Tricks of the Trade

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Last time in ToTT we had arrived at the point to start the explanation of the HF antenna arrays as used by the BBC from *c*. 1933 until the present day. I must confess that, in writing about antenna theory, I am a little outside my personal comfort zone as I have been occupied in the operations and maintenance of transmitters for most of my career, leaving the antenna engineering to others. However, early on as a technical assistant at Daventry, I was involved in the scheduled operations of antenna switching. This job involved cycling, often to the extremities of the Borough Hill site at all hours of the day and night, all year round in all weathers, to perform switching duties. So I feel I am partly qualified, at least, in that area. Luckily, the BBC provided a Technical Instruction, entitled "Short-Wave Transmission Lines and Aerial Arrays, T6" for use on the stations as a training aid and general text-book and I am grateful to the Curator, Neil Wilson of the "Wireless in the West" Museum at Washford, Somerset who has been able to loan me a first edition copy, dated 1949, for reference. Martin Ellen of the bbceng.inf website has obtained permission for reproduction for personal study and non-commercial use of long-obsolete BBC Technical Instructions and to him I am grateful. So, to the arrays…

General considerations

HF antennas fall into two groups, non-resonant and resonant. Non-resonant antennas, for example, rhombics, are of relatively simple construction and can be operated over a wide frequency range. Often they have a terminating resistance and, as such, appreciable RF power loss can occur. Hence, they are not suitable for high power broadcast transmission.

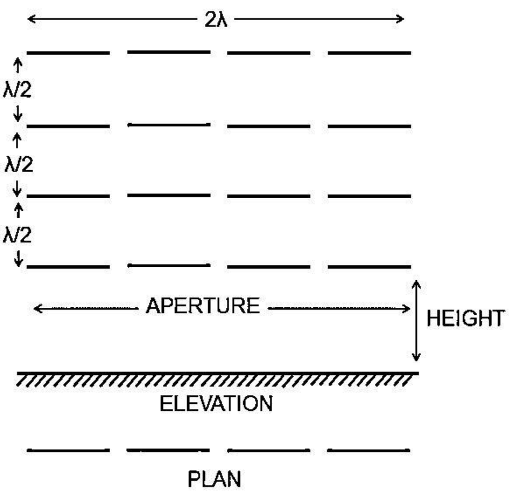

Figure 1. Layout of array curtain with 16 half-wave radiating elements

Resonant antennas operate at high efficiency on, or close to, the frequency for which the antenna is designed. These arrays are used at many HF broadcast stations throughout the world and the most common type comprises a vertical curtain of horizontal, end-fed half-wave radiating elements. These elements are arranged end-to-end in horizontal rows, with the rows being stacked vertically with a spacing of half a wavelength between them.

Parasitic reflector curtains, spaced a quarter-wavelength from the powered curtain, are used in many arrays to increase the directivity. By switching, either of the two curtains may be made the reflector curtain, thus making the direction of radiation reversible. Further, by splitting the radiating curtain into two halves and altering the relative phases of the current in them, the vertical plane of the main lobe of radiation can be set at an angle to the normal. This operation is known as slewing. **Figure 1** shows a typical arrangement of sixteen radiating elements in a curtain of an array.

This array produces horizontally polarised signals and was adopted in preference to vertical elements and vertical polarisation in the early stages of development at Daventry in the 1930s, as horizontal polarisation produced stronger signals in the target area.

The number of elements and their configuration determines the radiation pattern of a particular array; with a non-slewed array, the direction of maximum radiation is in the vertical plane normal to the array, referred to as 'bore-sight'. Thus, if an array is suspended north/south, then the bore-sight radiation would be to the east and west with no reflector and to the east or west with a reflector. The proximity of the lowest set of dipoles to the ground has an effect, caused by waves from the array in the direction of the ground being reflected upwards. This effect sets the take-off angle (TOA) and is of great importance.

In summary

- increasing the height of an array reduces the TOA
- increasing the aperture of an array by adding elements to each horizontal row increases directivity in the horizontal plane
- increasing the number of rows in the vertical direction increases directivity in the vertical plane and reduces the TOA.

Connecting the elements

For a curtain having four elements in each horizontal row, two vertical feeders are required and are connected together at the bottom of the array by a length of horizontal feeder.

As the voltage along a feeder is subject to a phase reversal over each half-wavelength, it is necessary to cross over the feeder wires between each row of elements to ensure that the currents in all elements are in phase. The effect of this connection to four radiators is shown in **Figure 2** as both crossed over and straight connection.

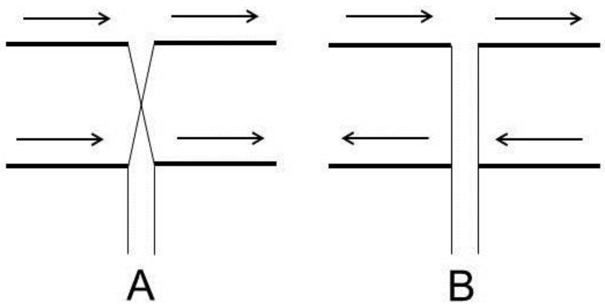

Figure 2. Method of feeding radiators to secure in-phase effect

Frequency bandwidth

Although an array is designed for a specific frequency, usually in the middle of a short wave band, it is desirable that it remains efficient over the whole band. The width of each band is about ±2% of the mid-band frequency.

In an array consisting of two curtains, one a parasitic radiator, the reflector curtain may reduce the efficiency of the array at other than the mid-band frequency: as the frequency is varied, the phase between the currents in the two curtains is rapidly altered from that necessary for maximum radiation.

Luckily, there are two means of reducing this effect:

- reduce the characteristic impedance (Zo) of the radiators
- adjust the impedance of the reflector to suit the operating frequency.

Single wire centre-fed full wave dipoles of 12 SWG copper wire have a Zo of about 550 Ω. If two of these wires are connected in parallel and spaced six inches apart, the Zo is reduced to about 390 Ω. Dipoles having two wires were the norm for many years.

However, over time with sender output powers increasing, the advantage of having essentially 'fatter dipoles' was exploited resulting in a greater power handling capacity of the array. It is important to remember that Senders 1 and 2 at Daventry were only 15 kW but, by 1939, 80 kW was the norm with 100 kW by 1941. By 1963, 250 kW had arrived.

By then some arrays had triangular radiators and, after the 1960s, cage radiators, often with up to seven wires, were used.

End effect

VMARS Members who have built antennas will be familiar with end-effect and the physics of it is no different in broadcast applications.

The inherent capacity of high-voltage support insulators at the ends of the radiators alters the end-effect, with the length of the radiators varying between 0.462 λ at 6 MHz and 0.444 λ at 21 MHz.

75 m band antenna differences

At Daventry and Skelton, 4 MHz antennas were provided and their construction was slightly different. No doubt, because of the much larger dipoles required, the sheer physical size of the array did not permit as many vertical elements so they were often limited to just a stack of two. In addition, again in an attempt to strengthen the array structurally, folded (Kraus) dipoles were used, which presented a Zo of about 320 Ω.

These folded radiator arrays were used for services where high directivity was not required. The use of a small aperture array was advantageous to the requirement for 75 metre band single-hop, almost continent-wide, night-time/darkness coverage. Those who have heard Skelton's 3952.5 kHz (later, 3955 kHz) BBC English and the 3975 kHz BBC foreign language services will testify to the fact. Extremely strong signals were received within Europe.

Coding of antenna arrays

Readers of ToTT in Issue 25 of Signal will no doubt have seen the references to array coding: it will now be fully explained.

The designation of a 'complete antenna' is given by a code in the basic form *Hm/n/h* where *H* refers to the horizontal plane of the radiators, *m* is the number of radiators in the horizontal row, *n* is the number of rows placed one above the other and *h* is the height of the lowest row above ground.

This designation is much easier to illustrate with a diagram and **Figure 3** shows two such examples.

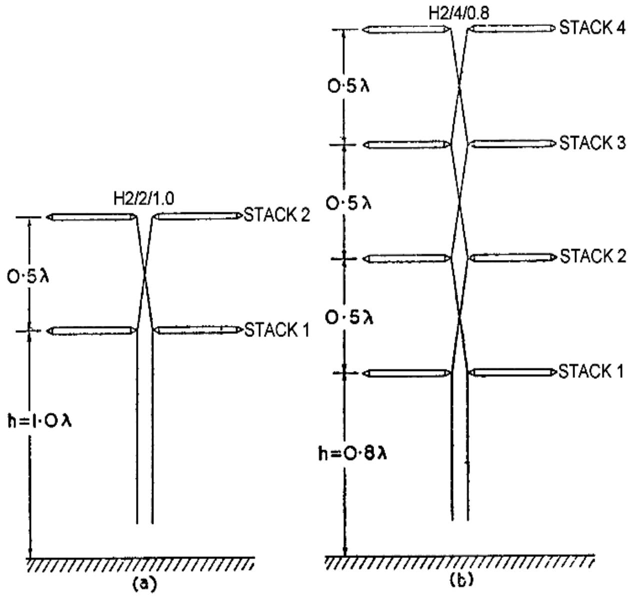

Figure 3. Examples of aerial array coding

In examples (a) and (b) there are two radiators in each horizontal row, therefore, both antennas are in the H2 class. Example (a) consists of two rows or 'stacks' as they are called and is, therefore, an H2/2 type. Example (b) that has four stacks is an H2/4 type.

The height of the lowest dipole above ground is in terms of wavelength λ so for (a) it is H2/2/1.0 and for (b) H2/4/0.8.

It is fair to say there were very few of the single curtain arrays in use; indeed the author can only remember one at Daventry for 6 MHz that was suspended between the two 500 ft masts erected in 1925 as the support for the original LF Tee antenna for 5XX. So, in the examples above, if a 'fixed reflector' was used, then the designation would have the letter *R* placed between the *H* and the first number, thus HR2, or HR4.

The spacing between the driven curtain and the reflector curtain is 0.25 λ.

More gain and more facilities

From the last ToTT we know that, from the early days at Daventry, use was made of the same array to transmit, for example, on a bearing of 79˚ and then reversed to 259˚. The coding for this facility was modified to include a second *R* meaning 'reversible'. So the coding becomes HRR2 and HRR4.

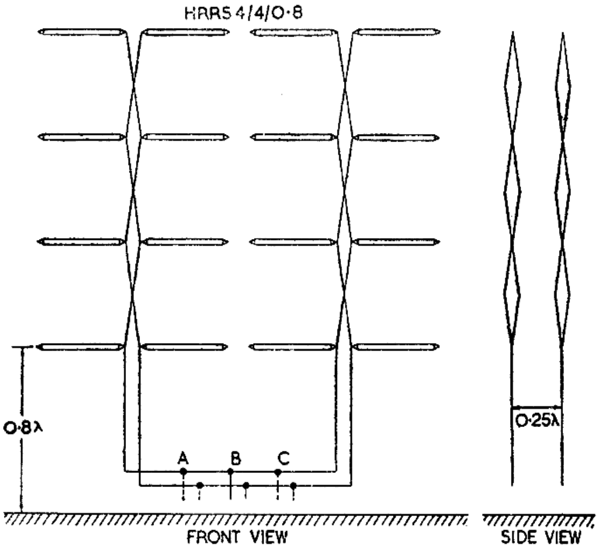

Figure 4. Aspects of HRRS4/4/0.8 aerial array

With reference to **Figure 4**, it can be seen that two stacks of dipoles have been placed side-by-side and fed at point B from a common, parallel feeder. Point B is equidistant from both vertical feeders and the arrangement, from a phased RF perspective, is balanced. The antenna aperture is now twice what it was previously.

If the input RF to the array is moved to either points A or C then the beam becomes slewed by a certain number of degrees from the natural bore-sight condition

The coding is, thus, amended by the addition of the letter *S* if slewing is possible and so the array is coded HRRS4/4/0.8, which means that it is

- horizontally polarised
- with a reflector
- reversible
- four dipoles high
- four (half-wave) dipoles wide
- slewing available
- height of lowest dipole 0.8 λ above ground.

For best DX, the height of the lowest dipole above ground should be 1 λ and so we have derived possibly the world's most common broadcast curtain array, the HRRS4/4/1.

Antenna gain of an HRRS4/4/1

The measured gain is theoretically 21 dB compared to a standard dipole which, with say a 250 kW input carrier power, gives about 30 MW ERP.

An additional feature is that just half the array can be employed, if desired. The antenna then becomes a HRR 2/4/1, the aperture is halved, the gain is reduced and the slewing facility is lost but the outgoing RF can be spread over a greater area of the earth's surface. This result is useful for wide-area coverage *e.g.* when transmitting to more than one country.

If this arrangement were specified in the schedule, the array number, for example at Daventry Array 5, would have the suffix 'A' added to become Array 5A.

Oddly, the convention as to which curtain was the 'A' side changed from site to site; at Daventry the left-hand curtain, viewed from the bore-sight angle, would be 'A' but at WOF, it was and still is, the right-hand side that fulfils this task.

Radiation patterns

The vertical radiation pattern of a HR4/4/1 is shown in **Figure 5**.

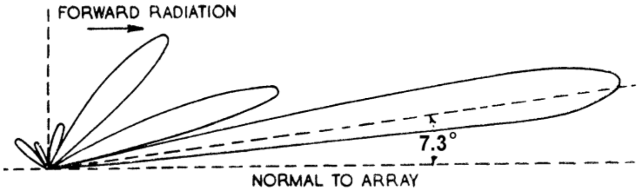

Figure 5. HR4/4/1 array polar radiation diagram for the vertical plane normal to the array

Here the backward and forward vertical radiation developed from the 7.3° TOA is illustrated by the main forward lobe with two minor upper lobes and some very small rear lobes.

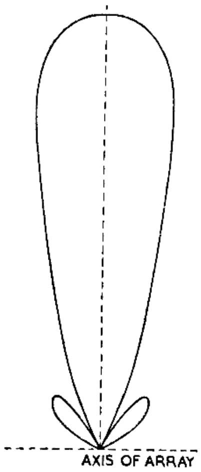

Figure 6. HR4/4/1 array polar radiation diagram for either of the two planes containing the axis of the array and inclined 7.3º to the horizontal

The horizontal radiation pattern of a HRRS4/4/1 is shown in **Figure 6** and the main forward lobe can be seen clearly. There are just two minor, side lobes.

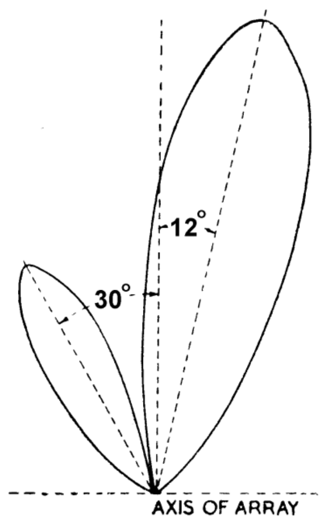

Figure 7. HR4/4/1 array polar radiation diagram for the plane containing the axis of the array and inclined 7.3º to the horizontal. Slew of 12º

The effect of slewing the beam by deliberately introducing an offset to what had been a balanced drive position between the two stacks is immediately obvious from **Figure 7**. A maximum of 12° slew is possible before the unwanted side lobe becomes too large.

So, the perfect array?

Well, on the face of it, the HRRS4/4/1 does look very good and, for many years, it has been the preferred choice of frequency managers and schedulers, with 21 dB of forward gain, the ability to reverse, slew and the use of the 'A' condition for a wider beam.

However, it is only a single band array, has a limited slewing capability and, even at 12°, there is a sizeable side-lobe.

Next time

A series of coverage charts will be presented that show the predicted coverage of the main bore-sight condition with the various options of slew and 'A' condition.

Dave Gallop G3LXQ offers an interesting theory regarding a design weakness of the HRRS4/4/1 and how this problem was overcome.

In addition we have some vintage photographs of array switching taken by Richard Buckby G3VGW and Jeff Cant. The photographs lead neatly on to some mechanical considerations.

Modifications to the manual switching arrangements were made and the arrays were converted to automatic, remote switching. All will be explained next time.

Continued from page 33

Although not recognised at the time, these limits had problems for the amateur services in the bands above 30 MHz. Problems arise because the 'spurious domain' is that part of the transmitted signal which lies outside of 2.5 times away from the centre of the necessary bandwidth of the signal. Leaving aside the question of what really is the 'necessary bandwidth' and how it is measured, this term has problems for narrow band transmissions at UHF and microwaves. Take a 10 GHz 100 W CW transmitter. The 'necessary bandwidth' is 200 Hz, so the spurious domain starts at 500 Hz from the carrier. The total power in the 1 MHz band between 500 Hz from the carrier and 1000.5 kHz from the carrier must be 63 dB down, which represents an average phase noise requirement of –123 dBc/Hz across the whole of the 1 MHz band. This target is impossible to achieve.

So what has happened in practice? Consider the US case published as Code of Federal Regulations CFR47 Part 97.307. Here the requirement below 30 MHz is for a spurious suppression of 43 dB (the official comment was that this choice was made to 'align with international requirements'), while the suppression requirements for transmitters between 30–225 MHz is 60 dB. For transmitters below 25 W, the minimum suppression required is 40 dB, without having to be below 10 µW.

Preparation of the European implementation of ITU-R Rec SM.329 was the task of a CEPT (Conference of European Posts and Telecommunications) Project Team, known as SE21, the 'SE' meaning 'Spectrum Engineering'. This process took some two years, the final proposal being accepted as European Radio-communications Committee ERC Rec. 74-01 at a meeting in 1998 in Siófok in Hungary. It may be found at http://www.erodocdb.dk/doks/doccategoryECC.aspx?doccatid=2.

During that time, I had joined SE21 for reasons connected with work and so was able, with some argument, to get the CEPT implementation to have practical limits.

Table 1 is an extract from Annex 6 of ERC Rec. 74-01. It can be seen that the minimum necessary bandwidth is considered as being 4 kHz, so the spurious domain starts at a spacing of 10 kHz. As the operating frequency band and the measurement bandwidth increase, so the assumed minimum necessary bandwidth increases, removing the anomaly of the close-in phase noise making the requirements in ITU-R Rec SM.329 impossible. Interestingly, at a late stage in the deliberations, the professional satellite community recognised that exactly the same problem applied to the narrowband satellite tracking beacons!

Although the International Radio Regulations require, *via* a complex set of intertwined requirements, compliance with ITU-R Rec SM.329, local interpretation varies. In the 48 CEPT countries, ERC Rec 74-01 is the applicable document and, as can be seen, is far less restrictive than ITU-R Rec SM.329 in the VHF range, although somewhat tighter than the Federal Communications Commission FCC requirements. Although ERC Rec. 74-01 has been revised four times since its original approval, Annex 6 for the amateur service has not changed, still being as I drew it up in 1997.

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