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A multi-band inverted-V dipole for portable operation

PART ONE

In this first part of a two-part article, GM3VLB describes one of his latest designs, which has been tried and tested.

At the time of writing, the author had activated 148 islands, 136 of these in the last eight years for the SCOTIA (and IOSA) Scottish island award programmes (for further information, see his website **www.gm3vlb.com**). Operating time is generally limited, with most operations (many of which have been 'solo') being of 1 or 2 days' duration. The majority of Scottish islands are uninhabited, and often inhospitable. Landings may have to take place in a strong Atlantic swell, and from very small craft such as a dinghy or RIB. ('rigid inflatable'). The time-consuming assembly of complex rotary beams has heretofore never been considered. Likewise, any amplifier would necessitate both a larger and heavier generator and more fuel. Even if used in conjunction with a beam, such a setup would be unlikely to give more than a few dB gain over the Kenwood TS-50S running 100W into a well-matched inverted-V near the sea. In practice, it has been found that 50W ($^1/_2$ an S-point less at the receiving end!) is frequently adequate. Indeed, given reasonable conditions and 'split' operation, the use of QRP is a perfectly viable option. All Scottish island operations have used one or more of either short, loaded 'fishing-rod verticals' or inverted-V multi-band dipoles. This article looks more closely at the latter.

The principal advantage of the inverted-V dipole is that it requires only one, central, support. The main 'mast' used by the author is ex-army and comes in a convenient shoulder bag containing eight 1m long fibre-glass poles, two sets of guys (three at the centre and three at the top) and a simple pulley system (an ultra-light-weight version using a 'roach pole' has also been constructed). The mast is easily erected by one person, even in a howling Hebridean gale, and supports the antenna, which acts as a resonant $\lambda/2$ inverted-V dipole on each of the 20m, 40m and 80m bands. The antenna can also be used on the 15m band, where it behaves as a $3\lambda/2$ dipole ($3\lambda/2$ means 'one and a half wavelengths' – 21.150MHz is 3 x 7.050MHz, so $\lambda/2$ on 40m is $3\lambda/2$ on 15m.

A second, lighter, multi-band inverted-V covering 10m, 12m, 15m, 17m (and 30m with end extensions) supported at about 7m by a roach pole, is also available. (The author has recently tested another design of the same overall length as the 20/40/80m version, but with a slightly different configuration and in which the 20m dipole is $3\lambda/2$ long, giving a small, though useful gain on this band and with two additional main lobes, giving increased global coverage - see the Appendix next month for details.

As stated above, these antennas are complemented by a variety of multi-band verticals, most of which can also be used /M on islands with vehicular access.

Operating /P on the island of Killegray, Outer Hebrides.

BASIC DESIGN CONSIDERATIONS

The multi-band dipole is set-up in inverted-V configuration, ie the central feed-point is at the apex of the Λ at the top of the mast, with the two halves sloping down to points about 60cm (2ft) above the ground. On 20m and 40m, it is designed to be *resonant* mid-way between the IOTA CW and SSB frequencies generally favoured by island operators and (corresponding in this case to 14.150MHz and 7.050MHz). On 80m, the design frequency is 3.772MHz. A switched linear balun transformer at the feed-point (giving a choice of two ratios, either 1:1 or 2.25:1) allows impedance matching as well as unbalanced coax-to-balanced dipole operation. The feed-line consists of a 13.6m length of 50Ω RG-58 coax (75Ω coax was used, unwittingly, for several years - see below). This is a velocity factor-corrected half-wavelength on 40m, two half-wavelengths on 20m and three on 15m. On these bands, the coax simply reflects the impedance at the load end – in this case, the input to the balun. On 15m, 20m and 40m, this is reasonably close to 50Ω, thus providing a good match to 50Ω coax and thence to the TS-50S.

On 80m, at a height of only 8m (0.1λ), the textbooks would suggest an input impedance of only a few ohms. In practice, it would seem to be quite a bit higher, and can approach 50Ω. However, at the time of the early experiments, the author did not possess an antenna analyser. A lower value of around 20Ω was therefore assumed (had the physics teacher not repeatedly said "Never *assume* anything boy!"?). A 2.25:1 balun was designed to raise this to nearer 50Ω to provide a better match for the coax and the TS-50S. When the system was tested using this balun, the VSWR was, indeed, as predicted. Switching over to the 1:1 balun resulted in an unusable VSWR! All worked perfectly - except the maths!

One day, some years later on the island of Rum, a coax fault occurred. The spare coax was installed. Result? High VSWR on 80m! With the help of island partner Alex, GM0DHZ, and whilst battling the most intense infestation of midges ever experienced, everything was tried and tested…to no avail.

Later, whilst repairing the faulty coax, it was noticed to be of slightly larger diameter. It had been made from a length of RG-59 salvaged from the author's 5Z4 days in the π-output 1960s! It was 75Ω coax and *not* 50Ω as originally thought!

So why did it work? Well, it's amazing how you can 'prove' something with the wrong mathematics! Now, by working backwards, and applying what was believed to be the correct quarter-wave transformer formula, but the terms of which had been inadvertently transposed, the actual antenna impedance had been 'proved' to be 33.75Ω – this had seemed entirely reasonable!

In fact, no-one had challenged this 'proof' until a few weeks ago when Dale, WB6BYU, in Oregon e-mailed me saying (ever so diplomatically!): "You're wrong mate! The formula should be: $Z^2_{coax} = Z_{load} \times Z_{rig}$.

If we again work 'backwards' using Z_{rig} = 50Ω and Z_{coax} = 75Ω, we get

FIG 1 © RADCOM 432

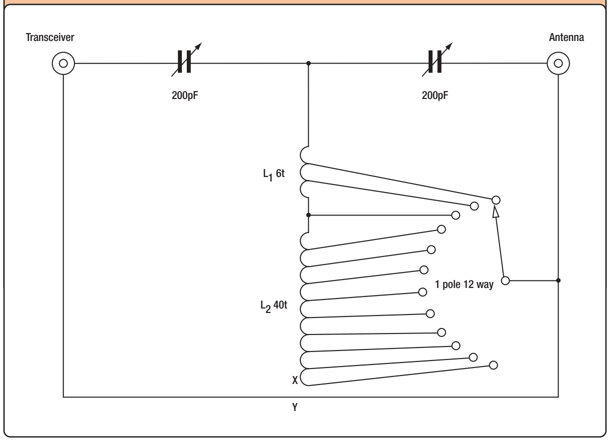
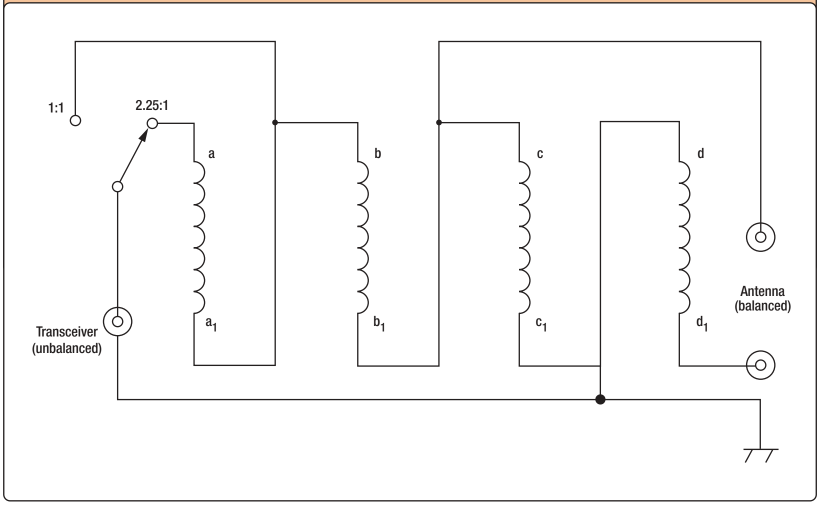


FIG 2a © RADCOM 433



Z_{load} = 112.5Ω.

Remembering our 2.25:1 balun, the antenna input impedance must in fact be 112.5/2.25 = 50Ω!

WB6BYU said that his own experiments indicated the input impedance *was* nearer this value and, if this was the case, all that was required was to use the 1:1 balun and 50Ω coax! This, in fact, is the case! This just shows that you shouldn't always believe what you read! Thanks, Dale...

ATU OR NO ATU?

Clearly, the antenna system is resonant and matched and an ATU is therefore not normally required on any of these bands (ie 15m, 20m, 40m or 80m).The author is basically 'anti-ATU', but does carry a very small homebrew T-match ATU consisting of two 200pF semi-variable capacitors, modified to have a shaft, and a switched 40-turn toroid + 6-turn fixed coil assembly – this is primarily used to tweak the GM3VLB multi-band fishing rod verticals which are also essentially resonant. See the ATU photograph.

Details of the ATU

Referring to **Fig 1**:
L1: 25mm diameter, 6t of 16SWG tapped at 2, 4 and 6 turns.
L2: T130-2 toroidal core, 40t of 18SWG, tapped at 2, 4, 7, 10, 14, 19, 25, 32 and 40 turns.
NB: Do *not* be tempted to connect x to y as this creates shorted turns which are not permissible when using toroidal cores.

CONSTRUCTION OF THE BALUN

Although now superfluous, the design and the construction details for the dual-ratio balun are included, as it may prove a useful accessory when attempting to match other balanced antennas. It is built into a standard 75 x 50 x 25mm ABS box (see diagrams and the photograph). Three eyes are screwed into a piece of thick (7 or 8mm) plastic in the top half of the box. One eye is for the pulley, and the other two for the dipole legs. The box contains the switched balun, consisting of a quadrifilar winding on a ferrite rod approximately 6cm long, a SPDT miniature toggle switch and a BNC socket with weather shield (the author uses a plastic bottle top). Brass bolts with wing nuts protrude through the back of the box to accept the 'spade' ends of the dipole. Inside the box, the connections are soldered to the heads of the bolts to reduce the risk of corrosion and/or poor contacts.

Fig 1: Circuit of the mini-ATU.
Details:
L1: 25mm diameter, 6 turns / 16SWG tapped at 2, 4 & 6 turns.
L2: T130-2 toroidal core, 40 turns / 18 SWG tapped at 2, 4, 7, 10, 14, 19, 25, 32 & 40 turns.
NB: Do *not* be tempted to connect X to Y as this creates shorted turns which are not permissible when using toroidal cores.

Fig 2: Wiring details of the quadrifilar dual-ratio balun.

Fig 3: Constructional details of the balun.

Fig 4: Details of the antenna.

Fig 5: Insulator construction.

Right, top: The mini-ATU.

Right, middle: The switched dual-ratio balun.

Right, bottom: One of the insulators.

Winding the Balun

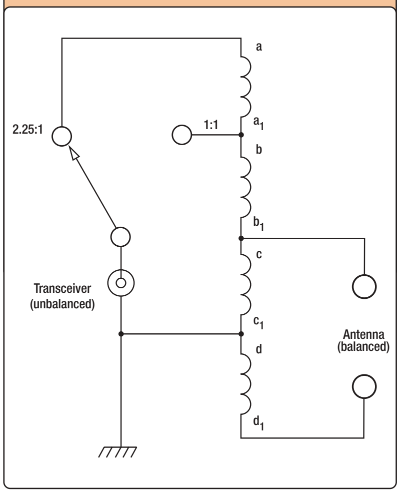
Fig 2 shows the circuit diagram of the dual-ratio balun, and **Fig 3** the constructional details. Stretch four 45cm lengths of enamelled 20 or 22SWG copper wire from a vice to remove any kinks. (different colours are ideal). Twist these together about eight times. Wind eight turns onto a 10mm diameter ferrite rod, about 6cm long (perhaps salvaged from a transistor radio?), holding the ends in place with tie-wraps (for example).

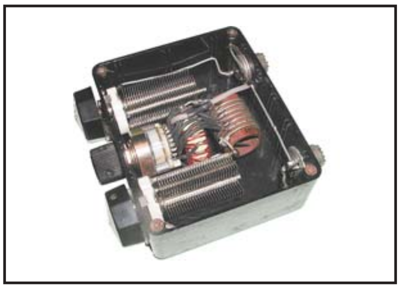
With tag-strip fixed to the ends on the windings (not shown), use further enamelled wire to make three links between a_1 and b, b_1 and c, and c_1 and d (make these links as short as possible). All links and joints should be soldered – do not rely on purely mechanical connections.

Construction of the dipole legs

There are two insulators (see the photograph and **Fig 4**) on each leg, made from suitable plastic (test in a microwave oven first!) about 60 x 20 x 5mm, each with a hole at each end to take a small S-hook attached to the small strain-relieving thimbles (**Fig 5**) at the ends of each element. A central brass bolt and wing nut allows a particular element to be connected or not (a plug and socket arrangement, or $^1/_4$in spade connectors could also be used). The lower ends of the 20m and 40m elements are soldered to the heads of the bolts whilst the upper ends of the 40m and 80m elements have 13 – 15cm 'tails' with U-shaped tags to fit under the wing-nuts. The thimbles can be pro-

FIG 2b © RADCOM 434





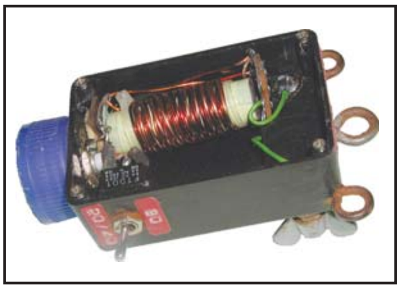


FIG 3 © RADCOM 435

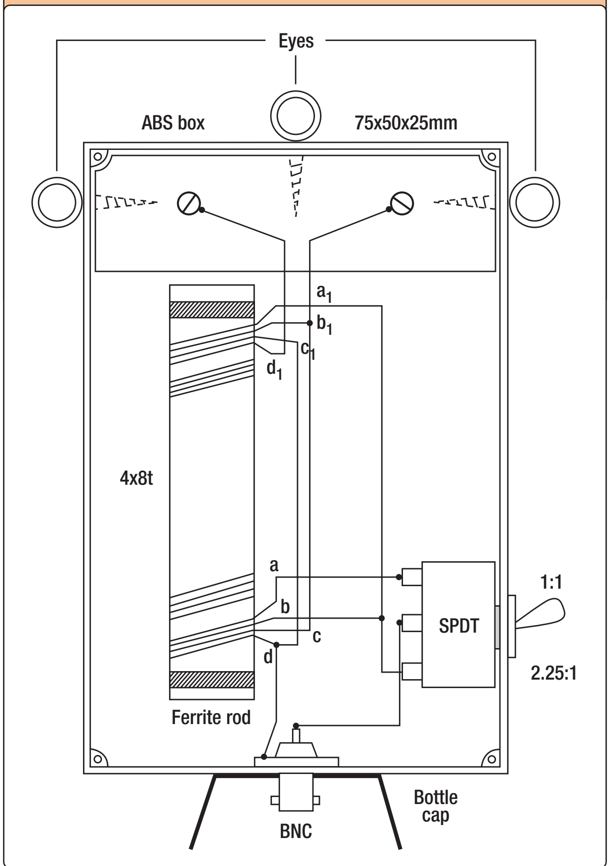


FIG 4 © RADCOM 436

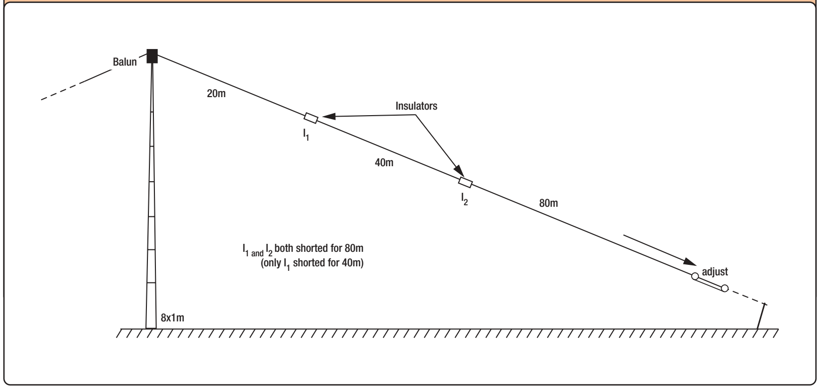
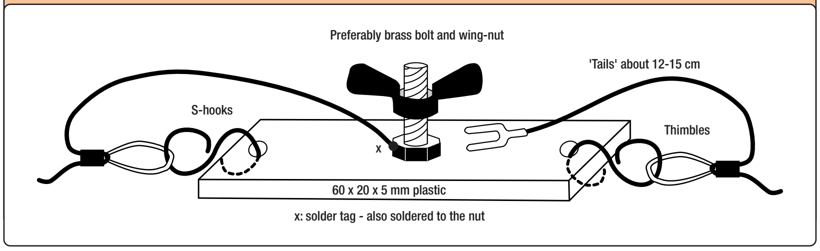


FIG 5 © RADCOM 437



fessional, metal or plastic, or can be otherwise improvised.

Band changing is simple – simply lower the dipole, disconnect the unwanted segment(s) and hoist the aerial up again - two minutes at most!

NEXT TIME…

GM3VLB looks at the numbers behind the design, the nature of the ground and the height of the antenna ends above it. Dimensions are given for the bands in use. ♦

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A multi-band inverted-V dipole for portable operation – PART TWO

In this concluding part of a two-part article, GM3VLB considers the dimensions of his inverted-V for several bands.

Before giving the dimensions for the inverted-V, here are some fundamental considerations.

(1) Length of a λ/2 dipole

Readers will be familiar with the following rule of thumb formulae which apply to *horizontal* dipoles either in free space or at least a half-wavelength above ground. If f is the design resonant frequency in MHz, we have the situation represented by **Equation 1**.

In practice, the length is shorter than this due to the so-called 'end-effect' of the insulators and their supports. **Equation 2** gives the physical situation.

Each leg of a λ/2 horizontal dipole is thus half of this, or 71/f metres long. For example, for a λ/2 dipole resonant on or about 14.150MHz , the length of each will be 71/14.15 or 5.02m (16ft 5in). This is about 0.95 of the free-space length of 5.30m (17ft 5in).

Thus, the relation of the physical and free-space lengths are related by **Equation 3**.

However, what is generally not made clear in the literature is that, as the ends are lowered towards the ground into what is known as inverted-V configuration, the resonant frequency *drops* – the antenna becomes too long! To maintain the original resonant frequency, the length of the inverted-V must therefore be *reduced*. This is probably the cause of much head scratching when trying to tune inverted-Vs. The author's experiments on inverted-V dipoles suggest the empirical formula given in **Equation 4**.

It is regrettable that the literature does not make this clear.

(2) Effect of height of the ends above ground

The above figures are not 'cast in stone'. They are very much dependent on the resonant frequencies chosen, the height of the mast and the 'apex half-angle', all of which in turn determine the height of the end insulators above the ground. In the author's case, with the frequencies chosen, a mast height of 8m and an apex half-angle of 68°, the end insulators of the 20/40/80m inverted-V are about 60cm (2ft) above ground.

Doubling the height of the end insulators above ground to 120cm (4ft) *increases* the resonant frequency to 3.830MHz (an increase of about 1.8%), whilst *lowering* them by 60cm (2ft) to ground level *lowers* the resonant frequency to 3.690MHz (this time a decrease of about 1.8%). It is apparent that the 80m antenna can be fine-tuned by increasing or decreasing the height above ground of the end insulators (achieved by longer or shorter cords).

The author feels this is another aspect of inverted-V antennas (with end insulators close to the ground) which is rarely, if ever, made clear. (Note: In each case, we are changing the capacitance of the antenna ground. Bringing the ends closer to ground increases the capacitance, thus decreasing the resonant frequency, and *vice versa*). There is negligible effect on 20m and 40m.

(3) Nature of the ground

The figures derived in this article refer to 'average' ground, if there is such a thing. Experience suggests one should, where possible, avoid solid rock, sand or severe undulations in the line of the antenna. Sometimes, however, choice is not an option, and variations in proximity to ground and in its conductivity, may affect the resonant frequencies and input impedances, and have, on occasion (rarely, fortunately), caused some serious head-scratching!

(4) Dimensions

Table 1 gives the lengths of each leg of a 20/40/80m inverted-V dipole. These lengths are the distances between the fixed end-points (in effect, the wing-nuts, or in the case of the lower end of the 80m segment, the centre of the end insulator). The 20m- and 40m-band frequencies are based on the average of the IOTA CW and SSB frequencies for the 20m and 15m bands, respectively.

As previously stated, the 15m band is available on the 20/40/80m version by using the 40m dipole as a 3λ/2 dipole for 15m. Similarly, the 20m dipole has been used (40/80m disconnected) as a 3λ/2 dipole on

Equation 1

$$\text{Free-space total length of a } \lambda/2 \text{ horizontal dipole} = \frac{492}{f}\ (\text{ft}) \text{ or } \frac{150}{f}\ (\text{m})$$

Equation 2

$$\text{Physical total length of a } \lambda/2 \text{ horizontal dipole} = \frac{466}{f}\ (\text{ft}) \text{ or } \frac{142}{f}\ (\text{m})$$

Equation 3

$$\text{Physical length of a horizontal dipole} = 0.95 \times \text{free-space length}$$

Equation 4

$$\text{Physical length of a } \lambda/2 \text{ inverted-V dipole} = 0.91 \times \text{free-space length of a } \lambda/2 \text{ horizontal dipole}$$

Equation 5

$$\text{Length of each leg of a } 3\lambda/2 \text{ inverted-V dipole} = \frac{212}{f}\ (\text{m})$$

10m, by adding about 2.4m each side and allowing these additional lengths to hang freely from the 20/40m insulators.

Table 2 gives the lengths of each section in each leg of the 10/12**/15/17/30m version of the multi-band inverted-V.

CONCLUSIONS

This form of inverted-V allows multi-band operation with one antenna from portable locations. It might be argued that it is perhaps not quite so convenient for the home location. This said, how often is rapid and frequent band changing required, even at home?

The author (together with 'Island' partners Alex, GM0DHZ, and Keith, MM0BPP,) has made over 100,000 QSOs from a great variety of island locations. With the inverted-V described, he has never needed to use an ATU, other than in exceptional circumstances such as an antenna system fault (broken conductor, or corrosion, or in an extremely adverse location. A site near the water (ideally *over* the water) and close to the landing point is always chosen in preference to height above sea level. Apart from anything else, the latter reduces the distance the equipment has to be carried.

The formulae and dimensions proposed are the result of much experimenting and experience. They appear valid whether the antenna is near the sea or far removed from it, and represent a good starting point for anyone contemplating putting up an inverted-V. There is no doubt that such an antenna will out-perform a horizontal dipole whose centre may be sagging well below the height of the end supports, an unfortunately all-too-familiar sight. If using a 10 to 17m inverted-V, ensure that the apex angle is *not less* than 110° (with the 20/40/80m version atop an 8m mast, the apex angle will generally be greater than 130°). In limited space, one can 'swing the ends round' slightly.

FINALLY

In his past life as 5Z4KL in the 60s and 70s, the author frequently and successfully used the ubiquitous G5RV, in its familiar form using 300Ω ribbon cable and 75Ω coax, always in inverted-V configuration, and often in the bush at heights as low as 6ft above the ground. Valved rigs were very forgiving – not so today's solid-state 50Ω output rigs and amplifiers. Prior to using a G5RV dipole as a multi-band antenna, you would be well advised to read the work done by ZS6BKW (see *Practical Wire Antennas*, by John Heys, G3BDQ) on improving this antenna, and the reasons for doing so. This book also gives guidance on the design of a doublet – arguably a far better multi-band alternative for the solid-state home station – using G5RV's own dimensions, chosen to avoid unwieldy reactances.

APPENDIX – a new configuration

Since drafting this article, the author has tested another configuration for the 20/40/80m version of his multi-band inverted-V dipole. It occurred to him that, by making the innermost dipole the 40m one, the next 'segment' could be used to extend this to a 3λ/2 (three half-wavelengths) on 20m. The length of the third segment on each side is adjusted accordingly to allow resonance as before on the 80m band. Dimensions are given in **Table 3**. ♦

Table 1: Lengths of each leg of an inverted-V dipole.

Band (m)	Chosen design frequency (MHz)	Balun switch position	Feedline (13.6m of 50Ω coax)	λ/4 (68/f, m)	'extra' length in each case (m)
20	14.150	1:1	2λ/2	4.81 (15ft 9in)*	
40	7.050	1:1	λ/2	9.65 (31ft 8in)*	4.84 (15ft 11in)
80	3.772	1:1	λ/4 txfmr	18.03 (59ft 1in)*	8.38 (27ft 5in)

* These are lengths on either side of the feed-point – the overall length is double this.

Table 2: Lengths of each section in each leg of the 10/12/15/17/30m version of the multi-band inverted-V.**

Band (m)	Chosen design frequency (MHz)	Balun switch position	Feedline (13.6m of 50Ω coax)	λ/4 (68/f, m)	'extra' length in each case (m)
10	28.250	1:1	4λ/2	2.41 (7ft 11in)	
12**	[24.940]	1:1	~7λ/4	[2.73] (8ft 11in)	[0.32] (1ft 0in)**
15	21.150	1:1	3λ/2	3.22 (10ft 7in)	0.81 (2ft 8in)
17	18.113	1:1	~5λ/4	3.75 (12ft 4in)	0.53 (1ft 7in)
30	10.125	1:1	~ 3λ/4	6.72 (22ft 0in)	2.97 (9ft 8in)

** In practice, the extra length (with its own 'U' spade terminal) for the 12m band (relative to 10m) is taped to the side of the 15m section and the appropriate spade terminal is connected to the end of the 10m section depending on whether 12m or 15m is selected.

Table 3: Dimensions for the 20/40/80m version depicted in Fig 6.

Band (m)	Chosen design frequency (MHz)	Balun switch position	Feedline (13.6m of 50Ω coax)	λ/4 (68/f, m)	'extra' length in each case (m)
40	7.050	1:1	λ/2	9.65m (31ft 8in)	
20	14.150	1:1	2λ/2	14.98m (49ft 2in)#	5.33m (17ft 6in)
80	3.772	1:1	λ/4 txfmr	17.91m (58ft 9in)##	2.93m (9ft 7in)

\# NB: The length of the 3λ/2 dipole is greater than 204/f (3 x 68/*f*). This is because the shortening due to end-effect affects only the outer 1/2-wavelengths of the 3λ/2 dipole. The *ARRL Antenna Handbook* suggests that the length of a *horizontal* 3λ/2 dipole is about 442/*f* metres rather than 426/*f* (3 x 142/*f*). In the absence of any accurate, theoretically-based formula, the author applied simple proportion and predicted an empirical value of 212/*f*. This gave a length of 14.98m for each leg of the 3λ/2 inverted-V dipole, which is indeed almost exactly the value of the length he obtained by experiment! The author would therefore suggest the use of **Equation 5**.

\## The additional length for 80m resonance is about 4in less than predicted by the 1/2-wave formula (68/*f*) previously proposed. This is negligible on 80m. In any case, the ends of the 80m dipole are folded back on themselves approximately 40 - 50cm (18in) to allow precise adjustment of the 80m resonant frequency *in situ*. The author passes the wire through one half of a twin terminal block connector (preferably with brass screws), then through the egg (or other insulator) and back into the connector block. This allows easy adjustment, without cutting the surplus wire.

FIG 6 © RADCOM 450

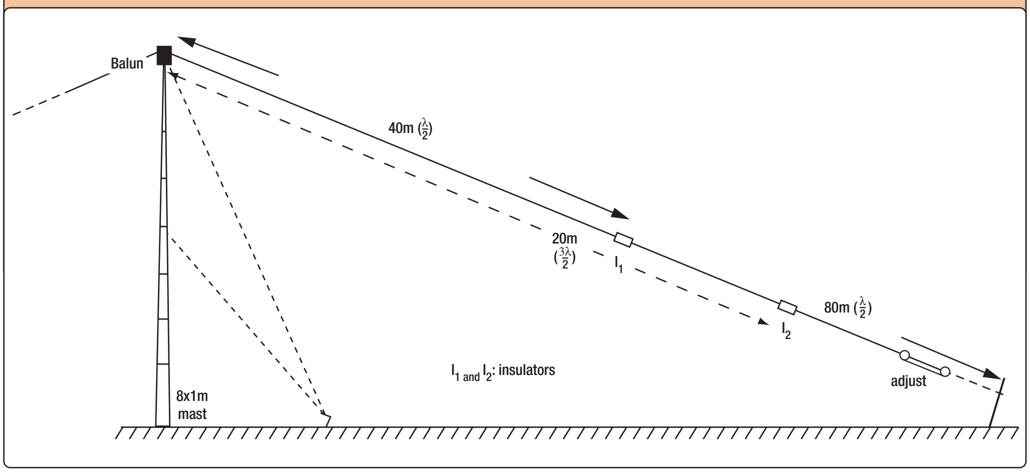

Fig 6: Alternative configuration for the 20/40/80m antenna, which is 3λ/2 on 20m.