Spring 2019

EECE 588
Lecture 14

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Broadside Arrays

- In many applications, it is desired to have the maximum radiation of the array occur at broadside (normal to the axis of the array.
- The first maximum occurs at:

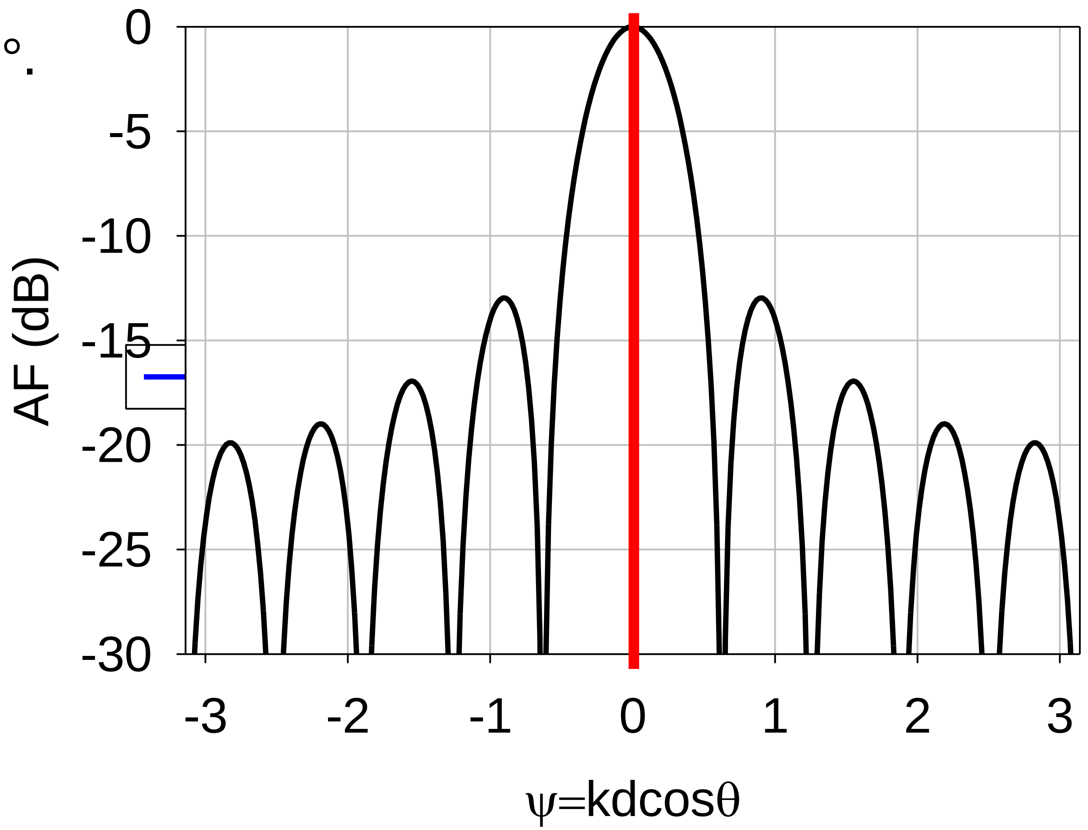
$$\psi = kd\cos\theta + \beta = 0$$

$$\psi = kd\cos\theta + \beta\Big|_{\theta=90^\circ} = \beta = 0$$

- Therefore, for broadside arrays, the phase difference between the elements must be zero.

Broadside Arrays (2)

- Go back to the array factor and see that if $\beta = 0$, then the maximum value of the function occurs $\psi = 0$.
- This happens for $\theta = 90°$.



Broadside Arrays (3)

- It is also important to make sure that there are no principal maxima at other directions.
- To make sure this does not happen, we have to have $d < \lambda$.
- If $d = n\lambda$ and $\beta = 0$, we have.

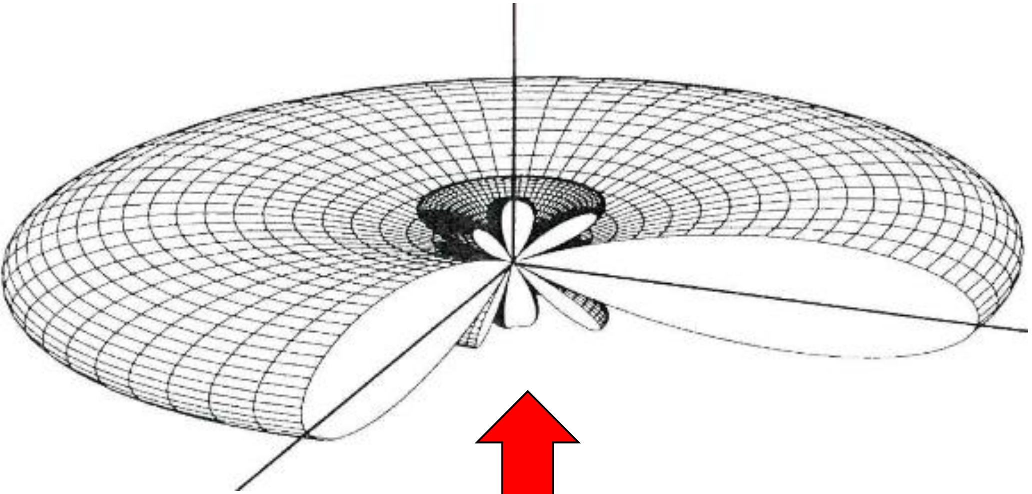
$$\psi = \frac{2\pi}{\lambda} d\cos\theta + \beta = 2\pi n\cos\theta\Big|_{\theta=0^\circ,180^\circ} = \pm 2n\pi$$

- But this value of ψ maximizes the array factor for $\theta = 0°$ and $180°$.
- In this case the array will have two other maxima at $0°$ and $180°$ in addition to the desired one at $90°$.
- If the spacing is increased beyond a wavelength, these two directions of maximum radiation will shift into the visible region.

Grating Lobes in Broadside Arrays

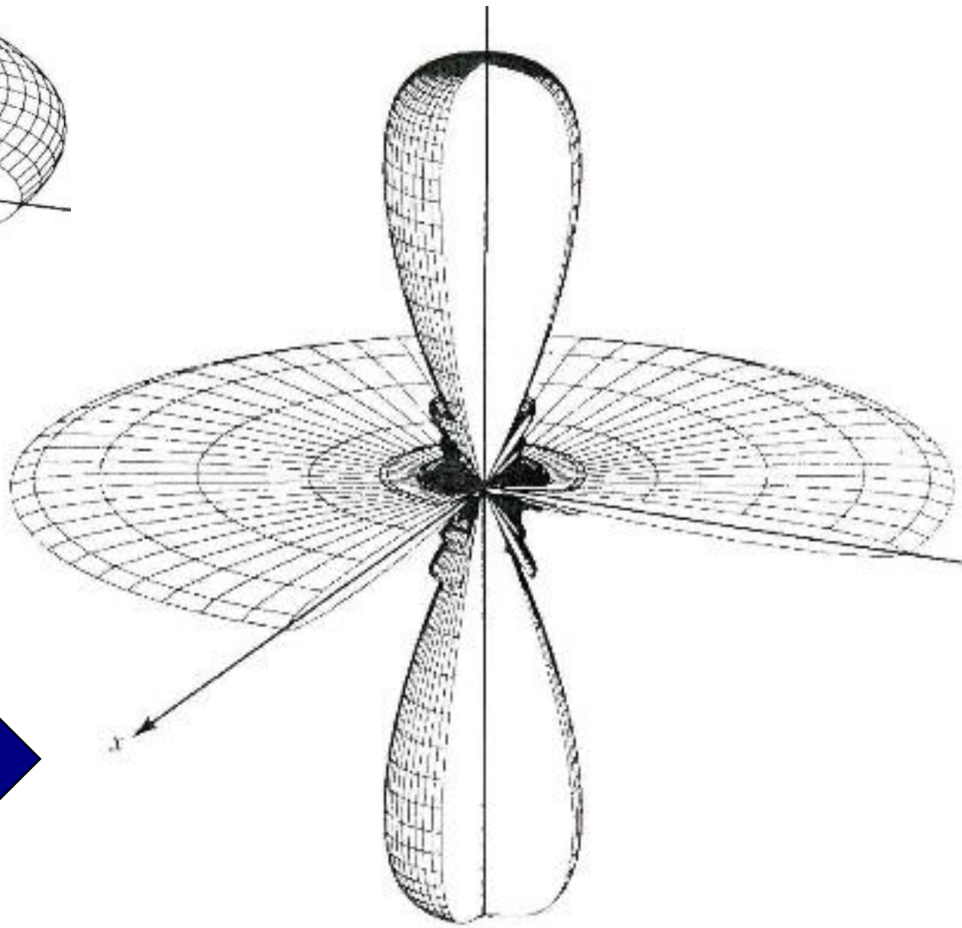
- Naturally we want to have only one maxima.
- Maxima in directions other than the desired one are referred to as the grating lobes.
- To avoid the grating lobes, the largest spacing between the elements should be less than one wavelength.

Grating Lobes in Broadside Arrays (2)



$$N = 10, d = \lambda/4$$

$$N = 10, d = \lambda$$



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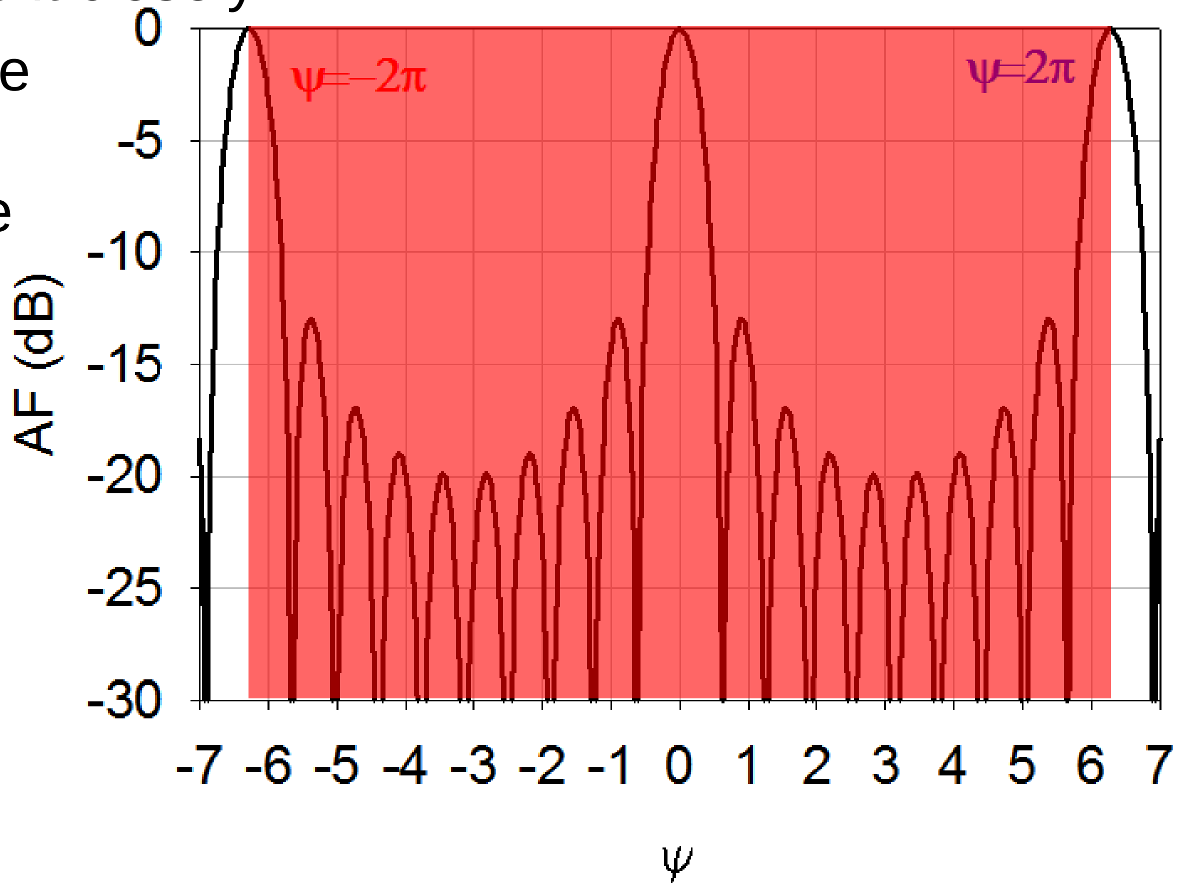
Grating Lobes in Broadside Arrays (3)

- To see why this happens, you can also go back to the array factor and examine it closely.
- Note that the visible region extends to $\psi = +/-\pi$ when we have $d = \lambda$.
- In this case, the periodic peaks of the AF now enter the visible region and manifest themselves in the form of grating lobes!



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Ordinary End Fire Arrays

- Instead of having the maximum radiation broadside to the axis of array, it may be required to direct it along the axis of the array.
- In end fire radiation, we desire to have radiation in either $0°$ or $180°$.
- To direct the first maximum toward $\theta = 0°$:

$$\psi = kd\cos\theta + \beta\,|_{\theta=0^\circ} = 0 \Rightarrow \beta = -kd$$

- For $\theta = 180°$:

$$\psi = kd\cos\theta + \beta\,|_{\theta=180^\circ} = 0 \Rightarrow \beta = +kd$$

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Sum and Difference Patterns in Arrays

- A difference pattern has a null at broadside instead of a peak.
  - This null can precisely locate the direction of a signal, because the null has a very narrow angular width compared to the width of the main beam of a corresponding sum pattern.
  - When the array output is zero, the signal is in the null. Slight movement of the null dramatically increases the gain of the array factor and the reception of a signal.
  - A regular sum array can be converted into a difference array by giving half the elements a $180°$ phase shift, or half the elements are one and half are minus one.

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Sum and Difference Patterns in Arrays (2)

- Array factor:

$$AF = \frac{1 - \cos\left(\frac{N\psi}{2}\right)}{j \sin\frac{\psi}{2}}$$

Applications include monopulse radar

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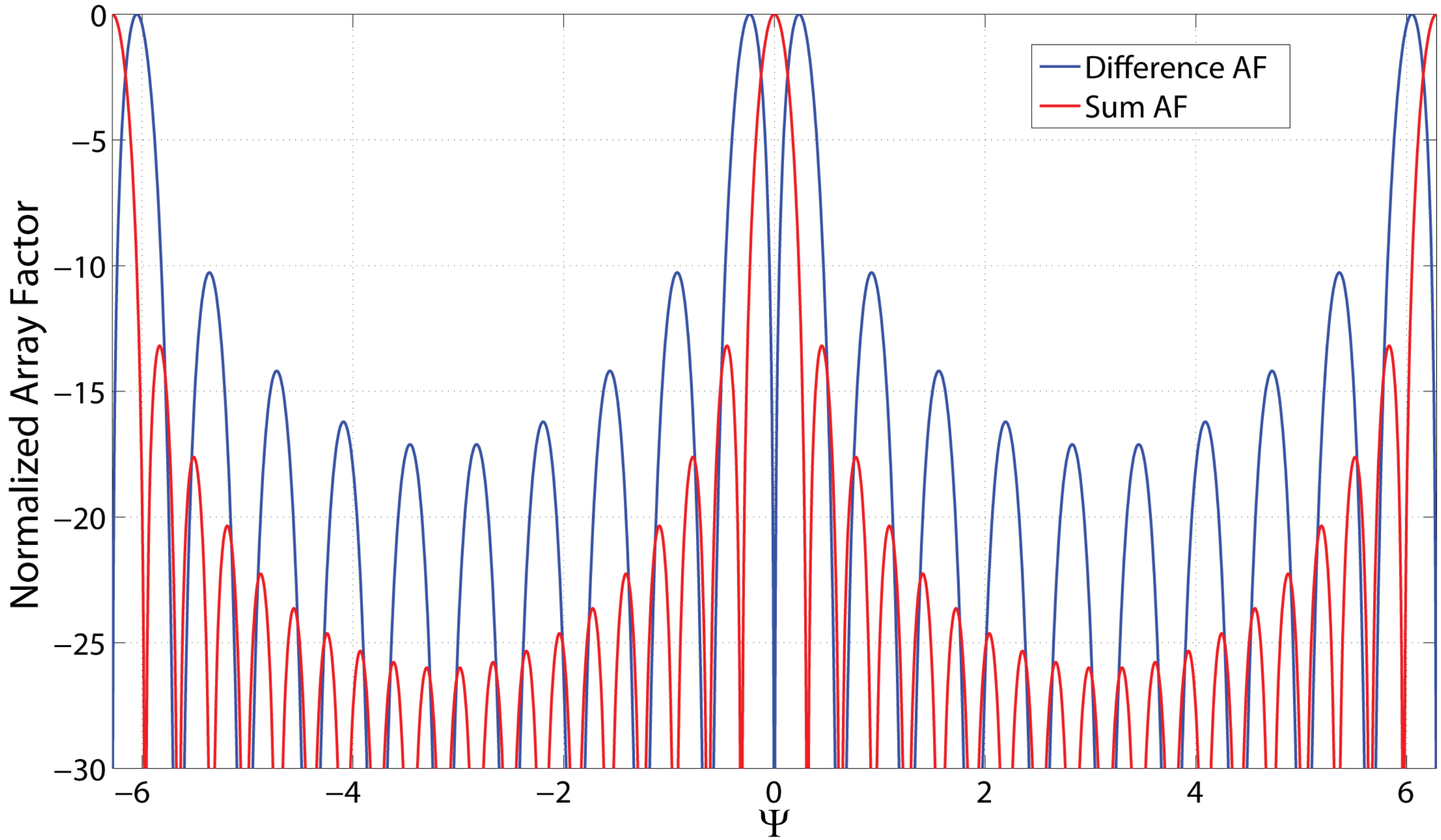
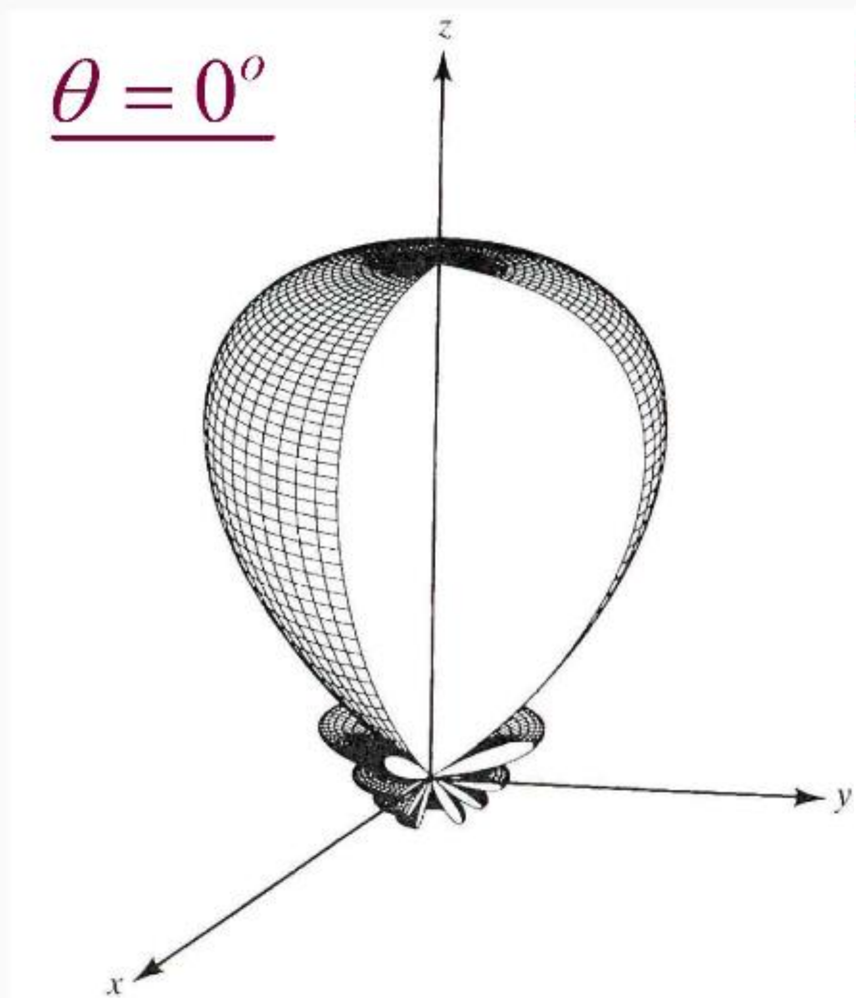
Sum and Difference Patterns in Arrays (3)

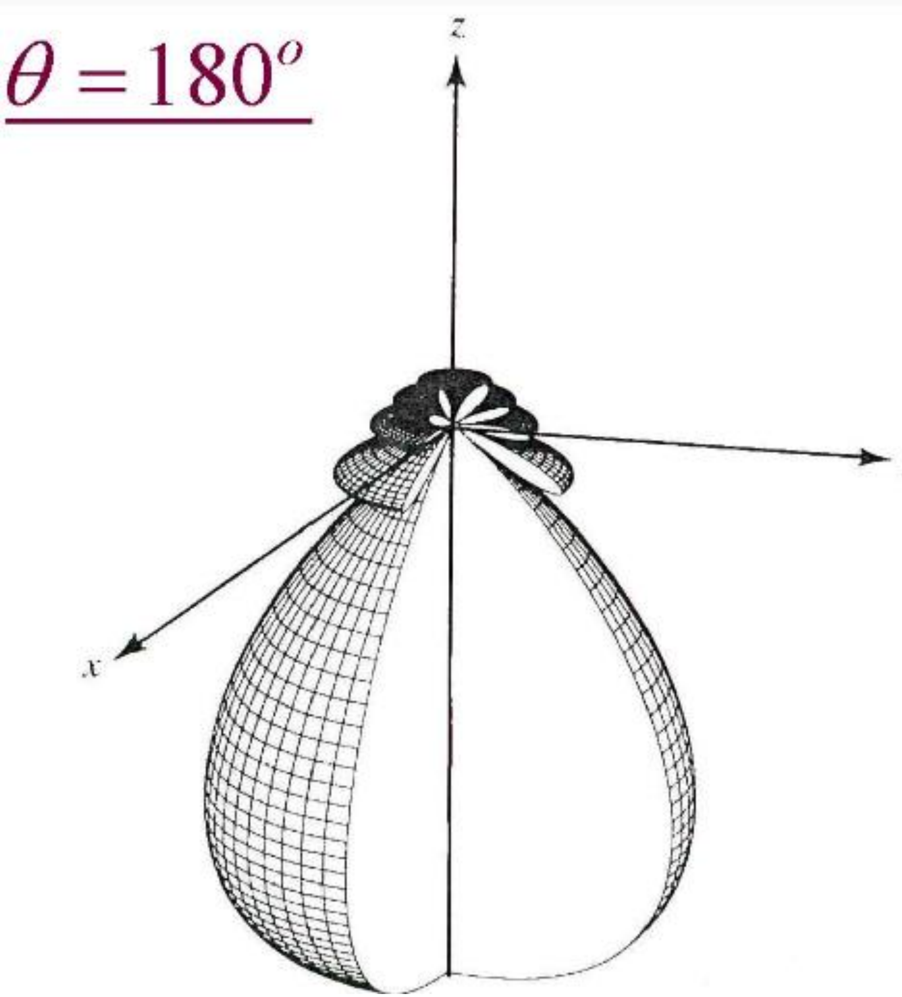


Ordinary End-Fire Arrays (2)

- If the element spacing is $d = \lambda/2$, end fire radiation occurs simultaneously in both directions $\theta = 0°$ and $\theta = 180°$.
- If the element spacing is $d = n\lambda$, then there will be a broadside maximum in addition to two end fire radiations.
- To have only one end fire maximum and to avoid any grating lobes the maximum spacing between the elements should be less than $d_{max} < \lambda/2$ or half a wavelength.

Ordinary End-Fire Arrays (3)





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Hansen Woodyard End Fire Array

- Hansen and Woodyard proposed a method of designing end-fire arrays with enhanced directivity compared to the condition we obtained before.
- The condition is to have the following phase shift between closely spaced elements of a very long array:

Maximum along $\theta = 0°$

$$\beta = -\left(kd + \frac{2.92}{N}\right) \approx -\left(kd + \frac{\pi}{N}\right)$$

Maximum along $\theta = 180°$

$$\beta = +\left(kd + \frac{2.92}{N}\right) \approx +\left(kd + \frac{\pi}{N}\right)$$

Hansen Woodyard End-Fire Array (2)

- To realize the increase in directivity based on the Hansen and Wodyard condition, we must also have (in addition to the desired phase shifts):
  - For maximum radiation along $\theta_0 = 0°$:

$$|\psi| = \left|kd\cos\theta + \beta\right|_{\theta=0^\circ} = \frac{\pi}{N} \quad \text{and} \quad |\psi| = \left|kd\cos\theta + \beta\right|_{\theta=180^\circ} \approx \pi$$

  - For maximum radiation along $\theta_0 = 180°$:

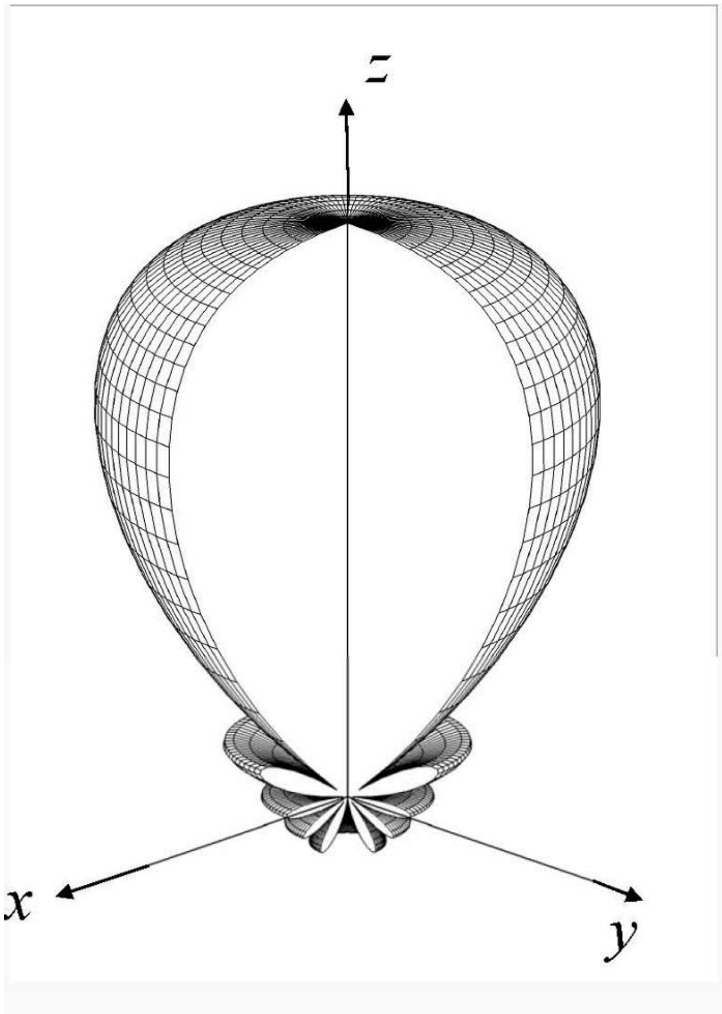
$$|\psi| = \left|kd\cos\theta + \beta\right|_{\theta=180^\circ} = \frac{\pi}{N} \quad \text{and} \quad |\psi| = \left|kd\cos\theta + \beta\right|_{\theta=0^\circ} \approx \pi$$

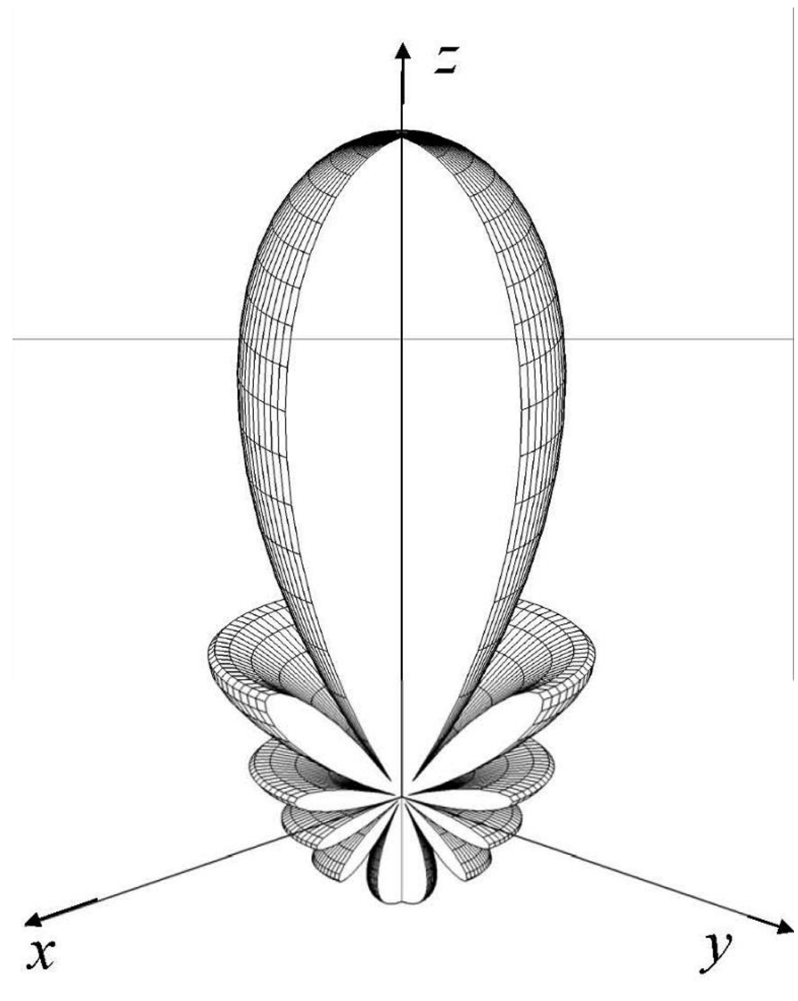
Hansen Woodyard End-Fire Array

- The condition of $|\psi| = \pi/N$ is realized by using the appropriate phase shifts.
- The condition of $|\psi| = \pi$, however, is realized by using the appropriate phase shift as well as the element spacing equal to:

$$d = \left(\frac{N-1}{N}\right)\frac{\lambda}{4}$$

Comparison Between Ordinary End-Fire and Hansen-Woodyard (N=10, d=λ/4)





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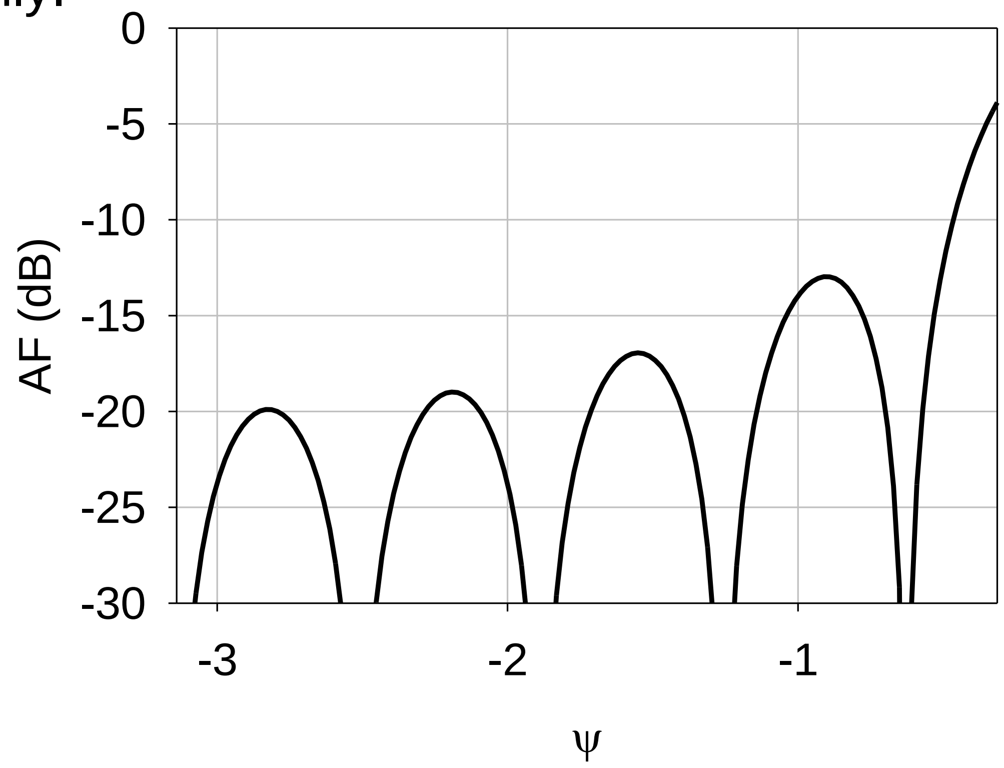
Hansen Woodyard End-Fire Arrays: My Perspective

- You can see the derivations of the Hansen Woodyard array in your textbook but I have a much better explanation.
- The conditions for the Hansen Woodyard, limit your visible region for $\theta = 0$ to $-\pi < \psi < -\pi/N$ only.
- This is plotted for $N = 10$.

• Note that the roll off in the array factor vs. ψ is much faster than the original array factor.

• This means a larger directivity and narrower pattern (beam width).



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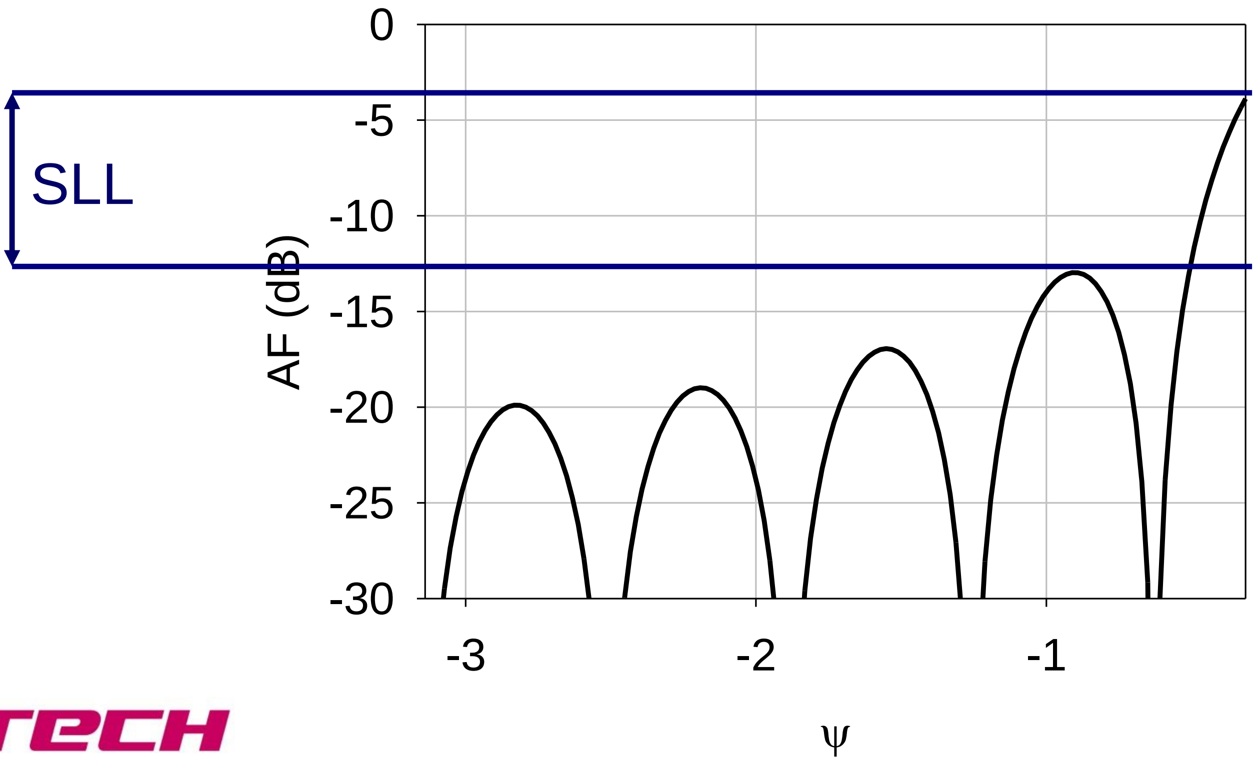
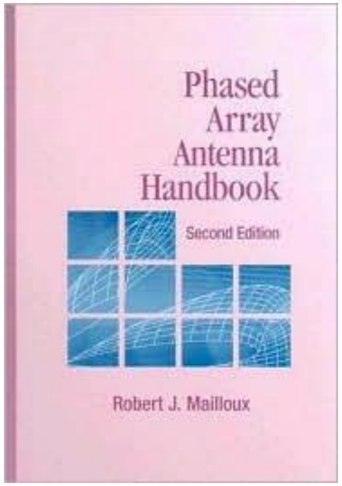
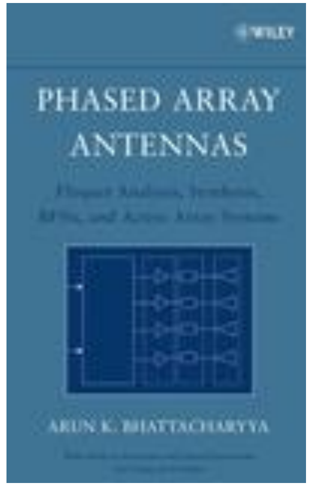
Hansen Woodyard End-Fire Arrays: My Perspective (2)

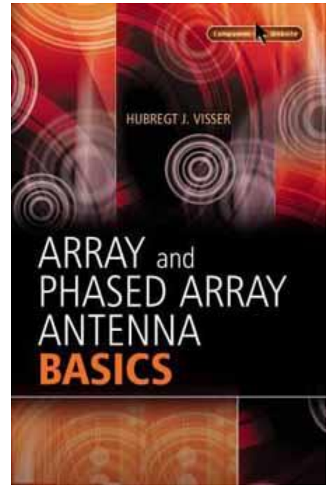
- Also you can see why the side lobe levels are higher compared to the ordinary end fire arrays

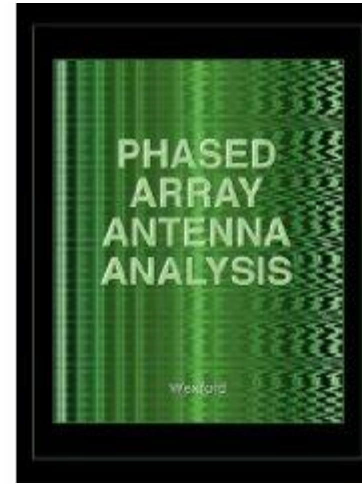


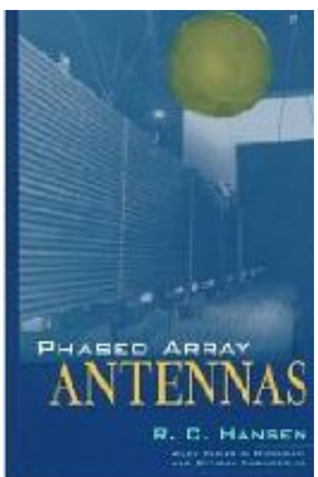
Phased Arrays (Scanning Arrays)











Phased Arrays – Some Nice Pictures

Dual X-/L Band Radar on Mig 31 (Passive Electronically Steered)

SPY Radars Used in Aegis Combat System

Phased Arrays – More Nice Picture

AN/FPS-108 COBRA DANE

1215-1400 MHz

Phased Arrays

- As we have seen, direction of maximum radiation can be changed by appropriate design of the array factor.
- It is natural to assume that the beam can then be controlled dynamically .
- The beam of an antenna can be directed towards any direction (in theory) by:

$$\psi = kd\cos\theta + \beta\,|_{\theta=\theta_0} = kd\cos\theta_0 + \beta = 0 \Rightarrow \beta = -kd\cos\theta_o$$

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Examples of Beam Scanning By Varying the Phase Shifts

- We are going to see a couple of videos.
- Scenarios shown in these videos include these:
  - Antenna Array with 10 Elements.
  - Uniform Excitation in Magnitude.
  - Variable Phase Shift to scan the beam from 90° (broadside) to 180° (grazing angle).
  - Differences:
    - d=0.25λ, d=0.5λ, d=0.75λ, d=1.00λ
  - Comparison of d=0.25λ and d=0.80λ

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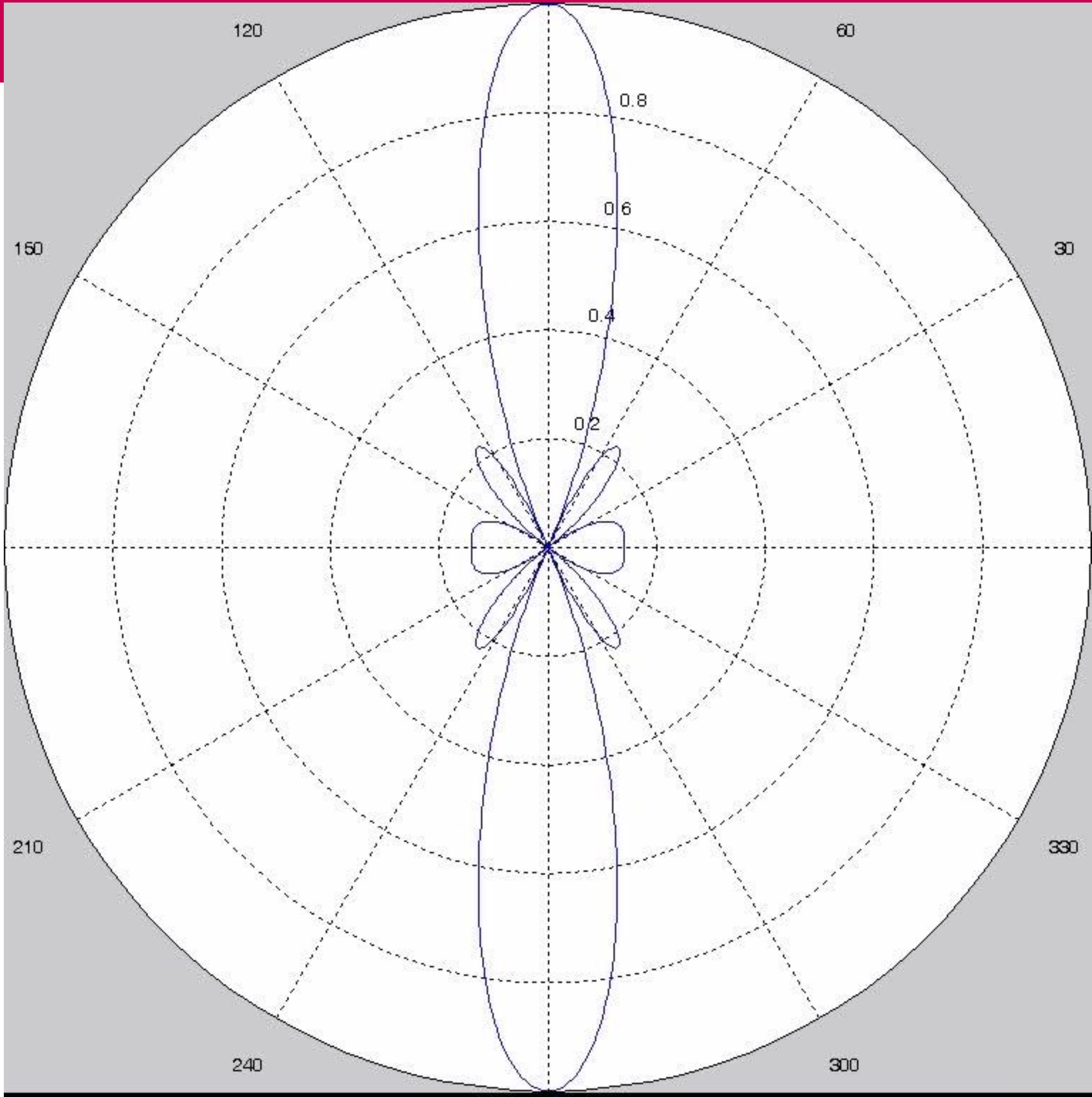
$d = 0.25\lambda$



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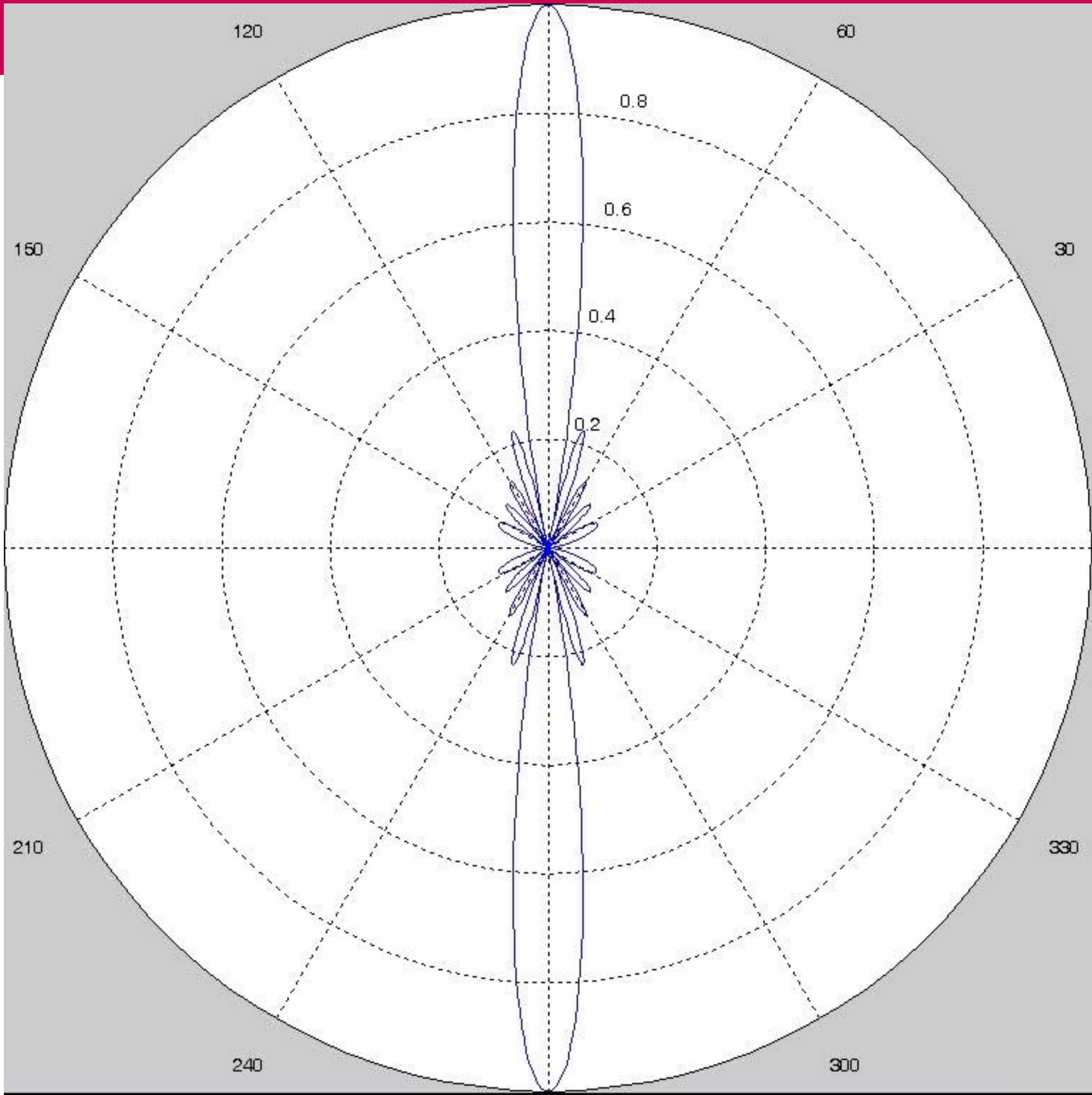
$d = 0.5\lambda$



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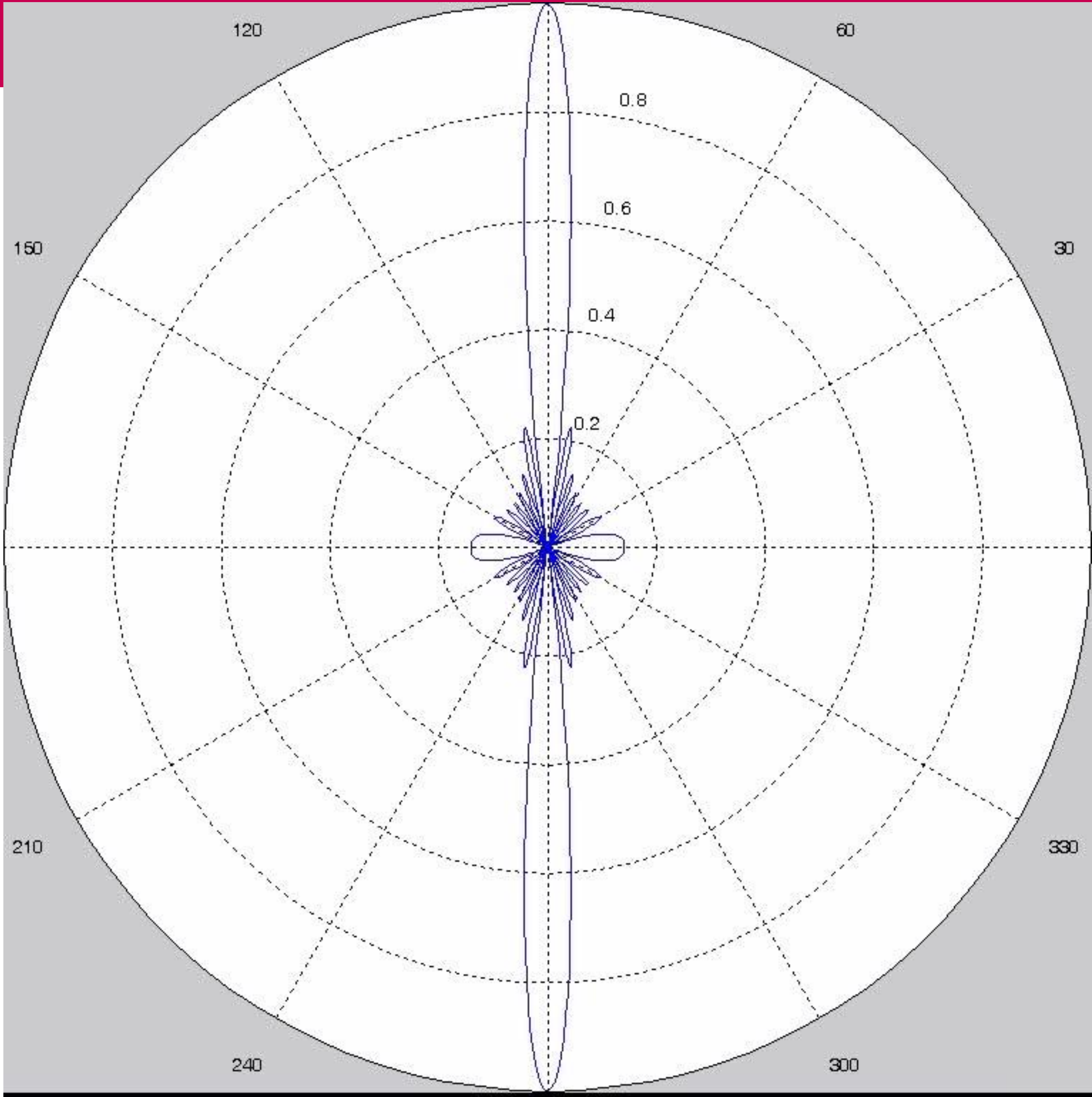
$d = 0.75\lambda$



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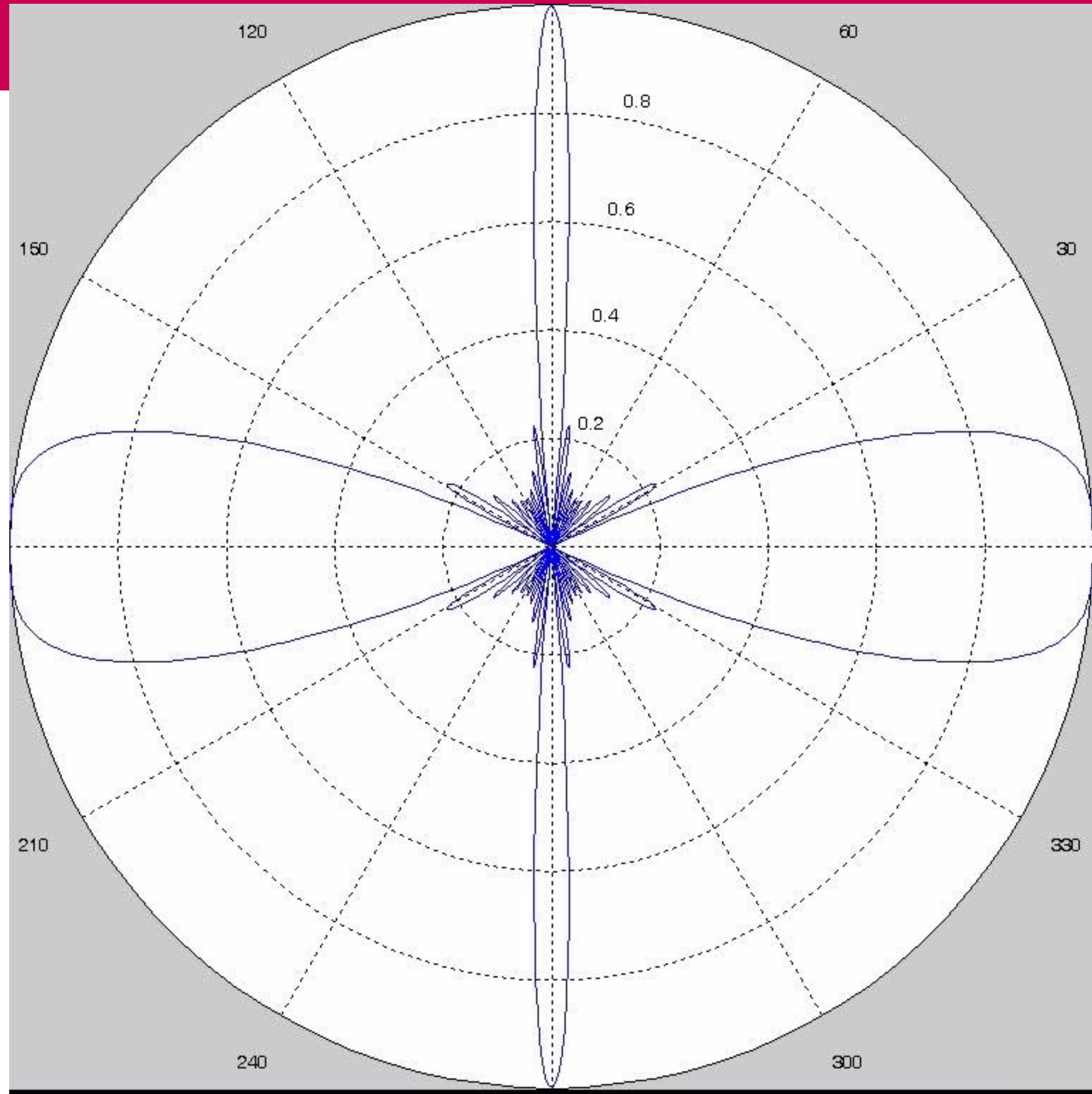
$d = \lambda$



Comparison between $d = 0.25\lambda$ and $d = 0.8\lambda$