A compact multiband dipole

In May 1982 I published a short note in Pat Hawker's much-missed *RadCom* column Technical Topics. It described an improved form of the venerable G5RV multiband dipole. Since then my version of the antenna has become known as the ZS6BKW, from the callsign I held in those days.

The ZS6BKW antenna will produce a better than 2:1 VSWR on parts of five amateur bands (7, 14, 18, 24 and 28MHz). There is no similar antenna that is not based on similar principles, or that does not include traps that achieves such performance. How it does this was described, in some detail, in the August 1985 *RadCom* **[1]** and then in considerably more detail in a professional journal **[2]** some two years later.

The key to how the antenna and its matching system behave is the Smith Chart *[which is discussed in this month's Antennas – Ed]* whereas optimisation of the antenna's performance requires a computer. In the early 1980s, and therefore well before the general availability of the powerful Method of Moments computer programs (such as NEC and then, more recently, MININEC, EZNEC and others), it was necessary to write special-purpose programs to analyse the G5RV configuration and then, from those results, to have another program synthesise the ZS6BKW with its much-improved performance. Many lines of code, written in BASIC, achieved both, albeit when running overnight on a computer that looked more like a very large domestic appliance than the sleek laptops and other devices we're all familiar with these days.

Since then, the ZS6BKW has been replicated by many amateurs around the world and it has also attracted the attention of certain manufacturers of wire antennas for the amateur market. Their price tags alone are fascinating! The behaviour of this antenna in the real world, where various losses all play a part, was examined in an article published in 2014 **[3]**. Not surprisingly, a well-constructed ZS6BKW, when used on its intended bands, comes out of it rather well. However there is one shortcoming that still remains: the antenna's size. In a more recent *RadCom* article **[4]** I pointed out the *dis*advantages of erecting the ZS6BKW as an inverted-V as opposed to its intended configuration as a horizontal antenna. Saving one pole and a bit of space causes severe degradation of the radiation pattern, with most of the energy being wasted at high angles on those bands where, for DX purposes, the dictum is the lower the radiation angle the better.

PHOTO 1: **The antenna in position prior to testing.**

I also became aware of attempts to reduce the size of the ZS6BKW by following the lead of the so-called half-size G5RV or G5RVjr. As you might expect, as soon as one halves the lengths of the antenna and its special matching section of transmission line as a space-saving measure, the number of bands covered reduces too. Instead of just compromising the 40m performance, as those behind the half-size version obviously expected (and presumably accepted), it turns out that both the 17m and 12m bands actually disappear too, leaving just part of the 20m and 10m bands for doing anything on. That's hardly a useful solution.

Bobtails and other animals

In 1948, when amateurs were once again designing and building their stations after the long years of prohibition throughout the war, many new and sometimes unusual antennas appeared as well. One of those was the Bobtail Curtain, first described by W6BCX. It consisted of three vertical wires, the centre one of which was fed at the bottom via a suitable matching network. The outer two vertical conductors were each separated by a quarter of a wavelength from the central one and they were top-fed by the horizontal sections of the antenna splitting left and right from the central conductor. The Bobtail Curtain is shown in **Figure 1**. It gave me an idea: to let the ends of the horizontal ZS6BKW drop vertically at two points equidistant from the centre of the antenna – the point at which it is fed through its special transmission line matching system. But that's where the similarity between the Bobtail and the inverted-U – which is what the new ZS6BKW becomes – ended. Finding those two points where the wires dropped vertically turned out to be remarkably quick and easy with EZNEC, the superb program developed by W7EL based on the NEC 2 computing engine.

The starting point was the conventional ZS6BKW (see **Figure 2**) with dimensions that have been shown to be just about optimum both on the computer and in practice. To recap, the antenna 'flat top' is L1, while the length of the series-section matching line is L2 (with its characteristic impedance Z2). Both of those lengths, L1 and L2, and the value of Z2, are the key elements in the design of the ZS6BKW. I began the analysis of the compact inverted-U version with all those values unchanged. Since we require the new antenna to radiate as well as possible on its intended bands there must be a significant horizontal length of wire, carrying maximum current, to produce the necessary near-vertical incidence skywave (NVIS) radiation on 40m, the band where that mode tends to dominate for most short-skip contacts. It is, though, just as important to ensure that it radiates at a reasonably low angle on all the higher frequencies, which does not happen when this type of multiband antenna is used as an inverted-V.

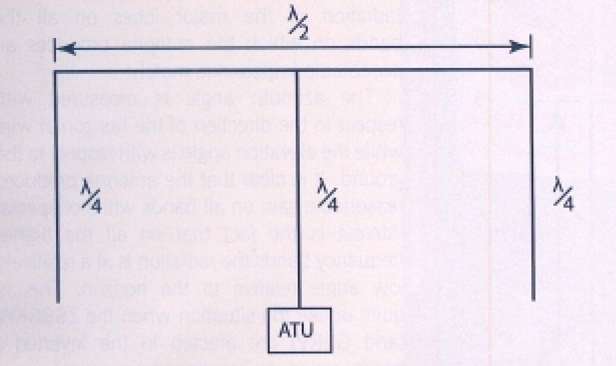

FIGURE 1: Bobtail Curtain single-band vertically polarised antenna.

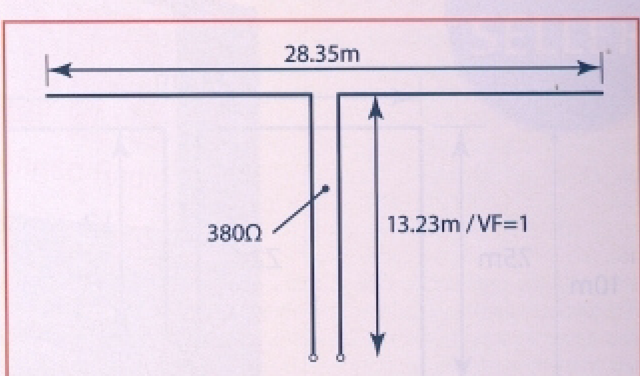

FIGURE 2: The horizontal ZS6BKW, which exhibits five-band performance for both NVIS and low-angle applications.

Computer simulation

To achieve optimum NVIS performance on 7MHz, the horizontal part of the antenna must not be more than a quarter of a wavelength above ground. This is to prevent a null forming in the vertical radiation pattern. Thus the maximum height of the new antenna is around about 10m. To achieve the largest current moment (the product of current and wire length) in that horizontal section of the antenna means that the points at which the ends of the antenna drop vertically must not be too close together. For my first pass in the computer analysis I chose these to be the mid-points of each of the dipole arms. Since the horizontal ZS6BKW was more than 28m long, this produces a significant reduction in size. I left both the length of L2 and its characteristic impedance Z2 unchanged. The computer results, in terms of both the impedance match and the radiation pattern across the bands, looked very promising and plotting the data on the Smith chart proved even more enlightening. It was clear that the value for Z2, which had proved to be ideal for the conventional horizontal ZS6BKW, was just about optimum for this new form of the antenna as well. This was most useful since it made the erection of an existing antenna in a more confined property very straightforward.

Another practical (and safety-related) consideration now came into play. The ends of the two vertical sections of the antenna should be high enough above the ground so as not to pose a shock hazard to anyone coming into contact with them because the ends of all open-ended antennas may carry high voltages. I arbitrarily set that minimum height as 2.5m. This immediately meant that the two vertical conductors would be 7.5m long given the 10m height of the antenna. *[Note that tall people might still be able to touch the end of a wire at that height – Ed]*. Another EZNEC simulation, taking full account of the real ground beneath the antenna, soon showed much promise. The impedance match was good on all the bands where the ZS6BKW matched with just the optimum matching frequencies being slightly high. In addition, the predicted radiation patterns on each of those bands were excellent: near ideal NVIS performance on 40m while, on all the higher bands, low angle radiation was produced.

PHOTO 2: Measuring the matching section.

A new compact multiband antenna

The antenna that resulted from the EZNEC exercise is shown in **Figure 3**. It will be seen that the length of the horizontal top section has been increased just slightly to 14.2m overall, with each of the vertical sections being 7.5m. The matching section L2 was initially exactly the same as it was in the conventional ZS6BKW. It should be noted that the velocity factor (VF) of L2 must always be taken into account because the physical length of a transmission line is always less than its electrical length, the two being related by the velocity factor (VF). Thus $L2_{phys} = VF \times L2_{elec}$. In the simulations described here, VF was assumed to be unity hence the physical length and the electrical length of L2 are the same. EZNEC allows the VF to be included and if other values are inserted in the program then L2 must be adjusted accordingly. It should also be appreciated that all antennas are affected by the environment in which they operate. In this case it's the proximity of the ground that is the major factor to take into consideration. The experimental results discussed later will make this clear. They will also show the

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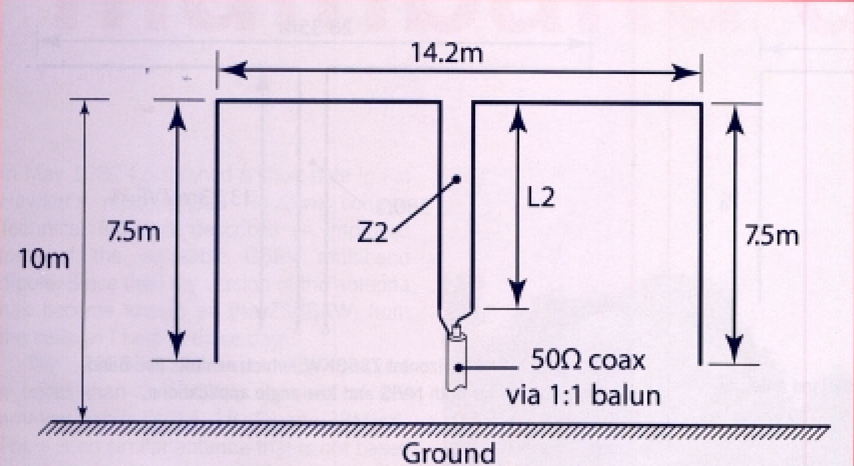

FIGURE 3: The new compact multiband antenna with its shortened 14.2m top and 7.5m ends. Details of the matching section L2 and Z2 are discussed in the text.

steps that may need to be taken to correct for slight variations in matching in particular installations.

Antenna gain, efficiency and radiation pattern

All these parameters are closely related. Gain is a measure of the power radiated by an antenna in a particular direction, or directions. It includes the effect of all losses. Radiation efficiency is the ratio of radiated power to the power fed into the antenna while the radiation pattern is the shape of the resulting radiated lobes of energy or field strength. Clearly this involves the concept of directivity and, unsurprisingly, there is a simple relationship between antenna gain and directivity. Gain G and directivity D are directly proportional to one another, being related by $G = \eta D$, where η is the radiation efficiency given by the ratio of radiation resistance R_r to the total resistance presented by the antenna to its feedline. Thus $\eta = R_r / R_t$, where $R_t = R_r + R_l$ and R_l is the loss resistance at the antenna's terminals made up of both conductor loss and any other losses induced by the ground and objects nearby.

When constructed of copper wire and erected about a quarter of a wavelength above the ground at its lowest frequency, the antenna's efficiency will be high on all its matched frequencies. As a result, most of the power fed to it will be radiated. The radiation pattern will naturally change from band to band because it is related to the distribution of current, in amplitude and phase, along the antenna conductors.

On 7MHz the horizontal top section is almost exactly one third of a wavelength long and the antenna looks like an end-loaded short dipole. The current reaches its maximum amplitude within that top section. Hence maximum radiation occurs from the horizontal part of the antenna in a broadside direction. By contrast, very little radiation takes place broadside from the two vertical sections because their currents are of equal amplitude but are out of phase and so the fields they produce cancel each other in that direction. However there is a significant change of phase between the fields produced by those vertical sections in a direction along the horizontal conductor and this leads to radiation essentially off the ends of the antenna. As a result, the horizontal radiation pattern is almost circular, being vertically polarised off its ends and horizontally polarised broadside to the antenna. The elevation pattern has a single broad lobe with its maximum close to the zenith or directly overhead. This is ideal for NVIS.

At higher frequencies the current distribution changes from band to band and, as a result, so does the radiation pattern. **Table 1** shows the gain and angles of radiation of the major lobes on all the bands on which the antenna produces an acceptable impedance match.

The azimuth angle is measured with respect to the direction of the horizontal wire while the elevation angle is with respect to the ground. It is clear that the antenna produces reasonable gain on all bands while of special interest is the fact that on all the higher frequency bands the radiation is at a relatively low angle relative to the horizon. This is quite unlike the situation when the ZS6BKW (and G5RV) are erected in the inverted-V configuration, as mentioned previously.

The 14MHz case is particularly interesting. The antenna actually performs as an end-fire array by producing two broad lobes off its ends with their maxima at 40° to the wire at either end. There are also two fairly deep nulls broadside to the antenna. Much less radiation is produced by the horizontal portion of the antenna because of phase cancellation that occurs along its length. By contrast, the two vertical end sections, though carrying currents almost out-of-phase with each other, are sufficiently far apart for there to be a significant reinforcement of the fields radiated in those end-fire directions. It should be noted, too, that the vertical elements are fed at the top, which means that no radials wires are needed at ground level to achieve this low-angle performance. The fields are vertically polarised, as we would expect, while the horizontally-polarised component is some 10dB weaker. This rather fortuitous situation leads to the very acceptable low angle of radiation of just 15°. This would not have been the case had the radiation been horizontally polarised because the conductor responsible for it is too close to its image in the ground with its oppositely-directed current leading to virtual cancellation of radiation at low angles. A similar though less pronounced effect occurs at 28MHz. On 18 and 24MHz the radiation is horizontally polarised and has its maxima broadside to the horizontal conductor.

To emphasise the advantage this compact antenna has over the inverted-V form of the ZS6BKW/G5RV at 14MHz, **Figure 4** shows the radiation patterns of both antennas in the elevation plane. The lower trace is that for the compact antenna. It will be noted how the inverted-V version radiates predominantly towards the zenith where the energy is,

TABLE1: Gain and radiation angles from band to band.

Band	Gain (dBi)	Azimuth	Elevation
7MHz	4.4	Omni	70°
14MHz	2.7	40°	15°
18MHz	5.6	90°	25°
24MHz	4.9	90°	15°
28MHz	6.0	55°	15°

TABLE 2: Comparison between the VSWR readings of the two antenna analysers.

Analyser 1					
f (MHz)	6.9	14.1	17.7	24.6	28.5
VSWR	1.7	1.5	1.5	2.2	1.5
Analyser 2					
f (MHz)	6.9	14.1	17.9	24.6	28.6
VSWR	1.3	1.5	1.5	2.2	1.5

essentially, lost. By contrast, the compact antenna produces its maximum gain at just 15° above the horizon and has a gain advantage, in some directions, of as much as 9dB over the inverted-V at that low elevation angle, which is ideal for DX operation.

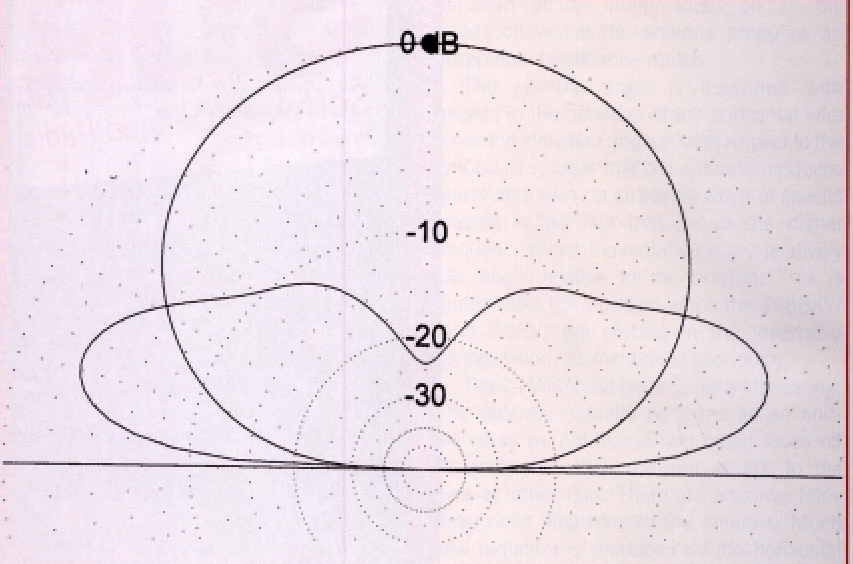

FIGURE 4: Comparison between the compact antenna and the full-size inverted-V form of the ZS6BKW on 14MHz. The lower trace shows the much lower radiation angle of the compact antenna.

The experiment

As always the crucial test of any fanciful idea is the practical assessment of its performance and an experiment to do this was a specific requirement of the design exercise. Carrying out such tests requires adequate space to erect the antenna-under-test (AUT in the jargon) so that it is sufficiently far from other objects and structures that might compromise its performance. This includes the means of supporting the antenna. Fortunately the computer is able to shed some light on that before one actually gets down to physically erecting the antenna. Supporting masts are simply included in the EZNEC model along with the antenna. After doing this it was discovered, unsurprisingly, that there is significant coupling between the two vertical wires and any parallel conductors such as poles or masts nearby. The effect of this is most noticeable at 7MHz, while being substantially less so above that. Clearly, this is a mutual impedance issue between the current-carrying vertical conductors and the nearby conducting masts which, in practice, may only be a very small fraction of a wavelength away. As the frequency is increased those distances now become larger, in wavelength terms, and the coupling is proportionately less. As one would expect, a quarter wavelength mast, 10m long, with its lower end buried in the ground in the normal way would couple most strongly because it is close to being resonant.

The solution is obvious. Use non-conducting masts (trees might be ideal), or insulate the mast from the ground by one means or another, especially if the mast is of near-resonant length at the lowest frequency on which the antenna operates. Since all this depends on personal circumstances no hard and fast rules can be laid down other than to warn that conducting supports, close to the antenna, may upset its performance.

For the experiments described here the antenna was erected between two telescopic, non-conducting poles with its centre held aloft about 9.5m above the ground on another telescopic insulated pole (see **Photo 1**). The two vertical wires were anchored to the ground, directly beneath the ends of the horizontal wire, by means of two ground stakes. The transmission line matching section, L2, was constructed as an open-wire line using insulated copper wire with spacing between the two conductors chosen to achieve a characteristic impedance Z2 of approximately 400Ω. Careful measurement indicated that it was 388Ω, which was quite acceptable. As important was the line's velocity factor (VF), which was also measured (see **Photo 2**). The average value from a number of measurements was found to be very close to 0.9. This was therefore the factor by which the original 13.4m electrical length of L2 was to be reduced in order to produce the best impedance match (and hence VSWR) on the five bands.

With the antenna pulled up to the maximum height of 9.5m, measurements of the impedance and VSWR at the input of L2 were made using an antenna analyser. Since two analysers, from different manufacturers, were available, it was a useful exercise to compare their readings. **Table 2** shows those measured results.

Based on these results some further analysis was done on the computer. By modelling the actual antenna as closely as possible and paying specific attention to its actual height above ground, the results shown in **Table 3** were obtained.

Allowing for the facts that the analysers were not specifically calibrated before use, the EZNEC model did not include any greenhouses and sheds beneath the antenna and that the assumptions made about the ground conductivity and permittivity may not have been valid for the particular test site in the Cheshire countryside, the agreement between the three sets of data is reasonable. It is apparent that the optimum frequencies are all slightly low relative to the low frequency limits of the various amateur bands. This can be corrected easily by making a slight adjustment to the length of the matching section L2. Shortening it by a few tens of mm at a time, and re-measuring the VSWR, will move those optimum frequencies higher. The predicted results shown in **Table 4** were obtained with a physical length of 12m for L2, based on its measured velocity factor of 0.9. This is equivalent to an electrical length of 12/0.9 = 13.3m, just slightly shorter than the 13.4m used originally in the computer model.

Only the 24MHz band fell outside the 2:1 VSWR target, though just marginally. Attempts to move it to within the 2:1 VSWR circle on the

TABLE 3: EZNEC predicted results of the compact antenna.

f (MHz)	7.0	14.1	17.9	24.6	28.5
VSWR	1.4	1.3	1.8	1.9	1.6

TABLE 4: EZNEC results for the modified antenna (top = 14.2m and ends = 7.5m at 9.5m height; L2 = 12m with VF = 0.9 and Z2 = 388Ω).

f (MHz)	7.1	14.2	18.1	24.9	29.0
VSWR	1.4	1.5	1.7	2.2	1.4

Smith Chart by adjusting L2 resulted in some of the other frequencies being compromised. However, most modern transceivers contain limited-range automatic antenna tuners; this marginally higher VSWR will easily be handled by that internal (or external) ATU and the full output of the transceiver should be realised. Matching on the other bands should not require the use of an ATU at all.

The need for a balun

This antenna, as well as its matching section of open-wire line, are electrically balanced, whereas the 50Ω coaxial cable generally used to connect that line to the transceiver is not. This means that it is advisable to use a balun between them. A 1:1 current balun is required and many suitable designs are available in the various handbooks and also online. One of the best is seen at **[5]**.

On air performance

Amateur radio in the 21st century functions alongside a proliferation of 'tools' mostly based on, or involving, the computer. One of those, which happened to be available at the test site (as was a convenient 100W transceiver), was the Reverse Beacon Network **[6]**, which provided almost instantaneous responses from suitably-equipped stations that received our test transmissions. NVIS propagation on 7MHz clearly favoured Europe while on both 14 and 18MHz (the only other bands that were 'open'); numerous reports came in from north America as well as some more exotic places such as Iceland. Given appropriate ionospheric conditions, QSOs are always possible. This compact multiband antenna immediately proved its worth and showed that it radiates at angles suitable for both NVIS as well as DX contacts on the higher bands.

Conclusions

This compact G0GSF version of the ZS6BKW antenna is an excellent compromise for those who (like the author) do not have the space to erect the full-size horizontal antenna. Even more important, though, is the improvement that results when compared with an inverted-V form of the ZS6BKW or the G5RV. This new compact antenna actually 'knocks spots off' its inverted-V rivals.

Acknowledgement

The enthusiasm shown by members of the Chester & District Radio Society to construct and test this new antenna is very much appreciated. My thanks must go to Bruce, M0CVP for making the antenna and its special matching section of open-wire line and to Steve, G6FDK for allowing us to use his excellent QTH for the tests. In addition, the assistance given by 2E0TPA, G0PJX, M3SHK and GW4OKT contributed, significantly, to a very successful operation. I also acknowledge my many discussions with Owen, VK2OMD (formerly VK1OD) on various aspects related to this antenna.

References

[1] Computer-aided design of a multiband dipole, B A Austin, *RadCom* Aug 1985

[2] An HF multiband wire antenna for single-hop point-to-point applications, B A Austin, *J IERE*, vol 57, no 4, Jul/Aug 1987. See www.mpoweruk.com/papers/GSRV_theory.pdf

[3] Highs and Lows of the ZS6BKW, B A Austin, *RadCom* April 2014

[4] Multiband inverted V antennas – the downsides, B A Austin, *RadCom* May 2017

[5] http://owenduffy.net/blog/?p=11489

[6] www.reversebeacon.net

Construction of the multiband dipole Feeder Section

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Brian Austin, G0GSF modified the design of his ZS6BKW antenna to produce a compact multiband version, described on the preceding pages. As President of Chester & District Radio Society, he suggested that it would be a useful and interesting exercise to build and trial such an aerial and it was agreed that the Society would do so.

The horizontal and vertical sections were simple enough to make from two lengths of wire 14.6m long, each terminated in a soldered ring terminal. The matching section of open wire feeder, the L2 section of the aerial, was more challenging. According to the design parameters, the impedance of the feeder needed to be about 400Ω so it was necessary to calculate the required spacing between the wires of the feeder, which is dependent on the diameter of the wire used. We developed a spreadsheet to give a guide to the required spacing in both tabular and graphical form; **Figure 1** shows the resulting graph. For the aerial under construction, a spacing of 20mm was chosen.

The material for the spacers was plastic strip 20mm wide and 3mm thick, purchased from a local hardware supplier. Two 2m lengths were cut into 40mm sections. Past experience had shown that fixing the spacers in position could be difficult. It was decided that this potential problem could be overcome by drilling two holes in the spacer for each wire and passing the wire through the first hole from the back of the spacer and then back though the second hole from the front of the spacer. Using this method the spacer is held firmly in place.

Having cut the two 2m long plastic strips into fifty 40mm long spacers it was necessary to drill the four holes in each spacer to accommodate the wire of the feeder and lock the spacers in place. A jig, the same size as the spacers (40mm x 20mm), was made in aluminium and the four holes of a diameter suitable for the wire of the feeder were accurately measured and drilled. Using this jig it was fairly simple to drill three spacers at once. **Figure 2** shows the constructional details.

The theoretical length of the feeder was calculated as 13.4m, assuming a velocity

PHOTO 1: General view of the feeder under construction.

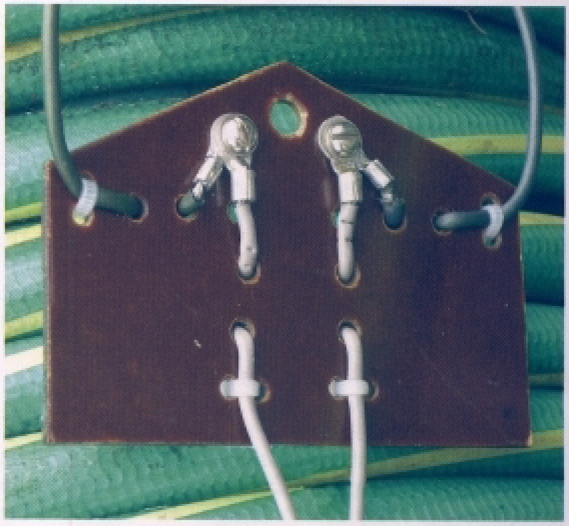

PHOTO 2: Close-up of how the feeder (bottom) meets the dark grey dipole wires via a small piece of Paxolin (SRBP) board.

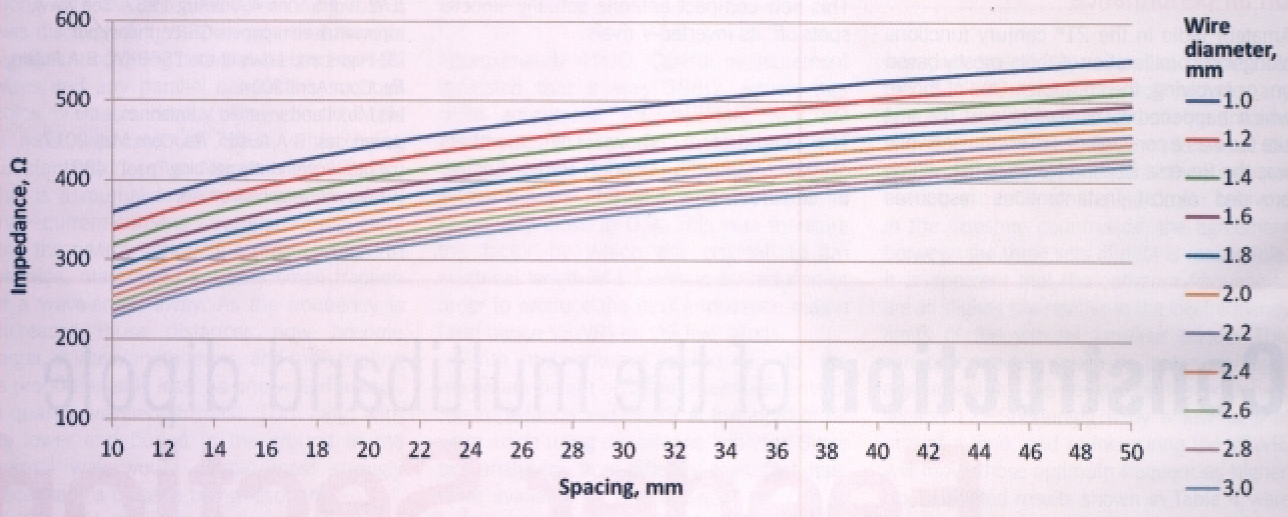

FIGURE 1: Graph of balanced line impedance vs spacing for various wire diameters. A spreadsheet of this data is available on request.

factor of 1. To make the feeder to be used in the trial two lengths of wire each 14m long were used, with the intention of trimming it to the required length when conducting the trial. The previously made spacers were then threaded onto the two wires of the feeder as described earlier to lock them in place, with care being taken to ensure that they were spaced along the feeder at intervals of about 300mm. This procedure is fairly time consuming but not difficult and is seen in **Photo 1**. The ends of the feeder wires to be attached to the aerial 'centre' were terminated with soldered ring terminals, permitting a simple connection to the aerial top, as shown in **Photo 2**. This also permitted simple disconnection to isolate the feeder when the time came to measure the actual characteristic impedance (Z2) and velocity factor. Z2 was measured and found to be 388Ω by using the standard technique of finding the input impedance with both short and open circuit loads and taking the square root of their product. This process is made easier if the line is about one eighth of a wavelength long. The velocity factor was measured and found to be very close to 0.9.

One end of the feeder was connected to the antenna with the other end free for connection to an antenna analyser as the trial proceeded.

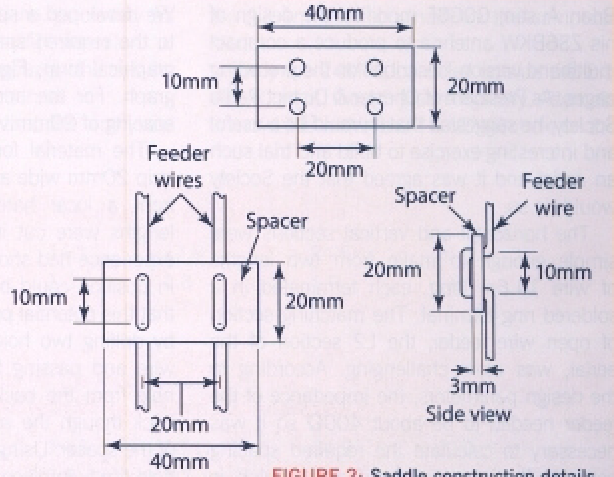

FIGURE 2: Saddle construction details.