RADCOM CONSTRUCTION FEATURE

All-Band Beam Antennas

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SMALL BEAM ANTENNAS

THE NEED FOR BEAMS capable of operating on four, five or even six bands, instead of the usual three, is becoming urgent as more of us seek refuge on the new (WARC) bands from QRM on the old ones. The new bands are narrow and as they fill up beams will become of special importance for those of us here in the UK. This is because most of our DX is to the west whereas QRM comes mainly from, or is caused to, stations in the east, being therefore in large measure preventable.

Unfortunately, this creates a major problem which cannot be resolved by beams designed on conventional lines. Traps have losses which, together with other design problems, escalate rapidly as the number of bands increases. Stacked beams suffer from interaction between elements which can lead to even worse problems, and log-periodic antennas are beyond the reach of most of us because of size, weight, cost and visual impact, as well as being inefficient in terms of gain for a given boom-length.

Continuous tuning of beam elements by means of servo-controlled capacitors has been suggested by the author [1]. However, this awaits new engineering developments and is unlikely to appeal to those looking for a simple answer compatible with the sort of constraints under which most of us have to operate. This would appear to leave as the only choice the use of loops or dipoles fed with open-wire lines operating in a resonant mode.

Open-wire lines tend to be viewed with disfavour, but objections seem to be based in part on misconceptions [2] and tend also to be waived in the case of the G5RV antenna to which the proposals herein bear some resemblance. It is of interest also to note that a typical open-wire line operating at an SWR of 20 has less loss than matched coaxial line of the same length, and important advantages follow from the fact that each element is required to have its own feeder so that all tuning can be carried out in the shack.

This affords a way of escape from bandwidth and other constraints with which conventional beams are afflicted. Also, because the beam is reversible, it is often possible to use simple and inexpensive methods of beam rotation.

Essential features are the use of feeders capable of operating efficiently at high values of SWR in conjunction with elements designed to radiate efficiently over the desired range of frequencies. The choice is restricted by the need to ensure that, at low frequencies, losses are negligible compared with the radiation resistance and, at the higher frequencies, energy is not wasted in the form of unwanted modes of radiation.

The superiority in these respects of the small delta loop (SDL) element **(Fig 1)** is convincingly demonstrated by **Figs 2 and 3**. Further advantages of the SDL array include a wide choice of methods of construction, some of which result in effective heights considerably in excess of the mast height; alternatively SDL arrays can be recommended to those looking for an 'invisible' antenna though, in a few cases, dipoles or some other shape of loop may be more suitable. Such exceptions and the use of 300Ω feeder are discussed later but in the meantime it should be noted that arrays based on the SDL in its simplest form as illustrated by Fig 1 are essentially compromises in which, at some cost in terms of operating convenience, complications have been removed from the antenna and transferred to the shack where they are easier to deal with.

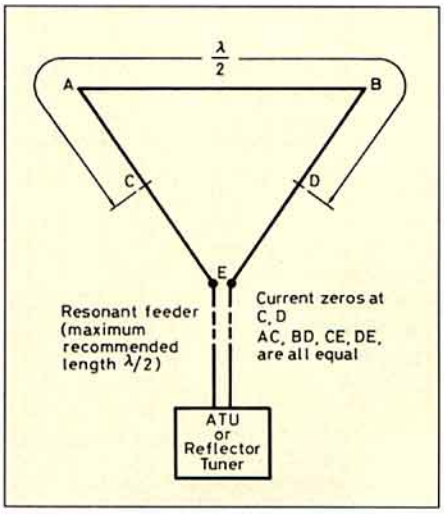


Fig 1: Original version of the Small Delta Loop. The distinctive feature is placement of the nulls in the centre of the sides in the case of the lowest frequency band (the 'main design frequency' or MDF) so that all radiation comes from the top. Reflector and driven elements are identical, tops being spaced about 11ft for 14MHz and the bottom corners brought in towards each other. The position of the zeros is not critical.

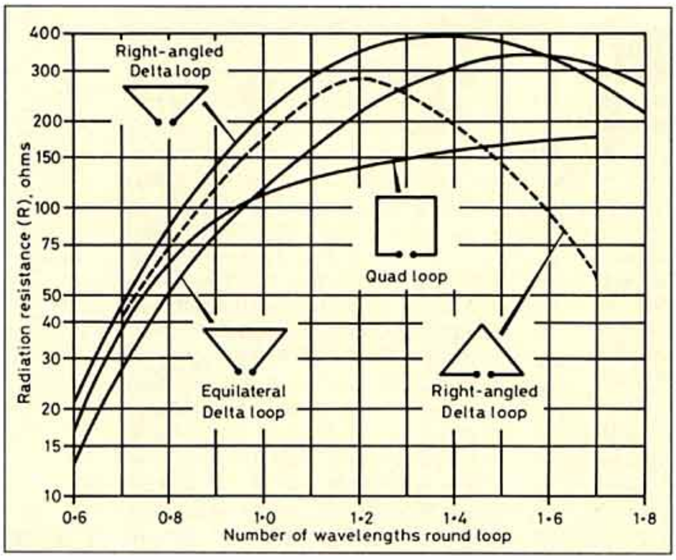


Fig 2: Variation of R with Loop size. R is radiation resistance as perceived at top centre, and size is measured in wavelengths of circumference. Values are approximate based on method described in Ref [1], p9.

Because of relatively large values of radiation resistance (R) there are few problems at the high frequencies. However, at the frequency assumed for the purpose of Fig 1, hereafter referred to as the main design frequency or 'MDF', the value of R (already low) is roughly halved by the transition at the bottom corner of the loop from a relatively high self impedance to the 600Ω of the line.

Any major change of operating frequency makes it necessary to retune, and tuning components will be subjected to somewhat larger currents and voltages. Despite this, it has been found possible, using short feeders, to work at frequencies well below the MDF.

For example a 21MHz loop will work efficiently at 18MHz, and improved versions described below can even be pressed into service on 14MHz subject to a slight loss (about 2dB) and the imposition of greater demands on the operator, such as the need for more frequent retuning in the event of QSY. At even lower frequencies, superdirective operation [3], which can be broadband, is possible for reception, switching to a vertical monopole mode for transmission.

EVOLUTION OF THE SDL ARRAY

THE FIRST VERSION OF the SDL array, based on Fig 1, has progressed through several stages of development which remain as useful options, leading up to 'impedance-transforming' systems which improve bandwidth, extend the frequency range, and ease constraints in respect of feeder length and type. Though originally conceived as an further improved version of the author's 'improved VK2ABQ', the present proposal also exploits features of the G5RV antenna together with favourable multiband properties of apex-fed delta loops.

In the case of the VK2ABQ, end portions of elements are bent inwards and act as capacitive end-loading for the centres thereby enabling them to radiate efficiently in spite of short length. At the MDF, the top halves of the sides of the SDL perform exactly the same function but, because they are bent towards the centre, radiation from them would be subtracted from the total. This would reduce the radiation resistance to an inconveniently low value were it not cancelled by that from the lower half of the sides.

In effect, one can regard the top side of the delta as a short end-fed dipole with capacitive loading. There is high impedance at the feedpoint which requires the use of high impedance feeder. This, apart from lower losses, avoids extremes of mismatch resulting from transitions between low and high Z_0 in 'worst case' situations which are bound to arise in attempting to cover a wide range of frequencies. It remains important to keep the SWR as low as possible, and guidelines provided by Figs 1 and 2 are supplemented by **Table 1** which includes a set of dimensions in current use.

It should be appreciated that a front-to-side ratio of 5dB compares favourably with a figure of 6dB for dipoles assuming a typical radiation angle of 30°, but there is also a small power loss amounting to about 0.6dB. The optimum placement of nulls is affected by a number of design details but is not critical. At 14MHz, a spacing of about 11ft between the top of the loops of a 2-element array ensures maximum gain whilst keeping R as high as possible, but the lower corners should be brought in towards each other to improve coupling. At the higher frequencies, the spacing should be reduced as a result of radiation taking place from the whole of each loop instead of only the top. **Fig 4** illustrates the close resemblance of the SDL in plan view to the 'improved VK2ABQ' and helps to explain deep endwise nulls usually observed at the MDF.

Loops as shown in Fig 1 require the addition of about 0.15λ of 600Ω line to bring them to resonance. As these stubs are fairly short, the halving of R noted above has little effect on performance provided feeders are matched into them. A problem was that half-wave extensions initially used to allow matching at ground level to much longer lengths of 600Ω line resulted in a loss of 1dB and the SWR bandwidth was halved to a mere 100kHz. This was overcome by using relays for switching stubs as shown in **Fig 5**. This resulted in acceptable performance but, because of high RF voltage at the relays, operation at frequencies below the MDF was ruled out.

An alternative to the stubs is to tune the loops to resonance at the MDF with series inductance at the lower corners. This results in the impedance being stepped up instead of down, but also increases the SWR at 18 and 21MHz due to large reactances being concentrated near points of maximum current. To prevent this becoming a problem in some instances, eg with smaller loop sizes, the inductances may be replaced by helical loading of the lower halves of the sides.

Bandwidth can be improved by using tubing elements formed into delta loops by end-feeding each element with thin wires. Several beams of this type have been constructed for use on one, two, or three bands and this implies the feasibility of converting most small Yagi arrays into SDL systems giving four or five band operation and improved performance. Any traps should be short-circuited, and to avoid problems with guy ropes the feed wires (18 to 21SWG) could be taken upwards to a lightweight T-shaped 15ft mast extension and from there dropped down as open wire lines at least as far as the boom. An element length of about 24ft is suggested but not critical.

The impedance-transforming loop (ITL) **Fig 6** is seen as an important step forward which, as recorded elsewhere [4,5], came about by accident as a result of seeking an explanation for some odd behaviour of a loaded folded dipole. Two-element arrays based on loops of a similar type were in use as the main antenna at G6XN for over four years. The main advantages being the ability to use long feeders without reduction of bandwidth and the achievement of efficient operation at frequencies well below the MDF by dragging the current zeros up into the loops away from the bottom corners. This reduces the mismatch and increases R, allowing 14 and 21MHz arrays to operate down to 10 and 14MHz respectively with estimated losses of less than 2dB, subject to use of short feeders or the provision of matching close to the antenna.

At the MDF, each loop consists of a stacked pair of l/2 dipoles. This adds up to an electri-

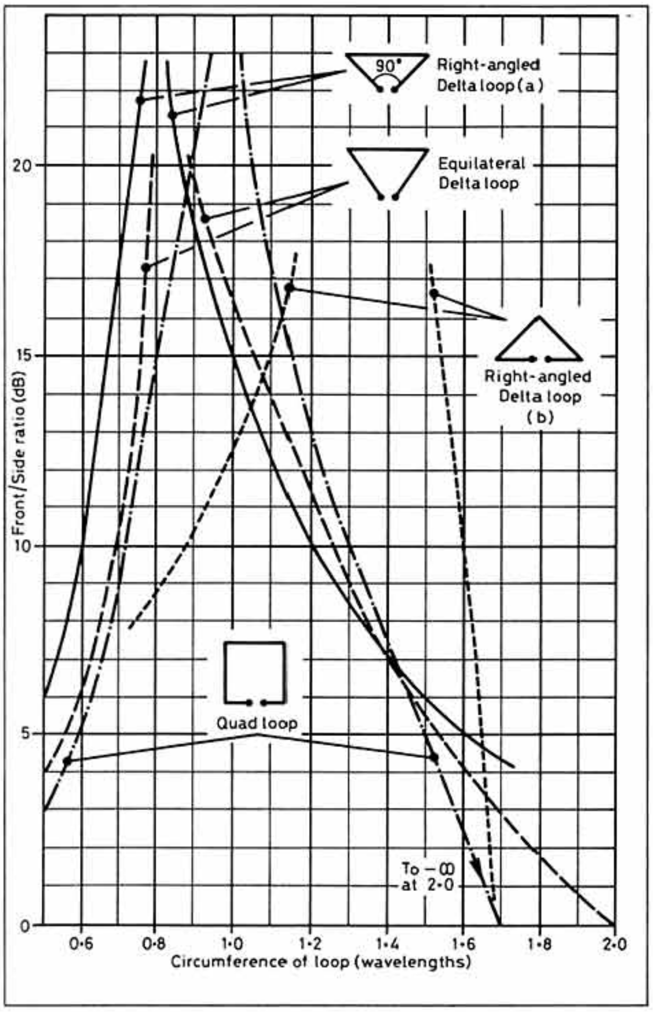


Fig 3: Variation of front:side ratio with loop size.

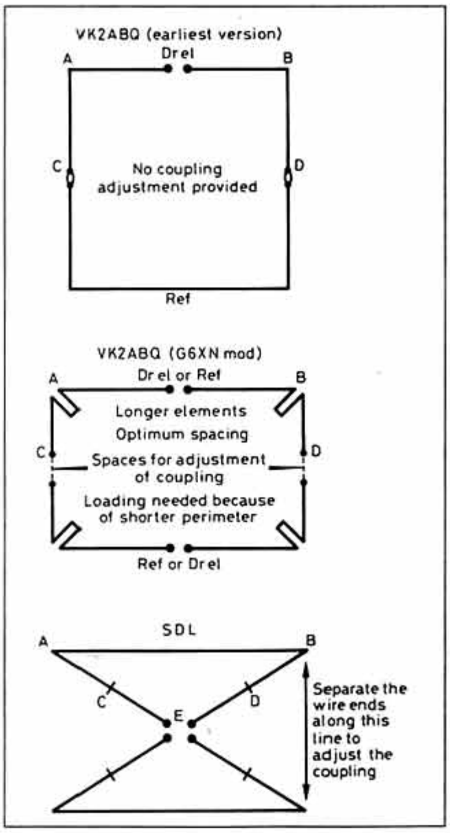


Fig 4: Plan views illustrating relationship between the VK2ABQ and SDL antennas. Lettering indicates corresponding points.

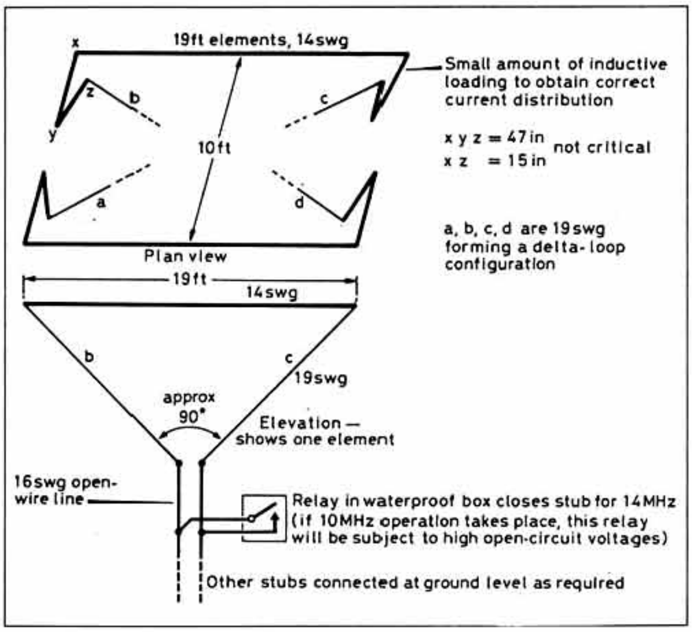
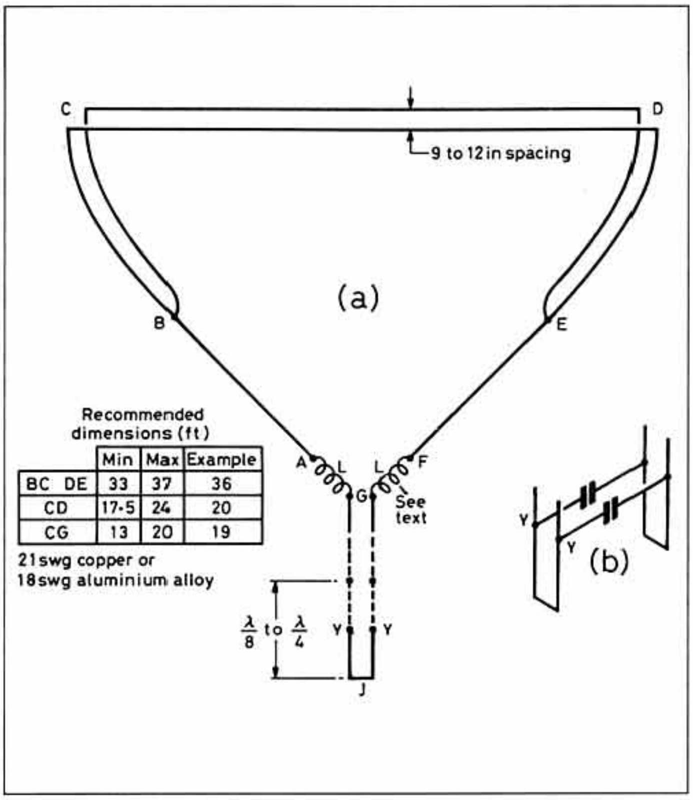


Fig 5: Early example of an SDL array using relays to switch in matching stubs at the MDF in order to permit the use of long feeders. Loading inductances at bottom corner as in Fig 6 avoid the need for relays (except possibly at ground level for 18 or 21MHz, see text).



Recommended dimensions (ft)

	Min	Max	Example
BC DE	33	37	36
CD	17·5	24	20
CG	13	20	19

21swg copper or
18swg aluminium alloy

Fig 6: Example of ITL Principle applied to the Claw antenna. Inset shows basic circuit for adjustment of coupling but see text for alternatives.

cal full-wavelength as in the case of a quad but physically much smaller because of inductive loading of the lower dipole.

The upper dipole uses two wires in parallel to achieve a low value of characteristic impedance Z_1, a higher value Z_2 being applicable to the lower dipole. This results in transformation of R to a higher value $(Z_1/Z_2)^2R$ at the bottom corner of the loop for presentation to the feeder.

In this case, because the unloaded dipole does most of the radiating, efficiency and bandwidth are not adversely affected by the loading. The current in the lower dipole is reduced in the ratio $\sqrt{(Z_1/Z_2)}$ which further helps to ensure negligible losses.

Table 2 compares a number of options, using figures calculated with the help of the Smith Chart from Fig 2, assuming values of 500 and 1000Ω for Z_1 and Z_2 respectively. Though suitable only as a rough guide they are in line with practical experience covering a large number of different constructions and demonstrate several interesting possibilities.

THE MINICLAW

FIG 7 SHOWS A SMALLER version of the Claw antenna designed for an MDF of 21MHz. Apart from the obvious attraction of smaller size, goals included better directivity on 28MHz and the reduction of losses on 18MHz by means of loading stubs at A and C, and the use of a heavier wire gauge for the lower dipole ABC.

The stubs have the effect of dragging the current zeros further up into the loop at lower frequencies whereas, at the MDF, being located at the zeros they leave the current distribution unchanged.

Following storm damage to the Claw the smaller antenna was pressed into service on 14MHz at a few minutes' notice, though apart from an earlier version fed with 600Ω line it had not previously been tried on this band. Used instead of the Claw for daily contacts with VK over a period of several months it was found to be only slightly worse, half the difference (4dB) being attributable to lower height. Coupling between elements needed no correction and front:back ratios were typically in excess of 20dB.

SINGLE-WIRE ELEMENTS

IT HAS TO BE CONCEDED that some readers will be deterred by the relative complexity of the ITL or, like the author, will be unable to arrange easy access for repairs. To ease the situation as a temporary measure the two wires of Fig 6 were replaced by single lengths of 20SWG enamelled copper, retaining the loading inductances and thereby some of the impedance transformation. This resulted in the loss of 10MHz and an increase of SWR to 5 or 6 on 14, 18 and 21MHz, but apart from some reductions in bandwidth there appeared to be no other adverse effects on performance despite the use of very long feeders (about 160ft). With short feeders (less than λ/2) beams using elements conforming strictly to Fig 1 were judged to be satisfactory in terms of gain though adjustments were more critical.

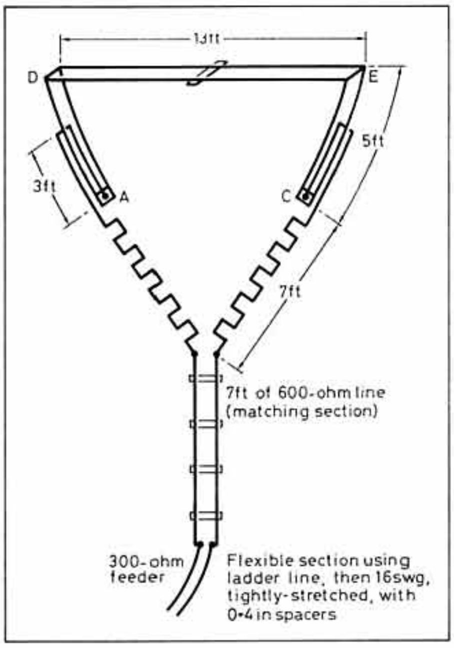


Fig 7: A smaller version of the Claw antenna.

CONSTRUCTION

1) Rotatable Beams

The usual form of Delta Loop uses horizontal wires held up by alloy side-arms and is unsuitable for multiband use due to the problem of insulation at the bottom corners and 'wrong way' impedance transformation in the loop. In the preferred arrangement, known from its appearance as the 'Claw', horizontal wires are supported by fibreglass spider arms (eg fishing rod blanks) angled upwards and outwards from the top of the mast, the angles being adjusted to ensure that wires are kept under tension since flexing can lead very quickly to breakage. Tips of rods should be cut back to about 0.25in diameter and lower ends extended if necessary.

The author was fortunate in having some 1in diameter fibreglass tube but other materials can be used if wires are kept well clear of metalwork or poor insulators such as wet bamboo.

To avoid RF excitation of the supporting structure at 28MHz, metalwork should not extend more than 5ft beyond the mast. Alloy or plastic sockets to hold the rods are attached to the mast with the help of short lengths of angle held in place with exhaust clamps. Points about 6ft along the arms are guyed back to a 5ft mast extension, and the ends of a boom of about the same length aligned with the beam heading. Alloy tube of 3/4in diameter is suitable for both items.

The 'boom' also supports the feeders together with the bottom corners of the loops, a spacing of about 3 or 4ft (not critical) being suitable though it may be varied for adjustment of coupling. The angle between adjacent arms is set with the help of spacing rods about 2ft out from the mast. Cord ties are used between points near the ends of the rods to set the spacing to about 0.15λ at the MDF. As the construction is unusual it may be encouraging to record the survival of the single-wire elements in one of the areas worst hit by the storms of January 1990. Breakages have occurred in the case of ITL elements and it is essential for both wires to be kept under tension.

Fixed Arrays

These can be erected in several ways:

(a) Hung between spreaders

(b) Suspended in or from trees, spider arms or self-supporting tubing elements being attached to branches or trunks, a suitable length of tubing element for an MDF of 14MHz being 24ft. The sides of the loops are formed by wires dropped down from the ends of the tubing to a point which, in many cases, can be within easy reach of the ground for the attachment of matching devices and feeders. In one case good DX performance was obtained on 7, 10 and 14MHz using 34ft elements at 40ft, the lower corners being at 6ft, and this could obviously be scaled for higher frequencies. Note that losses in trees can be large with very small elements and good results are unlikely below the MDF or with very close spacings. To illustrate this, a 14MHz SDL beam at 30ft with 9ft spacing was judged to be 'as good as in the clear' from daily SSB contacts with VK using another station as yardstick but after increasing the height to 40ft there was no improvement. This was eventually traced to a reduction in spacing to 6ft and would be consistent with an initial loss of about 1dB.

(c) 'Spiders Web' Arrays.

If suitable supports are available 'invisible beams' can be constructed using thin wires held up by nylon fishing line; though not yet tried, experience with other aerials supported in this way has been very encouraging. The line is very slippery and if sharp edges are avoided, can be pushed up over branches which thereafter serve as pulleys, although it is safer to run it through insulators.

The line is very elastic and can accommodate a lot of tree movement, about 8% of stretch being available.

(d) Inverted-V construction wire elements suspended from a light boom attached to a mast extension have been used successfully for both fixed and rotary beams. The corners were held up by fishing lines attached to trees or short posts at a suitable distance or, for rotary beams, spreaders attached to 'yard arms'. This is a useful alternative to the Claw assuming an apex angle in excess of 120°, or some restriction of frequency range. The use of short spreaders or, in the case of cords, shared supports greatly assists construction but tends to result in overcoupling between elements at the MDF and lower frequencies unless spacing between lower corners is increased.

ADJUSTMENTS IN THE SHACK

THESE CONSIST OF THE tuning and matching of the driven element, tuning of the reflector, and in some cases adjustment of coupling between elements. Since both elements have to be tuned, a 2-element array requires two feeders. The beam is reversible, and since only about 120° of rotation is needed it is often acceptable to dispense with the beam rotator.

Time-honoured methods are available for tuning and matching but, in the present instance, leave much to be desired. After years of 'hit and miss', an easier method has emerged. Since this applies to tuned feeders in general it will be described in a separate article, but in essence it consists of inserting between the operating position and the point of entry of feeders into the shack whatever length of 300Ω line is needed for establishing resonance, **Fig 8**. This allows all further operations such as fine tuning, matching, nulling and beam reversal to be carried out at a point adjacent to the transmitter, ie at low impedance, subject to insertion of the correct plug or (possibly) switching at the point of entry. It is only here that account must be taken of the possibility of rather large RF voltages. In some cases, series capacitance or other measures may be needed at this point for dealing with inconvenient line lengths.

In the case of beams, special benefits accrue from the above method since fine-tuning of the two elements can be ganged, and coupling may be increased or decreased by lapping together high current portions of the 300Ω lines which are adjacent to the operator. These methods are suitable for in-shack use with any value of external feeder impedance from 300Ω upwards.

Fine tuning requires variation of line lengths by the switching of small increments, or short additional extensions tuned by series capacitance. An ATU may be used, but with the correct balun it is not needed with valve output stages.

ALTERNATIVES TO THE SDL

THE NECESSITY FOR AN antenna to conform to its environment may dictate its shape or, for example, the availability of suitably-spaced trees might suggest a preference for centre-fed dipole elements. The common factor in all cases being the need for feeders capable of operating efficiently at high values of SWR. **Table 2** summarises important properties of most types of element suitable for small multiband beams.

Delta loops with the apex upwards and fed in the middle of the horizontal side are often easier to erect but, though sometimes used for monoband arrays, they are less suitable for multibanding. Despite this, rough estimates included in Figs 2 and 3, in conjunction with Table 2, suggest that useful coverage of up to one octave is marginally feasible. Such elements should be suitable for the construction, say, of an 'invisible' array formed by hanging thin wires down from the booms of TV and FM receiving aerials [10]. The quad, though likewise restricted, has the merit of being the easiest to fit into a narrow space.

Centre-fed dipoles with a length of about $\frac{5}{8}\lambda$ at the lowest frequency may be preferred if suitable supports are available, a spacing of about 10ft between centres being required for 14MHz. The ends are brought into close proximity to improve coupling and to maintain performance at higher frequencies.

Advantages of this type of element include improved bandwidth at 14MHz and, at 25-28MHz, extra gains of 2-3dB. However, due to the narrow beam-width, area coverage is restricted. Half-wave dipoles (including the VK2ABQ with short resonant feeders) can also be used.

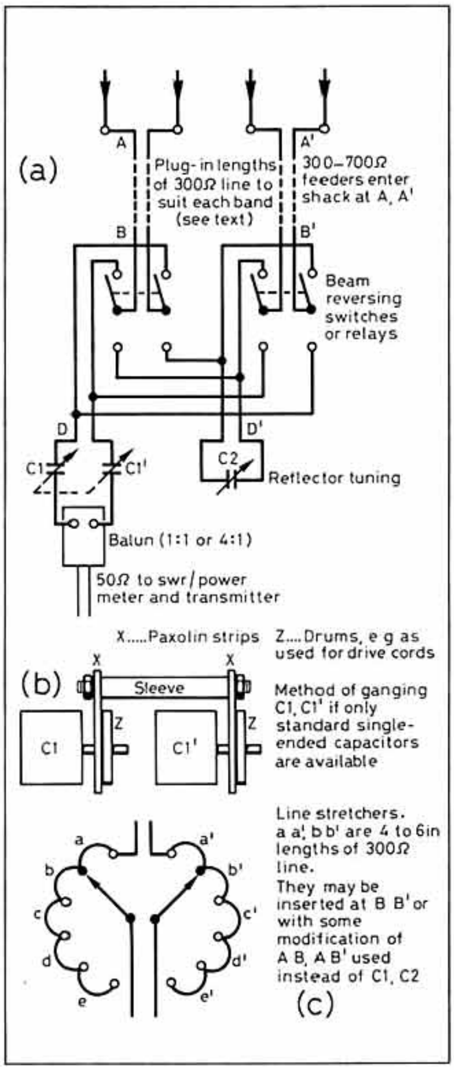


Fig 8: Tuning and matching.

To some extent the proposals herein have been anticipated by the DJ4VM quad [6]. This also uses resonant feeders and provides operation over an even wider range of frequencies, with up to 4dB extra gain at the highest frequencies and negligible endwise radiation. Disadvantages are a reduction of effective height compared with some forms of SDL construction, plus the larger size and high windage of quad antennas in general; its advantages may have also to be weighed against those conferred by use of the ITL principle. It is important to emphasize that *except* as just stated, and despite claims to the contrary, the quad does *not* provide appreciable extra gain [7,8].

Table 1
Comparison of characteristics of alternative elements.
With recommended spacings the values of R for a beam are comparable with these for a single element.

Type of Element (see Fig 9)	Circumference of Loops (wavelengths at 14MHz)	Span (ft)	Radiation resistance (R) in ohms at stated frequencies (MHz)				Front/side ratio (dB)		Possible height gain relative to support
			14	18	25	28.5	14MHz	28MHz	
120° Claw	0.8	19	50	130	320	344	20	7.6	15
90° Claw	0.7	20.4	46	140	370	400	18	7.1	9
Quad	0.72 (This is the critical size for coverage of 14-28MHz)	12.6	45	96	145	160	8.5 (but as near 21MHz)	7	
Modified VK2ABQ		20	50			270	12	9	
λ/2 Dipole		33	73			187	infinity, but typically only 6dB for a 30° radiation angle		
⁵/₈λ Dipole		42	135			135			
Folded Dipole	0.67	22	54			450	(See addendum)		
90° Delta Loop (type B)	0.75	20.5	54	160	240	160	8	18	7ft approx
	or 0.8	21	74	256	192	108	9	9	

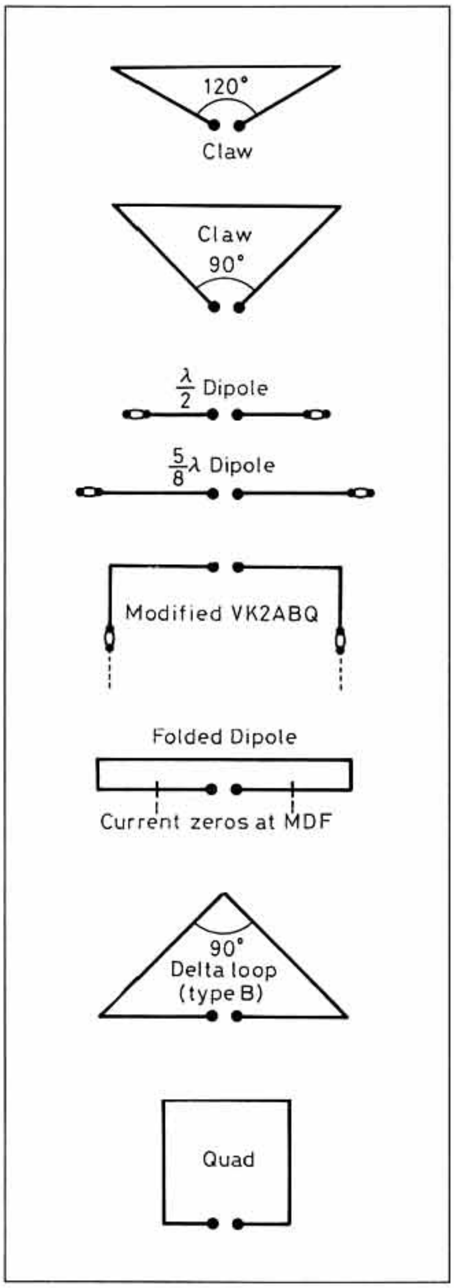


Fig 9: Elements used in Table 1.

THREE-ELEMENT BEAMS

A THREE-ELEMENT VERSION of the ITL array was constructed for 14-28MHz. A triband coaxial feed being devised for the centre element with resonant lines for the outer ones. This was very successful as an educational exercise, DX performance being virtually identical with 3-elements or any one of the three possible pairs. Except for an advantage of 1dB in the case of 3-elements at 28MHz, the main difference was extreme difficulty in optimising the performance when all three elements were in use, due to having too many variables. In practice the gain of Yagis with more than 2 elements tends to be closely related to boom length so that to obtain extra gain, one is forced into methods of construction which jettison the height gains listed in Table 1.

CONCLUSIONS AND RECOMMENDATIONS

IT WILL BE EVIDENT THAT a large range of options is available, with every installation probably a special case so that the aim here has been to present guidelines rather than blueprints. SDL arrays are well suited to an evolutionary approach, likely to appeal in particular to beginners and others looking for simple solutions to antenna problems, but they also afford scope for experimenters, particularly those faced with constraints imposed by the environment or by regulations.

Table 2
Estimated values of SWR for various options.

Type of Element	Band (MHz)	SWR in Main Feeder 600Ω line	300Ω line stub	300Ω line no stub
Equilateral loop as Fig (1), single wire, no loading, 56ft circumference i.e. 0.8λ at 14MHz. Stub (i.e. matching section) length 11ft	14	16	8	20
	18	4	8	2
	21	4.2	8	6
	25	6	3.7	12
	28.5	4.4	3.3	8
As above but ITL with loading at bottom corner	14	1.8		
	18	8		
	21	8		
	25	6		
	28.5	4		
As above but distributed loading	14	2.5	1.25	
	18	4.5	8	
	21	4	8	
	25	2.5	3	
	28.5	1.8	1.1	
Miniclaw, ITL Circumference 0.8λ at 21MHz (0.55λ at 14MHz) Stub length 7ft approx except for figures in brackets (11ft)	14	25	16(11)	50
	18	7	2(7)	8
	21	2.5	4	1.25
	2.5	.4	3	2.5
	28.5	3	3.5	6

Notes: Figures based on values from Fig 2 and Table 1, supplemented by rough estimates, 500 and 1000 ohms respectively, for Z_{01} and Z_{02}; in view of the complex shape, bends and assorted stubs accurate estimates are not possible but Z_0 (measured) was found (coincidentally) to be reasonably close to the 'single thin wire' value of 1000Ω for a helically-loaded lower dipole; leading coils yield a higher equivalent value of Z_{02}.

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