RADCOM TECHNICAL FEATURE

Single Support Directional Wires

Part One of a Two Part Article
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THE CURRENT SUNSPOT inactivity makes the lower frequency bands very useful for long distance contacts. Rotatable directional antennas both reinforce our transmitted signals and allow us to receive DX in the presence of strong short-skip signals. However, such antennas are often large and expensive. In this article I will describe the method used to design an electrically rotatable 80m antenna, supported by a single 18m mast.

SHORT MONOPOLES

WE ACCEPT THAT when a short vertical monopole is driven against ground it generates only a vertically polarised field and depending on the conductivity of the soil, the radiation will be confined to low angles of elevation. On the same basis a horizontal dipole close to the ground produces a predominantly horizontally polarised field concentrated at high angles of elevation. A sloping radiator might therefore be expected to produce both polarities with high and low angles simultaneously.

Fig 1 shows two types of sloping wire. A simple one like that in Fig 1a has a radiation field which can be represented by two vectors, one vertical and one horizontal. For example, **Fig 2** shows the total, V plus H, far field vertical radiation pattern for a wire of a third of a wavelength long, at 3.8MHz, driven against ground of average conductivity and having one end at a height of 18m (60ft). This length is convenient, incidentally, because it eliminates potential losses associated with inductive loading by requiring only a series capacitor for matching to a 50Ω feeder. The plot shows that horizontally polarised radiation in the vertical direction (90° elevation) is only about 3dB less than the maximum, vertically polarised, at 22° elevation.

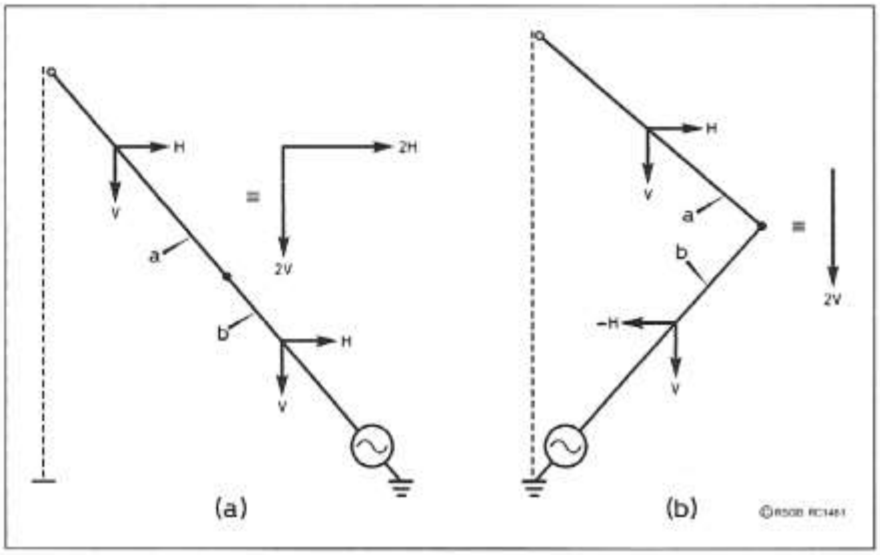

Fig 1: (a) A simple sloping wire radiates both horizontally and vertically. (b) Radiation from a 90° bent sloping wire is predominantly vertically polarised when parts a and b produce equal fields.

ANTENNAS FOR 80M DX

SEVERAL MONOPOLES suitably spaced from each other and all driven against ground are frequently used to produce fixed pattern directional arrays for use in the MF broadcasting band and many of these designs have been adapted for the 80m DX window near 3.8MHz. Arrays of three or four equally spaced monopoles can be configured to provide coverage over 360° in three or four switched sectors respectively. The most common configurations are: (a) Three elements in an equilateral triangle in which any one is driven whilst one or two are reflectors; b) Four elements in a square (four square) with two opposite corners driven, plus one a reflector and one a director. In both cases the director or reflector may alternatively be parasitically excited rather than driven because, unlike the broadcaster, the amateur is not concerned with achieving an accurately defined radiation pattern as a condition of his licence. These antennas are popular because they increase the far field strength when transmitting by up to typically 5dB compared with a single monopole and because they improve reception by differentiating both against local signals arriving from the ionosphere at high angles and interfering signals off beam at low angles of elevation.

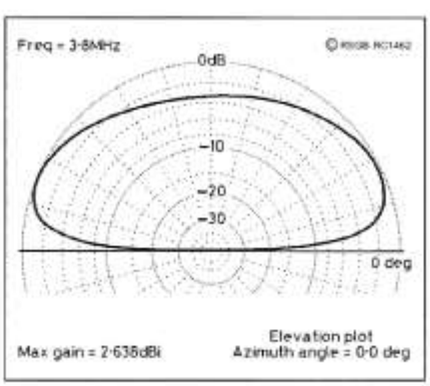

Fig 2: Elevation polar diagram of a one-third wavelength sloper.

WIRE RADIATORS

THE GOOD DX PERFORMANCE of the antennas above is expensive in terms of civil engineering and space required to accommodate both the radiating structures, their guys and the associated individual radial ground systems. Further complexities are the necessary remote switching, multiple transmission lines, power division, phasing and impedance matching networks accompanying each monopole.

Many directional antenna designs have been produced to simplify one or more of these aspects by using radiators formed by wires hung from a non-radiating mast. Obviously unless they are hung from horizontal booms fixed high on the support, at least part of each element will slope relative to the ground.

For the reasons given in the introduction and explained below, this sloping section of radiator is usually the cause of the limited effectiveness of wire beam antennas, particularly when used for reception.

THE BENT WIRE ELEMENT

THERE IS A SPECIAL form of long sloping wire that produces only significant vertically polarised low angle radiation which will now be described:

Consider the sloping wire above to be divided into two unequal parts, a and b, such that

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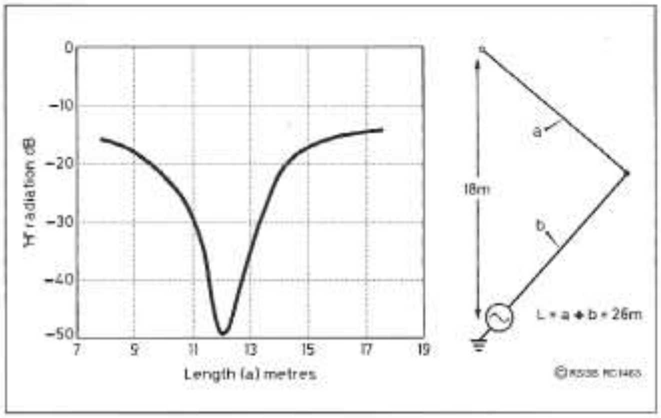

Fig 3: Attenuation of horizontally polarised radiation at vertical incidence versus top length (a) for a one-third wavelength bent wire element.

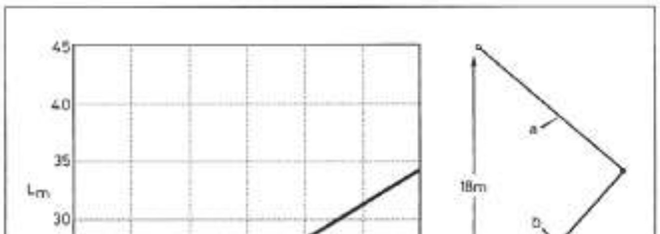

Fig 4: Optimum length (a) for wires of total length L with support of 18m.

each part has its own pair of identical V and H field vectors as shown in Fig 1a.

Now rotate the lower part, b, through 90° as in Fig 1b where what are now the H vectors add to zero eliminating horizontally polarised radiation in the far field. The V vectors now reinforce each other causing only vertically polarised radiation. (The current along the wire tends to follow a sine curve which means that the two parts of the wire will not be of exactly equal length when they are radiating equally. If they could be relied upon to produce equal radiation the optimum support height would be simply L / √2. For example 0.233 wavelength or 18.4m when L = a third of a wavelength).

The graph, **Fig 3**, shows how the calculated horizontally polarised radiation at 90° elevation (vertical incidence) varies with dimension (a) when the total length, L = a + b, is maintained at a third of a wavelength. Calculations of horizontally polarised radiation at various angles of incidence and wire length confirm that the particular dimensions producing a minimum at 90° very nearly give minimal for horizontally polarised radiation at other elevation angles.

Fig 4, gives the optimum length, a, for total lengths of wire, L, suitable for suspension from an 18m support. A support height much less than 18m is not recommended for the 80m band if good efficiency is required unless an exceptionally good ground system can be provided. The selected wire length and optimum, 90°, bend angle ideally define support height.

Readers with antenna design software may like to experiment to find the optimum shape for other support heights and wire lengths by scaling the support on a board and using a piece of cotton, also scaled, pinned at the support ends. A pencil placed to tension the cotton will show the parabolic curve representing possible bend locations. Input the bend position co-ordinates for angles close to 90° and plot the computed vertical radiation patterns until one is found to give a deep null at 90° elevation. Those accomplished in mathematics may be able to calculate the co-ordinates directly.

Where the radiator is formed from part of a guy the position of the bend determines the guying radius. This can be much greater than would normally be required for a given mast height.

It has been suggested by my friend G3CWC that the site area could be reduced significantly, when the support is either a self supporting or already guyed mast, by using light-weight horizontal spreaders to hold the wires away from the mast. Alternatively, fixings on additional shorter masts, trees or buildings may be considered but this is starting to defeat the object of simplicity.

Neglecting ground connection loss, the gain of the bent sloping wire only varies between 2.7dBi and 3.1dBi for total lengths 0.28 to 0.4 wavelength with the peak at 0.33 wavelength, all calculated for a support height of 18m and ground of average conductivity. Wire length is obviously not very critical. In practice the antenna may achieve higher net gain with somewhat longer wires because of their higher feed point resistance relative to a finite ground resistance. In a multiwire array, as considered below, longer wires giving wider effective spacing between elements will also provide a higher feed resistance. The radiation pattern of optimally bent sloping wires is shown in the table below where it is hardly distinguishable in shape from the pattern for a monopole of similar heights over the same ground. The bent wire may be supported from a mast, catenary, tree or the corner of a tall building for example.

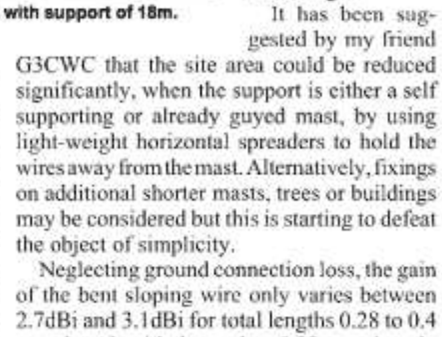

Fig 5: Elevation polar diagram of a monopole and reflector compared with that of a dual bent wire array.

EFFICIENT DIRECTIONAL ANTENNAS

THE SINGLE OPTIMALLY bent wire produces an azimuth radiation pattern within a small fraction of a dB of being omnidirectional at all angles of elevation. Directional antennas are easily formed by suspending two or more of these bent sloping wires from a single support. In fact, just as with the single element, such arrays produce radiation patterns comparable to those from a similar configuration of vertical monopoles. **Fig 5** shows an example where the vertical radiation pattern of a two element bent wire antenna is compared with that of a pair of quarter wave monopoles with an eighth-wave spacing, each array having a driven element and reflector.

In addition to saving most of the cost, civil engineering and feed complexity of a multiple monopole antenna the bent wire array also has the potential for higher radiation efficiency because of reduced dissipation at the shared ground connection:

On a given site a single set of ground wires radiating from the support can be expected to have lower resistance than, for example, one of the four individual systems required by the popular conventional four square array. If the individual radial systems have say 20Ω resistance and each monopole has, as is usual, the same feed current amplitude of say 1 amp the total ground connection loss given by I^2R will be 4 x 1 x 1 x 20 = 80 watts. Alternatively, if the same site area is covered by a single radial system we can assume for illustration that the ground resistance will be reduced to 5Ω.

As already indicated, in the four square all radiators have the same current amplitude, say 1 amp, but two of the elements are driven with currents of zero phase angle and the other two are driven with currents having phase angles of plus 90 and minus 90° respectively. The vector sum of all four currents returning via the common ground resistance of the bent wire version is therefore 2 amps. Ground connection loss is now reduced to 2 x 2 x 5 = 20 watts. Because the vector sum of the ground return currents in an antenna array is always less than the simple arithmetic sum of the individual currents in the elements, we can also expect efficiency improvements for arrays of two and three critically bent sloping wires when compared with their monopole equivalents having individual ground radial systems. ♦

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PRECISE CONSTRUCTION details are not included here because it is anticipated that anyone wishing to build this type of antenna may be constrained by his/her site. This is likely to dictate the number and size of the elements.

As an example, a simulation computer for a three element bent wire antenna, as used at G3LNP, is shown in **Fig 6**.

TYPICAL BENT WIRE ARRAYS

THE DIMENSIONS AND calculated performance, over average ground, using ELNEC, for some bent wire arrays of wire length (L) wavelength, having an 18m support and upper section length (a) assuming an efficient ground radial system is shown in **Table 1**. The first antenna is a quarter wave reference monopole.

The two and three wire arrays show alternative reflector and director results respectively. Although the theoretical gain when using a director can be higher than shown it will require an exceptionally good ground system for this to be realised. The capacitor is the nominal value for resonance of driven element/s at 3.8MHz. 'H and V beam' is the -3dB response angles of the total azimuth and vertical radiation patterns respectively. Note how horizontally polarised radiation (H pol) increases as the fixed support height forces the bend angle to deviate from 90°.

The photograph shows how I terminate my three wire 80m system on an 18m Versatower. The wires return to the tower somewhat above the base to clear the area for gardening activities. The radiators in this case, each 26.3m (0.33 wavelength) and 3mm diameter, also serve as guys. The weatherproof box contains all of the components necessary to switch, feed, tune and match the array. A fourth terminal serves to connect a pair of wires which form a gamma match used when driving the tower on 160m. Because of the combination of close spacing and the need to simplify beam switching it is appropriate to drive only one wire of the three and to tune the other two as parasitic elements. The simple circuit for doing this, with components inside the plastic box, is shown in **Fig 7**.

C1 is tuned by a motor from the operating position, for best F/B ratio, allowing both for wide excursions in operating frequency without loss of directivity and for pattern reversal by changing the parasitic elements between director and reflector. Once found, a fixed value of capacitance may be used if required because the HRP has a beamwidth of more than 120° and only three directions are strictly necessary to cover 360°.

The extra three null directions, obtained by reversing the pattern, are helpful on reception. C2 is fixed, chosen experimentally for lowest 3.8MHz VSWR and C3 is the 1.8MHz gamma match capacitor.

The relays are the small open 10 amp double pole type made by several manufacturers but they are close to their voltage handling capability when using a linear amplifier and it would be safer to use higher voltage types in this situation particularly when using the longer wires. Two and three element arrays may be controlled by multiplexing the DC relay voltages onto the RF feeder to avoid running additional cables to the mast.

Mast height can be linearly scaled for low band frequencies other than 3.8MHz. It is important to make all of the wires in an array identical and to symmetrically position them around the support because a single set of

Termination of three wires of an 80m system, on a 18m versatower. The weatherproof box contains all components to switch, match and feed the array.

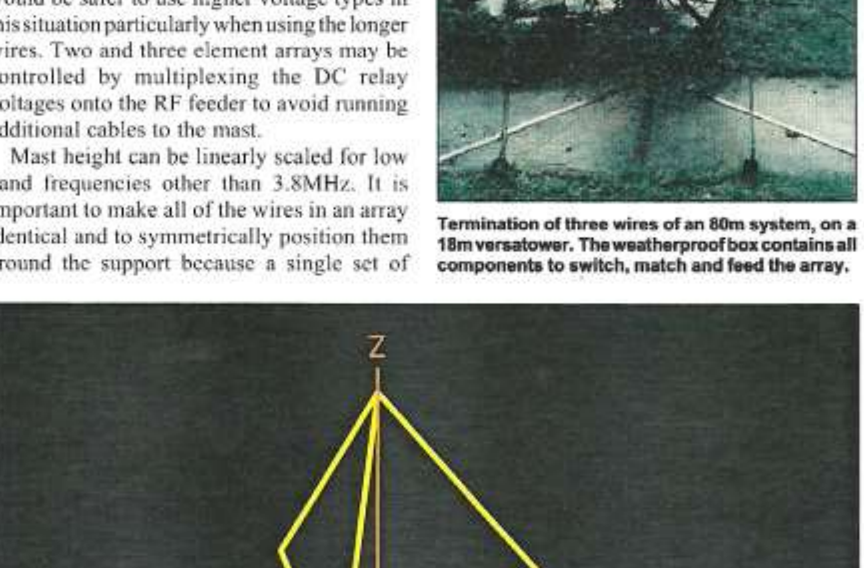

Fig 6: Computer simulation of the G3LNP vertical beam.

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tuning and matching components must function on all beam headings. Even with this precaution I found it necessary to trim two wires by a few centimetres to offset the influence of trees causing different resonant frequencies on each heading.

Switching and tuning circuits for two and four element arrays are shown in **Fig 8** and **Fig 9**. If you should construct a similar three wire antenna and want to experiment by driving all three elements, the 'reflector' currents should each be half the amplitude and lag 155° relative to the current in the front element. The design of phasing, and power dividing networks for all-driven arrays is outside the scope of this article and readers keen to try this should study references [1], [4] and [5].

It is advisable to make all of the capacitors variable, with wide spacing and to use the following method to determine their values:

For two and four elements disconnect all but one of the wires and drive the remaining one via the variable capacitor and a VSWR meter (located immediately at the capacitor). Adjust the capacitors for minimum VSWR at frequencies 3% above and below the working frequency. These capacitor values are the starting points for terminating director and reflector wires respectively. They will be close enough to get the antenna working in one direction, after which the relays can be introduced.

In the three element array the same method can be used except that two wires are connected to the capacitor. The capacitor for the driven wires, in all cases, is simply adjusted for minimum VSWR at the working frequency after re-connecting the other elements to their capacitors.

Final trimming, after connecting the relays and testing the control circuit, involves adjusting the tuning of the parasitic elements for minimum on a local signal received from the back direction. In areas with high lightning activity the wires should be individually connected to ground via high value 2 watt resistors or RF chokes.

The ground system here consists of 100 buried radial wires of lengths between 10m and 40m. I used mainly stranded cables of various sizes which had been scrapped because of perished insulation. The insulation was burned off the thicker cables and the strands of wire separated to provide maximum effect. The soil in the locality has an estimated conductivity of 4 mS/m and dielectric constant of 13.

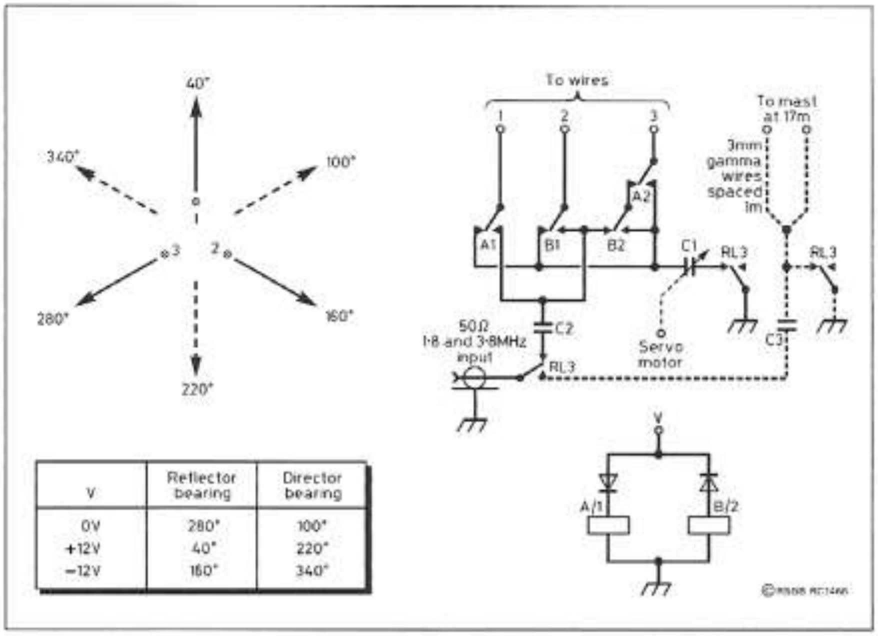


Fig 7: Switching and tuning of the three-wire array at G3LNP. This shows an additional relay used for connecting the gamma matched tower to the rig on 1.8MHz.

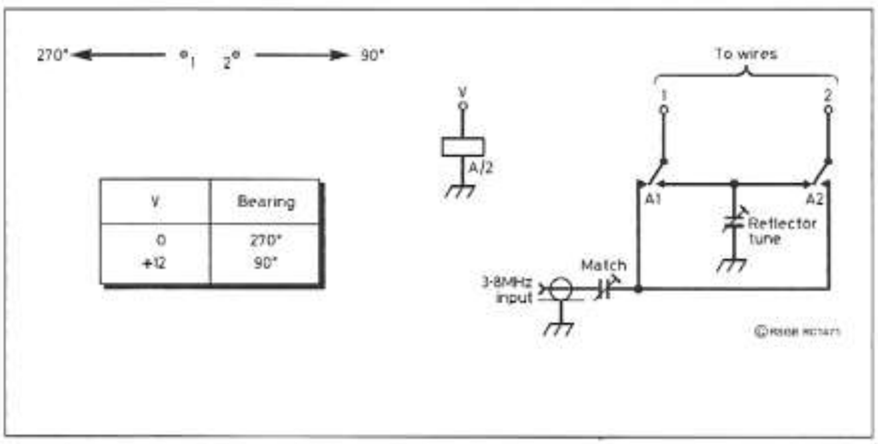


Fig 8: Two-element array switching and tuning arrangement.

TRANSPARENT SUPPORTS

YOU MAY POSSIBLY have wondered how the grounded steel support mast can be made transparent. Ideally, it should be non-metallic but if it is metal and less than about 0.3 wavelength long it should be insulated at the base and guy attachments (if used). Above this length it is usually acceptable to have the mast base grounded. Alternatively, it is possible to couple a high Q single turn loop, tuned to 3.8MHz, to the mast forming a trap [3]. Another technique is to tap on to the mast with a gamma match and capacitor to ground. The capacitor value and tap location is adjusted for minimum support current, corresponding to half wave resonance. The mast current will then be minimal when the base is grounded.

My mast carries a 203BA 20m Yagi on a 1m extension pole and this conveniently makes the support look like a half wave at 3.8MHz. Consequently this is the method which I rely on in conjunction with grounding of the 1.8MHz gamma feed wires.

The mast current can be checked with a 30cm diameter loop of wire, connected to a small lamp or thermocouple meter, spaced a few centimetres from the mast but clear of the wires. Compare the mast current with that in one of the bent wires using the same instrument. A ratio of more that 10:1 is desirable.

In the Four square case it may not be too important to prevent support current because the mast is in the plane of the two central elements and should have a symmetrical in-

Wires	L	a	Gain dBi	F/B dB	H beam degrees	V beam degrees	H pol db	Tune PF	VSWR 50Ω
1	.25	0	2.9	0	360	8-49	-inf	0	1.4
1	.28	.12	2.9	.2	360	8-49	-38	580	1.3
1	.33	.14	3.1	.2	360	8-49	-48	200	1
2	.28	.12	6.0	10/16	135	8-46	-38	700	2/3
2	.33	.14	6.0	10/18	140	8-46	-45	200	1.9/2.3
3	.33	.14	6.3	13/18	130	8-45	-45	200	1.6/2.1
4	.33	.14	6.5	22	120	8-44	-51	250	2.5
4	.4	.15	7.4	38	98	8-44	-33	80	1.3

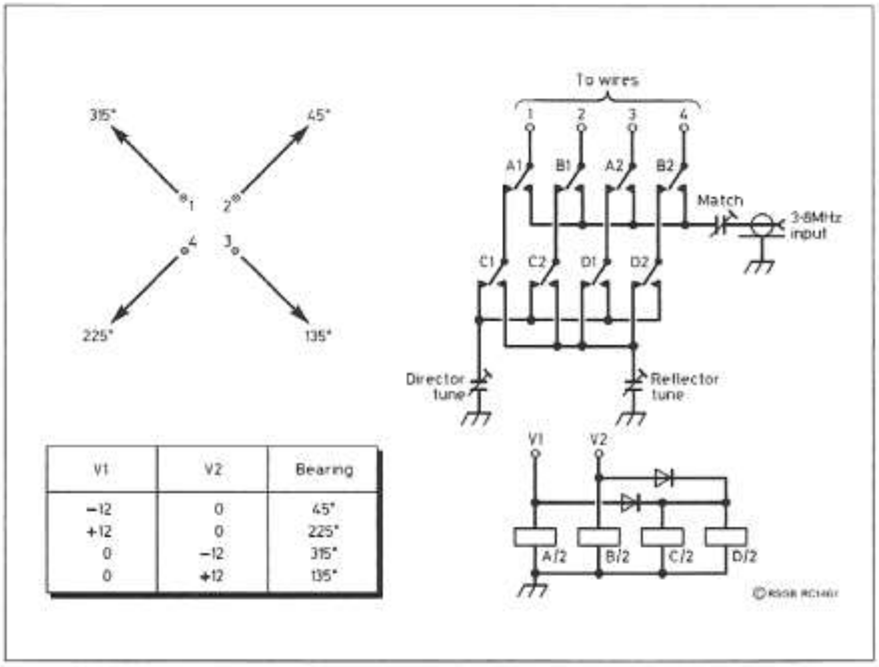
Table 1: The dimensions and calculated performance, over average ground, using ELNEC, for some bent wire arrays of wire length, L.

fluence on their radiation pattern whilst the other pair of elements, because of their opposing current phases, should not cause significant current to be induced in the mast.

RESULTS

YOU SHOULD BY now be convinced that adequate performance can be achieved with two, three or four elements without resorting to the complex circuits necessary for driving all of the elements in an array. The simplicity of using parasitic tuning is only offset by not always being able to obtain deep nulls in the radiation pattern of some configurations.

It was not practicable for me to fit a four wire array into the garden so I am unable to confirm how it would have performed from experience. I started experimenting with a single bent wire, progressed to two and am now happy with an array of three bent wires which usually enable me to receive reports from DX stations which are within an 'S' point of those given to other UK stations using directional antennas. I am able to compare the three element array with a reference half wave horizontal dipole of height 10m and only very rarely is the dipole equal to the array. Generally for DX the array is one to two 'S' points better than the dipole in any direction. Short skip signals are attenuated typically 30dB (5 'S' points) by the bent wire array compared with the dipole.



V1	V2	Bearing
−12	0	45°
+12	0	225°
0	−12	315°
0	+12	135°

Fig 9: Four-element array switching and tuning arrangement.

REFERENCES

[1] Devoldere, ON4UN, in *Low Band DXing*, ARRL.

[2] David, G4LQI, in *HF Antenna Collection*, RSGB.

[3] Brown, W6HPH, in *QST*, October 1979 or Chapter 6 in the 16th edition of the *ARRL Antenna Book*.

[4] Chapter 8, in the 16th edition of the *ARRL Antenna Book*.

[5] *NAB Engineering Handbook*, USA National Association of Broadcasters. ♦