Helical antennas for 435MHz

by James Miller B.Sc. G3RUH

An easy-to-construct design offering true circular polarization

This antenna design was produced for satellite working with Oscar-10, but it has also proved excellent for ordinary local and long-distance operation. It has eliminated at a stroke the frustration of accurately matching and phasing crossed Yagis to true circular polarization and obtaining an acceptable s.w.r. throughout the band.

Compared with other antennas it has a very wide bandwidth - a low Q - which makes it forgiving of dimensional inaccuracies. It is therefore easy to construct successfully.

This article describes 9 and 16-turn helices for the 430-440MHz amateur band. The nine-turn version simply has fewer turns and spacers, but it is short enough to permit end-mounting. Gain figures of the two versions are 12.8 and 15.2dB respectively. You can use more turns, but the mechanical penalties increase rapidly at this wavelength, whilst the extra gain per turn is marginal.

For many years Kraus[1] has been a central figure in promoting helix antennas, and a little detective work reveals dimensions identical to his figures in almost every design guide (for example the R.S.G.B. VHF/UHF Manual, ITT Reference Data for Radio Engineers etc.).

More recently, King and Wong in their brief summary paper[2] presented performance characteristics based on a large number of gain and pattern measurements of helices of 5 to 35 turns, with various pitch angles and other parameters. The paper augments and expands Kraus's theories.

The design of this antenna is based on that work. A pitch angle of 12.8° with a circumference of about 1.08 wavelengths are used. From King and Wong's curves this yields a maximum gain (allowing for mechanical tolerances) at 435MHz, for aerials of reasonable size (Fig. 1). These gains are typically 3dB lower than Kraus gives, but seem to be representative of actual practice.

Materials

In choosing materials I was guided by the need to make an antenna that could survive several years' weathering with only minor attention; and that for the most part used common material and needed simple workshop practice. I did not consider timber stable enough - but you could try it.

The reflector and boom are aluminium and the helix copper. The feed-strap is brass and the screws are zinc-plated. The spacers are of black Delrin. A waterproof N-type connector is used for the r.f. connection. For protection, the completed antenna should be varnished.

To ensure success, it is important to do things in the right order: for example, the length to which the spacers must be cut depends on the final diameter of the helix. Handling the helix itself calls for a boom through its middle and so it is easier to do drilling first. So:

- obtain all materials — see table 3;
- build up the reflector assembly;
- drill the boom;
- wind the helix and stretch along the boom;
- make and fit spacers;
- fix the copper spiral to spacers;
- fix reflector to boom;
- install feed strap;
- adjust s.w.r.

Reflector

The reflector is a nominally 600mm square piece of expanded aluminium fret, obtainable as *Expamet* 351A, which is widely used as a grille material. The size is not critical and 500mm square could be used if windage is a problem. Take especial care to cut the Expamet sheet without leaving jagged edges.

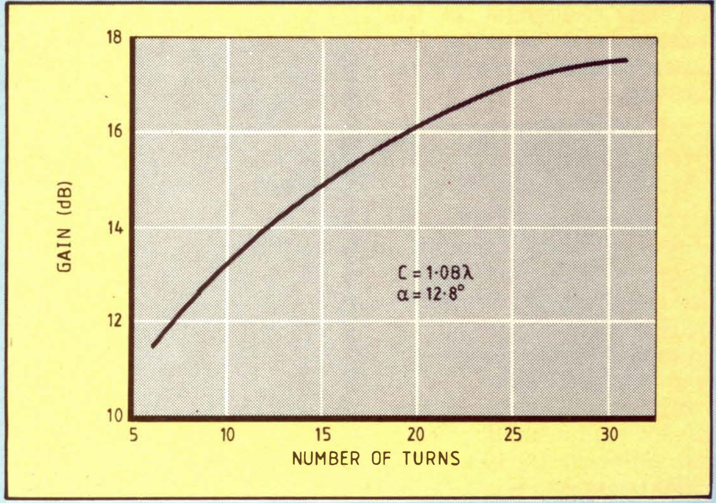
The mesh must be stiffened, or it will bend easily in a light breeze and may quickly break. In one prototype the support/stiffening was fabricated from a 100 x 100mm 16 s.w.g. (1.6mm) centre plate and some 10 x 10mm 18 s.w.g. (1.2mm) aluminium angle, and was quite satisfactorily strong and lightweight.

For the final version model I tried a simpler design, bent up entirely from 18 s.w.g. sheet metal (Fig. 2,3). The stiffening is bolted through the mesh with M3 × 10 screws and stiffnuts, using 16mm diameter washers on the front face, cut from waste metal. To keep the reflector all-aluminium, 3mm ($\frac{1}{8}$") pop rivets could be used instead of screws.

Once the stiffening is fixed, mesh can be snipped away to allow the boom and N-type connector through. The connector is a single-hole-fixing type and can be fitted either way round depending on whether the feed is to be from the rear or along the boom from the front.

Aluminium tube 19mm square and of 16 s.w.g. wall is obtainable from most ironmongers or non-

Fig. 1. **Gain versus number of turns for helical antennas having a pitch angle of 12.8° and circumference of 1.08λ (based on curves in reference 2). The 9 and 16-turn designs described here have gains of 12.8dB and 15.2dB respectively. At 435MHz, longer antennas would need a stronger boom.**



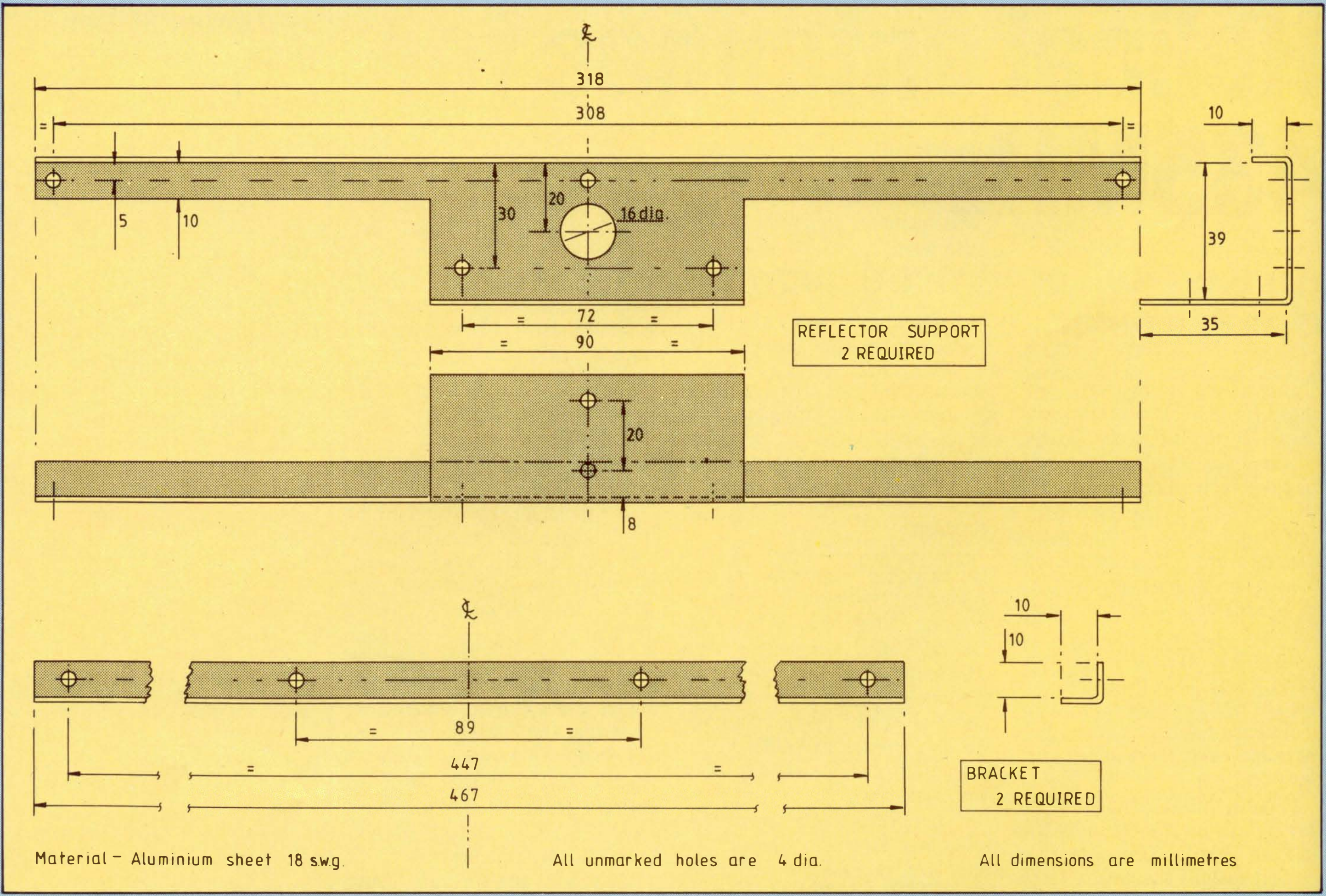


Fig.2. Reflector support is fabricated from 18 s.w.g. aluminium sheet; two of each part are needed. Assemble as shown in Fig.3. The parts are fixed through the reflector mesh with twelve 10mm M3 screws and stiff-nuts, backed with 16mm diameter washers cut from waste aluminium.

ferrous metal suppliers. You will need two or three metres, which will allow you a little surplus at each end to clamp the boom for support during construction.

Drill holes of 4.3mm diameter for the spacers and to secure the relector (see Fig.4). Spacers are used every 1.75 turns: the holes must therefore be alternately vertical and horizontal on a 3.5 turn (595mm) pitch. The first spacer is a quarter-turn into the helix; the last supports the end of the final turn.

First drill the spacer holes. Position the reflector mounting holes so as to locate the front face of the reflector 53mm from the first spacer hole. This will ensure an adjustment gap of about 5mm between the reflector and the start of the helix.

Helix

The helix is made from 10mm diameter copper central-heating pipe, which is readily available, easy to bend by hand and quite cheap. It usually comes in 10 or 20m coils. Each turn takes 0.7m, so you can get up to 13 turns out of a 10m length; 20m will make two antennas, one of nine turns and one of 16. If you can obtain odd lengths from a plumber then the pieces can be soldered together. Do not uncoil the raw tubing before winding.

You will need a mandrel around which to wind the helix. It should have a diameter of 229mm and, for comfort, a length of at least 180mm. A search around your attic, scrapyard or the shops may well produce a suitable object. I found a nine-inch cake tin exactly the right diameter though a little short, and I was able to wind the first prototype, somewhat unevenly, using two pairs of hands and a lot of patience. For subsequent models this experience prompted me to make up a proper drum of the correct size out of two plywood discs and some slats.

Particular thanks to Francis Pullen G4XXX for machining services during the development of this antenna, and to Cambridge Consultants Limited for the free use of facilities.

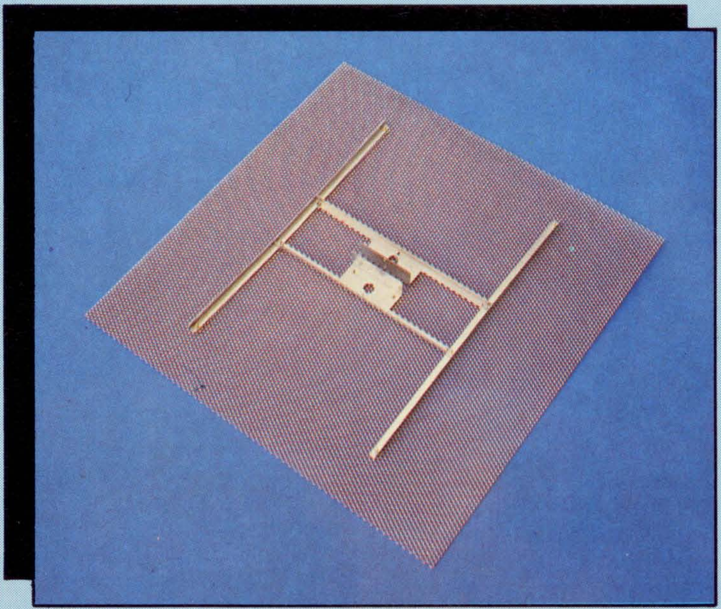


Fig.3. Rear view of the reflector showing assembly of support parts. Rear feed may be obtained by reversing the N-type connector and omitting the feedthrough insulator. Anti-static protection (not shown) can be effected with a small inductor from connector pip to a solder tag on the boom.

Table 1: measured performance data

Size	9	16 turns
Gain	12.8	15.2dB
3dB beamwidth	–	±11°
First nulls	–	±23°
Typ. sidelobe	–	–18dB
F/b ratio	–	14dB
S.w.r. (typ.)	less than	1.1:1
Overall length	1.59	2.78m
Weight incl. clamp	2.7	4.0kg

Table 2: electrical and mechanical design

Frequency	430–440MHz
Wavelength	λ = 690mm nominal
Pitch angle	p = 12.8°, circumference C = 1.08λ

	symbol	wavelengths	size, mm
Circumference	C	1.08	745
Diameter	D = C/π	0.344	237
Turn length	Lt = C/cos(p)	1.108	764
Turn spacing	S = C tan(p)	0.245	170
Tube diameter	d	0.014	10
Reflector		0.87	600 x 600

Table 3: materials

Quantities for a 16-turn helix [figures in brackets are for nine turns]:

Reflector:
Expamet 351A expanded aluminium mesh, about 600 x 600mm
Support/stiffeners fabricated from 500 x 250mm 18 s.w.g. aluminium sheet
12 M3 x 10 pan-head screws and stiffnuts, plated
12 16mm diameter washers drilled 3.3mm, cut from aluminium waste
2 M4 x 30 pan-head screws and stiffnuts
1 N-type socket e.g. Cirkit (formerly Ambit) part no. 10-01301
1 feedthrough insulator, 4mm dia. x 13.7mm e.g. Sealectro type FT310P51

Boom:
3 [1.8] metres aluminium tube, 19 x 19mm section, 16 s.w.g. wall thickness
2 19mm square plastic end plugs – e.g. Dexion finishers
1 antenna clamp, double U-bolt typ , e.g. Jaybeam type 9891 or similar

Helix:
13 [7] metres 10mm diameter copper micro-bore central heating tube
1 10mm end cap, e.g. Yorkshire type 61

Spacers:
1.2 [0.7] metres 16mm diameter black Delrin rod
10 [6] M4 x 30 screws, pan-head, plated

Feed strap:
100 x 7mm 16 s.w.g. brass strip

The following parts may be obtained from the author:

1. Pre-formed reflector support/stiffeners, screws, nuts, and washers: £15 per set.
2. Machined spacers with screw: £2.30 each.

Complete antennas and kits are also available to special order. Prices include carriage to U.K. addresses only. For more details, please send a stamped, self-addressed envelope to J.R. Miller, 3 Benny's Way, Coton, Cambridge, CB3 7PS.

There is no need to worry if the mandrel is not exactly 229mm in diameter, but be sure to err on the small side, since the design is already close to the maximum size for 440MHz. If your helix diameter ends up N mm less than nominal, then simply make the spacers (N/2)mm shorter.

Start winding about half a metre into coil. Holding the short end tight against the mandrel, pointing away from you, pull the long end down on to the mandrel into a curve. Slip the helix back an eighth of a turn and bend again. In this way a whole turn can be built up smoothly and will start gripping the mandrel as soon as tension is applied.

After winding the first turn, stop and inspect your work. Make absolutely sure you are winding a right-hand or left-hand spiral as you really want. If in doubt, compare it with a normal woodscrew. Most people instinctively wind left-handed spirals.

Continue to close wind the copper until you have 9 or 16 tightly coiled turns. The helix will spring out naturally to the desired (coiled) diameter of about 253mm outside.

Stretching

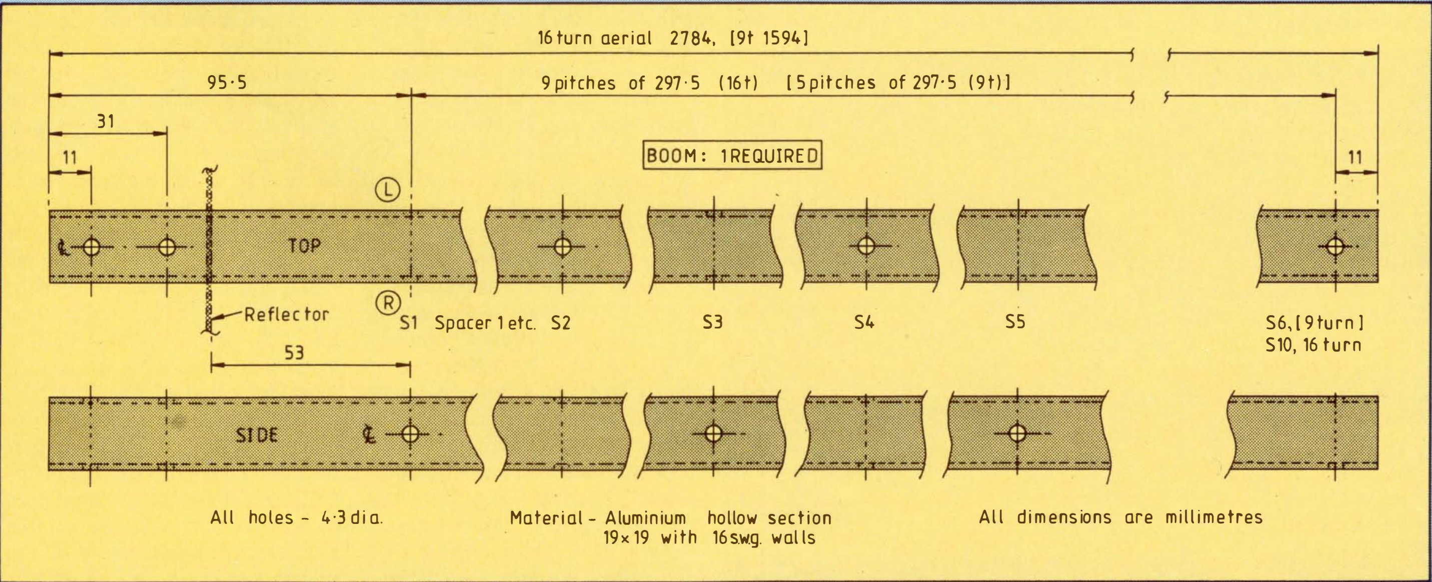
First mark the top of each turn: stick black tape along the outside of the coil, slit the tape between turns and smooth each marker down firmly

Support the boom at each end. Mark the location of the first and last turns on the boom (1.53 or 2.27m apart) boldly, with black tape.

Now slip the coiled helix over the boom. With an assistant holding one end, draw the other, gently stretching the coils apart, keeping the top markers vertical until the full extent is reached. Take care to avoid distorting the first and last turns through rough handling.

You should now have a fairly even helix with the correct average spacing of 170mm and nominal o.d. of 247mm.

Fig.4. **Boom drilling. Material is 19×19mm aluminium tube. The reflector is secured via two vertical holes to prevent twisting; spacers are used every 1.75 turns.**



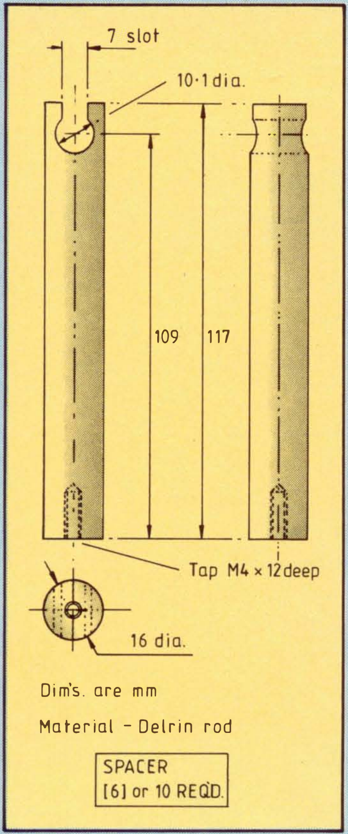
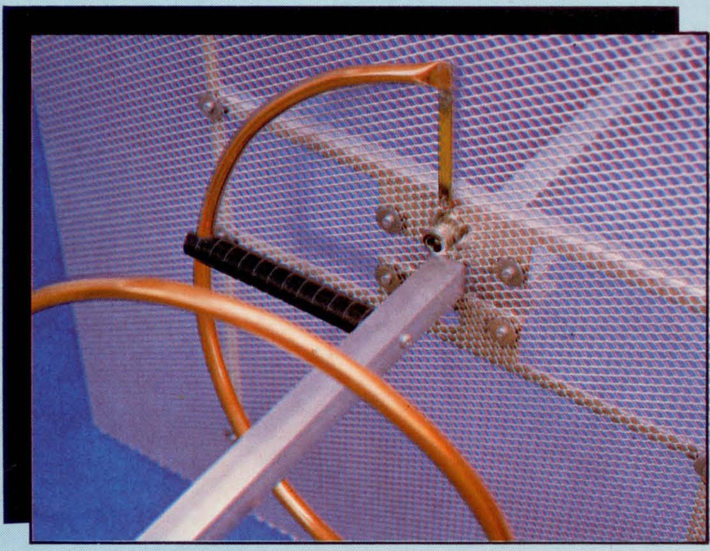


Fig.5. **Spacers are machined from 16mm black Delrin rod and are fitted at 1¾ - turn intervals. The helix structure snaps into the slot. A vee-notch may be used as an alternative to the slot and hole illustrated here: the copper is then secured by wire passed through a small hole beneath the notch.**

Fig.6. **The feed strap: an accurate match is found by adjusting the spacing between strap and reflector. An s.w.r. of better than 1.1:1 can be obtained easily over 430-440MHz.**



The spacers are made from 16mm extruded black Delrin rod, which can be obtained from plastics suppliers listed in the classified telephone directory; but any ultra-violet and weather-resistant loss-free material could be used instead. Cross sections of the spacers are shown in Fig.5. They can be made by hand using a saw and drill, though a lot of care will be needed; I used a lathe. You will needs six or ten spacers.

The slot in the top is wide enough to allow the copper tube to be snapped into place. Other methods of mounting may be just as effective, though. One possibility is a V-notch, with the tube secured by a couple of turns of 18 s.w.g. copper wire (as used in mains power wiring) via a small hole drilled beneath the notch. Whichever method is used, the tube centre must be supported 109mm above the boom surface, allowing for any error in the dimensions of the spiral.

Fix the spacers loosely to the boom in such a way that the start turn will be uppermost. Lift the helix on to the top spacers at 2,9 and 16 turns, guided by the markers, and secure it. Next, fix the spiral at the bottom, and then at the sides.

Fine adjustment of spacing may be needed to correct any distortion. Make up a 160mm-long gauge from a strip of metal: it should just slip between the turns.

Now bolt on the reflector assembly.

Feed strap

This consists of a strip of 16 s.w.g. brass, 7mm wide and about 100mm long running from the start of the helix down direct to the connector (for rear feed). For front feed, the strap is about 85mm long and runs to a feed-through insulator mounted on the reflector support. It is linked by an 18 s.w.g. insulated copper wire across to the connector pip.

Carefully squash flat about 10mm of the start of the helix so that the strap can be soldered flat, close and parallel to the reflector. The tube can be sealed up at the same time.

If a large soldering iron or blowtorch is available, a 10mm copper end-cap makes a neat finish for the front end of the helix; but while fitting it, temporarily remove the leading spacer from the heat.

Tuning

First make sure that all screws are tight. Using an s.w.r. bridge, adjust the spacing between strap and reflector, gently bending the first quarter turn as needed. The gap should be about 3mm. Relieve any stress at the connector or feed-through by re-melting the solder.

Tuning can be done at ground level, with the antenna on a two-metre pole. In fact, after the initial adjustments indoors, little further tuning seems to be needed when the aerial is taken outside.

Use no more then 5W when experimenting, and remember the e.i.r.p. at the sharp end is high: avoid prolonged exposure. With care a virtually perfect match can be achieved from 430 to 440MHz.

Installation

In a gale the force acting on the reflector is very high, and results in a considerable torque at the clamp. Therefore pay special attention to this fixing point. Use a double U-bolt design and install with care. If in doubt run an M8 bolt right through clamp and mast. There is just room.

Consider also the parking position when the aerial is not in use. Small rotators such as the Hirschmann 250 are not really suitable for the 16-turn antenna. Windage can be reduced by cutting the reflector to a 500 × 500mm square or to a circular pattern.

The centre of gravity of the 16-turn antenna is about 6.7 turns along the boom, and at this point the bending moment of 1.6kg.m results in a 20mm sag at each end, which is quite acceptable.

The nine-turn antenna can be fixed in the same way, or end-mounted with a counterbalance weight of moment 1.7kg.m referred to the clamp. (Front-end sag will be 20mm again).

Using a metal mast through the helix seems to produce no ill effect. Glass-fibre masts are becoming more common, but unfortunately are still expensive.

The antenna's finish can be preserved with a coat of yacht varnish. This will flake off if the metalwork in not first degreased using hot soapy water, blue Ajax or Inhibisol.

This type of antenna inevitably picks up a static charge which will damage pre-amplifiers or receivers that do not have a low input resistance to d.c. Check your system! A simple protector would be a 4.7kΩ 1W resistor from connector pip to boom, which I have not tried, or small inductor in the same place, (say 300nH, a few turns), which I have. You are warned!

Performance

I would have welcomed an opportunity to evaluate the antenna on a proper test range, but lacking both of these I had to devise another method. My local u.h.f. repeater is fortunately only 1km distant and it provides a strong, steady line-of-sight signal. I rotated the antenna in small increments and measured the response using a calibrated 1GHz variable attenuator.

With this test I was able to assess the nulls and sidelobes, and by graphically integrating the polar plot[3] I arrived at an estimate of the gain achieved (table 1).

In actual practice, performance has surpassed my expectation. Oscar-10 working has been transformed since my crossed Yagis were replaced. Terrestrial working is excellent, the circular polarization eliminating the need for dual feeds, changeover relays and the like. Of course there is a 3dB penalty for using circular instead of linear, but does anyone actually notice? The polarization from mobile signals constantly changes, and circular polarization should actually be better than vertical alone.

The prototype has been in use since December 1983, and apart from the redesigned reflector stiffening has needed no attention. Without doubt it has been one of the easiest antennas of all to design and build.