PA2ION
Dutch Radio Amateur
http://www.pa2ion.nl
HAM radio - computer programming - info exchange

Wanted: magnetic loop for 40-80-160 meter band with real power

Calculation, design and preliminary test of the tuning system. **DRAFT**

by PA2ION, 2011-02-05.

ABSTRACT

Many dwellings close together and an available area of 130m^2 are limiting factors for antenna design for the 80 and 160m bands. Tall magnetic loops might have their own problems like their weight, high costs, and an 'impressive' visibility for neighbours etc.
Calculations have been carried out for several magnetic loop antennas build with copper tubes having large diameter. It was focussed on a loop with 3.18m diameter because it is the largest possible object that can be placed in the intended backyard at a height of about 9m above street level and carrying a remote antenna tuning system. A computerized tuning control is preferred. The whole system with 25m long coax and control cables has to stay stable under long term outdoor conditions. To gain higher radiation efficiency the loop material will be copper plate with a thickness of 0.2-0.3mm having a width of 15-20cm. Now preliminary 'on air' function tests have been carried out with a test system consisting of a 1.54m magnetic loop from 16mm copper tube, home brew stepper electronics with a computer program delivering both intended results and learning facts.

Warning: avoid submersion in excessive electromagnetic fields during tuning tests and SWR measurements inside home: keep then at least a distance of 3 meter from the antenna with power input always less then 10 watt RF!
Direct body contact with a radiating antenna may cause serious injuries and lethal effect!

1. CALCULATION

1.1. Radiation efficiency of magnetic loops

For gathering of parameters the "Magnetic Loop Antenna Calculator – v1.6 from KI6GD has been used (see www.standpipe.com/w2bri/software.htm).

Antenna diam.(m)	pipe perimeter (mm)	MHz	Radiation Efficiency(%)	Capacity (pF)	Capacity (kV)	BandWidth (kHz)
3.18	30	7.100	73	33	3.3	26
3.18	60	7.100	84	40	3.1	26
3.18	90	7.100	89	45	2.9	27
3.18	120	7.100	92	49	2.8	30
3.18	242	7.100	96	62	2.4	30
3.18	314	7.100	97	68	2.3	32
3.18	400	7.100	97	74	2.1	34
3.18	490	7.100	98	80	2	36
3.18	30	3.550	19	190	3.4	6.7
3.18	60	3.550	33	217	3.9	4.5
3.18	90	3.550	42	237	4	3.8
3.18	120	3.550	49	253	4.1	3.5
3.18	242	3.550	66	303	4	3
3.18	314	3.550	72	328	3.9	3
3.18	400	3.550	74	353	3.9	2.8
3.18	490	3.550	79	377	3.6	3.1
3.18	242	1.800	15	1235	3.8	0.9
3.18	314	1.800	19	1328	4	0.8
3.18	400	1.800	23	1427	4.1	0.7
3.18	490	1.800	27	1521	4.1	0.6

Table 1: Calculation results for magnetic loops with 100W RF input

The results for 100W RF input into a 3m loop are listed in table 1.
Calculation results in table 1 score for a 3.18m copper loop with 40cm perimeter for the 40-80-160m band radiation efficiencies of **97%, 74% and 23%** respectively.

> Results are indications for pipe material but because of the lower weight (and costs) thin bronze plate material will be used. An adequate calculation procedure for such plates is at the moment not available. Some radio amateurs were mentioning possible corona effects due to the sharp edges of plates.

The dependency of the radiation efficiency for the pipe perimeter (diameter) is shown in figure 1: for a loop with about 3m diameter efficiency rates drop fast at perimeters less then 100mm for both 40 and 80m band.

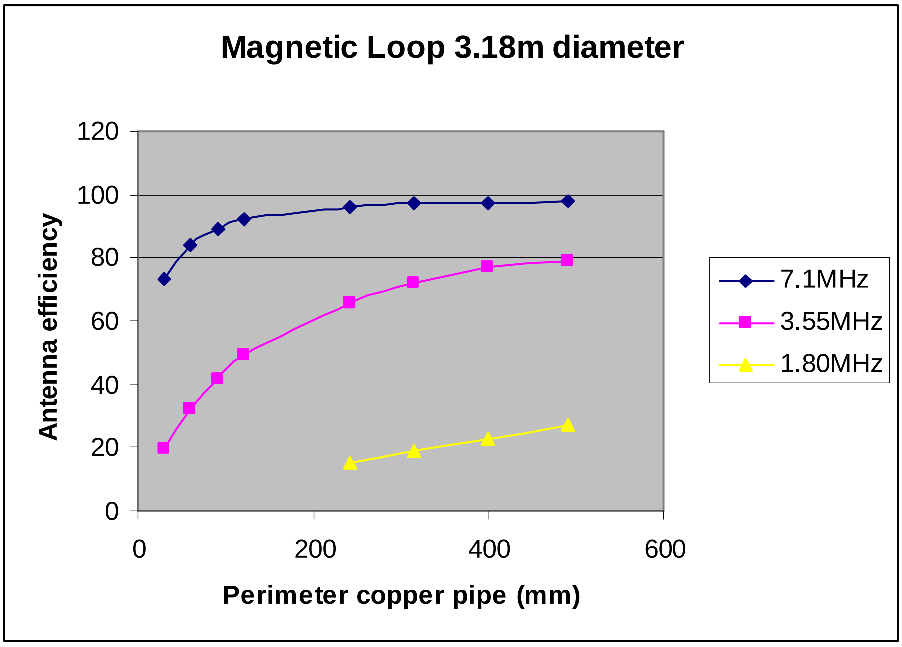

Figure 1. Diameter effect of copper pipe on radiation efficiency

<u>1.2. RF currents near loop capacitors</u>
For an 100W RF signal current values (Coulomb per second) were calculated from the capacitor data: voltage - capacity - applied frequency.

MHz	Capacity (kV)	Capacity (pF)	Current(A)
7.10	2.1	74	2.2
3.55	3.9	353	9.8
1.81	4.1	1427	21.2

Table 2. Mean currents at capacitors of a 3.2m loop (100W RF signal)

Results show in table 2 that high currents may occur towards the capacities for both 80m and 160m band. Adequate electrical connections and low resistance inside capacitors apparently are relevant factors to avoid antenna system degradation.

1.3. Effect of antenna bandwidth at operations

Multiband application is one reason why magnetic loops are used. Normally antenna and tuning capacitor(s) are integrated as one construction: they also need special measures for accuracy and stability of the total capacity when a small bandwidth occurs.

Here the capacity tolerance of the antenna system for a specific frequency has been defined as "the capacity unit that corresponds with a quarter of the bandwidth"
Calculation example using data from Table 3 for 7.090MHz:

$$Abs[(74.2 - 74.5) / (7.100 - 7.090)] * (34.2 / 4) = 0.26 \text{ pF}$$

MHz	Capacity(pF)	ΔpF/kHz	Calculated BandWidth (kHz)	Quarter of Bandwidth Capacity as minimal tolerance(pF)	Required Accuracy %
7.090	74.5	0.03	34.2	0.26	0.8
7.100	74.2	0.03	34.4	0.26	
3.550	352.9	0.21	2.8	0.15	0.04
3.560	350.8	0.21	2.8	0.15	
1.810	1410.9	1.57	0.7	0.27	0.02
1.820	1395.2	1.57	0.7	0.27	

Table 3. Bandwidth: consequences for tuning of a loop with 3.18m diameter made from copper pipe with 40cm perimeter.

More then 50% signal loss will occur when working outside the bandwidth that might result in a lot of problems for transmitter, signal quality etc.

- Tuning is nearly optimized when the antenna capacity is set within the tolerance.
- Stability: no change of antenna capacity should occur during transmitting.
- For the 160m band the speech audio spectrum is already wider then its calculated bandwidth of 700Hz!
- Results of table 3 clearly indicate that for 160m band poor tuning accuracy specification, system stability but also applied TX mode might cause potential breaking points for an acceptable practice.
- The large sensitivities require a tuning system and antenna both having a robust design. The tuning device must be able to handle very small capacity increments.
  Applied method: application of reduction gear connected with capacitors to get capacity increments of a quarter of the tolerance
  (for this system: 0.05pF).

Working with costly, delicate vacuum capacitors
A method for easy fine tuning can be an extra addition of a 20pF air capacitor suited for high voltages (wide spaced blades), connected to the main capacitor(s).
This method saves vacuum capacitors against early wearing and leakage caused by frequently tuning. This construction has been built and tested.

1.4. Effects of conductor thickness

RF currents do not flow through the full cross section of the conductor of the antenna.
At higher frequencies it is limited to the upper skin depth of the conductor.
Figure 2 shows skin depth – frequency relation for several metals.

It's indicating that at 1.8 MHz skin depth for copper is about 0.1mm.
Therefore in advance situation it is believed that there will be no confrontation with sudden effects while using copper plate only with a thickness of 0.2 – 0.3mm. Application of thin material cause desired limits of the antenna weight (3.5 – 5kg for 10 meter strip having a width of 20 cm). Real test conditions should prove its real behaviour.

The hardness and strength of tin-bronze(5% Sn), a conductivity comparable to that of pure copper and expected availability make bronze to favourite antenna material.

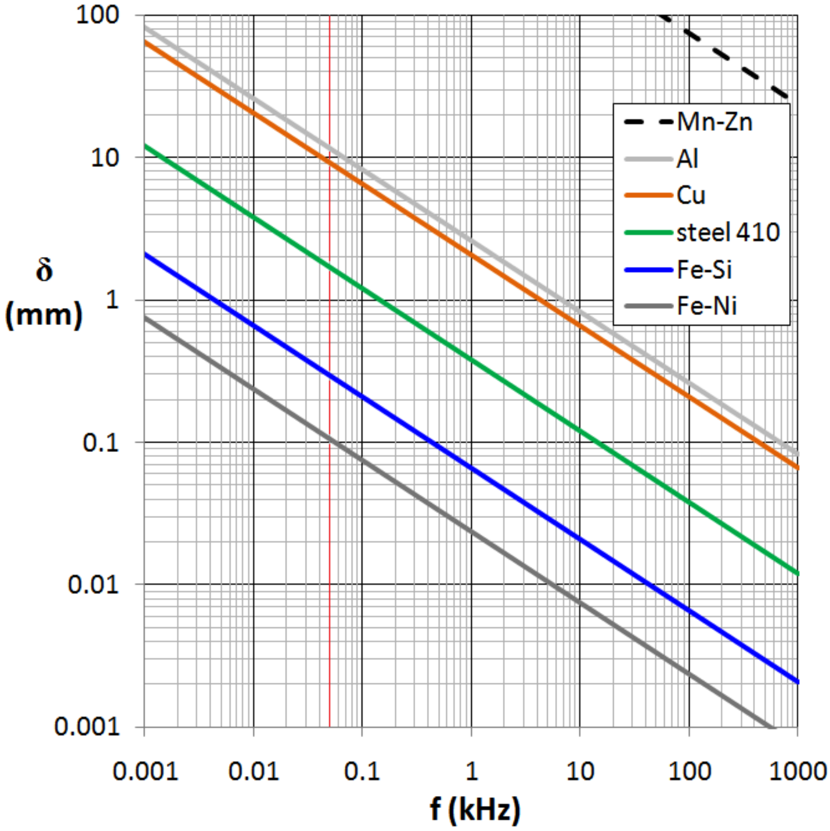

Figure 2. Conductor skin depth (y-axis) versus frequency (x-axis) (picture from Wikipedia).

1.5. Conclusion

Calculations here and also discussions with other radio amateurs indicate that a 3-band magnetic loop is a very delicate object that requires high stability and accuracy.
The project will be continued with implementation of findings established so far. We start with a tuner having one large variable vacuum capacitor of 1000pF combined with an air capacitor of 20 pF suited for several kV's. Later a second 1000pF capacitor will be added.

Building of working software, electronic devices for control of two stepper motors, motorized tuner already have been realized. Preliminary tests have been carried out.

2. CONSTRUCTION OF THE PLANNED ANTENNA SYSTEM

In figure 3 an overview of the final antenna system is shown.

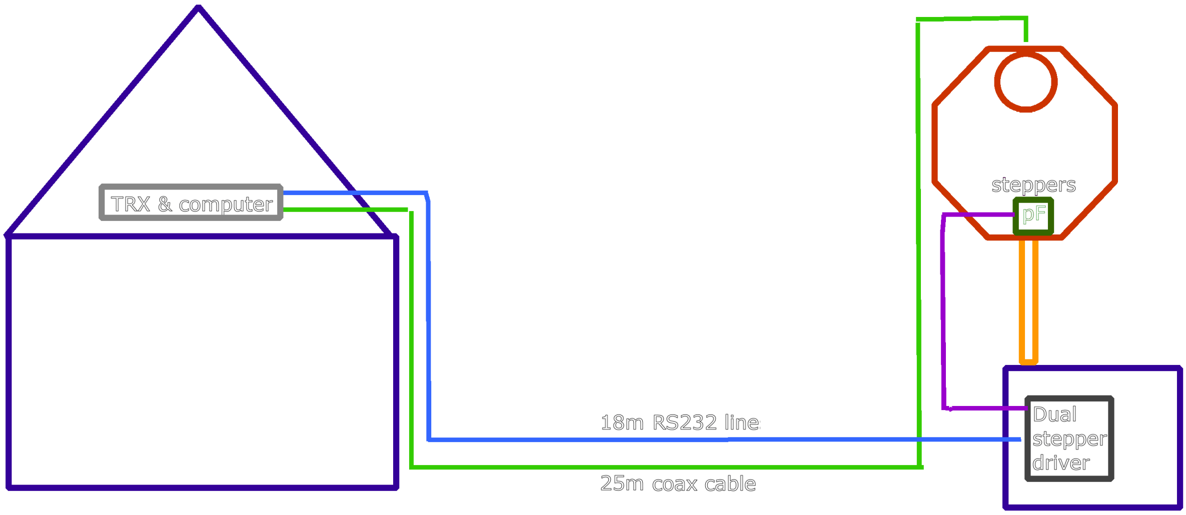

Figure 3. Overview of devices and circuits of the magnetic loop antenna system

<u>2.1. Software</u>

The electronic circuit driving two stepper motors is controlled by a home made computer VB6 program by sending and receiving signals over a (wired/wireless) RS232 line. Most of its characteristics already are visualized in figure 4.

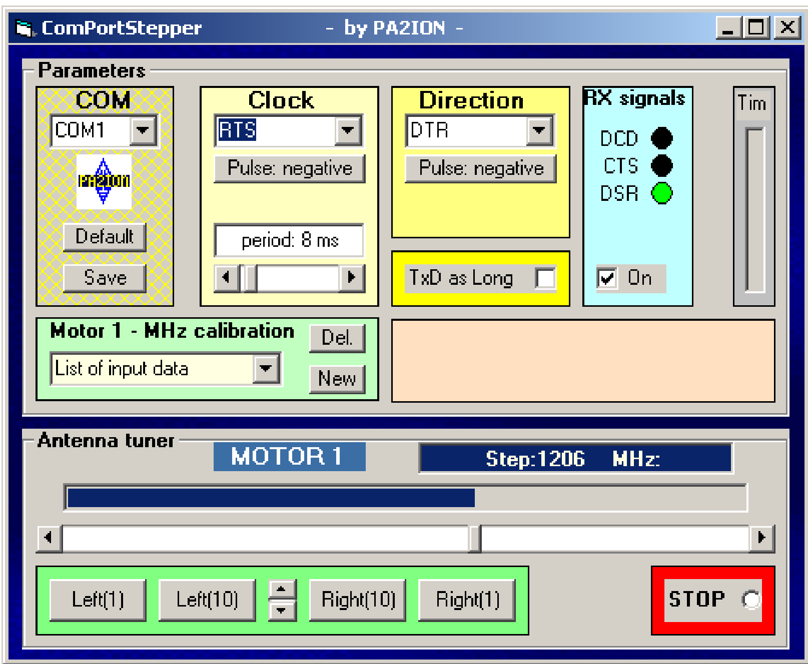

Figure 4. Windows program for control of electronic circuit driving 2 stepper motors

Summary of program features

- Storage of COM port parameter settings for the stepper driver communication
- Software timer – hardware timer combination for switching of stepper motors to power supplies from begin to end of tuning sessions.
- Storage of last stepper motor positions
- Storage of pairs of positions and frequencies as calibration for fast tuning
- Modes both for single and multiple stepping
- Position correction due to gear backlash, relevant at forward-backwards switching
- DSR port detects the selected stepper motor
- Ports DCD and CTS are reserved for future electronics being guards of the capacitor(s)

2.2. Stepper motor controller

Figure 5 gives an inside view of the homebrew product. Several pictures about circuit details etc. may be found in the Appendix.

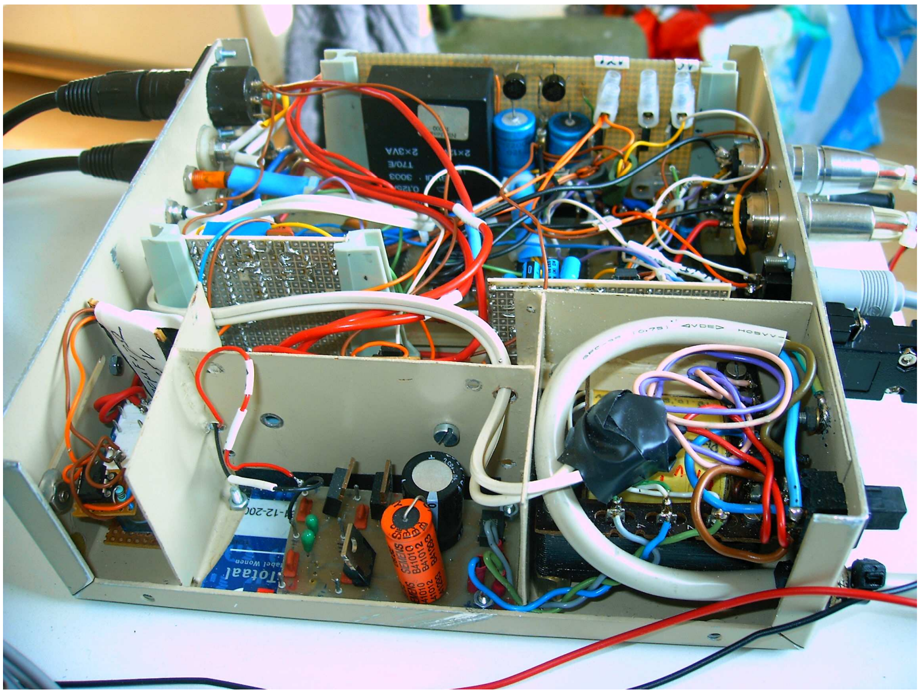

Figure 5. A view inside the housing of the stepper motor driver.

Some communication details of the dual stepper driver:

- Computer connections:
  A PC loaded with homebrew software uses a (USB-)COM port for sending and receiving of RS232 signals over 18m distance to/from an electronic circuit for control of 2 steppers motors. Distance electronic circuit to stepper motors is nearly 8m.

  The computer starts sending of one or more characters over the *TxD* line to start a timer that enables a relay which switches the stepper motors to the power supply. Then follows a pulse over the RTS line initiating sequentially electronic switches being the heart of the stepper driver causing a sequence of pulsated currents through the coils of the selected stepper motor (M1,M2) and moves the motor axis one discrete step.
  The mechanical relay has a long drop-off time (>50ms) by application of a 500pF capacitor to prevent short breaks of the power supply.

When making multiple steps an accompanying stream of *TxD* pulses prevents power interruptions. The software fires at tactical moments more *TxD* pulses to keep power on. Timer restart time is much faster then the drop-off of the relay.
Argument for 'power off' after antenna tuning are: a) blocking-off of RF signals to shack and computer by the relay b) avoiding heating of the stepper motor.

DTR status sets step direction by initiating reversed sequences of current pulses.

DCD and *CTS* are reserved for feed back of sensors at stepper motor – capacitor combinations to prevent damage when a capacitor should be forced outside its normal working range and as a hardware check at known capacitor positions.

- Capable for two stepper motors (5-30V, max.1.5A) giving enough power (Nm) to rotate (multi-turn) spindles of the (vacuum) capacitors.
- Selection of one of two stepper motors is done manually by a toggle switch near the computer enabling an electro mechanical relay. The relay status is watched with the *DSR* line of the COM port.
- Isolation of computer from RF radiation is provided by application of max232 optocouplers separating the circuit in *'hot'* and *'cold'* parts.

Figure 6. Housing for stepper circuits and in front of it two applied stepper motors

<u>2.3 Remote Tuning Unit</u>
Capacitors of a magnetic loop normally are fixed with short leads at the middle of the large radiating loop. This tuning unit has been prepared to be connected to a 20cm bronze plate loop with 3m diameter. During the experimental phase there has been started with only one vacuum capacitor of 1000pF and one 20pF air capacitor combined with reduction gear and stepper motors both having 200 steps per rotation resulting in capacity increments of about 0.05pF per step.

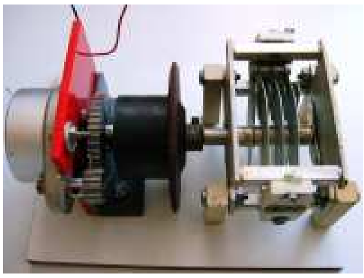

Figure 7A. Gear for 20pF capacitor

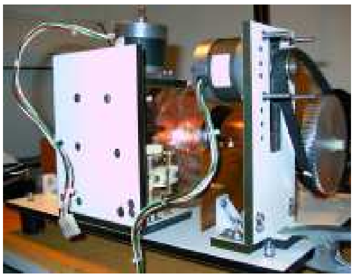

Figure 7B. Gear for 1000pF capacitor

Inside the housing extra space has been reserved for addition of a third, smaller designed 500(or 1000)pF capacitor with stepper motor for application of the 160m band.
Figure 7 shows the test setup with a 1.54m loop of 16mm diameter and gives an impression of the place of the capacitors in the tuner.
Plastic sheet has been wrapped around the vacuum capacitor as a first measure against flying parts in case of an incidents with chances of glass damage.
Massive fiberglass rod and rubber have been used for electric isolation of capacitors and gear.
Copper plates a width of 20 cm have been made for the planned loop consisting of 20cm bronze plate. The antenna will be connected at the underside of the housing for easier protection against water intrusion. The test antenna got an alternative connection point.
The Stepper driver circuit will stand more then 8 meter distance from the antenna.
Addition of a circuit with 8 diodes at the stepper motors enables a simple remote selection method.
The housing is built with strong, water proof Trespa® plates (resin with cellulose).
Construction of the tuner part at the antenna need solutions without large metal parts.

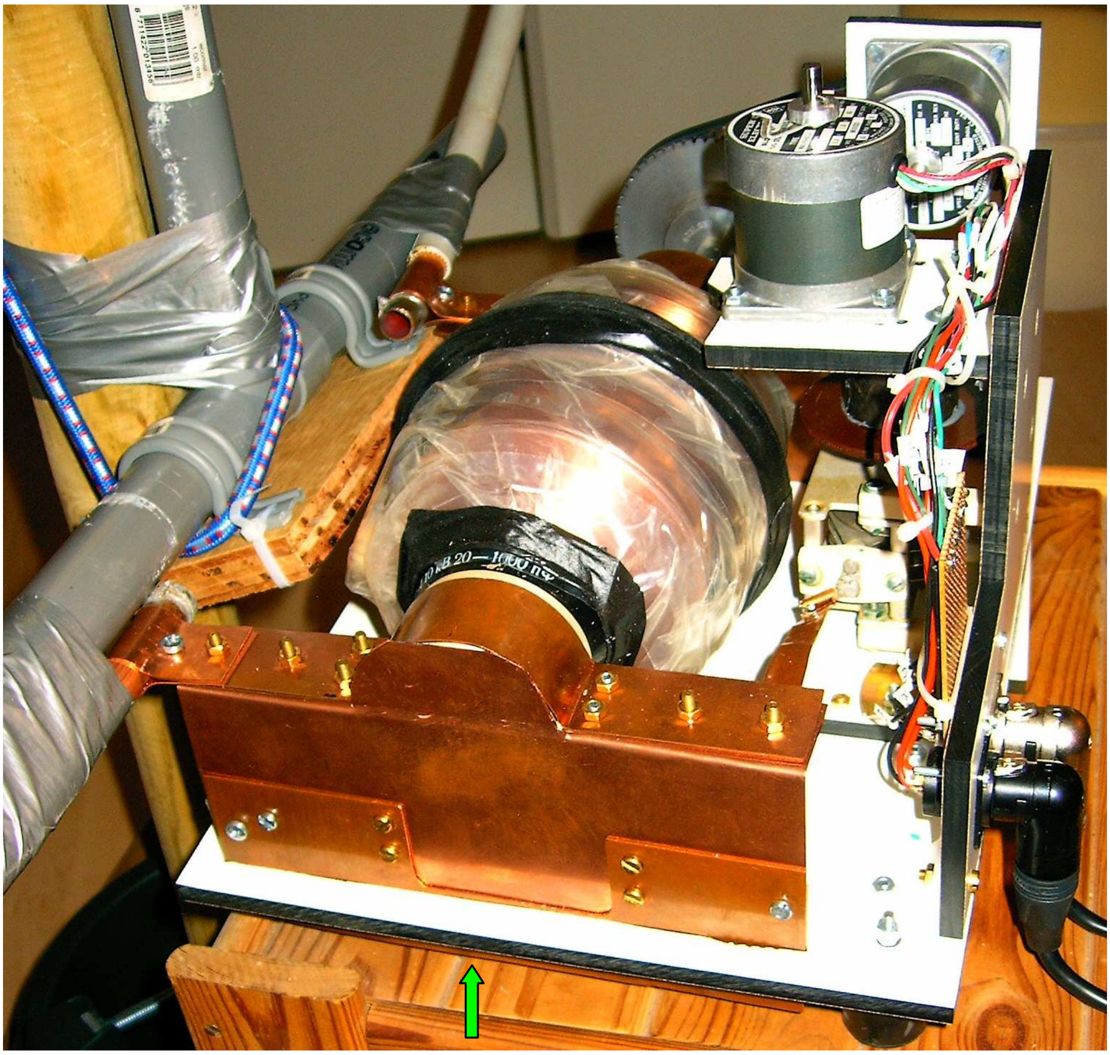

Figure 8. Indoor test setup of the tuning unit with 2 capacitors and a 1.54m loop
Green arrow is pointing to one underside place whereon the 3m plate loop later will be connected

Safety sensors for capacitors protection will be applied on the rotating parts when behaviour of the system during normal working conditions is known sufficiently.

Coming after the test phase:

2.4. Loop construction with bronze plate

2.5. Wooden antenna mast

2.5. Miscellaneous

- As alternative of long wired RS232 lines over tens of meters a low-cost wireless USB-2 server connected to an USB COM port can been used for computer communication. The specified WiFi working range is up to 100m under open field conditions.
  For the maximum distance calculation an attenuation factor of 3dB is a practical rule of thumb at WIFI signal passages through concrete wall and floor material.

Figure 9. WiFi USB-2 Server and USB RS232 device used in WLAN network

- Details 1.54m test magnetic loop: http://www.pa2ion.nl/DeProducten/magneticloopa.htm
  This loop has been made from 16mm copper pipe, wall thickness about 2mm. Relevant data for it are calculated efficiencies: 30% for 40m and only 4% for 80m band.

3. COMPONENT AND SYSTEM TEST *UNDER CONSTRUCTION*

Preliminary indoor tests

3.1. Software

Some first findings after a two days test period:

- Fine tuning by hitting selected buttons on a computer screen while watching the S-meter of a antenna tuner is a multi tasking act. The system works very well but that handling is for a man and 'mono-tasker' not the most ideal solution. Therefore it is decided that computerized tuning will stay reserved for two 1000pF capacitors and the 20pF air capacitor will be used as fine tuner with a new full hardware stepper motor controller with push buttons only.
- Working with 2 large, parallel capacitors requires storage of both frequency and position/capacity data of the two capacitors when used for calibration.
  For each capacitor a list of stepper position and capacity will be made. By interpolation the capacity for both capacitors can be calculated at actual stepper positions.
- Before actions with large capacity changing (or stepper motor positions) the addition of a confirmation moment for a frequency check is considered. It's saving time and equipment.
- Position correction due to gear backlash, relevant at forward-backwards switching will be implemented in a next version of the program.
- An ASCII text ini-file will be generated by the program: easy to read (and make safety copy) and to edit and delivers an overview of the (last) settings.

3.2. Stepper motor controller(s)

- Sometimes, only at the first start, an irregular stepping of a stepper motor. Maybe it can be ascribed to a relay with poor contacts but also the applied voltage was 20% beneath the required specification. Those facts need to be solved before final outdoor placement of the equipment.
- The equipment connected with long lines proved to be slightly sensitive for electromagnetic fields. It will improve when using WIFI for RS232 transport. In worst case a switching off of the power supply of the stepper motors have to be carried out.

3.3. Tuning system at a test antenna

- The setup with capacity increments of 0.05pF per stepper motor step proved to be a good choice. It's offering a smooth changing of the S-meter near its critical, optimal point. It is important that backlash of the gear of the air capacitor is limited (here 2 steps) to avoid confusion at repeatedly forward/ reversed stepping.

Final remark: until now it gave a lot of fun and nice stuff to think about.

To be continued – 73 Ron, PA2ION

APPENDIX

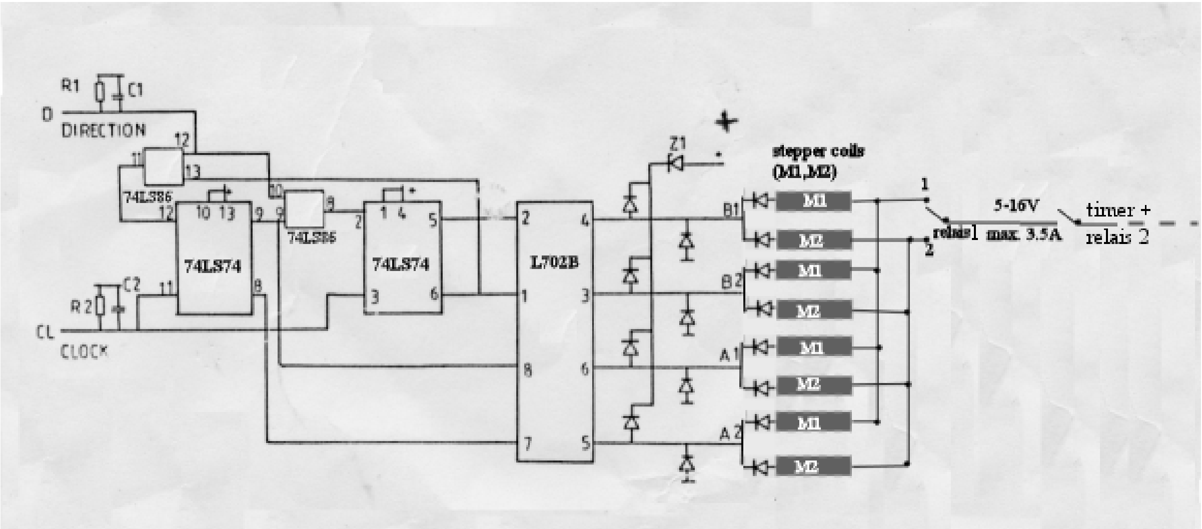

Fig. A1. Principle of the dual stepper driver system with relays for motor selection and power
Clock and direction are enabled by signals from the COM port of the computer

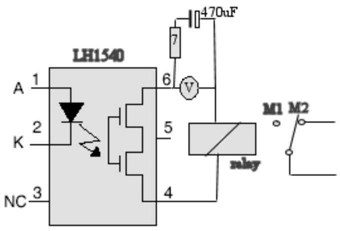

Figure A2. Mechanical relay with slow drop-off controlled by solid state switch LH1540 with optocoupler.

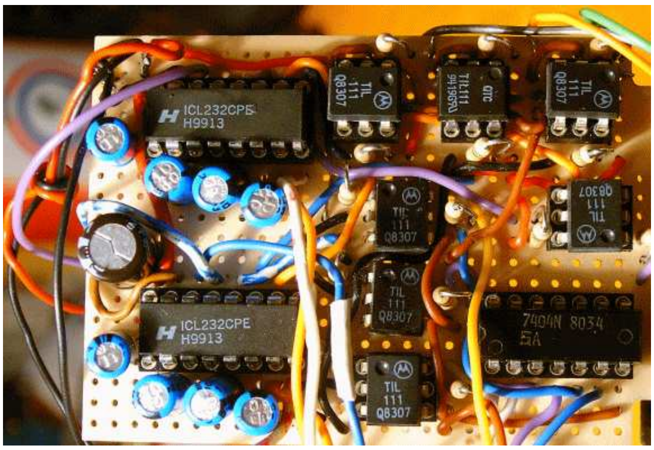

Figure A3. Ugly '*Spagetti*' circuit with 2 max232 ic's (optocouplers) to isolate RF currents from computer and shack.

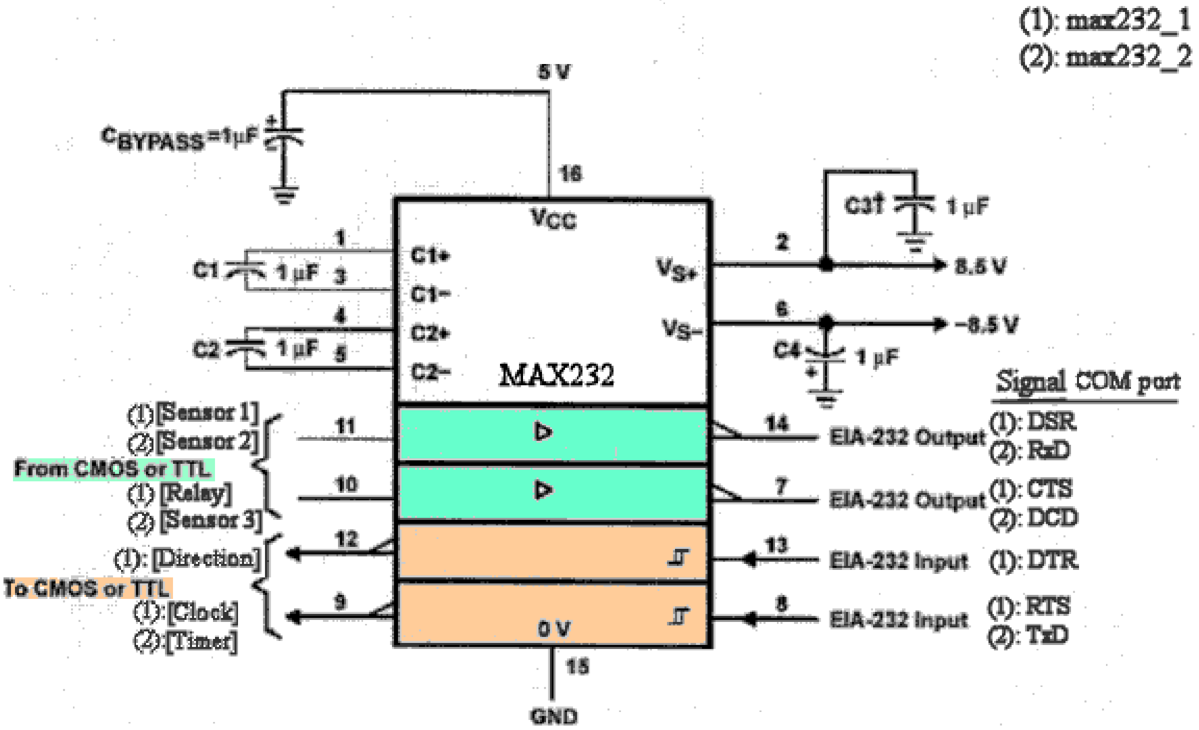

Figure A4. Overview how Max232 (2) are used in the stepper driver system

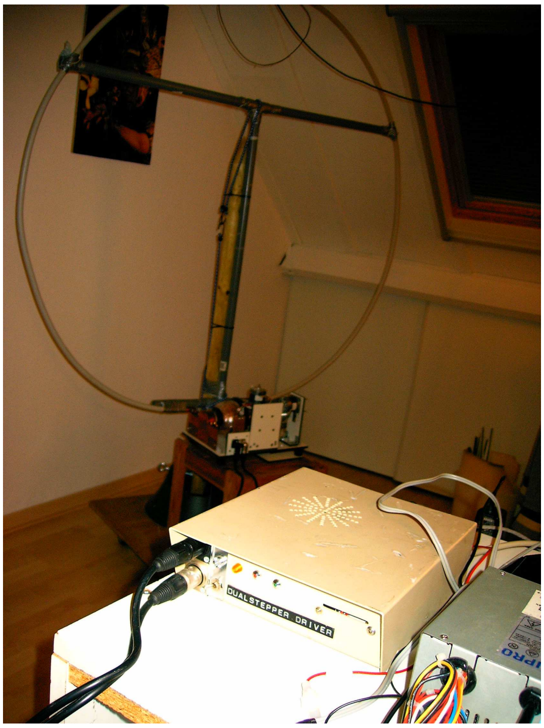

Figure A5. Setup at preliminary tests of computer program, stepper driver circuit and tuning device (Not intended but: 0,4 W ERP appeared to be to enough for QSO's on 80m band over 100km).

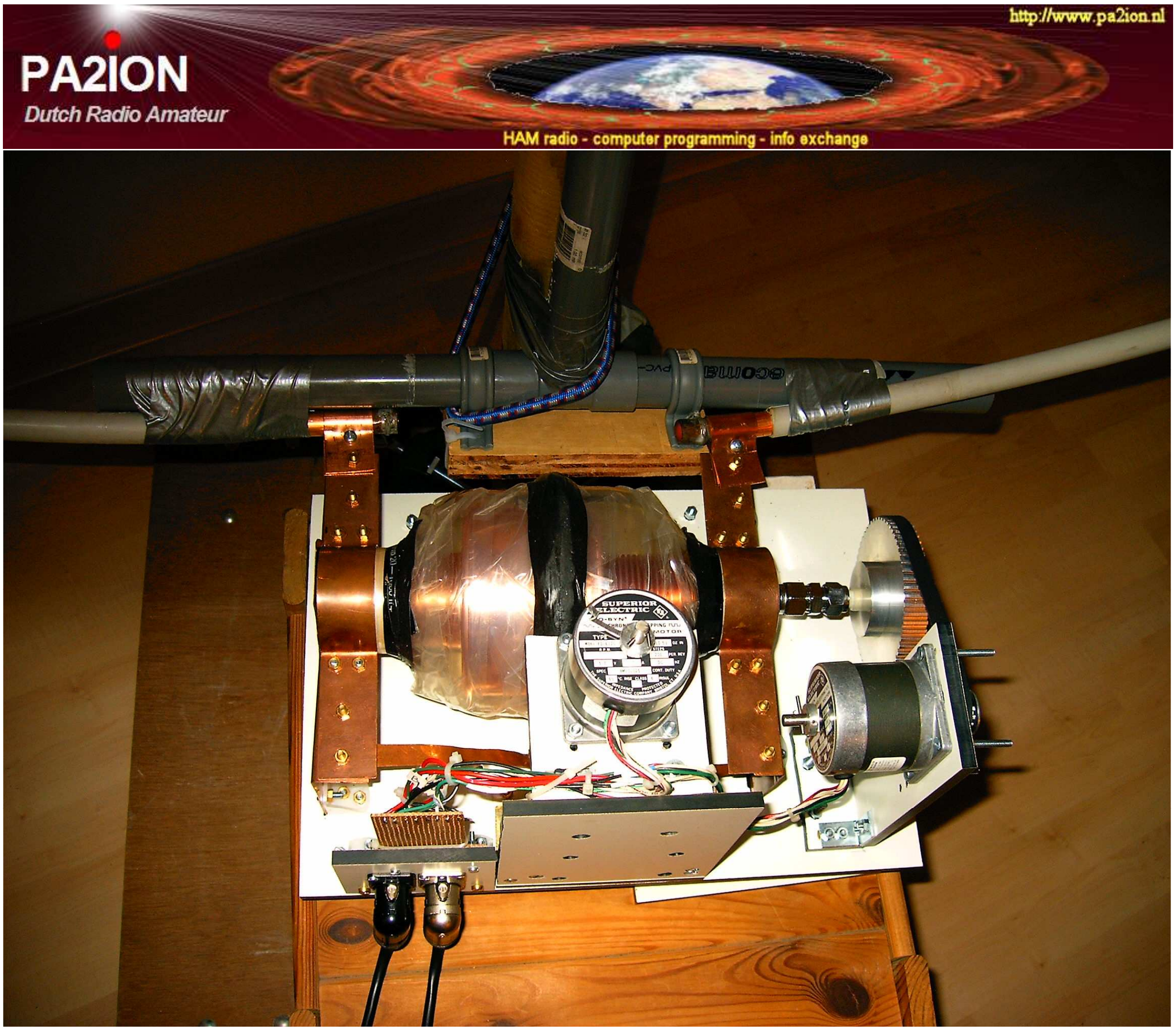

Figure A6. Alternative coupling of tuner with test antenna during preliminary tests.

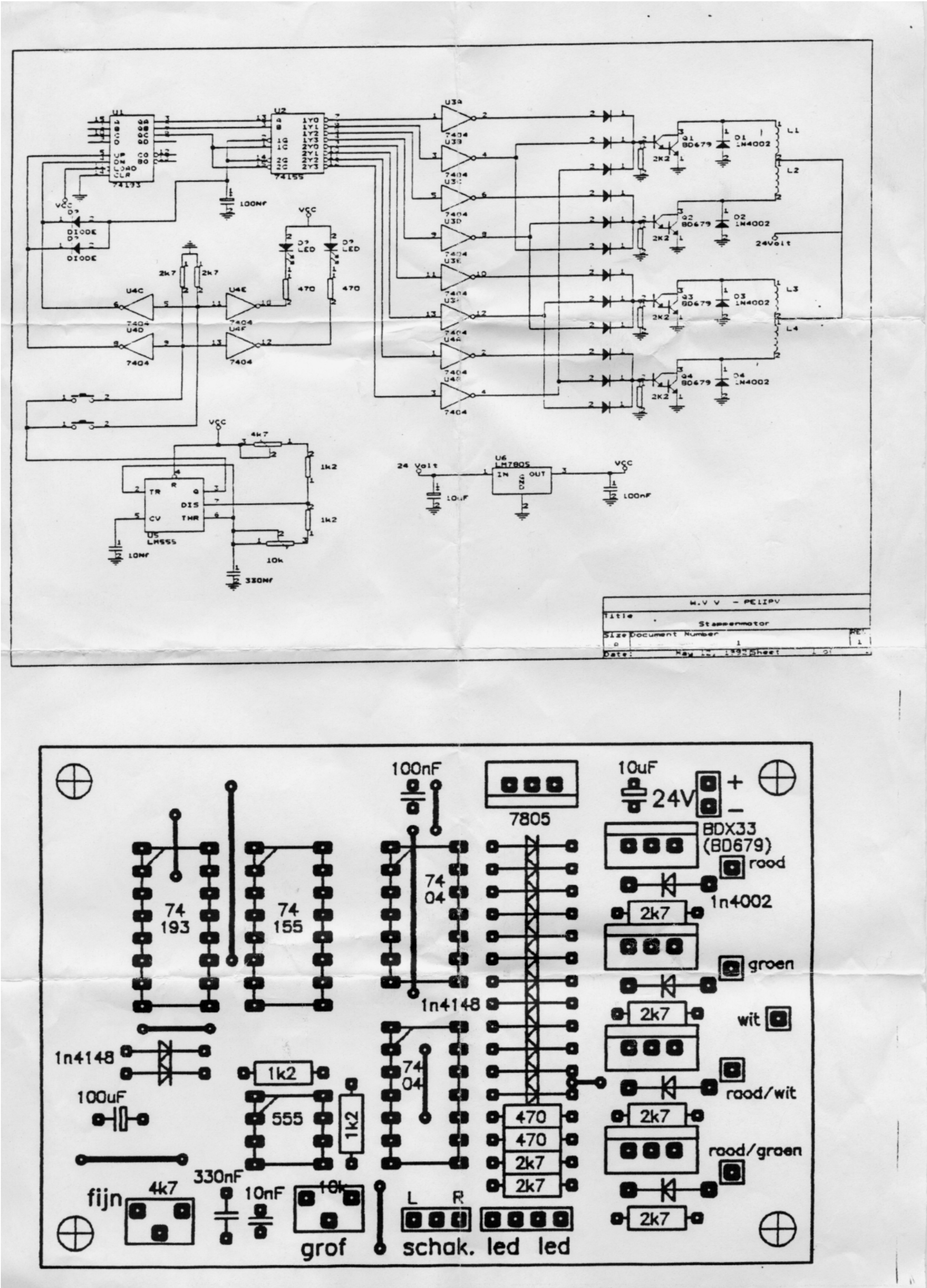

Figure A7. Schema and parts overview of the full hardware stepper driver.

under construction