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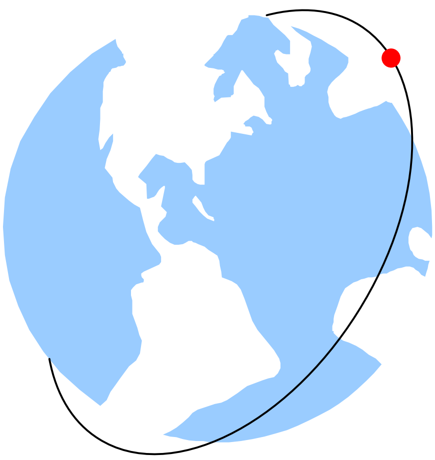
TECHNOTE 2003 - 1

WORKGROUP SATELLITES

Resonant Quadrafilar Helical Antenne



Theoretically the ideal antenna for the reception of polar orbitting satellites; in practice no longer a nightmare!

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Remarks

This TechNote 2003-1 is an addition to and should be read in conjunction with TechNote 1999-1.

The test results are obtained with an antenna with dimensions described in Table II (the same as in TechNote 1999-1, page 12).

This TechNote describes the recent results of measurements of the radiation pattern as well as older results on impedance and reflection coefficient, replacing the results of TechNote 1999-1.

The TechNotes and a description of how the dimensions in Table II are taken can be found at www.kunstmanen.nl\antennes.

Fig.1. The RQHA-12 under the Dutch sky

Introduction

The Resonant Quadrafilar Helical Antenna RQHA-12, as described in RIG-58 from September 1999, De Kunstmaan from February 1999 and as RQHAeng.pdf on www.kunstmanen.nl\antennes, has been on my roof for some years (Fig. 1), giving perfect reception of APT-pictures from polar orbiting satellites in the 137 MHz band. Although the performance is quite good, it has always been a weak point, that the radiation pattern was not measured. This test has been on my wish list for years, but I didn't had the equipment myself to do the measurements. Recently a little group was formed from members of the Dutch Workgroup Satellites or as we call it the 'Werkgroep Kunstmanen', who together could do the job: Harrie van Deursen, Arne van Belle, Peter Smits and myself, Robert Hollander. Two members of this group can be seen in action in Fig.6.

Measurement set-up

A mobile, battery operated, set-up was made by the group partly from existing units, while also some new units had to be made. A small transmitter and impedance matching network feed the transmitting antenna, which is a crossed dipole to produce circular polarised fields. Flipping the antenna changes the direction of polarisation from LHCP to RHCP. An attenuator is used to adjust the power, so that the receiver at approximately 100 yards is not overloaded. About 1 μW was used in the experiments. The DUT (device under test) was the RHQH-12, connected with a 50Ω cable with an electrical length of ¾ lambda to an antenna amplifier (HRA-137). This ¾ lambda is the total length of the cable from the top of the antenna to the amplifier, thus including the 'internal' cable of the 'infinite BALUN' and the 'length' of the connectors. This cable transforms the real impedance of the antenna at its terminals at the top of 31.5Ω @ 137.5 MHz (Fig. 2 and 3) to a real impedance of 79Ω, suitable for the antenna amplifier input.

The receiver was a HRX-137, fitted with a special buffered signal strength output. The output voltage as a function of the input voltage was calibrated. Although the output is approximately a log-function of the input, several wiggles show up in the curve due to the internal circuit of the CA3089. There are better signal monitor IC's, but a 9-th order polynomial fit represented our calibration curve nicely, so that this fitted curve could be used in the analysis of the measurements.

The output voltage was measured with an 8-input ADC-unit, made from a kit from Conrad-Elektronika. This ADC-unit is controlled by the control lines DTR and RTS from a serial port of a laptop and read out by the status lines DSR and CTS. A measuring program has been written to collect the data and store the data on disk. At intervals of selectable length, e.g. one sec, a selectable number of samples, e.g. 10, are converted and averaged to suppress noise to less than 1 mV. Not only the signal strength is recorded, also the voltages representing the angles of the AZ (azimuth) and EL (elevation) rotors, produced with multi-turn linear pot-meters coupled to the rotor shafts, are sampled almost at the same moment as the signal voltage. This procedure produces three values per sample record, completely defining the required information, independent of the speed of the rotors and without synchronisation problems. The relations between readings and angles were calibrated, and proved to be very linear (high impedance loading of the pot-meters was used).

A 12V battery from which a stabilised 15VDC is made by a DC-DC converter, specially made for this occasion, powers the whole set-up. It is the supply for the laptop, the receiver, the ADC-unit and the rotor steering. The receiver has an additional internal 12V stabiliser and the ADC-unit a 9V stabiliser, a second 5V stabiliser for the pot-meters and a 5V reference for the ADC. Recordings are +/- 1mV on a range of 5V.

Measurements

For our experiment we choose a site with two hills about 100 yards apart, one for the transmitter and one for the DUT. First we tested the effect of the circular polarisation of the transmitting antenna with a receiving antenna consisting of a simple dipole. A variation of 5.6 dB was found by an AZ-scan when the antennas were in line. The use of a reflector reduced this variation to 2.8 dB. We concluded, that the reception of the dipole is seriously influenced by the material at the backside of the antenna, in our case a rather massive piece of metal from the rotors. At the transmitting side a crossed dipole without reflectors was used. There we did not have any metal in the vicinity, except for the feed cable. The circular polarisation is probably not perfect, but good enough for the measurement of the radiation pattern. For a cross-polarisation measurement, to be done yet, we have to use a pure LHCP and RHCP field.

Then we mounted the RQHA-12 and made AZ-scans at three different EL-angles. One scan was made with the axes of the transmitting and receiving antennas in line, corresponding with the situation of a satellite overhead. A second AZ-scan was made at an angle of 45 degrees between the two axes, corresponding with a satellite at an EL of 45 degrees. The third AZ-scan was made with the axes at 90 degrees, corresponding with a satellite at the horizon. The EL-scan was made in two steps; first the EL-rotor tilted the RQHA-12 from axes in line and antennas facing each other over 180 degrees till the RQHA was irradiated from the back side. Then the AZ-angle was changed by 180 degrees and the same EL-tilt was performed to produce the second halve of the full EL-scan. The results are shown in Fig.4 and has to be compared with the theoretical pattern of Fig.5, taken from Kilgus [3].

Analysis

The dB values in Fig. 4 (vertical scale) are relative to 1µV at the input of the receiver from which the gain of the antenna amplifier should be subtracted to get the antenna signal. However, we are interested in the antenna gain and to get the antenna gain it is better to make a comparison with a dipole antenna, from which the gain is well defined. In our experiments this time we changed the transmitting power between the dipole and the RQHA measurements, as we realised after the measurements, so this comparison cannot be made this time. Only the patterns were measured, as shown in Fig.4. The absolute constant sensitivity at all AZ-angles is astonishing, although it was meant to be so. Also the EL-scan is very symmetric and close to what it should be (see Fig.5). The ratio of diameter over axial length of 0.44 was selected according to Wang [4] to get a decrease of 6dB at the horizon (remember, I live in the city and wanted some reduced sensitivity at the horizon to avoid terrestrial interference) and we indeed find a reduction of -6dB. Even the lobe at the bottom, which should not be there, is as was also found by Kilgus [1,2,3] (see Fig.5), the inventor of the quadrafilar antenna, on his antennas 30 years ago.

Conclusion

Although expectations were high, we are astonished by the results. It seems that all the care in making the construction pays off. From the electrical measurements it was already clear, that the phasing of the RQHA, with an inductive and a capacitive loop, is almost perfect. Now it is also clear that the radiation pattern is close to perfect. We conclude that the RQHA is not only theoretically an ideal antenna for the reception of polar orbiting satellites but that the RQHA can also be an ideal antenna in practice when properly made.

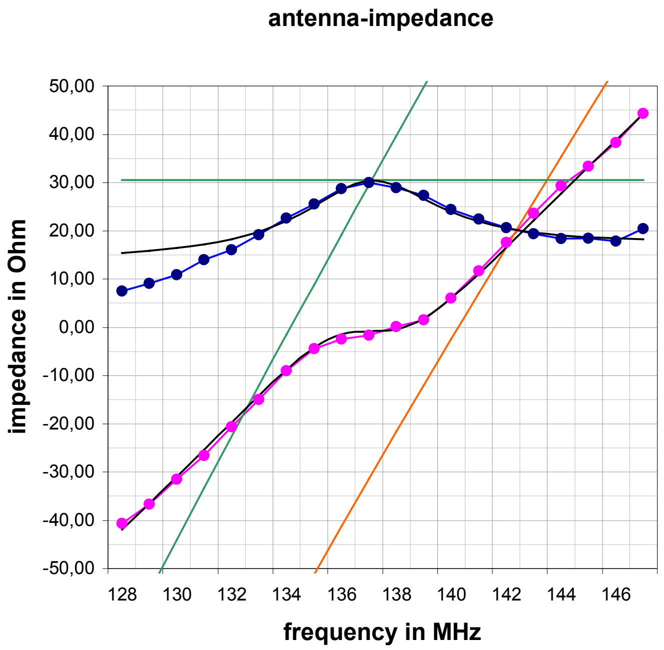

Fig. 2 Impedance of the RQHA-12 with elongation of 7.2% and difference of ±2,5%. R=31.5Ω at 137.5 MHz, the large loop is at resonance at 134.5 and the small loop at 140.5 MHz. A small capacitive offset is present.

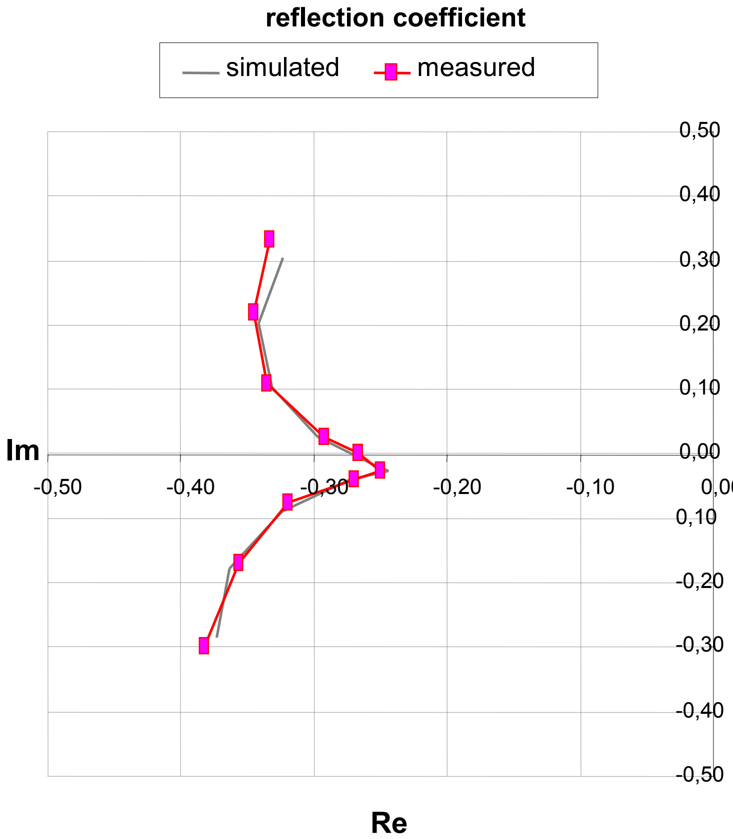

Fig 3. Central part of the gamma-plot of the RQHA-12 with elongation of 7.2% and difference of ±2.5%. The measurements are at 0.5 MHz intervals.

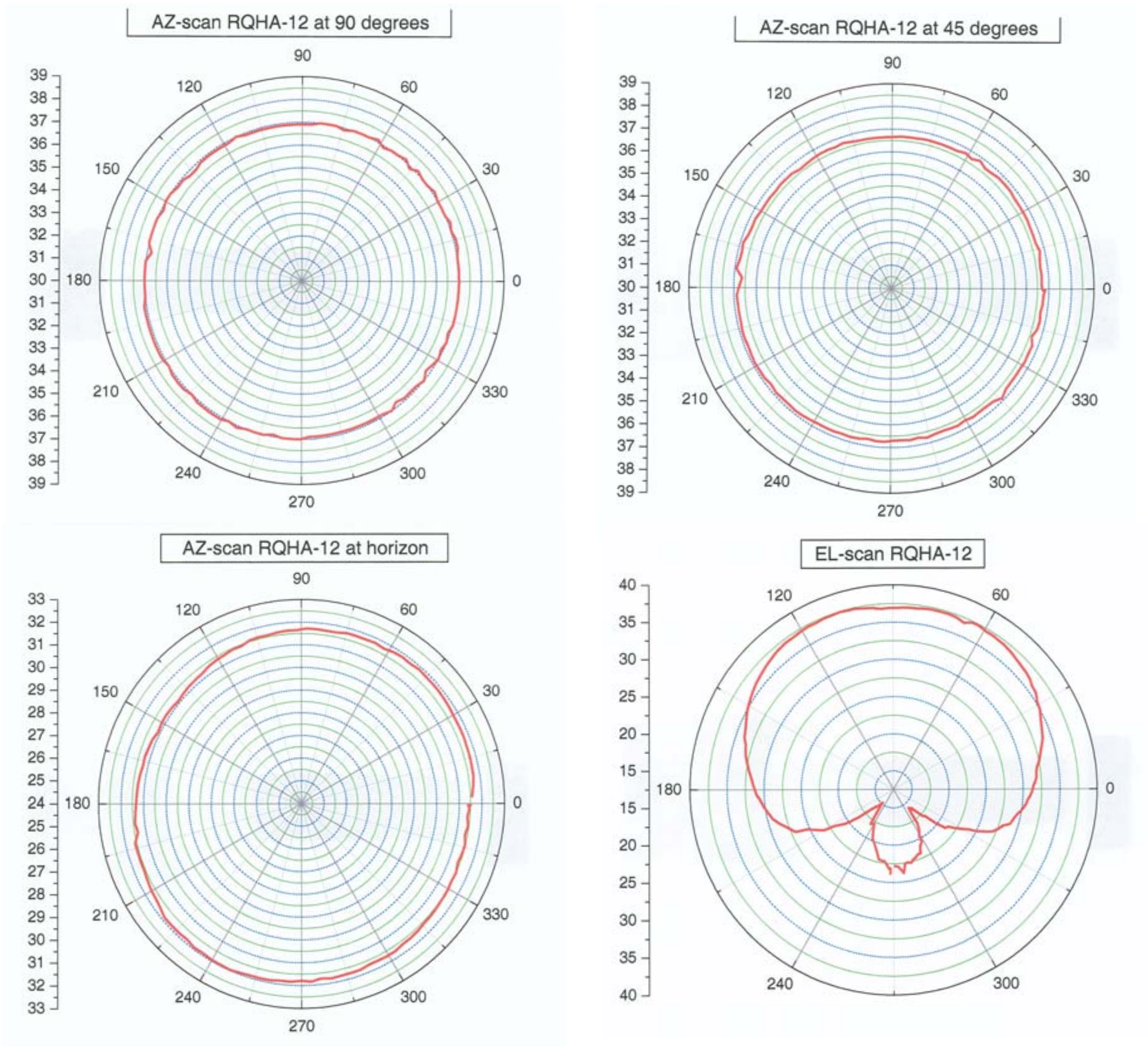

Fig. 4 Results of scans of the radiation pattern of the RQHA-12 with the dimensions of Table II. The vertical scale is in dB. The sensitivity is almost constant in all azimuth directions at constant elevation angle.

Table 1, Summary of radiation pattern features and comparison with theory.

	Measured now	Calculated Wang [4]	Calculated Kilgus [3]
-3dB beam width	135 deg	134 deg	130 deg
At 45 elevation	-0.7 dB		-0.2 dB
At the horizon	-6 dB		-6.5 dB
-18 dB at	-35 deg		-45 deg

Note: the aspect ratio height/ diameter for the RQHA-12 is 2.25, close to the value of 2.24 (L_{ax}=0.3λ) selected from the table of Wang. Kilgus has done his experiments with a quadrafilar antenna (a half turn half lambda volute) with an axial length of L_{ax}=0.27λ.

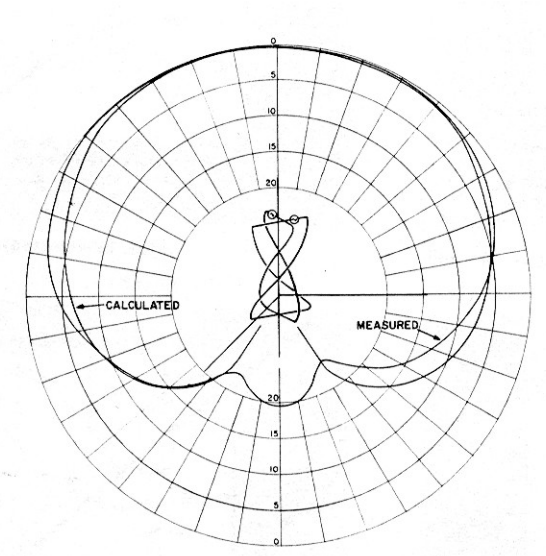

Fig. 5. Radiation pattern for a half turn half lambda volute with axial length of 0.27 λ (Kilgus [3]).

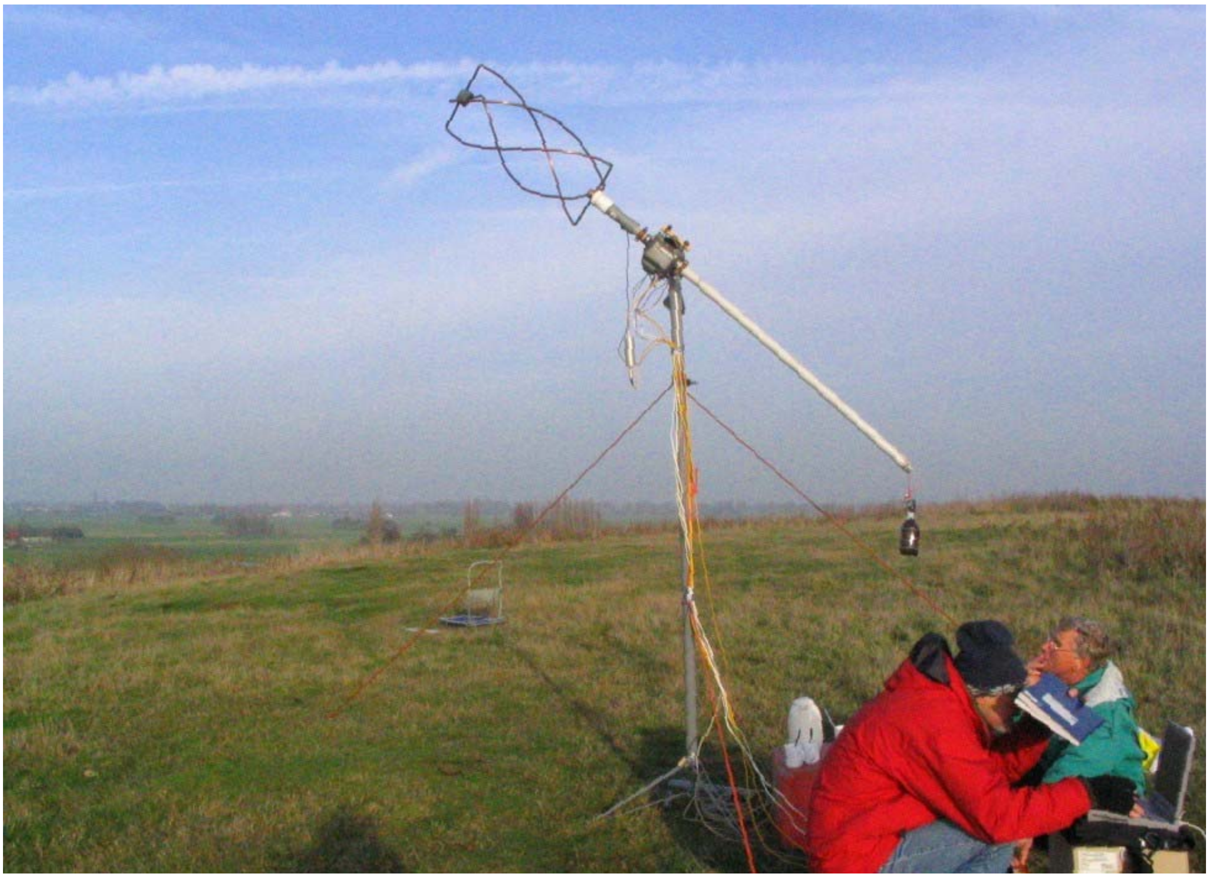

Fig. 6. The RQHA-12 under test (notice the weight to balance the set-up)

Table II, Design of the RQHA-12, the numbers in red denote design options to be supplied, the other dimensions are then calculated accordingly.

design-frequency		(MHz)	137,5
self-phasing		small and large loop	
number of turns		(n)	0,5
antenne halfloop length		(lambda)	0,5
wavelength in air		(mm)	2180
lengthening percentage			7,20%
mean loop-length			2337
aspect ratio	height/diameter		2,25
	diameter/height		0,44
mean diameter			312
mean height			702
deviation from mean			2,50%
bend (center-line to center-line)			15
effective length of bend			24
small loop			2278,9
loop length corrected for bend-shortening			2304,6
radial parts (four times)			153,9
radial part corrected for bend			138,9
helical parts (twice)			844,5
helical part corrected for bends			814,5
axial length			684,7
large loop			2397,2
loop length corrected for bend-shortening			2423,0
radial parts (four times)			161,8
radial part corrected for bend			146,8
helical parts (twice)			887,9
helical part corrected for bends			857,9
axial length			720,3

References

[1] C.C.Kilgus, “Multi-element, Fractional Turn Helices”, IEEE Trans. AP-**16**, Jul. 1968, p. 499-500

[2] C.C.Kilgus, “Resonant Quadrafilar Helix”, IEEE Trans. AP-**17**, May 1969, p. 349-351

[3] C.C.Kilgus, “Resonant Quadrafilar Helix Design”, The Microwave Journal, Dec. 1970, p. 49-54

[4] H.S.C.Wang, “Theoretical Design and Predictions of Volute Antenna Performance”, IEEE Trans. AP-**39**, August 1991, p. 1227-1230.

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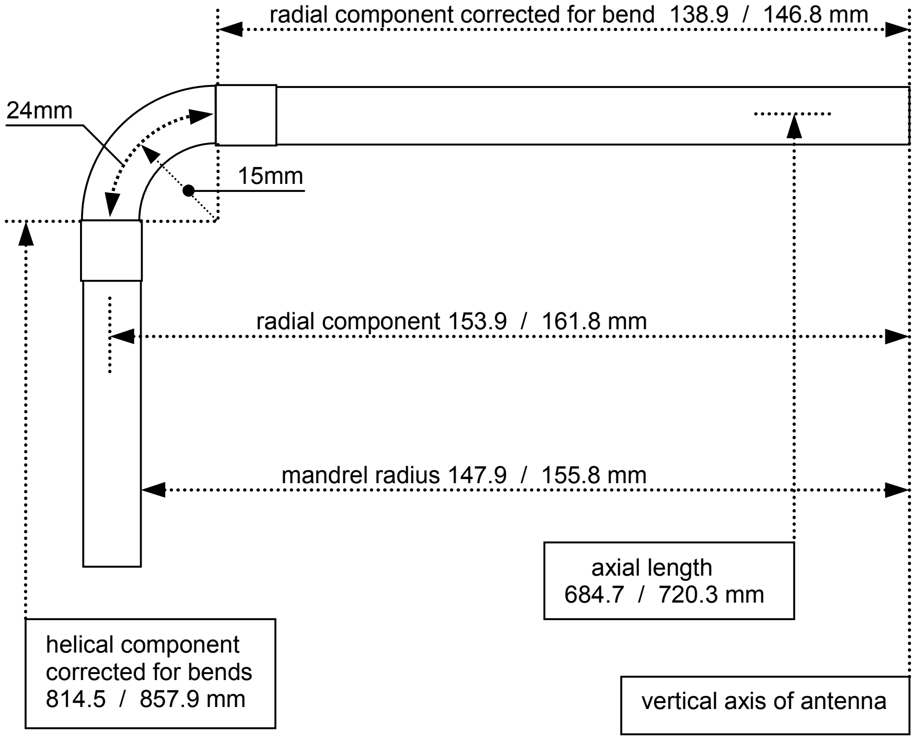
Appendix A Dimensions of an RQHA-12.

- The small loop is fitted inside the large loop
- The axial distance between the large and the small loop is 18 mm at the top in the Delrin box and 18 mm at the bottom in the copper block (centre to centre if you like).
- The radial component length have to be adjusted to the construction that you make; the 'radial component length corrected for the bend', measured to the vertical antenna axis has to be what is in the table.
- The dimensions indicated are for the small / large loop respectively.

- **The diameter of the copper tube is 12 mm**.



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