Optimal Cylindrical Antenna Arrays

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1. Introduction

The cylindrical arrays are an attractive subject of study for cellular base station antennas, particularly when omnidirectional scanning is needed. The mechanical size of the array should be minimized. The high sidelobe levels are a particular problem in cylindrical arrays [3]. Cylindrical arrays have also some 3-D capability, but that was not taken into account in these calculations.

This is a research for the optimal cylindrical array. Firstly the calculations are done for omnidirectional elements and patch elements, and secondly the properties for an optimal array are presented.

2. Optimal cylindrical array

This analysis was done for cylindrical arrays where the number of elements ranges from 16 to 48, because the original number of active array elements was selected to be 32. That high number of elements is useful in directional channel sounder measurements [1], but for an adaptive antenna array 8 elements might be the practical upper limit currently. The radiation pattern described as patch element radiation pattern is shown in Figure 3.

The optimal array can be defined in various ways. Here the optimal pattern was defined as 10° beamwidth at –20dB level, and maximum sidelobe level –20 dB. Stricter requirements for a base station antenna may not give much advantage, if the angular path spread is 5° and deepest sidelobes −10dB in practical situations [2].

In order to find the optimal combinations of the radius and element number, cost factor calculations were performed (Figure 1). The radiation pattern was calculated with a program that can have individually set radiation pattern, element weight (amplitude, phase), location and orientation of the antenna element. The theoretical background is given in [4]. The program calculates the cost factor indicating how much the pattern (in dB) of the real antenna differs from the desired array antenna pattern. The calculation was done for different numbers of active elements.

The weights for the elements were chosen so that they give narrowest main beam: equal amplitudes and phasing so that the elements are co-phased in the boresight direction. Then the sidelobes are inevitably high, but the idea was to find such arrays where the sidelobes are low by geometry.

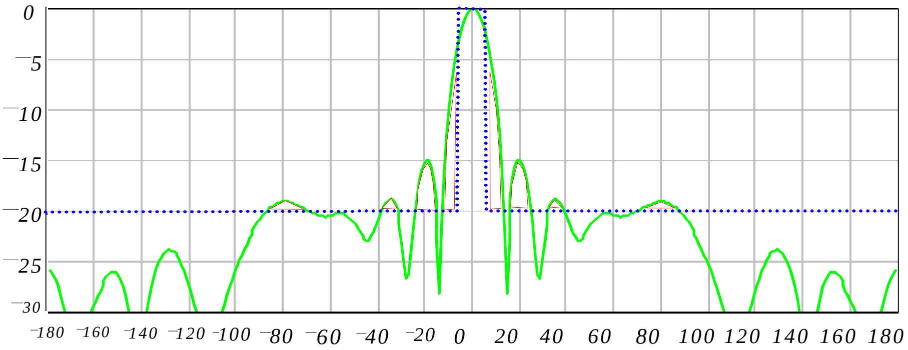

Figure 1. Example of the calculation of the cost factor: dotted line is the intended radiation pattern and the solid line is a real radiation pattern. The shadowed areas show the increments that are added to the cost factor.

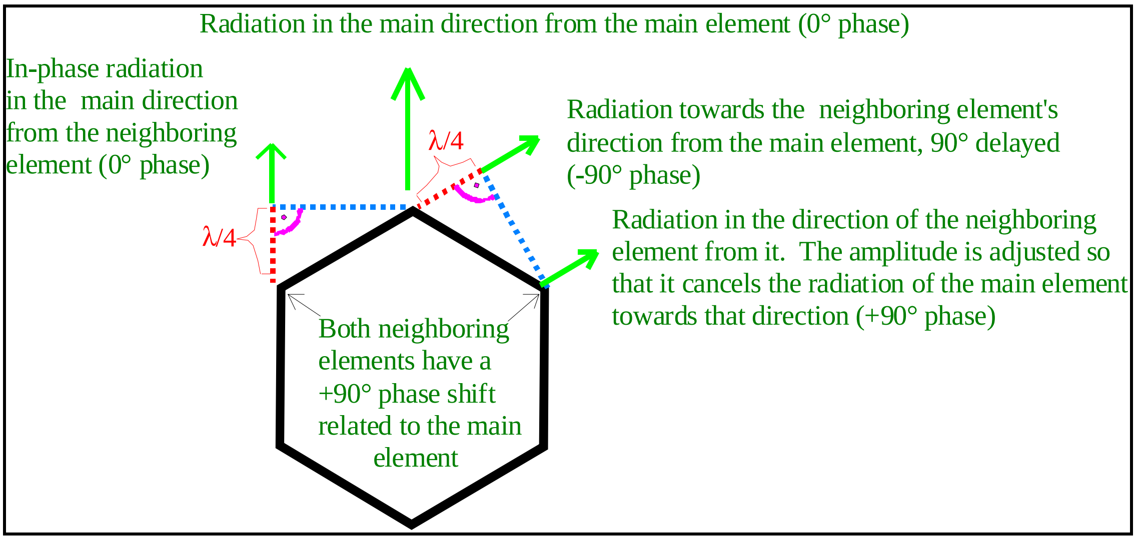

Figure 2. Operation principle of the cylindrical array, making use of array depth

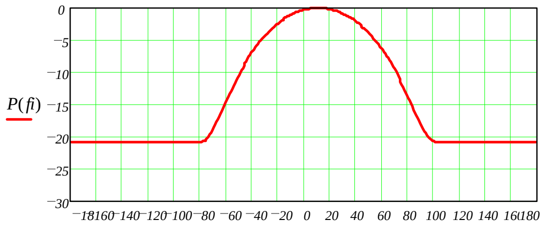

Figure 3. Patch element radiation pattern used in the calculations.

The following figures show optimal combinations of radius and numbers of elements. Optimum means the lowest cost factor for number of elements, versus radius. The optimal cost factor decreases when the number of elements increases. In the figures there are two straight lines showing the 0.5λ and the 0.75λ element spacing. In addition to those a line for the 90° or 0.25λ depth for the *second* element from the middle (towards boresight) element is shown. This depth is explained in Figure 2 [5]. For omnidirectional elements the results are shown in Figure 4. For five active patch elements the results are shown in Figure 5.

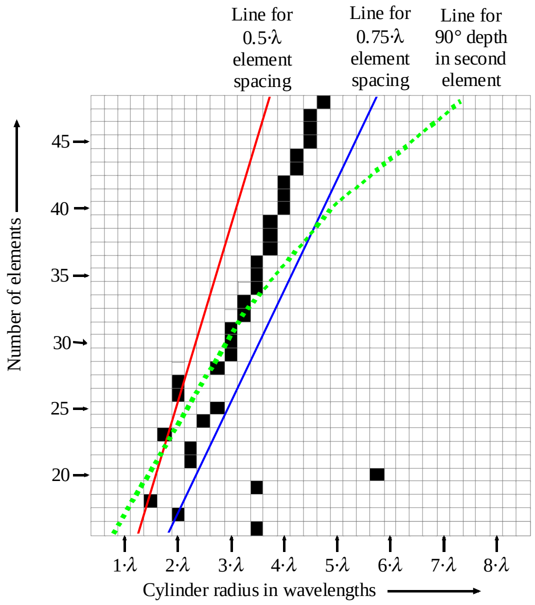

Figure 4. Optimal cylindrical arrays with omnidirectional elements. 7 active elements. Black squares show the optimum.

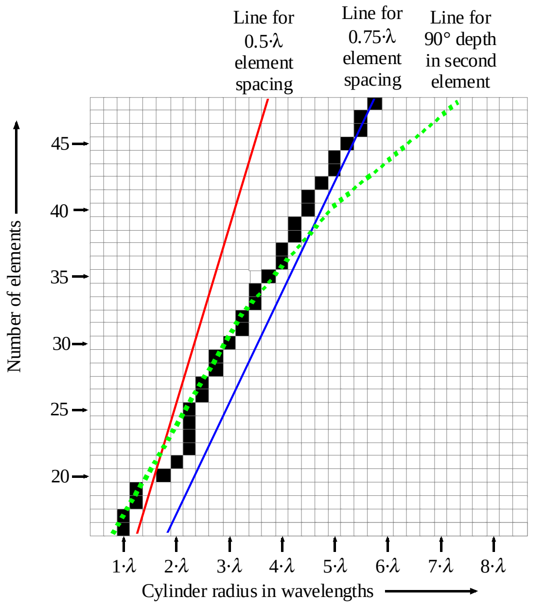

Figure 5. Optimal cylindrical arrays with patch elements. 5 active elements. Black squares show the optimum.

Patch elements with 7 active elements are shown in Figure 6, and with 9 patches active in Figure 7.

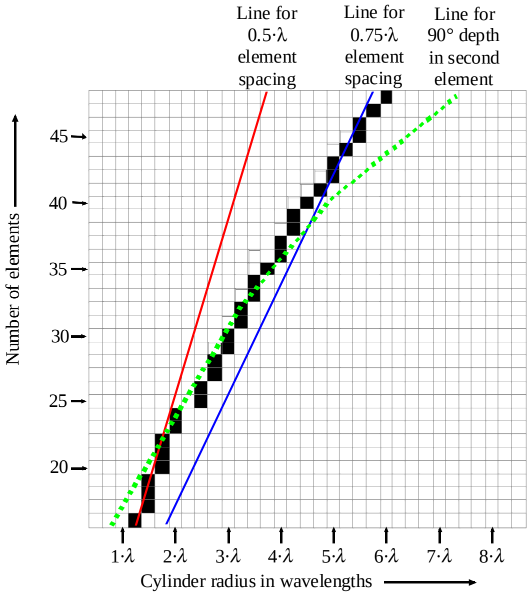

Figure 6. Optimal cylindrical arrays with patch elements. 7 active elements. Black squares show the optimum.

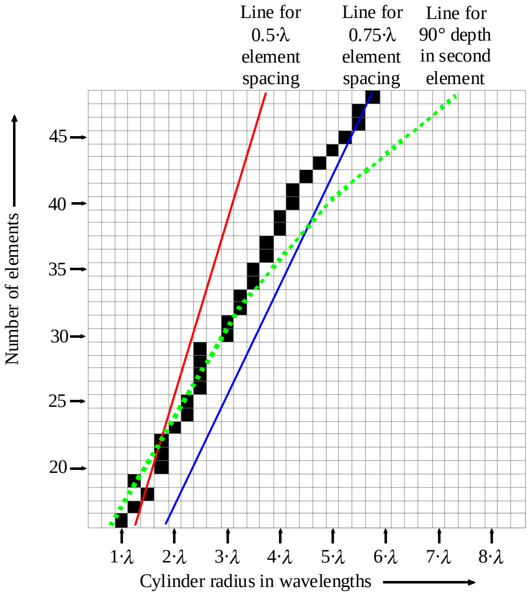

Figure 7. Optimal cylindrical arrays with patch elements. 9 active elements. Black squares show the optimum.

3. Properties of optimal arrays

From Figures 4 to 7 one can see that the optimal array element spacing is between 0.5λ and 0.75λ . For linear arrays the range is similar and 0.63λ was used in [5] so that the sidelobe levels stay reasonable when scanning the array. One can also see that the optimal array is close to the 90° depth line (second element pair from the center). Summing that up, the optimal cylindrical array has 90° depth in one array element pairs from the central element, and the element spacing is 0.63λ. Only few arrays fulfill both requirements. That requirement can be calculated by Equation (5) which is derived by Equations (1)-(4):

$$\alpha = \frac{2\pi R}{M} \tag{1}$$

$$R(1-\cos(N\alpha)) = 0.25 \tag{2}$$

$$\frac{2\pi R}{M} = 0.63 \tag{3}$$

$$0.25\alpha + 0.63\cos(N\alpha) = 0.63 \tag{4}$$

$$0.4\alpha + \cos(N\alpha) = 1 \tag{5}$$

R = radius
M = number of the elements
N = N^{th} element from the central element towards boresight

4. Calculated optimal arrays

The solutions for $N = 1$, 2 and 3:

$N = 1$: $R = 0.79\lambda$, $M = 8$ (In this case the second element pair from the center has close to 270° depth, which is also beneficial)

$N = 2$: $R = 3.1\lambda$, $M = 30$

$N = 3$: $R = 7.1\lambda$, $M = 71$ (In this case the 5th element pair from the center has 246° which is close to 270° depth, which is also beneficial)

In practical use the number of elements 32 is preferred over 30, causing a small difference in element spacing.

5. Discussion

This result is valid for element radiation patterns and active element numbers discussed in section 2. Narrower element beamwidths could give different results, but one has to bear in mind that the size of the elements with narrower beamwidths would be more than 0.5λ. An analysis that has all antenna elements active (and also adjusts all phases and amplitudes) testing for a wide range of radii and number of antenna elements would give better results, but would also increase computation times. Extending the theory below 16 or over 48 elements should be investigated in further studies. In general, the effects of the radius, number of elements (and thus the resulting element spacing and depth) and the element radiation pattern are difficult to separate, particularly with small cylindrical arrays.

6. Conclusion

The optimal cylindrical antenna properties are: the element spacing between 0.5λ and 0.75λ, and the depth of one or more element pairs compared to the central element towards the main beam should be 90° and/or 270°. For example a 32 element array with 3.25λ radius comes very close to this definition, the second pair has a 89° depth and element spacing 0.64λ. Optimized beamwidth is 13.2° at -3 dB level, and the sidelobe level is below –25 dB.

7. References

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