Designing and building a 70cm repeater aerial

Excellent performance at very low cost

PHOTO 1: The completed aerial with G0EVV for scale.

THE REQUIREMENT. In May 2009 the newly formed Northumbria Repeater Group decided to make an application to Ofcom to install a 70cm D-Star repeater to provide coverage of Northumberland. This would be located at Lynemouth on the North East coast. Colin, G7RWC applied for the repeater NOV with the callsign GB7NE. The application was soon approved for 439.450MHz.

We decided to go down the homebrew route. The repeater equipment was based on Tait 850 ex PMR equipment with a Satoshi GMSK node adaptor, (like GB7MH described in the February *RadCom*). Colin undertook to prepare the node adaptor systems and I was to build the aerial. What we needed was an aerial that would be robust and weatherproof whilst providing some gain to counter the 3.1dB measured feeder loss. The aerial was also needed as soon as possible so that we could undertake simplex tests. These were required in order to validate the computer coverage predictions prior to the completion of the hardware.

INVESTIGATIONS. I commenced the design by looking at the material on the web. One design in *Repeater Builder* by WB2EDV was a good start but the construction and matching looked to be difficult to achieve. Tetra–style 4-stack commercial dipoles also gave some inspiration. Slowly a plan came together: a stack of four folded dipoles, 3m high (**Photo 1**) should provide 8 to 9dB gain over a dipole for the 180° inland from the coast.

I have long believed that when designing aerials, the electrical bit is easy. The mechanical bit is difficult and keeping the water out is all but impossible. It was with this in mind that a trial folded dipole was constructed from 15mm copper water pipe and solder fittings. These materials are accurately made, plentiful, light and – most importantly – cheap!

When I constructed a test dipole, the resonant length was estimated using the usual formula for thick dipoles, but the length came out too long. The resonance was 50MHz below the desired frequency. Some hacksawing later, resonance at 435MHz was achieved. At resonance the feed point impedance of a folded dipole is about 280Ω, making matching to 50Ω difficult. If, however, the dipole is brought close to the support pole, the feed impedance falls. For 435MHz, a 50Ω match can be achieved at a spacing of 10 to 15mm. In addition the radiation pattern is offset, giving radiation predominantly on the side where the dipole is fitted. I found that the pole had only a slight effect on the resonant frequency, lowering it about 10MHz. The minimum SWR at resonance (measured with an aerial analyser) was 1.2:1. The dimensions for the dipole were 274mm long x 78mm wide (both dimensions to the outside of the pipes). The bandwidth of the aerial was found to be 10MHz at 1.5:1 SWR, just the job to cover the 9MHz transmit / receive split of the D-Star repeater. I also found that a 1mm change in dipole length changed the resonant frequency by about 2MHz.

Now came the cunning bit.

Instead of taking the coaxial cable to the gap in the dipole, I fed the cable through the hollow dipole from the support opposite the feed point. The RF current cannot therefore flow down the outside of the cable because the dipole tube becomes a Faraday shield; the cable also comes away from the dipole at the radiation-neutral on the blind side of the pole.

As a repeater, the aerial has to function satisfactorily receiving picowatts of power whilst simultaneously transmitting several watts on an adjacent frequency. The power ratio is more than 10^{16}:1. 'Rusty bolt' effects on repeater aerials (caused by corroded dissimilar metals) can cause havoc to signals due to intermodulation between the transmitted and received signal. For this reason I insulated the dipoles from the pole using plastic blocks (**Photo 2**) and secured them with stainless steel bolts. Similarly, all RF-carrying connections were either soldered or made with good quality N plugs.

To compress the azimuth response onto the horizon, the vertical spacing for the dipoles is important. Make it too narrow and the optimum gain would not be achieved. The spacing I used was copied from that used in *Repeater Builder*, corroborated from other sources. This spacing nicely fits onto the 3m pole, leaving 300mm for engagement with the support scaffolding tube.

FEED SYSTEM. Having understood how to make dipoles I began to look at how to feed the four dipoles in phase. Clearly the cable lengths had to be the same to avoid phase differences and tilt on the radiation pattern. Also, the cable had to pass inside the dipole so 6mm (RG58) diameter cable seemed to be the only practical solution. However, to minimise the losses, RG223 silver plated cable (the same diameter as RG58) was used. It cost just £8. The cables were cut to 1180mm, an electrical length of 5 half wavelengths (allowing for the velocity factor), to minimise mismatch issues.

To feed the aerials in phase I needed some form of 4-way power splitter. These devices are usually based on quarter- or half-wave transformers in the form of concentric tubes to form a transmission line of a particular characteristic impedance. Commercial devices are expensive, £100 not being unusual. I tested a couple of examples but I found that the matching performance was not as good as I had hoped.

PHOTO 2: Two of the plastic blocks fabricated to insulate the dipoles from the support pole.

Another cunning plan was needed!

If two load-matched 50Ω cables are terminated in a tee piece, the centre point impedance will be 25Ω. If two balanced feed cables are terminated at another tee where the centre point impedance is 50Ω, the input impedances must be 100Ω.

The formula for a quarter wave transformer is

$$Z_0 = \sqrt{(Z_1 \times Z_2)}$$

Where:
Z_0 is the characteristic impedance of the transformer
Z_1 is the input impedance
Z_2 is the output impedance.

Following the formula for a quarter wave transformer, the characteristic impedance of the cable making up the transformer needs to be

$$Z_0 = \sqrt{(25 \times 100)} = 50\Omega$$

So, to make the power splitter (**Photo 3**), all I needed was three N type tees, four N plugs and two 100mm pieces of RG213. To adjust the splitter I purchased four 50Ω N type terminations and used the aerial analyser to determine the cut length of the cable, making up the transformer for minimum reflection at 435MHz. This was a tedious job because two cables had to be cut equally to an accuracy of better than 1mm. The final length of my cables was 111mm from end of plug to end of plug. Eventually the transformers were satisfactory and could be coupled to the four stacked dipoles. Perhaps because I was coupling four tuned circuits and the resonant power splitter, I now had a double dip to 1.2:1 SWR: one at 432MHz and one at 438MHz. Perfection!

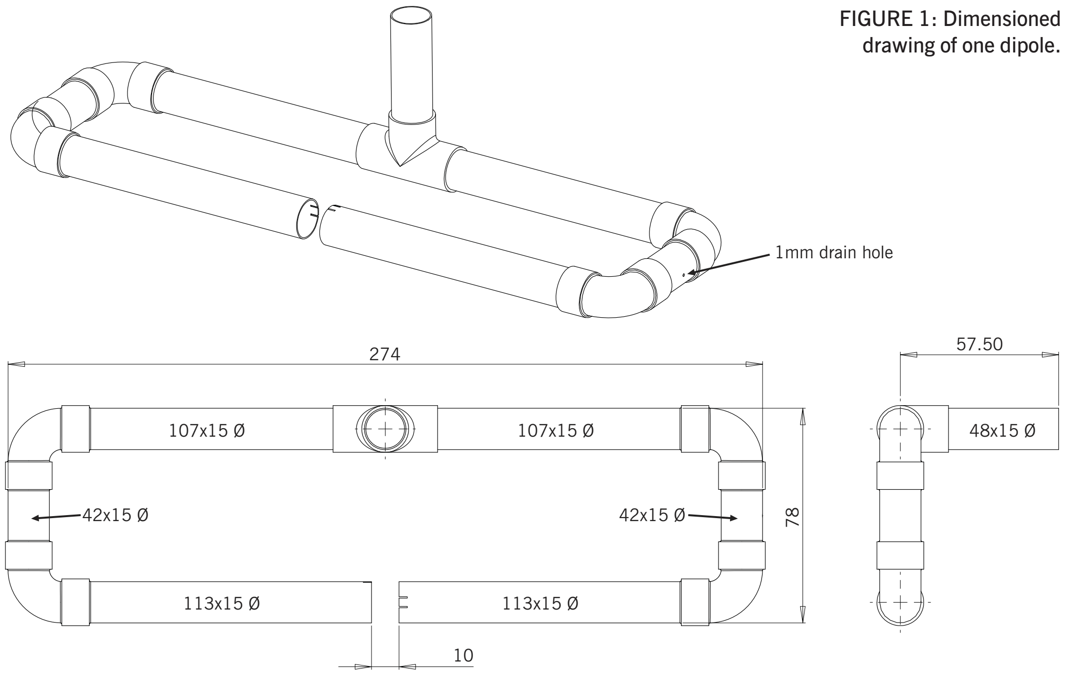

FIGURE 1: Dimensioned drawing of one dipole.

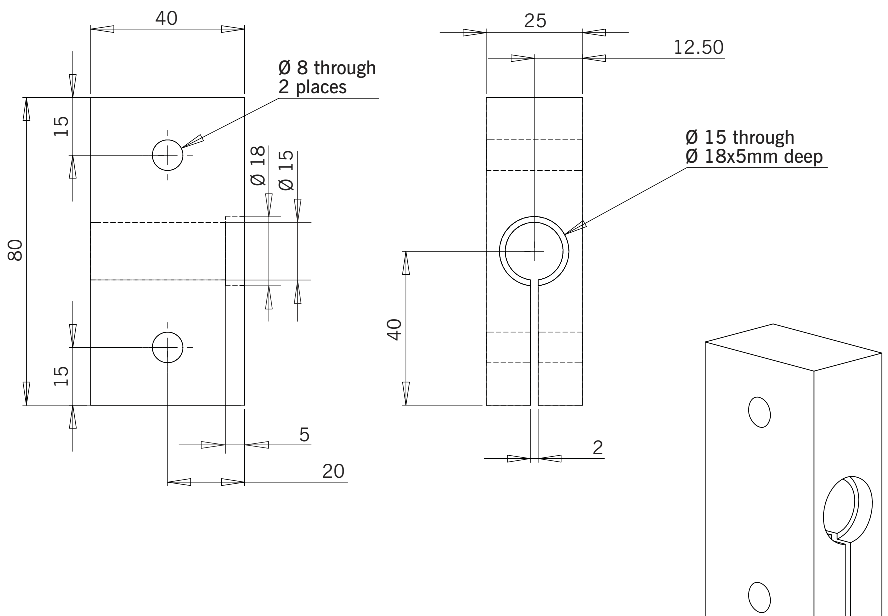

FIGURE 2: Details of the standoff block.

PHOTO 3: The 4-way power splitter.

CONSTRUCTION. To construct the dipoles I used a range of hand tools including a hacksaw and junior hacksaw. A pedestal drill is needed to drill the support brackets and the support pole. There are 11 soldered plumbing joints on each of the dipoles, for which a gas blowtorch is essential. I used the plumbing fittings without the solder ring to make the finished dipoles as neat as possible. To ensure repeatability, I constructed a simple metal jig from steel angle purchased from the local hardware shop. This ensured that the length of the dipoles was consistent when assembled but remember, copper expands when hot. Material and cutting lists are in **Tables 1** and **2**. Don't forget, measure everything at least twice before you cut it.

All of the pipe ends were carefully cleaned with wire wool, wetted with Bakers fluid and tinned, using a cotton cloth to remove surplus solder. The pipes were cut and filed square according to the cutting list, allowing 8mm for engagement inside the elbows. The feed connections are easy to solder because they're made from copper. To keep the water out, the feed point was covered with another plumbing fitting, this time a plastic, non-soldered straight coupling intended for 15mm pipe. This fitting uses O rings to seal against (mains) water pressure and is therefore very suitable for keeping the rain out. I also applied a small amount of impact adhesive to the cable screen at the termination to help prevent damp ingress into the cable.

To allow the dipole to breathe, I drilled a 1mm vent hole in the pipe that was to be fitted in the bottom arm of the dipole. At the feed point, four 3mm long slots were cut in the lower pipe and two in the upper pipe. After carefully tapping them inwards at 30°, they made perfect 'landing' areas for connections to the co-ax screen and core. I soldered these using an old copper block soldering iron, but a hot 100W electric iron could be used.

As supplied, the plastic straight coupling had a small step at the centre of the bore. This was removed using a 15mm drill before being loosely assembled on the upper side of the feed point (with a little silicone grease on the O ring seals).

I made several attempts to feed the cable from the support all the way round to the feed point. All attempts failed miserably! I found It was necessary to solder one 15mm coupling with the cable inside. The method I adopted was to feed a PTFE coated instrument wire through the part assembly and then use this to pull the cable through. Then, I covered the cable with a double wrap of plumber's PTFE tape 40mm either side of where the 15mm coupling was to be soldered. Finally, the dipole was assembled and quickly soldered, using a wet cloth to remove heat as soon as practicable. To plug the cable entry, a short piece of wooden dowel was drilled and fitted over the cable, using adhesive to close all the gaps. Outdoor grade silicone sealant would also probably have worked well. **Photo 4** shows a completed dipole.

I measured each dipole for resonant frequency and minimum SWR when mounted in position on the pole. Should the resonant frequency need adjusting I could free off the waterproofing coupling over the feed point and melt the joint on the support side upper leg. ±2mm adjustment could be made in this way, changing the resonant frequency by ±4MHz. Minimum SWR should be 1.2:1. A check at this stage is worthwhile to make sure that all of the vent holes are at the bottom. Not only does this mean they will drain correctly, it also ensures that the dipoles are all in phase, ie the cable passes through the lower leg.

The pole I used was a standard 38mm aluminium television aerial pole. Heavier gauges are available, but practice suggests that these are not necessary. The support blocks were cut from 25mm thick PVC based plastic sheet. The holes were marked out and drilled on a pedestal drill. The 15mm hole was counter bored to take the end of the tee piece. A 2mm wide slot was cut in the lower half of the block to finally clamp the dipole support. The vertical spacing for the dipoles on the pole was 530mm with 265mm above the top dipole (after WB2EDV).

During final assembly I cleaned all the metal surfaces with glass paper to ensure good paint adhesion. After the support blocks had been tightened to secure the dipoles to the pole, I applied silicone sealer to all of the gaps. Finally, when all was satisfactory, the whole assembly was given three coats of Hammerite smooth metal paint and the cable entries and power splitter was wrapped with Denso greasy tape.

SAFETY. To prevent the pole falling, should it snap from metal fatigue caused by the buffeting of the wind, I fitted a safety rope up the inside of the pole, securing it with a stainless steel bolt near the top of the pole. To prevent water ingress a rubber bung was also fitted at the top and the aerial pole was fitted into a short stub of aluminium scaffolding pole for clamping into position. The pole was connected to the tower's main lightning conductor to provide a measure of lightning protection and static drain. The dipoles were also earthed where the feed cable was connected to the lightning conductor.

TABLE 1: Bill of materials for four dipoles and feed assembly

3m 15mm copper pipe
8 x 15mm elbows
4 x 15mm tee
4 x 'Speedfit' 15mm straight couplings
8 x 80mm M8 stainless bolts nuts and washers
1 x 80mm M6 stainless bolt nut and washers
Piece of 25mm plastic sheet
6m RG223 coaxial cable
200mm RG213 coaxial cable
100mm of 15mm dia wood dowel
4 x N plugs, 5mm entry
3 x N tees
4 x 10mm N type plugs
Denso and PTFE tape

TABLE 2: Per-dipole copper pipe cutting list

2 x 113mm
2 x 107mm
2 x 42mm
1 x 48mm
Also, coaxial cable cut to 1180mm

FOOD FOR THOUGHT. GB7NE went on air at 1800 on 8 September 2009 and has worked reliably to date. For mobiles it covers most of Northumberland and up the valleys of the Wansbeck, Aln and Coquet. This suggests that the aerial is radiating as required.

There is a possibility that the matching arrangement, dropping 280Ω to 50Ω may however be compromising performance. I have therefore considered fitting a quarter wave transformer made from 72Ω cable at the feed to the dipoles. This would step up the impedance from 50Ω to 103Ω, making the mismatch less severe.

PHOTO 4: One completed dipole with feed cable.

PHOTO 5: A completed dipole mounted on the pole with part of the power splitter on the right.

$$72 = \sqrt{50 * Z_2}$$
$$Z_2 = 103\Omega$$

The transformer could be installed within the dipole pipe and the dipoles mounted further from the pole with perhaps a positive effect on the polar diagram.

Should the aerial be required to provide omnidirectional coverage, this could be accommodated by mounting two dipoles on each side of the pole, providing 6dB gain over a dipole. For the more ambitious, eight dipoles could be fitted and suitably phased to deliver 9dB of omnidirectional gain.

REFERENCES

[1] 440MHz Folded dipole Repeater Antenna, WB2EDV, *73 Amateur Radio* September 1987 and www.repeater-builder.com
[2] UHF Stack Side Mount Dipole Array, www.benelec.com.au
[3] 4 Element stacked dipole array, www.skymasts.com
[4] Cable and connectors from WH Westlake or others