THIS MONTH'S LEADING FEATURE

Phased Vertical LF Band Antennas

The first of two parts by Bob Whelan, G3PJT*

THIS ARTICLE DESCRIBES practical experience of designing, building and using Phased Vertical Array Antennas on 40m, over a period of 18 months.

WHY THE INTEREST IN PHASED VERTICALS?

DECLINING SUNSPOT ACTIVITY means that the LF bands have become more important. QRM is even heavier, commercial traffic continues to encroach or 'shares' the band with us.

Higher levels of amateur activity makes it necessary to put out a more competitive signal. A directional antenna for reception confers a big advantage of improved signal to noise.

Many amateurs do not have the space for the large antenna systems necessary for good performance on the bands below 20 metres.

Phased arrays offer a way of achieving modest gain and good reception directivity from a low profile antenna. It turns out that the practical gain over the average type of antenna used on the LF bands is impressive. Gains of up to 6dB and front to back ratios of 20dB can be achieved.

Table 1 shows the difference in reception between a ground mounted vertical element phased array (the so-called 4-Square) and a standard ground mounted Butternut vertical antenna.

I have been using 2-Element vertical and 4-Square phased arrays since mid-1993 and through 1993/4 and 1994/5 winters. I have had good results on 40 metres; in *CQ* WW 1993, 95 countries were worked over the CW weekend, in 1994, 111 countries and 34 zones. In 1994 I worked all the good 40 metre DX.

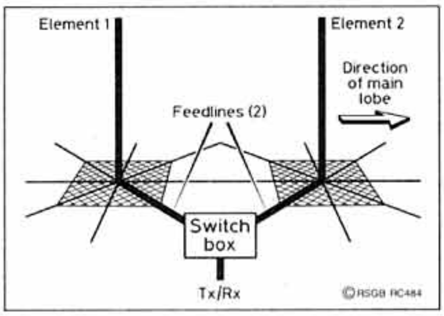

Fig 1: The 2-Element array using $\lambda/4$ radiators with elements spaced $\lambda/4$.

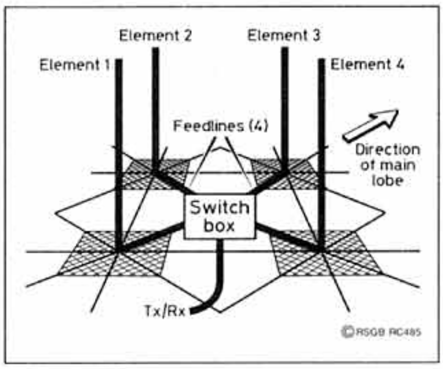

Fig 2: The 4 element array uses $\lambda/4$ radiators, arranged in a $\lambda/4$-Square, the so called '4-Square' array.

WHAT IS A 'PHASED ARRAY'?

A PHASED ARRAY is a set of similar (usually identical) antennas arranged in a regular geometric way and fed with a specific set of RF sources having a defined relationship to each other in terms of current magnitude and phase. For example, one of the simplest arrays is a pair of $\lambda/4$ verticals, spaced $\lambda/4$ and fed with RF currents which are equal, but 90° out of phase (quadrature).

Such an array has a gain of 3dB over a single vertical and is featured in many antenna books. However even such a simple array has to be set up properly and many have been disappointed with its performance when it has been constructed casually.

Country	Bearing	Best 4-Square	Butternut	Difference
1400-				
UB5	83	9	5	4
G		7	7	0
PA	84	7	3	4
OK	97	7	3	4
I	131	5	2/3	2/3
1700-1800				
JW	7	9	5	4
UA0	46	7	3/4	3/4
SM	48	9+6dB	9	1/2
SM		7	2	5
VS6	58	9	5/6	3/4
LY	71	7	2	5
VU	81	5	1/2	3/4
SP	87	9	7	2
9A	110	9	5/6	3/4
SV	121	7	5	2
I	131	5/6	1/2	4
EA	194	9+5	7	2/3
0800				
YV5		7	6/7	0/1

Table 1: Comparison with Butternut (6 Feb 1993), in 'S' Meter Units.

To design an array and get it to work requires a systematic approach. The approach outlined in this article is believed to be tolerant to practical variations from the ideal.

PRINCIPLES

THE PERFORMANCE OF a phased array [Note 1] is determined by several factors. Most significant of these is the performance of a single element of the array, the reinforcement or cancellation of the fields from the elements, and the effects of mutual coupling.

The radiation from a single element depends on the sum of the RF currents (I) flowing in all of its elemental parts. For the common ground mounted vertical which is often used in phased arrays [Note 2]:

$$I=\sqrt{(P/R)}$$

where P is the power applied and R is the feed point resistance. R consists of 2 parts, the loss resistance and the radiation resistance. The loss resistance (Rl) arises from the earth, matching and phasing components and losses in the radiator itself. The radiation resistance (Rr) depends on the geometry of the radiator.

The efficiency of a radiator is Eff= Rr/(Rr+Rl) which in terms of field strength = 10 log (Eff).

A ground mounted vertical with four radials has an efficiency of about 55% and the field strength would be only 2.57dB down from the same vertical over a perfect ground. This isn't the same as comparing the field strength from this vertical to another sort of antenna of course. Advertisements and articles which do this are rather misleading.

DIRECTIONAL EFFECTS

A PROPERLY DESIGNED and fed array can, in practice, produce impressive nulls. The key to good performance is being able to control the fields from the elements. Gain is a strictly relative term. The gain is relative to a single element of the array, however efficient that element is.

Mutual coupling between the elements in an array, changes the impedances of the elements from the impedances if the elements were in isolation. These effects can be large and will change current distribution and relative phases. The performance of an array is critically dependent on errors in currents or phase relationships.

A practical phased array system will consist of the set of radiators, the earth systems, feedlines, networks to shift phase and match

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impedances and a switch box. This box allows the beam headings to be changed by changing the current distribution amongst the elements in the array.

BACKGROUND

THERE ARE VERY good published descriptions of the design, construction and testing of phased arrays [1], [2], [3].

The feeding of phased arrays requires a general understanding of transmission lines and matching networks so a copy of Maxwell's book [4] is handy. However, for this article you won't need to do any detailed calculations.

ON4UN describes [1] the four basic approaches that have been described in the amateur literature. I have tabulated these approaches, see **Table 2**, to pick out features which would affect your ability to make your design work.

I recommend the Collins and Lewallen approaches [2] as they do not rely on making good quality RF measurements. RF measurements require some care and are beyond the scope of this article.

Working examples of both array types are in use in the UK and some of the key parts can be purchased if you don't feel confident to build and test them yourself.

To design and test my arrays I have made extensive use of CAD techniques, primarily with the ELNEC [5] antenna analysis program. Although the simple arrays to be described here can be built without it, for the more complex arrays, it is essential. Using this program, the radiation patterns can be modelled with an estimate of the element impedances. The current magnitudes and phase shifts can be optimised based on practical measurements and the various networks adjusted systematically.

There are two systems which you can build, use to gain confidence and make useful measurements.

a) The 2-Element array using $\lambda/4$ radiators shown in **Fig 1**, with elements spaced $\lambda/4$, has a gain of 3dB and a Front to Back ratio of 20dB with a Front to Side of about 3dB.

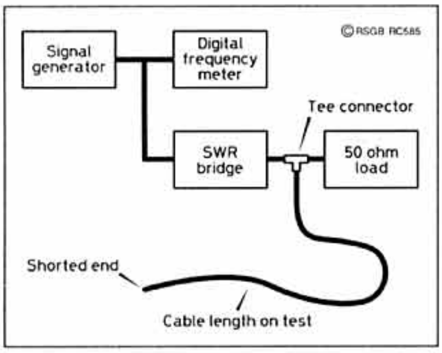


Fig 3: Measurement of coaxial cable velocity factor.

Peter Swallow, G8EZE, a member of the *RadCom* technical review panel comments:

"Arrays can be difficult to set up if mutual coupling is significant, as in the case of the four-square. The element in the direction of fire has a negative real impedance, ie it injects current into the corporate feed, making the radiation pattern sensitive to phasing errors and small impedance variations between the four drive circuits. The advice about poor connections is particularly pertinent.

This array should be fed with equal currents which are 90° out of phase: element 1, 0° and element 2, -90°. This gives the well known cardiod pattern. The lobe is in line with the elements, and the arrow shows the direction of maximum radiation.

b) The 4-Element array shown in **Fig 2**. This also uses $\lambda/4$ radiators, arranged in a $\lambda/4$-square, the so called '4-Square' array. This has gain of up to 6dB with a Front to Back ratio of 20dB with a Front to Side of 10 -15dB.

The elements are fed with equal currents in the following phase relationship.

Element 1	0°
Element 2	-90°
Element 3	-180°
Element 4	-90°

The array fires diagonally across the square in the direction of element 3, from element 1 to 3.

As was stated earlier the way to get consistent performance is to use a step-wise, systematic approach. For this reason build and debug the 2-Element first, it can be the first two elements of a bigger array. But unless you are sure what you are doing, to build a 4-Square from scratch is a demanding task.

LAYOUT

THERE ARE IMPORTANT geographical considerations in the siting of a phased array, because it is not possible to cover all azimuth directions equally and contiguously. Normally you will be restricted to two, three or four optimum directions from the aspect of gain and rejection. In the same way consideration has to be given to the effects of propagation.

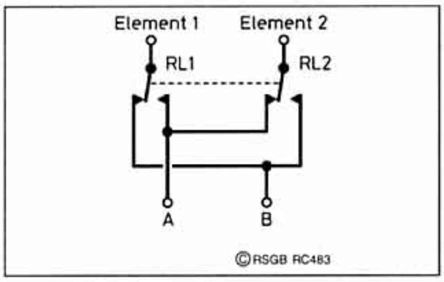


Fig 4: The connection points for two element arrays.

From Western Europe the main areas of interest suggest some basic orientations:

for a 2-Element , E - W.

for a 4-Square either NE - SW, NW - SE or N - S, E - W.

Clearly some choices have to be made and this entails an understanding of the nulls as well as the main lobes.

Anyone who has tried to work DX on the LF bands knows that the real problem is European QRM and general electrical noise. Most of this QRM seems to arrive on a bearing between 40 and 120 degrees; therefore, when listening to the west using the simple 2-Element array the back null of the array should be set to the east. This implies an orientation of 260 - 80° ie E - W for the alignment of the pair of elements. The advantage of the 4-Square now becomes more apparent in that the wider null allows better rejection and hence better received signal to noise ratios. The null angles are given in **Table 3**. All this is easier to visualise on a great circle map.

Because signals also arrive at a variety of elevation angles, users of phased arrays often comment on the large variations in directivity with distance and time of day. The arrival angle has a big effect on the apparent F/B ratio. The high angle daylight propagation from near Europe is fairly non-directional compared with the array performance over long distances (see Table 1).

Few sites are completely open. Whilst the presence of trees in close proximity does not seem to have much effect on performance, arrays sited in open terrain are more successful. Since ground losses in the general

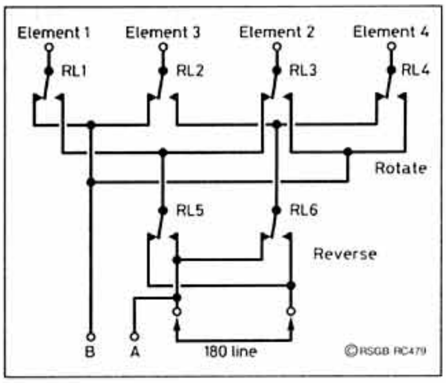


Fig 5: The connection points for four element arrays.

Author	Elements	Feedlines	Phase	Bandwidth	Measurements	Construction	Applicability
Gehrke	any	any	networks	moderate	critical	complex	all designs
Christman	any	specific	networks	moderate	critical	medium	most designs
Collins	$\lambda/4$	$\lambda/4$	hybrid coupler	good	tolerant	medium	90 deg only
Lewallen	$\lambda/4$	$\lambda/4$	L section Network	narrow	tolerant	simple	most designs

Table 2: Vertical phased array designs compared.

Antenna	Width of Forward lobe (-3dB)	Width of Rear null (> -10dB)
2-Element	166	80
4-Square	102	180 (>-10) 140 (>-20)

Table 3: Null angles of arrays.

locality govern the overall efficiency, a high conductivity or very wet area is an advantage.

SITE

CONSIDERATIONS OF orientation and earth plane (see later) govern the overall size of the site needed for an array. In the case of the 2-Element array an ideal site would be:

- 0.8λ wide by 1.05λ long ie 32m by 42m for 7MHz.

In the case of the 4-Square array the ideal site would be:

- 1.05 λ square ie a 42m square for 7MHz.

Few of us have this sort of area available and experience has shown that the earth planes can be reduced such that even an area of 4m by 14m could be used for a 2-Element array or a square of 14m for a 4-Square.

In fact there is nothing sacred about the $\lambda/4$ spacing. For example, providing that the current phase relationships are changed, satisfactory patterns can be obtained for spacings between 2.5 and 15m corresponding to spacings of $\lambda/16$ to $3\lambda/8$ at 7MHz. The optimum phase difference lying between 160° and 60° respectively (for equal current amplitude).

The practical meaning of this is that the exact spacing chosen can be close to $\lambda/4$ provided that the phase is compensated for best rejection. ELNEC can be used to find the optimum. The Collins method assumes 90° shifts and thus phase trimming is limited.

7MHZ LAYOUTS

A 7MHz, two element array has spacing = 10.63m

A 7MHz, 4-Square has its side = 10.63m. It is important that the square is indeed square and not a rhombus. The easy way to do this is to lay out two pegs 10.63m apart and position the 3rd peg so that it is 10.63m from one peg and 10.63 x $\sqrt{2}$ = 15.03m from the other. You can use the same procedure for the 4th peg.

Any conduit needed for the feedlines should be laid first.

At each peg and to support a wooden post, a Metpost [Note 3], is either driven 2 - 3 feet into the ground in the correct position or concreted into a hole. The element is self supporting. To reduce flapping in the wind I mount each element on a 3m x 3" square, wooden post using waste pipe as insulators .

EARTH SYSTEMS

THE OVERALL PERFORMANCE of an array depends on the efficiency of the individual elements. For ground mounted quarter-wave verticals performance is usually limited by the effectiveness of the ground system.

Losses depend on the site and the time of the year. Large radial systems offer one way of achieving a consistent result whatever the local ground conductivity [Note 4].

Earth planes will always be a compromise. I have based my ground systems for 7MHz on a 10 - 12' squares (0.1λ) of chicken mesh, supplemented with radials. This gives about 10Ω loss. With an array all of the individual ground systems have to be identical and bonded together. The reason for this is that the impedances of the elements should be as similar as possible. If not then the performance will vary with direction. This will be seen as reduced F/B ratio rather than forward gain.

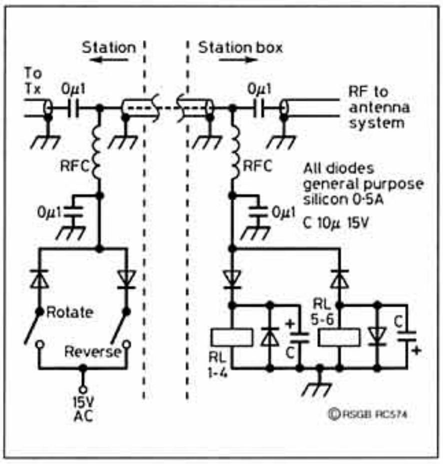


Fig 6: A circuit for powering the relays down the coax feedline from the transmitter.

At each element a plate or similar solid connection point should be provided. I am using 60cm (2ft) square thin aluminium sheets, see the photograph opposite. Mechanical joints should have a large area so that any contact resistance is minimised and stable. Don't rely on twisted joints they may seem satisfactory but they are unstable with the result that the phasing network settings will change. This can be bewildering.

As it is rather expensive to cover large areas with mesh it is necessary to use radials too. Needless to say the radials or mesh should be very close to the surface. pinned down on the surface of a lawn or under <2cm of soil. Pieces cut from metal coathangers bent into U shape work well as 'lawn pins'; they are nearly always galvanised or lacquered so they resist corrosion. The worms will bury the mesh and radials for you given a good grass growing summer.

One problem is that of corrosion caused by electrolytic action between dissimilar metals. Copper and aluminium joints are particularly bad. Try and avoid joints where corrosion is accelerated because of widely differing electrochemical or galvanic potential.

Looking at a Relative Galvanic Series [6] indicates that aluminium and zinc are compatible but copper should be tinned before joining to either. Always use stainless steel or heavily plated nuts and bolts. Joints should be kept dry, though its difficult to keep such joints dry when the best types of earth are wet!

All of the separate planes in an array should be bonded together and to a common earth point at the geometric centre. This allows the switching box and phasing lines to be placed at a common earth point. The feedline should be earthed to this point with a low impedance braid or tape.

One problem the builder of an array faces is how to make measurements of ground loss. A properly compensated noise bridge can be used to measure element impedance directly. Most noise bridges offered in the amateur market are unsuitable for this purpose.

ELEMENT CONSTRUCTION

ALL OF THE ELEMENTS in this discussion are $\lambda/4$ wave resonant, when no other element is coupled to them.

I used a three section construction, 4m of 32mm OD, 4m of 25mm OD and a top section of 15mm and 12.5mm to make the length to approximately 10.3m. Each joint is shimmed, pinned with a screw and fastened with a Jubilee clip to give a good contact. Each of the tubing joints should be taped to keep out corrosion.

This construction is self supporting but each element is attached to a 3m wooden post and insulated with plastic tubing. Large jubilee clips, U bolts and bridges or even heavy duty nylon self-locking cable ties can be used to fasten the insulated elements to the posts. I solved the problem of the elements slipping down through the insulators and shorting to the earth plane by using tape and a screw to pin the insulator.

The exact resonant frequency will have to be determined by *in situ* measurement of each element (with the others open circuit) so the length figures given here are approximate.

When you have the elements erected over the earth planes measure the resonant frequency with a GDO and digital frequency meter. Adjust the lengths so that the elements 2 or 4 are resonant at the same frequency. This might be 7.05MHz. The important point is that each element is resonant at the same frequency.

FEEDLINES

BOTH THE LEWALLEN and the Collins method use elements fed with $\lambda/4$ feedlines. 50, 75 or 95Ω cable can all be used, the higher impedances giving better component values in the Lewallen phasing circuits.

Note that, for 4-Square arrays, cable with velocity factors (VF) less than 0.707 will not reach the centre of the square. Foam or air

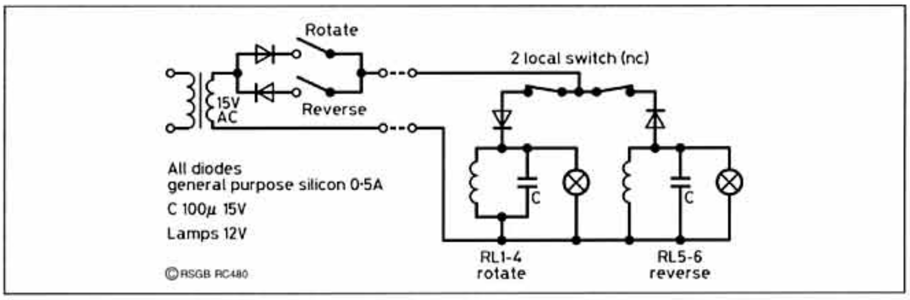


Fig 7: Relay switching circuit using separate 2 or 3 core light duty cable.

Base section of a vertical support showing the Metpost metal post support, vertical element fixed to the wooden post and the aluminium sheet section of the ground plane.

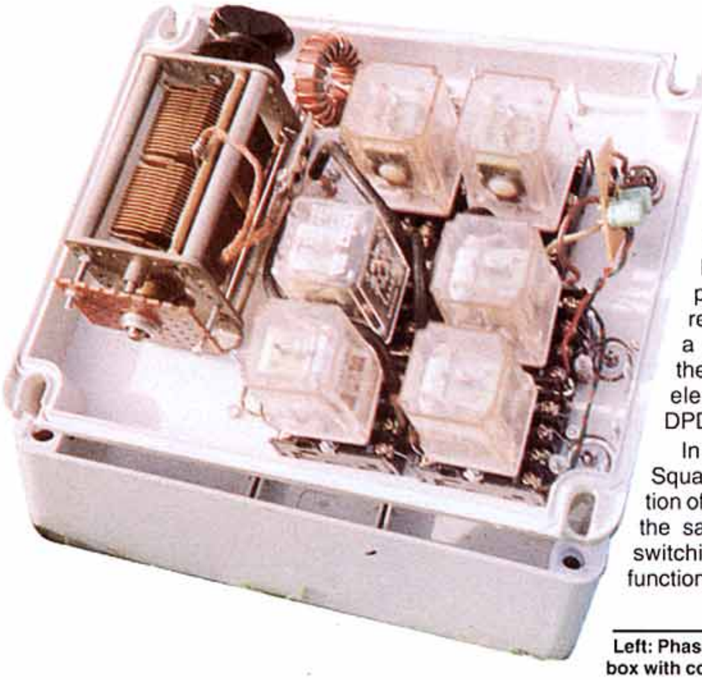
spaced dielectric cables with VF close to 0.8 should be used [Note 5]. To trim these to length the impedance and VF of the coaxial cable to be used have to be known. It is not accurate enough to assume the standard values of VF. The measurement procedure uses a signal generator, a digital frequency meter, a SWR bridge and a 50Ω dummy load. A GDO will not be accurate enough.

A suitable circuit is shown in **Fig 3**. The frequency at which the SWR is a minimum is measured. This should initially be lower than the target frequency. For 7MHz start with a feedline about 9m long. The feedline is then progressively shortened until the frequency for minimum SWR is 7.050MHz.

It should be possible to cut the transmission lines to within 20kHz. It seems best to fit a connector on one end and trim and short the other. Make a note of the frequencies for each feedline as it is a good way to search for cable faults if you have problems later.

To make up a $\lambda/2$ line use the same procedure except that you set the generator to half the frequency, ie 3.525MHz.

I used tails for the connection to the elements. These were lengths of tinned braid soldered to the braid and centre conductor of the feedline and tightly sealed with self amalgamating tape. Keep all the feedlines identical.



Left: Phasing line relay switching box with cover removed.

SWITCH BOX

TO BE ABLE TO change direction a switching system has to be used to exchange the feed currents between the elements. In the case of the simple 2-Element array a reversal of direction is a simple exchange of the feedlines to the two elements. In effect a DPDT relay.

In the case of the 4-Square array the selection of four directions uses the same principles. The switching circuit has two functions, a rotation of direction by 90° and a reversal of direction. With these two functions all 4 directions can be covered. This means that a switch box for a Four Square can be used for a 2-Element array.

The connection points for the Lewallen or hybrid coupler for two element and the four element arrays are shown in **Fig 4** and **Fig 5** respectively and table 4 in Part 2.

Internal connections between components should be short. The inner and outer conductors of the coaxial cable must be switched together (to avoid phase shift errors).

Plug-in, 8 pin, 10A DPDT relays are very satisfactory, (12 or 24VDC). These can be fitted in surface sockets with screw connections. (Maplin). A non-metallic, waterproof box is needed. A circuit for powering the relays down the coax feedline from the transmitter is shown in **Fig 6.**

The circuit can be used with a separate 2 or 3 core light duty cable, as shown in **Fig 7**. A further useful feature inside the switch box are one or two lamps to indicate the state of the relays. This is useful during array debugging.

After construction of the switch box it is most important to check the logic carefully. You need to be sure that RF is being distributed correctly to the feedlines. You can check the RF performance by measuring the SWR across the switch by using dummy loads on each antenna port and checking that the SWR is low and consistent for all switch directions (omit the phasing network).

The switch box should be located at the geometric centre of the array and bonded to the earth plane.

NOTES

[1] This section is based on the discussion by Lewallen, W7EL, *ARRL Antenna Book* (1988), pages 8-8 to 8-31.

[2] For this article it will be assumed that the elements are $\lambda/4$, ground mounted over an earth plane. The principles apply to elevated radials too but in this case the discussion and behaviour of the earth is different.

[3] A Metpost is a commercial metal post support sold at most garden centres.

[4] The region of greatest loss lies $<0.05\ \lambda$ from the base of the vertical radiator.

[5] See the Westlake advertisement in *RadCom*.

REFERENCES

[1] *Low Band DXing*, page II-53 to II-100, by Devoldere, ON4UN.

[2] *ARRL Antenna Book (1988)*, page 8-8 to 8-31, Lewallen, W7EL.

[3] 'Vertical Phased Arrays' by Gehrke, *Ham Radio*, (May, June, July, Oct, Dec,1983).

[4] *Reflections* by Walter Maxwell, W2DU, ARRL.

[5] ELNEC, Lewallen, W7EL, PO 6658, Beaverton, Oregon, OR 97007

[6] *Fighting Antenna Corrosion by* Roleson, KC7CJ, *QST*, (April, 1993).

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RADCOM
TECHNICAL
FEATURE

Phased Vertical LF Band Antennas

The concluding part by Bob Whelan, G3PJT*

THE TWO TYPES of phasing network are the Lewallen L section and the Collins hybrid coupler. Both of these can be home-constructed quite easily (the method of connection is shown in **Table 4**) but hybrids are also available commercially [Note 6].

LEWALLEN L SECTION

This a simple variable L section (**Fig 8**). The component values depend on the impedance at the end of the feedlines. Lewallen provides values for L and C for various values of loss resistance [1]. These are tabulated in **Table 5** for 7.050MHz and earth loss of 10Ω.

Different values of earth loss necessitate different values of L and C, for this reason variable components are preferable. Lewallen calculated that a change in earth loss from 10 to 30W increases C by about 30% and reduces L by the same amount. This gives some idea of the extremes of adjustment range that might be needed. These are not large ranges for readily available components.

As the RF voltages and currents in the phasing network are low (300VAC and <5A) it can be constructed from readily available components. Inductors can be wound on iron powder toroids (T-120-2 or similar). I wound a winding with bare wire (approximately 1mm) with about 20 spaced turns and tapped it as necessary. Fixed capacitors can be air spaced variables or good quality mica or ceramic. Values can be measured by use of a bridge or by measuring the value of a capacitor needed to resonate the inductor at a known frequency. Both the inductor and the capacitors should be variable so that they can be set close to the calculated values prior to testing.

HYBRID COUPLER

The circuit for a 90° hybrid coupler is shown in **Fig 9**. The values are given by:

$$L(\mu H) = \frac{Z_0}{2 \times \pi \times F_0}$$

and

$$C(pF) = \frac{10^6}{2 \times \pi \times F_0 \times Z_0}$$

Where F_0 is the centre frequency in MHz and Z_0 is the characteristic impedance in Ω. As the impedance's at the end of the feedlines have reactive components it is difficult to ascribe a value to Z_0. It is normal to use the characteristic impedance of the feedlines as a starting point.

By way of an example, for Z_0=50Ω:

$L = 1.2\mu H$, $C = 450pF$

Using the data for say a T200-2 iron powder toroid this inductance equates to about 9 turns. The two windings are then wound together onto the core and the inductance measured and adjusted to give the calculated value. The capacity between the windings is measured and subtracted from the calculated capacity above. The result is the capacitance needed for C1 and C2 can be made up from fixed capacitors to suit.

Assemble the hybrid and terminate ports 2, 3 and 4 with 50Ω resistors. Apply RD at 7.050MHz from a 50Ω source to port 1. You should measure equal RF voltages on ports 2 and 4, and no RF on port 3. The voltage on ports 2 and 4 should be half that applied to port 1. If you have a fast 'scope you should see a 90° phase shift between port 2 and 4. The hybrid can be trimmed with small changes to C1 or C2 or by squeezing or spacing the windings on the toroid core.

The networks in the circuits shown are designed to produce the correct current and phase relationships between the elements. They are *not* for matching the array to the transmitter. Depending on the values of earth loss resistance you may find that the SWR on the feedline to the transmitter is unacceptably high. In which case a simple fixed tuned L or π section will need to be used at the array end of the feedline to reduce the SWR to a low figure. This won't make much difference to the efficiency but it will help you spot faults many of which cause a change of SWR on the feedline. For my arrays the SWR has been low.

	2 element and 4-square (see Fig 4 and Fig 5)
L-section (Fig 8)	1 to A, 3 to B, 2 and 3 to earth, Feed to 1
Hybrid coupler (Fig 9)	2 to A, 4 to B, Feed to 1

Table 4: Phase shift network connections.

	Feedline Z	L µH	C pF
2-Element	50	0.94	361
2-Element	75	2.11	161
2-Element	95	3.34	102
4-Square	50	0.53	1282
4-Square	75	1.17	564
4-Square	95	1.88	360

Table 5: Phasing network component values.

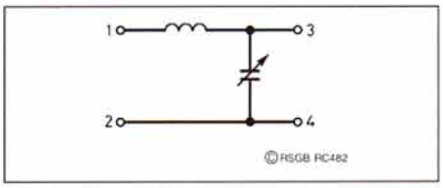

Fig 8: Lewallen simple variable L section. The component values depend on the impedance at the end of the feedlines.

INITIAL TESTING

AFTER CONNECTION OF the verticals to the feedlines and switch box there are a set of tests which can be made to check that the array system is at least functioning.

Measure the SWR on the main feedlines and check that it is approximately the same for all directions.

If it is *not* then suspect:

- One of the elements is not resonant correctly.
- One of the earths is not connected.
- One of the feedlines is O/C or S/C or otherwise damaged.
- There is a fault in the switch box.

The only way to find these faults is by systematically back tracking through the measurements you made as the various components were assembled and tested.

Human nature being what it is you will start by listening to a few signals. If the system is basically working you should be able to hear about 10dB F/B on signals in the main lobe as you reverse the beam direction. You may not notice much difference at all off the side. You may also observe that some near by signals show little change. This seems to be normal. If you are using a hybrid coupler the array should work with 15dB front to back ratio.

TUNING UP A 2-ELEMENT ARRAY

The procedure described here is a combination of measurement and common sense. it assumes that:

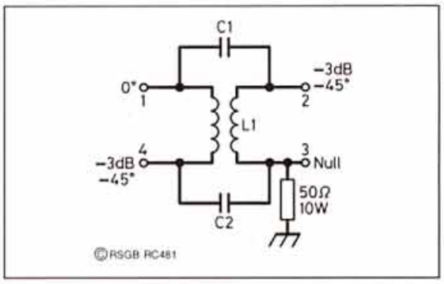

Fig 9: Circuit for a 90° hybrid coupler. The component values depend on the impedance at the end of the feedlines.

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The outstanding feature of the 4-Square its low visual impact thereby overcoming planning problems.

- You do not have access to RF test equipment.
- That even if you are building a 3 or 4 element array you will first build and understand how a 2-element works,
- You are using the Lewallen phase system (if you are using a hybrid coupler then the phase shift is preset but is also certainly not optimum).

Starting with a 2-element array fix up a vertically polarised test signal as far away as you can manage, say 4-5 wavelengths. Position the test antenna so that it is aligned with a null in the expected pattern, for a simple $\lambda/4$ spaced array this will be in line with the axis of the array.

Measure the values of the phasing circuit and set them to the expected values for your ground system.

Listen to the test signal on a receiver and switch the array so that it beams away from the test signal antenna. Adjust the phasing circuit L and C for the best null. I found that I was quite close, within 20%.

Re-measure the phasing L and C values. You can now back calculate the actual RF earth loss for your set up and hence calculate the phasing values needed for any array using similar grounds and elements.

If during this tuning procedure you suspect any poor or intermittent connections do spend time now to locate and eliminate them. It is next to impossible to tune up any array which has poor connections.

TUNING UP THE 4-SQUARE ARRAY

The radiation patterns of the 4-Square shows that the nulls in the pattern occur at 135° and 225°to the main lobe centred on 0°. The nulls are roughly 'in line' with a side of the square. Note that the nulls are not 'off the back' ie 180°. The null is the same alignment as the 2-element array and therefore the same test set up and procedure can be used.

There are two null positions 90° apart. The setting of the phasing network will be slightly different. If possible set the deepest nulls on Eastern Europe. Lewallen noted that such a procedure gave ambiguous results, this was not my experience except for the slight difference between the two null positions.

If you now listen to some on the air signals you should get nulls as deep as 20dB.

DIRECT ELEMENT CURRENT & PHASE MEASUREMENT

EARLIER I EXPLAINED that it is the current amplitude and phase relationships which determine the array performance. The measurement and tune up procedures of the previous section are approximate methods. It would be better to make direct measurements of current amplitude and phase. Then the array performance should be close to that expected through modelling and theory.

Whilst the measurement of current amplitude is easy using an RF current probe, rectifier and Hi Z voltmeter, the measurement of phase is difficult. Using a phase detector provides a way of setting up phase shift networks and checking the hybrid coupler used in the Collins approach. Unfortunately few amateurs have access to an RF Phasemeter or Vector Voltmeter.

For the Lewallen and Collins methods the voltages at the feed ends of the $\lambda/4$ feedlines are in phase with the current into the elements. Therefore all that is necessary is to measure voltages at the switch box with a phase detector and RF voltmeter. An oscilloscope can also be sued for phase measurements but again the estimation of the phase angle from the pattern is at best an approximate procedure (use alternative sweep).

CURRENT PROBE

Although the above approach works I have felt more confident measuring the element currents directly using a simple current transformer. About 10 turns on an ferrite toroid of about 15mm diameter gives enough pick up. A simple diode detector is connected across the winding. The lead carrying the RF current to be measured is passed once through the hole in the toroid. [A current probe is described on page 43 - *Ed]*.

MEASUREMENT OF PHASE

THE SIMPLEST PRACTICAL approach to measuring phase relies on the well known product detector and is shown in **Fig 10**.

For arrays with 90°, ie zero [Note 7], and other phase shifts are difficult to estimate as the measurements are dependant on amplitude. The simplest way of realising this circuit is to use a double balanced mixer such as the SBL1.

The attenuators on the input ports provide the correct terminations. The circuit has a very wide bandwidth.

With voltages of approximately 0.3V RMS at V1 and V2, the output voltage, Vout will be around 0.2VDC at zero phase shift. I use a 500-0-500mA centre zero meter (Ri=500Ω) and this reads about 400ma for θ=0°.

If V1 and V2 are non zero then Vout = 0 for shifts of +/-90°. The output can be used to determine the sense of the phase difference, since if Vout is +ve then q lies between +/-90°. If Vout is -ve then θ is greater than +/-90° but less than +/-270°.

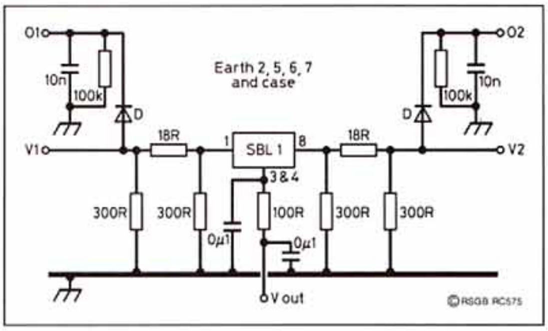

Fig 10: Phase detector circuit using a product detector.

To make measurements a pair of current probes are required of the same sensitivity. A probe is threaded onto each of the elements it is wished to compare. Each probe is connected with coaxial cable to the detector input, V1 or V2. The two cables must be the same electrical length.

To compare amplitudes it is only necessary to use a high impedance voltmeter to measure the voltage between O1 or O2 of Fig 10 and ground. O1 representing the current in the element connected to V1 and O2 representing the element connected to V1 and O2 representing the element connected to V2. If you wish to check for equal amplitudes just measure the voltage between O1 and O2. It should be zero if the currents are equal.

To compare phase, measure Vout. This should be zero for 90° phase difference (subject to Note 7).

Adjustment of both arrays and hybrid couplers can be done using this handy circuit. When adjusting an L-section phase shift network you will find that changing the L to c ratio will change the current ratios for 90° shifts. The test switches on the switch box are very useful during these tests since the current phase and amplitudes can be checked for various directions. due to variations in the earth systems and proximity effects of other antennas it is often not possible to get the same measurements for all directions. set the system for the best compromise.

RESULTS

BUT HOW DOES THIS ANTENNA sound from the other end? In February this year, John, G3HCT, operated as VK4CJB, and conducted a series of tests with Bob, G3PJT, on 40m. John reports that on both the long and short path the signal was "impressive". Under a wide range of propagation conditions contact was always made and often the signal peaked at S9. The array was 2-4 S units better than a sloper and on a par with a 2-element yagi at 70 feet. Signals on the G-VK4 path show rapid QSB but several times G3PJT was the only G signal audible. The phased array seemed to extend the time that the path was open.

So there you have, what more is there to be said.

NOTES

[6] Hybrid Couplers and switch boxes are available from Vine Antenna Products, see page 21.

[7] Zero output is also the result of two fault conditions, if either or both of the test signals are absent, or if there is gross amplitude imbalance between the two inputs.

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