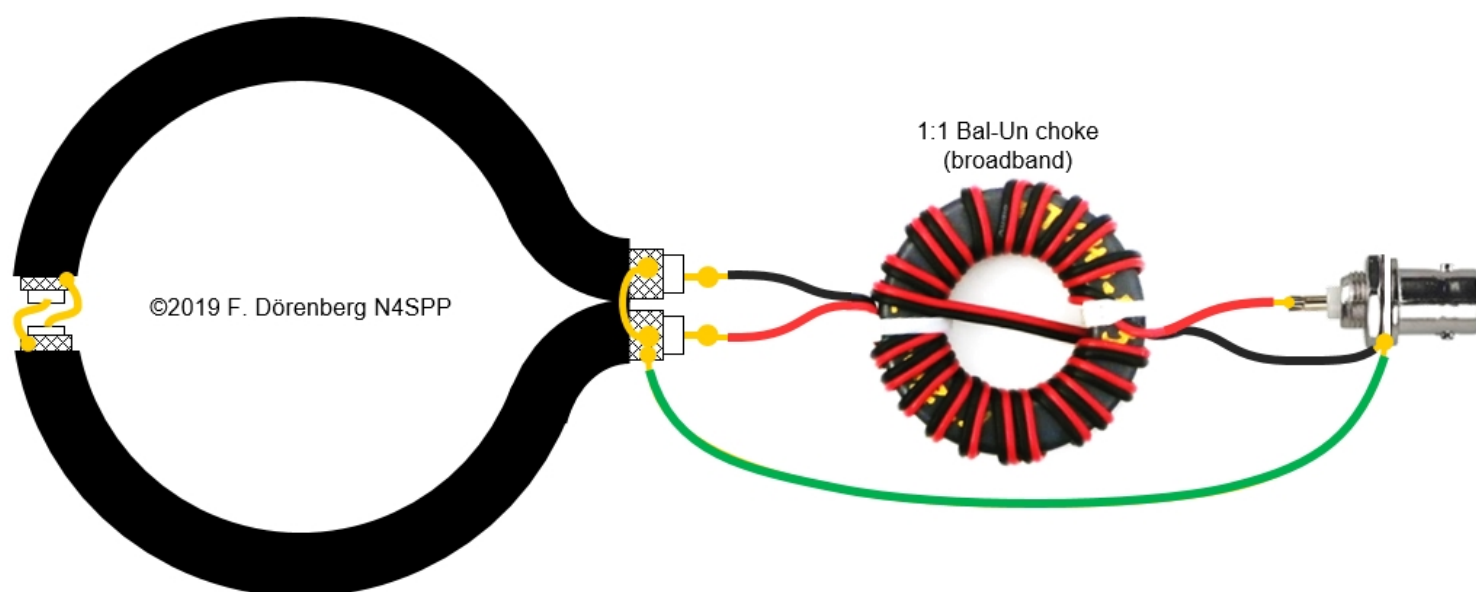


Figura 24E: Bucle de acoplamiento blindado balanceado - alimentado por cable coaxial (no balanceado) a través de un BalUn 1: 1

Hice este lazo de acoplamiento con cable coaxial de 7 mm. Este cable es bastante rígido, pero el espacio en la parte superior y el punto de alimentación deben estar absolutamente estabilizados y fijados en su lugar. Corté las piezas necesarias de la sección de un perfil angular de PVC rígido. Una tira de PVC de 3 x 20 mm proporciona el soporte vertical para retener la forma redonda del lazo. El área de la brecha se fija a una pequeña pieza angular con bridas para cables (tywrap). Vea la Fig. 24F. En el punto de alimentación, el cable también se fija a una pieza angular, con bridas 2x2. Este bucle podría ser intemperizado cepillando cantidades generosas de "cinta aislante líquida" en las partes coaxiales peladas en el espacio y el punto de alimentación.

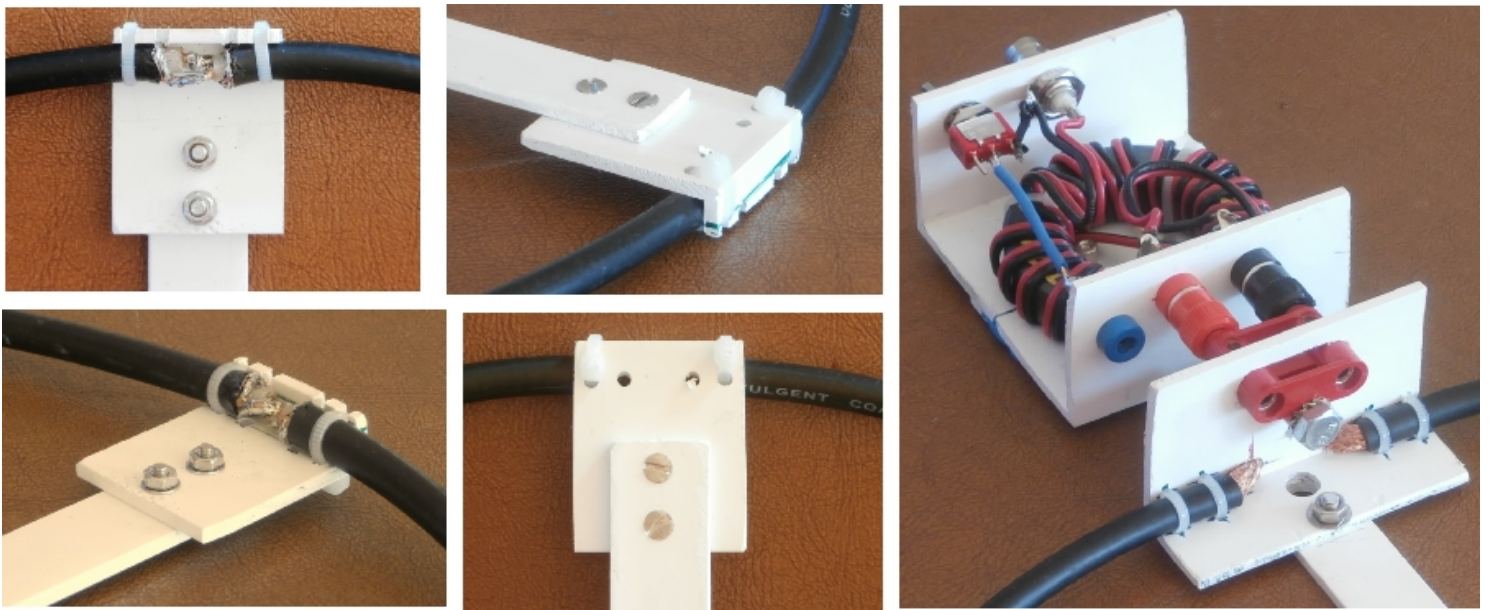


Figura 24F: Detalles de construcción de mi circuito de alimentación balanceada experimental

Probé la configuración de bucle de acoplamiento anterior (con y sin el cable verde) a principios de diciembre de 2019, usando mi bucle sin blindaje estándar como referencia. Podría lograr el mismo SWR bajo (cerca de 1) con ambos. Sin embargo, tuve que volver a sintonizar el bucle con el condensador de sintonización. Al recibir, no pude detectar una diferencia en el nivel de ruido de fondo. Al transmitir (usando un Web-SDR como receptor remoto), no pude detectar una diferencia en la intensidad de la señal.

Para el mismo diámetro, los bucles de acoplamiento no apantallados y los distintos bucles apantallados tienen una frecuencia de autorresonancia diferente (se mide fácilmente cuando no están acoplados al bucle principal).

Jochen Huebl (DG1SFJ) ha realizado algunas mediciones comparativas interesantes con un bucle de acoplamiento sin blindaje y con variaciones de bucle de acoplamiento blindado D y E (ref. 6A). El bucle de acoplamiento (en su caso: 16,5 cm (6,5"), 1/5 del diámetro del bucle principal) se colocó en el mismo plano que el bucle principal, frente al condensador de sintonización. Luego varió la distancia d entre los dos bucles: comenzando con el bucle de acoplamiento contra el bucle principal (con algo de aislamiento entre ellos), luego moviendo el bucle de acoplamiento más cerca del centro del bucle principal (máximo 10 cm / 4 pulgadas). Consulte la figura siguiente:

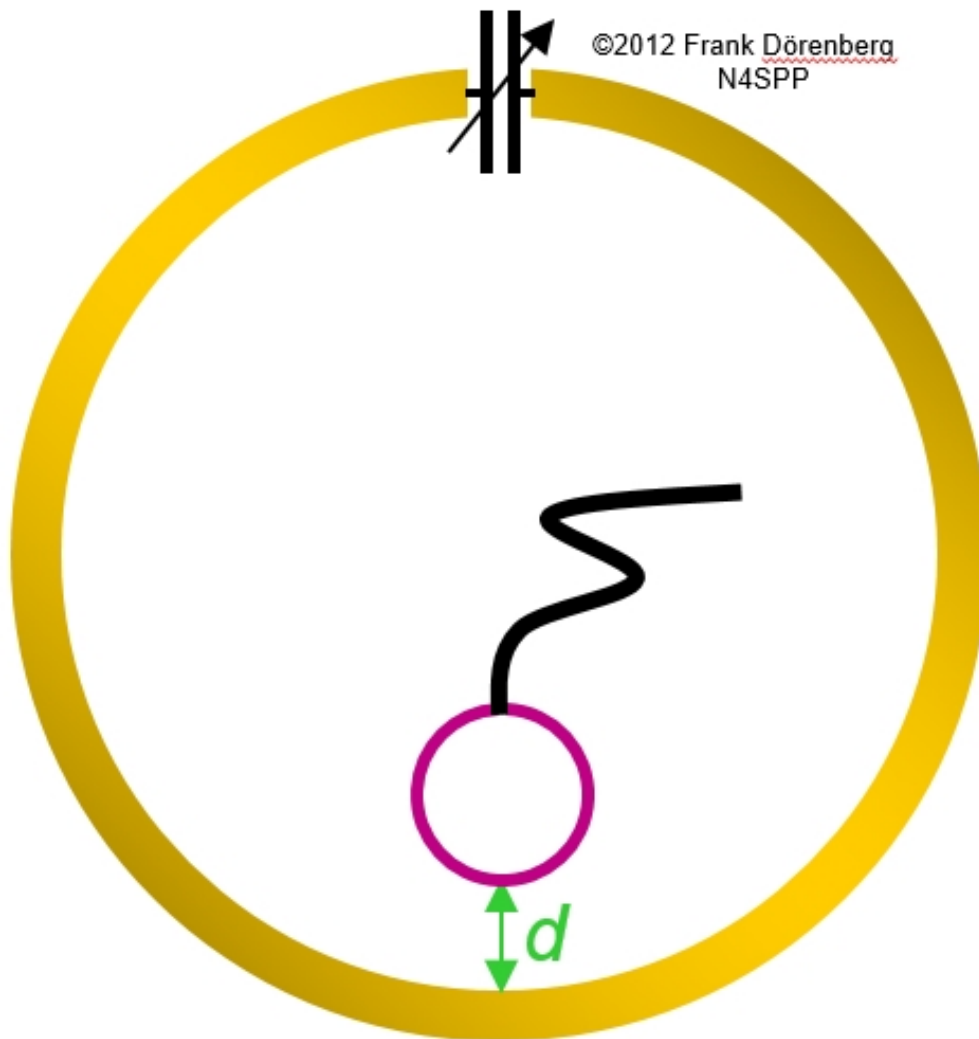


Figura 25: El experimento de Jochen Huebl (DG1SFJ)

A medida que el campo magnético inducido disminuye con la distancia, el acoplamiento entre los dos bucles se debilita cuando aumenta la distancia. Tenga en cuenta que básicamente no importa si el bucle de acoplamiento está *dentro* o *fuera del* bucle principal. Las **observaciones** de Jochen son:

La ROE aumentó linealmente con la distancia entre el acoplamiento y el bucle principal (de cerca de 1: 1 a aproximadamente 5: 1).

La ROE más baja se obtuvo con el bucle de acoplamiento más cercano al bucle principal.

Los bucles de acoplamiento blindados tenían una ROE ligeramente mejor que el bucle de acoplamiento sin blindaje.

El parámetro de red S_{11} es la magnitud del coeficiente de reflexión, expresada en dB. Es decir, $S_{11} = +20 \times \log(\text{abs}(\Gamma))$, donde Γ es un número complejo (una entidad vectorial). Tiene una magnitud que comúnmente se denota ρ y un ángulo de fase θ . S_{11} es 0 para una reflexión completa y negativo para todo lo demás. "Pérdida de retorno" es simplemente el mismo valor en dB de S_{11} , pero con el signo opuesto (al menos para dispositivos pasivos como sistemas de antenas). "Pérdida de retorno" no significa pérdida *debida a la* reflexión (= "retorno"), ¡sino que significa pérdida *de la* reflexión! Jochen observó que S_{11} aumentó rápidamente cuando la distancia se

incrementó de 0 a 2-3 cm (1"), luego se volvió más plano con un aumento adicional en la distancia. Durante el aumento de distancia inicial, sus bucles de acoplamiento blindados tuvieron un mejor acoplamiento: S_{11} fue más negativo en aproximadamente 6 dB (= pérdida de retorno disminuida en 6 dB) Consulte la figura siguiente.

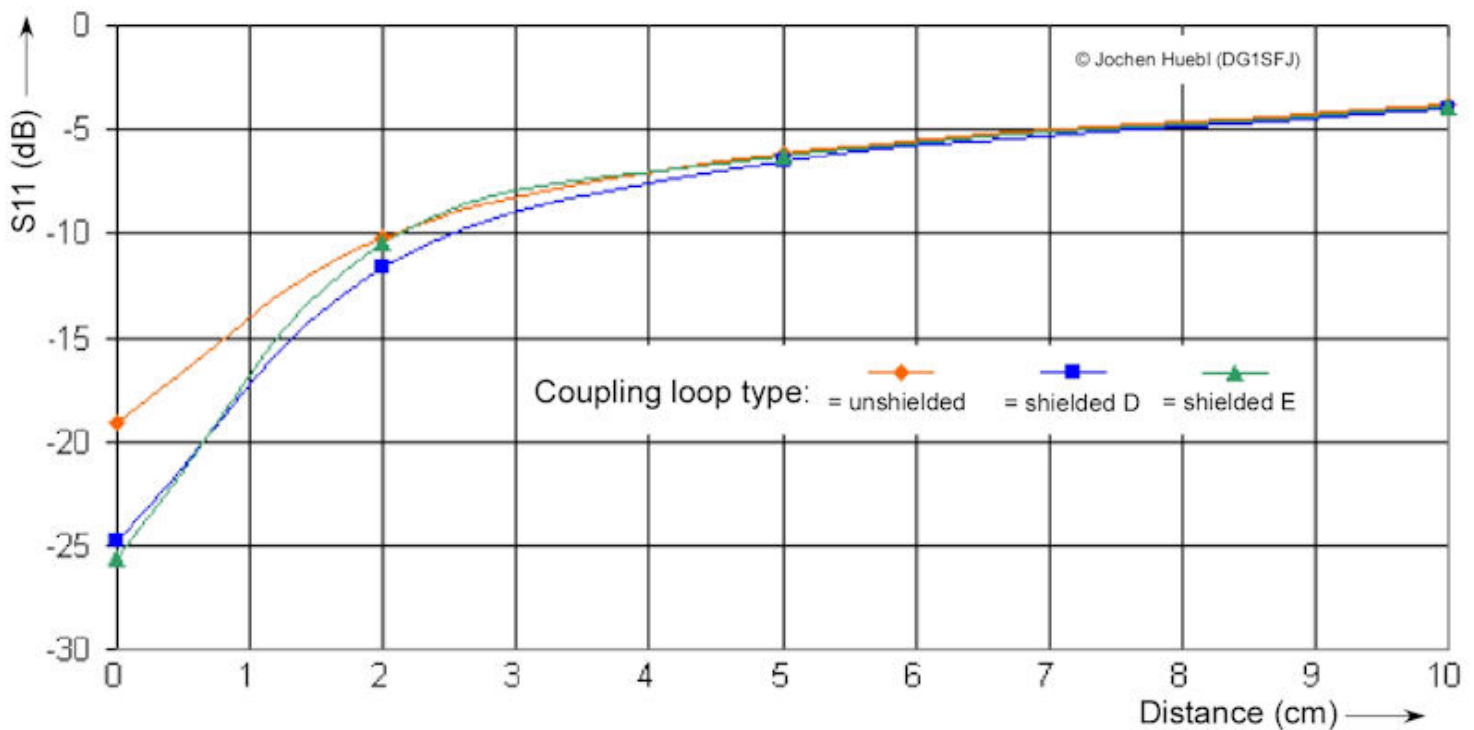


Figura 26: Pérdida de retorno S_{11} en función de la distancia entre el bucle de acoplamiento y el bucle principal, para una frecuencia determinada
(fuente: ref. 6A)

El bucle principal y el bucle de acoplamiento forman básicamente un transformador de núcleo de aire. Alguna literatura afirma que la relación de transformación solo depende de la relación del área de superficie de estos dos bucles. Como se muestra arriba, esto simplemente no es cierto, a *menos que* los dos bucles sean redondos, concéntricos y coplanares (= se encuentren en el mismo plano), y la corriente del bucle sea uniforme alrededor de la circunferencia del bucle. Árbitro. 6Q.

Tenga en cuenta que si el bucle de acoplamiento es demasiado grande, alejarlo del bucle principal puede mejorar la ROE. Asimismo, si el bucle es demasiado grande, se puede mejorar el acoplamiento (= SWR bajado), girando el bucle de acoplamiento alrededor de su eje vertical, de modo que ya no se encuentre en el mismo plano que el bucle principal:

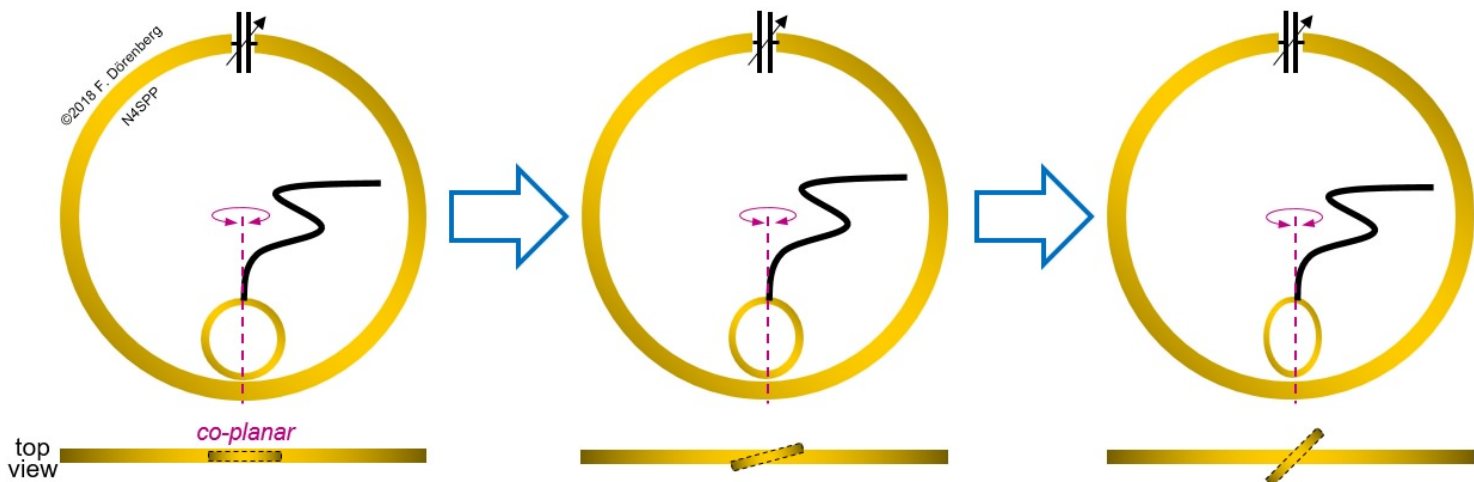


Figura 27: Girando el lazo de acoplamiento alrededor de su eje vertical para cambiar el acoplamiento con el lazo principal

En realidad, esta rotación se puede motorizar con control remoto (consulte [esta sección](#) más adelante), para mantener una ROE baja en un rango de frecuencia mayor de lo que es posible con un bucle de acoplamiento de ángulo fijo. Suponiendo que el patrón de radiación de la antena es simétrico, entonces el accionamiento del motor solo tiene que poder girar el bucle de acoplamiento alrededor de su eje vertical más de 90° como máximo. En realidad, el rango de rotación requerido será mucho menor que 90° : cuando los dos bucles están casi perpendiculares, el acoplamiento no será bueno. Tenga en cuenta que los métodos de acoplamiento asimétrico, como [Gamma Match](#), hacen que el patrón de radiación sea algo asimétrico. Los objetos cercanos a la antena pueden tener el mismo efecto.

El SWR cambia, si se cambia la altura de instalación del STL. El siguiente diagrama muestra las curvas SWR para mi 80-20 STL, con un bucle de acoplamiento blindado y con un bucle de acoplamiento sin blindaje. El lazo de acoplamiento blindado está hecho de un cable coaxial genérico "5D-2V" de $50\ \Omega$ con un diámetro exterior de 7,3 mm y una configuración de blindaje "E" en la Fig. 24B anterior. El bucle sin blindaje está hecho de tubería de cobre suave de 1/4 de pulgada (6,35 mm) de diámetro. Ambos lazos de acoplamiento tienen el tamaño estándar 1: 5 del lazo principal. Como se usa esta antena principalmente para 80 m, la posición del bucle de acoplamiento se ajustó para esa banda. Medí las curvas de ROE para ambos tipos de bucle de acoplamiento, con la parte inferior del bucle principal a 75 cm (3,5 pies) sobre el nivel del suelo (AGL). En mi caso, "suelo" es mi terraza embaldosada. El bucle de acoplamiento blindado parecía no ofrecer ninguna ventaja con respecto a la ROE, y tampoco pude detectar una reducción en el nivel de ruido recibido. Por lo tanto, las curvas tomadas a 2 m (6,5 pies) y 4 m (13 pies) son solo para el bucle sin blindaje.

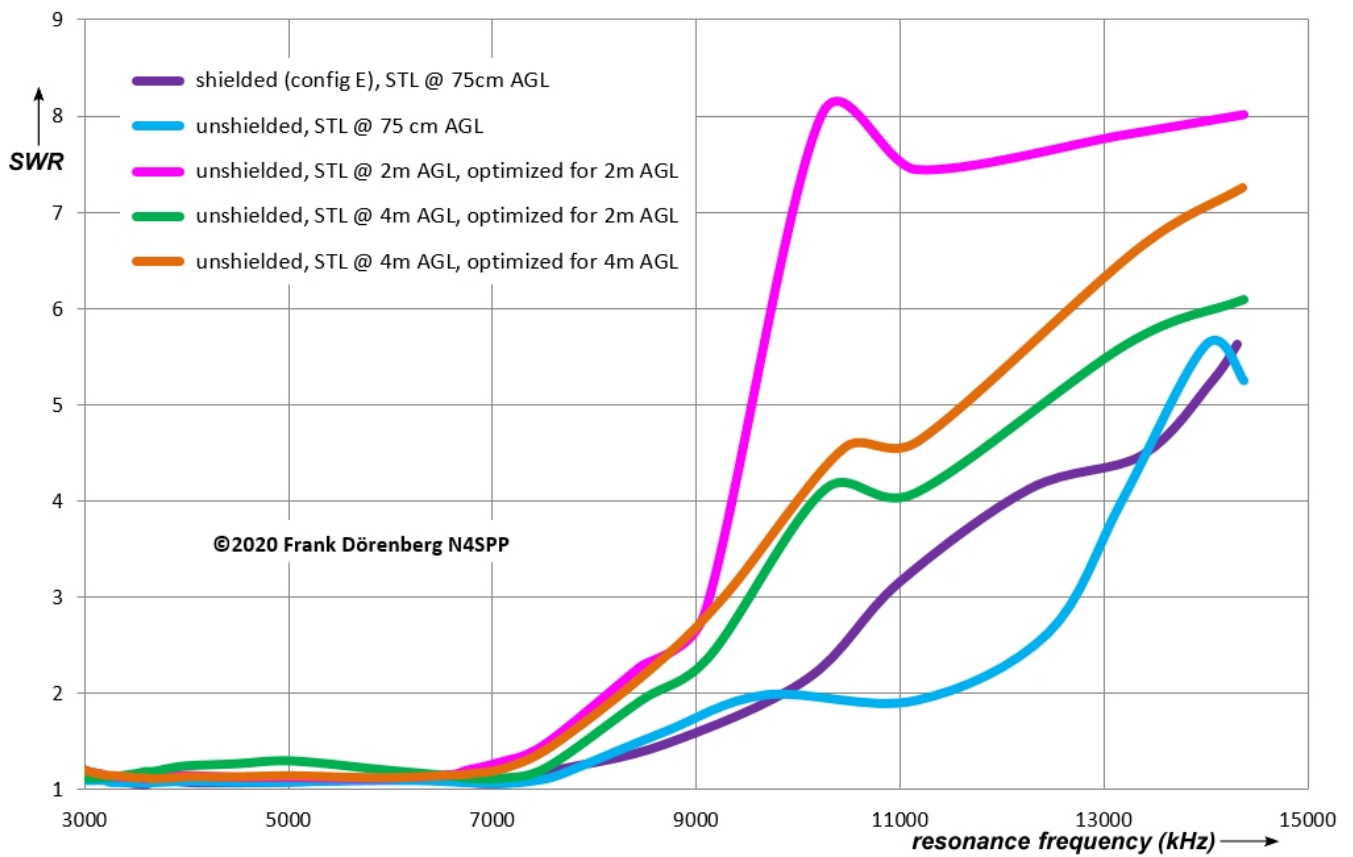


Figura 28A: Gráfico de SWR de mi segunda antena STL (80-20) , con bucle de acoplamiento blindado y no blindado

Al pasar de 75 cm a 2 m AGL, el bucle de acoplamiento tuvo que ajustarse ligeramente (= girar un par de grados más fuera del plano del bucle principal). De nuevo, al pasar de 2 ma 4 m AGL. También tenga en cuenta que, *para este tamaño y tipo de bucle de acoplamiento* , la ROE mínima alcanzable aumentó ligeramente al aumentar la altura de instalación.

El siguiente diagrama amplía la parte de 80-40 m del diagrama anterior:

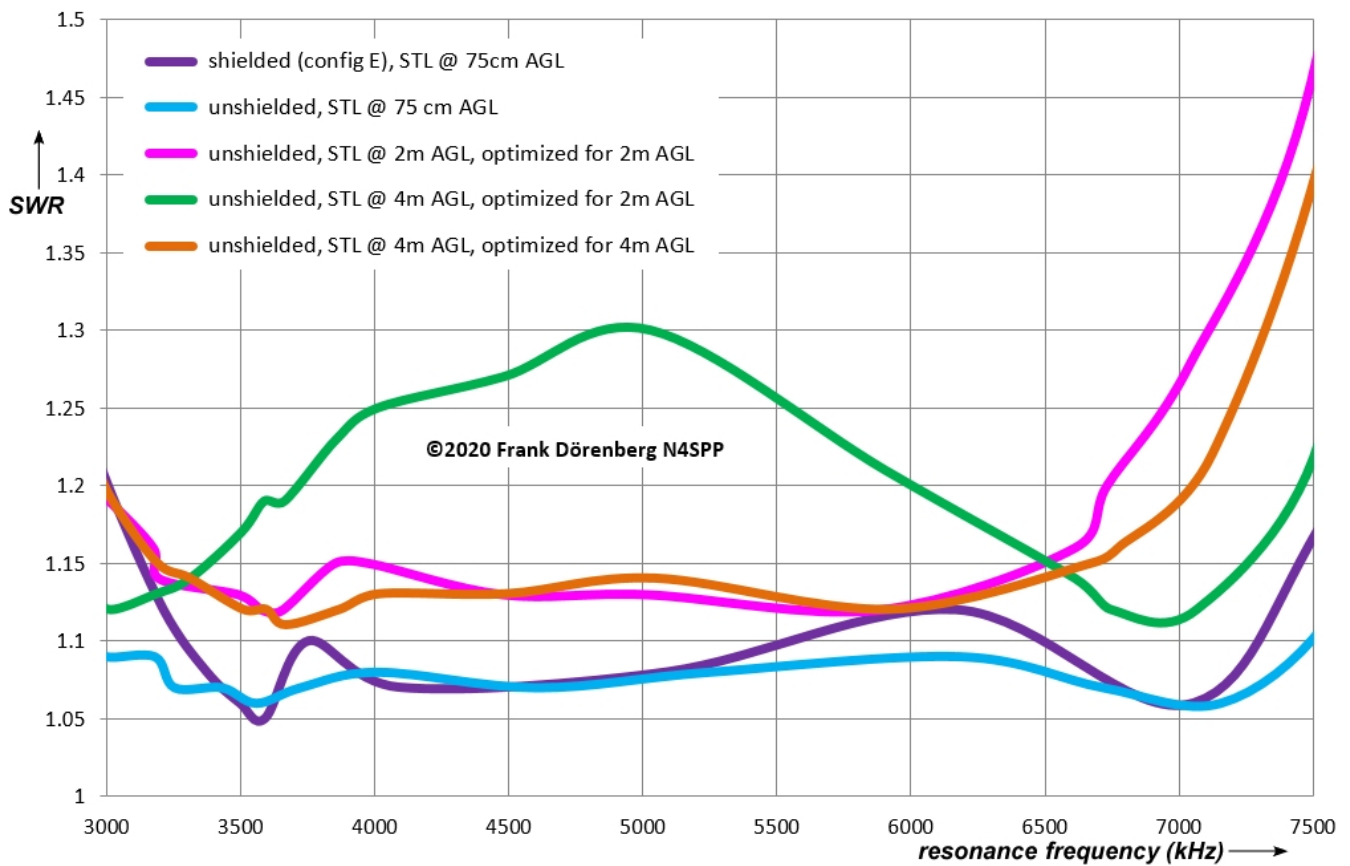


Figura 28B: Gráfico de SWR de mi segunda antena STL (80-20) , con bucle de acoplamiento blindado y sin blindaje

ACOPLAMIENTO CAPACITIVO

Los métodos de acoplamiento capacitivo consisten básicamente en uno o dos capacitores de sintonización y uno o dos capacitores de carga. Esto sugiere que hay varias configuraciones, como es el caso. Este tipo de acoplamiento es mucho más "apretado" que con los lazos de acoplamiento descritos anteriormente. Esto puede hacer que el sistema de antena sea más eficaz, aunque se reduzca la "Q" del bucle.

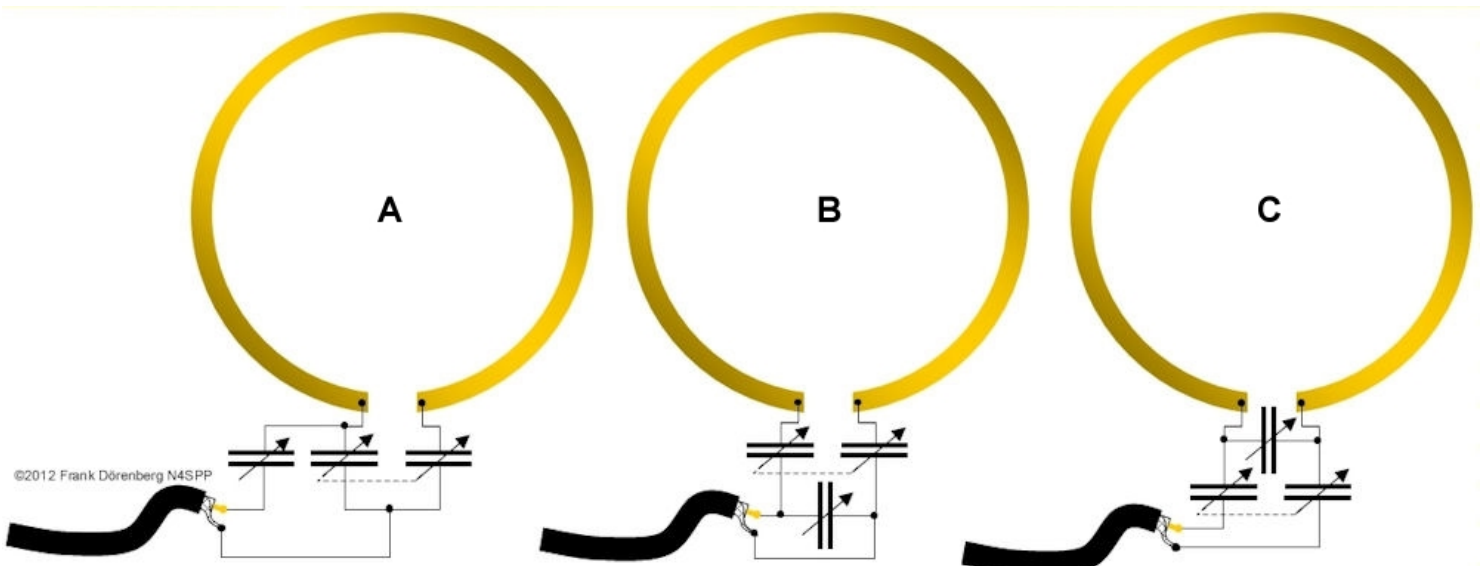


Figura 29: Métodos de acoplamiento capacitivo

La configuración B en la figura anterior se denomina "bucle Patterson" (ref. 6B, 6P) o "bucle Army". Se usó en aventuras en el extranjero del ejército de los EE. UU. En la década de 1960. El bucle octogonal para 2-5 MHz constaba de secciones de tubo de aluminio de 5 pies (1,5 m) (diámetro: 1,75 ", 4,5 cm). Los extremos de los tubos estaban chapados en oro para reducir la resistencia al contacto.

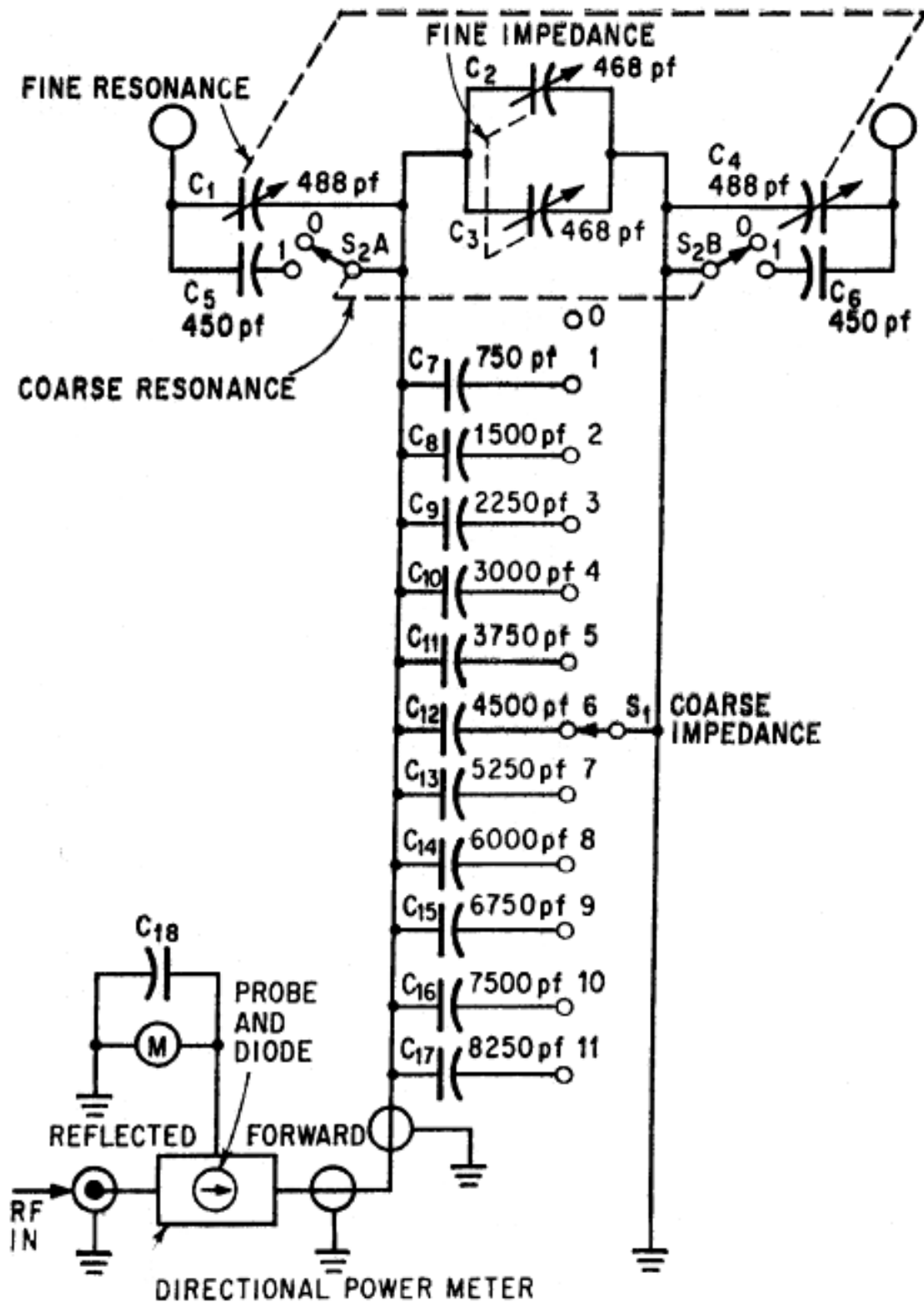


Figura 30: La unidad de ajuste y ajuste del bucle "Patterson"
 (fuente: ref. 6B; tenga en cuenta que la sintonización se realiza en función de maximizar la corriente de la antena, no minimizar la ROE)

ACOPLAMIENTO DE TRANSFORMADOR MAGNÉTICO (ANILLO DE FERRITA O HIERRO-POLVO)

Se puede hacer un acoplamiento de transformador simple, pasando el lazo de la antena a través de un anillo de polvo de hierro o ferrita (núcleo toroidal). El lado secundario del transformador está formado por una o más vueltas de cable aislado. El cable coaxial está conectado a través del devanado secundario. No se requieren ajustes ni otras manipulaciones.

Este método de acoplamiento solo tiene algunas variables simples:

El tipo de material del núcleo de ferrita o polvo de hierro.

El tamaño del núcleo.

El número de núcleos apilados.

el número de vueltas secundarias.

Hay muchas **ferritas** diferentes mezclas de materiales. Los más utilizados en los transformadores STL son las mezclas de Amidon / Fair-Rite / Micro Metals nr. 31, 43 y 61 (o equivalentes de otro fabricante). Los parámetros importantes de las hojas de datos (ref. 7) son las curvas de "Permeabilidad inicial y factor de pérdida versus frecuencia" y "Pérdida del núcleo versus densidad de flujo de CA". Tenga en cuenta que la permeabilidad de las ferritas varía con el nivel de flujo magnético. Por lo tanto, la inductancia de una bobina o transformador fabricado con dicho material cambiará con el nivel de potencia. El manejo de potencia de un lazo con acoplamiento de transformador a menudo está limitado por pérdidas en el núcleo, en lugar de la clasificación de voltaje del capacitor de sintonización. Estas pérdidas en el núcleo (principalmente pérdida por histéresis y pérdida por corrientes parásitas) aumentan aproximadamente con el cuadrado de la densidad de flujo en el núcleo, a cualquier frecuencia. Algunas recomendaciones:

Mix 43 se vuelve bastante con pérdida por encima de aproximadamente 7 MHz. Utilice esta mezcla de materiales para 80-40 mtrs, posiblemente 80-30.

Por debajo de 5 MHz, Mix 31 (una mezcla de manganeso y zinc) es probablemente una mejor opción que el tipo 43 (mezcla de níquel y zinc).

Para cubrir 20 mtrs y más, use el material Mix 61 (mezcla de níquel-zinc-hierro).

Tenga en cuenta que las propiedades de los núcleos de ferrita pueden variar hasta en un 30% de los valores nominales en las hojas de datos. Además, no

existen especificaciones de homogeneidad para el material de ferrita y pueden ocurrir puntos calientes a niveles de potencia por debajo del máximo.

Obviamente, el núcleo de ferrita debe ser lo suficientemente grande para que el anillo se deslice sobre el tubo de bucle y acomode el número requerido de vueltas secundarias. Más importante aún, los transformadores de RF de ferrita deben funcionar a un nivel de densidad de flujo del núcleo que sea acorde con el volumen y el área de la sección transversal del anillo de ferrita. Por el contrario, las dimensiones del núcleo deben ser adecuadas para el nivel de potencia y la frecuencia. El nivel de flujo máximo permitido es impulsado por la pérdida-tangente (= factor de pérdida por histéresis de disipación) de la mezcla de ferrita. Si se excede ese límite de densidad de flujo, entonces un efecto descontrolado hace que la temperatura del núcleo aumente muy rápidamente y finalmente (y posiblemente violentamente) ¡destruye el núcleo! Tenga en cuenta que la mezcla "61" tiene una temperatura de Curie (por encima de la cual las propiedades de la ferrita se destruyen permanentemente) mucho más alta que la del tipo "43": 350 ° C (660 ° F) frente a 150 ° C (300 ° F). Se pueden apilar dos o más núcleos para aumentar la capacidad de manejo de energía. Sin embargo, el apilamiento de núcleos también aumenta la inductancia total del transformador. Además, un *Un núcleo más grande* también da como resultado una mayor inductancia, en comparación con un núcleo más pequeño del *mismo* material. Por ejemplo, un toroide T-240-43 (2,4 pulgadas de diámetro exterior, tipo de material 43) tiene un valor A_L más alto (inductancia en μH por 1000 vueltas) que un FT-140-43 (1,4 pulgadas de diámetro exterior): 1075 frente a 885 ¡Experimente! Los núcleos muy pequeños como T-82 o T-130 están básicamente limitados a la operación QRP.

Como es un transformador 1: N para voltaje y corriente, N (el número de vueltas del secundario) debe elegirse de manera que $50 / N^2 = \text{impedancia del lazo en el punto donde el transformador está instalado en el lazo}$. Normalmente, N se determina empíricamente, por ensayo y error: comience con un número que sea demasiado alto, mida la ROE en la resonancia y luego reduzca en una o dos vueltas a la vez. En un bucle de transmisión pequeño, la corriente es básicamente constante alrededor de la circunferencia del bucle. Esto se ilustra en la [sección de introducción](#) en la parte superior de esta página. Por lo tanto, no hay mucha diferencia en el lugar donde se coloca el transformador alrededor del bucle. Sin embargo, si el tamaño del bucle aumenta a, digamos, $0,2 - 0,25 \lambda$, el bucle ya no es "pequeño" y la corriente a través del condensador es significativamente menor que la corriente en el punto opuesto al condensador. Esto significa que el acoplamiento con un transformador de núcleo de ferrita a continuación, *no* depender de donde el transformador se coloca a lo largo del bucle. Las vueltas del devanado

secundario deben distribuirse uniformemente alrededor del anillo de ferrita para minimizar la capacitancia parásita.

Uno de mis primeros experimentos con el acoplamiento del transformador fue con un transformador 1: 1 que comprende un núcleo de ferrita T-140-43 y un bucle coaxial de una sola vuelta. Consulte la figura siguiente. Esta configuración pone la impedancia de 50 ohmios de la línea de alimentación coaxial en serie con la impedancia de bucle muy pequeña. Esto da como resultado un desajuste significativo. Probé esto y encontré una ROE baja en todo el rango de frecuencia de interés, pero un ancho de banda que era al menos un orden de magnitud mayor que cuando se usan múltiples devanados de cable. Aún por explicar ...

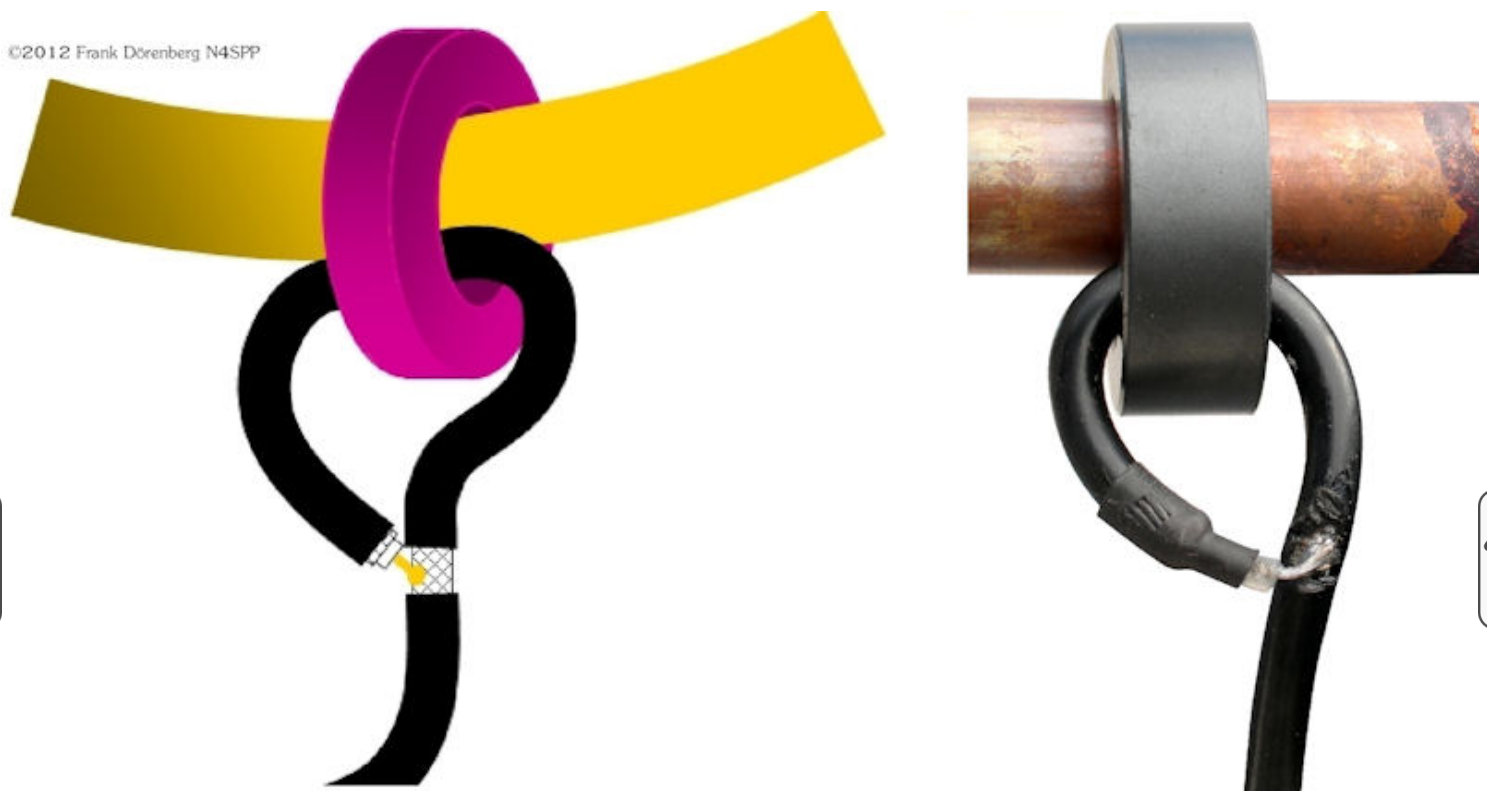
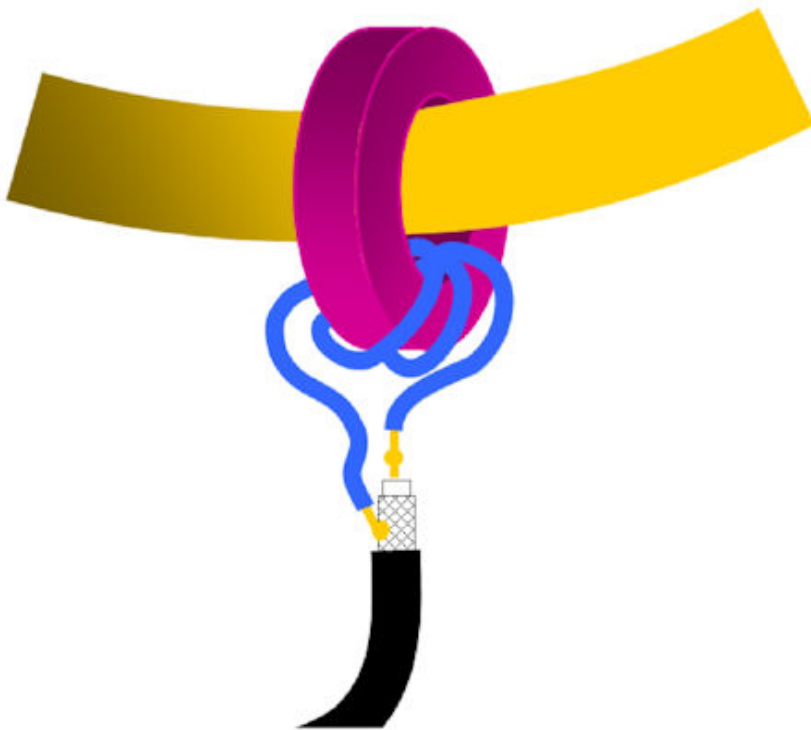


Figura 31: Acoplamiento de transformador de ferrita 1: 1 con bucle coaxial como devanado secundario



©2012 Frank Dörenberg N4SPP



Figura 32: Acoplamiento de transformador 1: N con núcleo de ferrita

Los dos gráficos siguientes muestran mis medidas para mis tres STL, con la mezcla de material de ferrita nr. 43 y 31 núcleos de transformador:

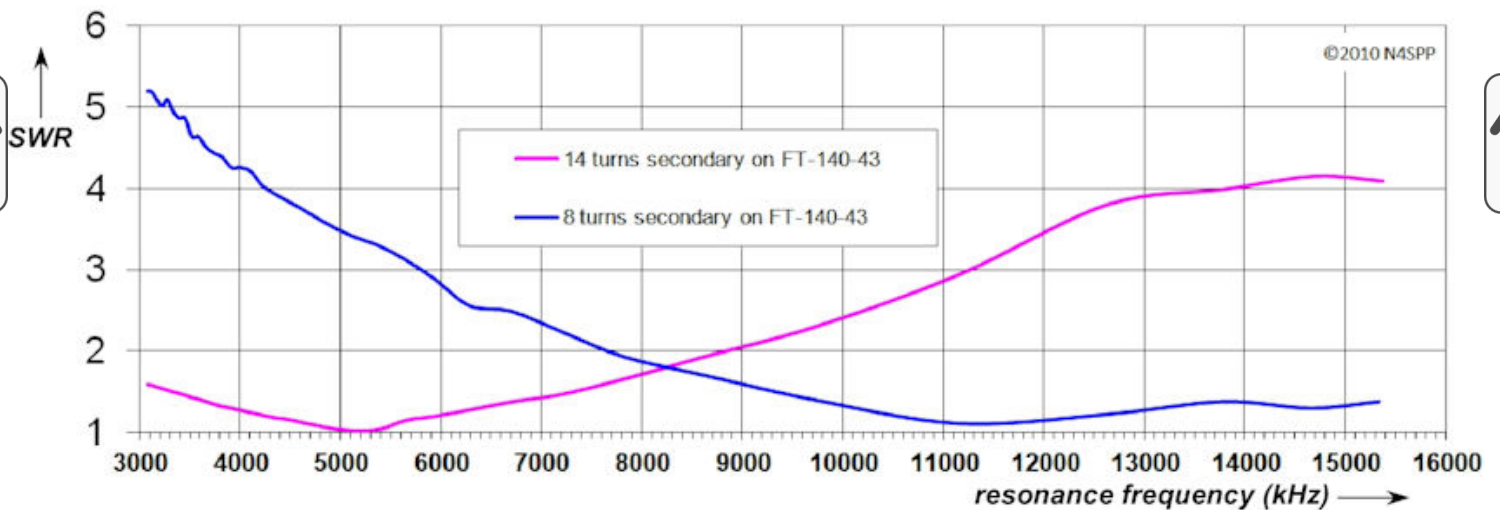


Figura 33: Gráfico de ROE de mi primera antena STL (80-20) , con un núcleo de transformador de ferrita FT-140-43

Los siguientes diagramas muestran barridos SWR de mi segunda antena STL (80-20) con un anillo de ferrita T-240 de mezcla de material # 31 y con 8-18 vueltas de alambre de instalación de cobre con aislamiento pesado (área de sección transversal de 1.5 mm^2 , 16 AWG):

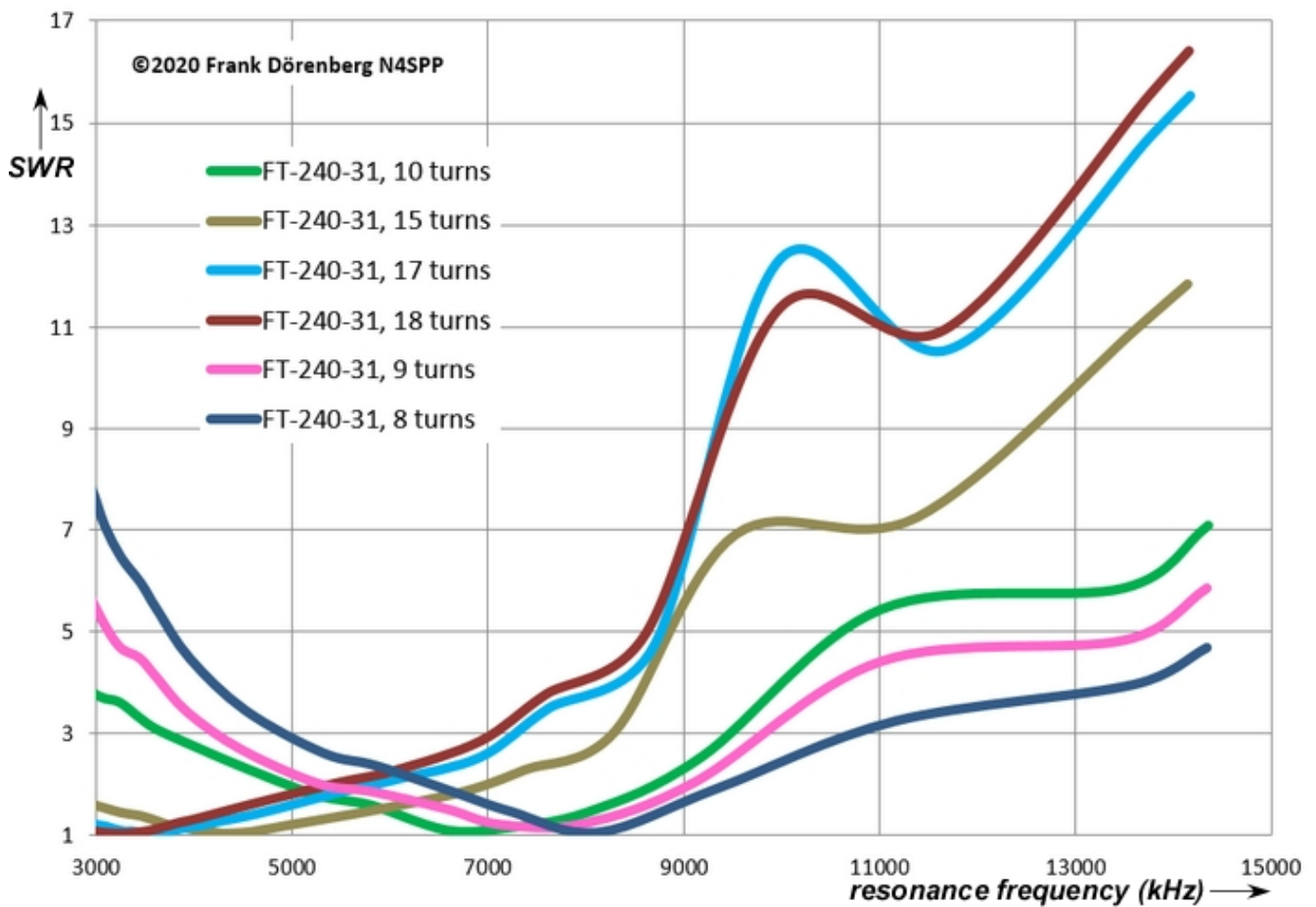


Figura 34A: Gráfico de SWR de mi segunda antena STL (80-20) , con un núcleo de ferrita FT-240-31

Utilizo esta antena casi exclusivamente en 80 mtrs, así que me decidí por 17 vueltas de cable. "Tecla abajo" con 100 vatios durante 1 minuto **no** provocó que la ferrita se calentara en absoluto, para frecuencias de resonancia en las que la ROE es mejor que 1,2. Para 40 mtrs, uso 9 vueltas. El siguiente diagrama amplía la parte de 80-40 m del diagrama anterior:

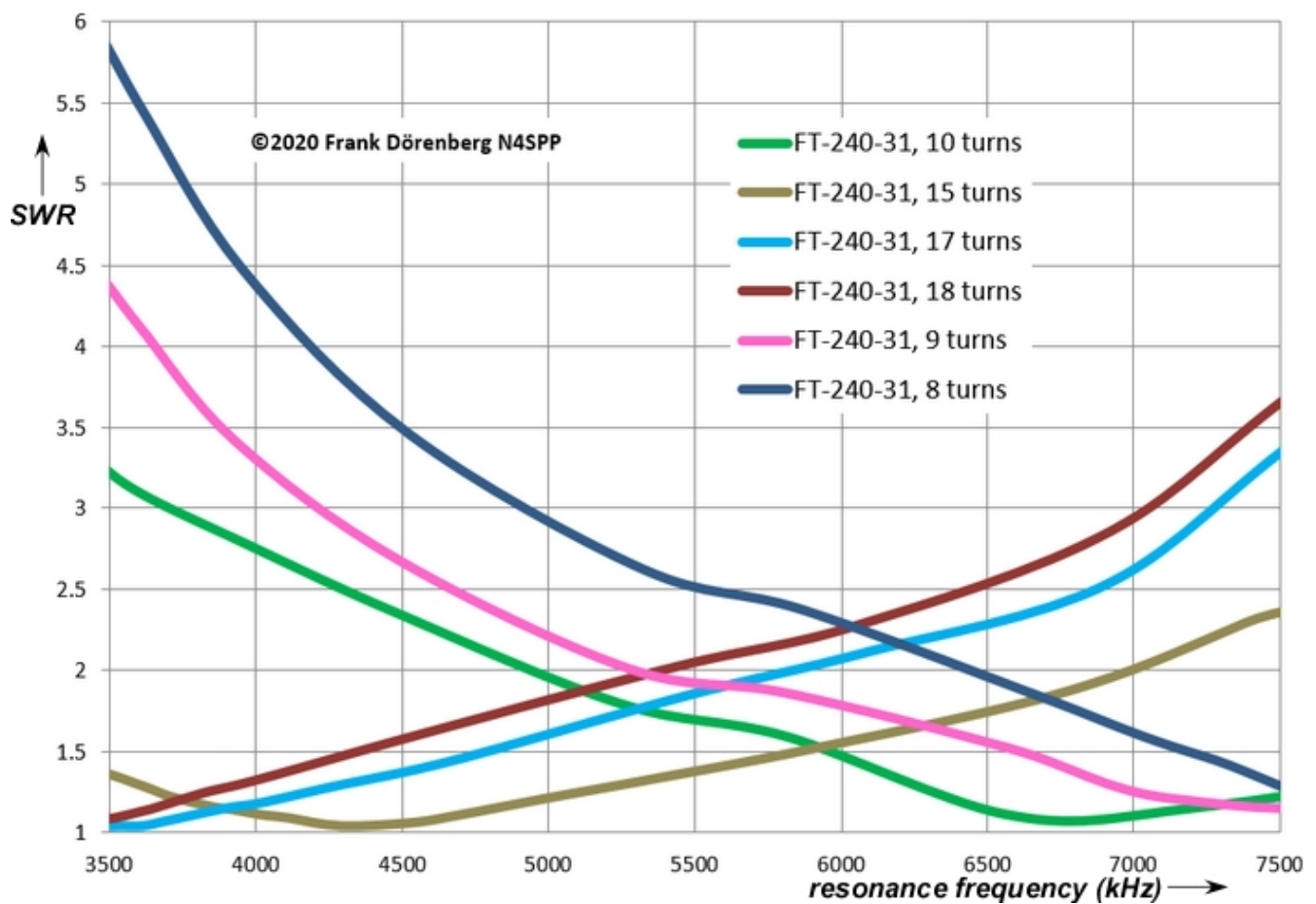


Figura 34B: Gráfico de SWR de [mi segunda antena STL \(80-20\)](#) , con un núcleo de ferrita FT-240-31

Tenga en cuenta que en la Fig. 34A / B, el rango de frecuencia de resonancia con una ROE <1,15 es (solo) de aproximadamente 750 kHz de ancho: banda única. Además, las curvas se registraron con la parte inferior del bucle grande a unos 75 cm por encima del suelo de la terraza. Al aumentar la altura del bucle, la posición de las curvas cambia y es posible que deba ajustarse el número de vueltas (+1 o -1).

Por supuesto, también probé un acoplamiento de transformador de ferrita con [mi pequeño STL \(40-10 m\)](#) :

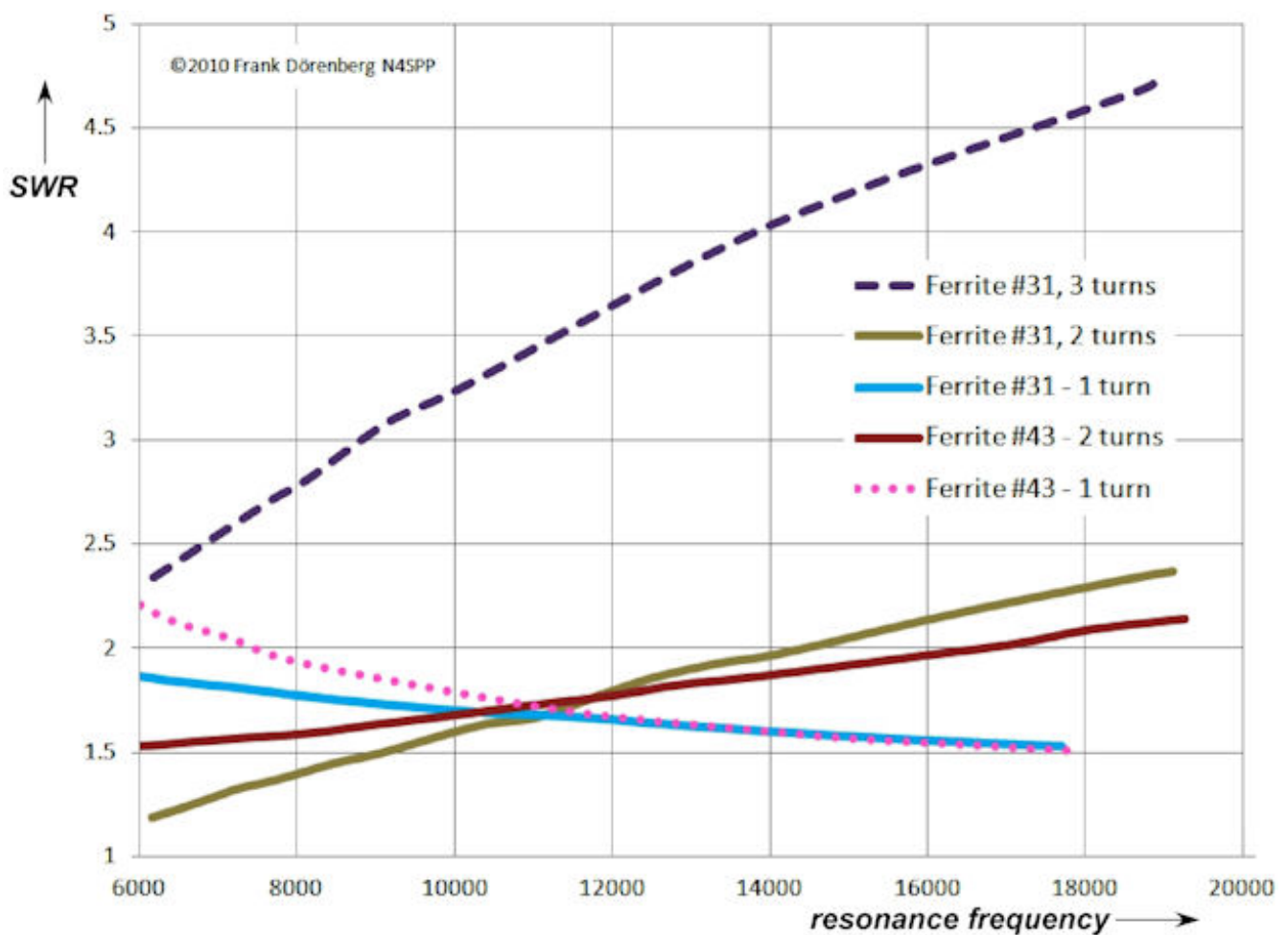


Figura 35: Gráfico de ROE de mi tercera antena STL (40-10), con núcleos de ferrita FT-140-43 y FT-240-31

László Rusvai (DL2JTE / HA7HN) ha realizado pruebas exhaustivas con el acoplamiento del transformador (ref. 6C / D). Uno de sus bucles iniciales tiene un diámetro de 1.2 m (4 pies) y está hecho de tubería de cobre de 20 mm (3/4") de DE. Usando un núcleo de **polvo de hierro** T200-2 y 2 vueltas secundarias, obtuvo ROE = 1.01 sobre un rango de frecuencia de 3,5 - 10,1 MHz. También confirmó que con una antena STL, la posición del transformador a lo largo de la circunferencia del bucle no hace ninguna diferencia, *para este tamaño de bucle y rango de frecuencia*. **Nota** : hice una prueba muy rápida con un T -200-2 núcleo en mi segundo STL, pero con menos de 10 vueltas, ¡SWR fue de al menos 20!

Otro lazo de 80 y más que probó, tiene un diámetro de casi 3 m (10 pies) y está hecho de alambre de cobre delgado (0.4 mm Ø, AWG # 26). Con un solo núcleo de ferrita, no podía obtener una ROE por debajo de 1,2. Obtuvo acoplamiento de banda ancha (ROE <1.1) con una pila de 9 **núcleos** de ferrita de tipo T-240-61 núcleos (tamaño FT-140 OK cuando no QRO). Ocho

noveno

de los núcleos están apilados firmemente en el bucle, el núcleo está solo en las dos vueltas secundarias. Vea el diagrama a continuación. Tenga en cuenta que, además, conecta un dipolo a través del condensador de sintonización.

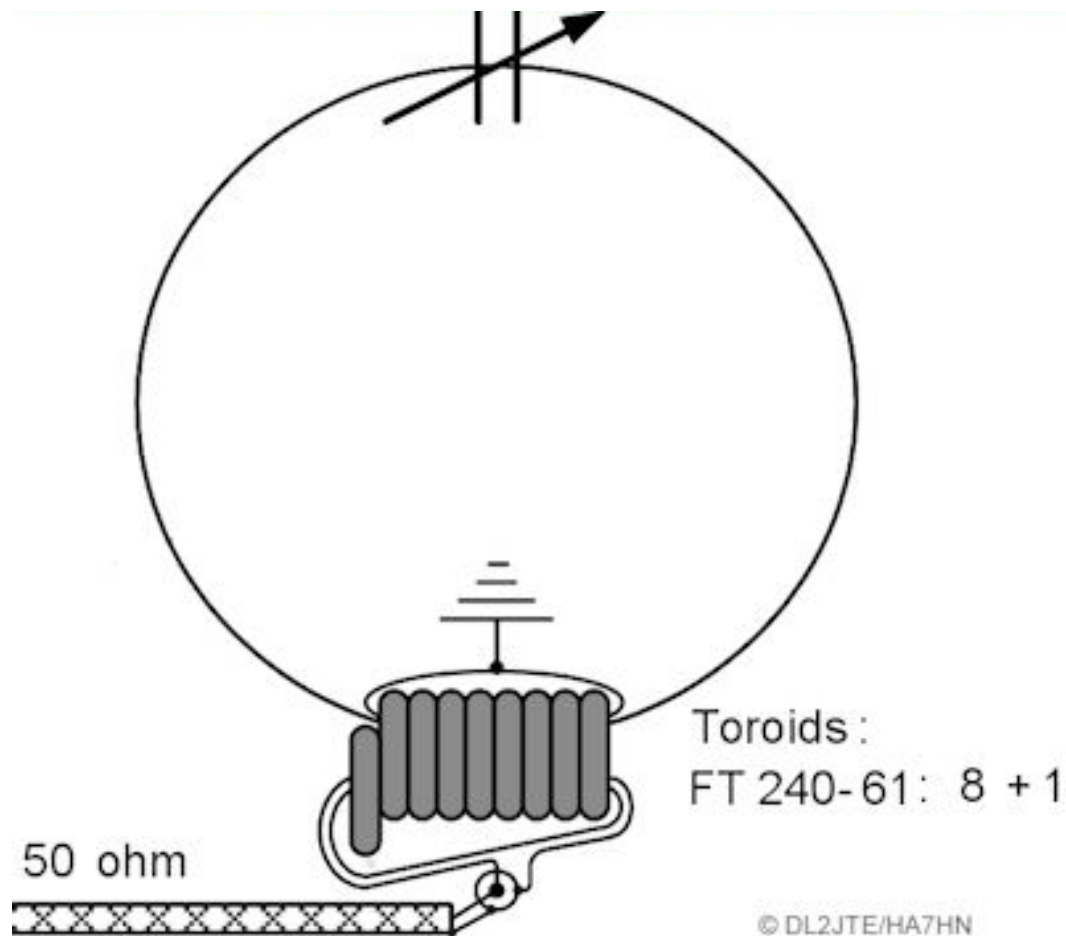


Figura 36: Acoplamiento de transformador por Lásló (DL2JT / HA7HN)
(fuente: ref. 6C / D)

Otra variación del acoplamiento del transformador toroidal es utilizar una pequeña cantidad de devanados primarios, en lugar de uno solo. Es decir, un transformador N: M. Esto requiere que se abra el lazo y que los devanados primarios se conecten a través del espacio. Para un bucle hecho de tubería de cobre, la transición al cableado puede no ser excelente. Pero no tengo experiencia con esto, ni referencias sobre su desempeño. Joe (W9SCXH) usó 2 giros primarios y 5 secundarios en un núcleo pequeño (= QRP) T-50-2 (polvo de hierro) en su lazo de alambre cuadrado de 30-15 mtrs (ref. 6F).

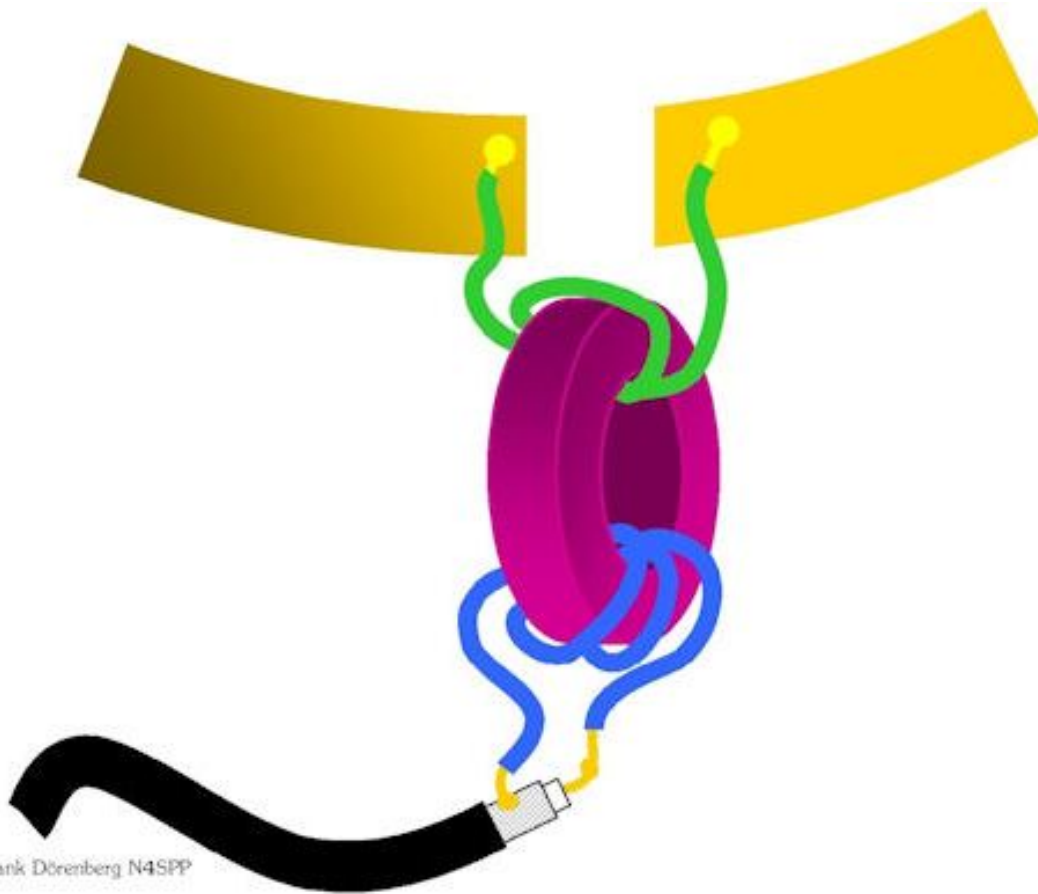


Figura 37: Acoplamiento de transformador $N:M$ con núcleo de ferrita

ADVERTENCIA : si está experimentando con varias formas de acoplamiento, **NO** deje un anillo de ferrita en el bucle y transmita a través de otro acoplamiento (por ejemplo, un bucle de acoplamiento, varilla gamma o transformador de ferrita). Cualquier anillo de ferrita no utilizado actuará como un estrangulador de corriente y se freirá si transmite con más de QRP (verá aumentar la ROE cuando eso comience a suceder). Otro síntoma claro es que el ancho de banda $SWR = 2$ será mucho mayor.

ACOPLAMIENTO DE TRANSFORMADOR AUTOMÁTICO (GAMMA MATCH, ETC.)

Recuerde la distribución de voltaje y corriente de una antena STL, como se explica en la parte superior de esta página:

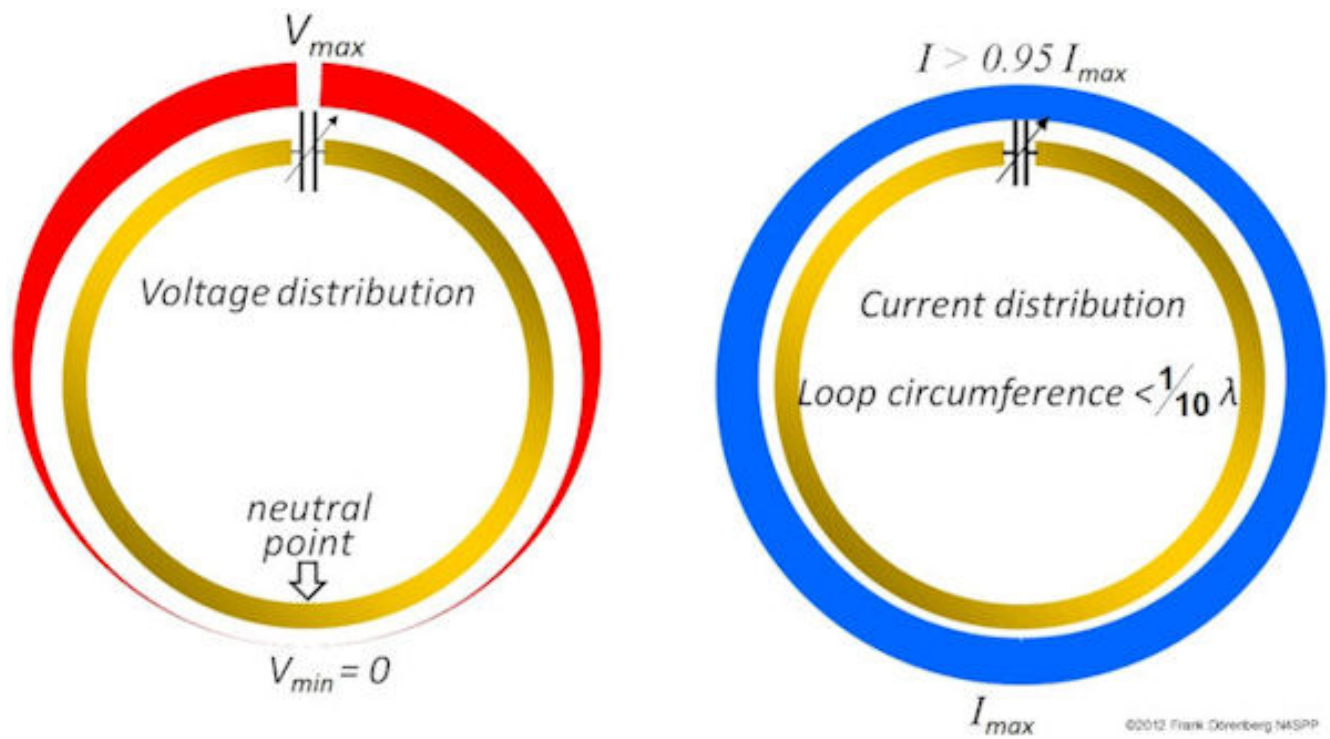


Figura 38: Distribución de voltaje y corriente de una antena STL

Claramente, la distribución de voltaje es simétrica con respecto al punto neutro ($V = 0$) que se encuentra enfrente del capacitor de sintonización. En una antena STL, la distribución de corriente es básicamente constante. La resistencia (impedancia) es el voltaje dividido por la corriente. Por lo tanto, un STL tiene una "distribución" de resistencia que se parece a la distribución de voltaje. El punto neutro es un punto de referencia conveniente. Si nos movemos a lo largo de la circunferencia del bucle, alejándonos de ese punto de referencia, encontraremos un punto en el que la resistencia es de 25Ω con respecto al punto de referencia. Hay un punto similar de 25Ω en el lado opuesto del punto de referencia, a la misma distancia de ese punto. Alejándonos más, encontraremos un par simétrico de puntos de 50Ω .

Cuando se utiliza un cable coaxial como línea de alimentación, necesitamos una toma asimétrica en el bucle. El blindaje del cable coaxial está conectado al punto neutro del bucle. El conductor del cable coaxial está conectado a una llamada **Gamma Rod**. La varilla se instala paralela al bucle. A cierta distancia del punto neutro, la varilla está conectada al bucle. El grifo generalmente se hace ajustable, para poder ajustar la longitud efectiva de la varilla. Este método tampoco tiene las limitaciones de potencia operativa que son típicamente inherentes a los componentes del [transformador](#) y [capacitivo](#). métodos de acoplamiento. Este método de acoplamiento es de banda ancha: según se informa hasta 10: 1, si la antena se instala lo suficientemente despejada (15-20 pies, 5-6 m) de cualquier objeto y al menos 1/2 diámetro de bucle sobre el suelo). pero la ubicación exacta del punto de derivación depende de la frecuencia. En mis propios experimentos, no he obtenido una ROE aceptable (menos de 1,5) en más de un rango de frecuencia de 2: 1.

Algunas notas:

La barra gamma agrega inductancia al acoplamiento. En un acoplamiento Gamma **Match** , normalmente hay un condensador variable en serie con la varilla, para cancelar esa inductancia. Árbiter. 6G, GH, 6J. En aplicaciones de "bucle mágico", este condensador de compensación se omite normalmente. Sin embargo, un condensador en serie pequeña (varios pF) puede aumentar significativamente el rango de frecuencia sobre el que se obtiene una ROE baja.

Como la configuración de la varilla gamma es asimétrica, el patrón de radiación está ligeramente sesgado, lo que provoca una relación de adelante hacia atrás que favorece ligeramente la dirección de la montura de la varilla gamma.

Al contrario de los métodos de [acoplamiento inductivo](#) y [acoplamiento de transformador](#) discutidos anteriormente, este acoplamiento está conectado galvánicamente al bucle de antena.

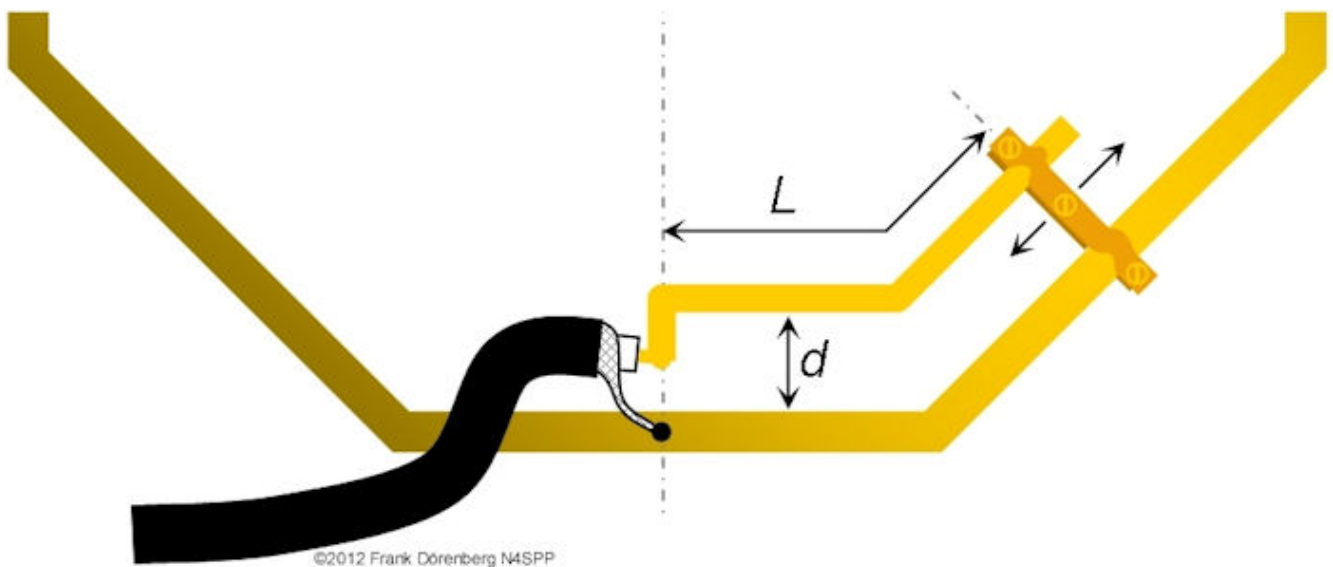


Figura 39: Acoplamiento de varilla gamma

En [mi primer bucle](#) , decidí insertar una pieza en T de cobre en el punto neutro, por si acaso alguna vez quería jugar con una varilla gamma. La pieza en T es para tubería de cobre de 16 mm de diámetro exterior (my loop), mientras que la conexión lateral es para tubería de cobre de 10 mm de diámetro exterior. Este último es perfecto para un conector hembra BNC de montaje en chasis. Perforé un agujero frente al conector BNC. Una sección de 1 m (3 pies) de cable de instalación doméstico pesado y aislado se suelda al conector BNC y se pasa a través del orificio que perforé. Eso sirve como Gamma Rod. Se puede usar una abrazadera de manguera (*Reino Unido* : "clip de jubileo") para fijar el extremo del cable en su lugar en el punto del grifo.



Figura 40: Pieza en T de cobre - insertada en el bucle principal en el punto neutro - con conector BNC

Árbitro. 6N proporciona las siguientes dimensiones nominales para la varilla y el punto de toma:

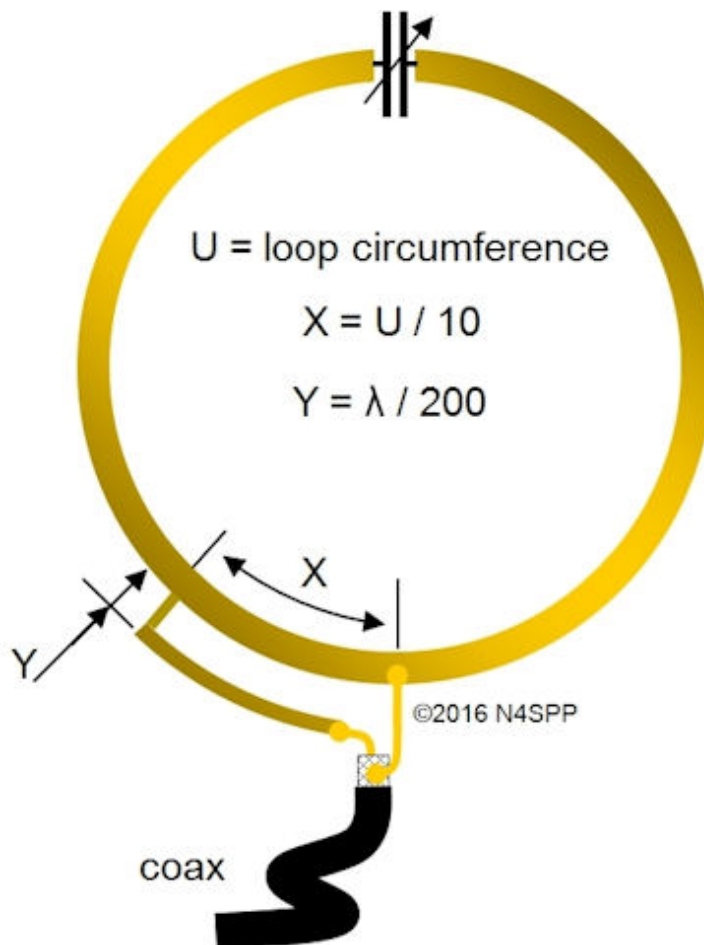


Figura 41: Dimensiones nominales del acoplamiento Gamma Rod (fuente: adaptado de la ref. 6N)

Las instrucciones para ajustar / afinar un Gamma Rod / Match son engañosamente simples:

"Cambie el tamaño, la forma, el material, la posición con respecto al bucle y el punto de derivación de la varilla gamma a lo largo del bucle, hasta que se obtenga la impedancia deseada"

Esto no es tan sorprendente, ya que la posición del punto de toma depende de las características de la varilla: longitud de la barra / alambre / tubería, diámetro de la varilla, forma del bucle formado por la varilla y el bucle, de centro a centro espaciado entre la varilla y el bucle, etc. Ver ref. 6H y 6J, considerando el bucle principal como un dipolo circular plegado que termina con el condensador de sintonización. La posición del punto de toma también depende del bucle y su construcción. En general, cuanto menor sea la Q del bucle (por ejemplo, debido a pérdidas en las uniones de soldadura), más lejos del punto neutro estará el punto de derivación. De manera convincente, cuanto mayor sea la Q, más cerca estará el punto del grifo del punto neutro, y más sensible será la posición del punto del grifo: mover el grifo solo un par de mm ($\approx 1/8$ de pulgada) puede generar un ¡diferencia!

Básicamente, esto significa que encontrar el "punto óptimo" para el punto de derivación es prácticamente 100% empírico. Esta es la razón por la que parece haber tantas configuraciones como constructores de antenas, y las configuraciones varían ampliamente. Aquí hay algunos ejemplos que he recopilado de diseños publicados en Internet (solo unos pocos indican detalles suficientes para reconstruir el diseño real):

Alguna literatura sugiere que el punto de derivación esté en la "circunferencia del bucle principal / 10" desde el punto central, y la varilla a una distancia de "circunferencia del bucle principal / 200".

Toque el punto en la "circunferencia del bucle dividida por 15,8" desde el punto central; la varilla es de tubo de cobre de 1/4 "de diámetro, a 6 cm ($2\frac{3}{8}$ ") de distancia del bucle ($3\frac{1}{2}$ pies de diámetro); comenzó a la mitad del bucle (es decir, 1/4 de circunferencia desde el punto neutro), toque final a 8,375 "(≈ 21 cm).

Toque el punto en la "circunferencia del bucle dividida por 10" desde el punto neutro; varilla a una distancia de $0,5\% \lambda$ del bucle.

Toque el punto en la "circunferencia del bucle dividida por 10" desde el punto neutro; varilla a una distancia de 20 cm (8 ") del bucle. Circunferencia del bucle 2,4 m (8 pies), longitud de la varilla 23 cm (10"); Bucle de 20 m.

Toque el punto en la "circunferencia del bucle dividida por 8" desde el punto neutro.

Toque el punto en la "circunferencia del bucle dividida por 11,4" desde el punto neutro; varilla a una distancia de 7,6 cm (3 ") del bucle con 20 pies (6 m) de circunferencia.

Toque el punto en la "circunferencia del bucle dividida por 7" desde el punto neutro; La varilla es de 12 "de alambre de 1/8", espaciada a 1 " (2,5 cm) del bucle de tubería de cobre de 5/16" (8 mm).

Toque el punto en la "circunferencia del bucle dividida por 4,3" desde el punto neutro.

Toque el punto en la "circunferencia del bucle dividida por 10" desde el punto neutro; la varilla es un tronco de 12 ", paralela al bucle principal a 1" de distancia

Toque el punto en la "circunferencia del bucle dividida por 4" desde el punto neutro; la varilla mide 9 "

Diámetro del lazo 1 metro, longitud de la varilla 31 cm, distancia entre varillas 11 cm

Toque el punto en la "circunferencia del bucle dividida por 10" desde el punto neutro. Circunferencia del bucle de 4 m (13 pies), varilla de tubo de cobre de 8 mm Ø, paralela al bucle principal a una distancia de 8 cm (3,25 ").

La construcción de Gamma Rod en sí también se puede considerar como una especie de bucle. Si el final del punto de grifo se elige relativamente cerca del punto central (donde se adjunta la trenza coaxial) pero conservamos el tamaño (área) del bucle, terminamos con la horquilla (talón) Match (también conocido como Beta Match).

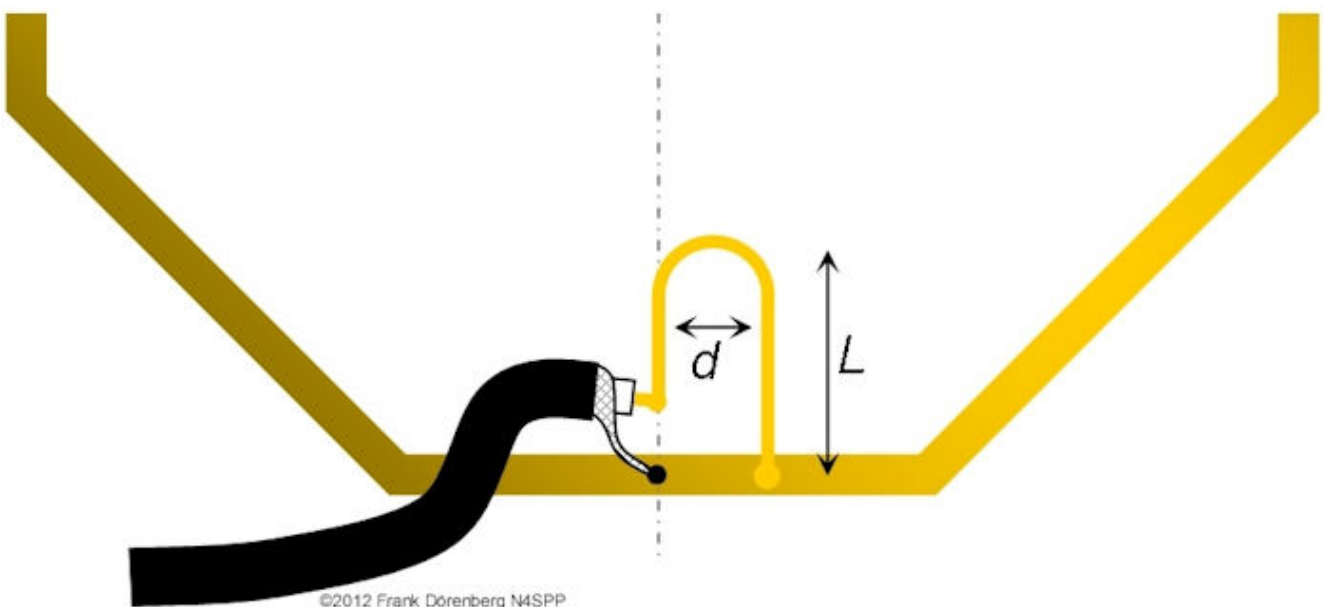


Figura 42: Acoplamiento de horquilla

Sin embargo, otra variación es el "Twisted" Gamma Match (también conocido como "Mu-Gamma" o "G3LHZ-Gamma", ref. 3B (págs. 12, 13, 20) y 6K). No tengo sugerencias sobre la longitud total del cable y el número de vueltas.

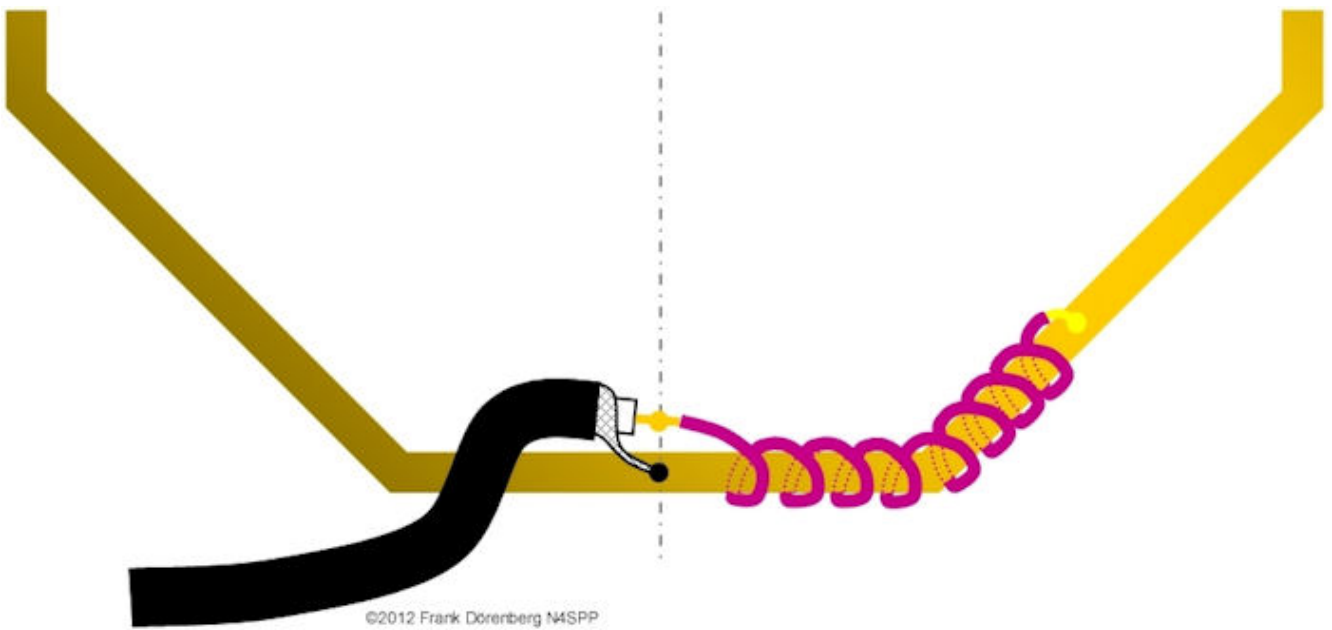


Figura 43: Acoplamiento Twisted-Gamma

Si se instala una varilla gamma en ambos lados del punto neutro, tenemos un **T-Match**. Se puede usar con una línea de alimentación de 2 alambres.

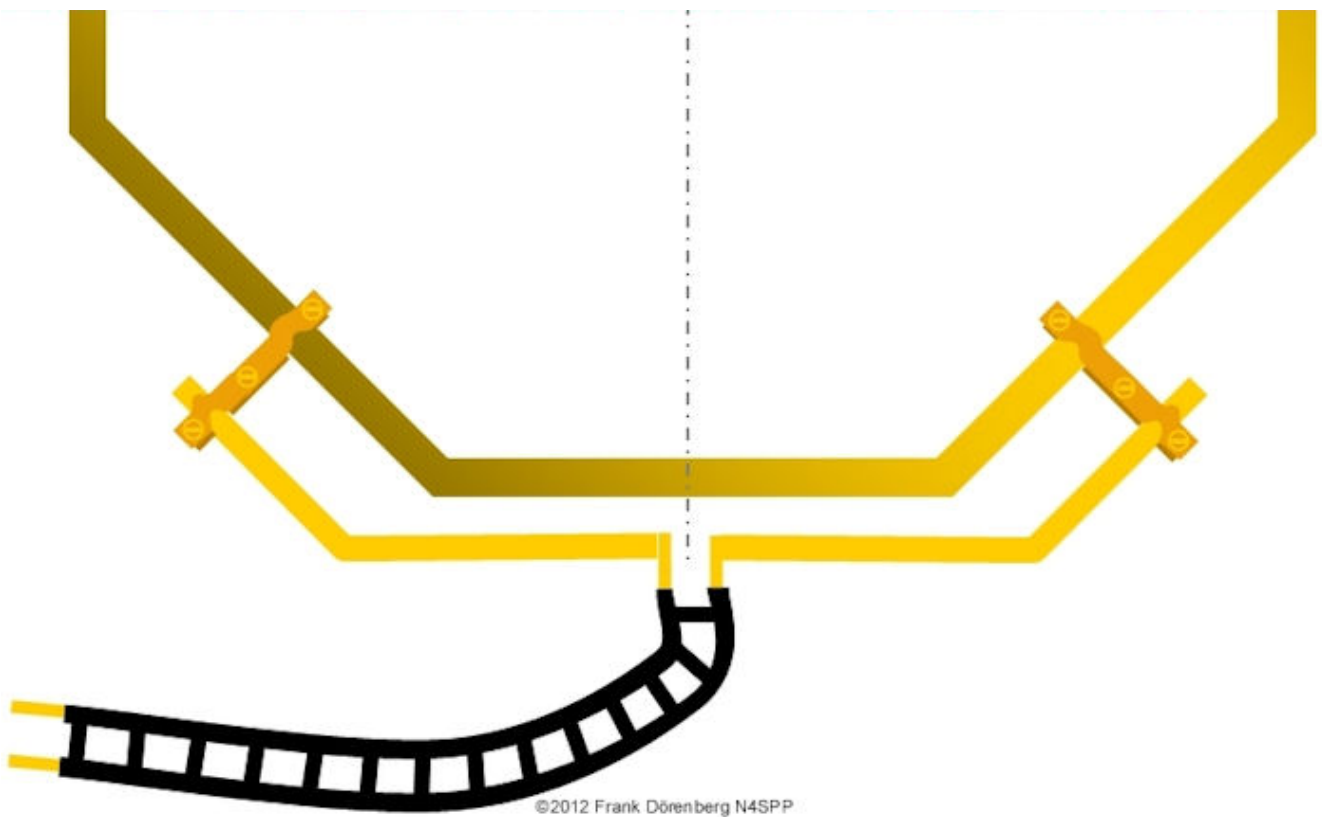
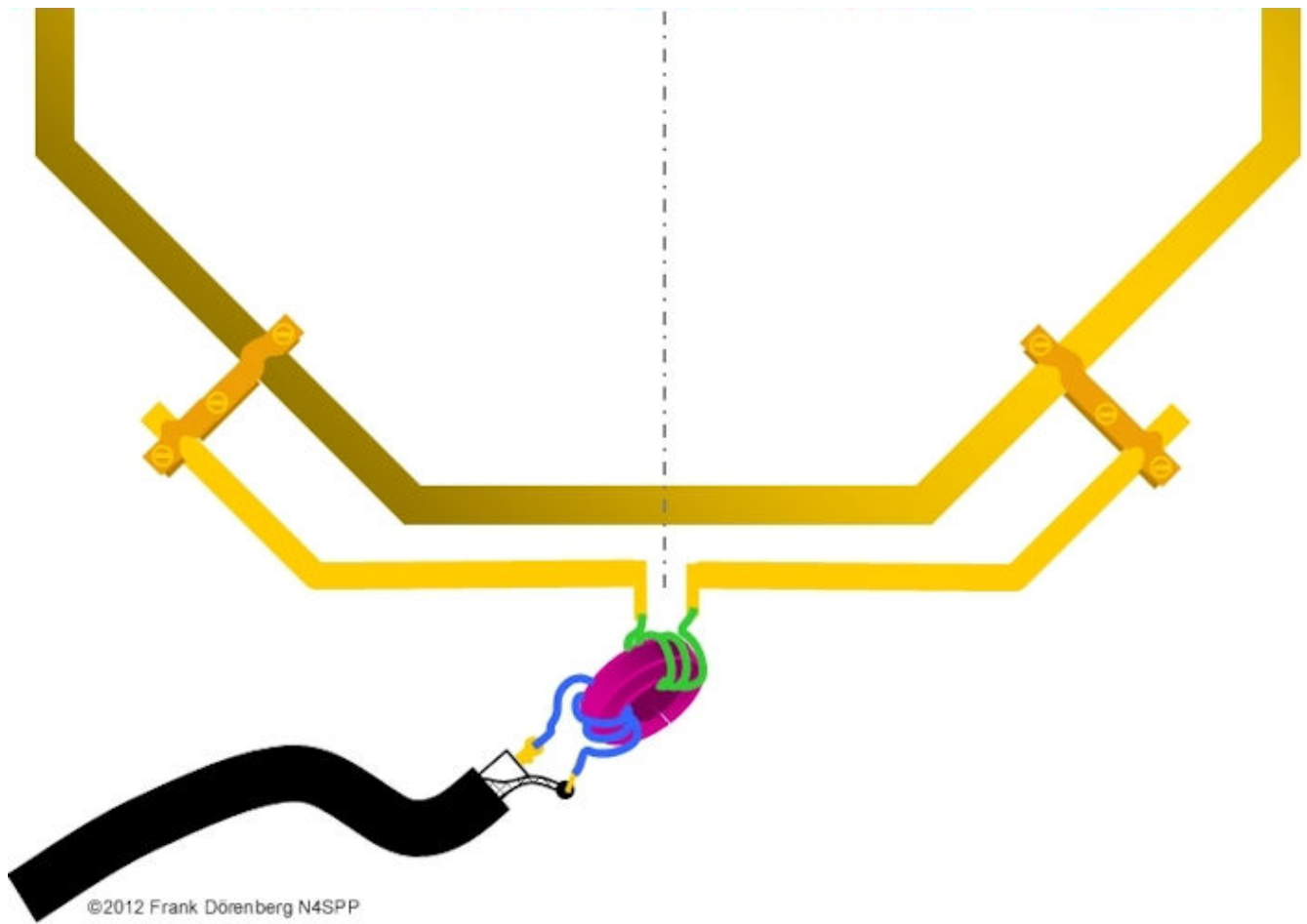


Figura 44: Acoplamiento T-Match

El T-match también se puede utilizar en combinación con un transformador N: M, para conectarse a un cable coaxial. Pero esto en realidad no debería ser necesario, si las dimensiones del T-Match se ajustan correctamente ...



©2012 Frank Dörenberg N4SPP

Figura 45: Acoplamiento T-Match combinado con transformador N: M

↑ ALGUNOS MODELOS DE SIMULACIÓN DE ANTENA ↑

"Los modelos siempre son incorrectos, pero algunos son útiles" (George EP Box, estadístico, 1976)

Por curiosidad y diversión, ejecuté algunas simulaciones de patrones de radiación de antena con el [excelente paquete de simulación de software gratuito 4NEC2](#). Se realizaron simulaciones para un bucle genérico con un diámetro de 2 m (6 pies 7 pulgadas), con un bucle de acoplamiento estándar que es 1/5 del tamaño del bucle principal. Las simulaciones se repitieron para varias configuraciones de un bucle orientado verticalmente: condensador de sintonización en la parte superior frente a la inferior, bucle de acoplamiento opuesto al condensador frente a junto a él, y punto de alimentación del bucle de acoplamiento hacia el centro del bucle principal frente a la derecha junto al bucle principal. No se realizaron optimizaciones de la posición del bucle de acoplamiento. En estos modelos, los bucles se modelan como polígonos de 18 lados. También es posible modelar bucles como una hélice de 1 vuelta con un paso ligeramente mayor que el diámetro del conductor del bucle. No realicé pruebas para comparar los distintos enfoques y técnicas de modelado.

Los modelos de simulación que utilicé fueron adaptados de los creados por Carol Milazzo (KP4MD), ref. 16A. Las adaptaciones incluyen 1) hacer que la

altura de instalación sea un parámetro variable, y 2) usar diámetros de conductor como los que se usan en mi propia antena: bucle principal de cobre de 12 mm ($\approx 1/2$ pulg.), Bucle de acoplamiento de cobre de 6,35 mm (1/4 pulg.), En lugar de alambre predeterminado de 2 mm de diámetro. Mis archivos NEC adaptados se proporcionan como ref. 16B.

NOTA 1: las simulaciones no tienen ningún objeto en ninguna parte, solo la antena a una cierta altura sobre el suelo que tiene una conductividad promedio estándar y una constante dieléctrica. Este no es en absoluto el caso en mi QTH, como se muestra en la sección " [Colocación de la antena](#) ". La simulación tampoco tiene en cuenta el acoplamiento entre el condensador y el entorno, etc.

NOTA 2: Me encontré con mensajes de error para el lazo de acoplamiento, al ejecutar el modelo para la banda de 80 m. Esto se debe al límite de longitud de segmentación mínima de la herramienta de $\lambda / 1000$ (≈ 8 cm ≈ 3 pulgadas en la banda de 80 m). También hay modelos flotando que no simulan un bucle de acoplamiento, sino que simplemente definen un punto de fuente de voltaje que se encuentra en algún lugar alrededor del bucle principal.

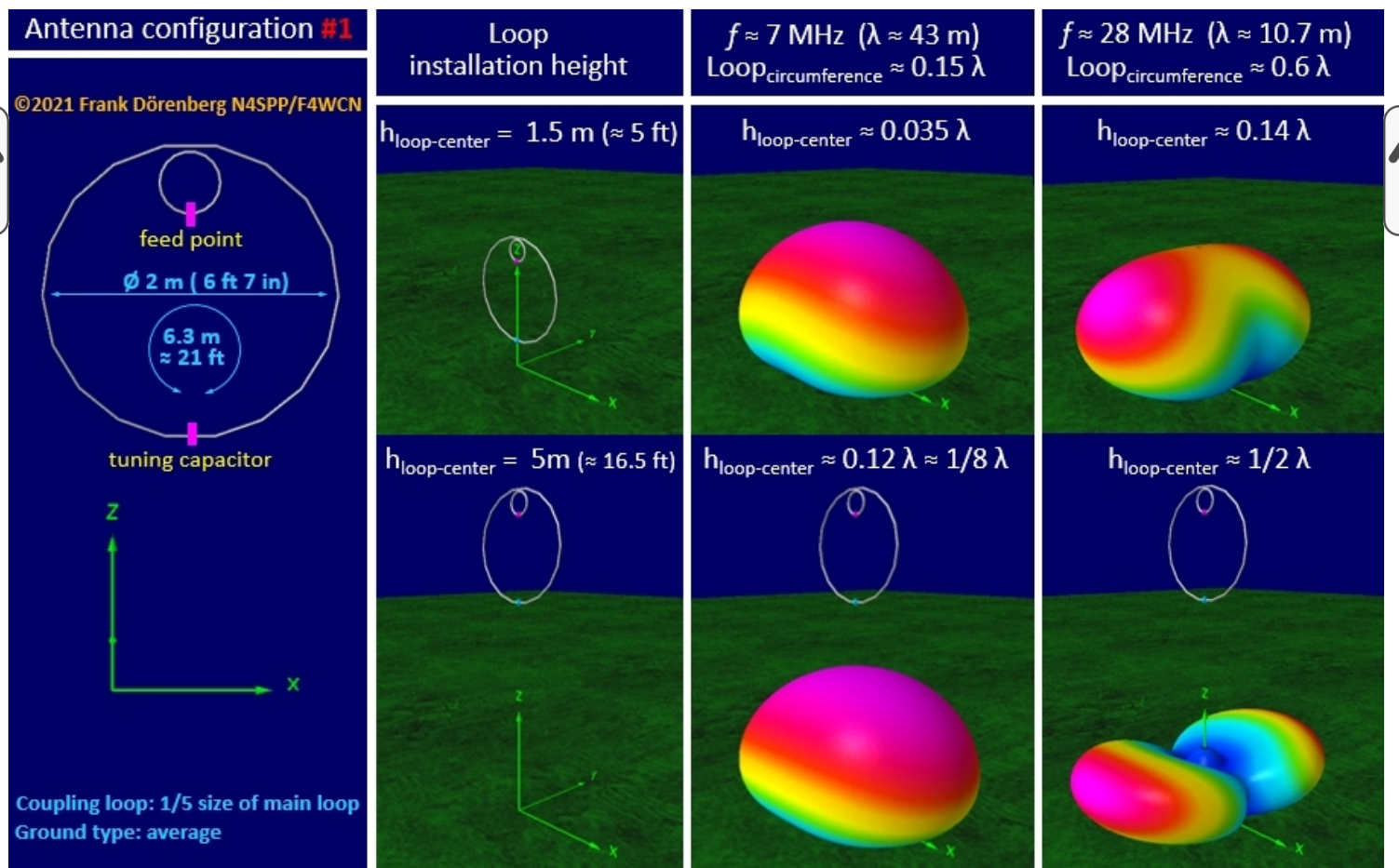


Fig.46A: Patrones de radiación 3D para la configuración de antena n. ° 1

Hasta una altura de instalación de alrededor de $1/4 \lambda$, el patrón de radiación no cambia mucho. Por supuesto, este no es el caso cuando hay edificios, árboles y otros objetos cerca de la ubicación de la antena.

La configuración n. ° 2 es simplemente la configuración n. ° 1 al revés. Los patrones de radiación son similares, ¡pero no idénticos!

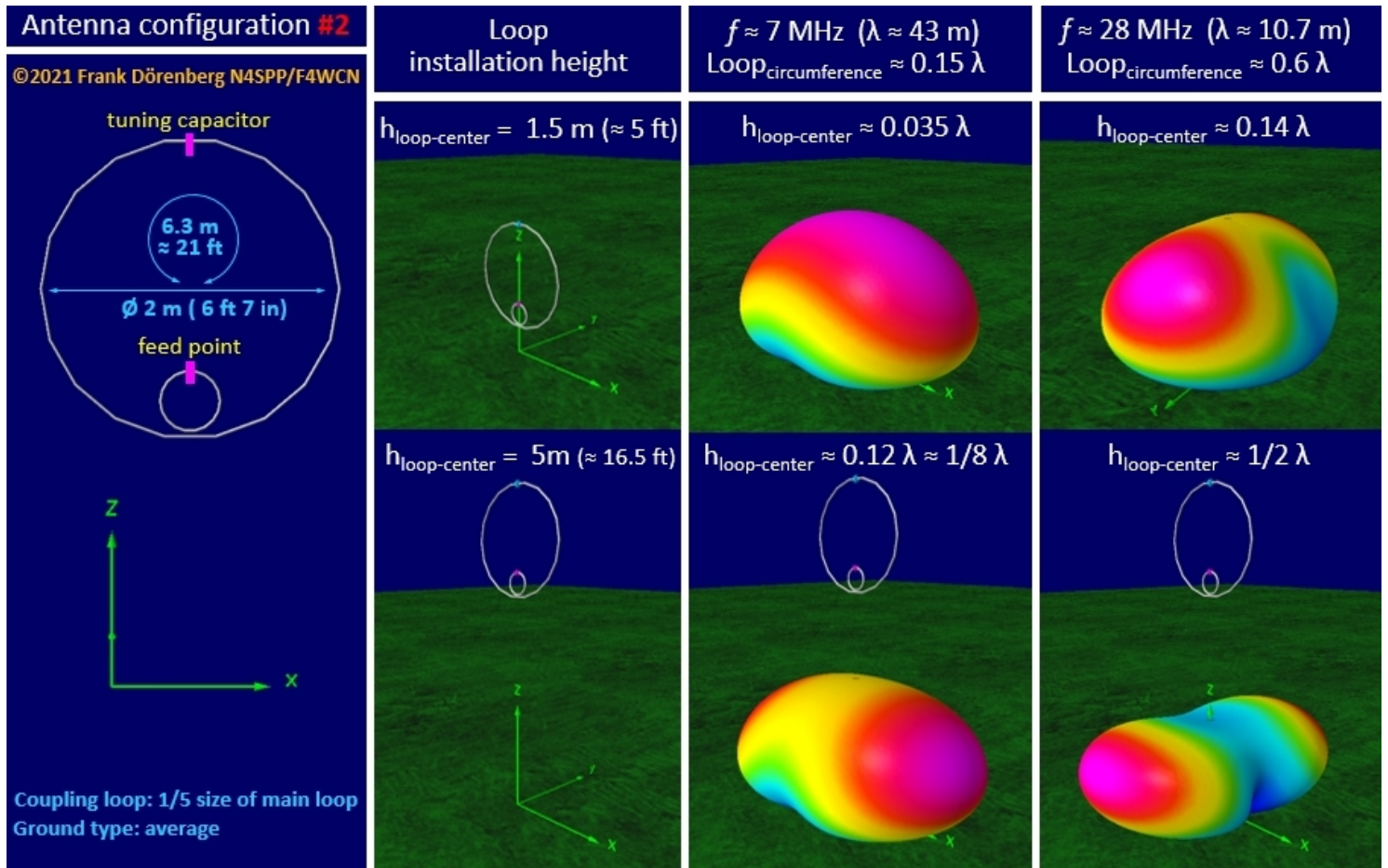


Fig.46B: Patrón de radiación 3D para la configuración de antena n. ° 2

Como siempre, las dimensiones y el espaciado en *relación con la longitud de onda* son de suma importancia. Algo interesante sucede con el modelo de simulación de la Configuración # 2, cuando el diámetro del conductor del circuito principal y de acoplamiento se reduce a los 2 mm (radio = 1 mm) del modelo original. Con esta reducción, el patrón de radiación 3D para 28 MHz a 1,5 m se alinea con el plano del bucle principal, en lugar de a 90 °. Gira 90 °, cuando el parámetro de altura del centro del bucle aumenta a alrededor de 2 m, que resulta ser el diámetro del bucle. No tengo una explicación (todavía) para este comportamiento ... En la Fig. 46A, la configuración de antena n. ° 1 tiene el bucle de acoplamiento en la parte superior, donde ya está por encima de 2 m cuando la altura del centro del bucle sigue siendo de 1,5 m.

Todo esto es solo jugar con el modelo ... Los resultados no son tan diferentes de [mis simulaciones de dipolos \(cortos\)](#) para varias frecuencias operativas (= tamaño del dipolo frente a longitud de onda) y alturas de instalación.

Como ocurre con todas las antenas, la eficiencia depende de la resistencia a la radiación. Para un STL, la resistencia a la radiación a una frecuencia dada es proporcional al cuadrado del área de la superficie. Por lo tanto, más grande es mejor. Para una circunferencia dada (= longitud total de la tubería de cobre), un bucle circular tiene el área de superficie más grande de todas las formas. Sin embargo, no tengo acceso a un doblador de tubos / tuberías, y los tubos de cobre recocidos (tratados térmicamente) son bastante duros y rígidos. Así que decidí construir un bucle octogonal en lugar de un bucle circular. Pero como se deduce a continuación, un bucle circular tiene un área de superficie que es solo un 5% más grande que un bucle octagonal con el *mismo* circunferencia (= longitud lineal del material requerido, como alambre o tubería). Para un bucle cuadrado, la diferencia es mayor: para la *misma* circunferencia, un bucle circular tiene un área de superficie que es aproximadamente un 27% más grande (= factor $4 / \pi$) que la de un bucle cuadrado.

Para un **círculo** con radio R y diámetro D :

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

$$Circumference = 2\pi \cdot R = \pi \cdot D$$

$$\Rightarrow Area = \pi \cdot R^2 = \frac{\pi}{4} \cdot D^2 = \frac{1}{4\pi} \cdot Circumference^2$$

Para un **octágono** con lado L :

$$Circumference = 8 \cdot L$$

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

Después de algunas manipulaciones básicas, podemos derivar que para circunferencias iguales (= longitud total de la tubería de cobre), los bucles circulares y octagonales tienen básicamente la misma área de superficie:

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

Tenga en cuenta que la resistencia a la radiación de un STL aumenta con el cuadrado de la superficie del área del bucle. Para la misma circunferencia, un bucle redondo tiene una

resistencia a la radiación que es $1.055^2 = 11\%$ más grande (= mejor) que el octágono.

Sin embargo, esa no es toda la historia. Claramente, maximizar la superficie es bastante importante. Normalmente, tenemos espacio para un "bucle" con un cierto ancho y alto. Tomemos el caso simple en el que "ancho máximo" y "altura máxima" son lo mismo. En este caso, un bucle cuadrado tendrá la mayor superficie posible. Obviamente, esta no es la forma con la circunferencia más pequeña, sería un bucle redondo. Sin embargo, un cuadrado con una construcción estándar tiene uniones de codo soldadas, estofadas o soldadas en las cuatro esquinas, lo que *puede* introducir una resistencia a la pérdida que no tiene un bucle redondo de una sola pieza. Para un ancho = alto = D dado, y todo lo demás permanece igual, obtenemos las siguientes áreas de superficie y resistencias *relativas a la radiación*.

$$Area_{circle} = \frac{\pi}{4} \cdot D^2 \approx 0.78 D^2 \longrightarrow R_{rel-rad, circle} \propto 1$$

$$Area_{octagon} = \frac{2}{(1+\sqrt{2})} \cdot D^2 \approx 0.82 D^2 \longrightarrow R_{rel-rad, octagon} \propto \frac{1}{(0.82^2)} \approx 1.5$$

$$Area_{square} = D^2 \longrightarrow R_{rel-rad, square} \propto \frac{1}{(0.78^2)} \approx 1.6$$

En base a eso, el bucle cuadrado tendría la mayor resistencia a la radiación (pero la resistencia a la pérdida mencionada anteriormente sí influye en la eficiencia ...). Solo para tener en cuenta.

De todos modos, decidí hacer un bucle con una circunferencia de unos 5 mtrs (16 pies). El octágono resultante tiene 1,5 m de alto y ancho (5 pies). Este tamaño es bastante manejable, pero la circunferencia es subóptima para 80 mtrs: solo alrededor de 0.06λ . Tenga en cuenta que las conexiones entre el bucle y el condensador aumentan la circunferencia, pero apenas el área de superficie del bucle. El soporte en forma de cruz está fabricado con tubo de PVC estándar. El "mástil" cabe en mi pesado paragüero de hierro fundido.

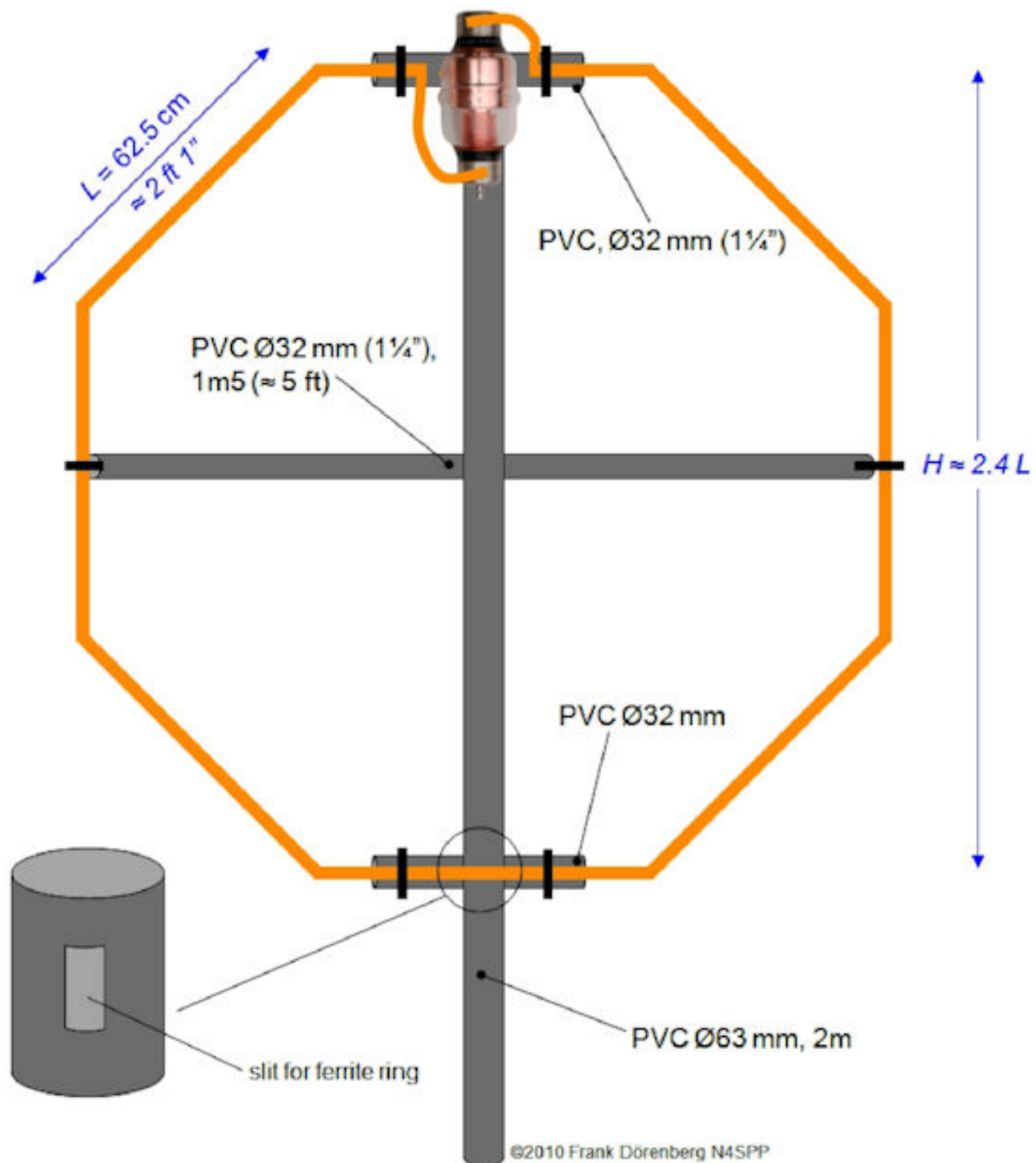


Figura 47: El concepto de construcción de mi primera antena STL: 1,5 m (5 pies) de alto y ancho

Un bucle octagonal requiere nueve secciones de tubería de cobre recta. Están conectados con codos de cobre, *no es necesario doblarlos*. Nota: el estándar de la industria es referirse al diámetro *exterior* cuando se habla de tubería y al diámetro *interior* cuando se hace referencia a tubería. Solo para que lo sepas, hihi.



Figura 48: Las partes de "plomaría" de mi antena STL (tubería, piezas de codo, pieza en T) y una herramienta de corte

Estos son los componentes de cobre de este bucle (todos los estándares europeos de 16 mm de diámetro exterior (DE), $\approx 5/8$ ich):

7 secciones de tubería de cobre, cada una de 62,5 cm (24,6 ") de longitud

2 secciones de tubería, cada una de 29 cm (11,4 ") de longitud

8 codos, 45°, hembra a hembra, para tubería de 16 mm de diámetro exterior

2 piezas de codo, 90°, hembra a macho, para tubería de 16 mm de diámetro exterior

2 piezas de reducción, de 16 mm a 10 mm de DE (para conectar el tubo al trenzado al condensador)

1 pieza en T de cobre, 2 x 16 mm de DI, 1x 10 mm de DI (para el acoplamiento de varilla gamma como se describe arriba)

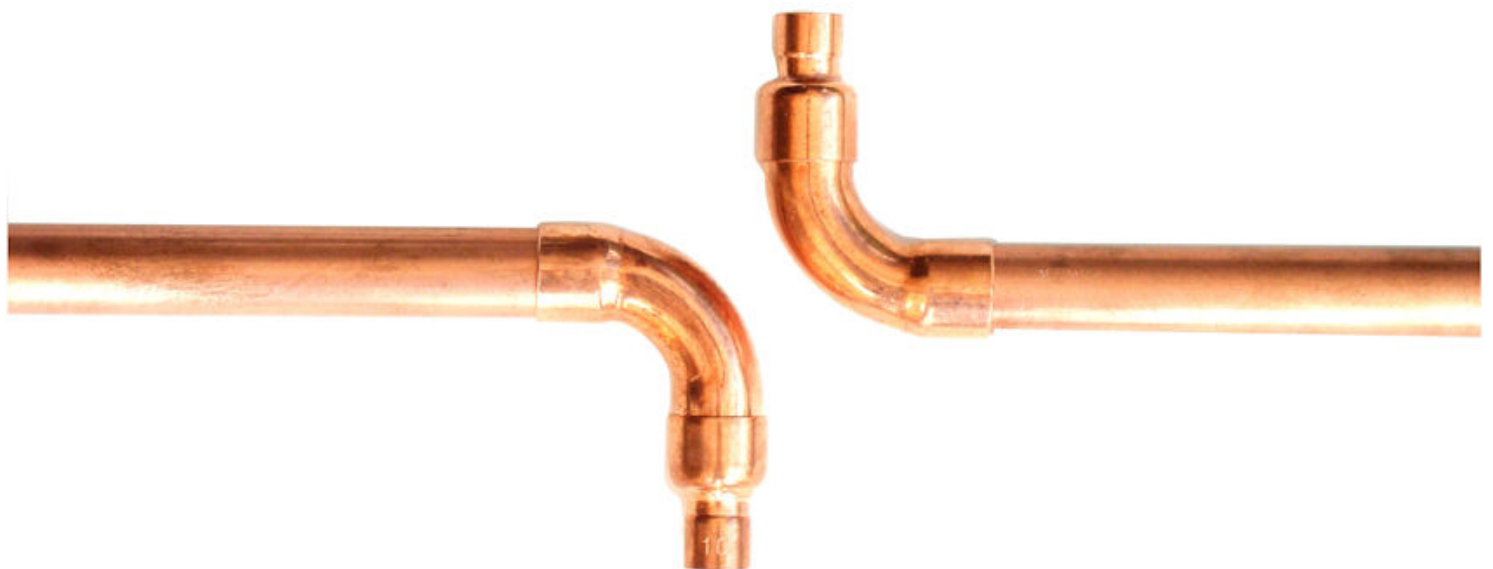


Figura 49A: Terminación de los extremos del lazo, para conexión al condensador

(El espacio de "chispa" entre las piezas del codo de arriba debe tener al menos la misma tensión nominal que el condensador: aquí: 10 kV)

Componentes para conectar el condensador de sintonización al lazo:

2 abrazaderas de manguera de acero inoxidable (*Reino Unido* : clips de jubileo), lo suficientemente grandes para las tapas de los extremos de mi condensador de vacío (6 cm de diámetro exterior, 2,4 ")

Trenza de cobre de 2 x 25 cm (10 ") de grosor y ancho (también disponible en una tienda de suministros automotrices, como correa de tierra para baterías de automóvil). Alternativas: trenza de 2 capas plateada de cable coaxial de gran diámetro o cobre pesado de múltiples hebras alambre (por ejemplo, AWG # 4)



Figura 49B: Abrazaderas de manguera y alambre pesado de múltiples hilos para conectar el lazo al capacitor

Componentes para la placa de montaje del condensador:

Tabla de cortar de polietileno de 10x12 cm (4x5 "), de 8 mm (5/16") de grosor, de la cocina.

2 pernos, M6, inoxidable (lo suficientemente largos para atravesar el tablero + 2 mm de espesor del PVC de 63 mm de diámetro exterior + tuerca de seguridad).

2 arandelas, 6 mm DI.

2 tuercas autoblocantes, M6, inoxidable.

4 bridas grandes (bridas para cables). Por alguna razón, los negros (es decir, las corbatas), generalmente se sostienen mejor a la luz del sol que los blancos ...

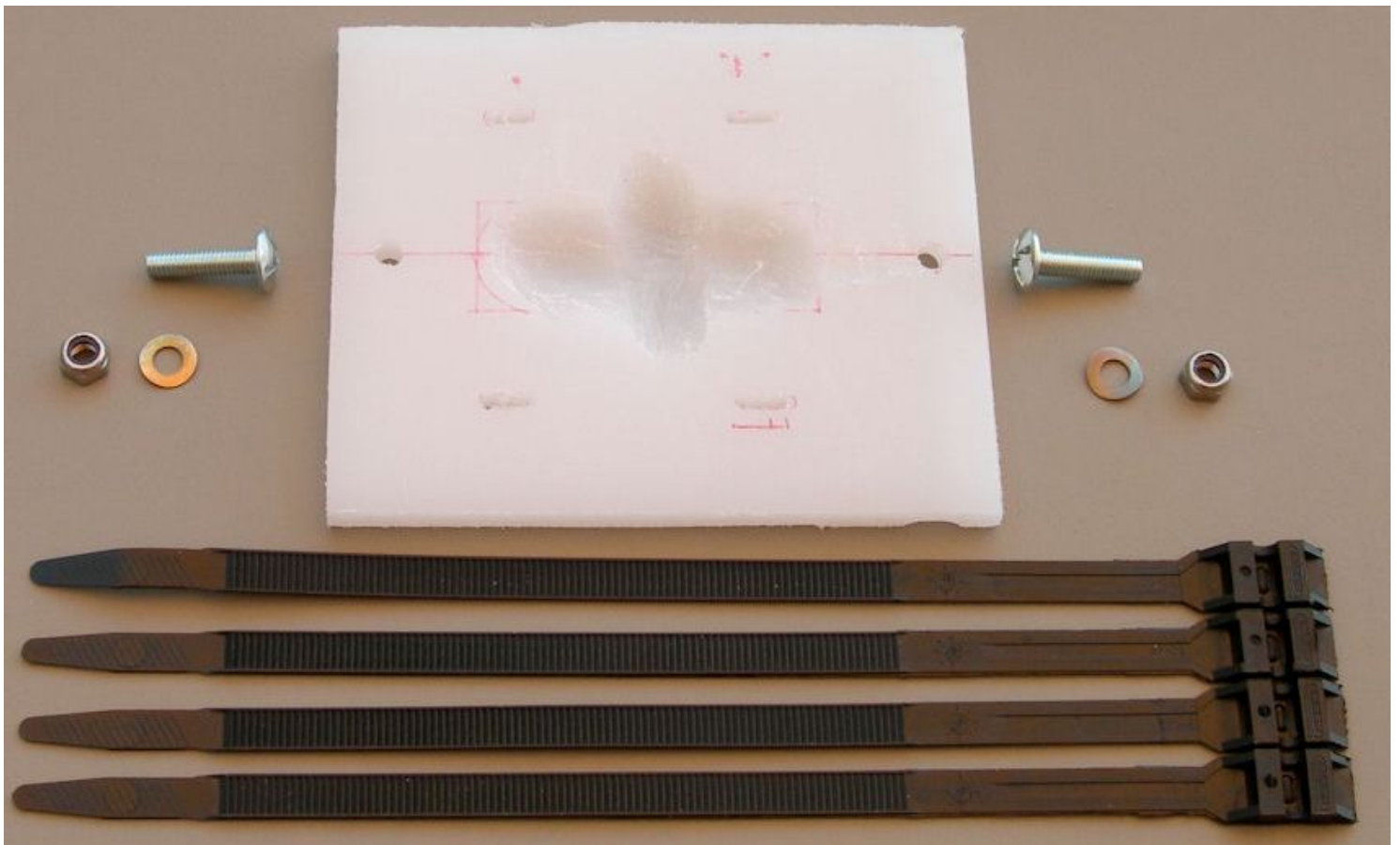


Figura 50: Los componentes de la placa de montaje para el condensador de vacío

La "botella" del condensador de vacío no es un cilindro. Usé una broca para tallar huecos en la tabla de cortar, para la forma de la "botella". También corté ranuras de 2 x 2 en el tablero, para pasar las ataduras a través del tablero. Bueno, de hecho hice una serie de pequeños agujeros para cada hendidura. Cada par está espaciado menos que el ancho del condensador (10 cm), para poder hacer que las bridas aprieten más la botella sobre la placa.



Figura 51: Los componentes de la placa de montaje para el condensador de vacío

Componentes para el mástil y los travesaños:

Tubería de PVC de 2 m (6,6 pies), diámetro exterior de 63 mm (2,5 ") - mástil

Tubo de PVC de 1,75 m (5,7 pies), diámetro exterior de 32 mm (1,25 ") - riostra transversal principal

2 secciones de tubería de PVC de 40 cm (16 "), diámetro exterior de 32 mm (1,25") - soportes superior e inferior

6 abrazaderas a presión para tubos de 14 mm de diámetro exterior (sí, más apretadas que los 16 mm de diámetro exterior del cobre)

6 pernos M6x45 para las abrazaderas (lo suficientemente largos para pasar a través del tubo de PVC de 32 mm de diámetro exterior y dentro de la tuerca de la abrazadera)



Figura 52: Una de las seis abrazaderas de tubo

Inicialmente, traté de soldar las piezas del codo de cobre a la tubería de cobre recta con un soplete de propano / butano doméstico y una soldadura de plata de plomero. Un soplete así no genera suficiente calor concentrado. Así que llevé mis piezas a un plomero amigable del vecindario, que usó su soplete de oxiacetileno. ¡Mucho mejor! ¡Hice un poco de planificación previa y coloqué el portaequipajes en el automóvil para llevar el bucle ensamblado a casa!



Figura 53: Soplete de propano

Obviamente, un soplete de acetileno + oxígeno hará un trabajo mucho mejor que un soplete de propano: puede soldar con él, en lugar de solo soldar. Sin embargo, son muy caros y normalmente no se pueden alquilar. Pero le pagas a un taller de soldadura local para que lo haga, o le preguntas a un plomero amigable (lo cual terminé haciendo).



Figura 54 La parte posterior del montaje del condensador
(el orificio en el mástil es para insertar una llave de tubo para apretar la tuerca en el perno inferior de la placa de montaje del condensador)



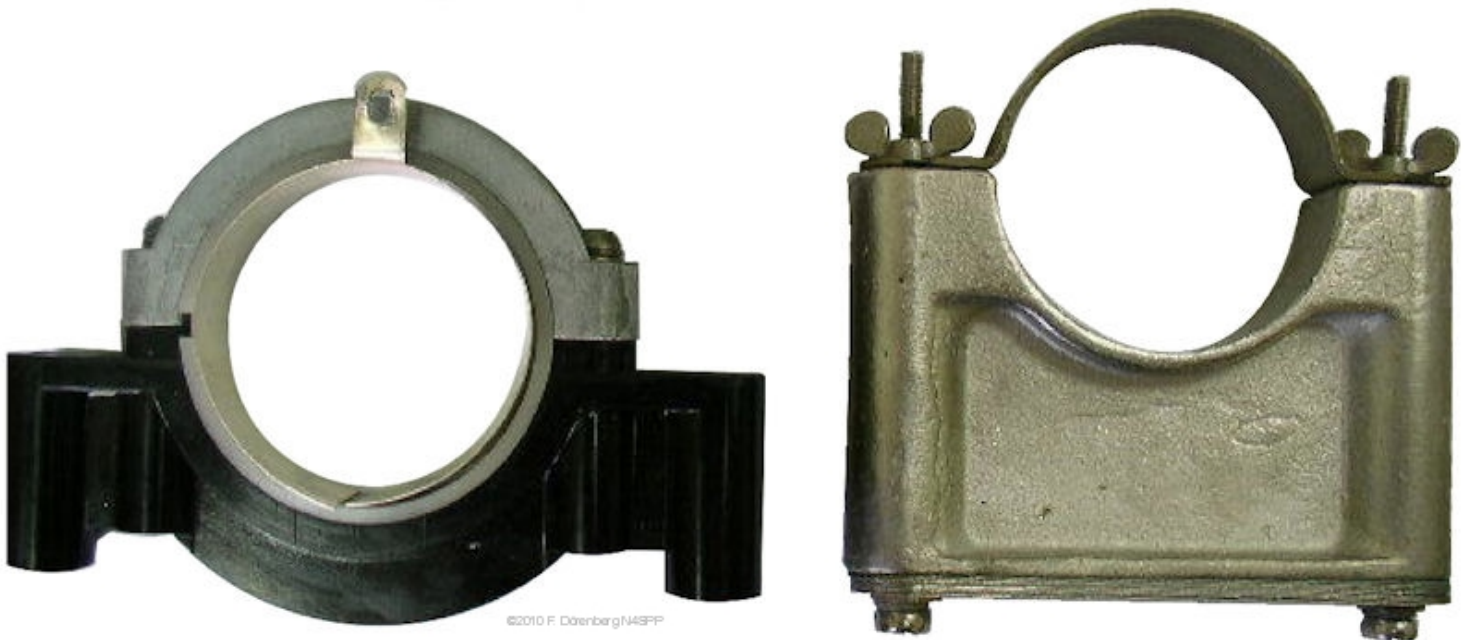
Fig.55: Primer plano del cable de conexión del condensador, soldado a una pieza de reducción de cobre en los extremos del bucle





©2011 F. Dörenberg N49FP

Figura 56: Primer plano de la abrazadera de la manguera con el alambre grueso soldado sobre ella



©2010 F. Dörenberg N49FP

Figura 57: Abrazaderas de montaje producidas comercialmente para un condensador de vacío

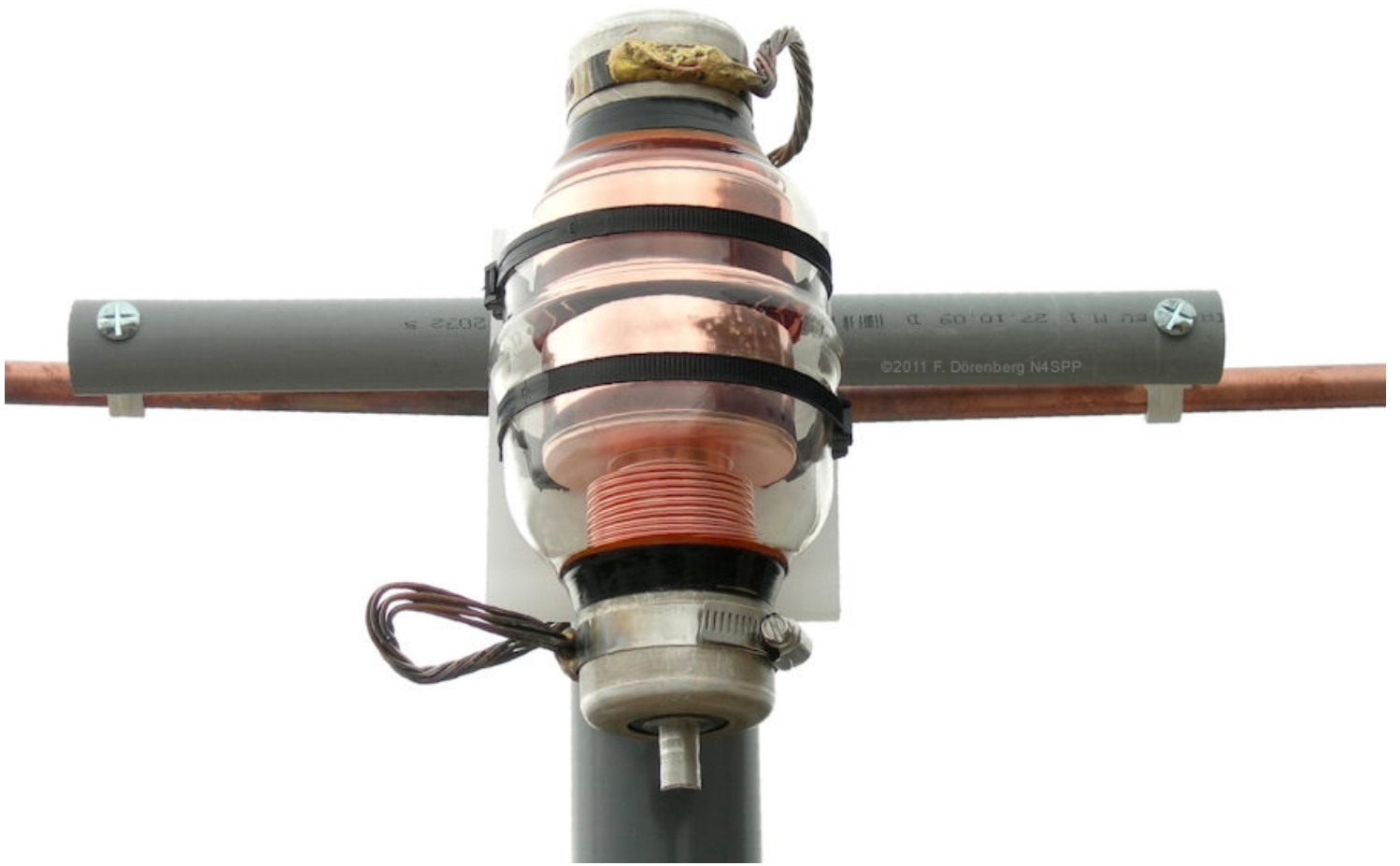


Figura 58: El condensador de vacío montado en la parte superior del mástil

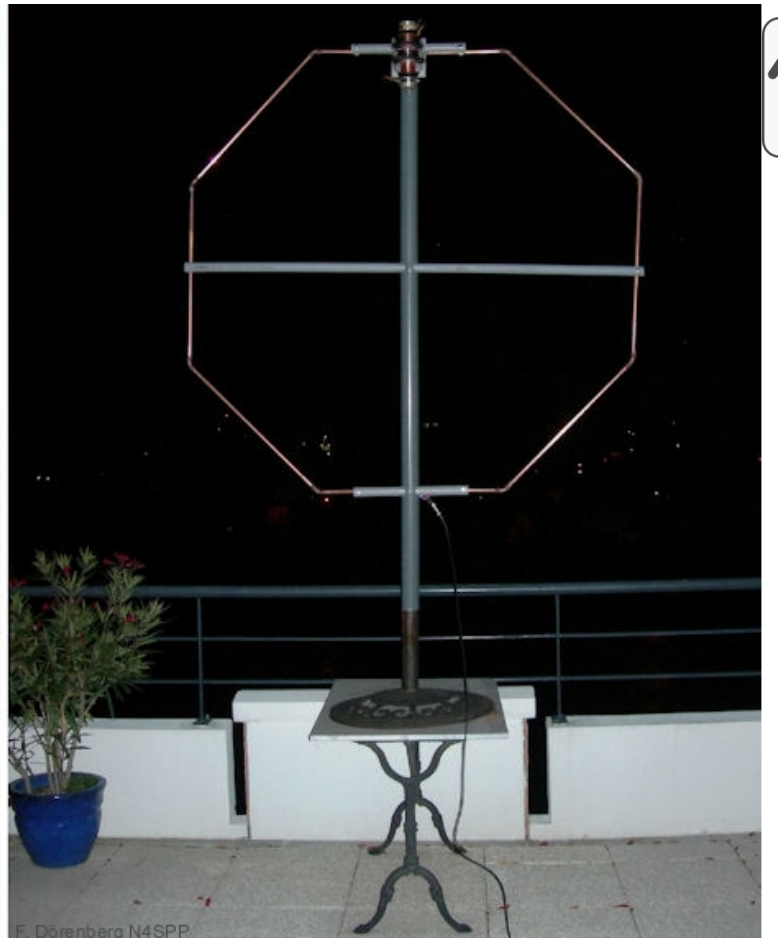


Figura 59: Mi primer STL, erigido en mi terraza. Hermoso en cualquier momento del día o de la noche, hihi



Figura 60: Otra imagen de este STL.
(es el paragüero el que está inclinado, no mi STL. Finalmente tomé el molinillo y lo arreglé a fines de 2015)



Fig.61 : Mi miniVNA : un analizador de antena diminuto para 0,1-180 MHz, con conexión USB a una PC

Como tenía varios núcleos de ferrita FT-140-43 en stock, eso es lo que usé. Estos núcleos tienen un diámetro exterior (OD) de 1,40" y un diámetro interior de 0,9" (≈ 23 mm). Este es lo suficientemente grande como para deslizarse sobre un tubo con un diámetro exterior de 16 mm (5/8") y todavía tiene espacio para aproximadamente 16 devanados de cable de instalación pesado

2

aislado de 1,5 mm (AWG 14-16). La calculadora G4FGQ (ref. 2D) predice que mi bucle requeriría 24 devanados secundarios a 3.5 MHz y 8 a 14.230 MHz, para un núcleo de ferrita de "grado adecuado". K3JLS (ref. 6E) usa 3 vueltas de cable esmaltado 14 AWG en un FT-240-43 para su bucle de 40-20 m. AA5TB (ref. 8A) utilizó 2 giros en su bucle de 30 m.

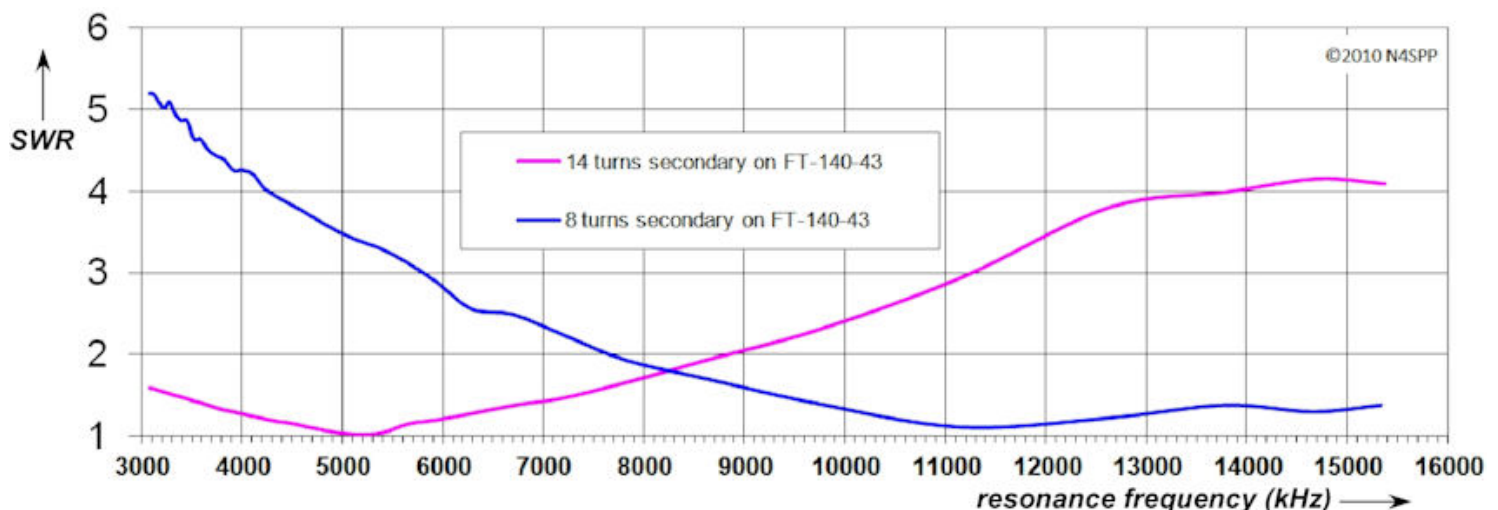


Figura 62: Transformador de acoplamiento: núcleo de ferrita FT-140-43 con 8 y 14 vueltas secundarias

(la parte inferior del bucle de la antena se coloca a 80 cm (2,5 pies) sobre el suelo)

Los gráficos anteriores sugieren que se puede obtener una ROE viable ($<1,5$) en un rango de frecuencia de $2^+ : 1$. Sin embargo, me gustaría tener $4: 1$, para cubrir 80 - 20 mtrs ...

La siguiente curva muestra que para una capacitancia máxima (500 pF), la frecuencia de resonancia es 3064 kHz; con capacitancia mínima (15 pF) ronda los 15,8 MHz. Este rango cubre 80-20 mtrs y es más grande de lo que estimaron las diversas calculadoras, ¡me queda bien! Tenga en cuenta que las conexiones entre el bucle y el condensador de sintonización aumentan el tamaño del bucle.

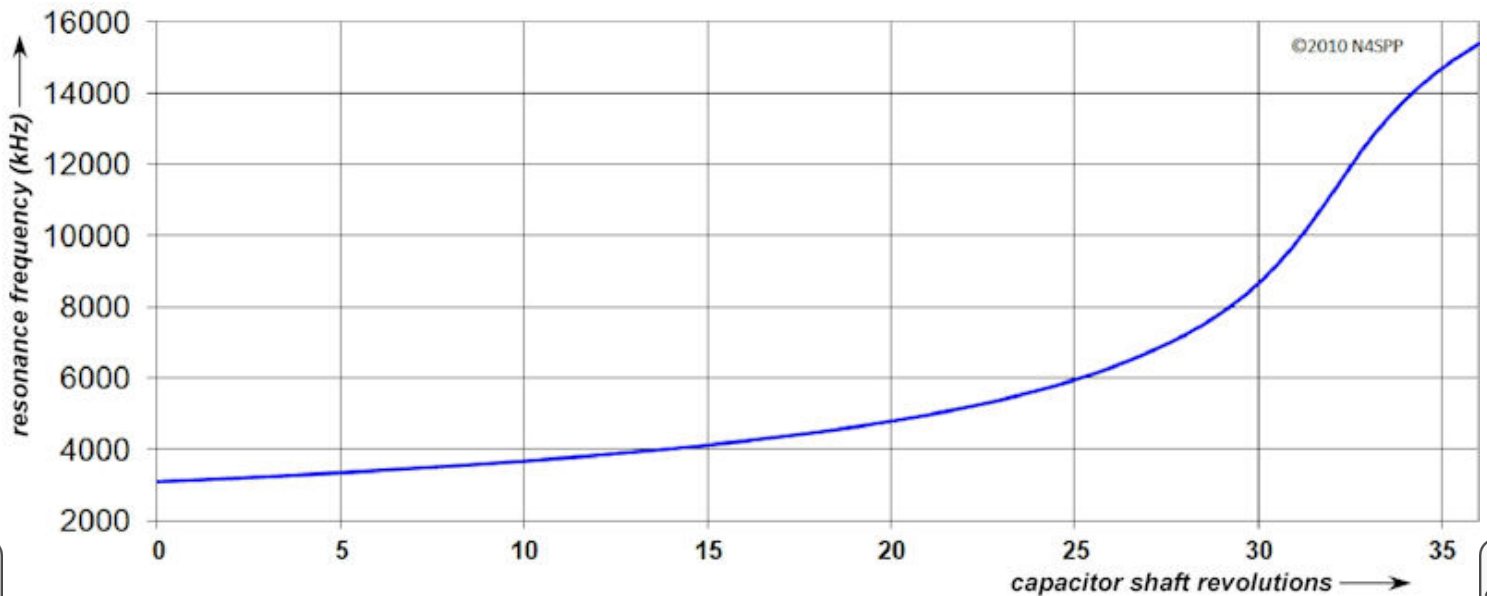


Fig.63: Transformador de acoplamiento: núcleo de ferrita FT-140-43 - misma curva para 8 y 14 vueltas secundarias

Como el bucle resonante es un circuito LC, la frecuencia de resonancia varía con la raíz cuadrada del valor del condensador de sintonización. Mi condensador tiene un rango de capacitancia de 15-510 pF = $1:34$. Como se muestra arriba, medí un rango de frecuencia de resonancia correspondiente de aproximadamente 3-15.8 MHz = $1: 5.2$, mientras que el rango de frecuencia de resonancia esperado sería $1: \sqrt{34} = 1: 5.8$; la diferencia se explica por la precisión de la medición de capacitancia y la capacitancia parásita del lazo. Las calculadoras de bucle (como la ref. 2A-2E) estiman que esta capacitancia parásita es a menudo del mismo orden de magnitud que el valor mínimo de un capacitor de sintonización. Nota: leer ref. 2F para advertencias sobre las calculadoras de bucle magnético.

La siguiente gráfica muestra que hacia la capacitancia mínima, la capacitancia no varía linealmente con la posición del eje del capacitor: la curva de frecuencia vs capacitancia ya no es cuadrática. Esto es causado por efectos de borde en el condensador de vacío, cuando sus placas concéntricas tienen poca o ninguna superposición.

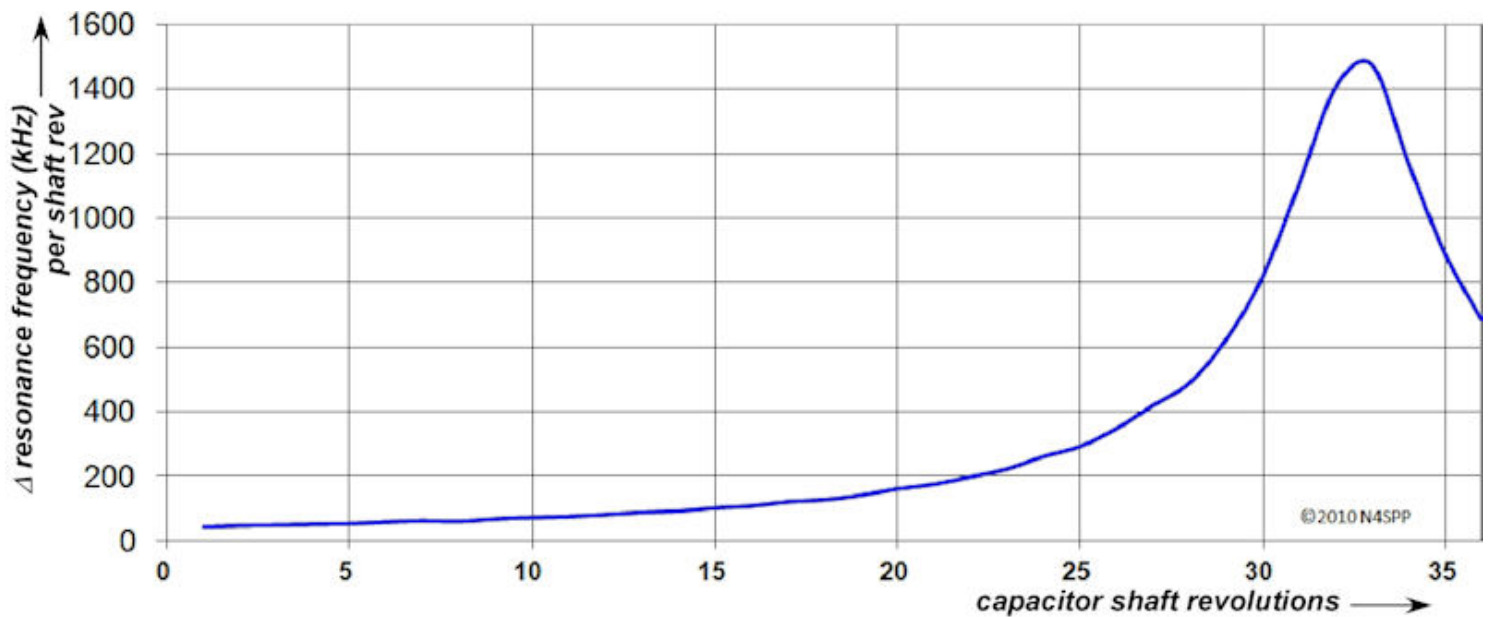


Fig.64: Cambio no lineal en la frecuencia de resonancia frente a la posición del eje varco
(acoplamiento con núcleo de ferrita FT-140-43)

El factor "Q" (Calidad) depende inversamente del ancho de banda. Es una medida de la pérdida del circuito resonante: la energía máxima almacenada en el circuito, dividida por la energía promedio que se disipa por ciclo, en el circuito en resonancia. Esto se puede expresar como:

$$Q = \frac{1}{BW} \cdot \frac{SWR - 1}{\sqrt{SWR}} = \frac{f_{res}}{\Delta f_{SWR}} \cdot \frac{SWR - 1}{\sqrt{SWR}}$$

donde BW es el ancho de banda normalizado para un SWR dado (referenciado a $SWR = 1$ en f_{res}). Por ejemplo, el ancho de banda entre las frecuencias de "media potencia" (= las frecuencias de -3 dB) es el ancho de banda entre las frecuencias $SWR = 2.62$. La siguiente gráfica muestra tanto el ancho de banda como Q para el acoplamiento del transformador de ferrita con 14 devanados secundarios. El ancho de banda varía desde 6,8 kHz alrededor de 3 MHz hasta 50 kHz alrededor de 15 MHz. La Q asociada varía de 450 a 300, con un máximo de 600 alrededor de 5 MHz.

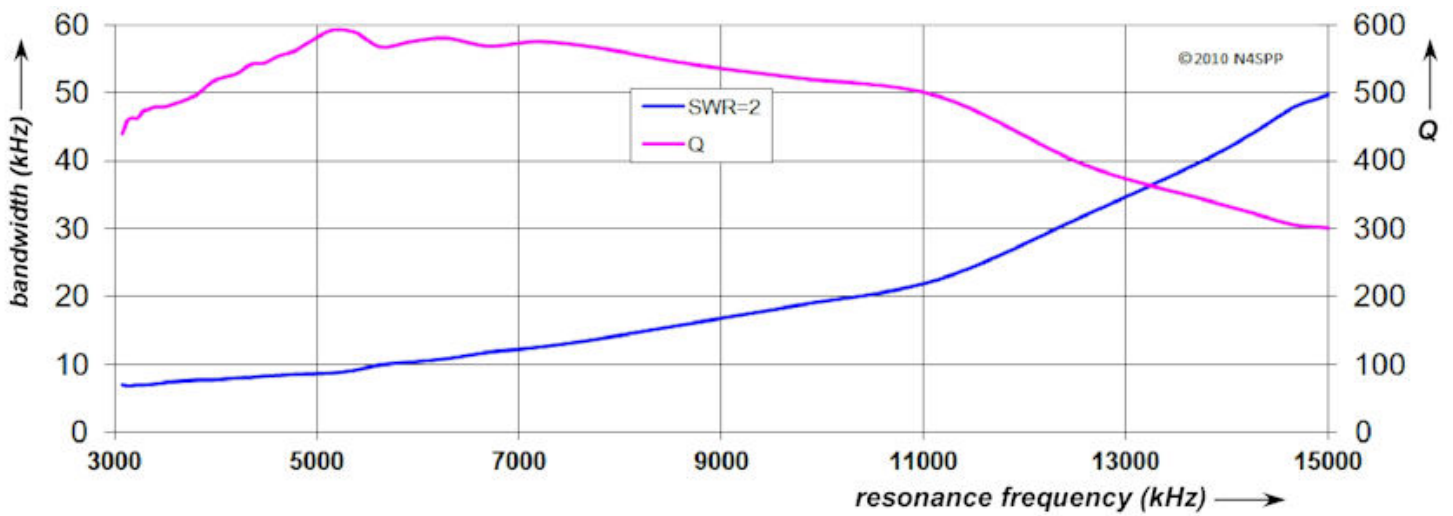


Fig.65: Ancho de banda y Q - acoplamiento del transformador con núcleo FT-140-43 y 14 espiras secundarias

Construí este STL principalmente para DX en 80 mtrs. Para probar las antenas por mí mismo, normalmente uso receptores remotos en Internet: [Web-SDR](#) . Las capturas de pantalla de la visualización en cascada de un Web-SDR en los Países Bajos (mi QTH está en el sur de Francia) mostraron claramente mi señal:

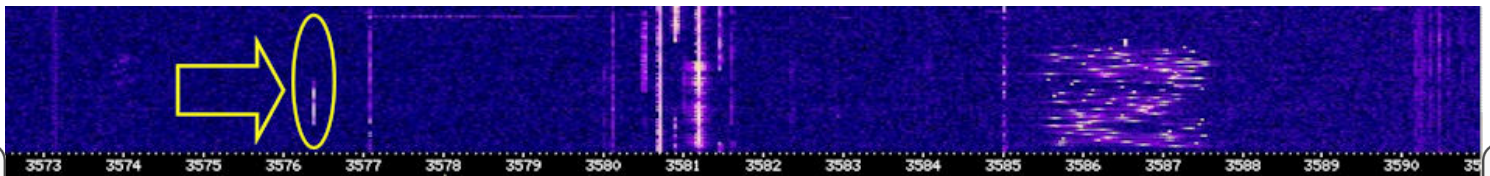


Fig.66: Mi portador, visible (con algo de atenuación) en la pantalla en cascada de un Web-SDR 80 a una distancia de 1000 km (600 millas) (19 de octubre de 2010, 19:00 hora local, 80 vatios)

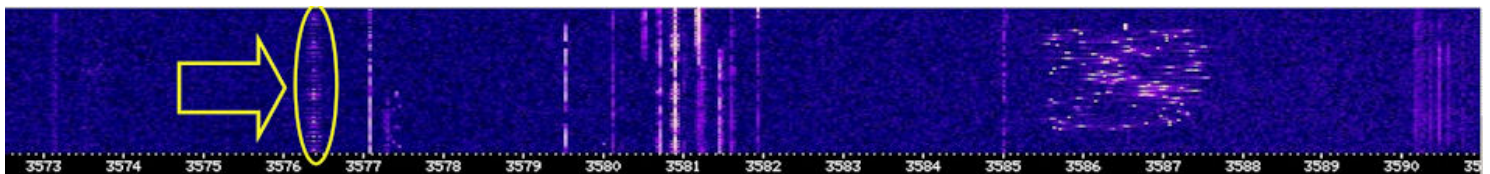


Fig. 67: Las mismas condiciones que las anteriores, pero ahora enviando una serie de caracteres "E" en modo Hellschreiber

Los Web-SDR tienen audio. Entonces, cuando opera en modo digital, puede imprimir sus propias señales:

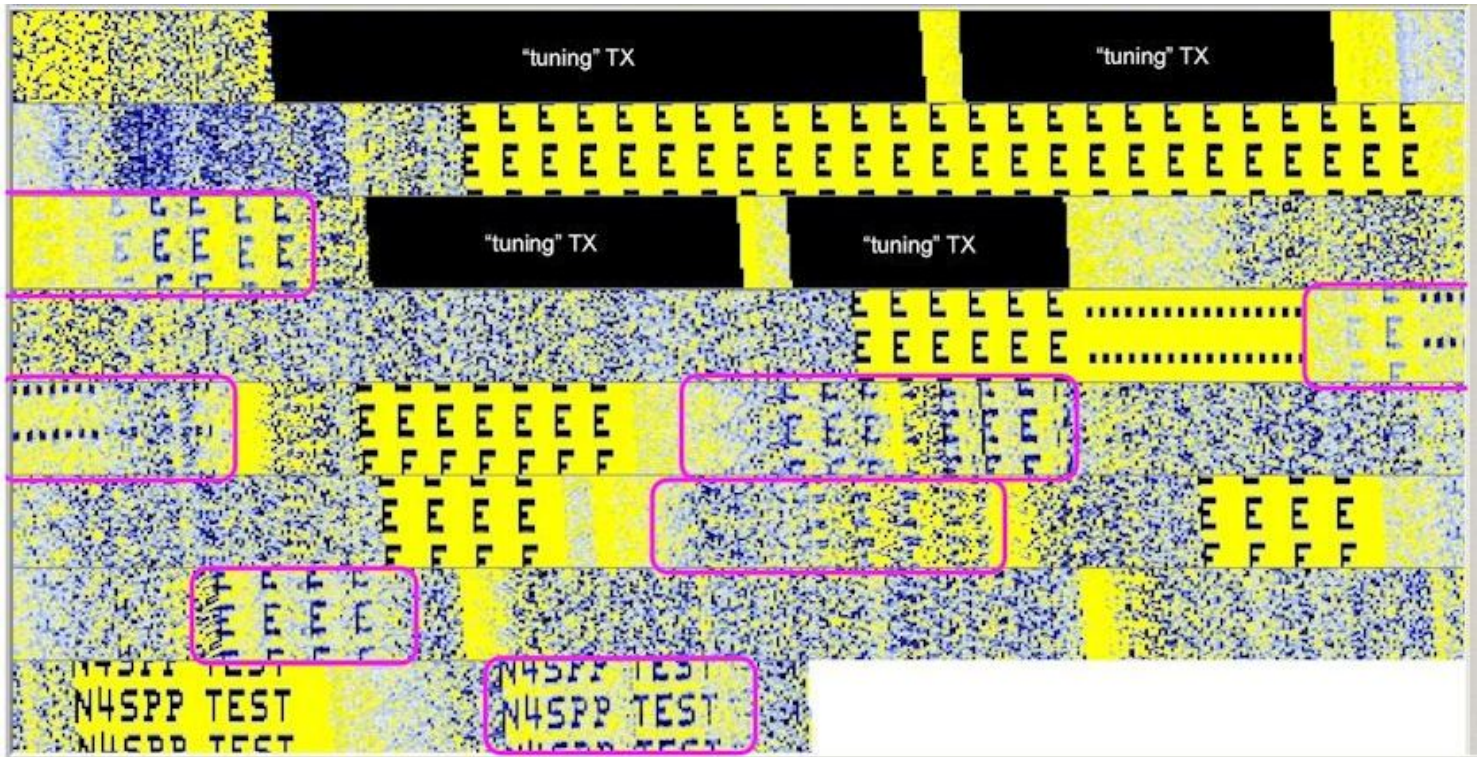


Fig.68: Mi señal Hellschreiber, recibida en 80 mtrs por un receptor Web-SDR a una distancia de 1000 km (600 millas)

(31 de octubre de 2010, 17:00 hora local, 80 vatios; mi señal recibida en el SDR-RX está en las cajas magenta)

En las pruebas anteriores, el plano del bucle (¡no la apertura del bucle!) Apuntaba al receptor remoto. Cuando giré la antena 90 grados, el medidor S de ese receptor bajó aproximadamente 2 puntos (12 dB). En noviembre de 2010, hice algunas pruebas de recepción comparativas con el bucle y mi [dipolo](#) corto "[Cobra](#)" (2x7 m). Un relé coaxial permitió una conmutación AB rápida. El bucle era notablemente más silencioso que ese dipolo y un par de puntos S más fuerte. También realicé algunas pruebas en 40 mtrs con mi querido amigo Rolf, DF7XH, a una distancia de 750 km (465 millas). Con todas mis otras antenas (dipolos cortos y verticales cortos), solo tenemos una comunicación marginal en el mejor de los casos. Esta vez fue FB y 59+ en ambas direcciones.

También hice un experimento rápido instalando el bucle horizontalmente. Parecía bastante "sordo" en 80 mtrs, ya que está instalado a solo 2 mtrs (= 0.025λ) sobre el suelo, y el suelo es "pobre" (concreto). Como no estoy interesado en los QSO locales, no perseguí esto.



Figura 69: Mi STL, instalado horizontalmente

El mástil de mi STL se instala encima de otro mástil de PVC con una pieza en T de PVC. Corté una hendidura en la pieza en T, para que pueda sujetarse al mástil STL y aún así sujetarla firmemente, sin necesidad de pegar nada.



Figura 70: La pieza en T de PVC modificada

MI SEGUNDO BUCLE DE TRANSMISIÓN PEQUEÑO

Algunas "lecciones aprendidas" de [mi primer ciclo](#) :

Reduzca las pérdidas en el bucle reduciendo el número de uniones: doble la tubería de cobre larga en forma circular u octogonal.

Utilice un método diferente para conectar los extremos del bucle al condensador de vacío:

Después de aproximadamente un año y medio después de la construcción, la resistencia de CC total de la parte de cobre del bucle no ha cambiado: sigue siendo de 3,2 miliohmios (medido con un medidor de miliohmios profesional HP4328A). Me doy cuenta de que esto no dice nada sobre las pérdidas de RF. Sin embargo, la resistencia entre el alambre de cobre y las abrazaderas de manguera de acero inoxidable había aumentado a poco más de 4 miliohmios, ¡por abrazadera! Esto mata la eficiencia de la antena. Todas las calculadoras de ciclos (ref. 2) mostrarán esto rápidamente, y ya había notado una disminución en el rendimiento con el tiempo. Nota: leer ref. 2F para advertencias sobre las calculadoras de bucle magnético.

Como estoy principalmente interesado en usar esta antena para DX en 80 m, o 80-40:

Aumente la circunferencia del bucle de 5 a aproximadamente 7 m (16 a 23 pies). Es decir, de $0,06 \lambda$ a casi $0,09 \lambda$ en 80 mtrs. Esto todavía está muy por debajo del óptimo 0.15λ , pero en 80 mtrs, ¡ese óptimo implica un diámetro de 4 m (13 pies)! ¡El tamaño aumentado duplicará el área del bucle y debería duplicar la eficiencia de la antena en 80 m!

Pruebe un acoplamiento de varilla gamma o cambie a anillos de ferrita hechos de material tipo 31. Esto debería ser mejor que el material tipo 43 para frecuencias por debajo de 10 MHz.

Simplifique la conexión del condensador de vacío al mástil.

Obviamente, tuve que hacer un bucle y un mástil nuevos, que es lo que hice a fines de 2012. Esta vez, utilicé un rollo de tubo de cobre blando de 20 pies (6,1 metros) con un diámetro exterior de 5/8 de pulgada.

No cometa el error de montar un lazo de este tamaño dentro de la casa: probablemente no entre a través de una puerta normal. No te metas en un rincón, hihi.



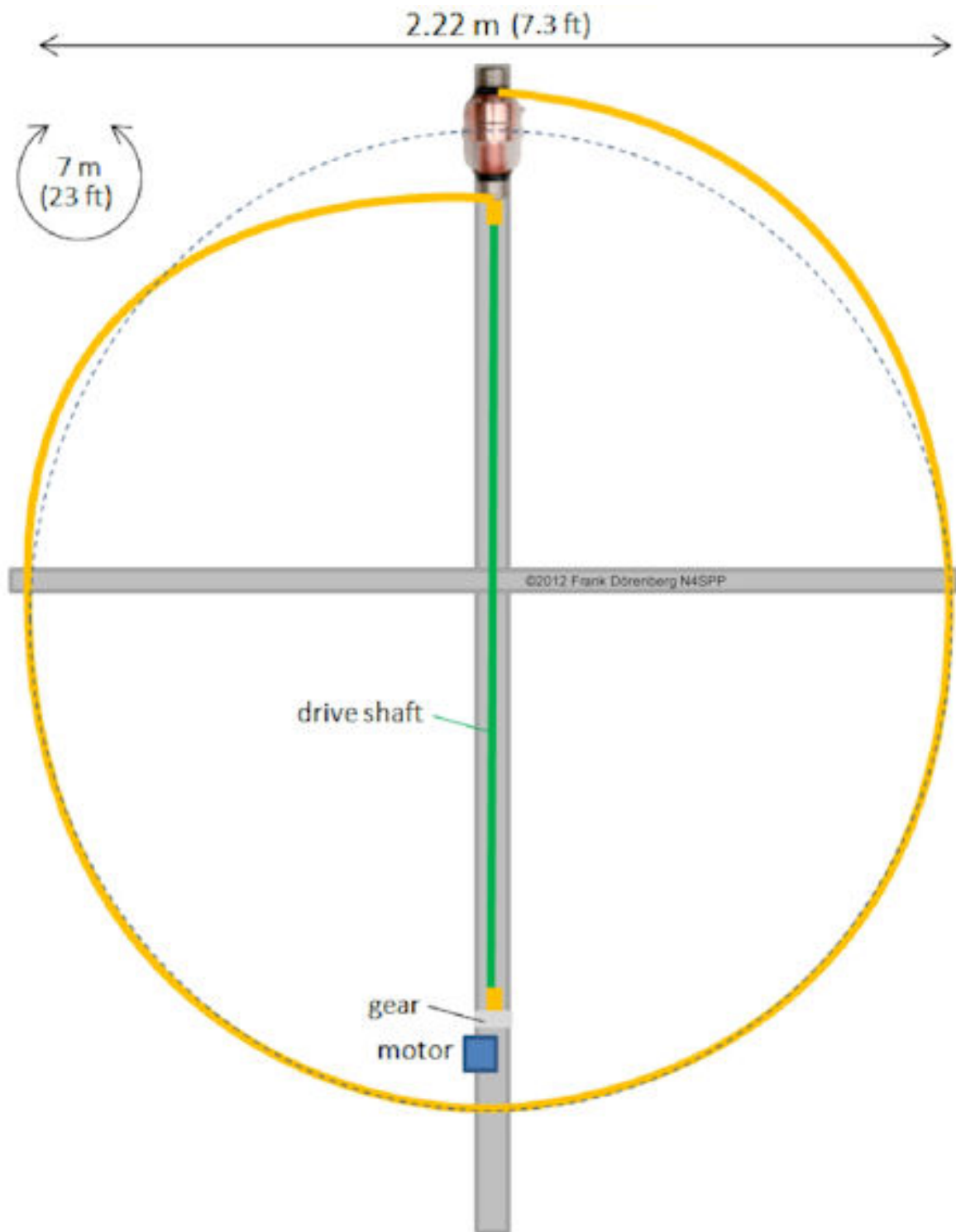
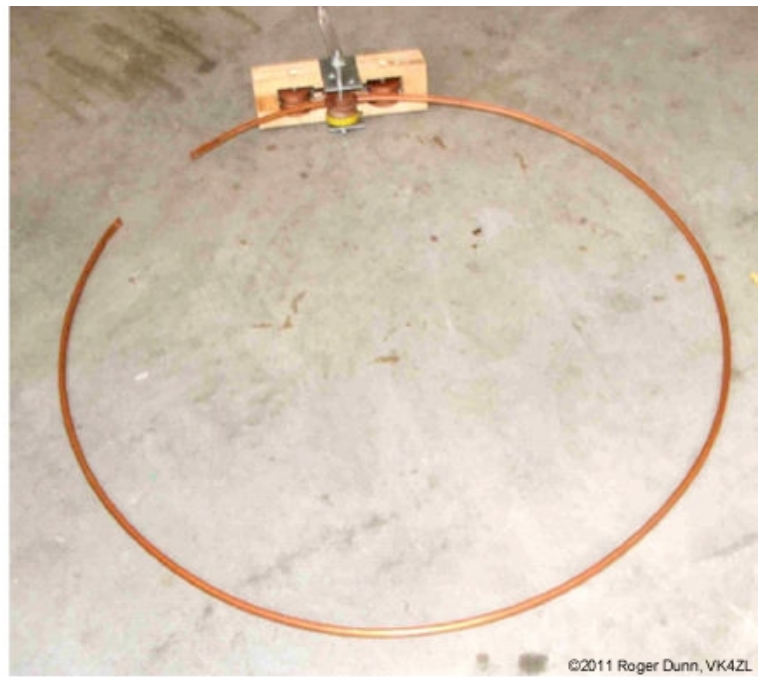
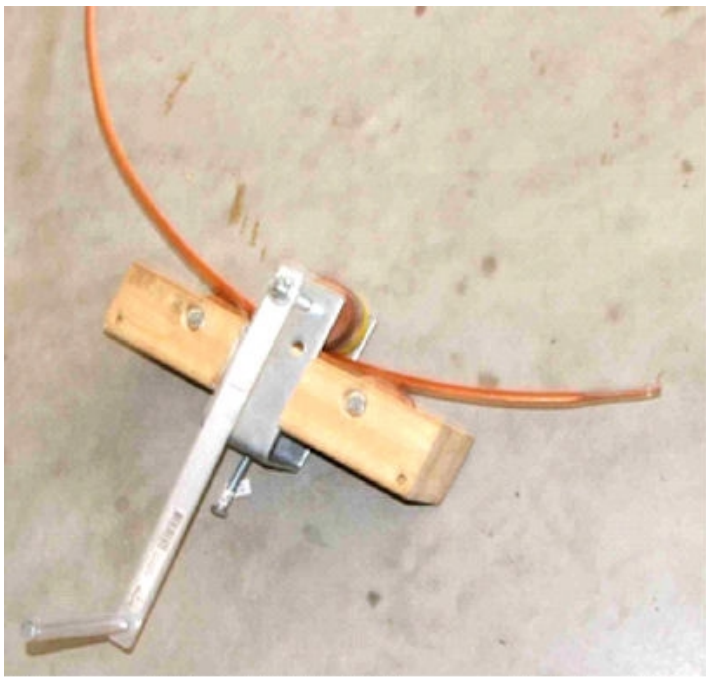


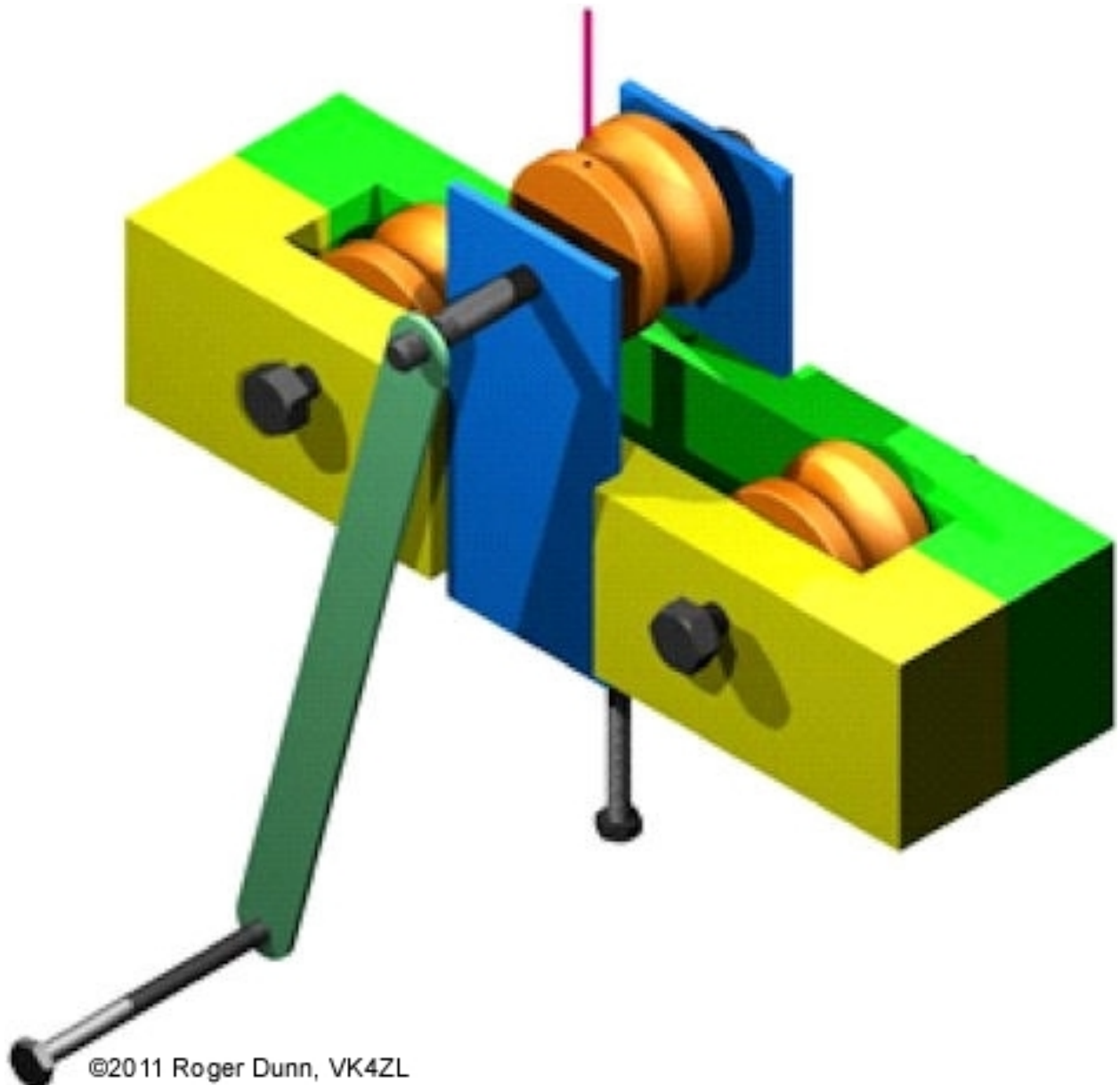
Figura 71: Diagrama de mi segundo STL

Mi segundo bucle es (casi) circular. Una empresa local que fabrica barandas para escaleras y balcones me dobló mi tubería de cobre. Sin embargo, se puede construir en casa una dobladora de tubos, pero solo funcionará *con* tubos *blandos* , no con tubos *endurecidos* (tratados térmicamente), que normalmente se venden como tubos rectos, no enrollados.



©2011 Roger Dunn, VK4ZL

Figura 72: Dobladora de tubos construida por Roger Dunn (VK4ZL)
(descripción: ref.10; fotos e imagen utilizadas con permiso)



©2011 Roger Dunn, VK4ZL



Figura 73: Una robusta dobladora de tubos fabricada por Twan van Gestel (PA0KV)

(Fotos utilizadas con permiso; su gran lazo con condensador de vacío motorizado se describe en [su sitio web](#) [pdf])

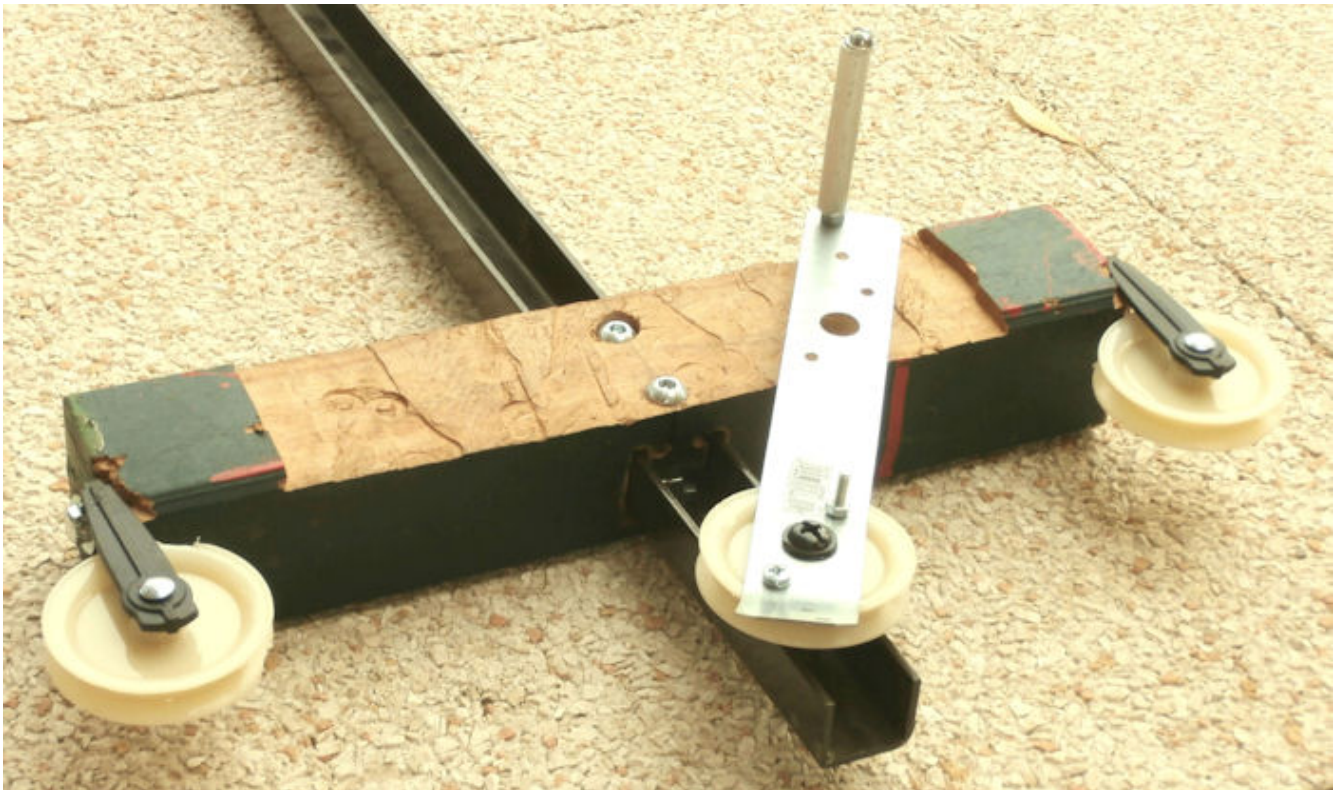


Figura 74: Un doblador de tubo ajustable que hice para mi [tercer STL](#) (más pequeño)

(mi tercer STL está hecho de un tubo de cobre blando de 12 mm (0,5"))

Hice abrazaderas para el condensador de vacío con una tira de cobre suave, de unos 2-3 cm de ancho (≈ 1 ") y 2-3 mm de grosor (≈ 0.1 "). He jugado con la idea de platear el bucle de cobre y las abrazaderas para reducir aún más la resistencia a la pérdida de RF (ref. 9A), pero puede que no valga la pena el

esfuerzo (ver la mitad de la página de la ref. 9B). Las abrazaderas están dimensionadas de manera que la circunferencia interior sea aproximadamente 1-2 mm demasiado pequeña para las tapas de los extremos del condensador. De esta manera, cuando aprieto el perno de la abrazadera, queda bien y apretado. Usé pernos de acero inoxidable y una arandela de acero inoxidable pesada en ambos lados de la abrazadera. Cuadré las arandelas para que encajen mejor y también para que toquen todo el ancho de la parte circular de la abrazadera. Pellizqué (con cuidado) los extremos del lazo de cobre con un par de alicates vise-grip™ (de bloqueo).



©2012 Frank Dorenberg NASPP

Figura 75: Abrazadera de conexión de cobre para mi condensador de vacío

La "botella" del condensador de vacío ahora está unida directamente al mástil, con dos grandes bridas. Con mi primer STL, las bridas se pasaron a través de las ranuras de la placa de montaje. Aquí, se pasan a través de ranuras en el mástil de PVC. Las abrazaderas no inmovilizan por completo el condensador. Sin embargo, una vez que los extremos del bucle de cobre se unen a las abrazaderas, la instalación es bastante estable.



Figura 76: Mi condensador de vacío, conectado al mástil y conectado al lazo

Terminé de construir el bucle en enero de 2013 y tomé algunas medidas con mi analizador miniVNA. Usé un anillo de ferrita FT-240-31 para el acoplamiento. La primera medición, con un solo devanado secundario (solo un cable pegado una vez a través del anillo de ferrita), mostró una impedancia de aproximadamente 10-12 ohmios. Entonces, necesitaba una relación de transformación de 4: 1 para acercarme a 50 ohmios. Es decir, un transformador de corriente 2: 1. Entonces dupliqué el número de vueltas secundarias a 2. También agregué un estrangulador de corriente 1: 1 justo en el transformador de acoplamiento. Los gráficos confirman la idoneidad del material de ferrita tipo 31 para las frecuencias más bajas.

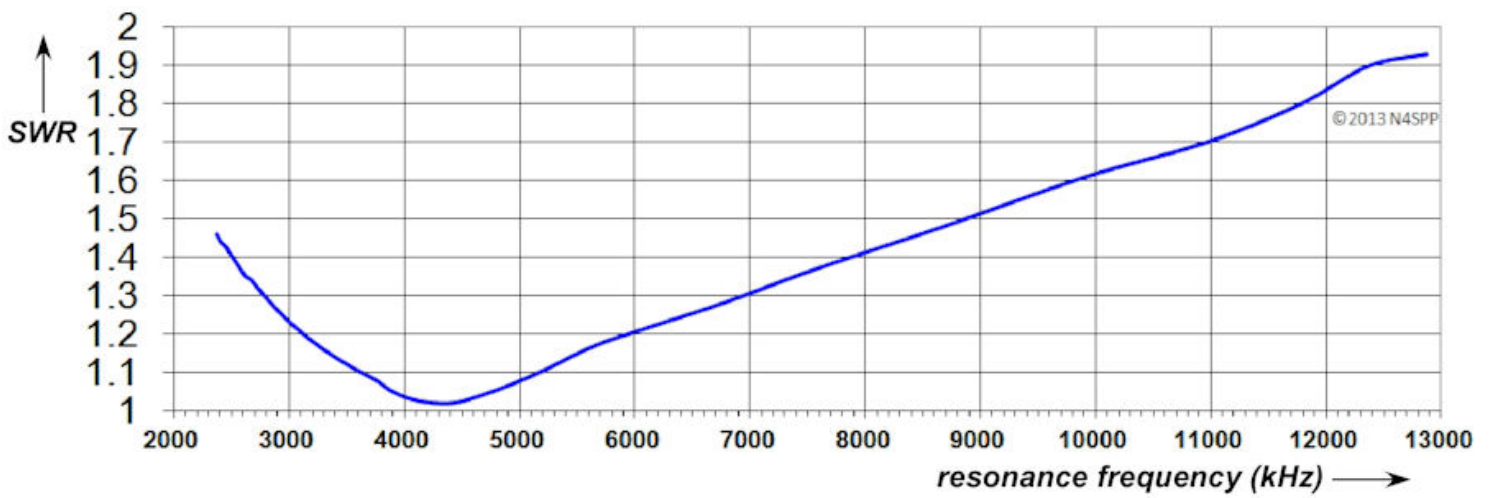


Fig.77: Transformador de acoplamiento: núcleo de ferrita FT240-31 con 2 espiras secundarias, inductancia de corriente 1: 1 en el punto de alimentación

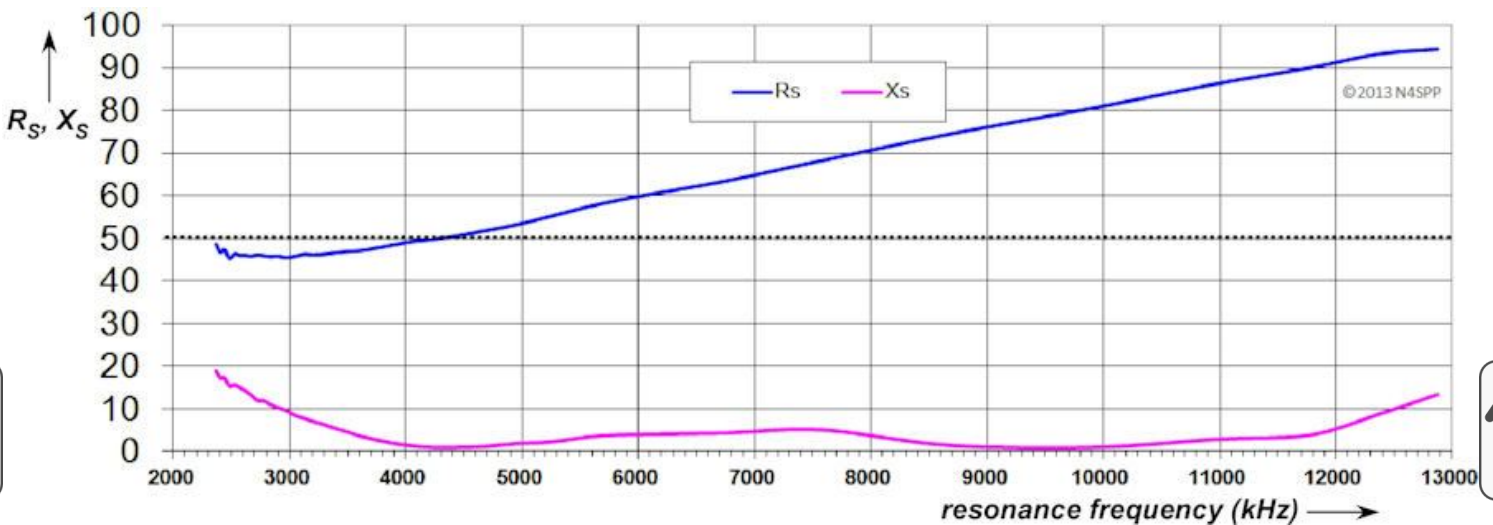


Fig.78: Transformador de acoplamiento: núcleo de ferrita FT240-31 con 2 espiras secundarias, inductancia de corriente 1: 1 en el punto de alimentación

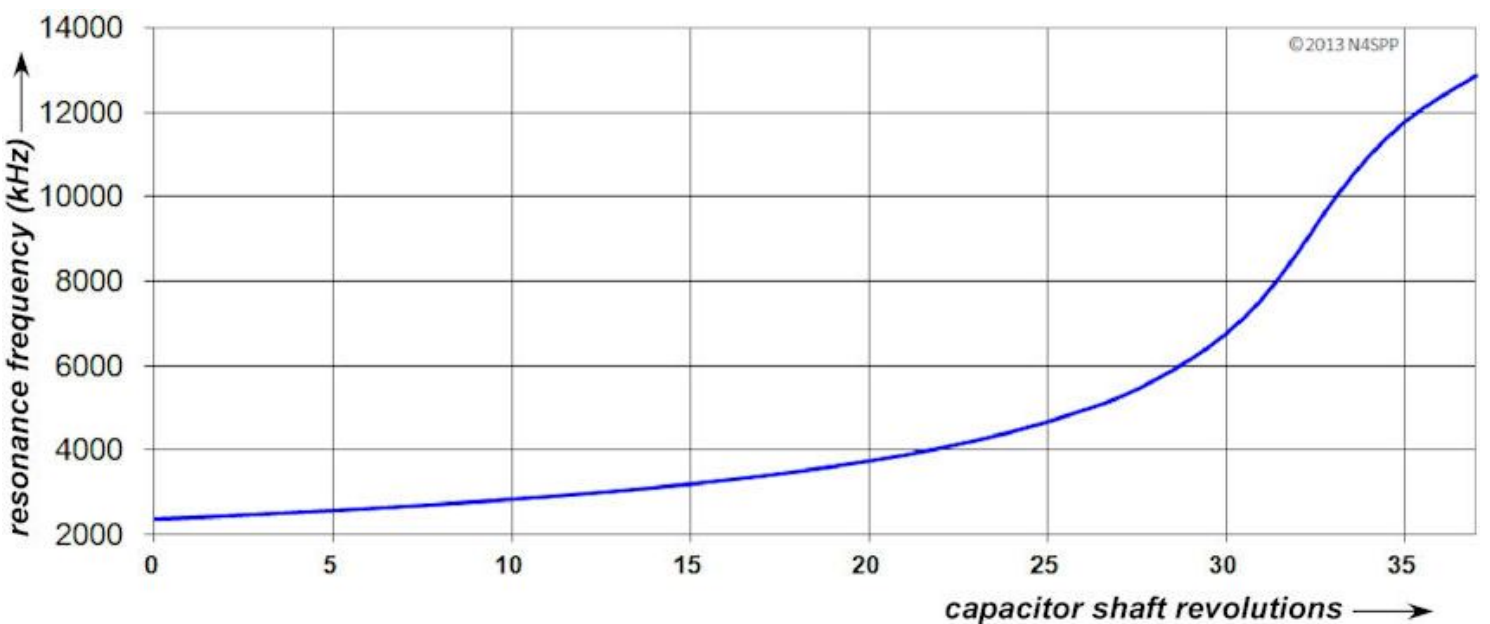


Fig.79: Transformador de acoplamiento: núcleo de ferrita FT240-31 con 2 espiras secundarias, inductancia de corriente 1: 1 en el punto de alimentación

Medí los siguientes valores de ROE para varias ubicaciones del transformador de ferrita alrededor del bucle principal:

Ferrite position	SWR	R_s	X_s
0° = at capacitor	1.1	47.5	3.9
45°	1.1	48.8	4.7
90°	1.1	48	4.4
125°	1.07	48.9	3.3
180° = opposite capacitor	1.04	50	1.8

Fig.80: ROE para varias posiciones del transformador de ferrita alrededor de la circunferencia de mi STL
(transformador: 2 vueltas secundarias en FT-240-31 core, 3600 kHz,)

También probé un bucle de acoplamiento estándar de tamaño 1: 5, hecho de tubería de cobre suave estándar de 1/4 de pulgada (6.3 mm) . Monté el lazo de acoplamiento en el mástil de PVC de 63 mm con abrazaderas de PVC, por lo que su posición es fácil de ajustar hacia arriba y hacia abajo, y girar alrededor del mástil. Inicialmente, había montado el bucle de acoplamiento con el conector BNC en la *parte inferior* , es decir, cerca del bucle principal. Como tenía el conector BNC en el *exterior* del bucle de acoplamiento, el espacio entre el bucle de acoplamiento y el bucle principal es bastante grande. SWR era bueno, pero quería aprovecharlo al máximo. En lugar de hacer un bucle de acoplamiento con el conector BNC en el *interior*, Acabo de dar la vuelta al bucle de acoplamiento. Ahora el bucle de acoplamiento podría colocarse muy cerca del bucle principal. Vea también la discusión sobre el acoplamiento alrededor de la Fig. 25-27 anterior.

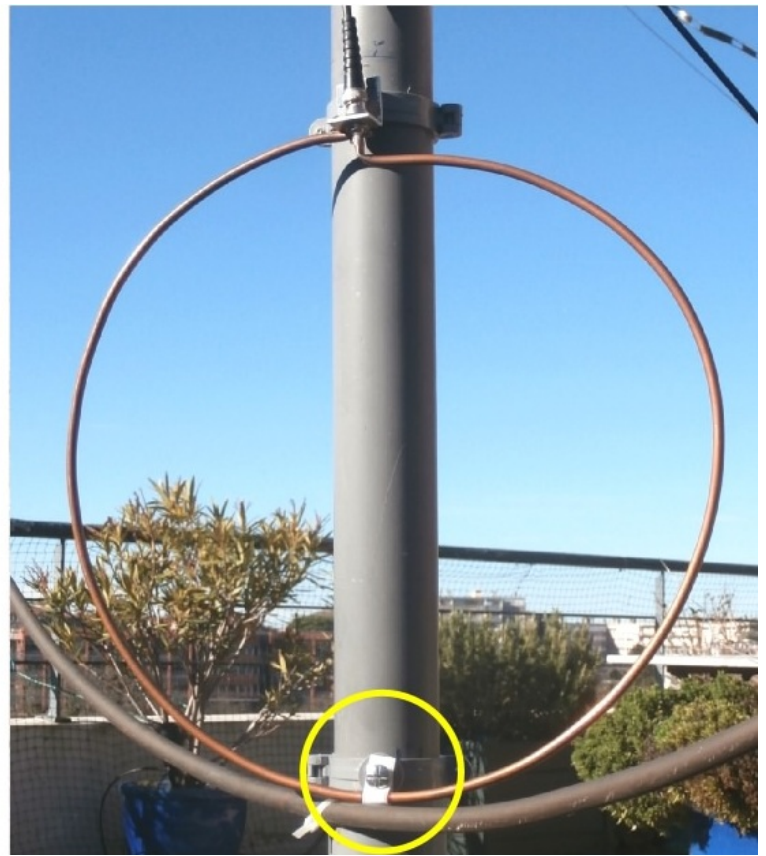
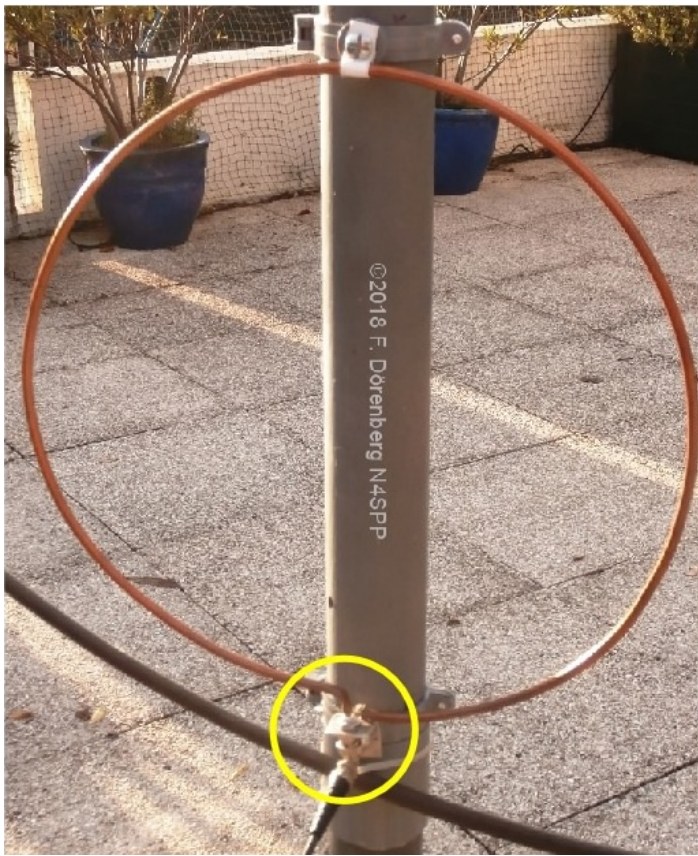


Figura 81: Las dos configuraciones de mi lazo de acoplamiento
(el conector BNC está montado en un pequeño soporte en L de aluminio)

Tenga en cuenta que en las dos fotos de arriba, el plano del bucle de acoplamiento no está alineado con el plano del bucle principal: el bucle de acoplamiento se gira alrededor del mástil hasta que se obtiene la ROE más baja. Entonces, sobresale a ambos lados del plano del bucle principal. Sin embargo, para una ROE mínima, el ángulo entre los dos bucles es mayor en la foto de la derecha. Esto es de esperar, ya que el acoplamiento es más estrecho. Si el bucle de acoplamiento hubiera sido un poco más pequeño, el ángulo requerido también habría sido menor.

Prefiero este tipo de bucle de acoplamiento a los métodos de acoplamiento del transformador de anillo de ferrita. Motivos: fácil de ajustar, sin límites de potencia, mayor rango de frecuencia.

Con ambas configuraciones, SWR es bastante bueno en un rango de frecuencia de al menos 1: 3 (en mi caso, 80-30 m). La segunda configuración es básicamente perfecta en ese rango. El pequeño ancho de banda confirma la muy alta "Q".

Coupling loop with BNC at bottom

Frequency (MHz)	SWR
3.584	1.1
7.085	1.2
10.140	1.3
14.075	2.5

©2018NASPP

Coupling loop with BNC at top

Frequency (MHz)	SWR	Bandwidth (kHz) SWR=2	Bandwidth (kHz) SWR=1.5
3.583	1.03	3.2	1.9
7.090	1.05	10.2	5.8
10.120	1.15	16	8
14.110	1.92	13	-

Fig.82: ROE frente a frecuencia para las dos configuraciones de bucle de acoplamiento: condensador de sintonización en la parte superior del bucle principal

(la posición del bucle de acoplamiento se optimizó para 80 m; "BNC en la parte inferior" frente a "BNC en la parte superior" solo afecta la distancia entre el bucle de acoplamiento y el bucle principal)

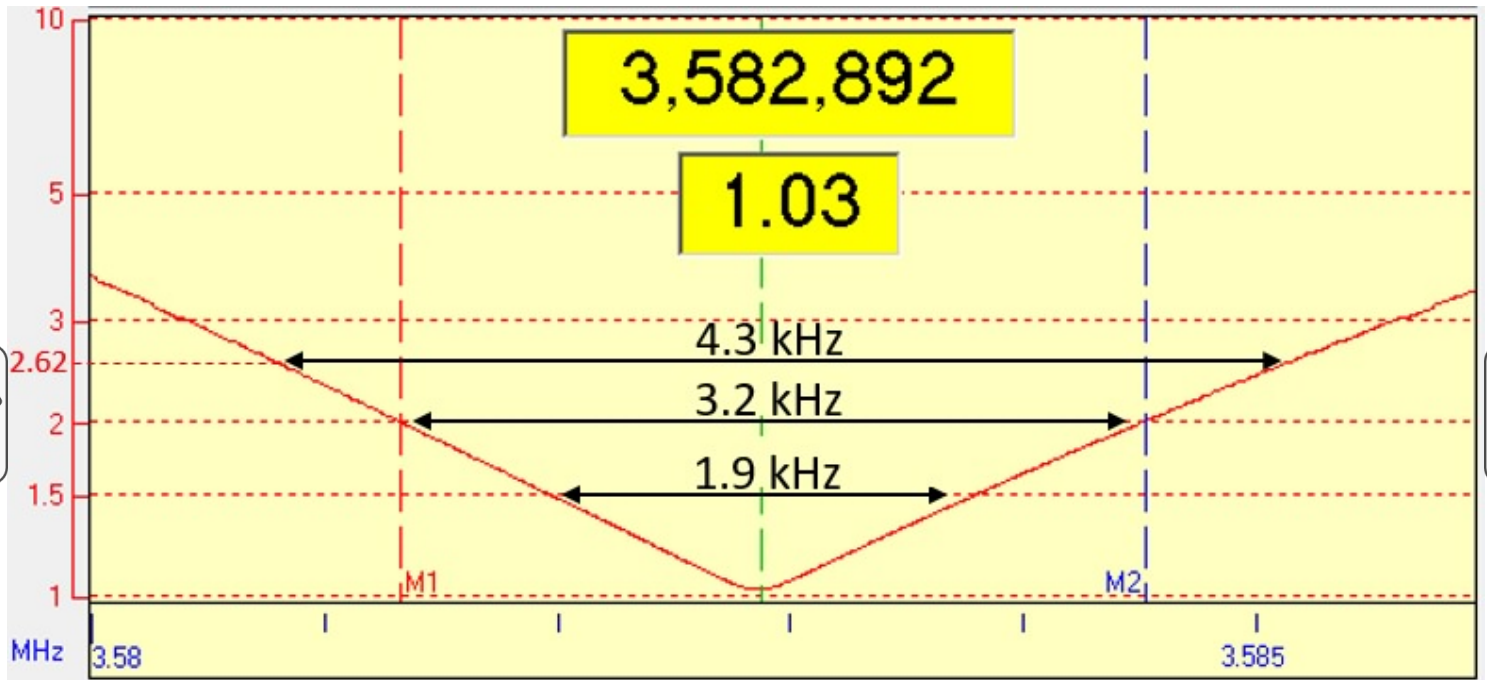


Figura 83: ROE frente a frecuencia en la banda de 80 m

La siguiente tabla muestra la eficiencia y "Q" de mi bucle, calculada con una calculadora en línea (ref. 2G) para el ancho de banda de ROE medido que se muestra en la Fig. 81:

Inputs:		Results:	
N4SPP Mag Loop Antenna		Perimeter (λ)	0.0729
Frequency for min VSWR (<1.5) (MHz)	3.583	-3dB BW (kHz)	4.24
Loop type	Cirde	Q	845
Loop perimeter (m)	6.1	Loop inductance (μH)	6.18
Conductor diameter (mm)	13.3	X (Ω)	139
Min VSWR	R<R0	Cs (pF)	7.81
VSWR	1.03	Rtotal (Ω)	0.165
Bandwidth @ VSWR (kHz)	2.618	Rradiation (Ω)	0.00557
Rr/Rrfs (pu)	4.3	Efficiency (%)	3.387
Directivity (dB)	1.000	Efficiency (dB)	-14.7
	1.761	Gain (dBi)	-12.9
Calculate			

Figura 84A: Cálculos basados en mediciones en la Fig.81
(calculadora: ref. 2G)

Con esta calculadora de particular, la "Q" resultante es 845 y la eficiencia es de alrededor del 3,4%. Tenga en cuenta que esta calculadora asume que la antena se coloca en un espacio libre. Es decir, lejos del suelo y de los objetos. Se utilizaron los ajustes predeterminados de la calculadora para los parámetros "Rr / Rrfs" y "directividad", en lugar de ajustarlos para efectos de suelo.

Con base en la inductancia del lazo (6.18 μH) y "Q" (845) como se calculó anteriormente, y asumiendo una potencia de transmisión de 100 W, el voltaje pico a través del capacitor a la frecuencia de resonancia de 3.583 MHz se puede estimar con la siguiente fórmula (ref. 2H):

$$V_{peak} = \sqrt{2 \times P_{transmit} \times Q_{loop} \times X_{loop}} = \sqrt{2 \times P_{transmit} \times Q_{loop} \times 2\pi \times f_{res} \times L_{loop}}$$

$$= \sqrt{2 \times 100 \times 845 \times 2\pi \times 3.583 \times 10^6 \times 6.18 \times 10^{-6}} \approx 4850$$

Para el mismo ancho de banda de media potencia medido, las fórmulas de la ref. 3E rinde una "Q" de 833 y una eficiencia del 7%, también para espacio libre:

están separados por 6 m (20 pies). El suelo de la terraza también es de hormigón armado.



Figura 85: Situación de colocación de STL en mi terraza

En un extremo de la terraza, hay un voladizo de hormigón armado y una pérgola de vigas en I de acero resistente a tierra a la pared con la terraza del vecino. En la parte superior del voladizo, hay una vista libre en todas las direcciones y la antena está a unos 25 m (80 pies) sobre el nivel de la calle. Cuando puse mi antena aquí (con mi pesado paragüero de hierro y la parte inferior del bucle a 75 cm sobre la superficie), apuntando en la misma dirección, sucedieron dos cosas. En primer lugar, SWR cambia de 1.1 a 1.3. No tan bueno (la potencia se reduce en un porcentaje o 2), pero no me molesté en ajustar mi bucle de acoplamiento. A pesar de este deterioro, mis señales en una estación receptora DX en 80 mtrs (ca. 1000 km, 620 mi) aumentaron de 1/2 a 1 punto S, es decir, de 3 a 6 dB. ¡Esto equivale a duplicar la potencia!

A fines de 2019, hice un experimento similar. Esta vez, pegué el mismo lazo en [mi mástil de manivela telescópica de 6 metros](#) . Elevé la parte inferior del bucle a unos 4 m (\approx 13 pies) por encima del suelo de la terraza. La frecuencia de resonancia cayó alrededor de 2 kHz. Tanto el condensador de

sintonización como [el bucle de acoplamiento están motorizados](#) , por lo que podría optimizar fácilmente la ROE sin bajar la antena. En el mismo receptor remoto, la señal recibida era ahora 1-2 puntos S más fuerte que con el bucle a 75 cm ($\approx 2,5$ pies) sobre el suelo de la terraza. ¡Eso es el equivalente al aumento de potencia en un factor de 2-4! No hace falta decir que estoy bastante satisfecho con esta actuación. La diferencia / mejora se explica por varios factores.

Aumentar la altura de la instalación (aquí: de <0.01 a 0.05λ en 80 mtrs) disminuye las pérdidas del terreno (absorción) (ref. 2K).

Nota: el suelo de mi terraza consta de baldosas de cemento grandes, elevadas 10 cm (4 pulgadas) por encima de la base de hormigón con pedestales. La mayor parte del año, hay agua debajo de toda la terraza (¡afortunadamente, los mosquitos no parecen reproducirse allí!).

El patrón de radiación, la impedancia del punto de alimentación y las pérdidas se ven afectados por los objetos cercanos:

Objetos conductores cercanos como línea de alimentación de antena, cercas metálicas (p. Ej., La barandilla de mi terraza conectada a tierra y la pérgola conectada a tierra), canaletas metálicas para lluvia (la mía mide aproximadamente 60 m de zinc de largo), líneas eléctricas domésticas (p. Ej., El cableado de mi sistema de iluminación de terraza), tuberías de agua, árboles y plantas.

Reflexiones (y "apantallamiento") de las paredes, el piso y las estructuras de acero circundantes.

Objetos dieléctricos como suelo local y terreno cercano, la estructura de la vivienda, árboles y plantas, personas y animales.



@2020 Frank Dörenberg N4SP



Figura 86A: Mi STL cerca del piso de la terraza y 4 mtrs arriba

A fines de febrero de 2021, decidí tomar algunas medidas más. Los diagramas polares en la siguiente figura muestran cómo la ROE y la frecuencia de resonancia varían cuando mi antena está instalada en un paragüero de acero pesado (parte inferior del bucle a 60 cm (2 pies) sobre el piso de la terraza) y se **gira** 360 ° con pasos de 10 °. A 60 °, el plano del bucle apunta directamente a la pérgola de acero y paralelo a la pared de hormigón blanco en las fotos de arriba (la pared exterior paralela de mi apartamento no es visible en estas fotos). Claramente, esta es una situación con un acoplamiento complejo entre la antena de bucle y el entorno, en particular las barras de refuerzo de acero en las paredes y en el piso debajo de las baldosas, así como la pérgola de acero, que también está conectada a tierra de la red eléctrica. sistema. Claramente, este acoplamiento complejo varía cuando se gira la antena y / o se cambia la altura de instalación.

La rotación se inició con el plano del bucle en la dirección norte-sur (0 °), una frecuencia de resonancia de 3579,24 kHz y el bucle de acoplamiento se ajustó para obtener la mejor ROE (1,03):

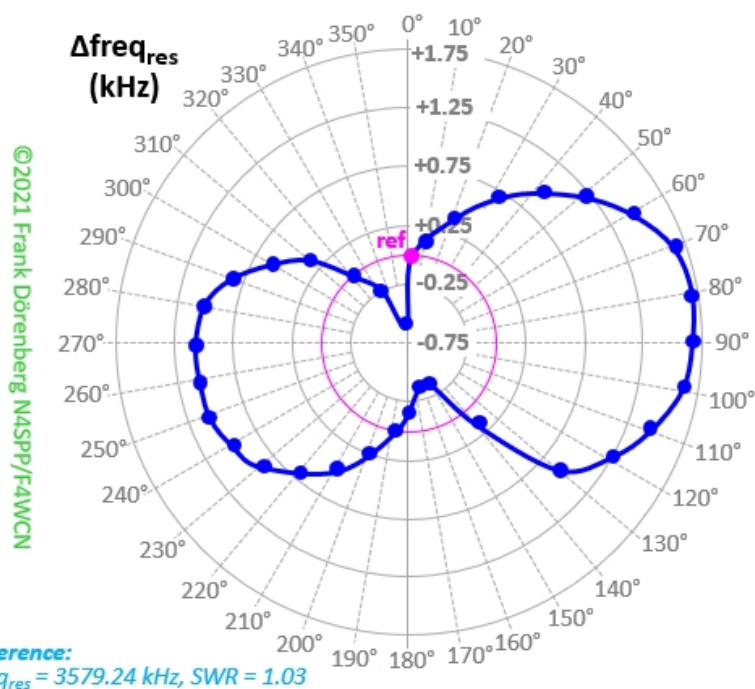
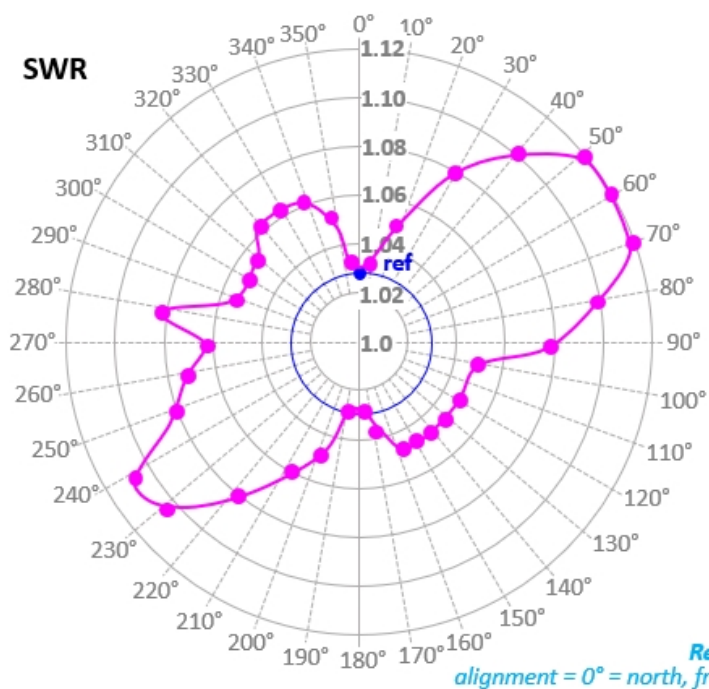


Figura 86B: variación en SWR y FREQ_{res} cuando mi antena es girada - en mi ubicación, a una altura fija
(la parte inferior del bucle está a 60 cm (2 pies) sobre el suelo, como en la imagen de la izquierda en la Fig.84A)

La frecuencia de resonancia varió en 1,75 kHz como máximo (casi el 5%) y la ROE aumentó de 1,03 a 1,12 como máximo. Es decir, no es necesario ajustar el lazo de acoplamiento. Nota: los cambios de frecuencia y ROE son bastante sensibles a cómo el cable coaxial y el cable de control de crivación del motor se dirigen lejos de la antena. La asimetría en la dirección Este-Oeste se debe a la asimetría del bucle y de las paredes y estructuras metálicas más grandes de mi terraza. Vea la Fig. 86A arriba. No estoy seguro del valor atípico alrededor de 270 ° en el gráfico de ROE. Tampoco tengo una explicación para la diferencia de 20 ° en la dirección con la desviación máxima en los gráficos SWR y Δfreq_{res} ...

Para medir la dirección, simplemente pegué mi teléfono inteligente en la parte superior del [capó](#) de [mi motor](#) con un trozo de cinta adhesiva de doble cara y usé la aplicación de brújula del teléfono:

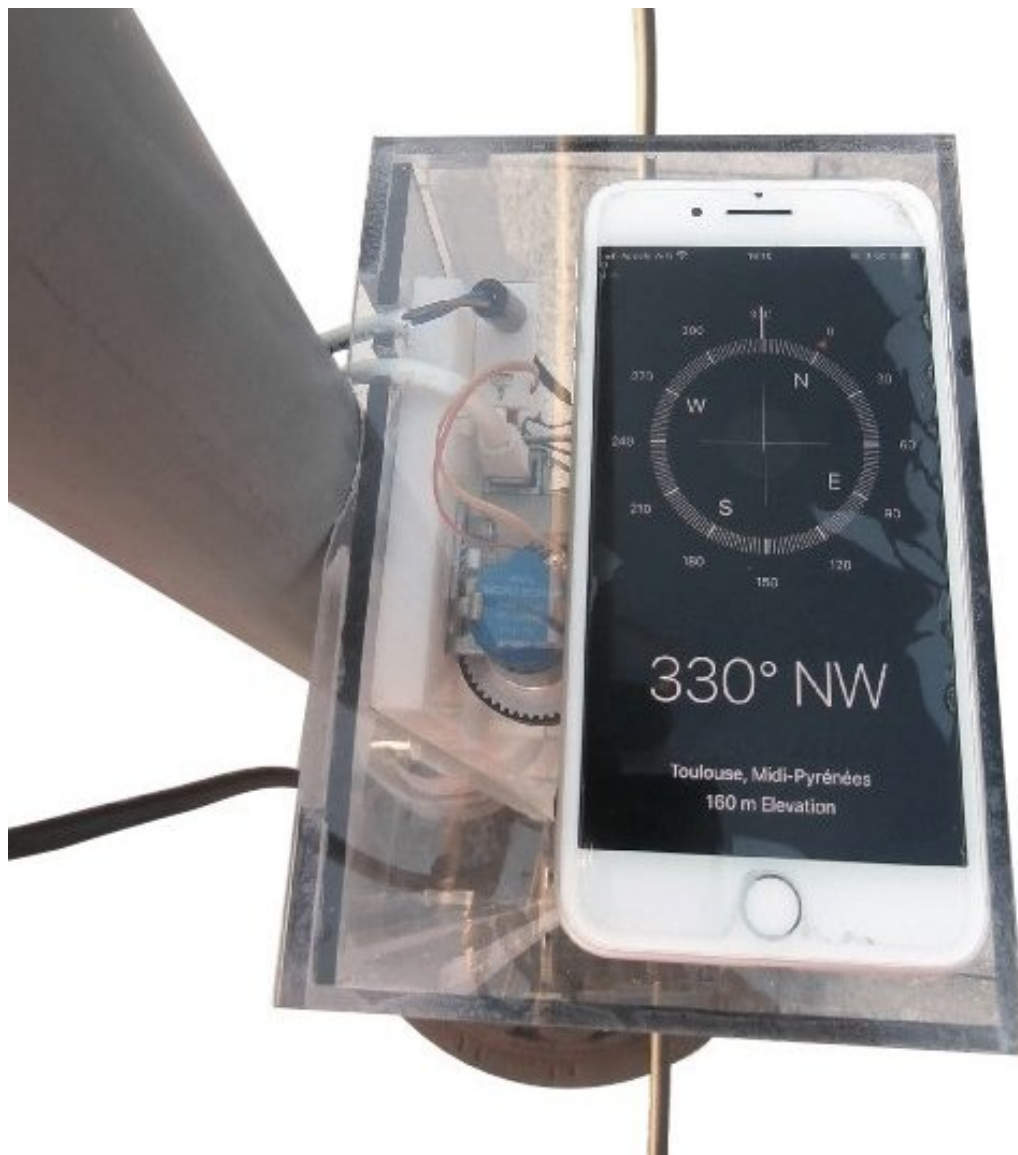
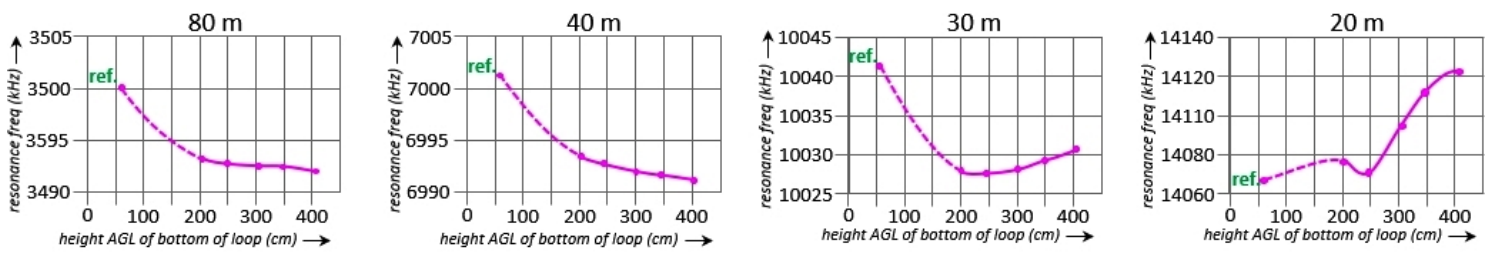


Figura 86C: midiendo la dirección del plano del bucle con la función de brújula de mi teléfono inteligente

El SWR y $FREQ_{res}$ variación es mucho mayor cuando se aumenta la altura de instalación de la antena, en lugar de girar la antena a una altura fija. Los siguientes gráficos ilustran esto claramente. En cada parcela, se toma una medida de referencia con mi antena de cuadro en el paragüero y la parte inferior del bucle a 60 cm (2 pies) sobre el suelo. Luego coloco mi mástil telescópico en el mismo lugar que el paragüero (esto es fácil con [el trípode de mástil que construí recientemente](#)), y elevó la parte inferior del bucle con incrementos de 50 cm desde aprox. 2 ma 4 m. Mi antena de cuadro Mk 2 tiene una circunferencia de 6 m. Esto es aproximadamente 0.07λ , 0.14λ , 0.2λ y 0.28λ en las bandas de 80 m, 40, 30 y 20 m, respectivamente. Entonces, solo en la banda de 80 m es un bucle de transmisión pequeño: $<0.1 \lambda$, por lo tanto, amplitud de corriente casi constante alrededor de la circunferencia. Todas las mediciones se realizaron con [mi analizador de antena miniVNA](#) .



©2021 Frank Dörenberg N4SPP/F4WCN

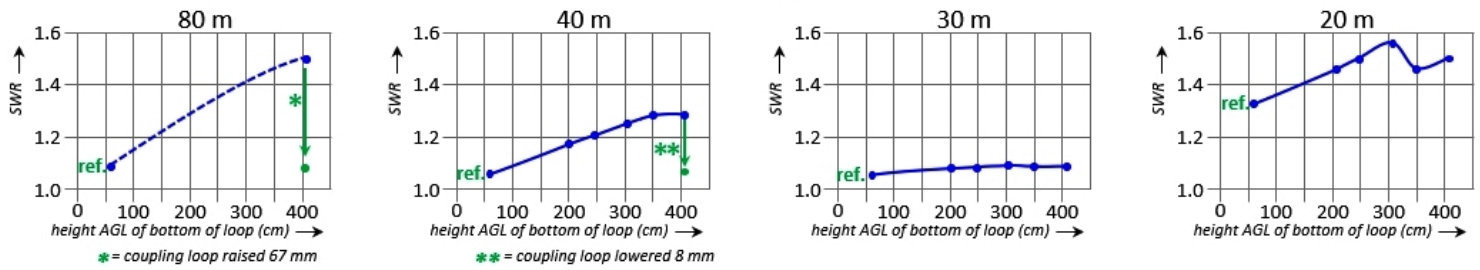


Figura 86D: variación en SWR y frecuencia *res* cuando mi antena está levantada - en mi ubicación
(solo se cambia la altura de instalación de la antena)

El aumento de ROE en las bandas de 80 y 40 m se corrigió fácilmente moviendo mi bucle de acoplamiento hacia arriba o hacia abajo, ¡por eso había hecho un [nuevo motor con control remoto](#) para hacer esto!

En general, y no del todo inesperado, las parcelas muestran que la variación es más pronunciada cuando se alejan del suelo y de la pérgola (a 2,5 m sobre el suelo). Tenga en cuenta que a 4 m (≈ 13 pies), la parte inferior del bucle está a una altura de aproximadamente $0,05 \lambda$, $0,1 \lambda$, $0,13 \lambda$ y $0,2 \lambda$ en las bandas de 80 m, 40, 30 y 20 m, respectivamente. Al elevar la antena, la frecuencia de resonancia parece disminuir primero y, por encima de una altura de aproximadamente $0,1 \lambda$, comienza a aumentar nuevamente. El cambio *más pequeño* en la frecuencia de resonancia se observó en la banda de 80 m: 8 kHz o 0,23%. El *mayor* cambio en la frecuencia de resonancia se observó en la banda de 20 m: 55 kHz o 0,4%. En las bandas de 40 y 30 m, el cambio fue de 11 kHz, o aproximadamente 0,14%.

Un factor que contribuye a la variación de la frecuencia de resonancia frente a la altura es la configuración del bucle: mi condensador de vacío variable bastante grande se encuentra en la parte inferior del bucle. Las placas cilíndricas de cobre del condensador son completamente unmallado a la frecuencia de funcionamiento más alta (= capacitancia más pequeña), y completamente mallado a la frecuencia más baja. La frecuencia de resonancia del bucle está determinada por su autoinducción y capacitancia: tanto inherentes como parásitas debido al acoplamiento con el entorno. Cuando se aumenta la altura del bucle, hay menos capacitancia parásita debido al acoplamiento a tierra. Esto es más notorio cuando el valor de capacitancia del condensador de sintonización es relativamente pequeño, es decir, a frecuencias de funcionamiento más altas, donde la inductancia total del bucle

es más dominante en la determinación de la frecuencia de resonancia. Como de costumbre, ¡todo es relativo!

En marzo de 2021, realicé algunas pruebas de transmisión en la banda de 80 m durante un período de 15 minutos poco después de la puesta del sol local (no 80 m DX hasta la puesta del sol). Normalmente uso receptores Web-SDR (disponibles las 24 horas del día, los 7 días de la semana) para tales pruebas, para ver mi propia señal en sus respectivos diagramas de cascada y en su medidor S. Para obtener las lecturas más limpias del medidor S, minimizo el ancho de banda ajustable del Web-SDR. Esta vez utilicé cuatro receptores Web-SDR simultáneamente:

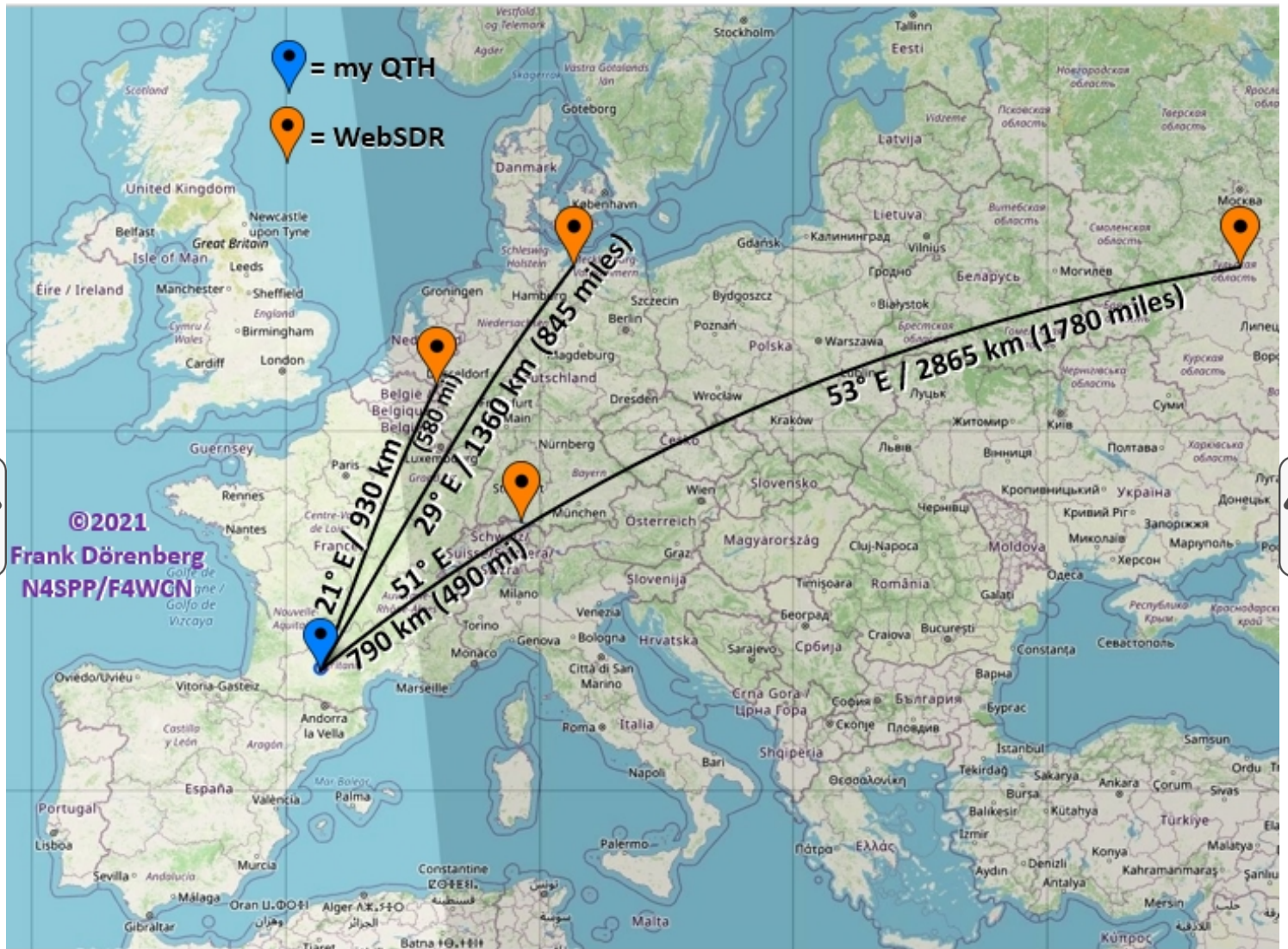


Figura 86E: mapa con ubicaciones Web-SDR relativas a mi QTH en el sur de Francia

(la mayoría de Web-SDR en todo el mundo están aquí: www.websdr.org)

La potencia de salida de mi transmisor era de alrededor de 100 vatios. El plano del bucle se alineó con la dirección de $\approx 20^\circ / 200^\circ$. Grabé la intensidad de la señal del medidor S de cada Web-SDR para tres configuraciones: **1)** mástil de antena instalado en el paragüero, parte inferior del bucle a 60 cm (2 pies) sobre el piso de la terraza, **2)** antena instalada en mi mástil telescópico, asomando entre las vigas de acero I de mi pérgola, la parte inferior del bucle

90 cm (3 pies) por encima de la pérgola, y **3) lo mismo**, pero la parte inferior del bucle 200 cm (6,5 pies) por encima de la pérgola. Tenga en cuenta que cuando mi antena está instalada en el paragüero, la pérgola protege la "vista" de la antena en la dirección de todos los Web-SDR que utilicé.

Station: N4SPP/F4WCN QTH: Toulouse/France QRA : JN03qo
 Date: 9 March 2021
 Local sunset: 18:53
 Antenna: Small Transmitting Loop / "Magnetic Loop".
 Loop circumference: 6 m Direction of plane of the loop: 22° E / 202° W
 QRG: 80m / 3592 kHz
 SWR < 1.2

Propagation condx:
 foF2 at Dourbes at 19:51: 3550 kHz

©2021
 Frank Dörenberg
 N4SPP/F4WCN

Solar-Terrestrial Data - http://www.n0nbh.com		Current Solar		HF Conditions	
09 Mar 2021 1848 GMT				Band	Day Night
SFI 77	SN 12			80n-40n	Fair Good
A 6 K 1 / P1ntry				30n-20n	Fair Fair
X-Ray 95.5				17n-15n	Poor Poor
304A 101.7 @ SEM				12n-10n	Poor Poor
Ptn Flx 39				Geomag Field	VR QUIET
Elc Flx 975				Sig Noise Lvl	S0-S1
Aurora 1/n=1.99					
MUF Boulder 21.55					

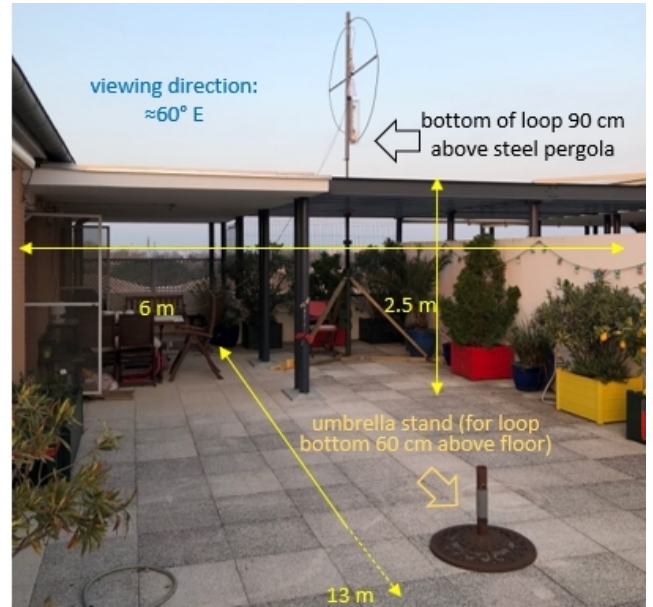


Figura 86F: condiciones durante mis pruebas y posiciones de la antena

The table below shows the data that I recorded. The very high local QRM level clearly went down for the highest installation. Signal strength at the remote receivers was about 1-2 S-points higher for the highest installation. This is equivalent to of a factor 4-16 increase in power!

RX	Bearing & distance from my QTH	S-meter readings for transmission of constant carrier		
		Loop 200 cm above middle of pergola Local time: 19:10	Loop 90 cm above middle of pergola Local time: 19:16	Loop 60 cm above terrace floor (in umbrella stand) Local time: 19:27
F4WCN / Toulouse / France	-	QRN/QRM: S6½ - 7	QRN/QRM: S7-8	QRN/QRM: S7-8
WebSDR Maasbree / Netherlands	24° E, 930 km	QRN/QRM: S4-5 MY SIG: S9	QRN/QRM: S3-5 MY SIG: S8-9+	QRN/QRM: S4-5 MY SIG: S7-8
WebSDR Wismar / northern Germany	37° E, 1360 km	QRN/QRM: S4-5 MY SIG: S6-8	QRN/QRM: S4-5 MY SIG: S6-8	QRN/QRM: S4-5 MY SIG: S5-6
WebSDR Tulla / Russia, south of Moscow	53° E, 2830 km (180 km south of Moscow)	QRN/QRM: S5-6 MY SIG: S6-7	QRN/QRM: S5-6 MY SIG: S6	QRN/QRM: S5-6 MY SIG: S3-4
WebSDR Lake Constance / Germany	57° E, 775 km	QRN/QRM: S2 MY SIG: S5-6	QRN/QRM: S2 MY SIG: S4-6	QRN/QRM: S2 MY SIG: not checked ☹️

Figure 86G: signal levels at four Web-SDR's for three different antenna positions & heights

Not bad at all!

EFFECTS OF CORROSION

I sometimes get emails from fellow amateur radio operators, who claim that the surface oxidation of the copper loop causes a significant increase in loss resistance. This would supposedly cause a significant decrease in performance. These operators claim that the loop should be polished until all oxidation is removed, and the copper is nice and shining. The same opinion can be found in forums. However, none of these people are able to provide *any* references from refereed, scientific literature, or from credible experiments, that support their opinion. Some of them actually report significant loss of performance. However, when I ask them, they cannot at all exclude that they have a problem with corroded contact surfaces between the loop and the tuning capacitor. Corroded connections do cause IR loss! And this is quite noticeable with "high Q" HF magnetic loop antennas and the associated high resonant circulating current levels, as well as rectification effects (incl. harmonics). If your STL is "high Q" (= narrow bandwidth at resonance, with SWR close to 1), then your antenna simply does not have any significant loss resistance - no matter how oxidized the loop is.

If you search around, you will quickly find out that there is little or nothing published on this topic. Which is why this misconception perpetuates... The following is my current understanding:

Copper oxides are semiconductors, and for HF antennas can be considered as insulators. Therefore, the longitudinal electric field is not high enough to overcome the potential barrier and there will be no conduction current along the antenna surface. Likewise the tangential electric field is not high enough to cause conduction current. There will be essentially little or no *conduction* current in the oxide. However, there will be *displacement* current (which is the kind of current that makes an antenna radiate, which is good).

I'm sure you are familiar with "skin effect". At RF, most of the current in the conductor flows in the outermost layer of a conductor. As frequency increases, the skin effect crowds the current into an increasingly thinner thinner part of the outermost layer of the conductor. This causes conductor loss to increase at higher frequencies. If we add an insulating layer to the outside of an antenna radiator conductor, nothing much changes, other than dielectric constant and VL - but not losses. Antennas made of insulated wires work without any problems. The current does not flow in the insulator, it is crowded into the conductive part of the wire/pipe/tube directly underneath the insulation.

When the outside of a copper conductor oxidizes, the diameter of the conductor is reduced by the tiny thickness of the oxide layer. On realistic tube/pipe diameters such as used for magnetic loop antennas, this reduction is negligible. Copper oxide is fairly good insulator (contrary to popular belief, silver oxide is not a good conductor), as are

most oxides. Of course, if copper oxide were a *good* conductor, you would not notice any difference in performance either.

Copper oxide *would* cause a problem if it were a half way decent conductor (which it isn't). In that case, RF losses would indeed go up significantly, as the skin effect would force the current into the less-conductive outer layer.

The possible significant losses with, e.g., copper oxide have to do with its relative dielectric constant (= relative electrical permittivity) and its relative magnetic permeability. This is a highly complicated matter, even for "pure-and-clean" conductors, see ref. 9C. These properties do indeed decrease the skin depth, thereby increasing losses. This is also why you want to avoid bare (= without copper or silver plating) iron and steel conductors for RF applications: iron oxide has a very high magnetic permeability. The effect of the permittivity and permeability depends on frequency.

Corrosion at connections will cause significant loss resistance! In my loop, I very carefully remove all corrosion before I tighten the connection between the ends of the loop and the capacitor brackets. If I loosen the connection a year or two later, they are still perfectly clean, with no visible corrosion. The loop itself, however, is fully covered with black copper oxide (CuO, "cupric oxide", tenorite). Note that this oxide is a p-type semiconductor. Fully oxidized connections may cause strange rectification effects on small signals.

Conclusions:

For **HF** frequencies, there is no credible theory or evidence that surface oxidation on the loop causes significant loss resistance! Oxidized copper does have higher loss than bare copper, but this effect does not become noticeable until you get to the upper portion of VHF and above. **However**, oxidized copper contact surfaces (e.g., between loop and tuning capacitor) do cause significant losses!

MOTOR DRIVE FOR THE VACUUM CAPACITOR

My loops are installed on the terrace of my penthouse apartment, so they are quite accessible. Even so, it is entirely impractical having to go outside several times to manually adjust the capacitor position when changing operating frequency, or when the resonance frequency drifts away for whatever reason. Standing next to the loop also de-tunes it a bit. The loop has a very narrow

bandwidth, esp. on 80 m. A remote-controlled motor-drive for the capacitor is a must! The basic motor options are a stepper motor (*D*: Schrittmotor, *F*: moteur à pas), and a DC motor. Especially with a DC motor, down-gearing will be required.

[\[Stepper motor\]](#)

[\[DC motor\]](#)

STEPPER-MOTOR DRIVE

When I built my first STL, I could not figure out an easy way to motorize the vacuum capacitor with a DC-motor, while providing end-stop protection at both ends of the motion range of the shaft (36 revs). So, why not make a little science project out of it?

Primary parameters for the motor-drive are:

- required minimum torque at the capacitor shaft,
- required minimum angular resolution, and
- drive speed.

Note that "precision" and "accuracy" are not on this list. I am not particularly interested in the ability of the drive-system to move *exactly* to some (pre-)selected position, or exactly follow some predefined acceleration and speed profile. Depending on the outside temperature, the alignment of the moon, planets and the stars, etc., the exact capacitor shaft position for a given resonance frequency will vary. So, one will have to search around a bit anyway, for fine-tuning. It is important, however, to change the position just a tad.

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) manufactured by [Jennings](#): 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.

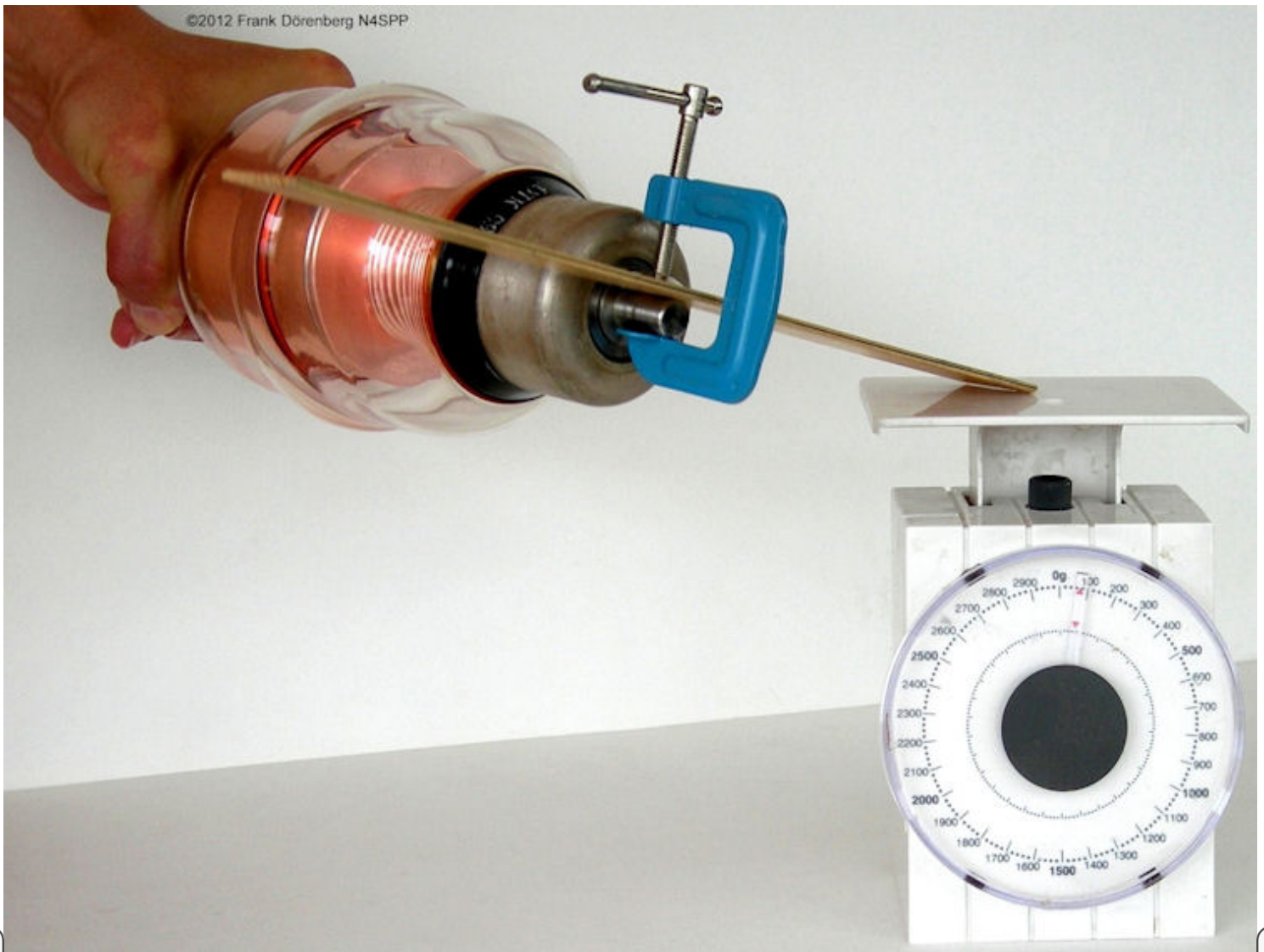


Figure 87: Determining the torque values of my capacitor

Here are the measurement results:

Depending on the turn-direction, I measured about 80 to 100 grams 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 gram, 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., $150 \text{ N.cm} (\approx 208 \text{ oz.in})$. If the motor-drive (motor + gearing) delivers less than this, I do not have to worry about not having end-stop protection. I decided to not measure the torque required to go beyond the end-stop of the capacitor, hihi.

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.

Let's simply assume that the capacitance changes linearly with rotation of the capacitor's shaft (which is actually only true for about 2/3 of the motion range). Then we get $500 \text{ pF} / (36 \text{ rev} \times 360^\circ \text{ per rev}) \approx 0.04 \text{ pF} / \text{degree}$. For my first STL, one of the loop calculators (ref. 2B) suggest the following:

In the middle of the 80 m band:

Calculated bandwidth is about 3.5 kHz. I actually measured 4.6 kHz for my loop. The difference is probably because I did not enter a value for additional loss resistance in the calculator...

A capacitance change of 1 pF results in a calculated change in resonance frequency of 4.2 kHz. I.e., 0.24 pF per kHz.

At the high end of the 20 m band:

Calculated bandwidth is about 52 kHz. I actually measured 61 kHz.

A capacitance change of 1 pF results in a calculated change in resonance frequency of 275 kHz. I.e., only 0.004 pF per kHz.

Clearly, variation around the minimum capacitance (highest frequency) is the critical case!

Let's assume that practical 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 $20\% \times 52 \text{ kHz} = 10.4 \text{ kHz}$. That is: $10.4 / 275 \text{ kHz/pF} = 0.038 \text{ pF}$! Based on the $0.04 \text{ pF} / \text{degree}$ change in capacitance as estimated (assumed) above, I need an angular positioning resolution of better than $0.038 \text{ pF} / 0.04 \text{ pF/deg} = 0.95 \text{ degree}$.

Note that an air variable capacitor goes through its 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!

A secondary design parameter is the **minimum drive speed**. We don't want to wait an hour for the capacitor position to move from min to max value, or 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 rev/sec.

Now we can choose a motor and associated drive electronics. Gearing must be added, as necessary for torque, speed, and/or position resolution. There

are two basic options:

Stepper-motor,

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). If the DC motor is not a brushless type, then (as a minimum) a noise suppression capacitor must be installed across the motor wires. Otherwise the brushes will generate electrical noise when tuning the antenna in receiver mode.

Open-loop control of a DC motor is simple. Apply DC power with the correct polarity, and turn off that power when at the target position. Speed can be controlled (again: open-loop control without position feedback, no speed regulator) with a cheap and simple Pulse Width Modulator (PWM) circuit, such as I used for [my third STL](#). Small DC-motors with large down-gearing are relatively inexpensive.

Stepper motors do not have built-in position feedback, but their movement *is* deterministic, as long as the motor does not stall or lose sync. Their control/driver electronics are more complicated than what is needed for DC-motors. 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...

When one of my colleagues donated a stepper-motor (thank you Helmut!), I decided to throw all caution to the wind, and go with that. It is an old 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, and as a 1.8° uni-polar DC stepper motor. As I needed better than 0.95 deg positioning resolution, at least 2:1 gearing is required.

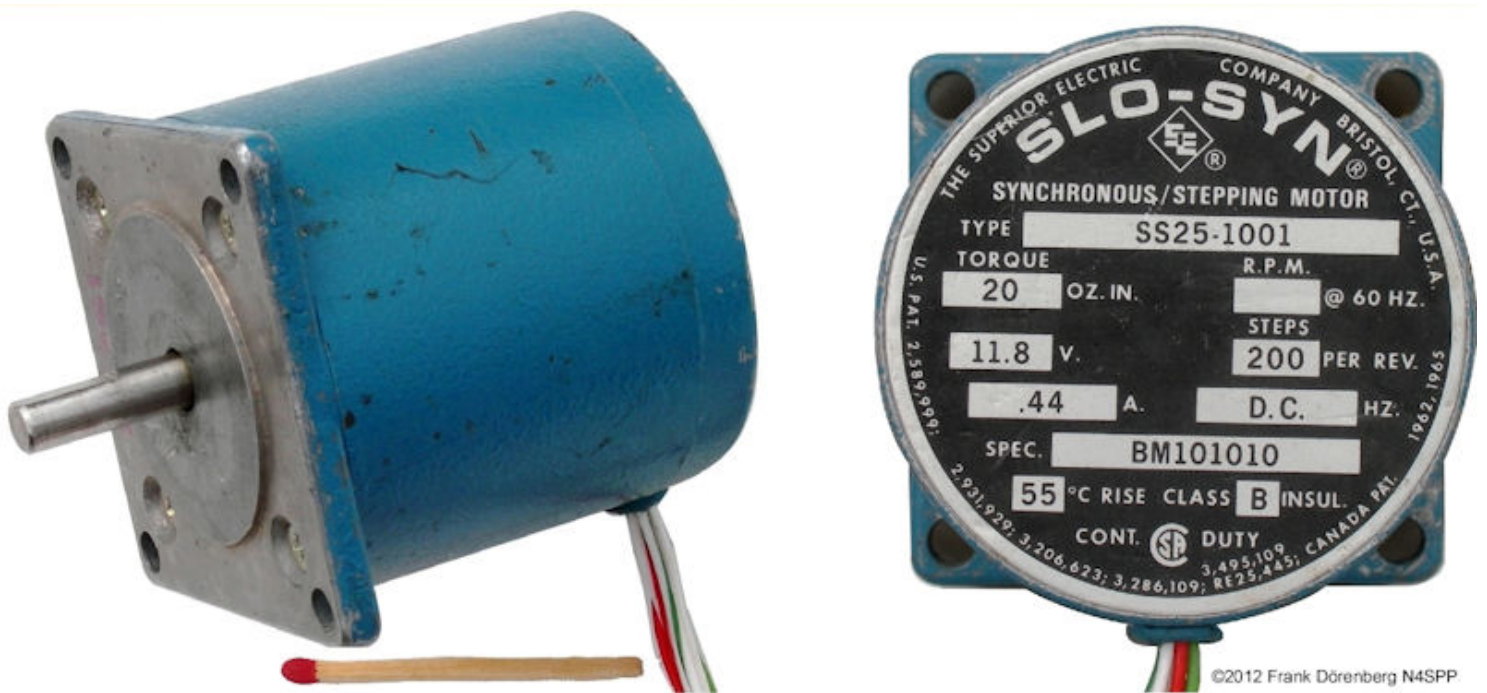


Figure 88: An old Slo-Syn SS25-1001 motor

"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)	15 (67)	25 (111)	23D	1.3	0.6

Figure 89: Specification of the Slo-Syn SS25 stepper motor

There are several kinds of stepper-motor 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 that is used.

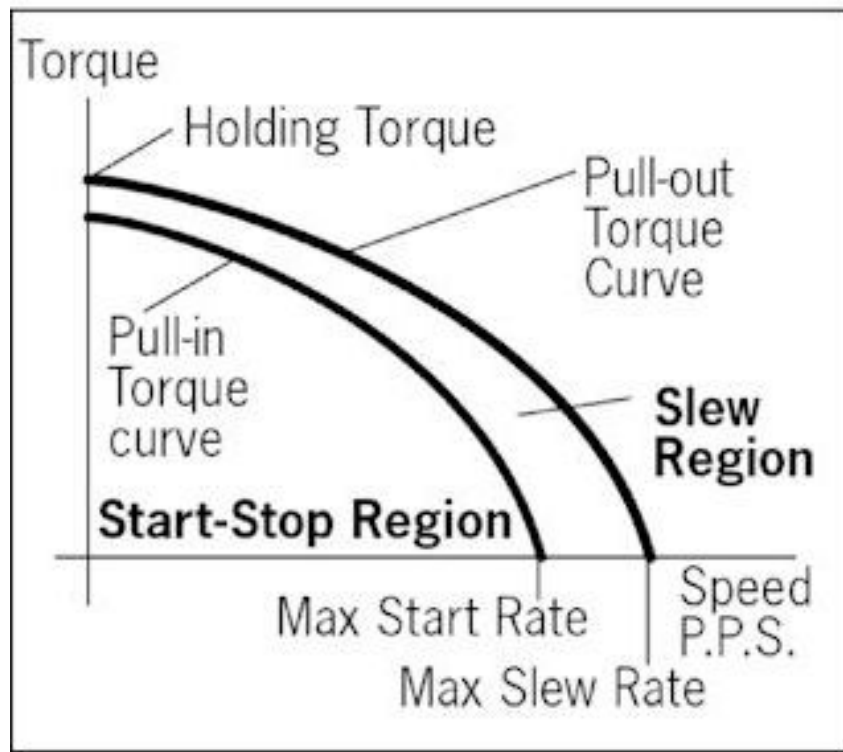
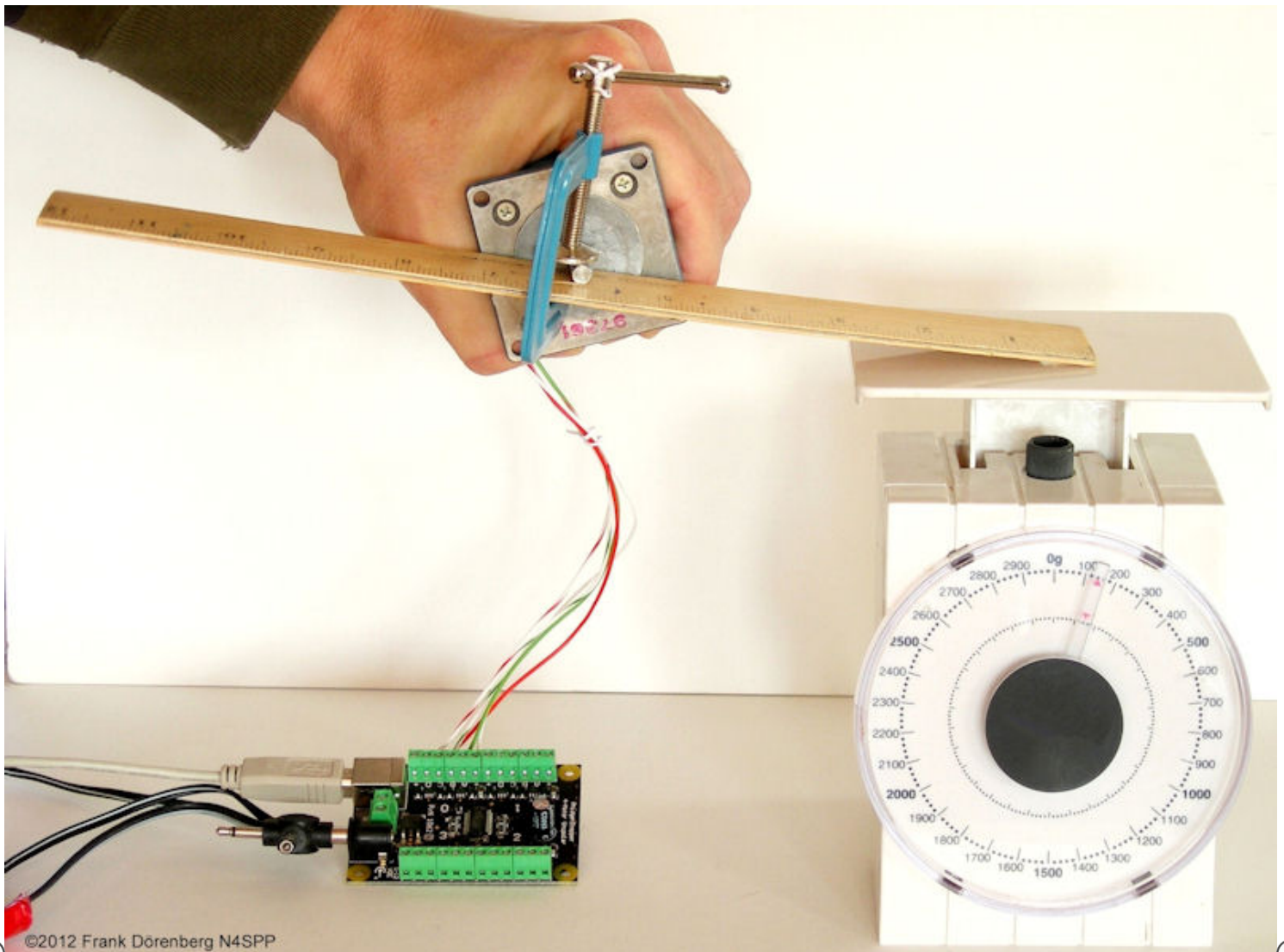


Figure 90: Typical shape of the torque curves

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! But why not determine the actually required 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.



©2012 Frank Dörenberg N4SPP

Figure 91: Determining the break-away torque value of my SS25 motor

With my 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 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.

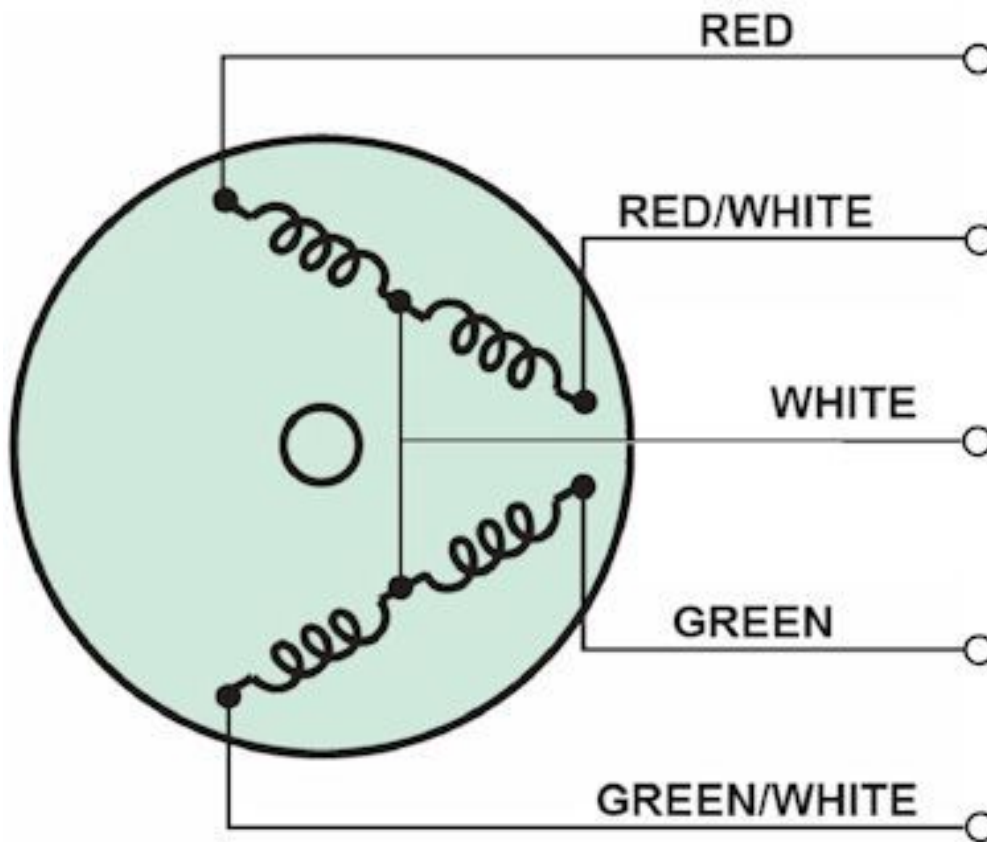


Figure 92: Wiring of the SS25

We have a motor, so now we need to control it. I wanted 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! It does come with some rudimentary software, to check out the card and the motor.

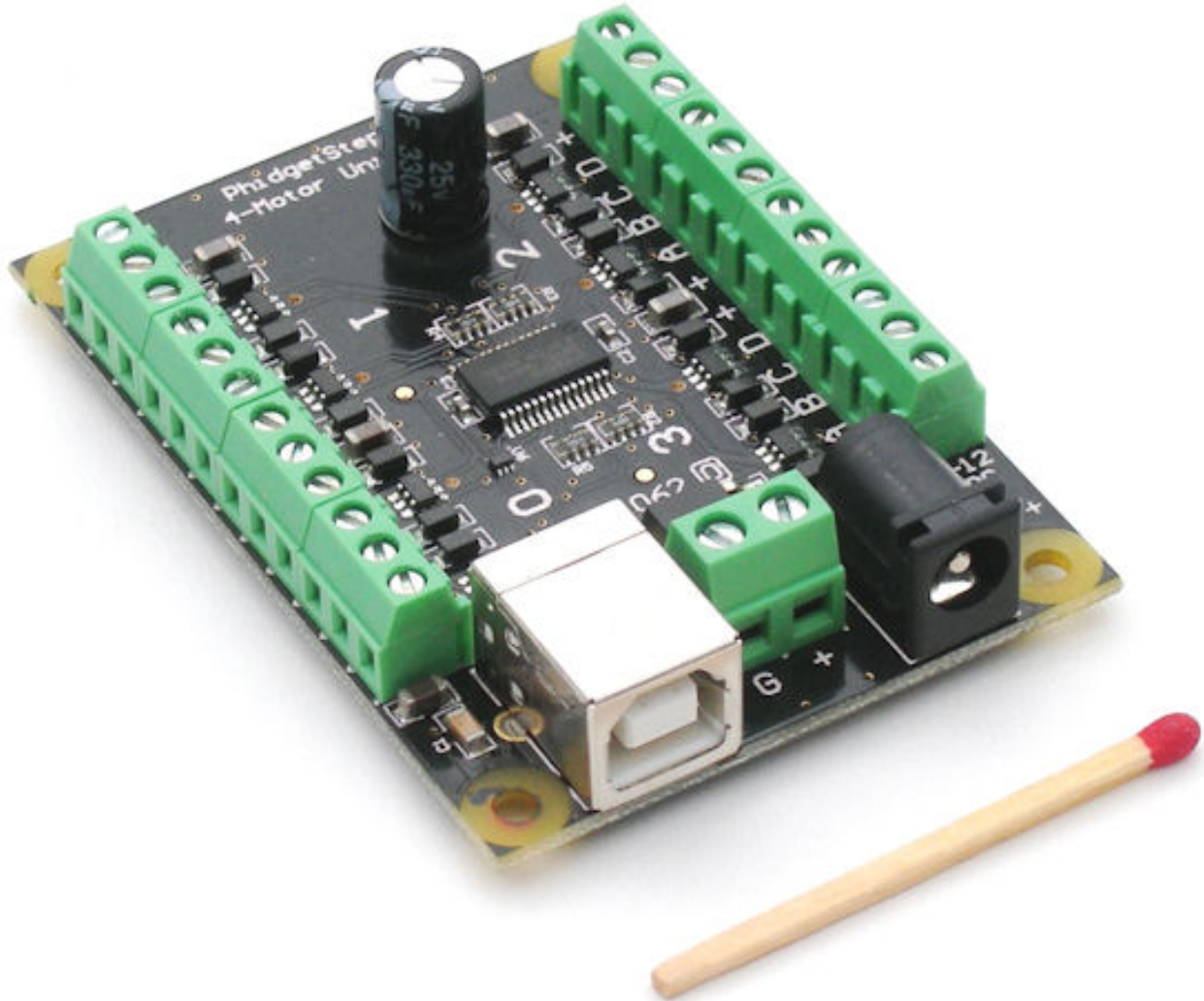


Figure 93: The small USB controller board for four uni-polar stepper-motors

The unipolar [Phidgets](#) card (model 1062) does not support speeds above 383 half-steps per sec! That is almost 1 rps with a 1.8 deg stepper motor (200 full steps/rev).

This Phidgets card uses half-stepping: the drive alternates between "two phases energized" and "single phase energized". This provides smoother motion and doubles the angular resolution from 1.8° to 0.9°. However, when half-stepping, 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) out of my SS25 motor! This means I will probably need a 4:1 gear ratio between the motor and the shaft of the variable capacitor...

Phidgets also sells a controller card (model 1063) for a single bipolar motor. As the name suggest, control of bipolar 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 very 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 (November 2011) and is quite pleased!

Some other controller hardware options are:

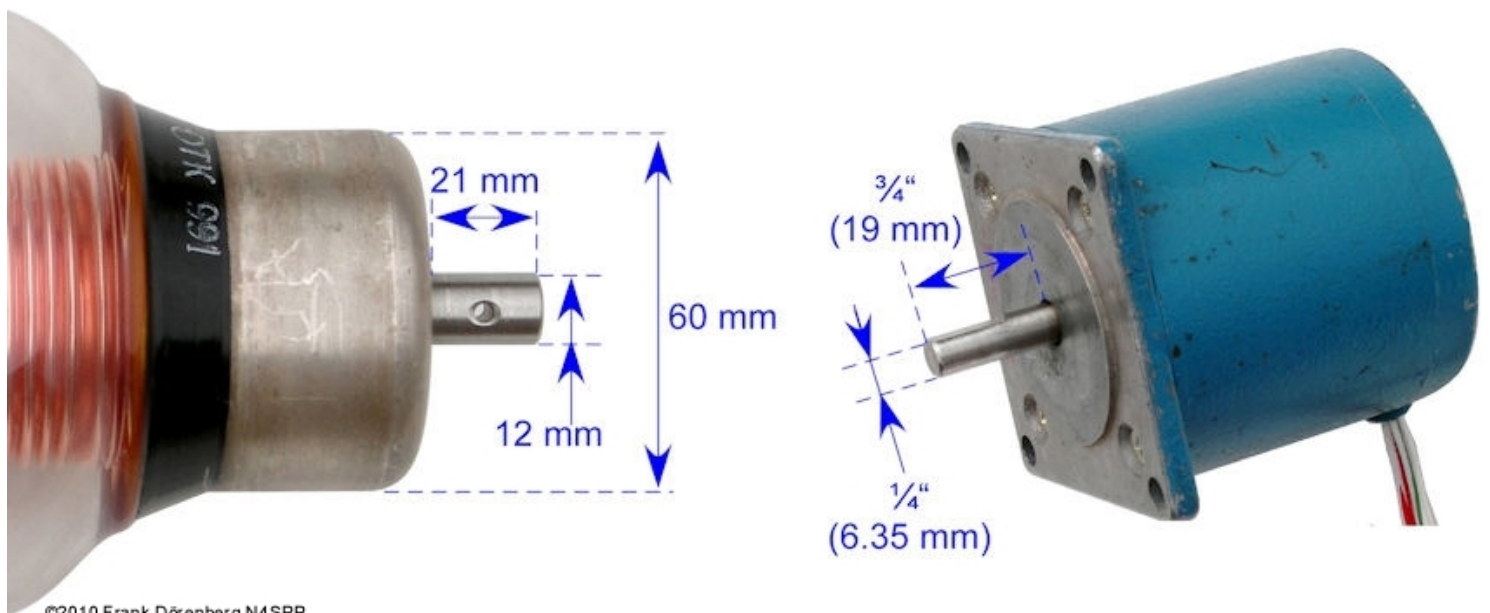
The "[Stepper-Bee](#)" card.

The "[Motor Hawk](#)" card. Twan van Gestel (PA0KV) has made a big loop (160-40) with a Gamma match, and used one of these cards for a stepper motor in his 2015 design. He made nice controller software in Visual Basic. See [here](#).

Both come with more useful demo software than the Phidgets.

External links last checked: January 2016

The next step is choosing a mechanical coupling of the motor to the shaft of the variable capacitor, including the necessary down-gearing.



©2010 Frank Dörenberg N4SPP

Figure 94: 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.



Figure 95: 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 of the belt (i.e., the distance between the centers of adjacent teeth). 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.



Figure 96: Plastic flanged pulley

Some 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 on 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 only half its circumference, unless the pulleys have the same size):

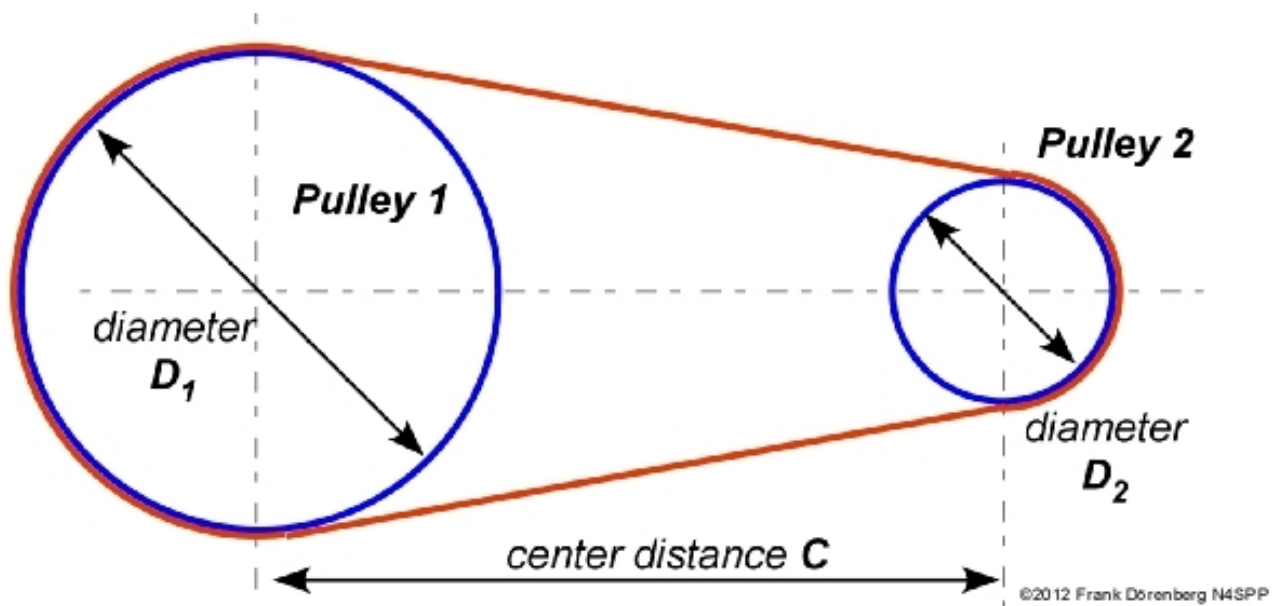
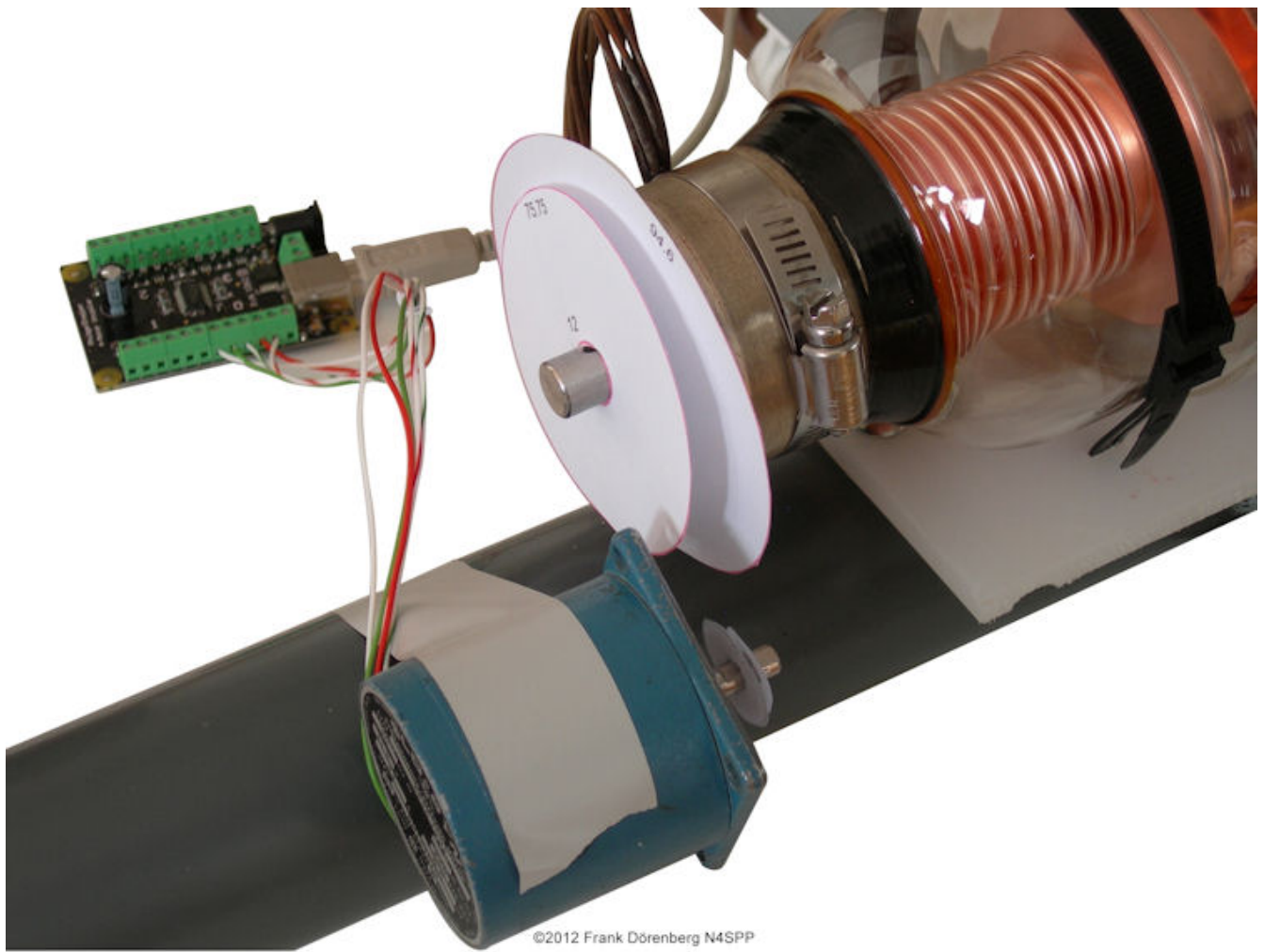


Figure 97: Pulley configuration parameters

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

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., a standard T2.5 x 6 x 200 belt.



©2012 Frank Dörenberg N4SPP

Fig. 98: paper disk "pulleys" on the motor and capacitor shaft to check dimensions and clearances

I installed the motor onto the antenna mast with two "worm drive" hose clamps (a.k.a. radiator clamps; *UK*: "jubilee[®] clips").



©2012 Frank Dörenberg N4SPP

Figura 99: Las poleas y la correa instaladas en el motor y el condensador (observe el "estrangulador" del toroide de ferrita de 5 vueltas en el cableado del motor)

NOTA : ¡Tuve que revisar mi elección de material de cinturón! El cinturón original fue reforzado con cordones de tensión de acero incrustados. Como puede ver en las fotos a continuación, esto provocó un arco entre la correa y la polea del motor. Afortunadamente, no se produjeron daños en la tarjeta controladora, la PC o mi transceptor. Claramente, se deben usar cinturones de poliuretano o neopreno reforzados con cordones de fibra de vidrio, poliéster o poliuretano.

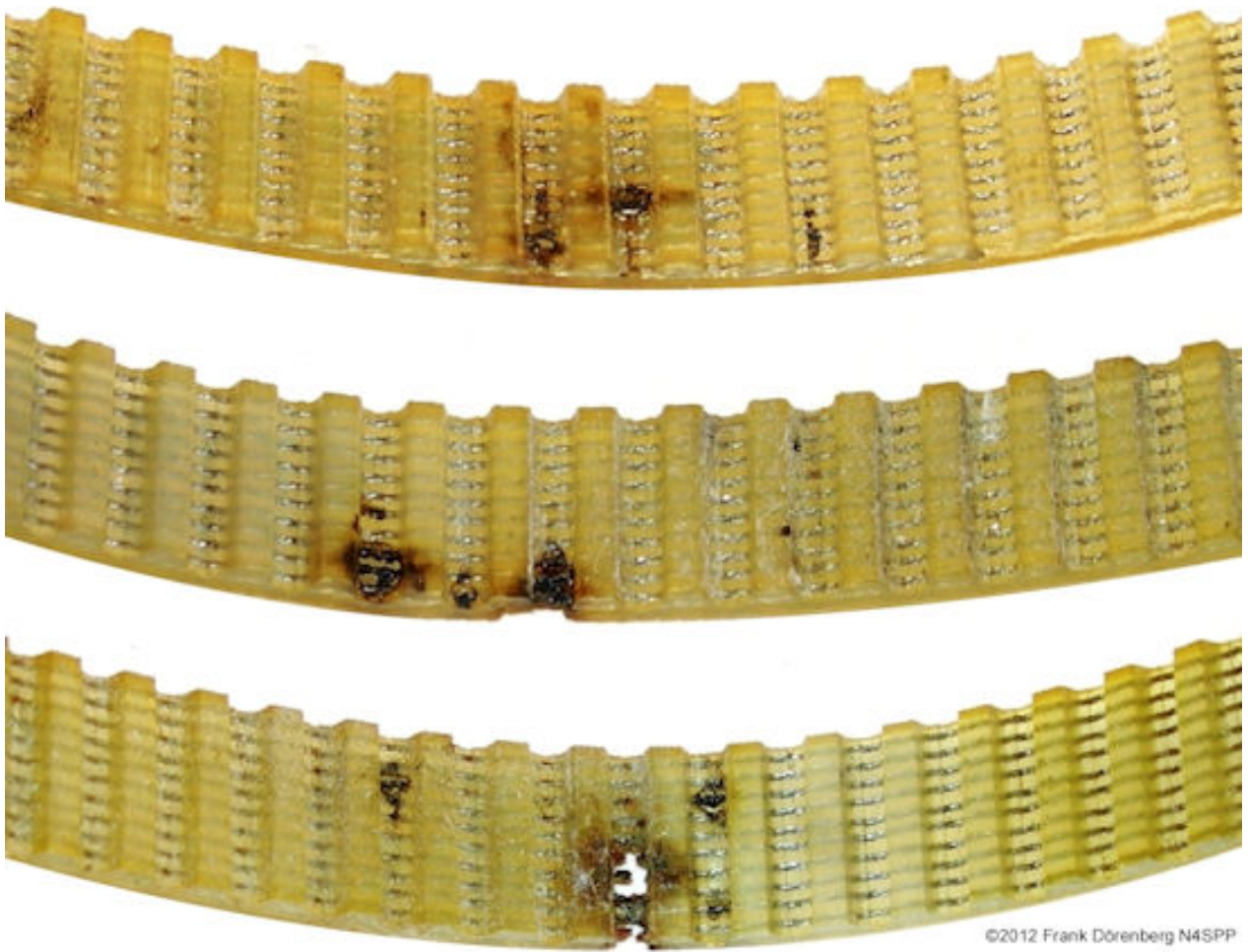


Figura 100: Daño por arco eléctrico en la correa reforzada con acero



Figura 101: Daño por arco eléctrico en la polea del motor paso a paso

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.

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 damage 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. This has been adequate so far (I use 100 W max).



Fig. 102: Toroidal current choke on the CAT5 cable between controller card and stepper-motor

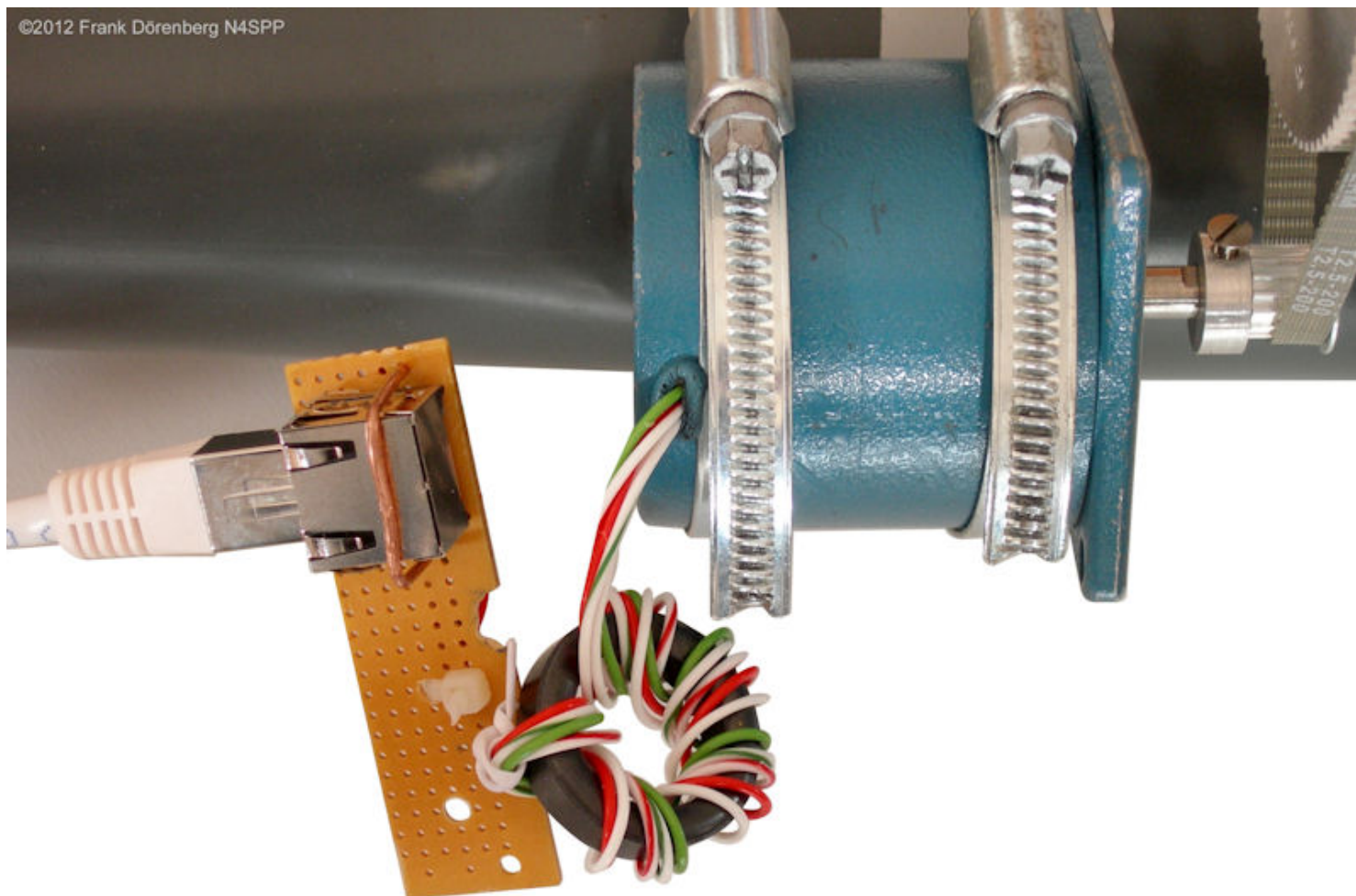


Figure 103: A second ferrite ring current choke is placed at the motor

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.

I may 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 regular 16 mm 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 3 adapters: 16-to-10, 10-10 (female-female), and 10-to-12 mm. I will install a ball bearing with 16mm bore on the rod, close to the motor.

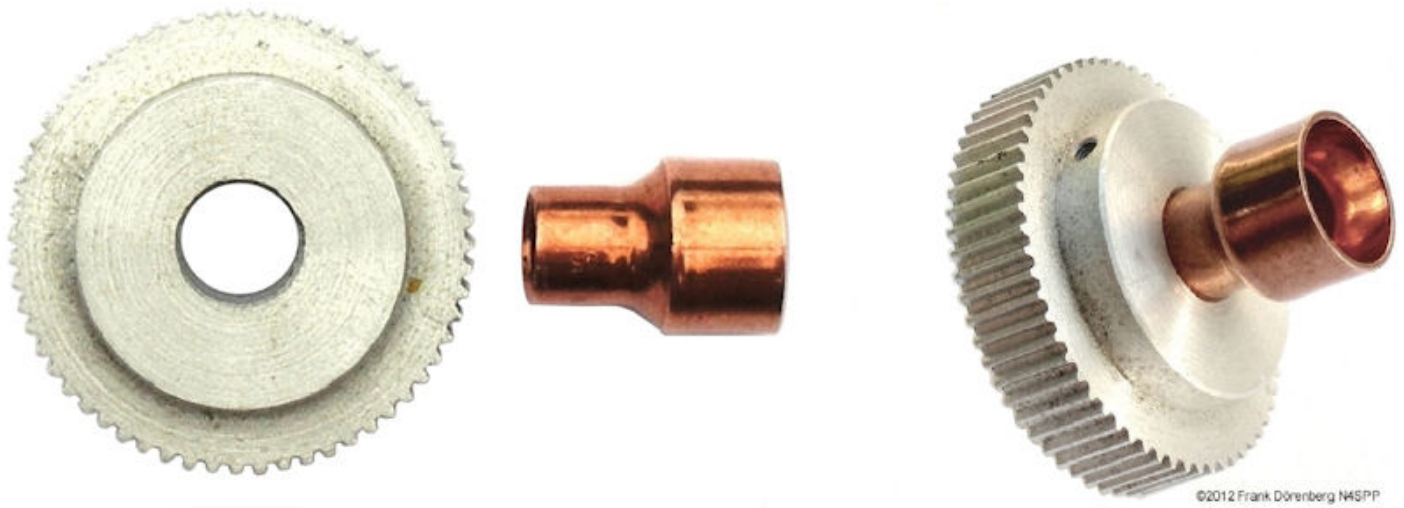


Figure 104: Gear wheel and copper adapter piece



Figure 105: Plastic drive-shaft with gear wheel installed

STEPPER-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 a quite decent controller with a nice Graphical User Interface (GUI). My GUI has three tabs: "Control", "Cal", and "Config".

Next time around, I may have a go at Visual Basic, though it is limited to "Windows". 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.

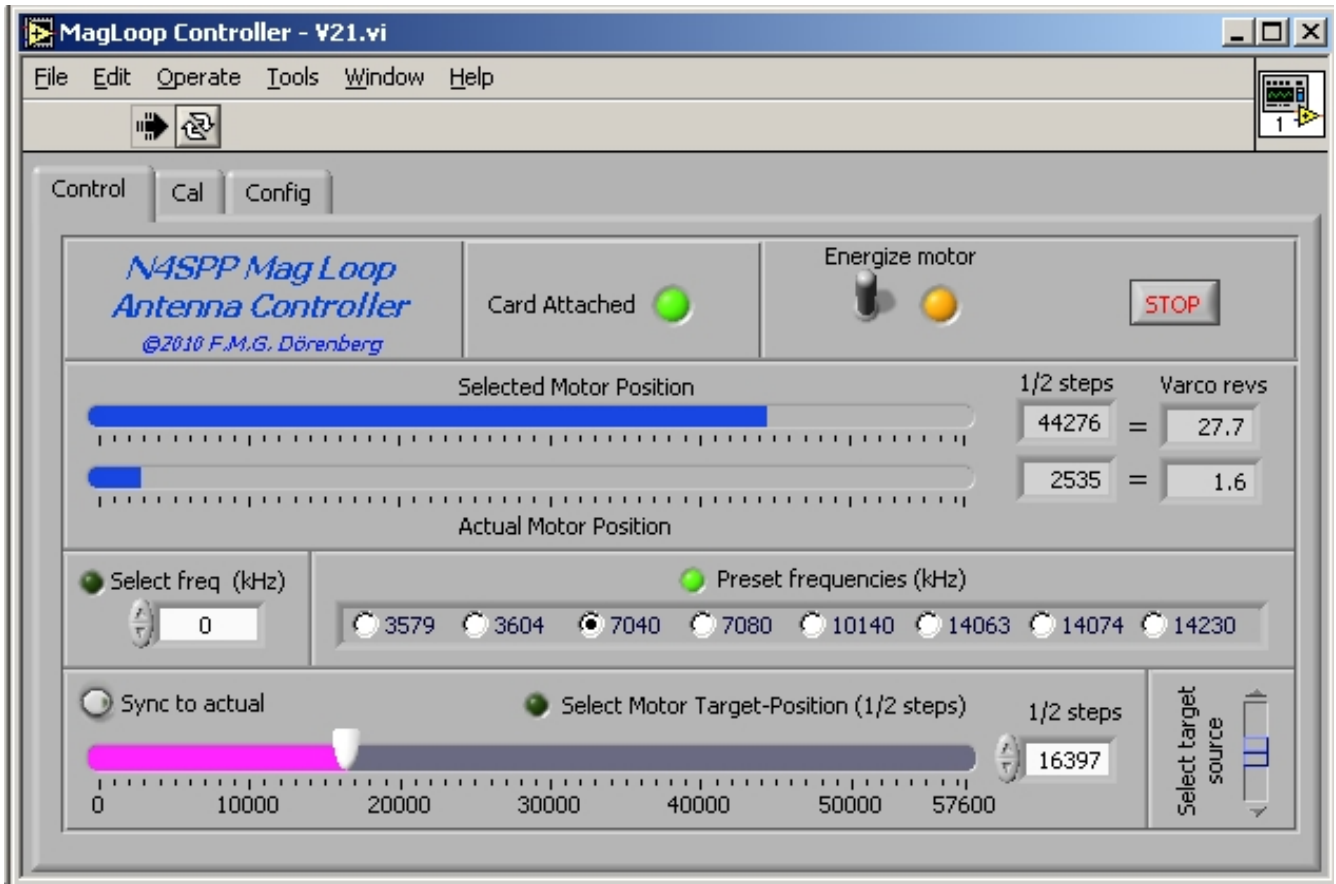


Figure 106: The "Control" tab of the GUI of my varco motor-drive control software

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.

Three ways to enter the desired motor position. A 3-position slide switch (lower right-hand corner) is used to select one of them (a small LED lights up next to the selected source):

Type-in the desired antenna frequency (followed by "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 $\frac{1}{2}$ -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 $\frac{1}{2}$ 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 of 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 ($\frac{1}{2}$ -steps/sec), the number of $\frac{1}{2}$ -steps per revolution of the motor, gear ratio between the motor and the tuning capacitor, offset ($\frac{1}{2}$ -steps), number of capacitor revs for end-to-end travel.

Preset frequencies of the operator's choice.

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).

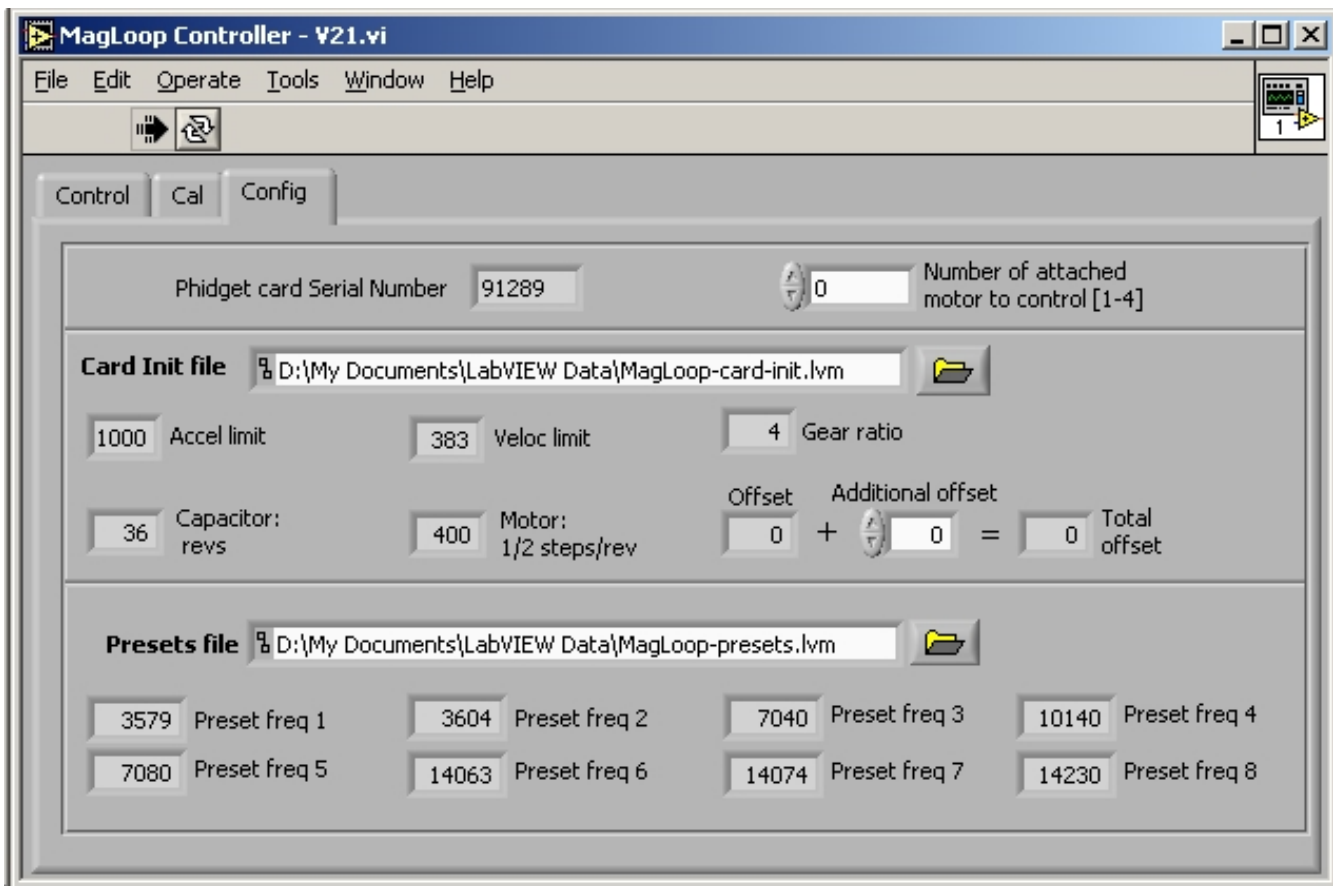


Figure 107: The "Config" tab of the GUI of my varco motor-drive control software

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 red from the presets data file. The file location has a default, but a browser button can be used to locate the file.

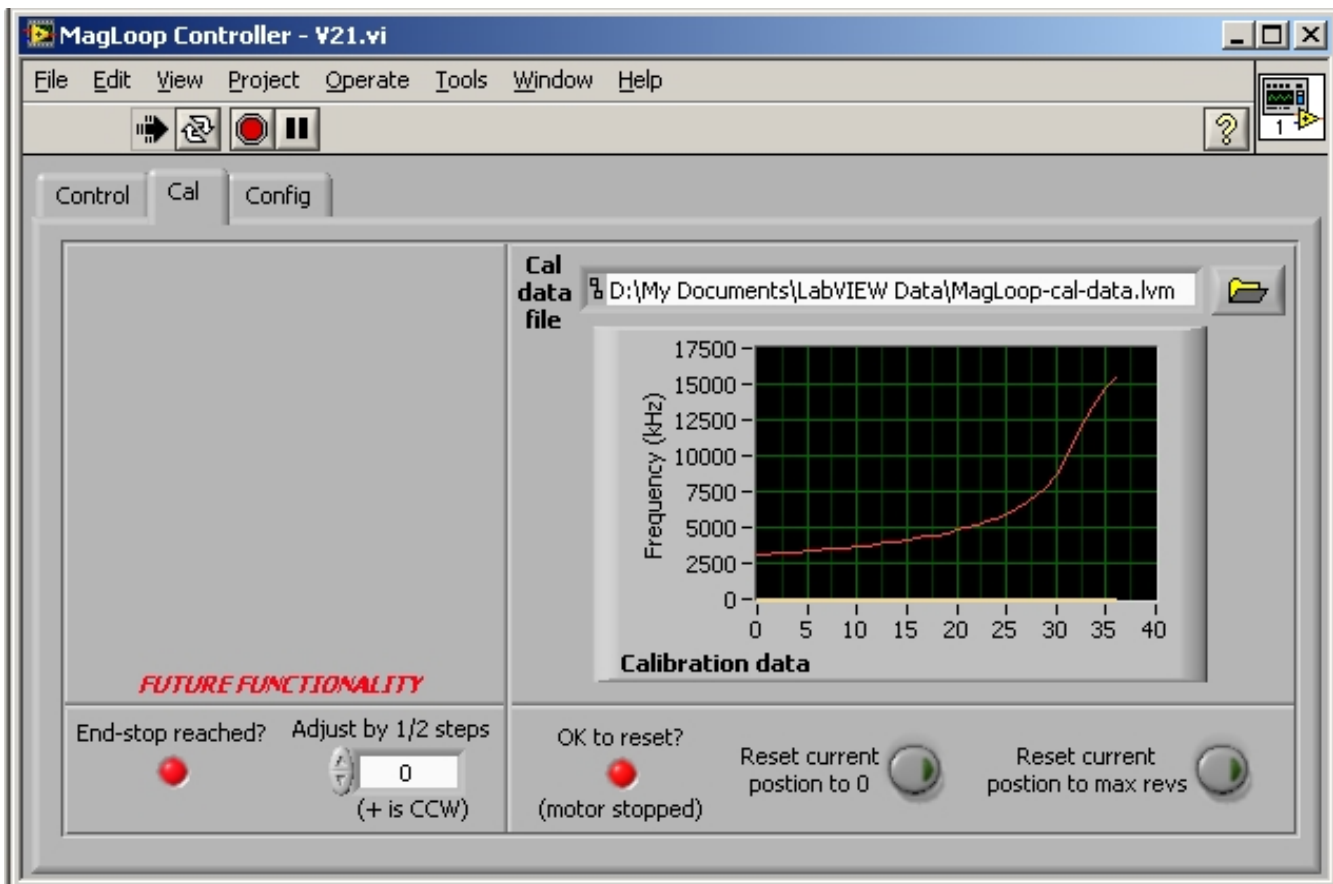


Figure 108: The "Cal" tab of the GUI of my varco motor-drive control software

The "Cal" 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 $\frac{1}{2}$ -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.

IMPORTANT: I have made the entire design and software package of my controller application available below. It comes without guarantees. Please note that I do not have the time to provide support for its installation or operation. Sorry!

The graphical design (detailed block diagram) of V21 of my controller is [here](#) (the image has enough resolution for fully zooming-in on the details).

The actual LabView "virtual instrument" design file (.vi) of my controller is [here](#).

LabView "Pro" supports creating a LabView-independent .exe file. The zipped executable package of my controller 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 with my software.

Of course you must install the drivers that came with the Phidgets card (or download from phidgets.com). I used [this executable drivers package](#).

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 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).

This means that I do **not** know if my software can work at all with Phidgets cards other than 1062 and 1063! You can try it at your own risk. Sorry: I can not provide support for your experiments.

In 2016, Patrick Nobecourt (F5TJZ) adapted my design in LabView2015, to make it work with a Phidgets 1067 card for his NEMA17 motor. He included current monitoring/protection and increased the velocity limit. Patrick actually uses two cards and two motors in the remote matching unit for his vertical antenna: one for a vacuum variable capacitor, the other for a variable inductor. His .vi design file is [here](#), the two executable are [here](#), and the associated initialization data files are [here](#).

DC-MOTOR DRIVE

Before I get into all the details of the DC motor-drive that I developed for my vacuum capacitor, here is a simple-yet-effective way to motorize such a capacitor - **if the shaft of the capacitor moves in & out of the capacitor as the shaft is turned**. Unfortunately, this is not the case with my capacitor.

If the shaft *does* move out when the shaft is unscrewed, then an inexpensive small DC-motor with down-gearing can be used. If mounted on a thin, flexible L-bracket, the motor (and the bracket) will be pushed away from the capacitor when the shaft unscrews. This can be used to actuate a micro-switch when the shaft is approaching its maximum position. With some simple circuitry, the motor will then only be allowed to reverse direction. The geared-down motor can produce a certain maximum torque. It should be small enough, such that it cannot damage the capacitor when the shaft is completely screwed in. The motor will simply stall at that point. This is easily detected with a simple motor-current monitor, consisting of an LED across a current-sensing resistor in series with the supply voltage. Ref. 11A.

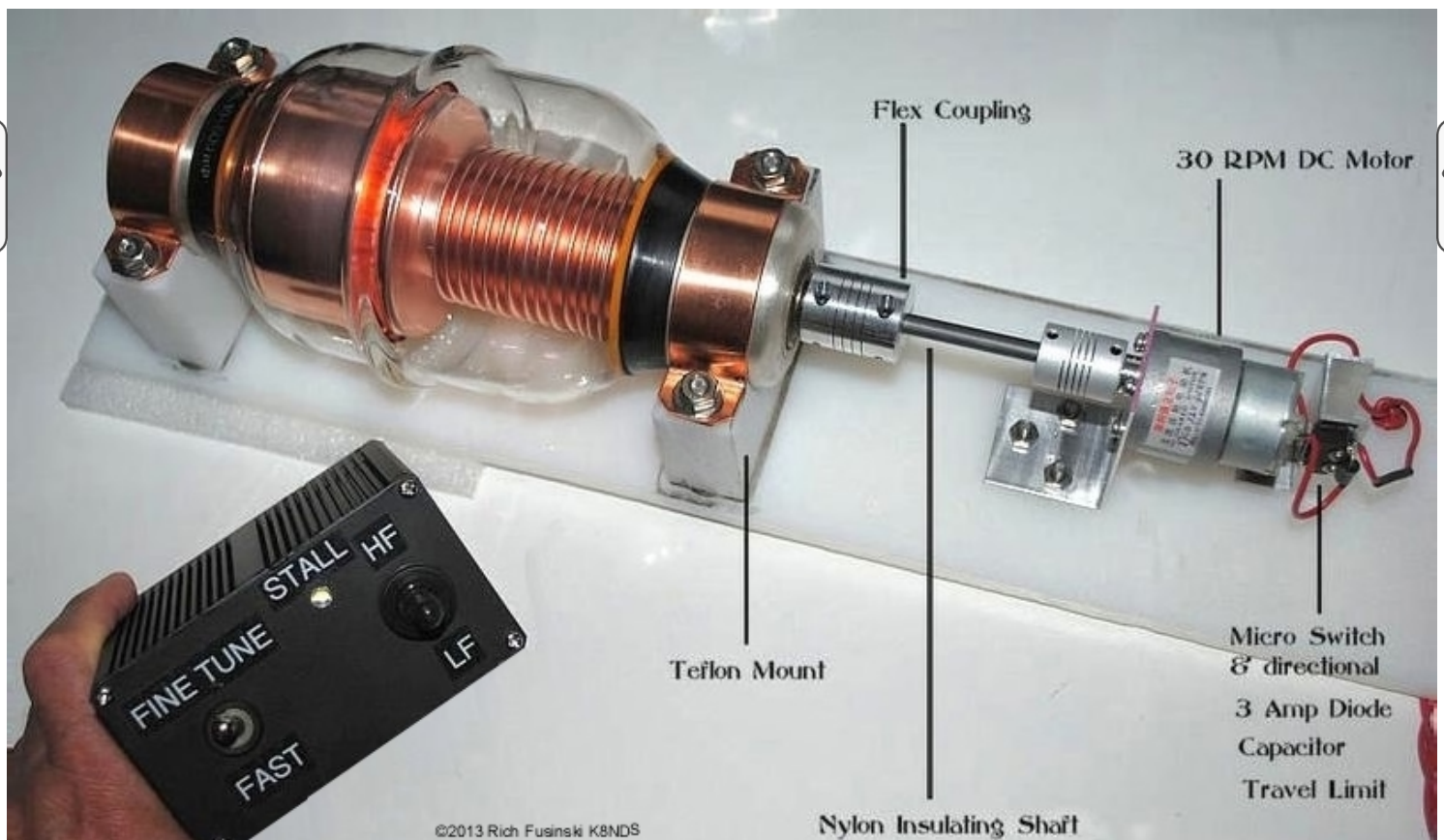


Figure 109: Motor-drive with end-stop protection by Rich Fusinski (K8NDS)

(source: ref. 11A)

This concept can actually be expanded to provide end-stop protection for a capacitor shaft that does *not* move in & out. The rotational movement of the

motor-capacitor shaft has to be converted to linear motion. This can be done with a threaded rod (lead screw, feed screw) and a screw nut that is installed on the rod. It has to be prevented from turning with the shaft, and only be allowed to slide along the rod. The nut can then actuate a micro switch (or two such switches, to obtain end-stop protection at both ends of the motion range). An implementation of this by Dominique, F1FRV, is illustrated below (ref. 11F). The design includes a remote control unit and a 10-turn potentiometer (down-gear) for position feedback.

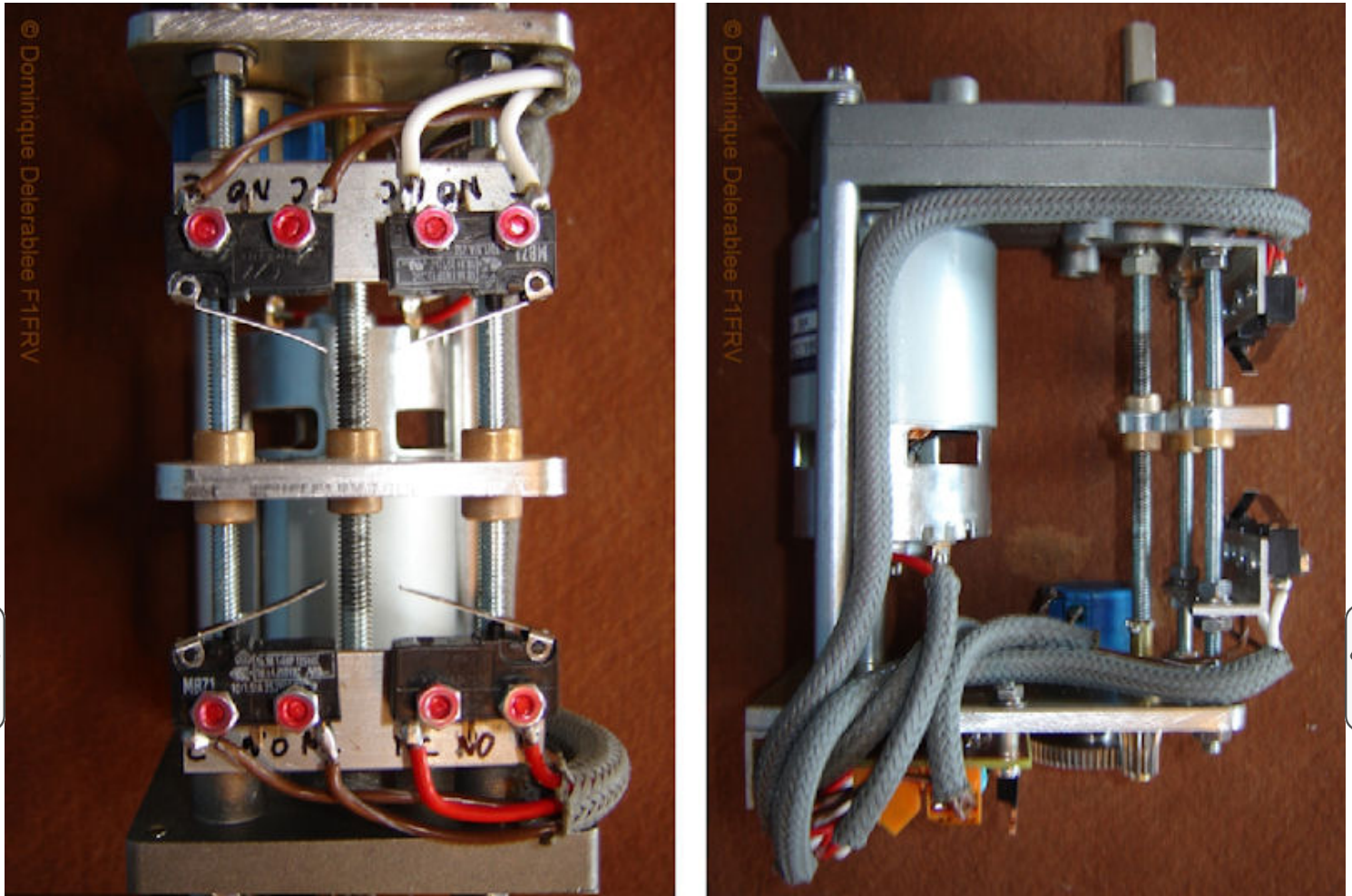
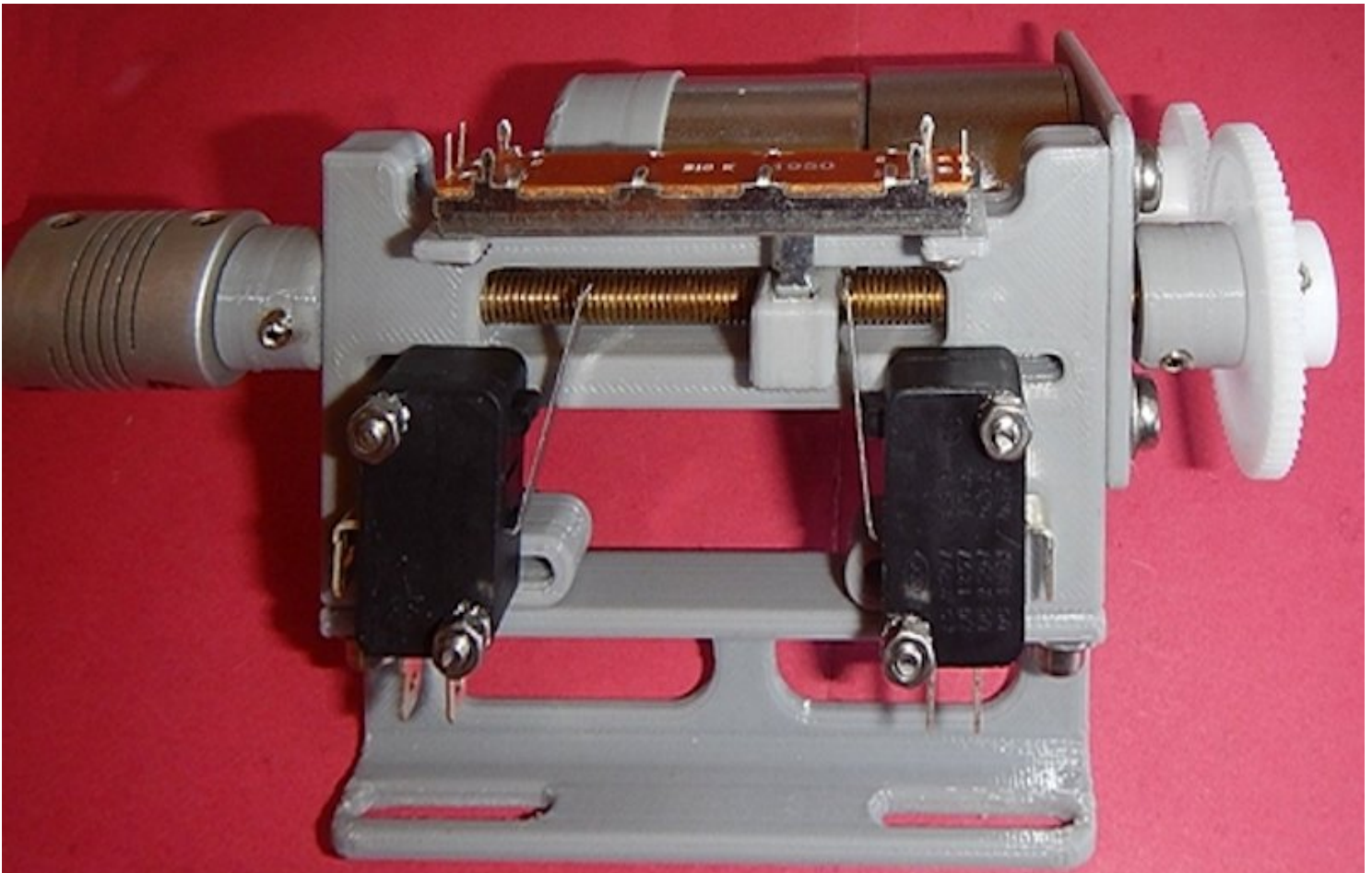


Figure 110A: Top view & side view of the 2004 motor-drive by Dominique Delerabee (F1FRV)
(source: ref. 11F)

I liked Dominique's implementation: it is compact, and the shafts are inherently properly aligned. However, the important parts of his design are not readily available. So I decided to roll my own - not very compact, but basically all parts available via eBay. See the next section.

In 2020, Dominique updated his design, with the structure and some other parts made with a 3D printer:



*Figure 110B: Top view & side view of the 2020 motor-drive by Dominique Delerablee (F1FRV)
(source: ref. 11G)*

MY DC-MOTOR DRIVE

At the heart of my drive system is a small 12 volt DC motor:

The shaft of my vacuum capacitor makes 36 turns, end-to-end. I would like the motor to turn the required 36 revs in about 1 minute. I.e., a speed of about 36 rpm.

I selected a motor with a gearbox that has 2 output shafts. This way, I can add a multi-turn potentiometer for position feedback in the shack. If you do not want this feedback, you can use a motor with a single output shaft. However, I recommend that you do add the feedback, or at least get a 2-shaft motor, so you can easily add the feedback when you finally find out that you really need or want it.

I purchased the motor via eBay ("worldwide" search on "DC 12V 35RPM Double Shaft Worm Geared Motor GW31ZY"). It delivers a nominal torque of 147 N.cm (15 kg.cm). This is plenty! The output shafts have a diameter of 8 mm.

I made the motor mount out of pieces of 8 mm thick poly kitchen cutting board, and threaded holes for the bottom mounting screws.

When I completed the construction, I found that a matching metal mounting bracket was also available via eBay ("worldwide" search for "worm gear motor mounting bracket")...

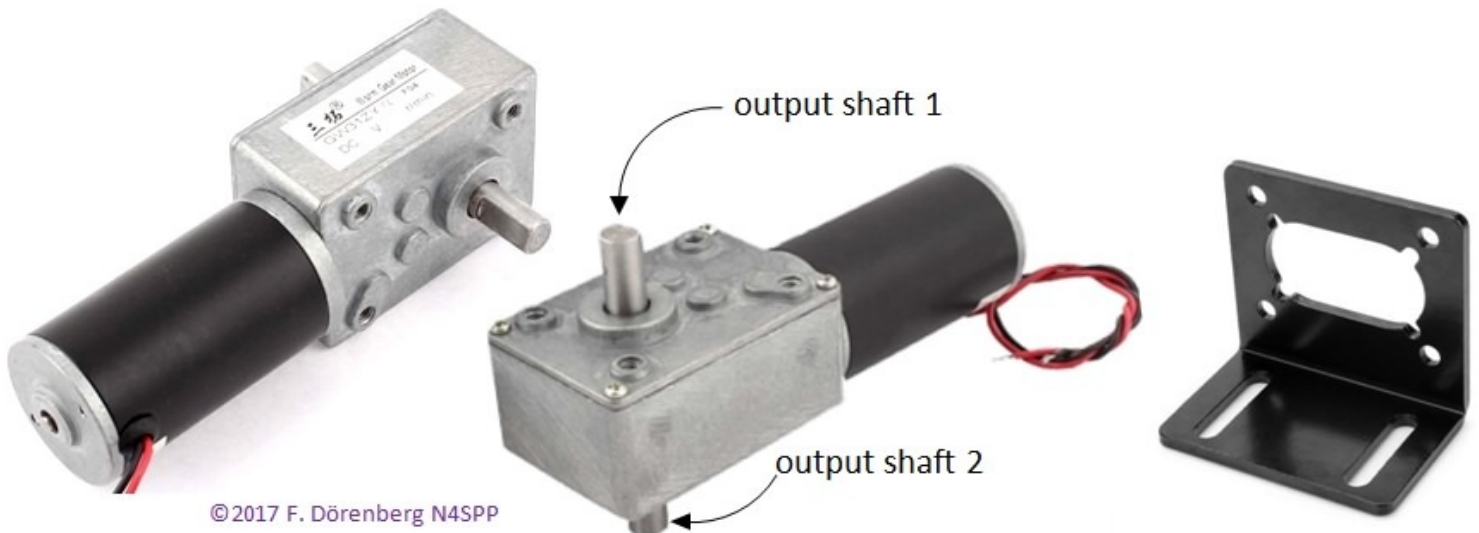


Figure 111: The 35 rpm / 12 VDC motor and a matching mounting bracket

The motor must turn the shaft of the capacitor, so we need a drive shaft system. Its purpose is threefold:

Connect one motor shaft to the capacitor shaft.

Convert the shaft rotation to linear motion, with actuation of an end-stop switch at both ends of the linear travel.

Connect the other motor shaft to a multi-turn potentiometer for position feedback.

I selected a lead screw (feed screw, threaded rod, *D*: "Spindel, Leitspindel", *F*: "vis-mère") with a length of 200 mm (20 cm, 8 inch) and a pitch of 2 mm. I.e., the thread makes $200/2 = 100$ turns. A nut can spin on the lead screw. For 36 revs, this nut will travel $36 \text{ revs} \times 2 \text{ mm/rev} = 72 \text{ mm} = 7.2 \text{ cm}$. The nut must be prevented from turning. It shall only translate along the lead screw. To do this, I used an 8 mm guide shaft. It is installed parallel to the lead screw. A slider block can move freely on the guide shaft. The lead screw nut is fixed in a groove of a piece of poly cutting board that is mounted onto the slider block.

I mounted the lead screw just above the guide shaft. The two pillow block bearings of the lead screw are raised with standard M6x30 mm standoffs (I also needed washers between the standoffs and the bearings, to raise the bearings another 3 mm). Sets of a lead screw with one or two guide shafts and mounting material are easily available via eBay (do "worldwide" search for "Lead Rod Linear Shaft Rail Support Slide Block Couplings").

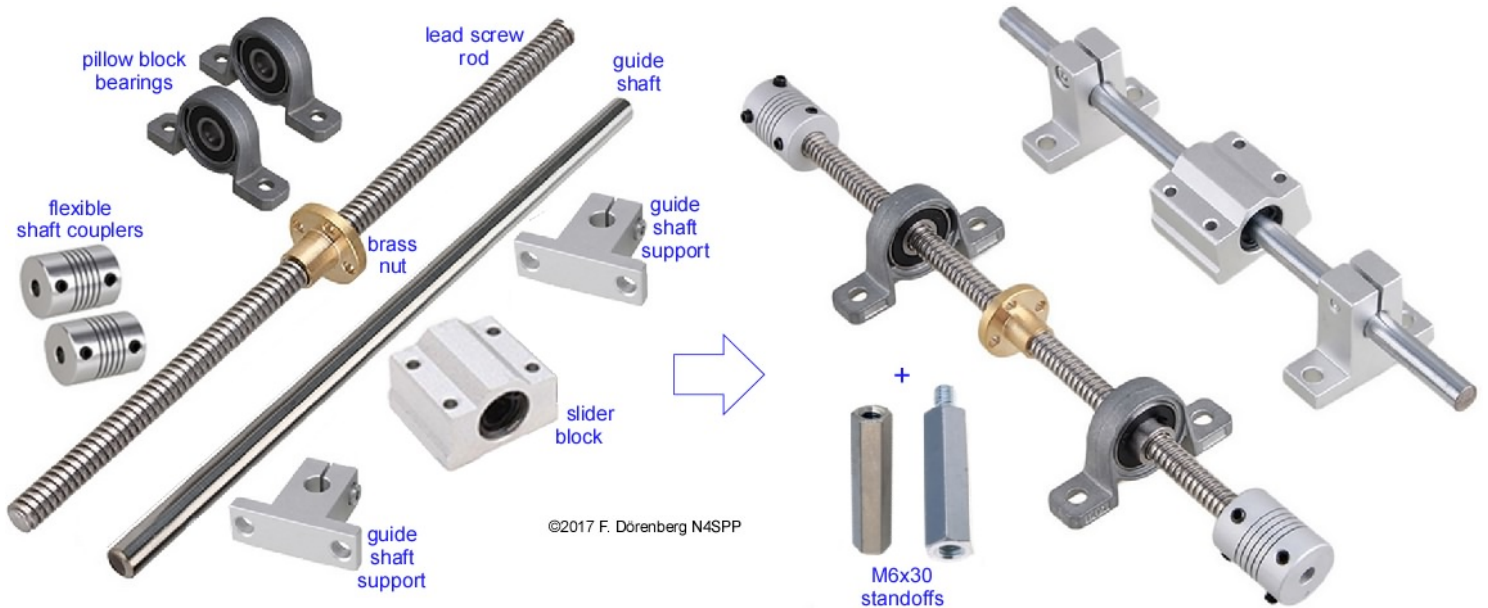


Fig. 112: The assembly for converting shaft rotation to linear motion - for actuating the end-stop switches

One end of the lead screw is connected to one of the motor shafts. This is done with a flexible shaft coupler (8 mm to 8 mm). The other end of the lead screw must be connected to the capacitor shaft. This must be done via an insulating shaft, to avoid the capacitor voltage from ever reaching the drive system and remote control. I used a 10 cm (4 inch) section of acetal copolymer (polyoxymethylene-C, POM-C). This is acetal resin, a thermoplastic that was discovered in the 1920s by the German scientist Hermann Staudinger. POM trade names incl. delrin® (= acetal homopolymer = POM-H). This insulating material has high strength and stiffness, good dimensional stability, is abrasion resistant, easy to machine (lathe, mill, drill, laser cut,...), and is generally unaffected by solvents, fuels, other chemicals. Its mechanical properties are somewhere between metal and plastic. Two flexible shaft couplers are required: 8-to-8 mm between the lead screw and the insulating shaft, and an 8-to-12 mm coupler between the insulating shaft and the capacitor shaft (12 mm diameter).

The motor is probably strong enough to destroy the capacitor when continuing to drive when the end of the capacitor's shaft is reached. In the opposite direction, the capacitor shaft becomes unscrewed and can fall out of the capacitor. So, we need end-stop protection at both ends of the 36 rev travel! This is why we convert shaft rotation to linear motion, and use micro-switches to detect reaching the end of the travel. The micro-switches must be "single pole, double throw" (SPDT) types. I.e., with three contacts: common, "normally open" (NO), and "normally closed" (NC). The switches are not only used to interrupt power to the motor, but also to enable changing the motor direction away from the end-stop.

The capacitor shaft makes 36 revs, and a standard multi-turn potmeter makes 10 turns. So we need 4:1 down-gearing. I decided to do this with two gears

(note: "gear wheel" is a misnomer) and a small timing belt (toothed belt, synchronous belt). The pulley on the second motor shaft has a width of 10 mm and 15 teeth. This is a flanged pulley, so the belt will stay on. The pulley on the potmeter shaft has a width of 10 mm and 60 teeth. The belt is an 8T2.5x150, i.e., 8 mm wide, with a "tooth" pitch of 2.5 mm, and length of 150 mm (= 60 teeth).

The capacitor and the entire drive system are mounted on a 10x60x1.1 cm plate of acetal copolymer (polyoxymethylene-C, POM-C), bought via eBay. All holes are countersunk on the back side of the plate, and used with countersunk ("undercut") M4, M5, and M6 screws. See the photos below.

IMPORTANT: even though flexible shaft coupler are used, alignment of the capacitor shaft, the leads screw rod, and motor shaft must be done very accurately! This means that the various holes in the POM plate must be located accurately: much better than 0.5 mm = 0.02 inch = 20 thou. So, you must use a caliper when marking the drill holes, and use a drill stand to drill straight and at the marked location!

IMPORTANT: as stated, the capacitor shaft shall not be driven all the way to its physical limits. To avoid destroying the capacitor, the end-stops are carefully adjusted such that only 35 of the 36 capacitor shaft revs are used, with 1/2 rev margin at each end. I mounted the micro-switches on a small piece of poly kitchen cutting board. It has a slot in it, so its position can be adjusted parallel to the lead screw and guide shaft over a distance of about 1 cm (see Fig. 112 and 116 below). Make sure that the micro-switches are wired correctly: before fixing the flexible shaft coupler to the capacitor shaft, drive the motor so as to center the lead screw nut about half way between the micro-switches. Then drive in one direction and manually actuate the associated micro-switch. Then repeat in the other direction. As stated before, the lead screw nut will move over 70 mm for 35 revs. So the micro-switches must have a nominal spacing of 70 mm, plus the length of the slider block on the guide shaft. Adjust the position of the second micro-switch, such that it switches after moving exactly 35 revs away from the opposite switch. Then drive until the micro-switch corresponding to the capacitor's hard mechanical limit is actuated (CW rotation for my capacitor). Then manually rotate the capacitor shaft to that stop, and back off 1/2 rev. At this point, the capacitor "bottle" is fixed in place. I used two long cable ties that go through the mounting plate. Note that the plate has a hole for the nub of the capacitor bottle. See the far left side in Figure 113. Now the shaft coupler on the capacitor shaft is fixed. Likewise, the 10-turn potentiometer has physical limits. The 4:1 down gearing of the second motor shaft results in $35 / 4 = 8.75$ revs of the potmeter shaft. This leaves a margin of $(10 - 8.75) / 2 \approx 0.6$ revs on each side of the travel of the potmeter shaft. Once the micro-switches are adjusted, the system is driven until one of the micro-switches is engaged. Make sure (!!!) you know the turn direction of the second

motor shaft during this system movement. If you get the direction wrong, you will immediately destroy the potmeter! Turn the potmeter shaft all the way to limit that corresponds to the actuated micro-switch. Then back off 1/2 rev and do not rotate that shaft any more, until the timing belt is installed.



Figure 113: Top view of the DC motor drive assembly with vacuum capacitor

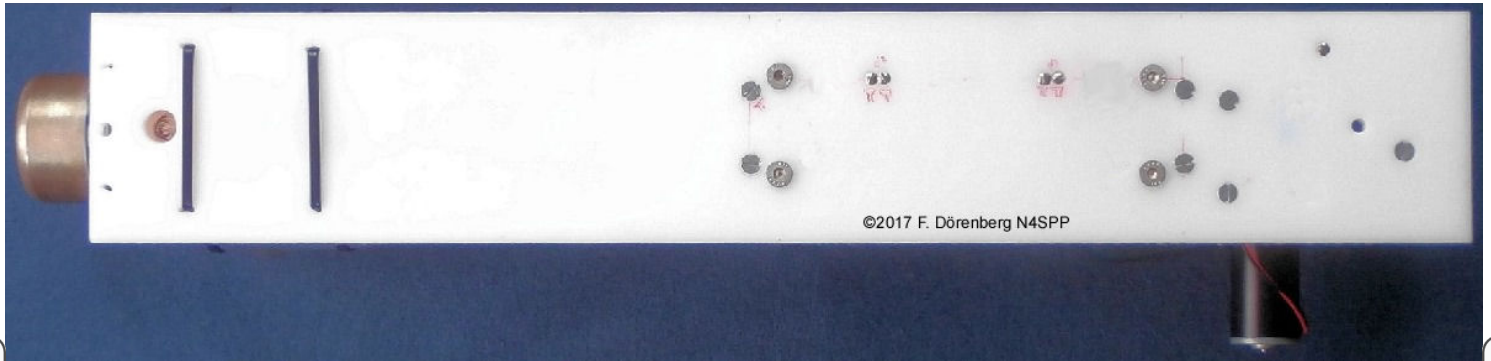


Figure 114: Bottom view of the DC motor drive assembly

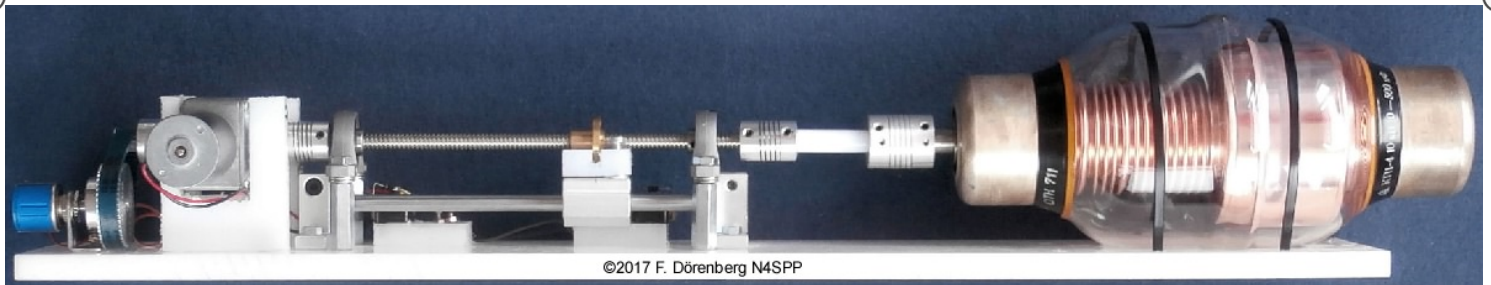


Figure 115: Right hand view of the DC motor drive assembly

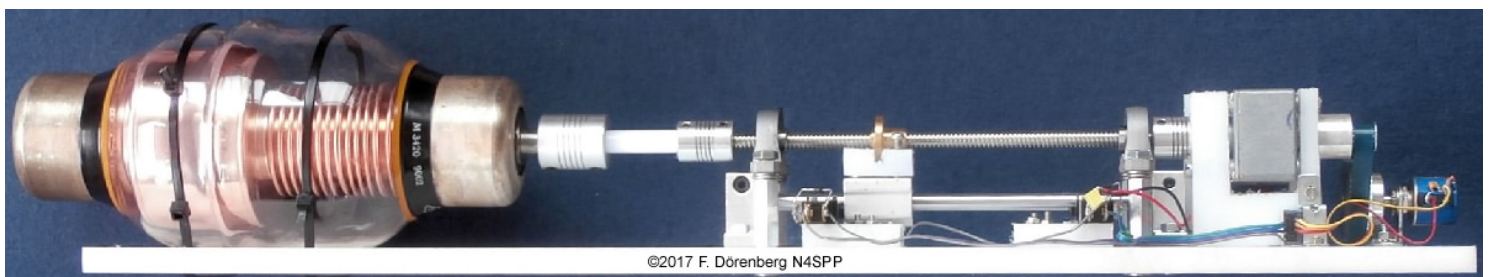


Figure 116: Left hand view of the DC motor drive assembly

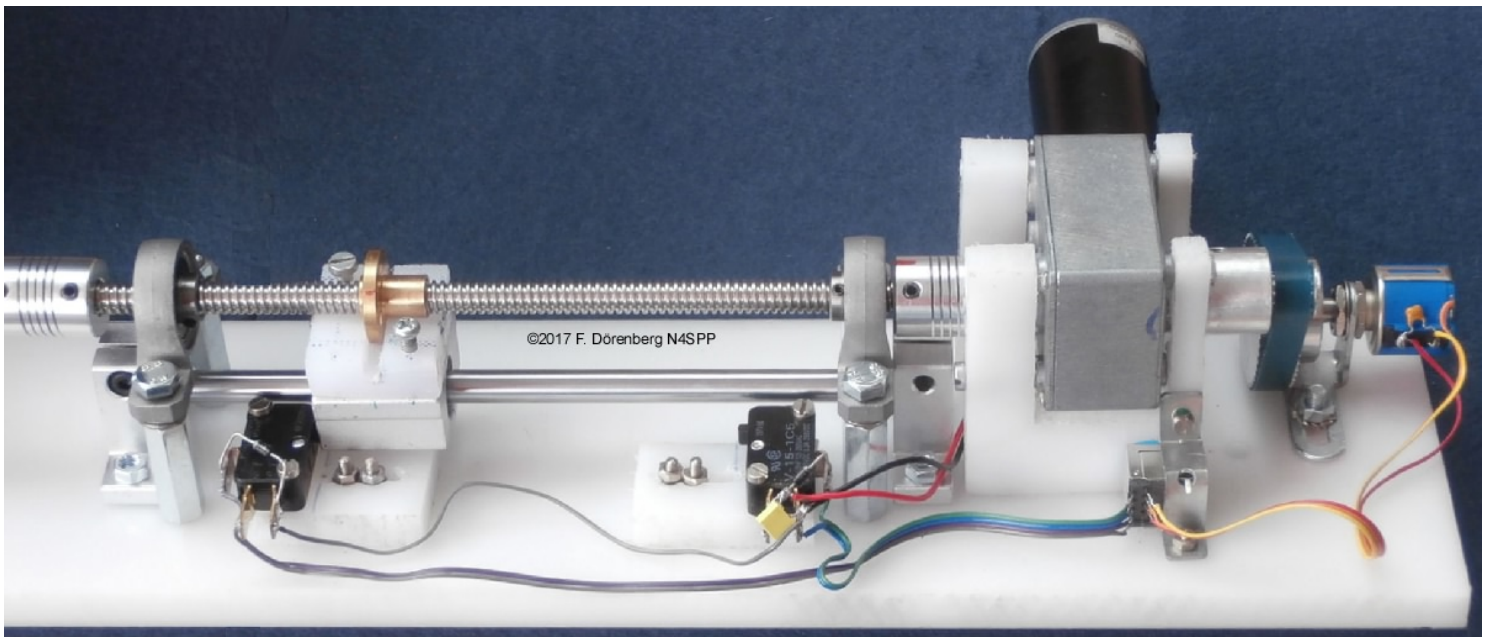


Figure 117: Close-up view of the drive shaft, end-stop slide, motor, and position feedback potmeter

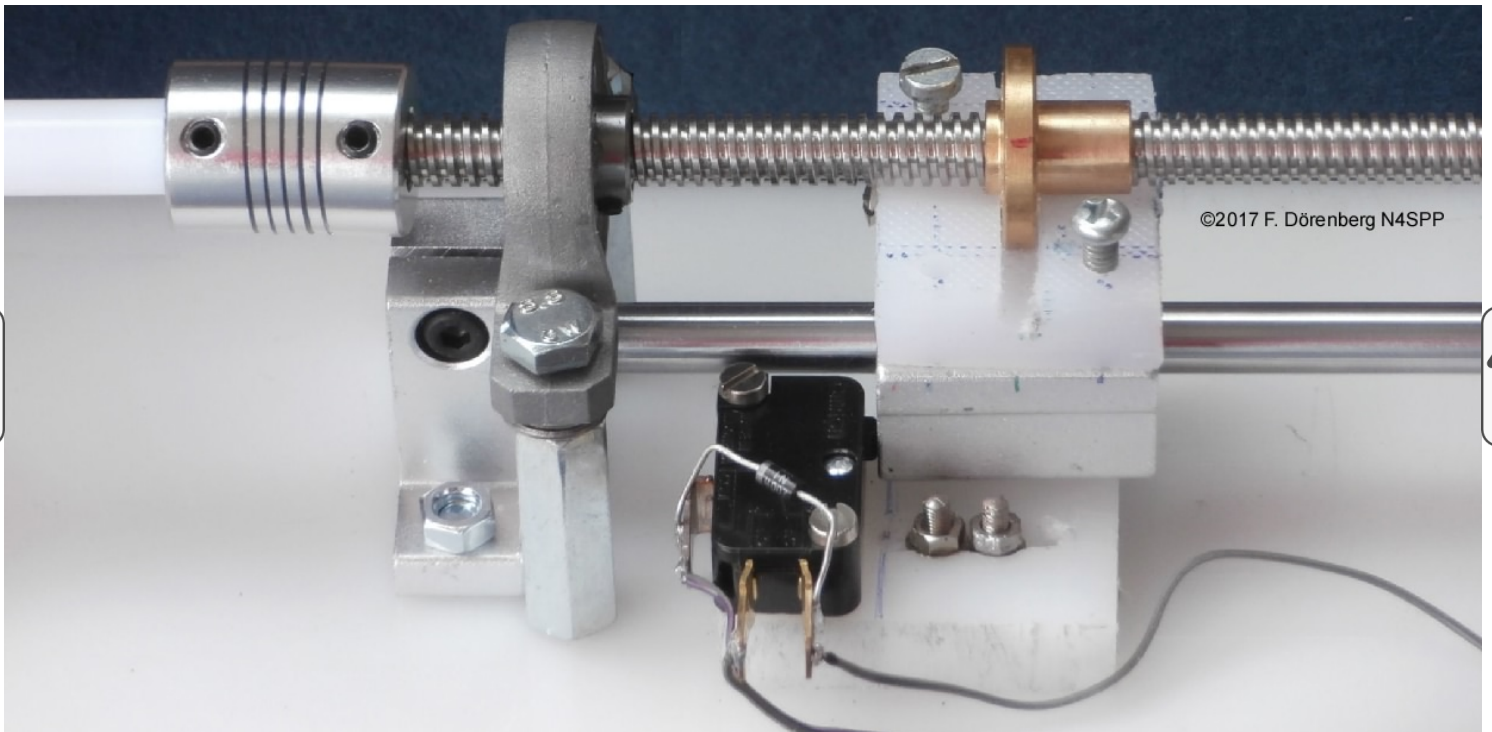


Figure 118: Close-up view of one end-stop with micro-switch, actuated by the sliding block

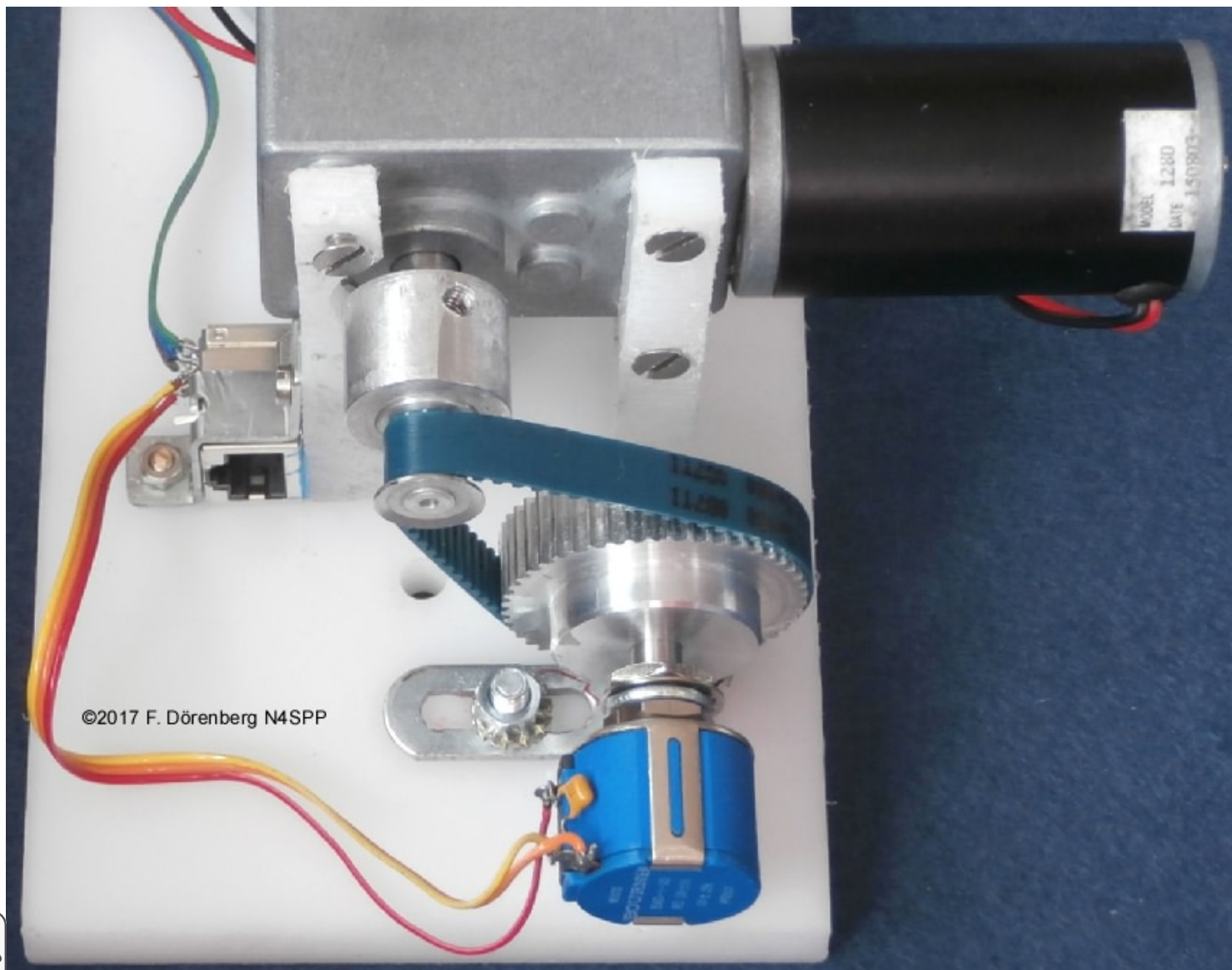


Fig. 119: RJ45 connector and second output shaft of the motor's gear box with 4:1 belt drive to the 10-turn potmeter

The complete drive (capacitor + plate + motor drive) weighs a hefty 4.2 kg (9.3 lbs), about twice the weight of the capacitor by itself. The drive assembly is mounted onto the PVC mast (63 mm diam.) with two M6 bolts. Initially, I installed the loop with the capacitor drive at the top. Clearly, this configuration keeps the high-voltage part away from people and animals. However, it also makes the antenna very top-heavy. My antenna is not installed permanently on my terrace. On a windy day, I attach guy wires to the upper half of the PVC mast, in three or four directions. When I stick the loop on top of my telescopic mast (see Fig. 83B above), I install the capacitor at the bottom. This is more stable. This has another effect: my loop has a circumference of about 6 m (20 ft). This is about 0.07λ in the 80m band, and the current around the loop is basically uniform. In the 40m - 20m bands, this is about $0.15 - 0.3 \lambda$ and the current is higher at the neutral-voltage point across from the capacitor. As "current radiates", having the highest current point a bit closer to free-space (obstacle-free), might just help a bit with the far-field strenght in the bands where the circumference is $> 0.1 \lambda$. NOTE: I have neither modelled this, nor verified this statement experimentally!



Figure 120: Motor drive installed on the PVC-tube antenna mast

WEATHER PROTECTION FOR THE MOTOR DRIVE

The motor drive definitely needs to be protected against rain and other forms of precipitation, as well as dust and dirt.

Originally (February **2018**) I made a hood by combining two inexpensive plastic storage boxes that measure 35x20x15 cm (LxWxH, $\approx 13.8 \times 8 \times 6$ inch). I cut one end of both boxes and of both lids. I combined the two boxes with industrial 1-sided sticky "duckt" tape (sometimes referred to as "duck" tape, which is a brand name; I actually used Gorilla[®] tape), both on the outside and on the inside of the seam, and combined the two lids with industrial 2-sided sticky tape. **NOTE 1:** these clear plastic storage boxes are made for *indoor* use, so they have no UV protection. Outdoors, they will become brittle and opaque fairly quickly, depending on how sunny your QTH is! **NOTE 2:** regular sticky tape, such as electrical insulation tape is useless for this application.



Figure 121: Protective hood made of two clear plastic boxes and their lids

The merged lids are installed between the plate of the motor drive and the PVC mast. I drilled two 20 mm holes in the hood at the appropriate place for the ends of the 12 mm diameter copper tubing of the main loop. With a thin blade saw, I then very carefully cut a slit between each hole and the open side of the hood. This makes it easy to install and remove the hood. An other hole was made for the cable between the motor drive and the remote control box. I closed the ventilation holes at the top, but left the ones at the bottom open.



Figure 122: Weather protection Mk 1 - installed

The above protective hood was basically a short-term solution, and not suitable for continuous outdoor exposure. Also, it was not nearly as weather-tight as I would like. Also, sooner or later (typically "sooner"), the sticky tape comes undone. As I don't leave my loop antenna out in the weather permanently, this was not that big of a problem. Of course, I do want to be able to use the antenna when it is raining. So I have to do much better!

Early **2021**, I designed a completely new protective hood. This time it is made of clear, colorless **polycarbonate (PC)**, e.g., Lexan™). This material is harder and stronger than acrylics such as plexiglass (with trade names such as Plexiglas (with one "s"), Acrylite, Lucite, Perspex). It is also easier to drill and cut than plexiglass - without breaking or cracking it. It is also available with UV protection (plexiglass is inherently more UV-resistant). On the downside: it is about 35% more expensive than same-dimensions plexiglass sheet. Another issue is bonding sections of polycarbonate. You absolutely can **not** use (and do **not** want to use) cyanoacrylate glue (a.k.a. "Super-Glue"). PC requires a special one- or two-component "glue", in general a Methyl Methacrylate Adhesive (MMA) solvent. The good stuff is **toxic!**, so you have to do the glueing outdoors or in a very well ventilated area! I used SCIGRIP® 16 glue. Note that some MMAs are colored when cured - not what I wanted! SCIGRIP 16 is (still) available at do-it-yourself stores and on-line shops in the US (,but not for sale in southern California) and the UK. It is on the "hazardous material" list in mainland Europe, and basically not allowed to be shipped to there (and only

surface-mail within the US). As my current QTH is in Europe, I had to do some creative importation from the UK, and I only managed to get a 1 pint can (16 oz., \approx 475 ml !) + applicator bottle, instead of a 1.5 oz or 5 oz. tube + plastic "micro tip" applicators. One or two 1.5 oz. tubes would have been enough...

As you can see in Fig. 113-120 above, the DC motor sticks out one one side of the white POM base plate of the motor drive. However, to mount the hood, I need a base plate that is wider then the entire motor drive, including the DC motor. I did not want to transfer the motor drive to a new, wider plate. So, unfortunately, I had to add a second back plate behind the existing white plate. A lesson learned...

The next Figure shows the the design. All polycarb pieces have a thickness of 4 mm, with exception of the two "wing" guide strips on the back (5 mm, though 4 mm would also have done the job). The hood design is basically a long box, with an open back and bottom. The back side is not completely open: it has narrow "wings" that slide behind the new back plate that is attached between the original white POM plate and the PVC mast. On the inside of the two side walls of the box, close to the guide "wings", there are two more guide strips. They are installed such that there is a small gap that is slightly wider than the thickness of the new back plate. Polycarb has only half the weight of same-dimensions glass - nevertheless, my hood + back plate adds a hefty 2.5 kg (\approx 5.5 lbs) to the antenna. This brings the total weight of the antenna to 12.3 kg (\approx 27 lbs)!



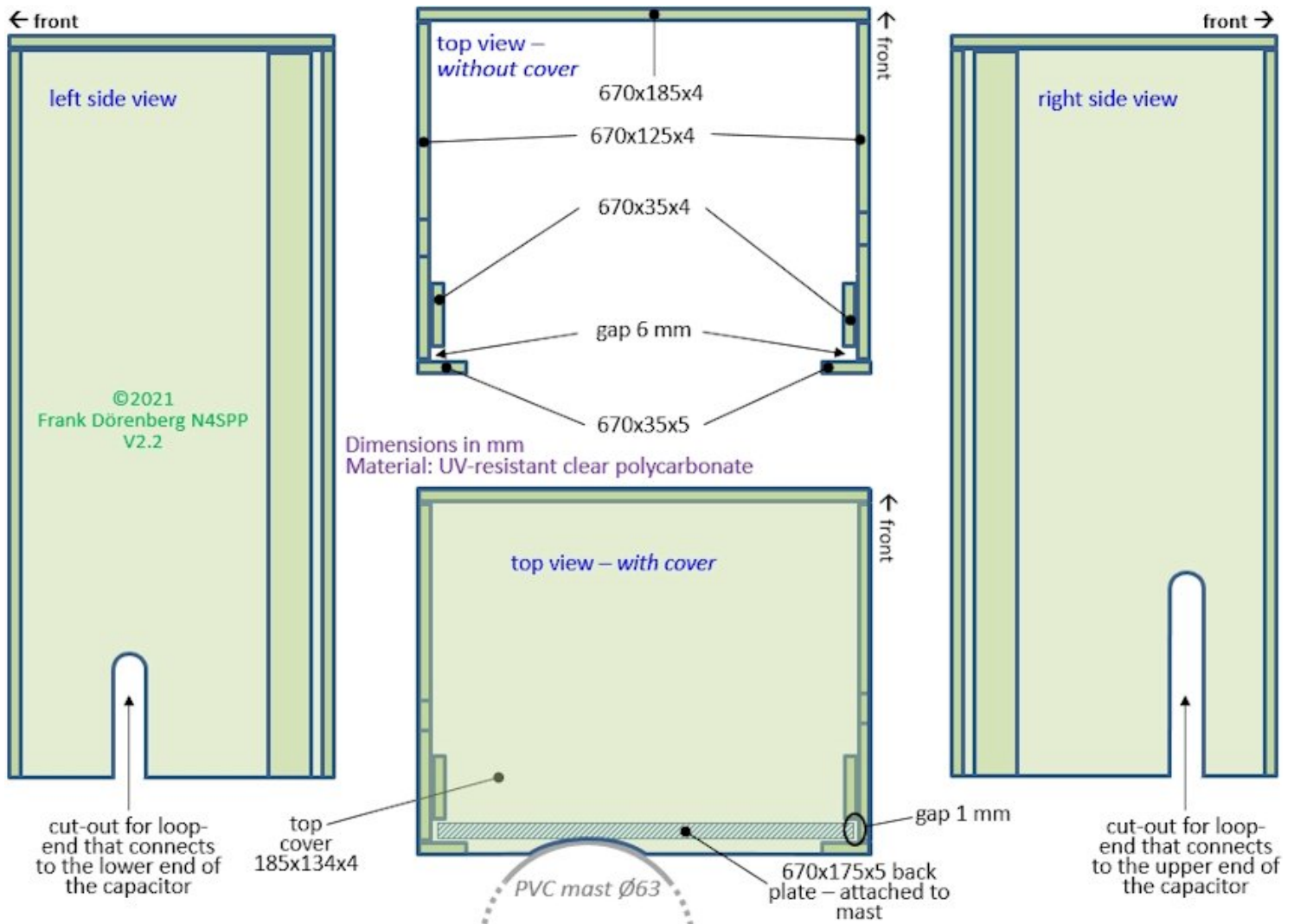


Figure 123: my design for the sliding hood

The next figure shows the polycarb plates that were accurately cut per the design above.

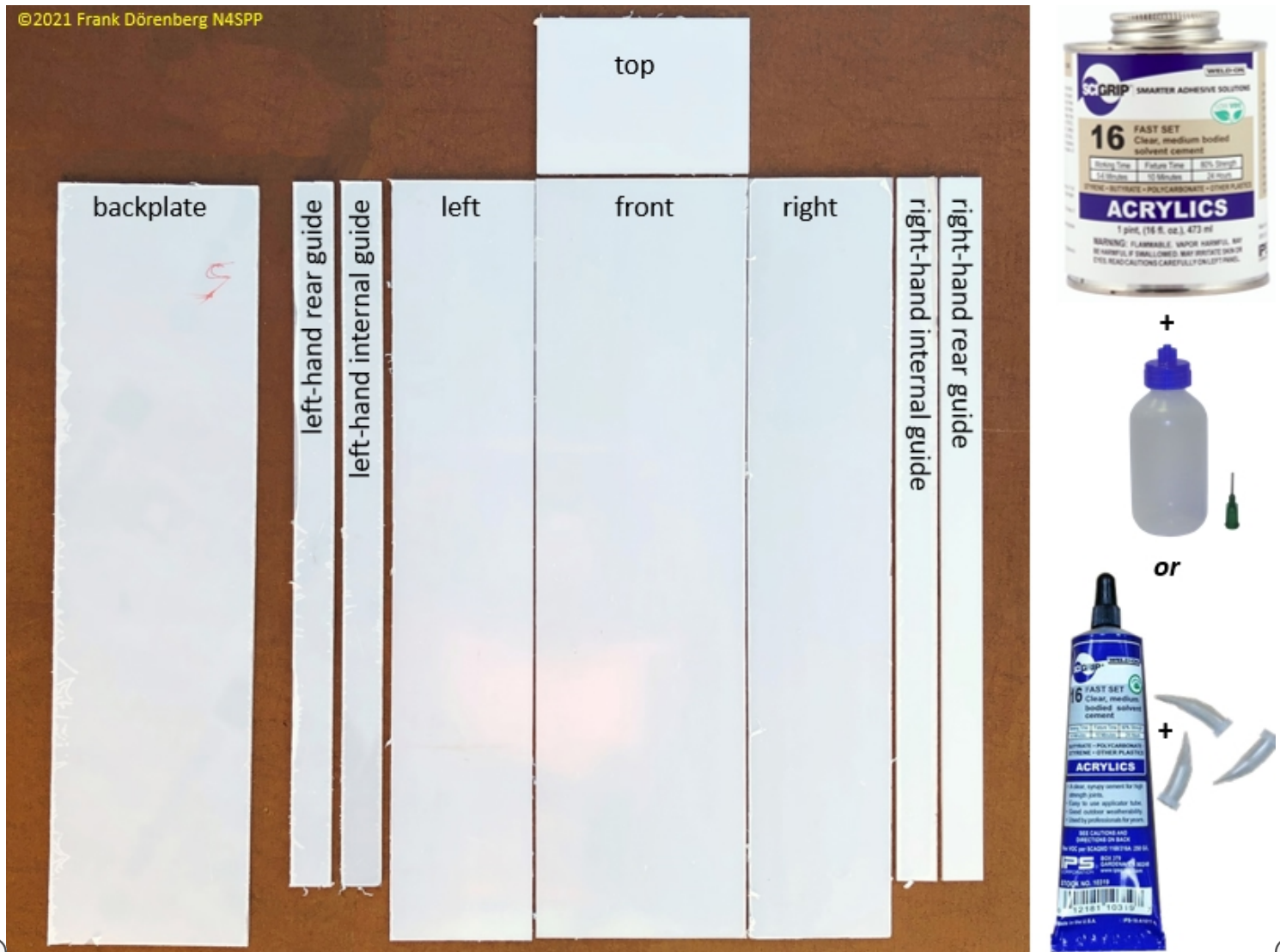


Figure 124: the custom-cut pieces of polycarbonate sheet - white protective film on both sides

The vacuum capacitor will be inside the box. The two ends of the copper tubing of the main loop are attached to the ends of the capacitor. So they will have to stick out sideways, through the left and right side of the hood. Where they will pass through the hood, I slowly drilled a hole that is slightly larger than the diameter of the tubing. Before drilling, I covered the location of the hole on both sides of the plate with painter's masking tape. Clamp the polycarb plate onto wood backing, to help prevent splintering the exit hole when drilling through the plate. Slowly pre-drill with a small drill and then slowly increase the drill diameter. Next, I had to make the cut-outs for sliding over the copper tube ends. I stuck a wide strip of masking tape between each hole and the bottom end of that side plate. Then I marked two parallel lines, spaced by the hole diameter, from the hole to the bottom end of the plate. I used a sharp hacksaw with a very thin blade ("kerf") and fine teeth. Note that I always use a Japanese-style hand saw for this kind of work! Contrary to western saws, they cut on the *pull*, not on the *push*. This makes it much easier to cut straight and precise! Saw slowly, without applying a lot of force.

One more small operation to do before glueing all the pieces together. The two "wing" guide strips on the back of the box will have to slide down *behind* the

back plate. To maximize weatherproofness, I want the top plate of the box to also cover the tops of these guide strips. However, this will cause some interference between the top of the box and the PVC mast, in the area where the back plate touches the mast. I filed away a small round indentation into the back side of the top plate. See the left-hand photo in Fig. 126. The depth of this indentation is equal to the thickness of the guide strips (5 mm in my design). The radius is that of the PVC mast (which has a 63 mm OD).

Now we can finally glue all the pieces together. As I indicated above, I used SCIGRIP 16 MMA. And I first watched a couple of YouTube instructional clips (search for "bond polycarbonate", "weld polycarbonate", and/or "weld acrylics"). Out of pieces of scrap wood, I also improvised a couple of simple jigs, to maintain 90° angle between pieces that I am glueing, and to help maintain pressure. Solvent glues have "working time", "fixture time", and "80% of final strength" curing time. See the label on the glue can or tube, and product datasheets. For SCIGRIP 16, this is 5-6 minutes, 10 minutes, and 24 hours, respectively. However, this depends a lot on ambient temperature etc. I found the working time (between application of the glue, joining the pieces, and making final position & angle adjustments) to be closer to 2 minutes than 5-6... I tried to apply the glue with the applicator bottle and the specified 16 gauge injection needle. I found the flow too small. Pouring straight from the bottle without the screw cap caused the flow to be too hard to control. I settled for using the bottle with the screw cap, but without the needle. See Fig. 125 below for the final result. I am pleased - not too bad for a first polycarb project! But not perfect: if you look closely at the photos below, you will see some sags where, or where I squeezed it out from between two joined pieces. You cannot wipe off excess glue without leaving a mark!

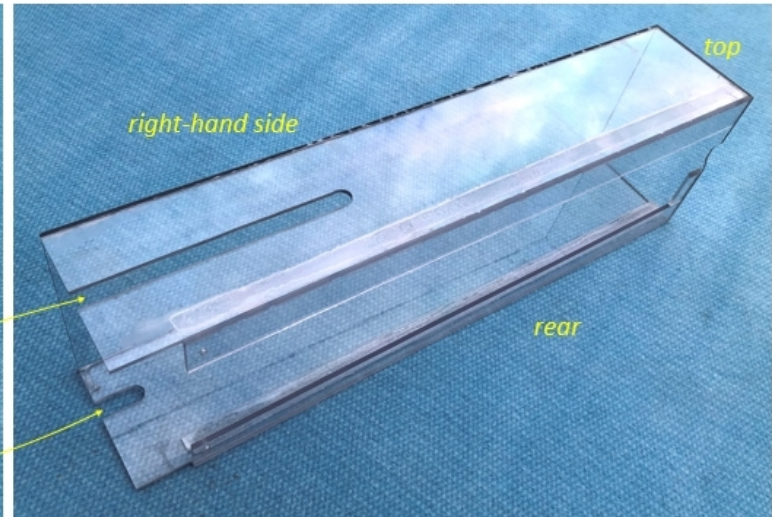
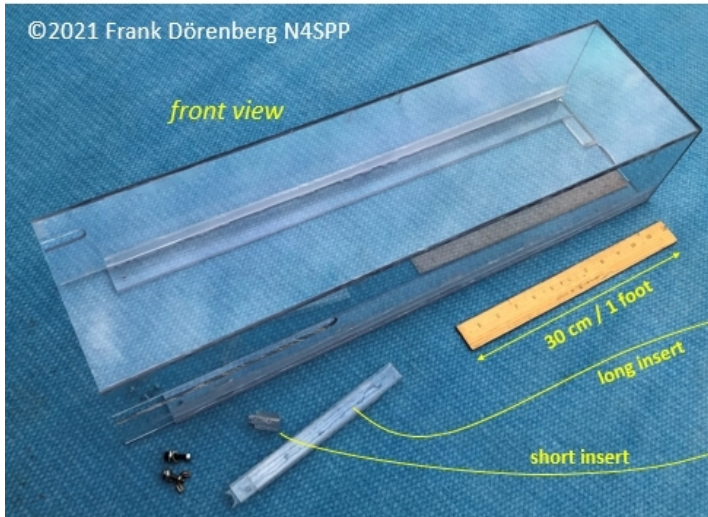
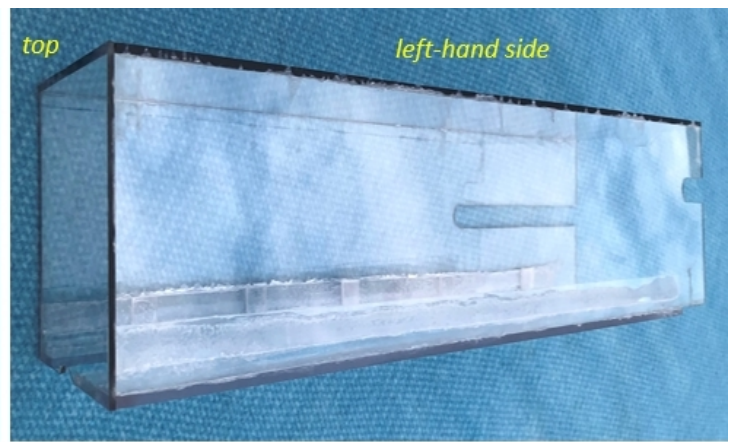
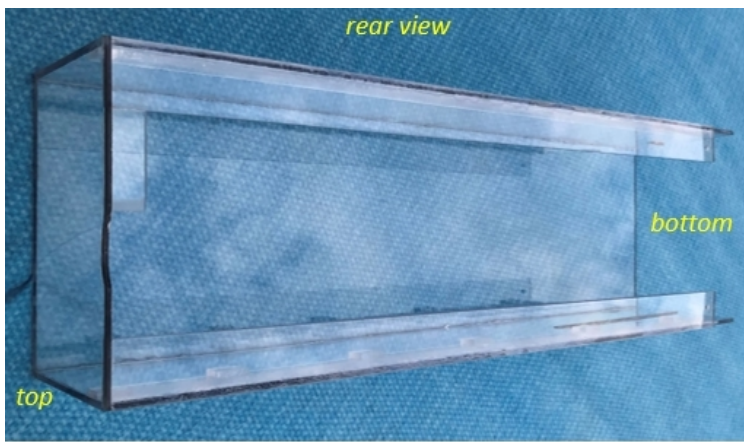


Figure 125: The various pieces of the hood - all glued up

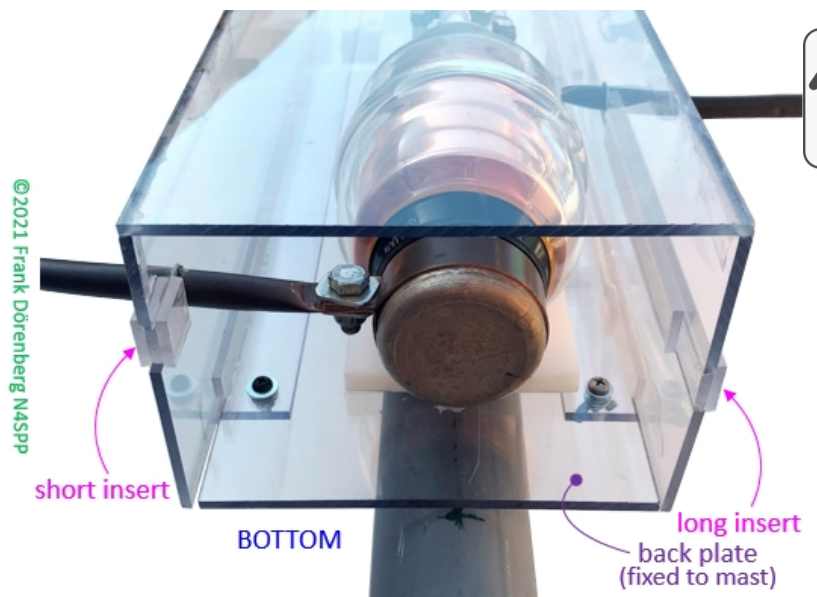
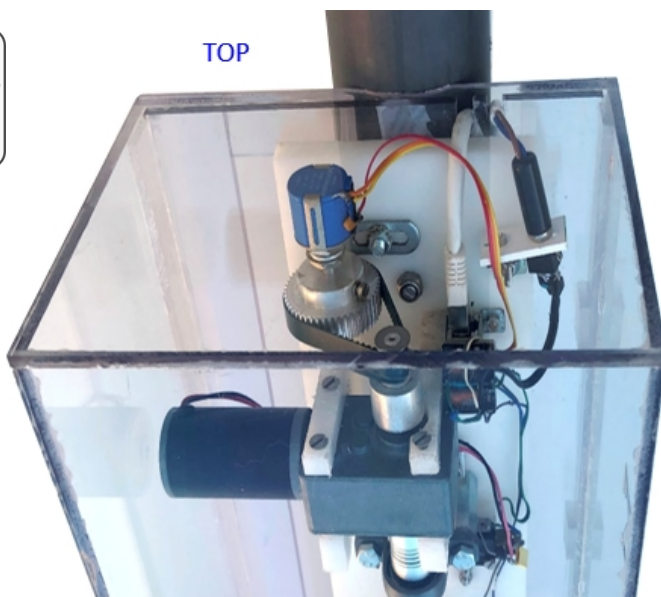


Figure 126: top and bottom view of the installed hood

Do not throw away the two narrow strips that were cut out for the copper tubing! One is a lot longer than the other. I did not want to leave the cuts in the side of the box open. So, I re-used the cut out strips. The polycarb supplier that I used, has 35 mm minimum width for ordered cuts. For the internal guide strips, I actually only needed about half that width. So I cut those guide strips in half lengthwise before gluing them in. My cuts are not nearly as precise and smooth as the machine-cuts, but the resulting narrow strips all still have one smooth long side. They are 5 mm wider than the narrow strips that I had cut

out the sides of the box. I glued a piece of narrow strip to both sides of each cut out strip. See Fig. 127 for the long cut out. This way, I obtained two inserts that fit snugly in the cut outs. They stay in place all by themselves.

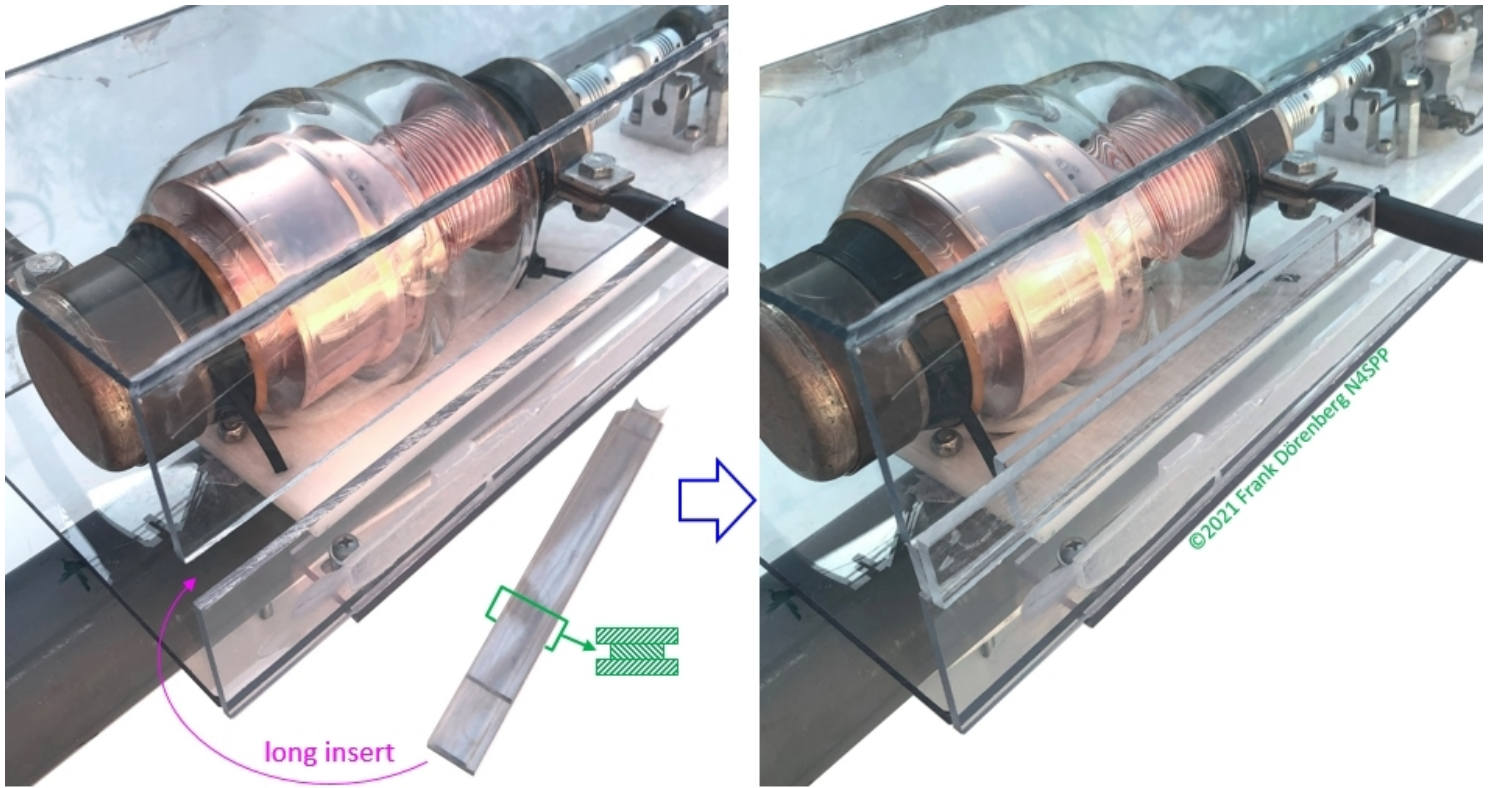


Figure 127: The long insert at the bottom of the right-hand side of the hood

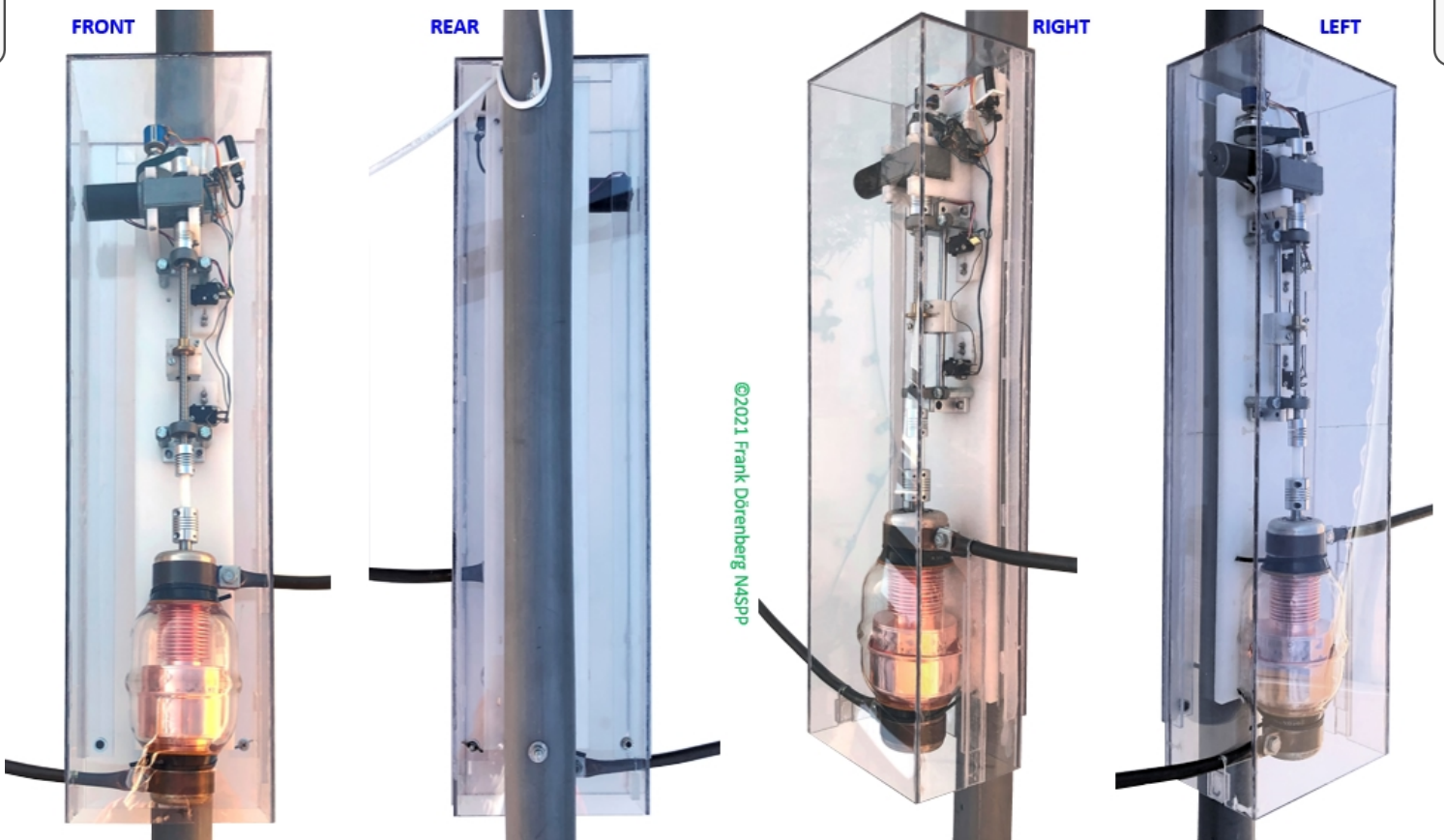


Figure 128: views of the hood - installed onto the mast-mounted back plate

Polycarb plates are stiff, but they are still a bit flexible. And my box is long compared to its width, and the back is open. So the bottom of the box does not snugly fit the width of the back plate. No problem. I drilled through the bottom end of the guide strip "wings" and the backplate, while holding them in the desired position. Two screws + wing nuts now hold it all in place perfectly. See the left two photos in the Figure above, and the left photo in the Figure below.

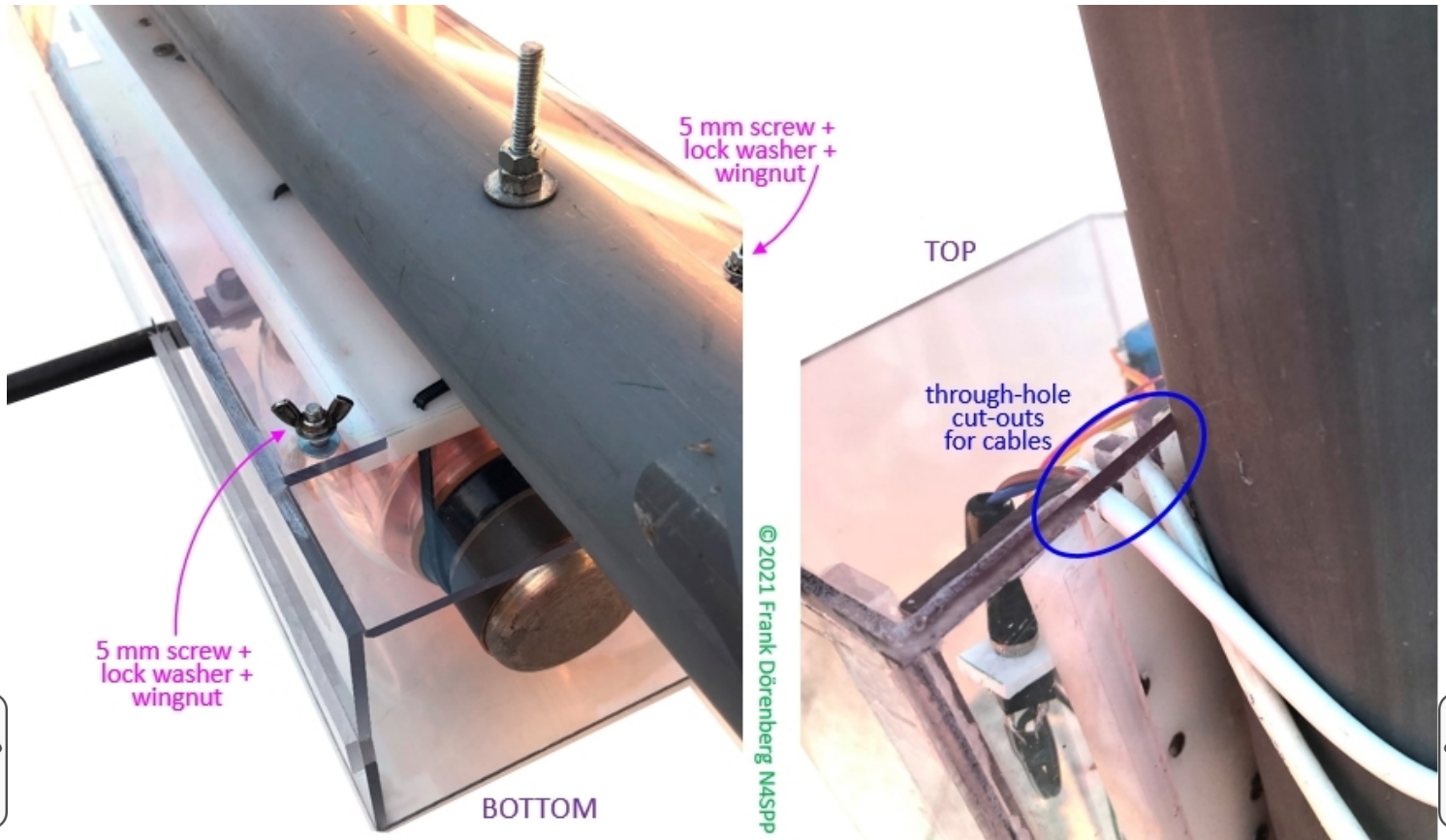


Figure 129: fixation of the hood bottom and entry of the remote control cable & the power cable to the coupling loop drive

Two more holes to drill and we are done! Two cables have to enter the box: the 1/4" diameter (6⁺ mm) ethernet remote control cable and the 6 mm diameter power cable to [the coupling loop DC motor drive](#). I drilled two holes (with pre-drilling) in the back plate, near the top. The holes are angled upward to the inside of the box, so water cannot drip into the box via the holes. With my hand saw, I cut out the material between the holes and the top of the back plate. So

I can feed the cables to the inside of the box, without having to remove the connectors on the cables. See the right-hand photo in the Figure above. The cables also have a drip loop: they are angled downward on the outside of the backplate and then upward.

The next photo shows my 80-20 loop antenna with its new hood, on top of [my telescopic mast](#), with the [tripod support](#) that I also recently designed and built:



Figure 130: my 80-20 loop antenna with its new hood

REMOTE CONTROL BOX

Obviously, I need a remote control box. It should have the following controls, indicators, and interfaces:

Power on/off switch.

Selection of motor rotation direction: clockwise (CW), off, counterclockwise (CCW). This will correspond to "increase frequency" and "reduce frequency" (or vice versa).

Indication of the drive shaft position (some representation of 0-36 revs).

Indication of "end-stop reached", separately for the CW and the CCW direction.

Motor stall current warning (not mandatory, but nice to have and easy to implement).

Standard 12-13.8 VDC input (13.8 is the normal supply voltage for transceivers and for charging 12 volt batteries).

Multi-wire cable to the motor drive: 2 wires to the motor, 2 wires for the "NO" contact of the CW and CCW end-stop switches, 3 wires for the position feedback potentiometer. So, at least 7 wires. I decided to use a standard Ethernet cable (8 wires).

I originally intended to install one or more ferrite rings on these cable, as common mode chokes. However, with 100 watt transmit power, I did not notice any interference in any equipment in the house. So I did not install such rings. Not good! As you can see in Fig. 132 and 135 below, the 12 VDC powerplug on my remote control box is a little too long. The common/ground barrel is exposed. It became "RF hot", which is a rather unpleasant experience! I have added a ferrite choke on the power cord between the control box and the power supply (near the power supply). I placed another one on the control cable to the motor drive (at the control box end). This took care of my problem. I did not give the placement of the the ferrites much thought. Note, however, that a ferrite choke is most effective at the point along the cable where the common mode current wave is at its maximum, per the standing wave pattern. Depending on the length of the cable, there may be several such points - and they move with the operating frequency (frequency band).

Fig. 131 below shows the simple schematic for a remote control box. It includes high/low speed selection, by switching in a series-resistance of a couple of ohms. The shaft position feedback indication is done with the 10-turn potmeter. I use a separately regulated; supply voltage of 9 VDC for the

(the project box measures 7x10.5x2 cm; high-low speed switch and the associated resistor is not shown in the left-hand photo)

Reducing speed with a series resistor (= voltage drop) also reduces motor torque. For fine-tuning the antenna, this is very undesirable! So, I decided to modify my remote control, and re-use the simple Pulse Width Modulator (PWM) controller of [my small STL project](#). My PWM is a 6-24 VDC, 3A type (inexpensive purchase via eBay; search for "DC motor speed control PWM"). It measures only 3x5 cm ($\approx 1.2 \times 2$ inch):



Figure 133: The small PWM speed controller card

The PWM circuit must be placed before the "direction" toggle switch. This means that the brightness of the green motor direction LEDs and the red end-stop LEDs now depends on the duty cycle of the PWM (= speed setting)... To me, that is a small price to pay for being able to smoothly (and continuously) vary the motor speed between zero and max - with full torque! **It just works beautifully!**

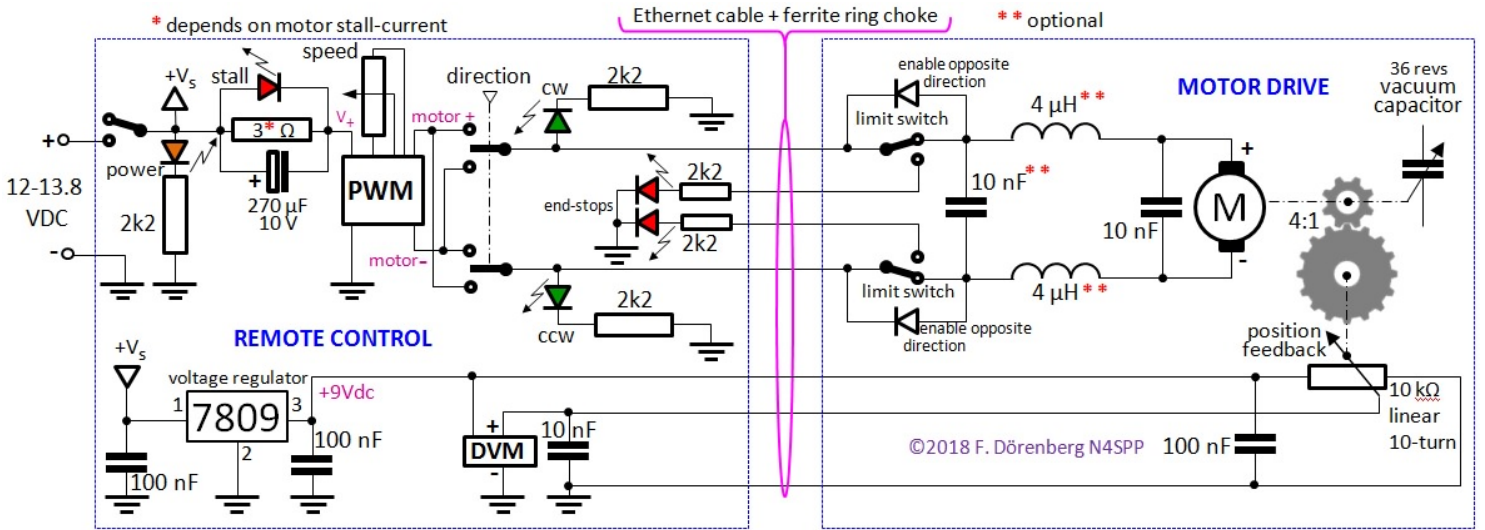


Figure 134: Remote control schematic - with PWM variable speed adjustment

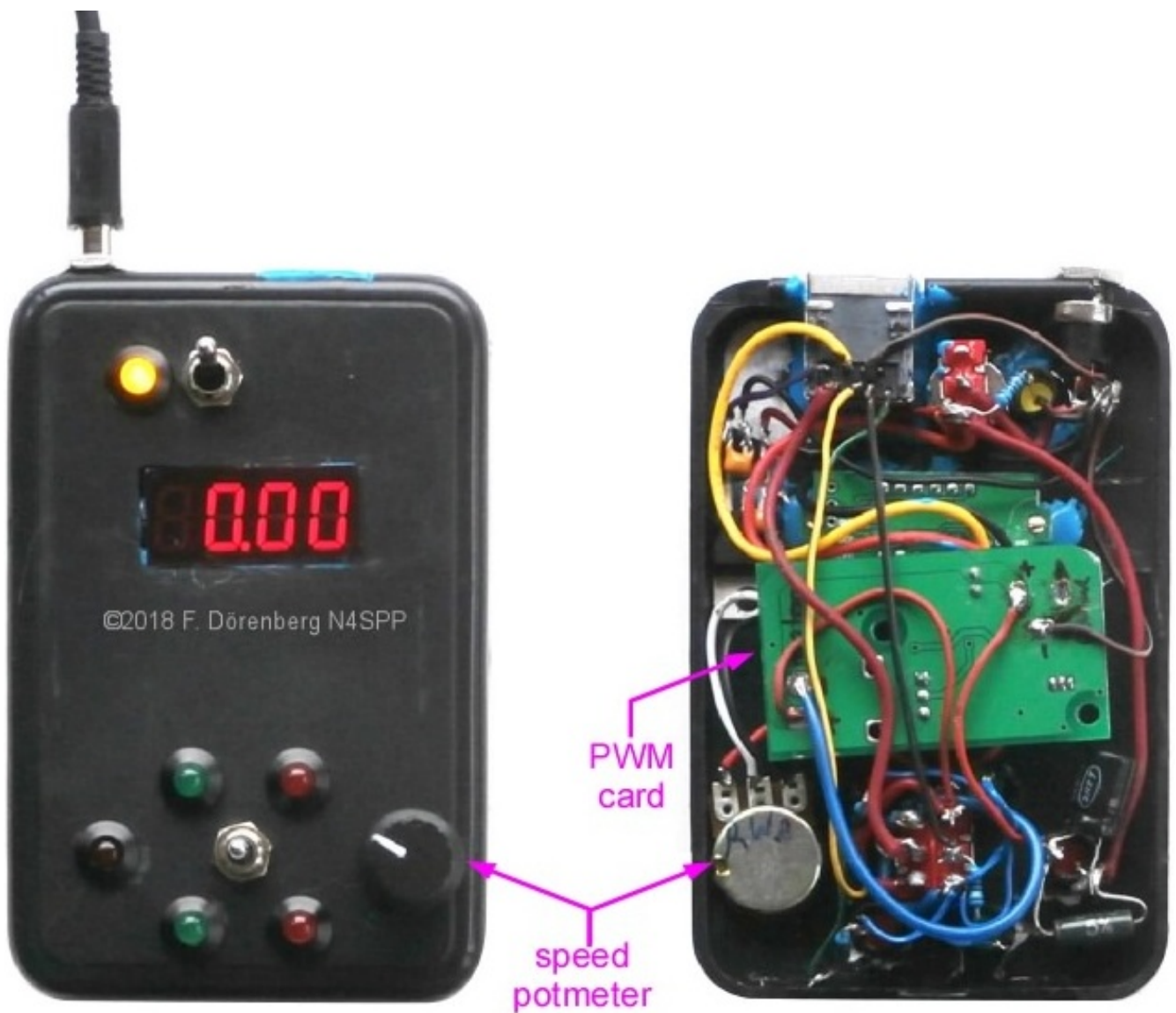


Figure 135: The prototype remote control box - now with variable speed adjustment
(red contrast filter added to the 4-digit DVM display)

MOTOR DRIVE FOR THE COUPLING LOOP

One of the standard coupling methods is a Coupling Loop, see the "[Inductive coupling](#)" section above. This is basically an air-core transformer. Normally, the configuration is as follows:

The size of the coupling loop is fixed. Standard recipe is 1/5 the size of the main loop.

The position of the coupling loop is fixed, after adjusting it once for lowest SWR on the frequency (or the middle of the frequency range) of interest.

Sometimes the shape of the coupling loop is (also) adjusted to obtain best SWR.

It should be relatively easy to obtain $SWR < 1.1$ (except maybe when the antenna is placed indoors).

In my experience, once the coupling loop has been properly adjusted, SWR remains < 1.2 over a frequency range of about 1:2.5. Beyond that, the SWR gradually (and rapidly) becomes worse than 1.5. Also, if you change the installation height of the antenna, the SWR will change noticeably. In 2018, I acquired [a 6 m \(20[±] ft\) telescopic mast](#) (German army surplus). Depending on the weather conditions (we have a lot of heavy wind at my current QTH), I use my STL anywhere between 50 cm and 4m above ground level (= my terrace floor). Raising and lowering the mast several times to re-adjust the coupling loop is no fun. So, I decided make the coupling between the coupling loop and the main loop variable, with remote-control motorization.

In principle, there are several basic ways to do this:

Change the shape of the coupling loop. This is not very practical with a rigid coupling loop, and I did not try this.

Rotate the coupling loop about its vertical axis, such that it no longer lies in the same plane as the main loop. See Figure 136 and [the next section](#).

If the orientation of the main loop and the coupling loop is close to perpendicular (90°), then the coupling factor is basically zero. There is no need whatsoever, to be able to go this far. I decided to design my motorization for a maximum swing of about $40\text{-}50^\circ$ (= $20\text{-}25^\circ$ to either side of co-planar or parallel).

Keep the coupling loop co-planar with the main loop, but translate (= slide) it up or down, such that its distance to the main loop changes. See Figure 137 and [the following section](#).

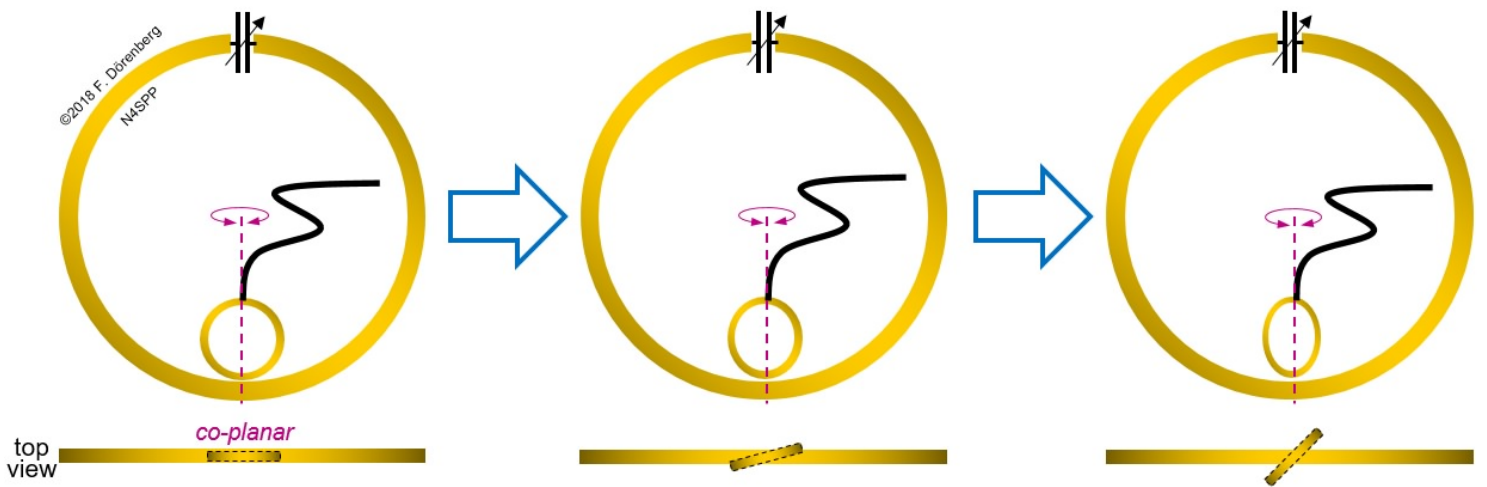


Fig. 136: Rotating the coupling loop about its vertical axis to change the coupling with the main loop

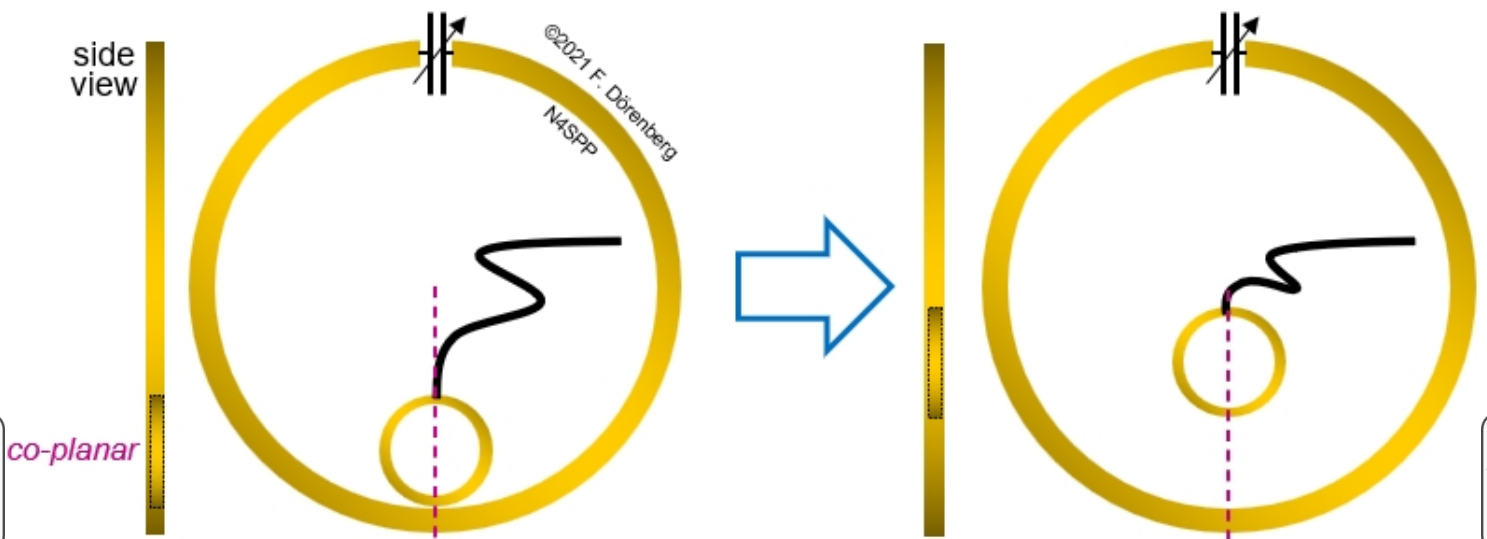


Fig. 137: Translating the coupling loop to change the coupling with the main loop

COUPLING LOOP MOTORIZATION - PART 1: ROTATION

There are several ways to motorize rotation of the coupling loop out of, and back into, the plane of the main loop:

Stick the mounting-end of the coupling loop onto the shaft of a very-low-rpm DC motor. To get low enough RPM (e.g., 0.2-0.3), you will have to use motor with a attached down-gearing. And even then, you probably want to add (or need) variable PWM motor rpm control, to further reduce the rpm of the coupling loop. And you will have to add two end-stop switches:

Unless your STL is dimensioned for VHF, or is really self-supporting (= made of large diameter rigid tubing), your STL will be attached to a support mast. This makes it impossible to place the coupling loop exactly in the plane of the main loop.

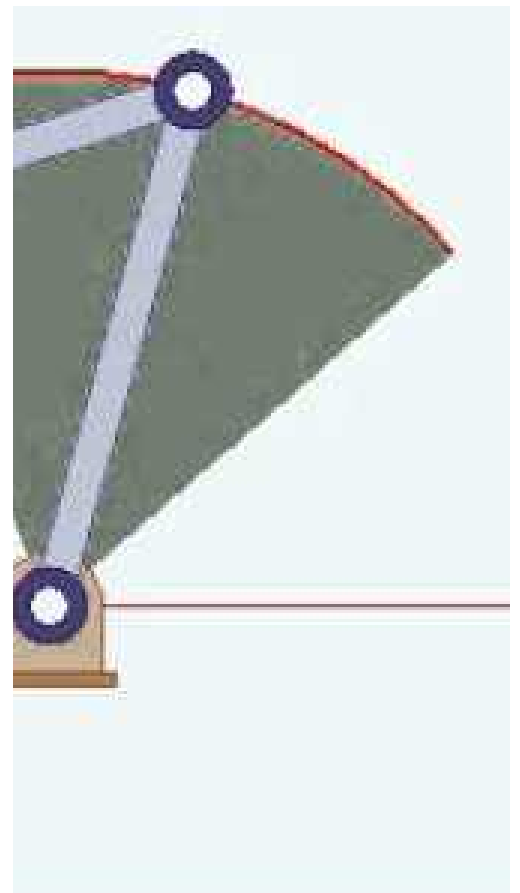
This also makes it impossible to rotate the coupling loop 360° without hitting the mast.

Also, there is a coax cable attached to the coupling loop. It will wrap around itself, or the coupling loop drive, if rotation is unlimited. Not good when you don't have visual contact with coupling loop!

Rotate the coupling loop not about its own axis, but about another axis. This *other* axis is parallel to the vertical axis of the main loop, and preferably close to the latter. Again, rotation has to be limited - with end-stop switches, or mechanically.

The standard way to convert 360° motor shaft rotation to a limited rotation angle ($>0^\circ$ but $<180^\circ$) of the load, is to use a double-eccentric (= "off center") drive. This is also known as "crank-and-rocker" and "4-bar linkage". No end-stop switches are required!

This is the same method that is used in continuously oscillating fans for room ventilation.



0:00 / 0:26

Motion of a double-eccentric / crank-and-rocker / 4-bar-linkage arrangement

source: [YouTube](#)

In the video clip above, it looks like the linkage only has 3 bars. However, it is generically called a 4-bar linkage. The fourth bar is the "vertical" offset between the axis of rotation of the motor and of the load. I.e., if the motor is moved up or down along the gray vertical line in the image.

A crank-and-rocker mechanism has several parameters that must be chosen to obtain the desired angular swing range:

The length of the crank on the motor shaft (= distance between shaft axis and swivel point at the end of the motor crank).

The length of the crank on the load (= distance between axis of rotation of the load, and swivel point at the end of this crank).

The length of the push-pull bar between the two cranks (= distance between the two swivel points).

The distance between the two axes of rotation.

I like a good challenge, so I decided to implement the eccentric-drive method - yes, you may call me crazy. When I started this little project, my coupling loop was mounted onto the PVC mast with two standard PVC tube clamps. By loosening the clamps a little bit, they can rotate around the mast without too much resistance or wiggle. I use the same approach during manual adjustment. I decided to motorize the clamp that is farthest from the main loop. Somehow, this clamp must be rotated around the mast with a small electric motor. I do not need position feedback for this motor, and I did not want to add end-stops.

For installation on the antenna mast, these parameter must be chosen such that the cranks, and the bar between them, do not touch the mast. Otherwise, the drive mechanism will self-destruct! This can all be calculated with trigonometry. Good luck! Or, you can model it with a CAD tool - which I don't have. I simply took a large sheet of paper, drew the cross section of the PVC mast tube on it (scale 1:1), added the rotation radius of the coupling loop, and assumed a simple mount for the small 12 Vdc / 3 rpm motor that I happened to have. I placed the motor 135° away (= behind the mast) with respect to the plane of the main loop. Then I started to play with crank lengths and the push-pull bar length:

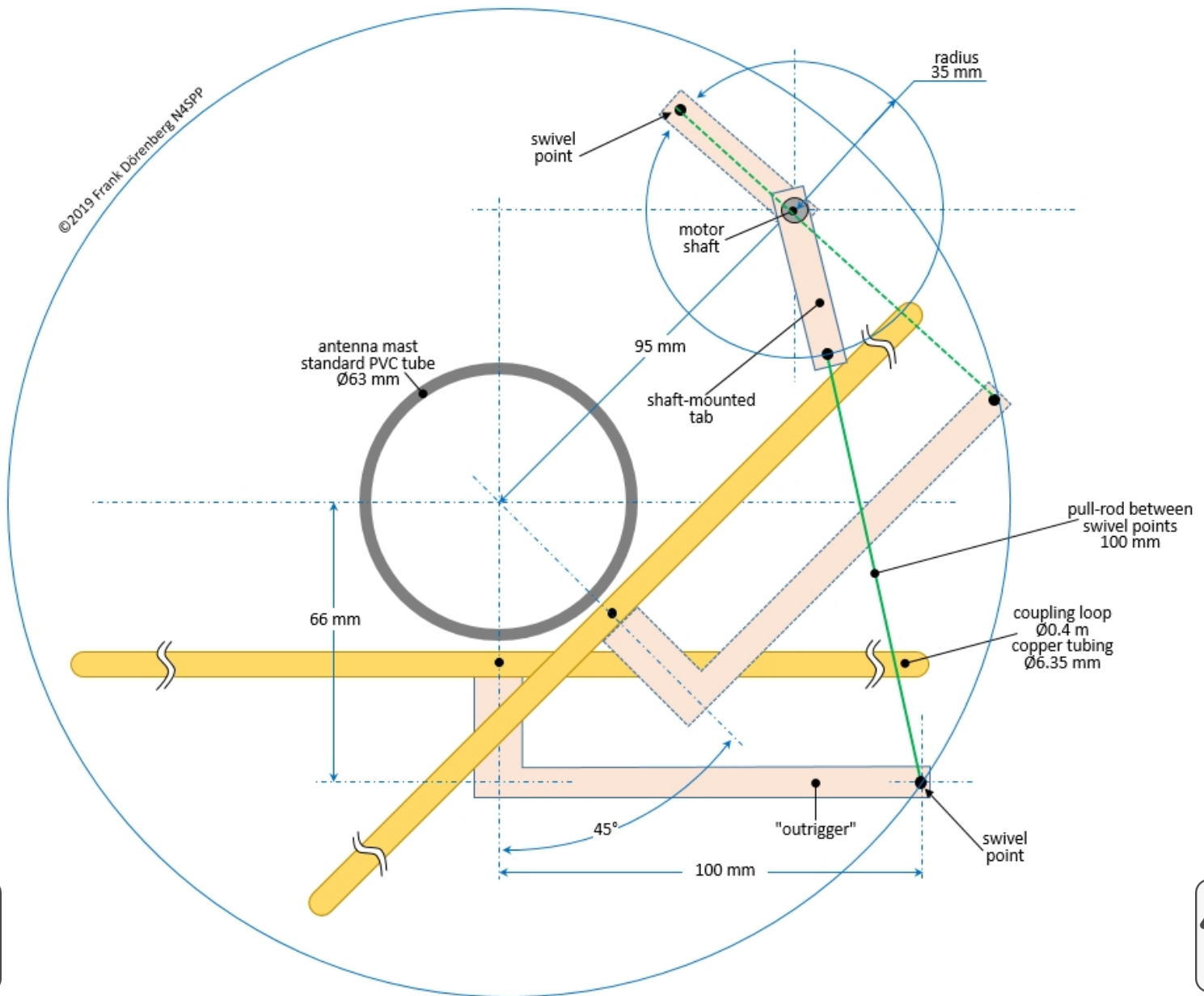


Figure 138: Design drawing of my double-eccentric drive

The drawing above shows the dimensions that I finally selected. The motor mount, the two "arms", and the push-pull bar are all made of 11 mm thick polyethylene (= kitchen cutting board). This material is light, strong, and easy to machine (drill, saw, grind,...). I fixed the motor mount to the PVC tube mast with a standard "munson" type tube/pipe clamp and a heavy angle bracket. The swivels are made of 6 mm bolts, with washers and lock nuts (= nut with a nylon insert).



Figure 139: Side view of the double-eccentric drive for the coupling loop

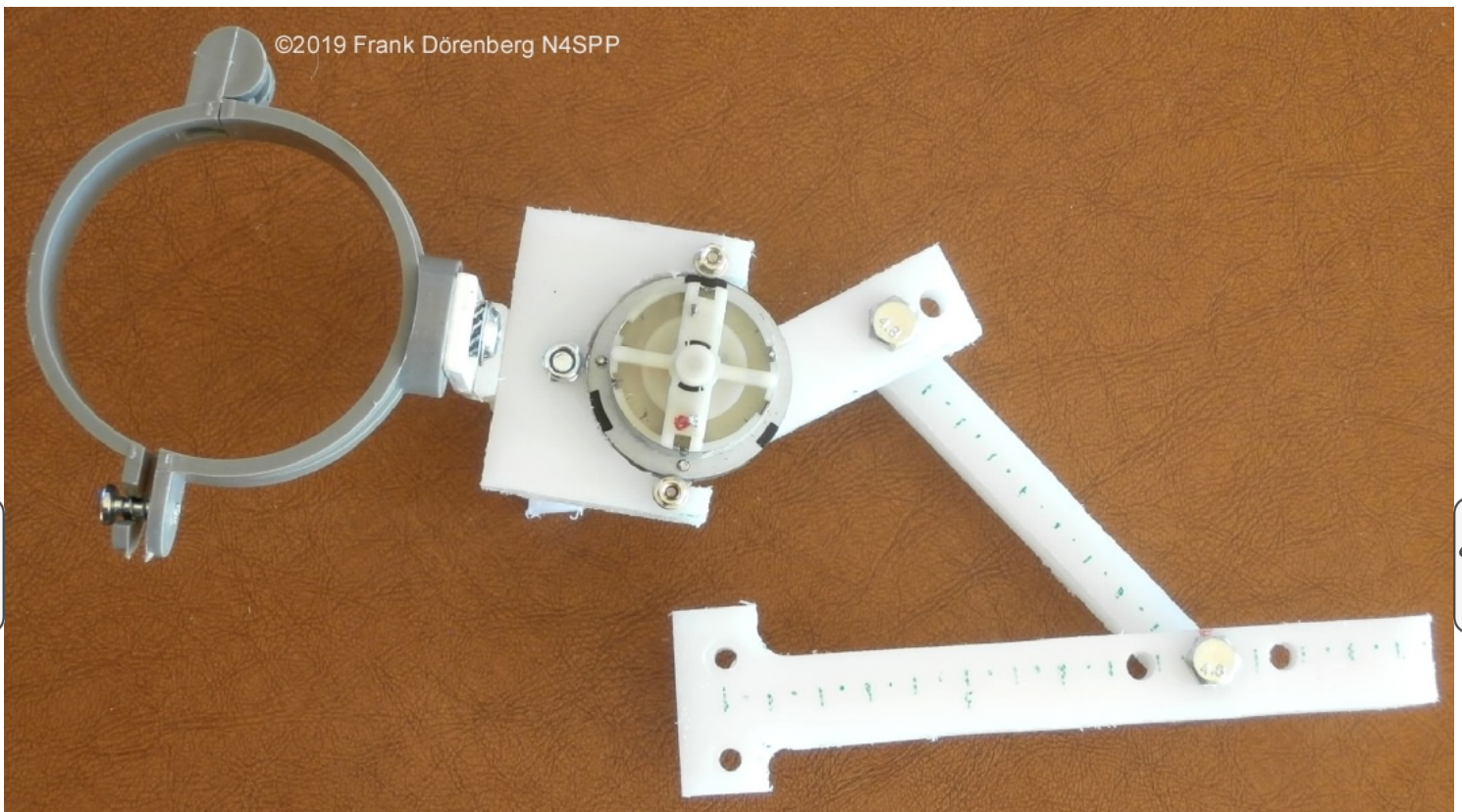


Figure 140: Top view of the double-eccentric drive for the coupling loop

Note that the crank bars on the motor shaft and on the coupling loop have some extra length and holes. This was done, just in case I needed to make some adjustments to the swing range. Actually, my original design was very close to "perfect".



©2019 Frank Dörenberg N4SPP

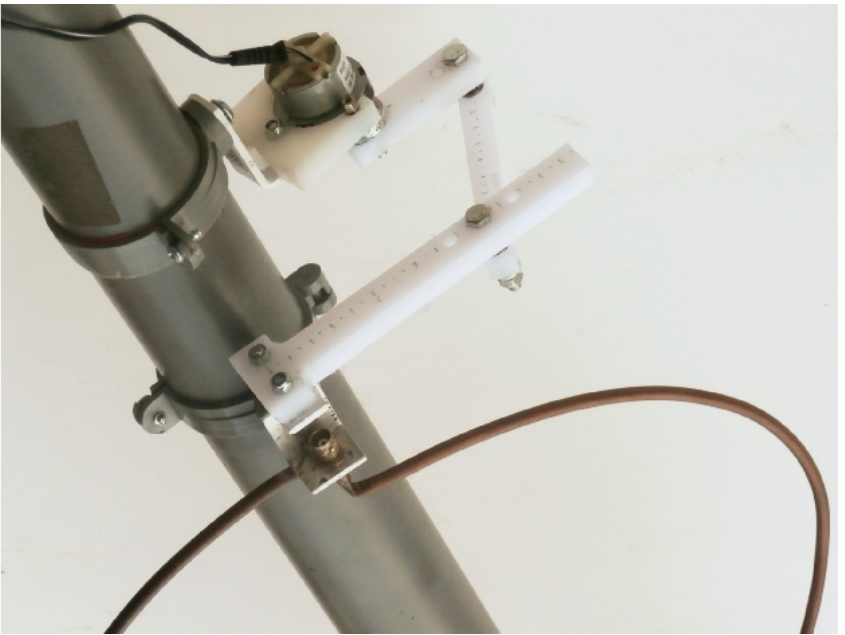
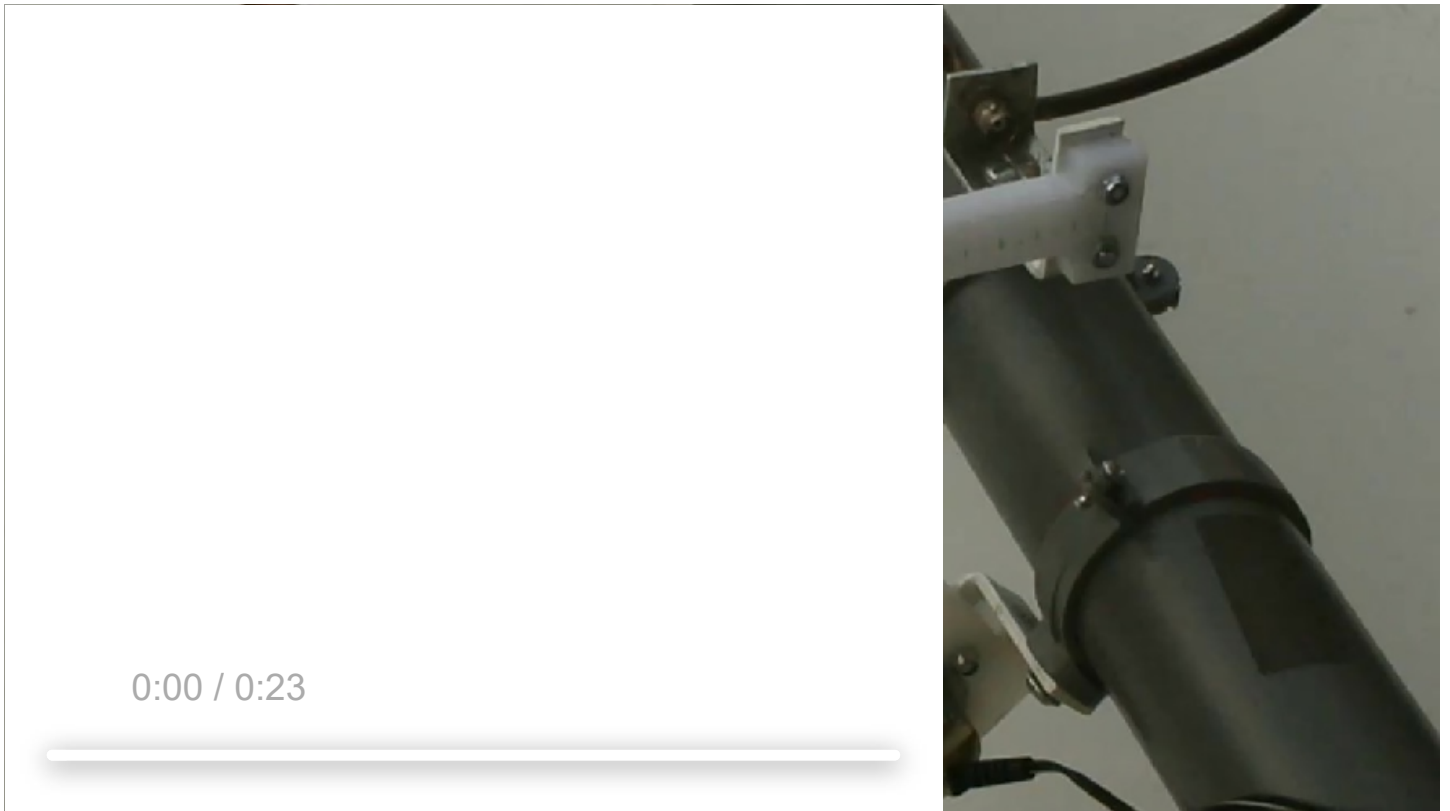


Figure 141: the double-eccentric drive for the coupling loop - installed



Full motion cycle of the motorized coupling loop (max speed)

©2019 Frank Dörenberg (N4SPP)

Note: clearly, it is very difficult (if not impossible/impractical) to make this motor drive weatherproof!

I am using the same remote control method as for [motorizing the tuning capacitor](#), see Fig. 124. I use a standard 8-conductor ethernet cable between motor drive(s) on the antenna and the remote control box in the shack. With only the capacitor drive motor + position feedback + end-stop switches feedback, only 7 of 8 conductors of the cable are used. I use the 8th conductor

to actuate a small relay at the antenna. It switches power between the capacitor drive motor and the coupling loop drive motor. Other options are to run a separate cable with a separate control box. Or: run a separate cable and switch the control box between the two cables at the shack end. I clearly prefer my solution with the relay. I did not have a small 12 volt **DPDT** relay in my junk box, so I used two very small 5 volt **SPDT** relays (type DR-5V) that I happened to have, and connected their solenoids in series:

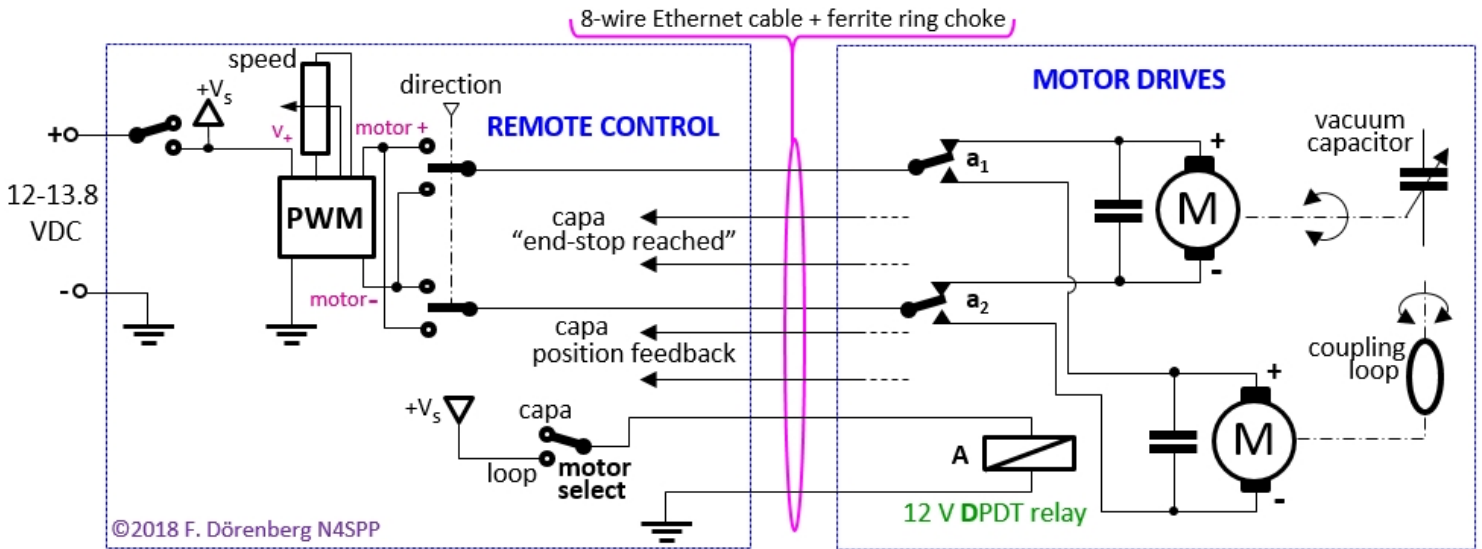


Fig. 142: Simplified remote control schematic - with toggle switch for motor-selection and one DPDT relay

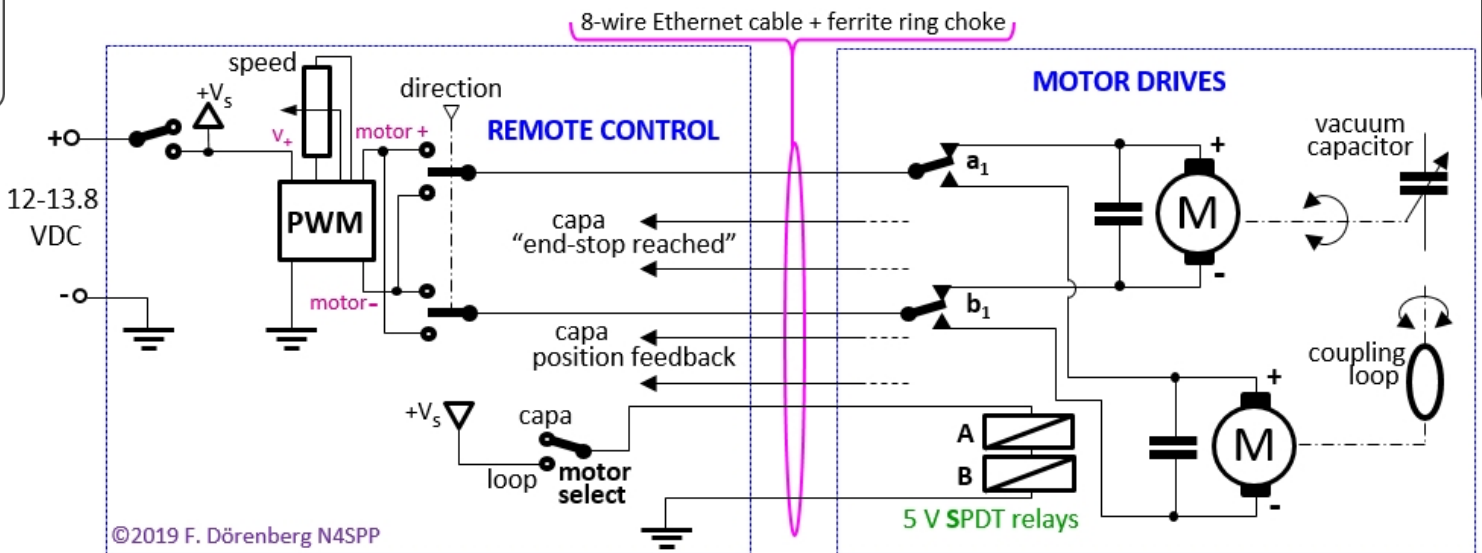


Figure 143: The remote control box - with toggle switch for motor-selection and two SPDT relays



Figure 144: The remote control box - now with a toggle switch for motor selection

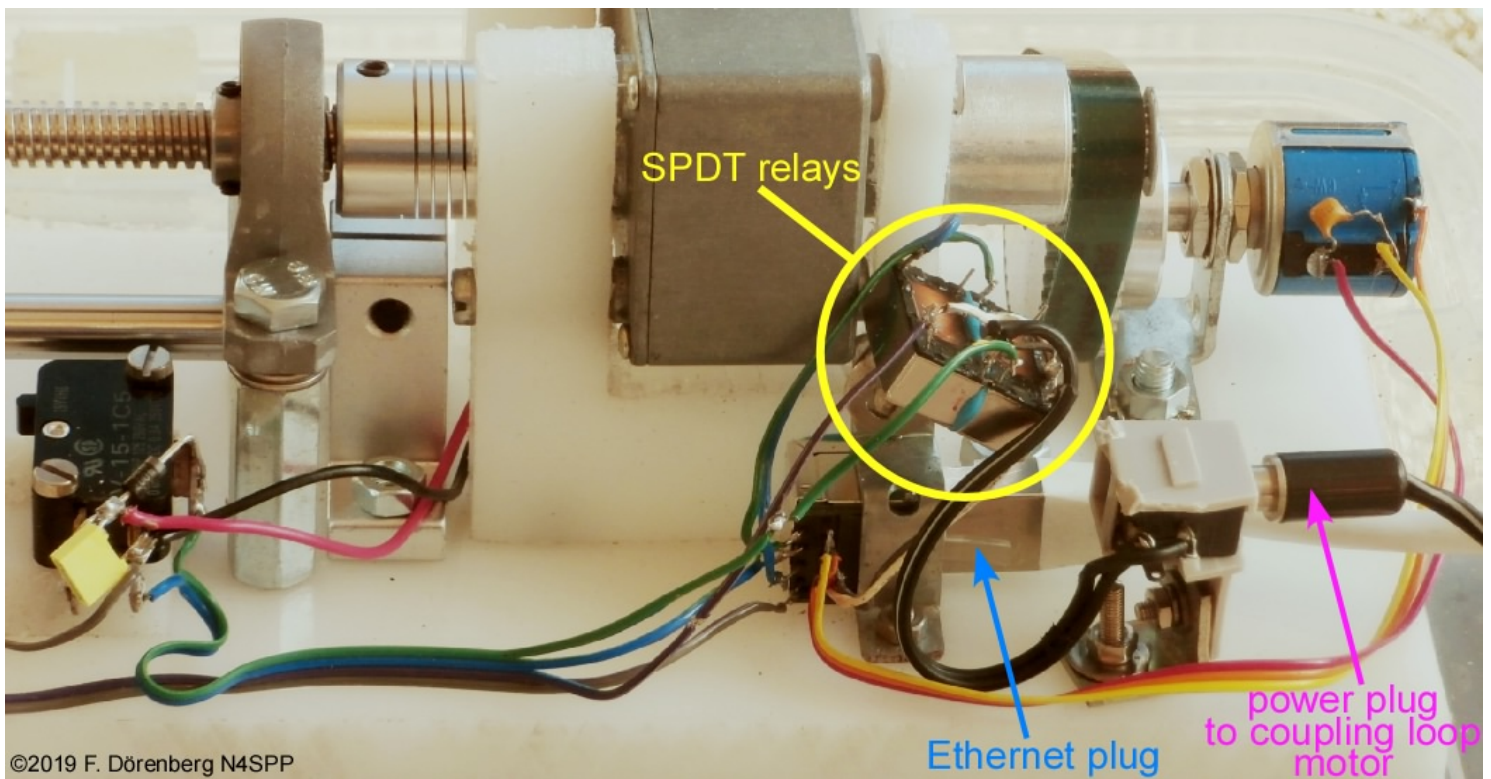


Fig. 145: The SPDT relays (glued together with blue Loctite) near the Ethernet cable connector at the antenna
(compare to Fig. 118)

Note: I could have added more relays, all controlled by the same signal, to also switch end-stop switch wiring and position feed back wiring (if I had added any of these to my coupling loop drive).

COUPLING LOOP MOTORIZATION - PART 2: *LINEAR TRANSLATION*

I completed a linear translation drive in January of 2021, two years after my eccentric rotation drive. Mechanically, this is *much* easier. It is also *much* easier to weatherize. I use exactly the same motor control box and motor switching at the antenna, as shown above for the rotation drive.

Instead of constructing a translation drive myself, I went the easy route: I bought an off-the-shelf 12 VDC motor drive via eBay (search for "electric linear actuator"; prices vary considerably). Such actuators are typically used for opening/closing skylight windows and for rotating satellite dish antennas. They are available with a large variety of stroke (= extension distance) and force. I got one with a stroke of 100 mm (= 10 cm = 4 inches), a nominal speed of 5 mm/sec, and an enormous force of 1000 N (≈ 100 kg, ≈ 220 lbs). This stroke is more than I need for normal operation, but I wanted to have plenty of margin for experimentation. Such actuators have built-in end-stop switches (the SPST contacts are not accessible), or a simple slip-clutch mechanism. They work

well in combination with a PWM variable speed controller. Of course, the length of the actuator housing is a bit larger than the stroke. More expensive linear actuators may include a built-in potentiometer for position feedback.

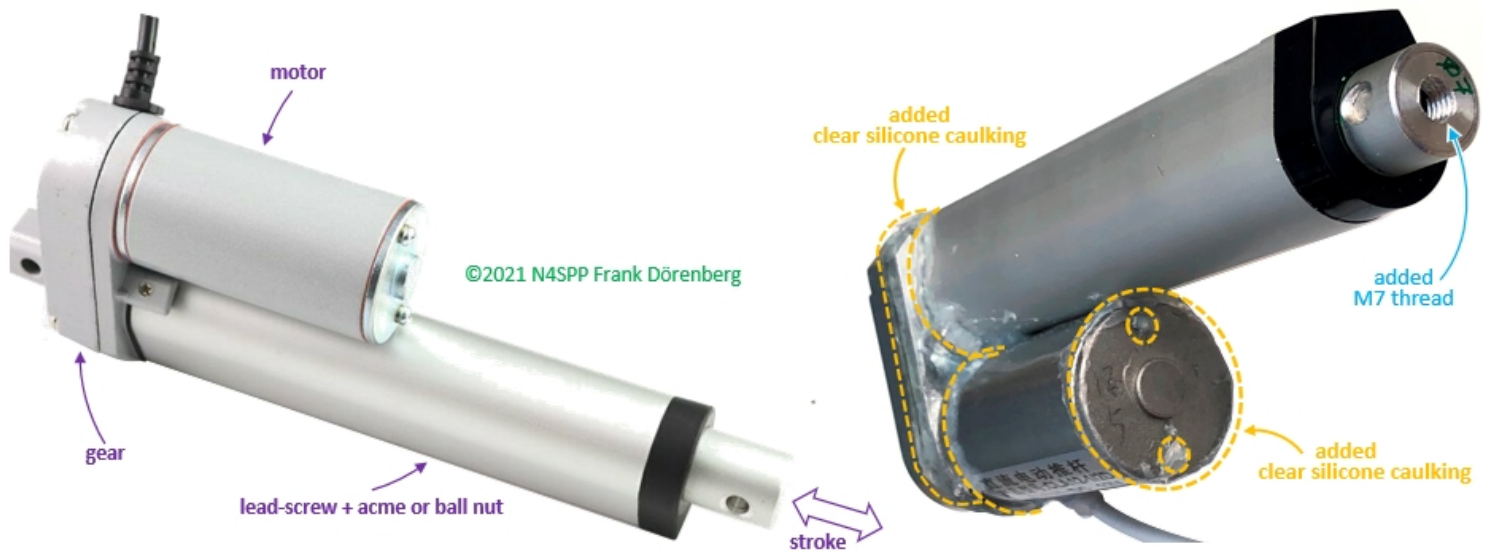


Fig. 146: Linear actuator - M7 thread added for attaching my coupling loop, silicone caulking added for weatherproofing

I re-used the soft copper tubing (standard 1/4 inch = 6.35 mm diameter) of my previous coupling loop, and built a weatherproof box to mount it onto the tip of the actuator, with an M7 bolt. I did not have a suitable mounting box at hand, but I did have a 2 meter section of standard 4 cm wide hard PVC angle profile. I cut pieces out of it, and glued them up with regular PVC glue. The box looks like a tiny birdhouse. Via the entry hole, I can access the coax cable with a soldering iron, and access the M7 mounting bolt (with hex socket) - without having to break open the box. The entry hole is closed off with a piece of clear plastic. The two ends of the copper tubing enter via standard cable glands (*F*: presse-étoupe, *D*: Kabelverschraubung). I used PG07 glands. They are watertight (IP68 standard), and are made for cables with a 3-6.5 mm diameter - perfect for my copper tubing!



©2021 Frank Dörenberg N4SPP
V1.0

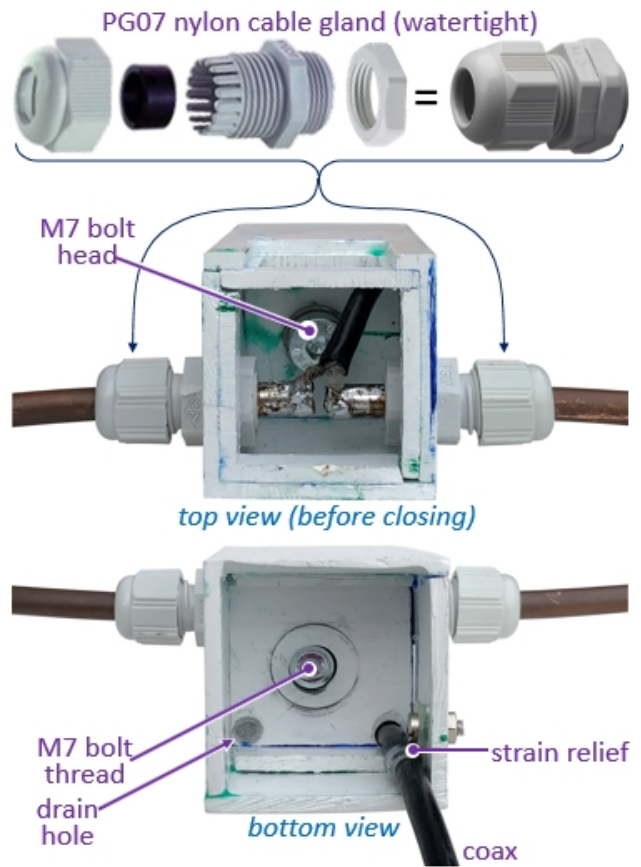


Fig. 147: My new coupling loop with mounting box

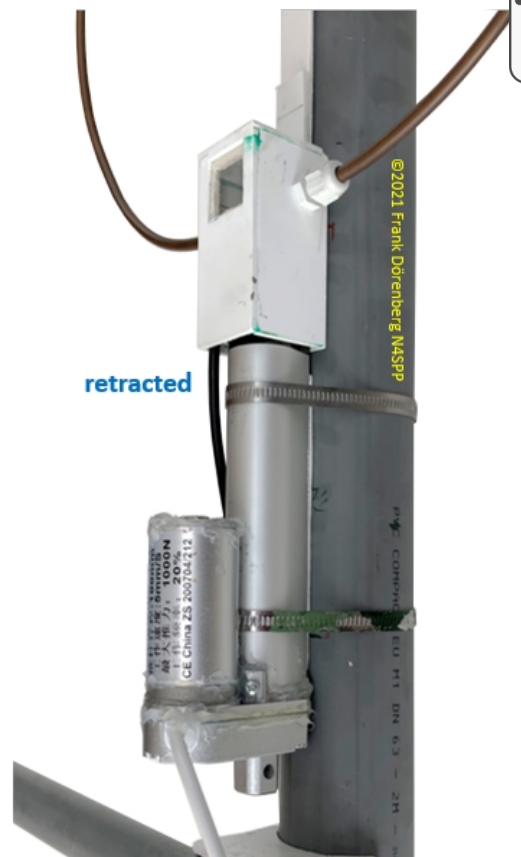
The coupling loop drive is firmly mounted onto the PVC mast of my STL with two hose clamps (UK: "jubilee clips"):



©2021 Frank Dörenberg N4SPP



extended



retracted

©2021 Frank Dörenberg N4SPP

Fig. 148: My coupling with linear motor drive

Mounting height was adjusted such that with the actuator fully extended, the coupling loop almost touches the main loop. Note the small black shrink tubing insulation at the top of the coupling loop. The point of the main loop that is diametrically opposite of the variable capacitor (i.e., half way around the main loop), is electrically neutral. But I decided to add some insulation anyway.

When fully retracted, the bottom of the "birdhouse" completely hides the black top of the actuator. See the right hand photo in Fig. 148 above. In this parking position, no rain water can enter the actuator via the top.

Fully extended, the actuator rod has noticeable radial play and backlash (rotational play). However, I tilted the coupling loop slightly against the PVC mast of the STL, and the back of the "birdhouse" rides against the PVC mast. This appears to sufficiently stabilize the installation.

For my specific main loop, my coupling loop, my installation location, and my installation height:

NEXT PROJECT: AUTOMATIC TUNING

To be added...

Two methods: select operating frequency and vary the capacitor value so as to minimize SWR or to maximize power or current. Typically do not result in exactly the same capacitor setting.

Work on this has been done by the (primarily) Japanese "MLA 48" group, in particular Hajime Nakajima (JR1OAO). His automatic antenna coupler measures the RF voltage and current at a point along the coax to the antenna. The position of the coupling loop position is adjusted based on the ratio of these two parameters (effectively an impedance value), to minimize the SWR. The measured phase angle between the current and voltage is used to adjust the motorized tuning capacitor until the resonance frequency matches the operating frequency. Note: the phase angle to be adjusted/calibrated is measured at the antenna feedpoint (or a point along the transmission-line that is at an electrical distance of a whole multiple of $1/2 \lambda$ away from the feedpoint).

Just like the motorization of the tuning capacitor can be automated, so can the coupling loop drive. Excessive luxury. Switchable.

REFERENCES

Ref. 1: "[Magnetic Loop Antenna](#)" with video clips about radiation direction and voltage/current distribution of STLs, Ben Edginton (G0CWT)

Ref. 2: Loop calculators and formulas:

Ref. 2A: [KI6GD calculator](#)

Ref. 2B: [AA5TB calculator, version 1.22F](#), accessed 15 March 2021 (Microsoft Excel file - if you don't have MS Excel on your PC, you can download a freeware viewer from Microsoft [here](#))

Ref. 2C: "[66pacific on-line loop calculator](#)" (based on ARRL Antenna Handbook)

Ref. 2D: [RJLOOP1 calculator](#) for performance of single-turn magloop antennas of various regular shapes and [MAGLOOP4 calculator](#) for performance versus height and type of ground, by [Reg Edwards \(G4FGQ, SK\)](#)

Ref. 2E: "[DG0KW Magnetic - Loop Antenna - Calculator](#)", Klaus Warsow (DG0KW); note: 3 GUI languages selectable via the "options" tab.

["Quick reference Guide"](#) [pdf]

Ref. 2F: "[Small transmitting loop calculators – a comparison](#)", Owen Duffy (VK1OD, VK2OMD), November 16, 2015 [pdf]

Ref. 2G: "[Calculate small transmitting loop gain from bandwidth measurement](#)", V. 1.03, on-line calculator for efficiency and gain of a small single turn transmitting loop in free space from VSWR bandwidth, matched frequency, loop radius and conductor radius or resonating capacitance, Owen Duffy (VK1OD, VK2OMD), 2014/2015.

Ref. 2H: "[Estimating the voltage impressed on the tuning capacitor of a small transmitting loop](#)", Owen Duffy (VK1OD, VK2OMD), 6 June 2017. Accessed 29 August 2019. [pdf]

Ref. 2J: "[Accuracy of estimation of radiation resistance of small transmitting loops](#)", Owen Duffy (VK1OD, VK2OMD), Version 14 August 2015. Accessed 5 January 2020. [pdf]

Ref. 2K: "[Small transmitting loop – ground loss relationship to radiation resistance](#)", Owen Duffy (VK1OD, VK2OMD), Version 8 August 2015. Accessed 5 January 2020. [pdf]

Ref. 3: Some discussions about the efficiency of STL antennas:

Ref. 3A: "[Magnetic loop or small folded dipole?](#)", M.J Underhill, M.J. Blewett, Proc. IEE Conf "HF Radio Systems and Techniques", 1997, pp. 216-224

Ref. 3B: "[Small Loop Antenna Efficiency](#)", Mike Underhill (G3LHZ), May 2006

Ref. 3C: "[All sorts of small antennas – they are better than you think – heuristics shows why!](#)", Mike Underhill (G3LHZ), February 2008

Ref. 3D: "[Small, high-efficiency loop antennas](#)", Ted Hart (W5QJR), in "QST", June 1986, pp. 33-36

Ref. 3E: "[How Efficient is Your QRP Small Loop Antenna?](#)", Amir Findling (K9CHP), Kazimir Siwiak (KE4PT), in "The QRP Quarterly", Summer 2012, pp. 22-23; accessed 6 June 2019 [[pdf](#)]

Ref. 3F: [Small-Loop-Antenna-Efficiency-calculator](#), Microsoft Excel spreadsheet (based on ref. 3E) by Frank Dörenberg (N4SPP), 6 June 2019.

Ref. 4: Flat-strip and PCB STL antennas

Ref. 4A: "[The Midnight Loop - An Experimental Small Transmitting Loop ~ Theory & Practice ~](#)", [G. Heron, N2APB and J. Everhart, N2CX](#), Massachusetts QRP Convention 2010, 52 slides.

Ref. 4B: "Portabel-Magnetschleifantenne für das 2-m-Band", Tomas Schiller (DC7GB), in "[Funkamateurl](#)", [Nr. 8/17](#), pp. 746-748. [[pdf](#)] *See note at bottom of this page.*

A kit is available from the "Funkamateurl" shop [here](#). [[pdf](#)], retrieved 16 March 2021.

Ref. 5: Helically-wound STL antennas

Ref. 5A: "[Helically Loaded Magnetic Loop Antenna](#)", web page by Rich Fusinski (K8NDS). Accessed 29 June 2019.

Ref. 5B: "[Helically Loaded Fractional Wave Loop Antenna](#)" Yahoo-group. Accessed 29 June 2019.

Ref. 5C: "[Slinky Loop aerial](#)" by Tom Haylock (M0ZSA), in "RadCom", November 2010, p. 49.

Ref. 5D: "[A Helical Loop Antenna for the 20-meters Band](#)", by Vladimir Kuzmin (UA9JKW), in "Antentop", Nr. 5, 1-2004, pp. 60-62.

Ref. 5F: "[The SLINKY-HULA](#)", by John Heys (G3BDQ), in "Practical Wireless", November 2003, pp. 44-45.

Ref. 6: Coupling and Matching Networks

Ref. 6A: "[Magnetic Loop Koppelschleifen](#)" [in German: "coupling-loops for magnetic loops"], Jochen Huebl (DG1SFJ). Source:[dg1sfj.de](#).

Ref. 6B: "[Down-to-Earth Army Antenna](#)", K. H. Patterson, in "Electronics", 21 August 1967, pp. 111-114. Source:

worldradiohistory.com, accessed 19 September 2020.

Ref. 6C: "[The DL2JTE Loop: A Novel Antenna - Translation, possible theory of operation and comments by Paul Lukas - N6DMV/HA5CCV](#)", [antenneX](#), Issue No. 168, April 2011 (translated from "Die HA-Loop-Antenne - auf Vor- und Endselektion kommt es an", László Rusvai (DL2JTE/HA7HN), in "[CQ-DL](#)", 10-2011, pp. 717-719).

Ref. 6D: "[Neue Speisetechnik für Magnetic Loops](#)" [new feeding method for magnetic Loops], László Rusvai (DL2JTE/HA7HN), in "[CQ-DL](#)", 6-2007, pp. 421.

Ref. 6E: "[Building the Magnetic Loop Antenna](#)" [ferrite ring transformer], (KJ3JLS).

Ref. 6F: "[The Rockloop - A Compact Antenna for the 15, 20 and 30 meter Bands](#)" [incl. ferrite transformer], C.F. Rockey (W9SCH), SPRAT, Nr. 60, autumn 1989, p. 15.

Ref. 6G: "[How to design gamma-matching networks](#)", Harold Tolles (W7ITB), in "Ham Radio Magazine", May 1973, pp. 46-55.

Ref. 6H: "[An examination of the Gamma Match](#)", D.J. Healy W3PG/W3HEC, in "QST", April 1969, pp. 11-15, 57. [[pdf](#)]

Ref. 6J: "[What's with the Gamma Match Equations?](#)" (Gamma Match Equations and Associated Confusion), [Bill Wortman \(N6MW\)](#).

Ref. 6K: "The G3LHZ Twisted Gamma Match", p. 3 in "[Surrey Radio Contact Club Newsletter](#)", no. 797, February 2009.

Ref. 6M: "[My Experiments - Antennas](#)", Jo Lourenço (CT1ECW). [[pdf](#)]

Ref. 6N: "DX-Antennen mit spiegelnden Flächen - Teil 12 & 12b", Hans Würtz, in "CQ-DL", 2/1983, pp. 64-67 and 4/1983, pp. 170, 171.

Ref. 6P: "[The Army Loop in Ham Communication](#)", Lewis G. McCoy (W1ICP), in "QST", March 1968, pp. 17, 18, 150, 152.

Ref. 6Q: "[Sources of Magnetic Fields](#)" & "[Inductance and Energy in Magnetic Fields](#)", Sen-ben Liao, Peter Dourmashkin, John W. Belcher. Source: chapter 9 and 11 of [course notes](#) used in Physics 8.02 "Electricity and Magnetism" at MIT.

Ref. 6R: "[Nogmaals koppellus voor raamantennes](#)" [in Dutch], Koos Fockens (PA0KDF), in "Electron", October 2000, p. 405.

Ref. 7: "[FAIR-RITE Material Data Sheets for Materials Nr. 31 -98](#)", Fair-Rite Products Corp; [Core Loss vs. AC Flux Density - Type 61 Material](#); [Initial Permeability and Loss Factor vs Frequency of Type 43 material](#)".

Ref. 8: Some general STL "Magnetic Loop" articles and links (incl. NEC modeling)

Ref. 8A: "[Small Transmitting Loop Antennas](#)", by [Steve Yates \(AA5TB\)](#), August 2013.

Ref. 8B: "[Welcome to W2BRI's Magnetic Loop](#)", by Brian Levy (W2BRI).

Ref. 8C: "[G3LDO's experiences with a small transmitting loop antenna](#)", in "RadCom", September 2010, pp. 34, 35.

Ref. 8D: "Loop Antennas", Chapter 5 in "ARRL Antenna Handbook", 21st edition.

Ref. 8E: "[An Overview of the Underestimated Magnetic Loop HF Antenna](#)", by Leigh Turner (VK5KLT), V1.2, October 2015 (used with permission).

Ref. 8F: "[My Magnetic Loop Antenna](#)", A. Krist (KR1ST), in "AntenneX", Issue No. 111, July 2006. [[pdf](#)]

Ref. 8G: "Small Gap-Resonated HF Loop Antennas", Kai Siwiak (KE4PT), Richard Quick (W4RX), in "QST", September 2018, pp. 30-33. [[pdf](#)] *See note at bottom of this page.*

Ref. 9: corrosion, silver plating

Ref. 9A: "[Silver plating RF components](#)" by Dirk Winand (ON4AWU).

Ref. 9B: "[Components and materials](#)" by [David Knight \(G3YNH\)](#).

Ref. 9C: "[Measuring the permittivity and permeability of lossy materials: solids, liquids, metals, building materials, and negative-index materials](#)", J.R. Baker-Jarvis, M.D. Janezic, B.F. Riddle, R.T. Johnk, P. Kabos, C.L. Holloway, R.G. Geyer, C.A. Grosvenor, NIST Technical Note 1536, US Dept. of Commerce, National Institute of Standards and Technology (NIST), 2005, 160 pp. Source: [nist.org](#), retrieved 22 June 2020.

Ref. 10: "[Tube roller](#)" by Roger Dunn (VK4ZL), September 2011, 2 pp.; used with permission.

Ref. 11: Motor drives for tuning capacitors

Ref. 11A: "[Helical loop - direct drive with limit travel and motor stall Warning LED on control unit](#)" (about half way down the page) by Rich Fusinski (K8NDS), 2013. [[pdf of schematic](#)]

Ref. 11B: "Easy Step'n - An Introduction to Stepper Motors for the Experimenter", David Benson, Square 1 Electronics, 200 pp.

Ref. 11E: "[To automatically tune a Magnetic Loop Antenna](#)" [stepper motor control with display] by [Loftur E. Jónasson \(TF3LJ / VE2LJX\)](#).

Ref. 11F: "[Multiturn Coils and Capacitors Drive](#)", Rev. 2, Dominique Delerablee (F1FRV). [[pdf](#)]

Ref. 11G: "[F1FRV Flea Market](#)" [French & English on the same page], Dominique Delerablee (F1FRV), accessed 2 November 2020. [[pdf](#)]

Ref. 12: Capacitors

Ref. 12A: "[Variabele condensator in olie](#)" [in Dutch], Otto Kühn (PA9OK, SK), in "Electron" (VERON), December 2010, pp. 527-529. *See note at bottom of this page.*

Ref. 12B: "Vacuum Capacitors", G.H. Floyd, in "Proceedings of the IRE", Vol. 32, Nr. 8, August 1944, pp. 463-470.

Ref. 12C: "[A highly stable reference standard capacitor](#)", John Hersch, in "General Radio Experimenter", Vol. 37, No. 8, August 1963, pp. 1-8. [[pdf](#)]

Ref. 12D: [Equation 13.5](#) in "Capacitive sensors", Section 13.2 in "Handbook of modern sensors: physics, designs, and applications", Jacob Fraden, Springer-Verlag New York, 2010, 663 pp.

Ref. 12E: "[Electrical properties of atmospheric moist air: a systematic, experimental study](#)", Hugh Carlon, U.S. Army Research Directorate, Chemical Research, Development & Engineering Center, Report nr. CRDEC-TR-88059, September 1988, 31 pp. [[pdf](#)]

Ref. 12F: "[The Dielectric Constant of Air at Radio Frequencies](#)", A. B. Bryan, I. C. Sanders, in "Physical Review", Vol. 32, Iss. 2, August 1928, pp. 302-310.

Ref. 12G: "[Vacuum Capacitor Characteristics](#)", Jennings Technology Tech Note. [[pdf](#)]

Ref. 12H: [p. 73](#) in "Capacitive sensors: design and applications", L. K. Baxter, IEEE Press, 1997, 320 pp.

Ref. 12K: "[Diagnostic of vacuum on the basis of the dielectric strength](#)", W. Chmielak, Z. Pochank, in "Przeglad Elektrotechniczny", Vol. 88, Nr. 12b/2012, pp. 311-314. [[pdf](#)]

Ref. 12L: "[Vacuum Variable Capacitors - An Introduction to their Design, Rating and Installation](#)", Lars Giers, in "Cathode Press" (The Machlett Labs, Inc.), Vol. 23, Nr. 4, 22 February 1994, pp. 22-29. [[pdf](#)]

Ref. 12M: "[Measuring the loss in variable air capacitors](#)", Alan Payne (G3RBJ), Issue 2, September 2013, 14 pp. [[pdf](#)]

Ref. 13: Variable inductors

Ref. 13A: "A New Tune for the Loop", John Seager (G0UCO), in "QEX", September/October 2010, pp. 35-37. Accessed 9

April 2019. [[pdf](#)] *See note at bottom of this page.*

Ref. 14: Radiation safety

Ref. 14A: "[HF Small Transmitting Loop - Safety Compliance Distances \(FCC, ICNIRP, and Canadian Guidelines\)](#)", Peter DeNeef (AE7PD), rev. 17 February 2019. Accessed 20 June 2019. [[pdf](#)]

Ref. 14B: "Safety Distances for HF Small Transmitting Loops", by Peter DeNeef (AE7PD), in "[RadCom](#)" (RSGB), [June 2017](#) (accessed 20 June 2019), pp. 46-47. [[pdf](#)] *See note at bottom of this page.*

Ref. 15: Shielded coupling loops

Ref. 15A: "The Screen Loop Aerial - A Theoretical and Experimental Investigation", R.E. Burgess, in "[The Wireless Engineer](#)", [Vol.16, No. 193, October 1939](#), pp. 492-499. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15B: "Special aspects of balanced shielded loops", L.L. Libby, in "[Proc. of the I.R.E.](#)", [Vol. 34, Issue 9, Sept. 1946](#), pp. 641-646. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15C: "[Characteristics of the Mobius Strip Loop](#)", Carl E. Baum, "Sensor and Simulation Notes VII", 1964, 15 pp. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15D: "[Analysis of the Moebius Loop Magnetic Field Sensor](#)", Paul H. Duncan, in "IEEE Trans. on Electromagnetic Compatibility", Vol. EMC-16, no. 2, May 1974, pp. 83-89. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15E: "[Probing the magnetic field probe](#)", Roy Ediss, in "EMC & Compliance Journal", Issue 47, July 2003, 6 pp. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15F: "[Using close field probing to reduce EMC design risks - Part 1](#)", Keith Armstrong, in "EMC Journal", Issue 112, June 2014. Retrieved 20 August 2019. [[pdf](#)]

Ref. 15G: "A Practical Approach to building and Evaluating a Broadband Active Loop Antenna, looking at the Mobius, Conventional Shielded and Wire Loops", Everett Sharp (N4CY, frmr. N8CNP), in "[Medium Wave News](#)", [Vol. 62, Nr. 2, May/June 2016](#), pp. 11-20. Retrieved 20 August 2019. [[pdf](#)]

Loop antenna simulations

Ref. 16A: "[A Universal HF Magnetic Loop Antenna NEC Model](#)", Carol F. Milazzo (KP4MD), 16-Sept-2011. [[pdf](#) [NEC1](#) [NEC2](#) [NEC3](#)]

Ref. 16B: "[NEC simulation model for Config #1](#)", "[NEC simulation model for Config #2](#)", Frank Dörenberg (N4SPP/F4WCN), 4 March 2021.

Nota : por motivos de derechos de autor, este archivo se encuentra en un directorio protegido con contraseña. [Comuníquese conmigo](#) si necesita acceso para fines de investigación o estudio personal.

Última comprobación de enlaces externos: octubre de 2015, a menos que se indique lo contrario

Back  to Top

Actualizaciones
y novedades

Póngase en contacto con
N4SPP

Mis otras
páginas ▲

Acerca de

