A NEW HIGH PERFORMANCE HF RECEIVING ARRAY

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INTRODUCTION

Current advances in the design of active receiving antennas have enabled arrays to be produced which not only equal the performance of conventional passive devices but outstrip them. This paper is concerned with the design of a multidirectional receiving array for use at base stations for marine and aeronautical communications or for the major nodes of an international point-to-point network.

The central receiving station for a major HF communications network requires a high performance antenna capable of providing coverage over a full 360 in azimuth. This azimuth coverage must be divided into a number of overlapping sectors. Each sector beam should have low side lobes and back lobes so that signals arriving from other azimuth directions are rejected and cannot interfere with low level signals in the wanted sector. Furthermore the sector beams should have constant shape as the operating frequency changes. This will ensure that adjacent beams overlap by an optimum amount at all frequencies, and that the required range of angles of arrival will be served adequately across the whole HF band.

FORM OF DESIGN

Arrays which have been used for this function in the past include clusters of rhombics and log periodic dipole arrays, planar arrays of monopoles and Luneberg lenses. Some of these antennas have undesirably narrow bandwidth (the rhombics), or excessive dependence of radiation pattern with frequency (as with circular arrays of monopoles). Others are prohibitively expensive (the Luneberg lenses) or become unwieldy if the lowest frequency required is made too low. Furthermore, the level of suppression of unwanted side and back lobes is often poor. In recent years small active receiving antenna elements have been developed for the HF band. However, on examining the ways in which these elements have been deployed to form arrays, it will be seen that, although the active element is itself broadbanded in its performance, the arrays in which they are used suffer from the classical restraints which relate antenna dimensions and beamwidth. Thus a simple endfire array has a beamwidth which increases as frequency falls; its useful bandwidth is restricted by fundamental equations describing the behaviour of arrays. In order to overcome these unwanted variations, attention was turned to the possibility of designing an active log periodic array. This would have the advantage of having almost constant performance over a very wide bandwidth - rather surprisingly we are making use not of the wide bandwidth of the active elements, but of their compact size and ease of erection. Having designed an active log periodic sub-array, these are then arrayed as a rosette to produce the required pattern of sector coverage.

THE ACTIVE LOG PERIODIC ARRAY

The design of an active log periodic array may most easily be understood by analogy with the more familiar log periodic dipole array. The array comprises a number of identical active elements spaced in the manner characteristic of any linear log periodic array. The output from each active element is connected in parallel across a single unbalanced transmission line which runs along the axis of the array. The connection to each array element is made through a simple bandpass filter whose function is to determine the contribution which each element makes to the array output at any frequency. It may be observed that the filter parameters of centre frequency and Q factor replace the more familiar parameters of element length and length/diameter ratio.

The element positions and filter centre frequencies are related by the equations:

$$\frac{X(n)}{X(n-1)} = \frac{fo(n)}{fo\,(n-1)} = \tau$$

where x(n) , x(n-1) are the distances of the nth and (n-l)th elements from the array apex, and fo(n) and fo(n-1) are the centre frequencies of their bandpass filters. τ is the design ratio.

The familiar parameter α, the angle at the apex containing the array elements, is no longer apparent, but it has been found useful in array design to define a pseudo angle by converting the centre frequency for each element to the equivalent quarter wavelength. Thus α may be redefined as

$$\alpha = \cot^{-1} (fn.xn / 75).$$

The lines connecting individual elements to the main transmission line may have equal or varying lengths - any variation conforming to a log periodic law - and their characteristic impedance may be equal to or different from that of the main transmission line. As usual the unfed end of the transmission line may be open or short circuited or terminated by a matched load impedance.

The conventional phase inversion of adjacent elements is achieved using a simple 1:1 transformer. Conventional phase inversion is not always used.

As will be seen the design has a wider range of parameters than a conventional array, and easier control of some of the familiar parameters such as the bandwidth of individual elements.

ANALYSIS

Analysis is made comparatively simple because of the almost vanishingly small level of coupling between the elements of the array. In consequence the currents in each element are obtained from the analysis of a network of terminated transmission lines, the terminations themselved being frequency dependent. Using Carrel's (1) method a matrix is developed which represents the system parameters. This is then solved to yield individual element currents. If we treat the transmitting case - in which the amplifier inputs are connected via the filters to the main transmission line - and we assume that the amplifiers are not transparent, i.e. the output impedance is independent of input termination, the input impedance matrix only contains non-zero terms on the leading diagonal. This is a useful simplification. The appeal to reciprocity is legitimate as the amplifiers themselves are not part of the network being analysed.

The radiation patterns of the LP array may now be computed from the set of element currents, the directional characteristics of the chosen array elements and the characteristics of the ground. The radiation patterns of an element row have been measured at various frequencies in the HF band to confirm the method of analysis.

The log loop array is further described in Hanna and Collins (2).

THE ACTIVE ELEMENT

The discussion of the design of an active log periodic array has so far made no reference to the actual element used. Although any broadband active element could be used, the unidirectional characteristics of the array will be enhanced if the basic element also has unidirectional properties, the array radiation patterns being obtained from the product of the element pattern and the array factor. For this reason terminated loop elements have been used. These are more fully described in reference (3).

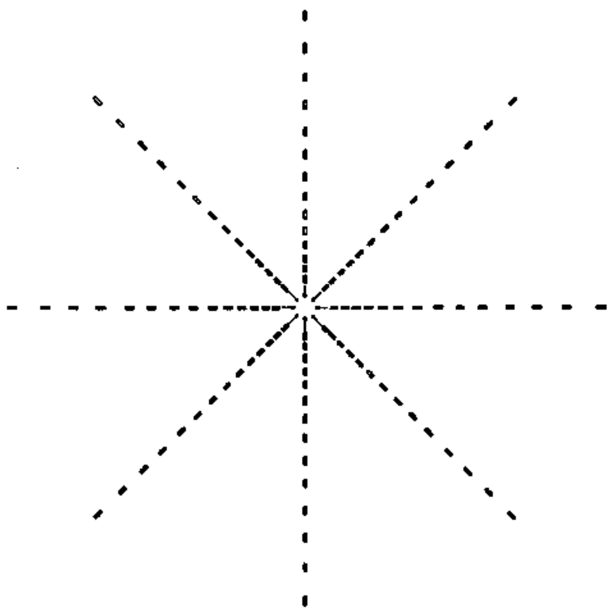

Figure 1. Rosette arrangement of log periodic rows.

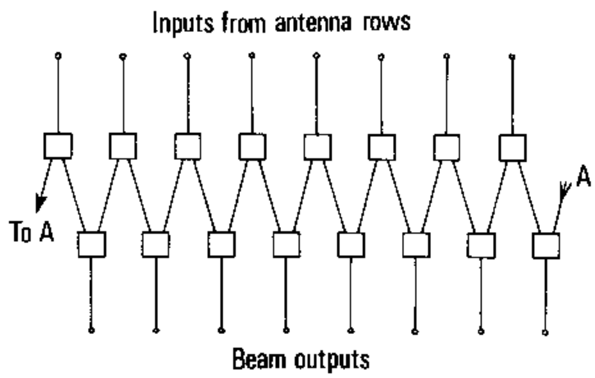

Figure 2. Beam forming network.

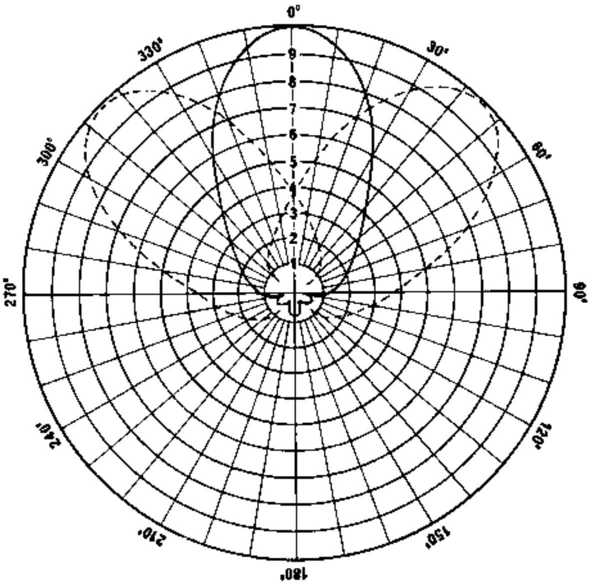

Figure 3. Azimuth radiation patterns for a typical multibeam array.

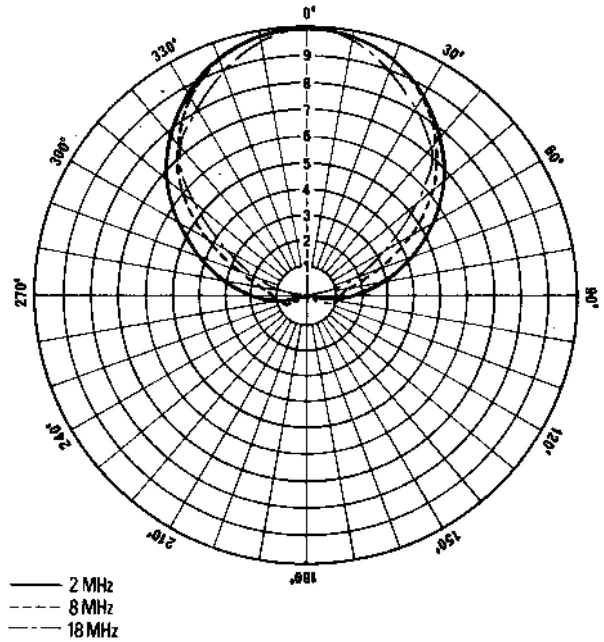

Figure 4. Azimuth radiation patterns of a single beam for a 6-beam array.

THE MULTIDIRECTIONAL SYSTEM

The method adopted to provide a full multidirectional system is to group a number of radially firing logloop arrays together (Figure 1). The number of arrays may be between 6 and 12 according to the number and width of sectors required. The arrays are arranged to fire inwards towards the array centre; the low mutual coupling between the active antenna elements very much reduces the performance disturbances which take place when conventional wire structures are used in this manner. In order to make maximum use of the occupied space for the array, the outputs of the array rows are split using 3dB hybrids and outputs from adjacent rows are combined. This procedure reduces the width of the main array beams, reducing the row length needed. Frequency independence is maintained as all rows are arranged to have a common apex at the array centre. Each main array beam is formed from the output of two adjacent rows and each element row contributes to two array beams. If additional intermediate beams are required they may be formed by combining the outputs of three adjacent rows, but in this case both amplitude and phase weightings are needed to obtain a satisfactory beam shape. It is interesting to note that the vertical beamwidth of the array is not affected by the combining system described; the objective of wide elevation coverage is satisfactorily achieved with a typical vertical 6-dB beamwidth of 45 degrees and no nulls below 60 degrees .

It has been found that by using the system described it is possible to design arrays with azimuth beamwidths from 90 degrees to as little as 35 degrees. The extreme simplicity of the beam forming network may be seen from Figure 2. Azimuth radiation patterns for a typical multidirectional array are shown in Figure 3. The excellent beam shape and good beam overlap are clearly seen.

The radiation patterns of the sector beams are remarkably stable in shape even when low values of τ are chosen in the interest of minimising the number of elements used in the array. Thus an array of 6 radial rows designed with $\tau = 0.8$ will cover the band 2-24 MHz with a directivity of 10 +/-ldB if 14 elements are used in each row. The azimuth radiation patterns of this array are shown in Figure 4.

<u>Reliability</u>

The array has high redundancy both in the rows and the array itself. The failure of any loop within a row is of little consequence as a large number of elements contribute to the output signa] at any frequency. If a complete row of elements is disabled, for example by the rupture of a cable, the result is a reduction of 3dB in the array output signal. No angular coverage is lost as the adjacent beams both become broader.

To confirm that the array is operating correctly, DC and RF monitoring facilities may be provided.

<u>Noise And Intermodulation</u>

The filters which limit the signal output of each active element to a restricted bandwidth also limit the noise output from each element to the same bandwidth. Thus at any frequency the 'unused' elements contribute no noise to the row output, either from internal or external sources. The main beam-forming network is a simple low loss passive system. Only those rows of the array which contribute signal to a beam output can also contribute noise to it. Thus the noise performance of the whole array may be computed if we know the characteristics of the active element and the ratio of the signal output of the array to that of a single element. This last parameter is computed from the element currents determined during the analysis of the log periodic row.

Intermodulation products produced in the active elements will not in general be removed in beam forming and may be generated in any array element. It is therefore very important that the IMP performance of the array elements should be suitable for the electromagnetic environment in which they are to be operated.

A further general discussion of noise and intermodulation in active antenna systems may be found in reference (4).

<u>CONCLUSION</u>

The active log periodic rosette array provides an extremely attractive solution to the design of a multibeam HF receiving antenna. Constant directivity, beam overlap and vertical coverage are combined with low side and rear lobes over a bandwidth of 3-1/2 octaves or more. The array has simple feeder and beam forming networks; its simplicity combined with its high degree of redundancy make for excellent reliability. The attractive technical performance of the array is combined with modest site requirements and minimal impact on the rural landscape.

<u>REFERENCES</u>

1. Carrel, R.L., 1961, <u>Univ. of Illinois, Tech. Rep. No. 52</u>

2. Hanna, K. A. H. & Collins, B.S., 1976, IEE Conference Publication No. 139, pp 35-38.

3. Collins, B.S., 1974, Communications 1974, Paper 5.3.

4. Collins, B.S., 1978, IEE Conference Publication No. 162, pp 278-280.

Various features of the elements and arrays described are the subject of current patent applications.