# Narrowbeam cylindrical antenna array with sparse antenna spacing

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## Abstract

**In this paper we suggest a cylindrical array, which utilizes signal cancellation and sparse element spacing. The array has narrow beamwidth and low sidelobe level. The beamwidth is about 12° for a 35 element array having -20 dB sidelobe level. Omnidirectional coverage area is obtained by a combination of commutation and phasing. The array has less elements and smaller size than a respective array consisting of linear panels.**

## 1 Introduction

Here we propose an antenna array design method that makes use of the antenna spacing, combined with directive antenna elements. It produces a narrow beam and relatively low sidelobe levels in a cylindrical antenna array configuration. The array could be used in adaptive base station antennas or in 2D propagation channel measurements to obtain narrow beams with small number of antenna elements. Simulated results are given in this paper with implementation examples for the center frequency of 2.15 GHz, which is the frequency of operation of the channel sounder system for adaptive array antennas developed at Helsinki University of Technology [1].

## 2 The principle

The cylindrical array normally has a wide main beam and high sidelobes [2] or it has a high number of elements [3],[4].

The idea is a ***combination of a λ/4 depth distance between array elements in the boresight direction in a cylindrical array and a 90° phase shift between them to cancel the grating lobes***, while making the array as sparsely spaced as possible in order to produce a narrow beam and to reduce the complexity of the electronics.

To explain the principle used in this paper to enhance the properties of the cylindrical array, let’s study a 6-element array (Figure 1)

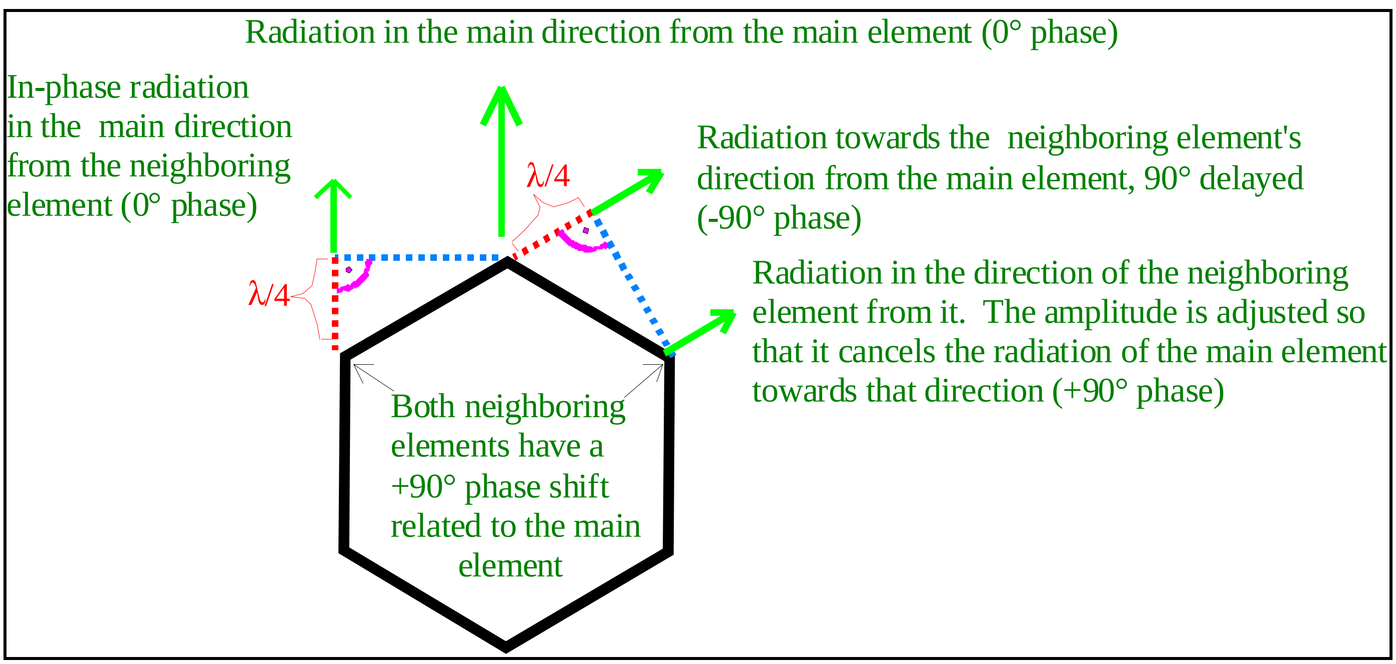


***Figure 1.*** *Operation principle of the proposed cylindrical array.*

The idea makes use of the depth in the array, so that the appropriate spacing and phasing of the neighboring elements cause an additive pattern towards the main direction and a canceling pattern towards the direction of the neighboring element. This principle can be applied in various ways, but the goal here is to provide a cylindrical antenna array for propagation measurement purposes and for adaptive antennas. In propagation measurements the horizontally omnidirectional scanning ability is useful. In adaptive antennas using digital beamforming, the minimizing of the number of the elements is desirable and low backlobe at the 180° is often desired to attenuate the late reflection from the back. Whether this kind of array can provide deep nulls in adaptive operation is still under research.

## 3 Validation of the theory

In order to verify the theory, calculations were performed that give a cost figure with various numbers of antenna elements and various array radii. 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 in [5]. It can also calculate the cost figure indicating how much the pattern (in dB) of the real antenna differs from the desired array antenna pattern.

In this example the element radiation pattern is assumed to have a horizontal behavior of $0.1+\cos(\phi)^2$ within $\phi$ = -90°...90° and 0.1 elsewhere. A typical example of such an element is the stacked patch antenna. The 3dB beamwidth of the element is then 70°. (The element pattern was not normalized but the final antenna array pattern was normalized.) The optimizations with other element patterns like the omnidirectional pattern gave comparable results. The optimal array is calculated compared to a pattern where the 3dB beamwidth is 10°. The sidelobe level is –20 dB which is a common requirement.

Cylindrical arrays often make use only a part of the elements at a time to reduce the complexity of the pattern computation [2]. Then the cylindrical array resembles functionally an arc array. To produce similar patterns into various directions the active elements can be switched successively (rotated) along the cylinder surface. The beam can be also formed to the intermediate directions between switched directions by adjusting the weights, resulting in a similar radiation pattern (Figure 5).

This test is using 5 active elements of the whole array, because 3 elements quickly caused too wide element spacing. Wide element spacing like 1.3·λ caused sidelobe levels of about -10...-15dB, which was too high for the channel sounder but may be all right in microcellular base stations in congested areas. The optimal cylindrical array was first searched with equal amplitude excitation of the elements, and phasing adjusted so that it resulted in the narrowest main beam

Combinations of various radii (0.5·λ...8.75·λ) and number of elements (8...48) were evaluated. Out of 1083 combinations, the combinations causing minimum costs at the smaller radii (1·λ...5·λ) are listed in Table 1.

One can see (Table 1) that the minimum combinations have the second weight (Weight2) close to 90° phasing except for the smallest radius 1·λ. This result is in agreement with the design principle described in Section 2. With 1·λ radius it could be expected (based on the idea that the second weight is 90°) that the optimum number of antenna elements $N$=17. The antenna spacing is low for 17 antenna elements which causes the beamwidth to be wide and therefore the cost function is high. With 2·λ radius the expected number of elements is $N$=25 and with 3·λ radius $N$=30, which are close to the values in Table 1. With 4·λ the expected $N$=35 which holds. With 5·λ the expected $N$=39, but the resulting optimum was at $N$=42 which is again quite close. The case where the radius is 5·λ and N=42 resembles a combination of 6 panels of linear arrays of 7 elements each, but has smaller diameter (140 cm compared to 147 cm at 2.15 GHz).

The calculations of the cost as a function of $N$ revealed interesting results (Figure 2). As expected, the cost decreases when the number of the antenna elements increases, because then the main beam is sharper. But the minimum and maximum (achieved at each element number for different values of the radius) curves are not monotonous.

***Table 1.*** *Combinations causing minimum costs at various radii*

| Number of elements | Radius | Element spacing | Weight1 phase | Weight2 phase | Cost |
|---|---|---|---|---|---|
| 14 | 1·λ | 0.46·λ | 36° | 137° | 1119 |
| 24 | 2·λ | 0.52·λ | 24° | 96° | 621 |
| 28 | 3·λ | 0.67·λ | 27° | 107° | 457 |
| 35 | 4·λ | 0.73·λ | 23° | 93° | 393 |
| 42 | 5·λ | 0.75·λ | 20° | 80° | 367 |

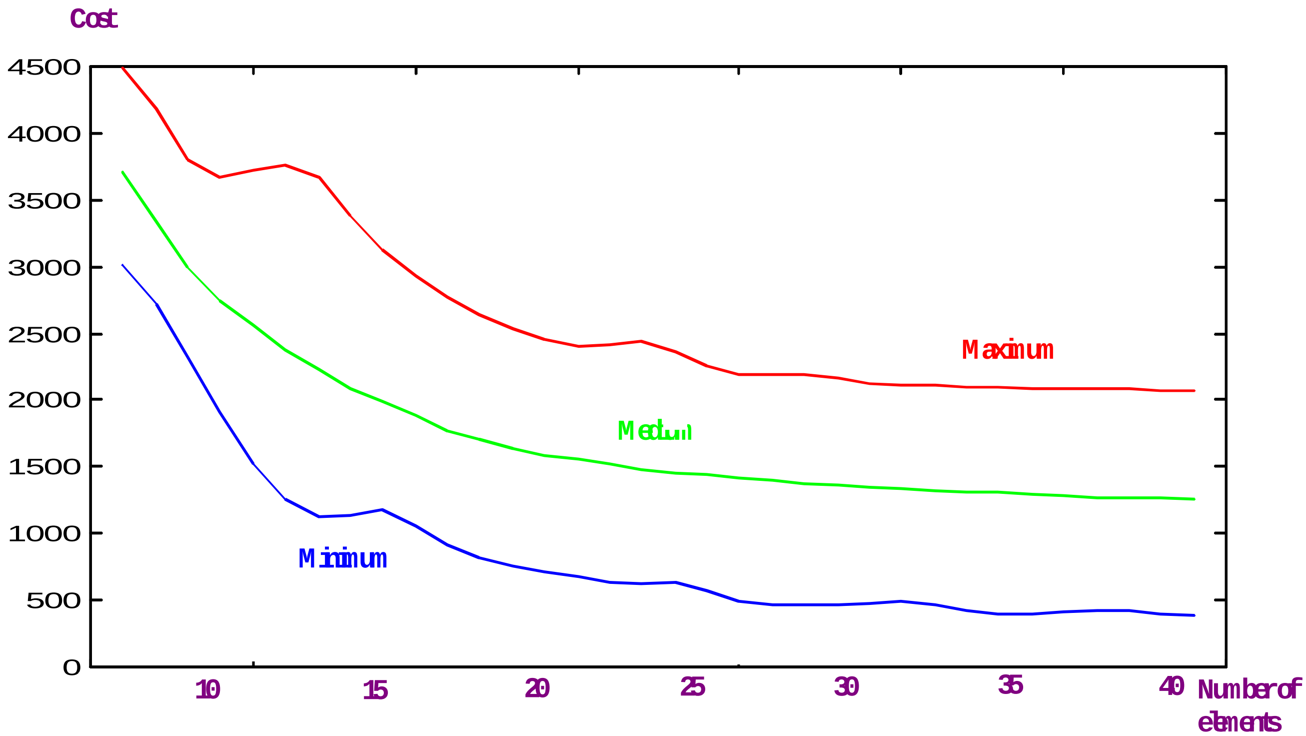


***Figure 2.*** *The cost function versus the number of elements. There are local minima at 14, 22and 27 elements.*

The cost versus radius is even more interesting (Figure3). The minimum costs are located at where the radius is an integer number of wavelengths. Currently there is no explanation for that. Also the tests with the omnidirectional element pattern gave similar results.

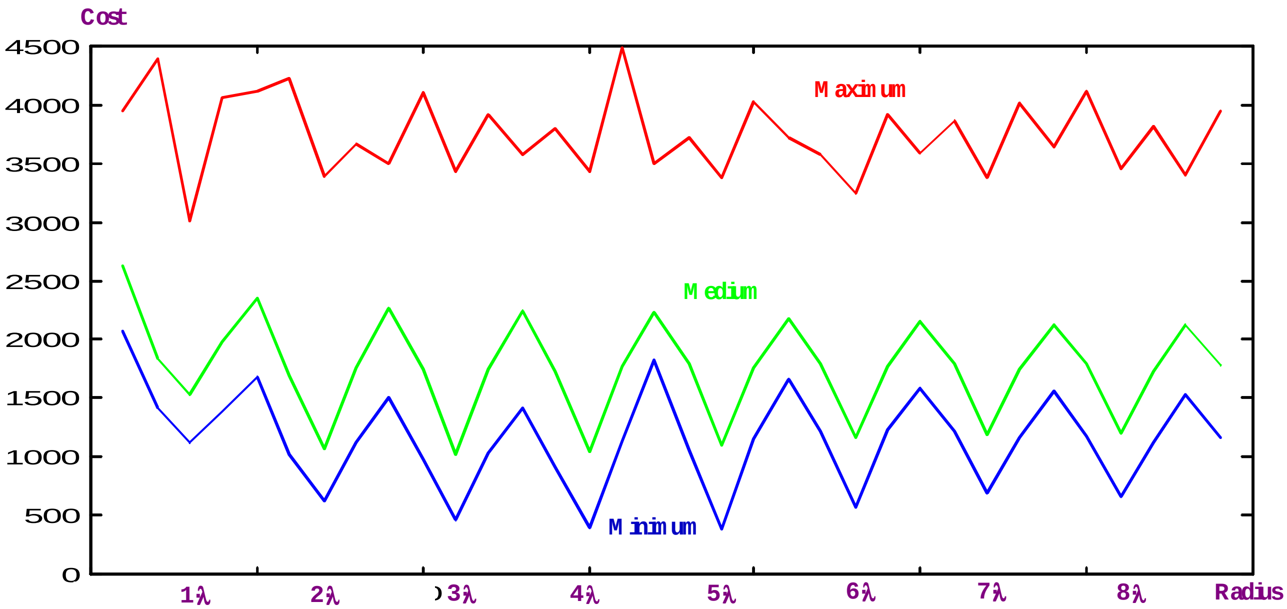


***Figure 3.*** *The cost function versus radius. The minima are at 2, 3, 4 and 5 · λ*

## 4 Calculated array patterns for a 35 element array

The array weights were optimized to produce a final pattern that is as close to the requirements as possible. This optimization was done with 7 elements in order to get narrower radiation pattern. If the 5 element pattern is the optimum, then the weights for the elements at the edge will become zero. The 7 active elements of an array of 35 elements correspond to a 72° arc antenna. In the best case all the variables: radius, number of the elements, and the element weights (amplitude, phase) should be optimized simultaneously, but currently it is a huge task.

By using a 35-element array, where 7 or 8 adjacent elements are in use at a time (amplitude and phase are controlled) to produce a directional beam, the radius becomes $4\cdot\lambda$ which means that the diameter is 113 cm at 2.15 GHz. By switching or commutating the selected elements, a coverage of 360 degrees can be obtained. In this example the element pattern is again $0.1+\cos^2(\phi)$. The 3 dB beamwidth of the array is close to 12° and the sidelobes are 20dB or more below the main beam top (Figures 4 and 5). The bandwidth of the structure is about 10 % (± 5 %) without significant degradation of the pattern. However, a ±10% change in the frequency causes significant changes in the radiation pattern. But also then the problem can be partly compensated by adjusting the weights at different frequencies.

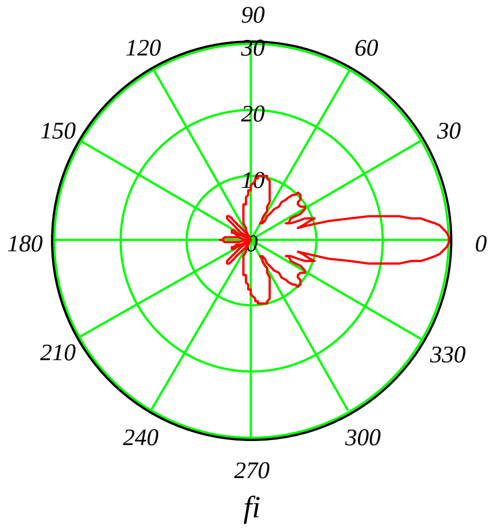


***Figure 4.*** *Radiation pattern in the horizontal plane for the 35 element cylindrical array. 7 active elements are used with optimized weights for -20dB sidelobe level and narrow beamwidth. (W0=1 at 0°, W1=1 at 20°, W2=0.7 at 90°, W3=0.7 at 190°). 3dB beamwidth is 12.1°.*

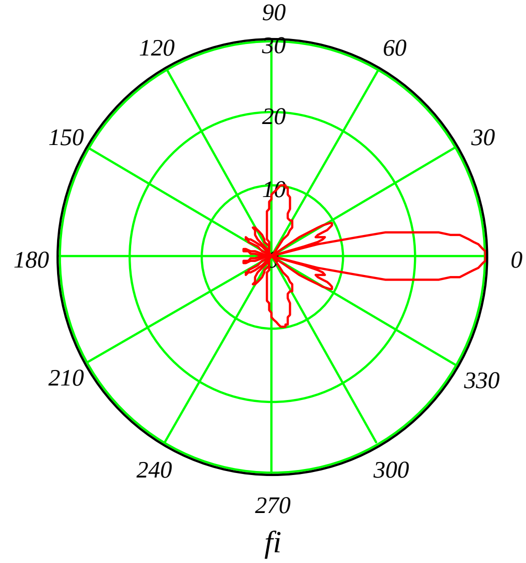


***Figure 5.*** *Radiation pattern for the 35 element cylindrical array. Now the boresight direction is in the middle of the 2 central active elements. 8 elements are active in order to get an even number of elements in this special case. The weights are optimized manually for -20dB sidelobe level and narrow beamwidth. (W0=1 at 0°, W1=0.7 at 50°, W2=0.7 at 140°,W3=0.4 at 270°. The 270° depth has a similar effect as the 90° depth). 3 dB beamwidth is 11.5°.*

### *Comparison with the linear array*

The linear array requires 6 panels, if one scans ±30°. It means 42 antenna elements and 124 cm diameter. The panel consists of a linear 7-element array, because it corresponds the number of the active array. The element pattern is the same as above. Chebyshev weights are used in order to get -20 dB sidelobes and a sharp main beam.

The spacing is $0.60\cdot\lambda$ because the $0.73\cdot\lambda$ element spacing gives only ±16° scan angle if one wants to keep the grating lobes below -20 dB. One can notice that it is possible to use a $0.73\cdot\lambda$ spacing with the cylindrical antenna, although it is not feasible in the comparable linear array. Therefore the $0.73\cdot\lambda$ spacing is called sparse spacing here. With the $0.73\cdot\lambda$spacing the 3dB beamwidth of the linear panel is 11.1° when not scanned but when scanned to 30° the grating lobe would level be –6dB. At 16° scan angle the 3dB beamwidth is 11.5°. However, 360 degree coverage would require 12 panels of 7-element arrays, which would mean that the total antenna array would have a 276 cm diameter at 2.15 GHz.

The radiation patterns for the linear array suitable for scanning ±30° are below (Figures 6 and 7). In this case the beamwidth is wider than for the cylindrical antenna: 13.5° when not scanned and 15.5° when scanned to ±30°.

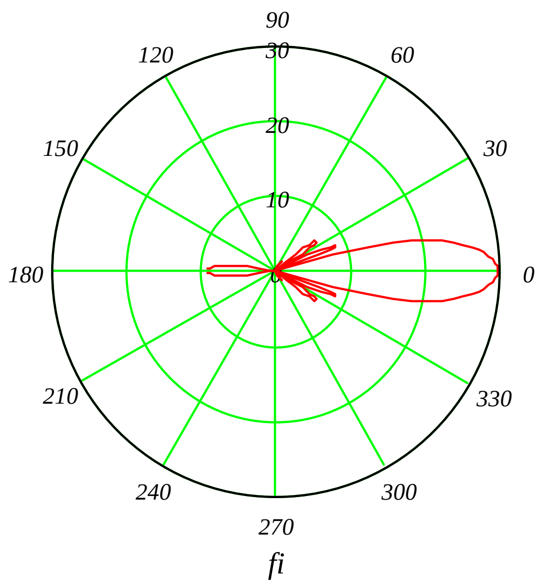


***Figure 6.*** *The radiation pattern in the horizontal plane for a linear 7-element array with 0.60· λ spacing, 0.1+cos$^2$(ϕ) element pattern, Chebyshev weights and 0° scan angle. (all weights have same phase, W0=1, W1=0.916, W2=0.694, W3=0.544) 3 dB beamwidth is 13.5°.*

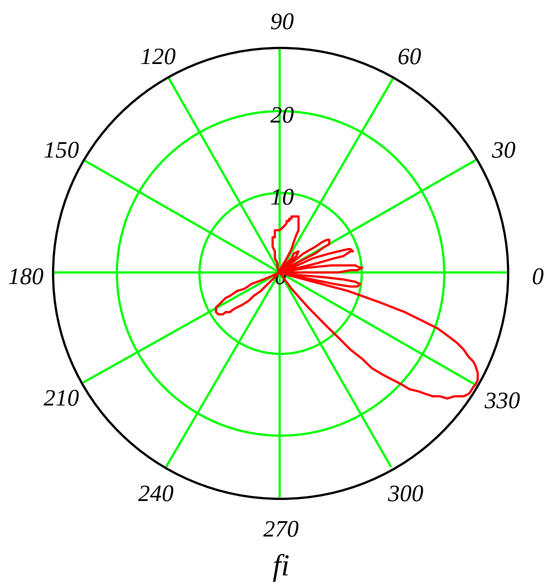


***Figure 7.*** *The radiation pattern in the horizontal plane for a linear 7-element array with 0.60· λ spacing, 0.1+cos$^2$(ϕ) element pattern. Same Chebyshev weights as in figure 6. Scanned to 30° scan angle. 3 dB beamwidth 15.5°.*

## 5 Conclusions

The optimal cylindrical array has one element pair at the 90° depth of the central element. It enables smaller onmidirectional antenna array diameter and a smaller number of elements than in linear array panels with comparable sidelobe levels. Due to the principle that the beam steering is based mostly on commutating, constant amplitude weights can be used for all directions. Also the comparably sized cylindrical array has narrower beamwidth.

## References


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