Array Configurations

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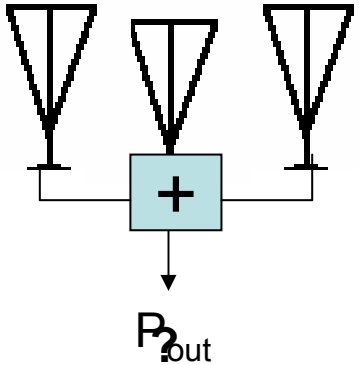
Revision!



- Depends on spacing
  - Power received depends on effective area
    - Effective area= λ^2 . (Gain) . $(4\pi)^{-1}$

Gain

- The ratio of the power received by a distant source at a given angle to the power that would have been received by the same source if your antenna is replaced with a ‘ideal’ omni directional antenna- for now just consider peak gain
- Let the radiation pattern of the antenna be $E(\theta,\varphi)$ where E is the electric field and θ,φ is the angular direction of the source

- Assuming zero antenna losses

- $$\text{Gain} = \frac{4\pi \, |E_{peak}|^2}{\int_0^{2\pi} \int_{-\pi/2}^{\pi/2} |E|^2 \sin(\theta) \, d\theta d\varphi}$$

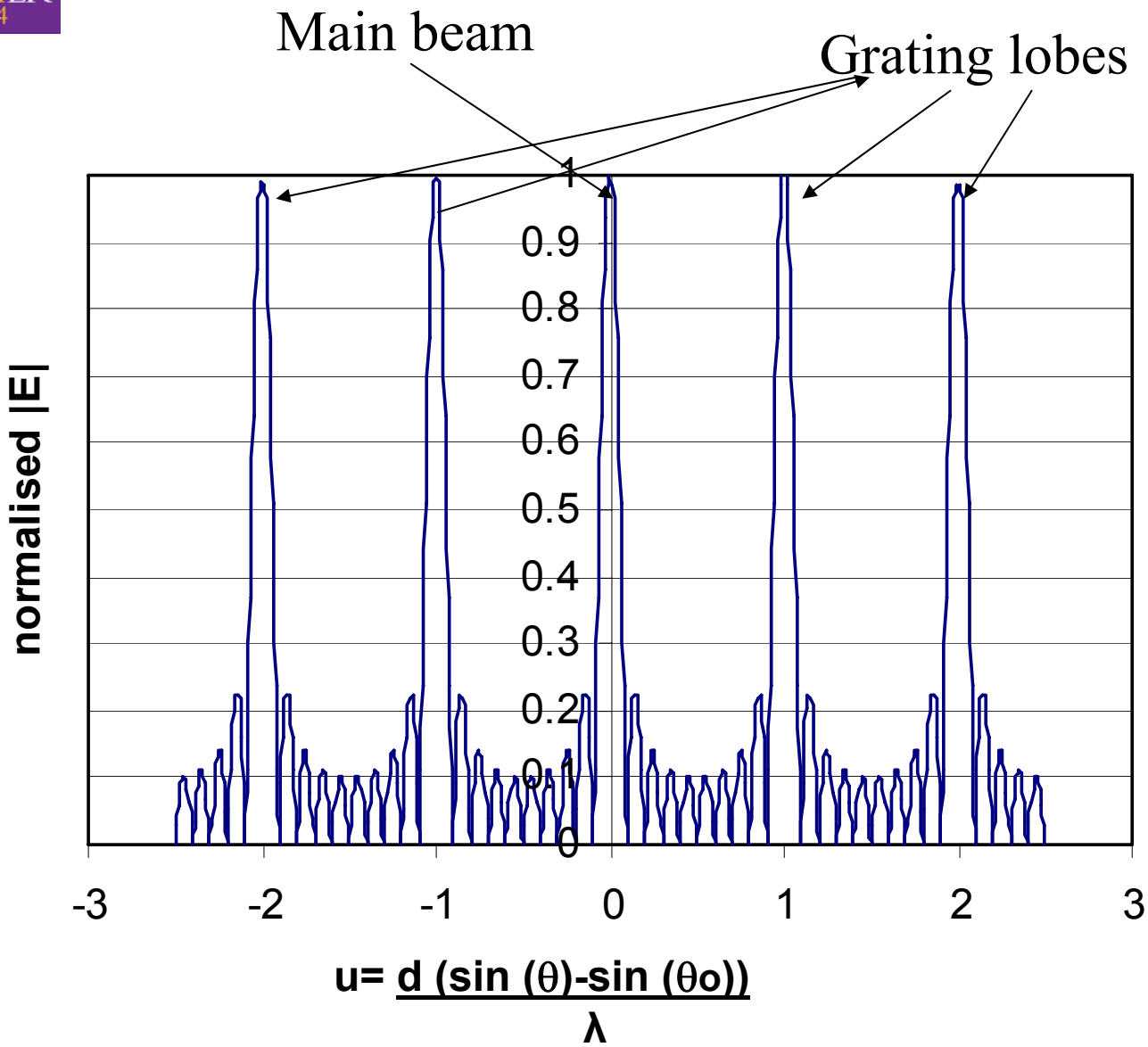
- Define $u = \frac{d(\sin(\theta) - \sin(\theta_o))}{\lambda}$

Where the scan angle of the main beam is θ_o

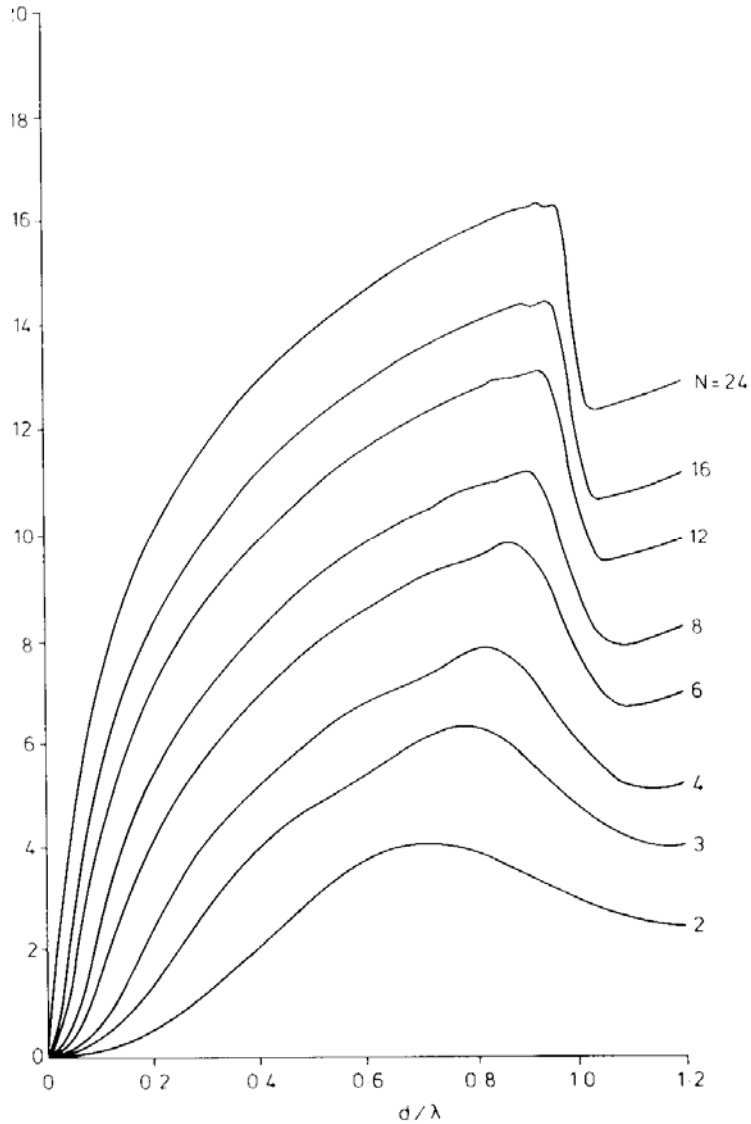
- Then for uniform , equal spaced array and omni-directional elements

$$E(\theta) = \frac{\sin(N \pi u)}{\sin(\pi u)}$$

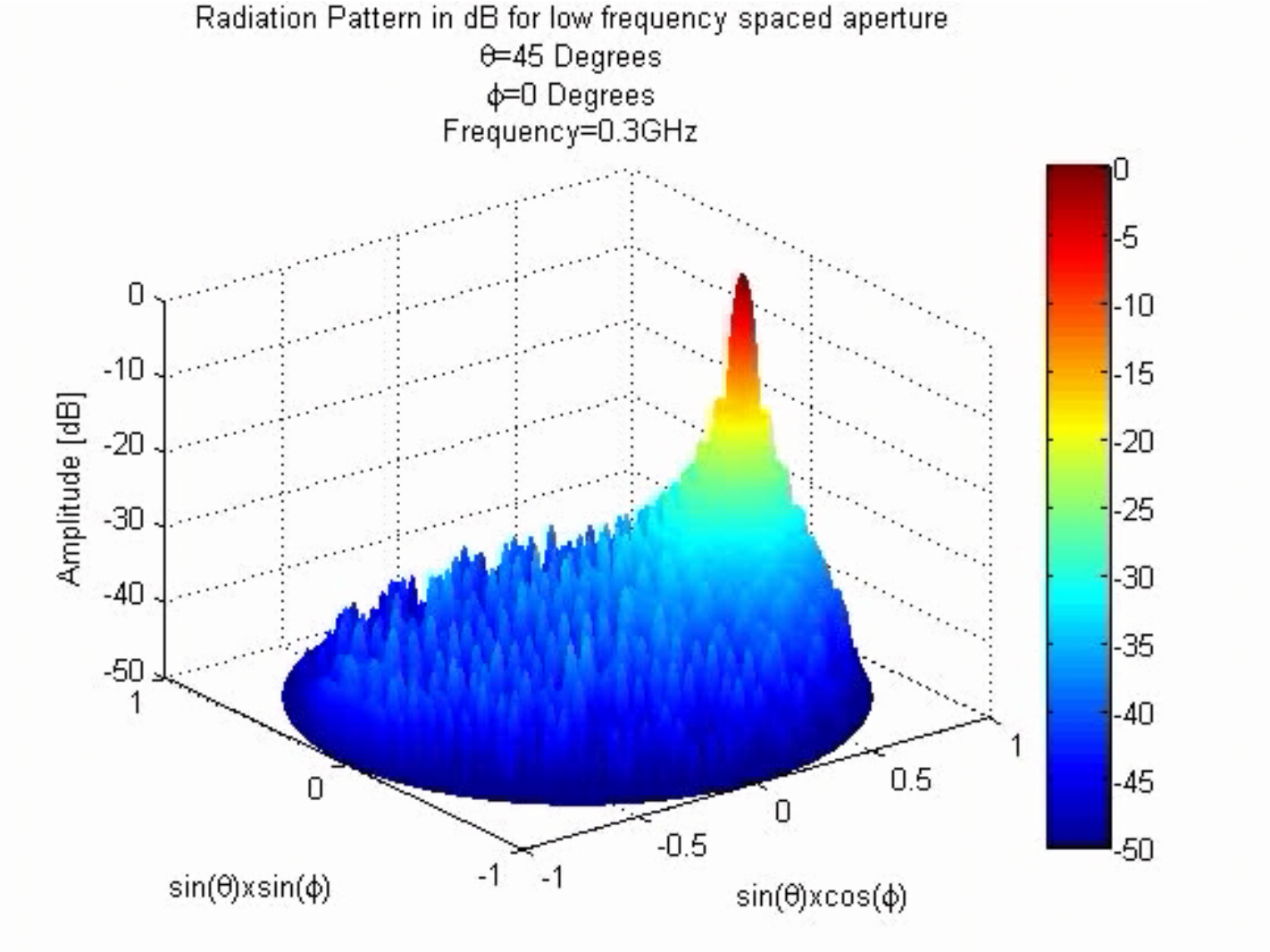
This has a peak value a u=0,+/- 1,+/-2……

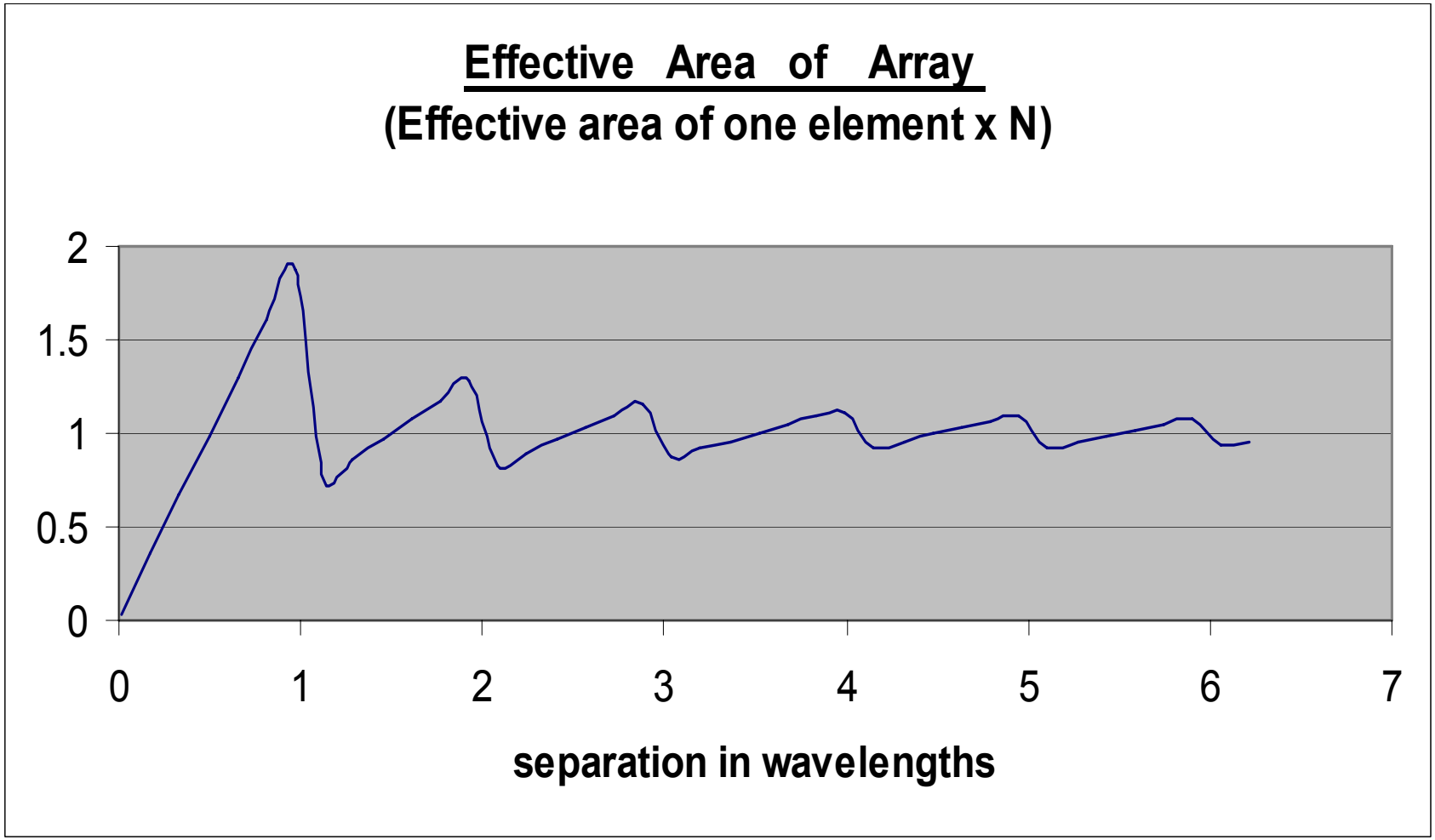

Main beam
Grating lobes
normalised |E|
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-3
-2
-1
0
1
2
3
u= d (sin (θ)-sin (θo)) / λ

Gain dB



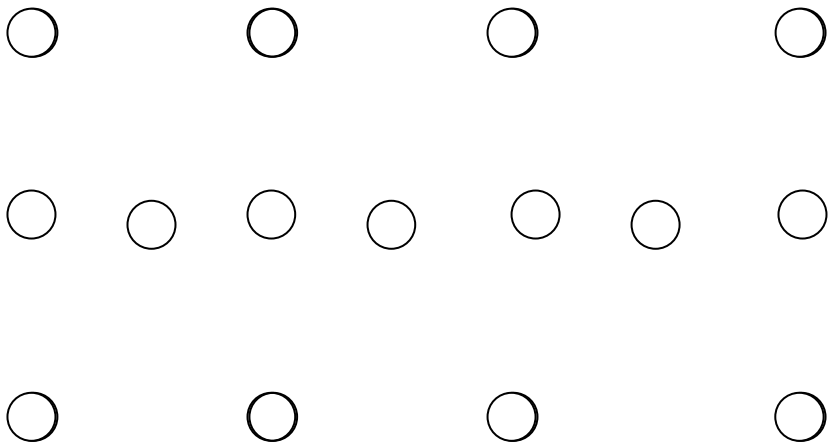
d/λ

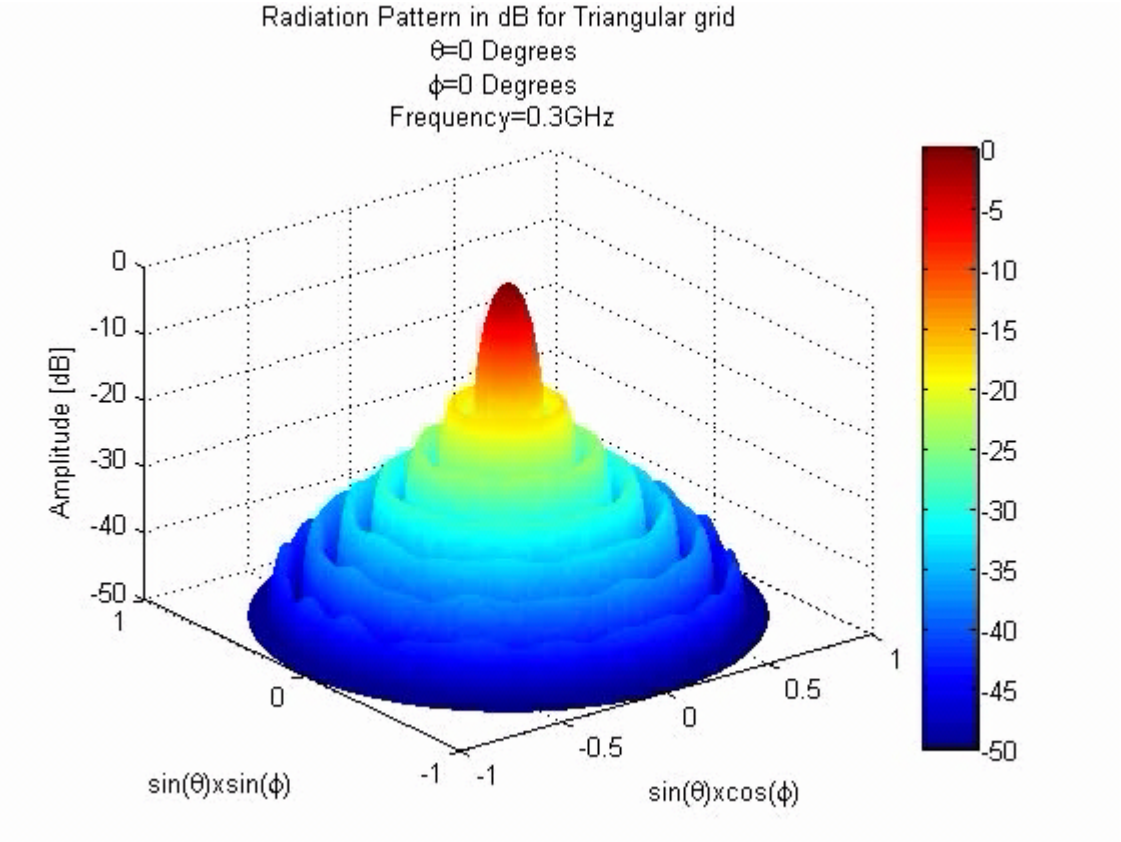

Radiation Pattern in dB for low frequency spaced aperture
θ=45 Degrees
ϕ=0 Degrees
Frequency=0.3GHz
Amplitude [dB]
0
-10
-20
-30
-40
-50
1
0
-1
-1
-0.5
0
0.5
1
sin(θ)xsin(ϕ)
sin(θ)xcos(ϕ)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50


Effective Area of Array
(Effective area of one element x N)
2
1.5
1
0.5
0
0
1
2
3
4
5
6
7
separation in wavelengths

- If we want to avoid grating lobes and maintain sidelobe control we need to adequately sample the aperture at high frequencies – this leads to inefficiency at low frequency
- So can we sample the aperture more efficiently than using a square grid?

Triangular grid



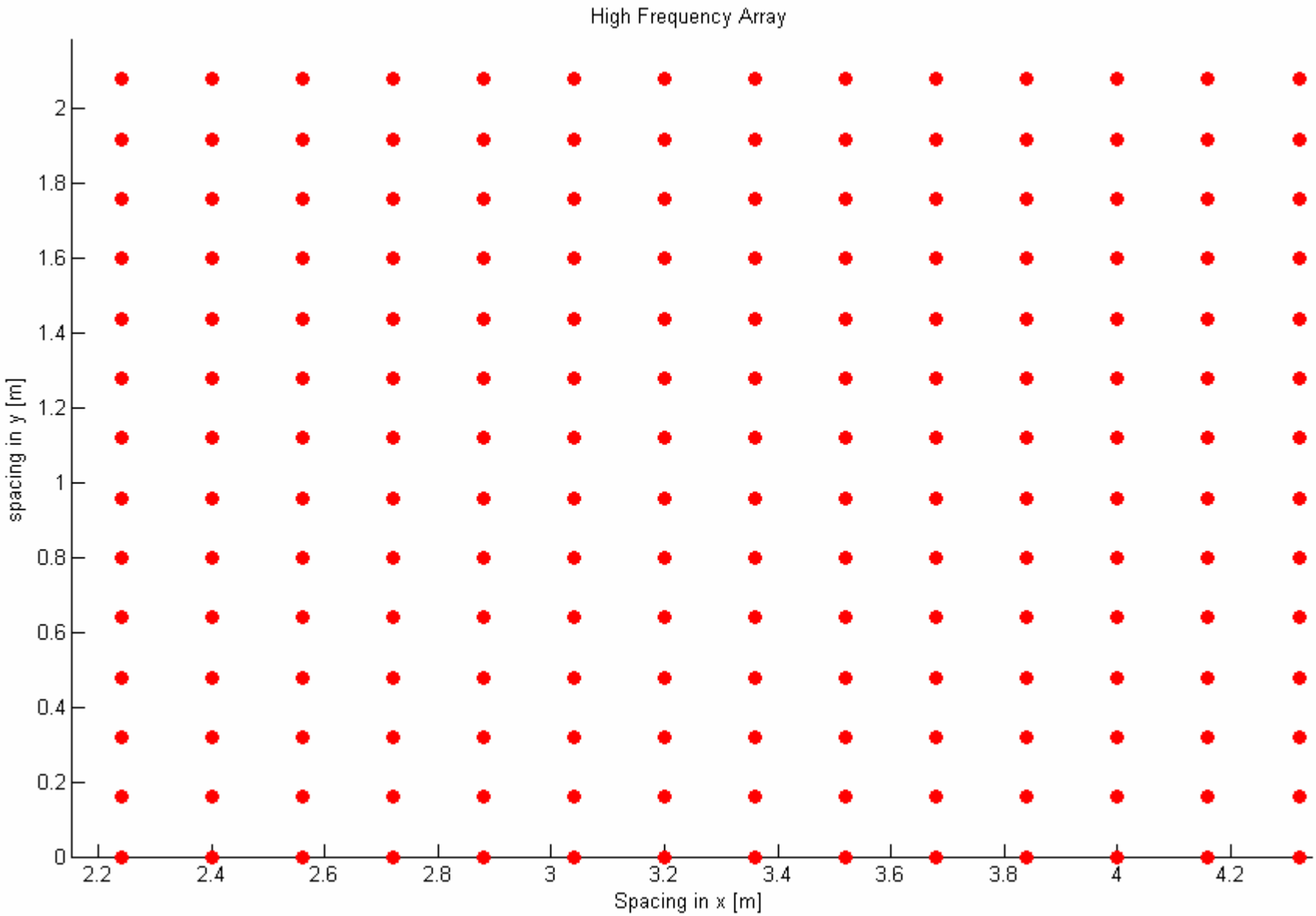

Radiation Pattern in dB for Triangular grid
θ=0 Degrees
ϕ=0 Degrees
Frequency=0.3GHz
Amplitude [dB]
0
-10
-20
-30
-40
-50
1
0
-1
-1
-0.5
0
0.5
1
sin(θ)xsin(ϕ)
sin(θ)xcos(ϕ)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50

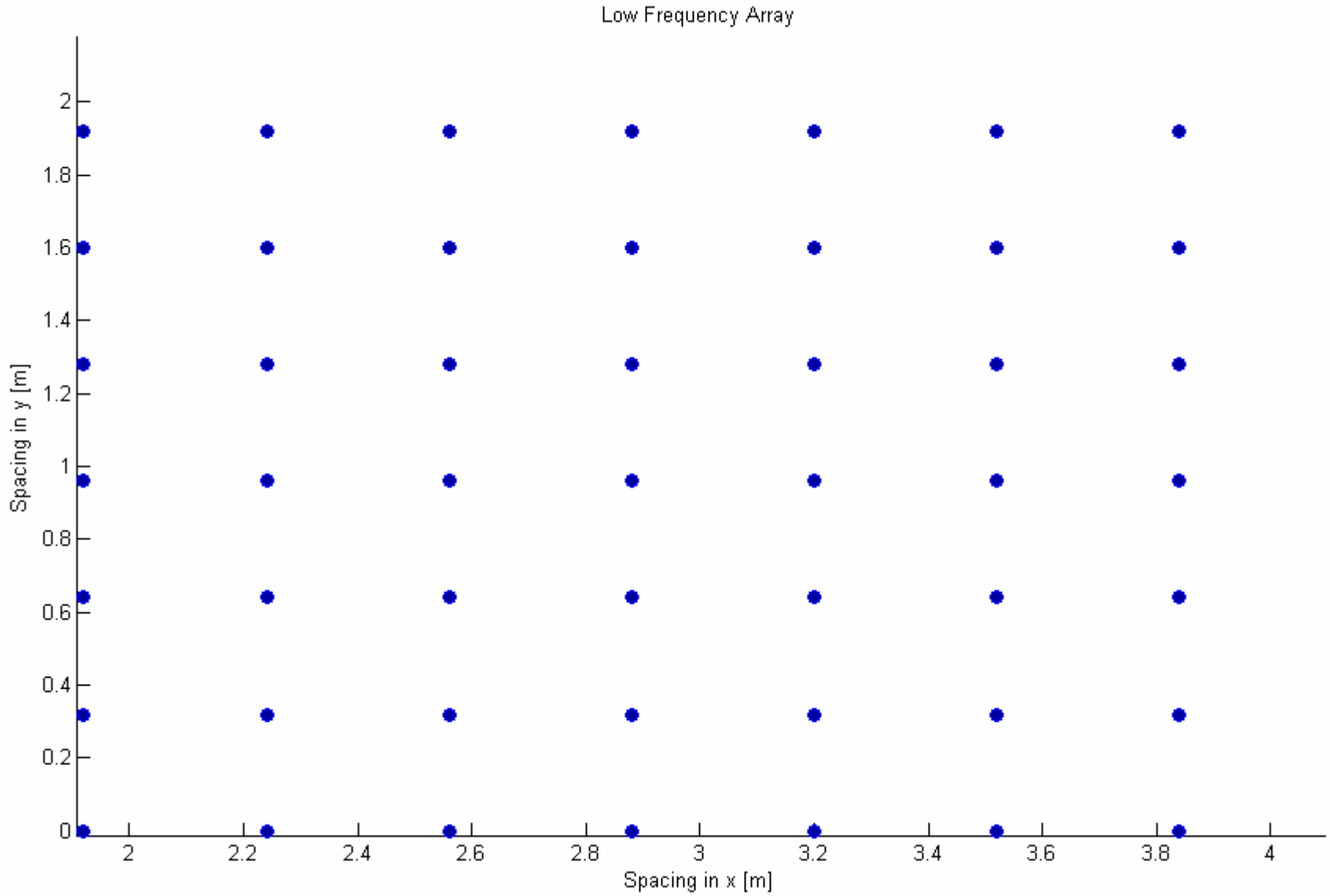
Triangular grid

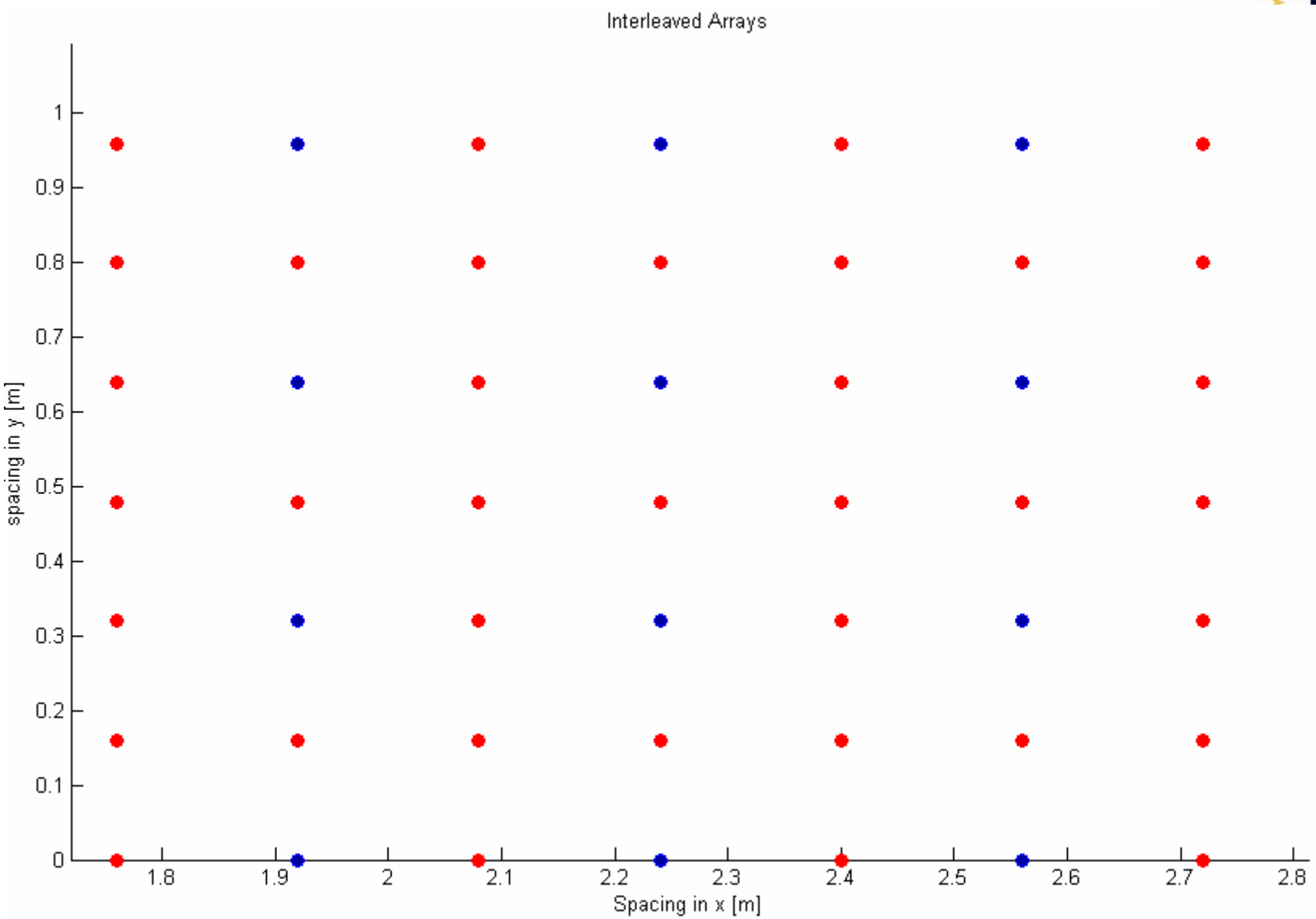
- The a triangular grid arrangement has advantages
- As the beam is scanned at higher frequencies, this effect would delay the arrival of the grating lobe into real space as a function of element separation. Hence allow extra spacing between the elements and therefore extra flexibility with the element design
- About 12% decrease in number of elements needed for no loss in effective area
  - Disadvantage mutual coupling difficulties

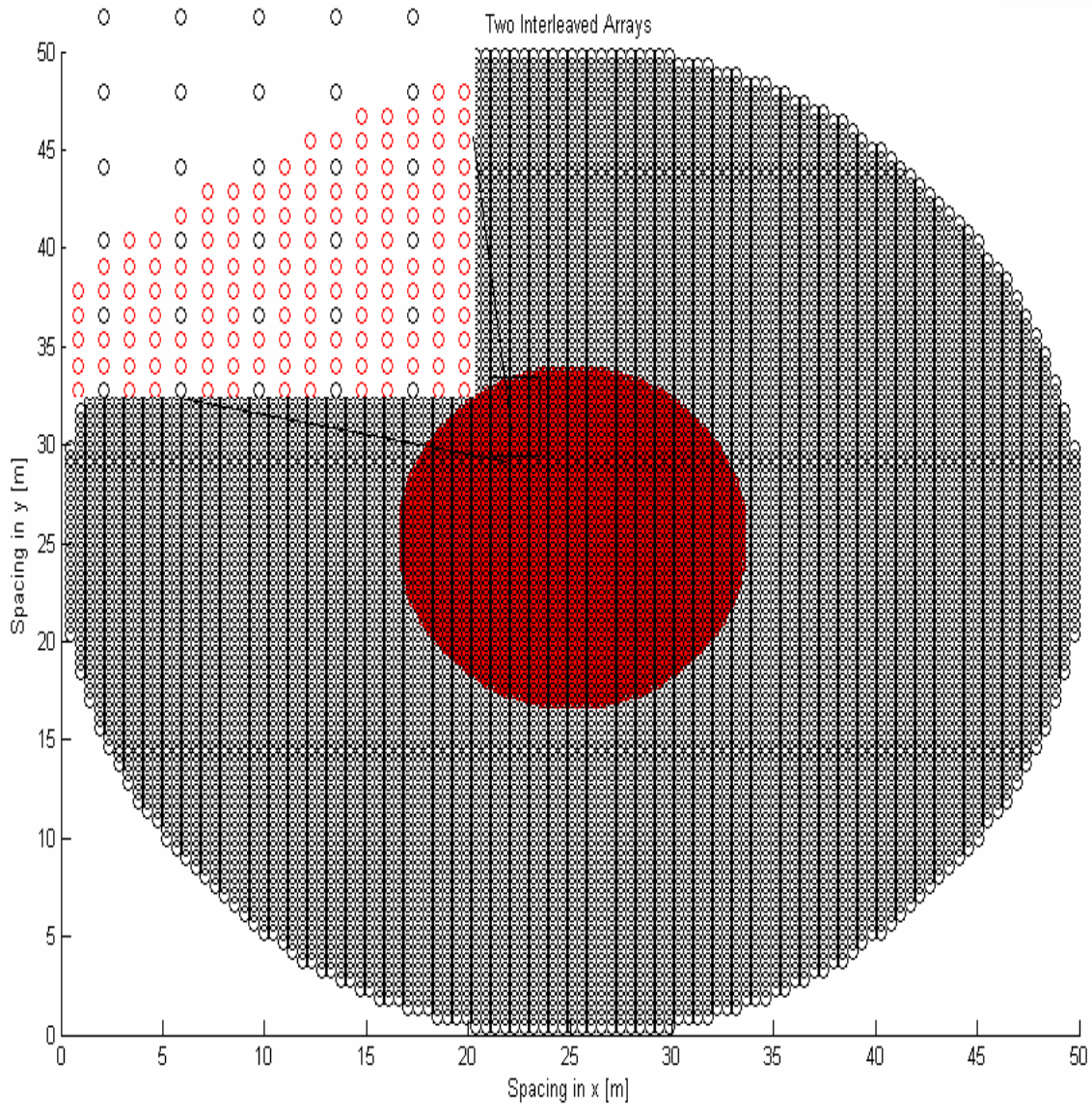
Band Interleaving

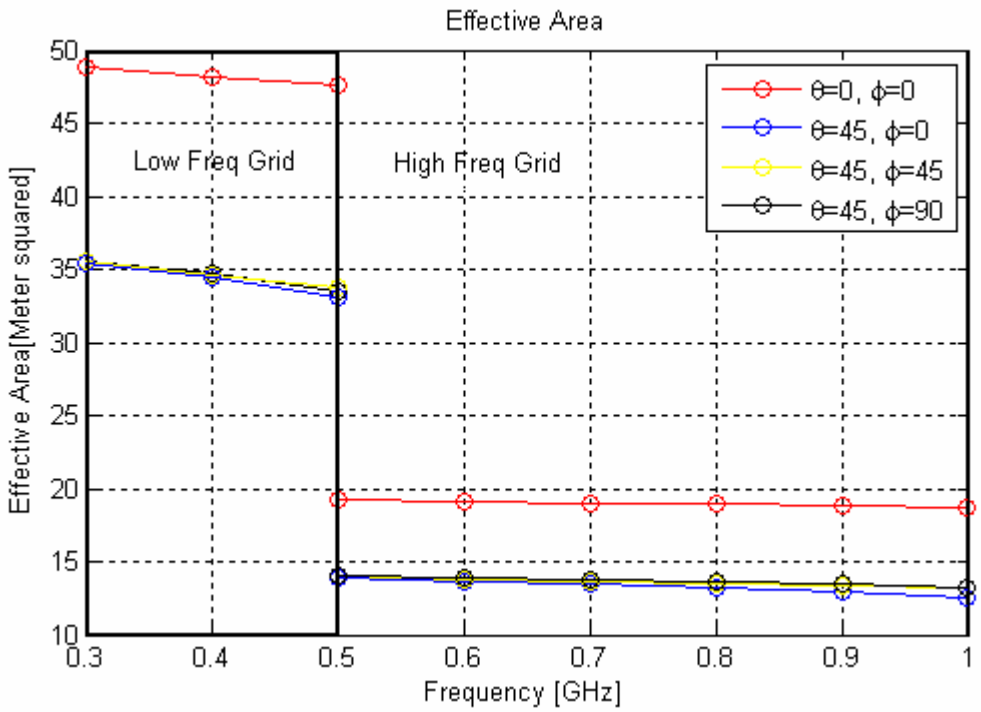
- Element separation depends on frequency and are geometry
- Since increasing in frequency requires narrower spacing between the elements, It is possible to select elements differently within the grid without losing performance.
- In other words use the narrow spaced elements working at the whole band where widely separated elements will only be required to work at low frequencies.


High Frequency Array
spacing in y [m]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4
4.2
Spacing in x [m]

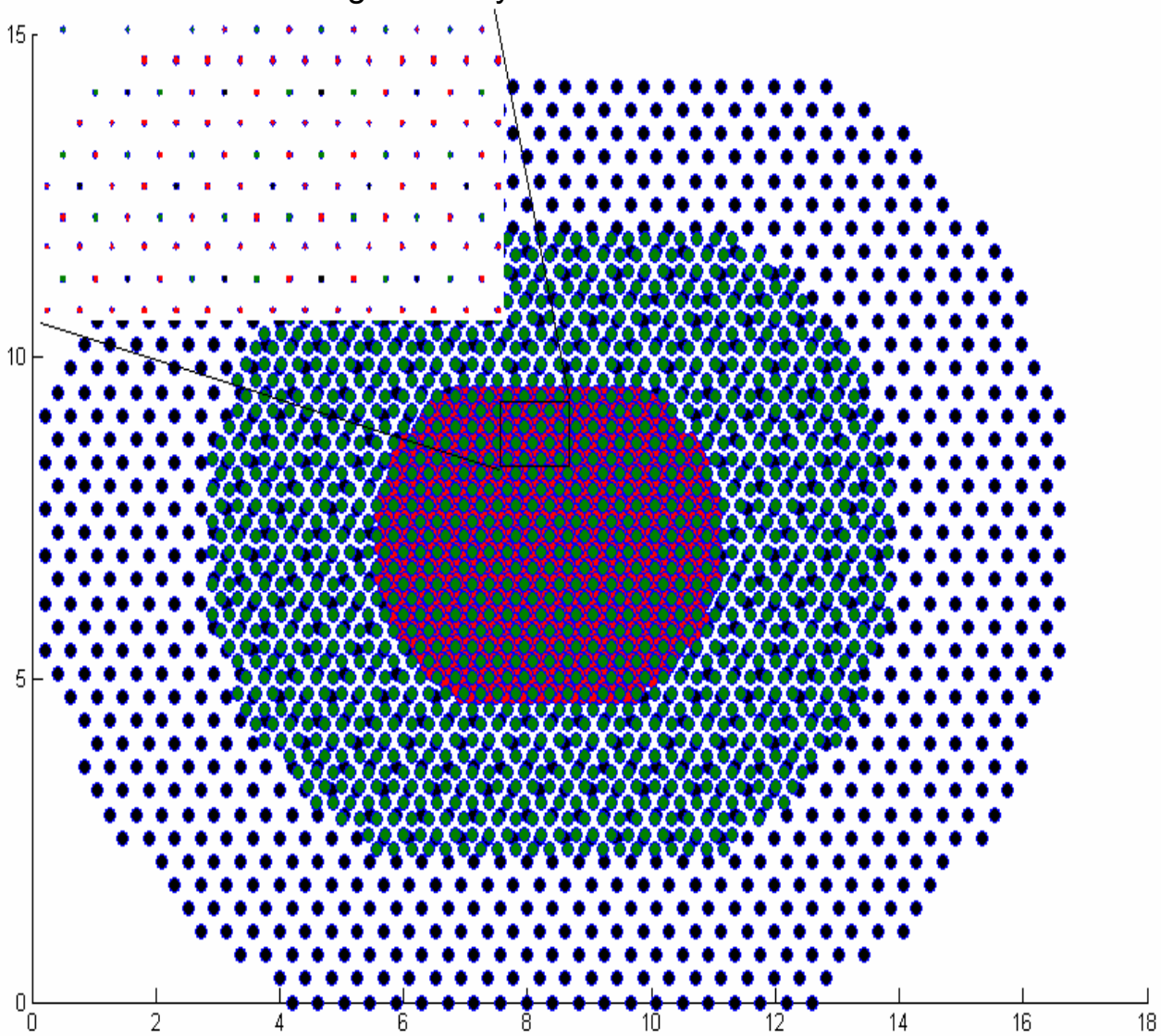

Low Frequency Array
Spacing in y [m]
Spacing in x [m]
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2
2.2
2.4
2.6
2.8
3
3.2
3.4
3.6
3.8
4


Interleaved Arrays
spacing in y [m]
Spacing in x [m]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.8
1.9
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8


Two Interleaved Arrays
Spacing in y [m]
Spacing in x [m]
0
5
10
15
20
25
30
35
40
45
50

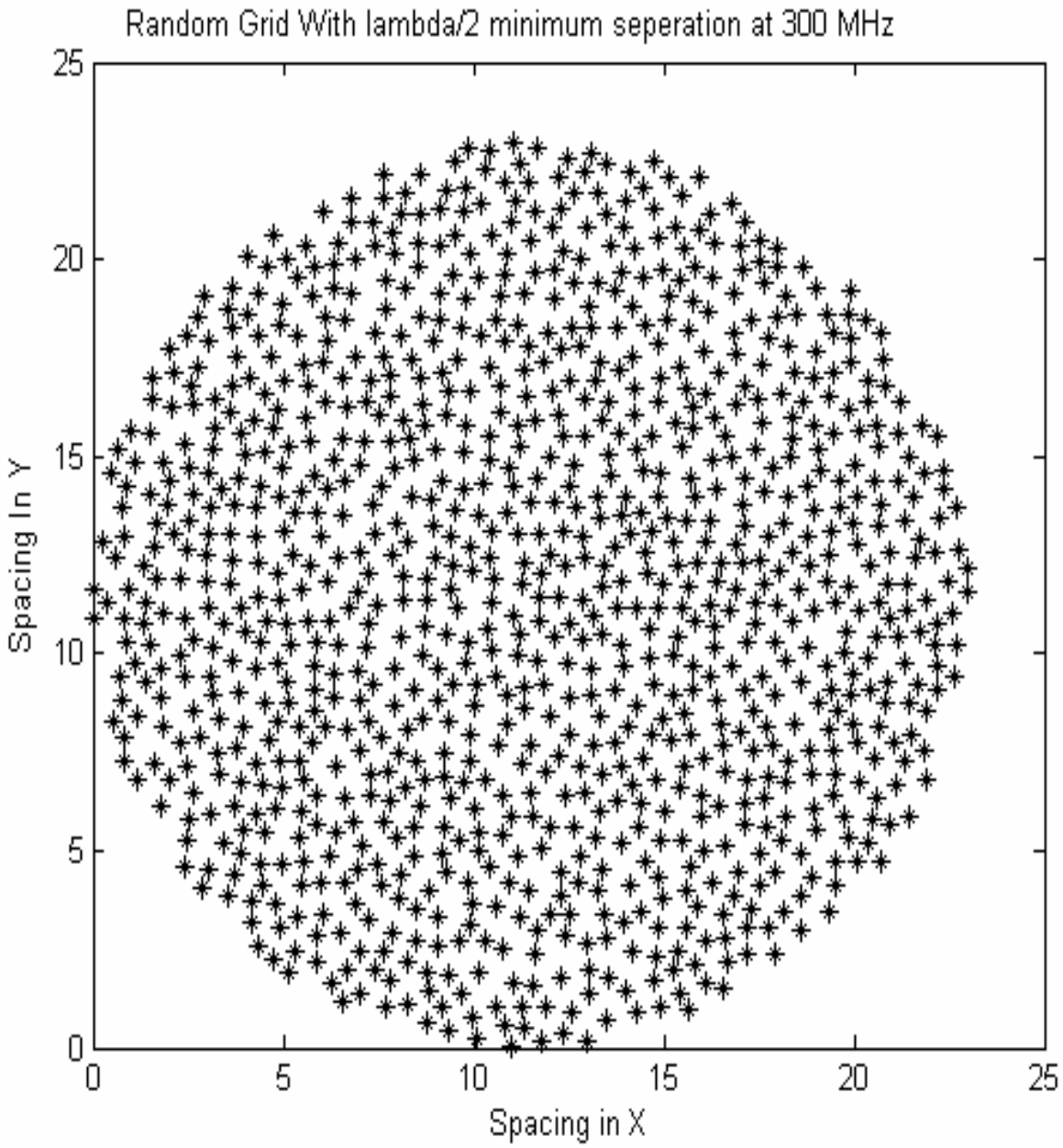

Effective Area
Effective Area[Meter squared]
Frequency [GHz]
Low Freq Grid
High Freq Grid
θ=0, ϕ=0
θ=45, ϕ=0
θ=45, ϕ=45
θ=45, ϕ=90
50
45
40
35
30
25
20
15
10
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Interleaved Triangular array with circular outline

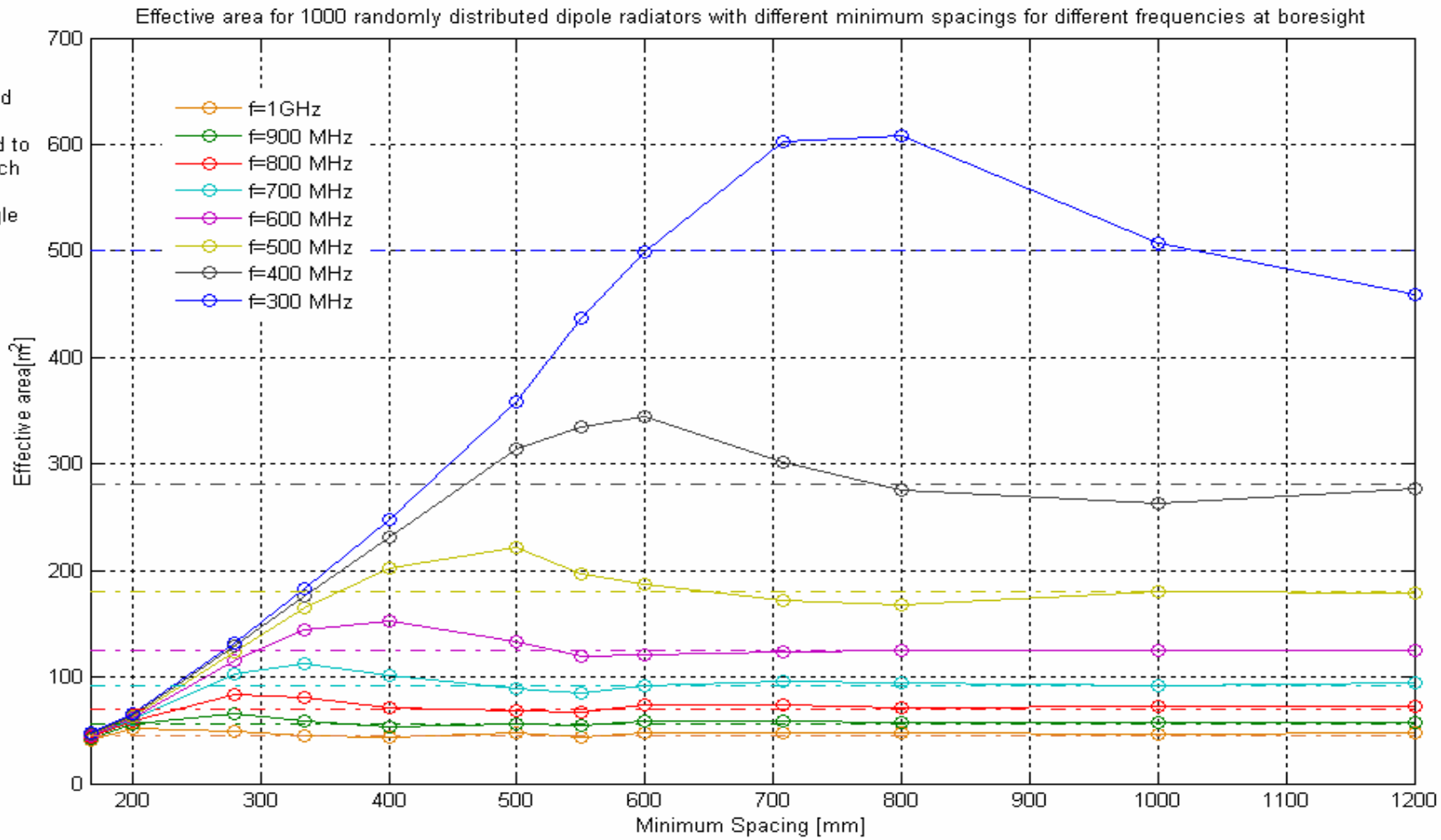


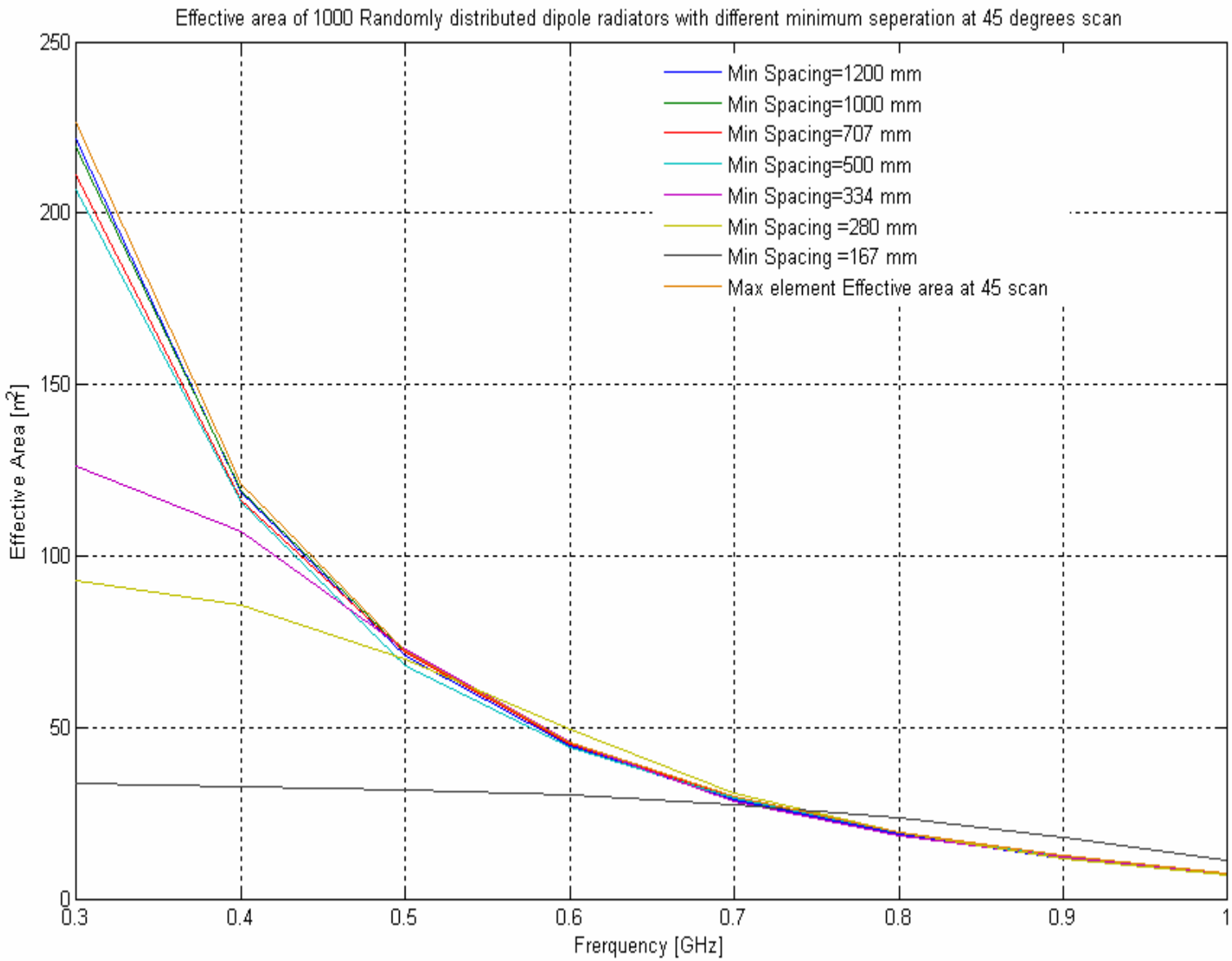
Random Array with minimum separation

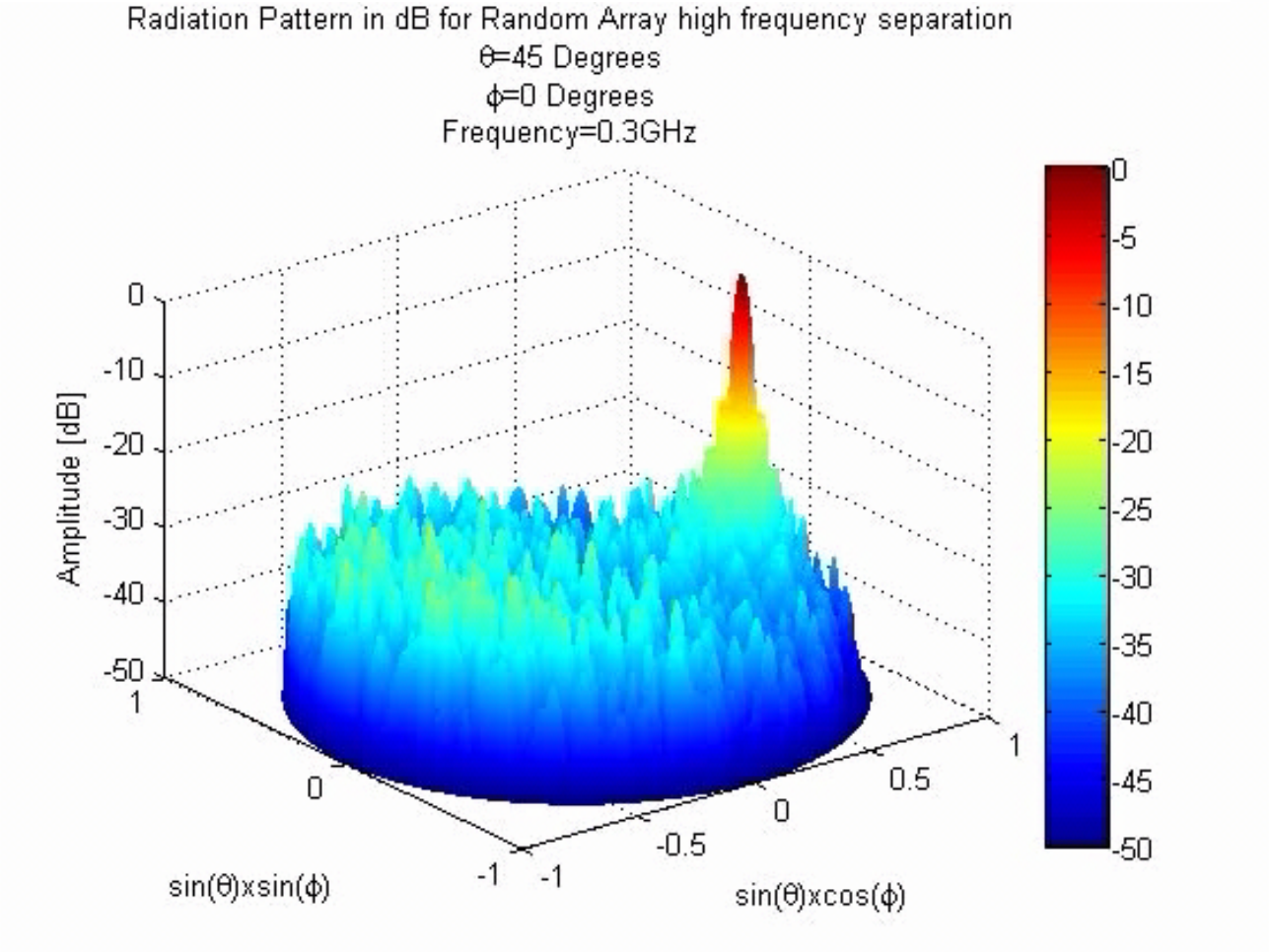
- Randomly place antenna elements with the condition that no two elements can be closer than a certain specified separation


Random Grid With lambda/2 minimum seperation at 300 MHz
Spacing In Y
Spacing in X
0
5
10
15
20
25

Note: The dash-dotted lines correspond to N*A for each frequency. A is a single element effective area at boresight



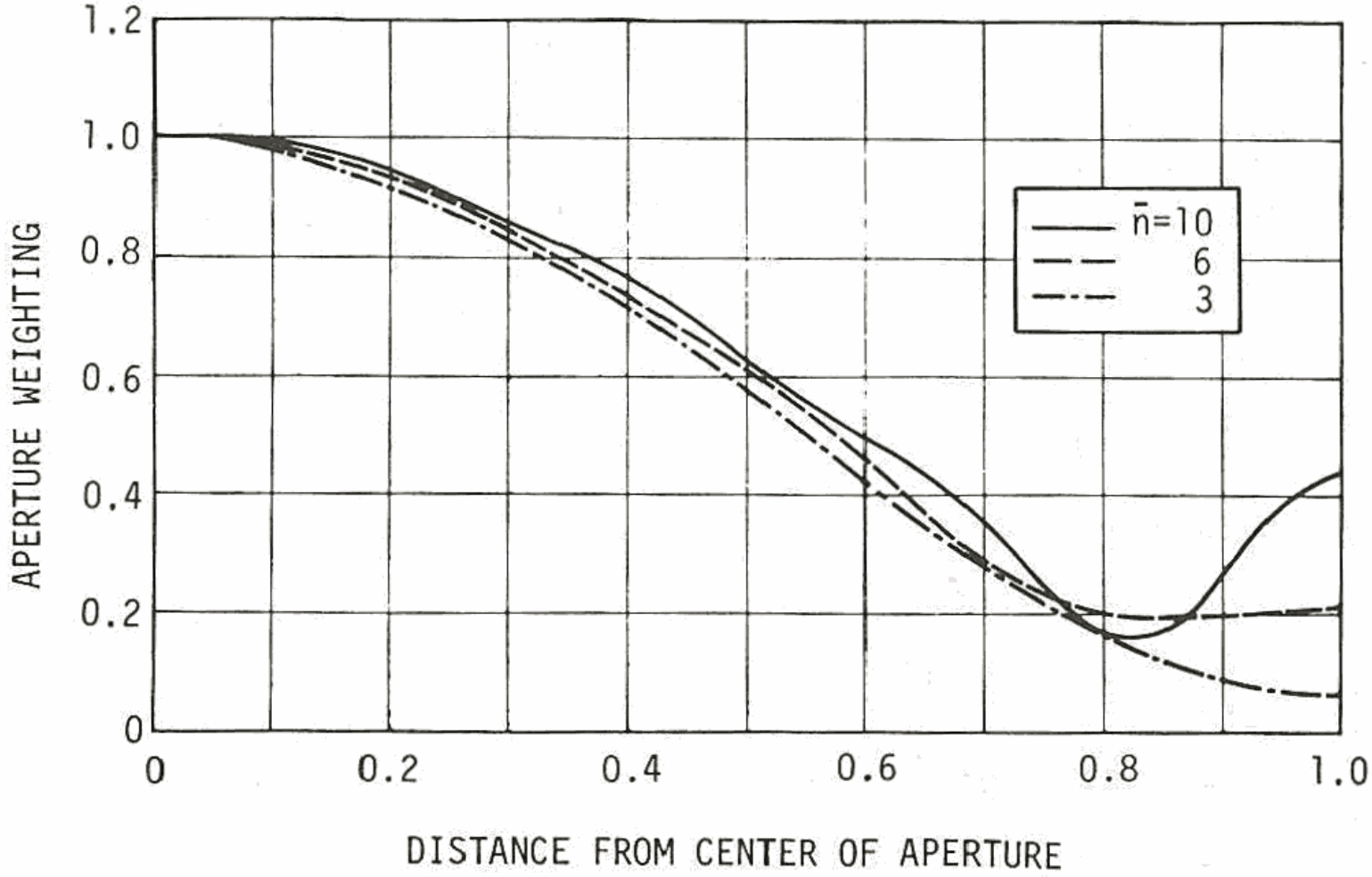

Effective area of 1000 Randomly distributed dipole radiators with different minimum seperation at 45 degrees scan
Min Spacing=1200 mm
Min Spacing=1000 mm
Min Spacing=707 mm
Min Spacing=500 mm
Min Spacing=334 mm
Min Spacing =280 mm
Min Spacing =167 mm
Max element Effective area at 45 scan
Effective Area [m2]
Frerquency [GHz]
250
200
150
100
50
0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Radiation Pattern in dB for Random Array high frequency separation
θ=45 Degrees
ϕ=0 Degrees
Frequency=0.3GHz
Amplitude [dB]
0
-10
-20
-30
-40
-50
1
0
-1
-1
-0.5
0
0.5
1
sin(θ)xsin(ϕ)
sin(θ)xcos(ϕ)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50

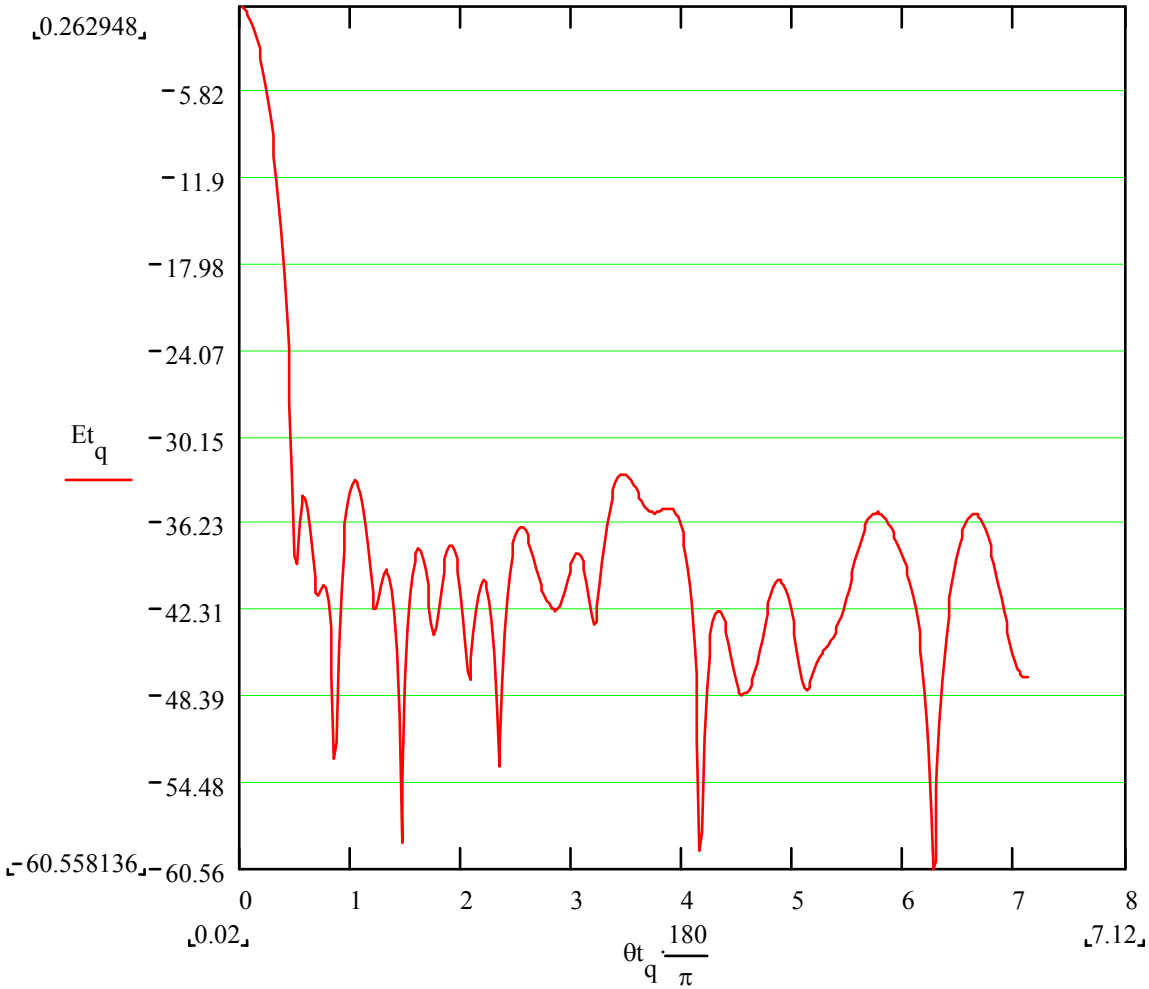
Sidelobe Control

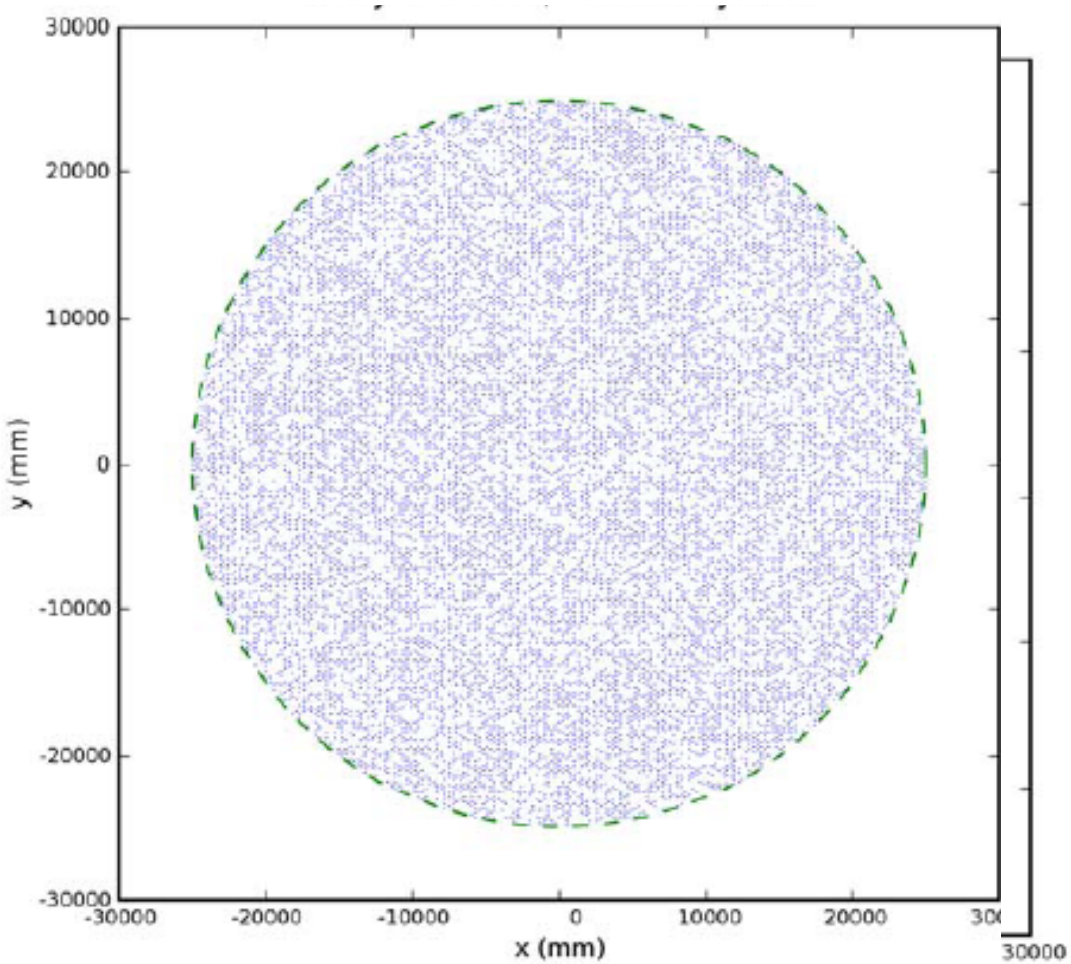
- Basic Fourier Theory shows to control sidelobes we need to reduce the amplitude at the edge of the array

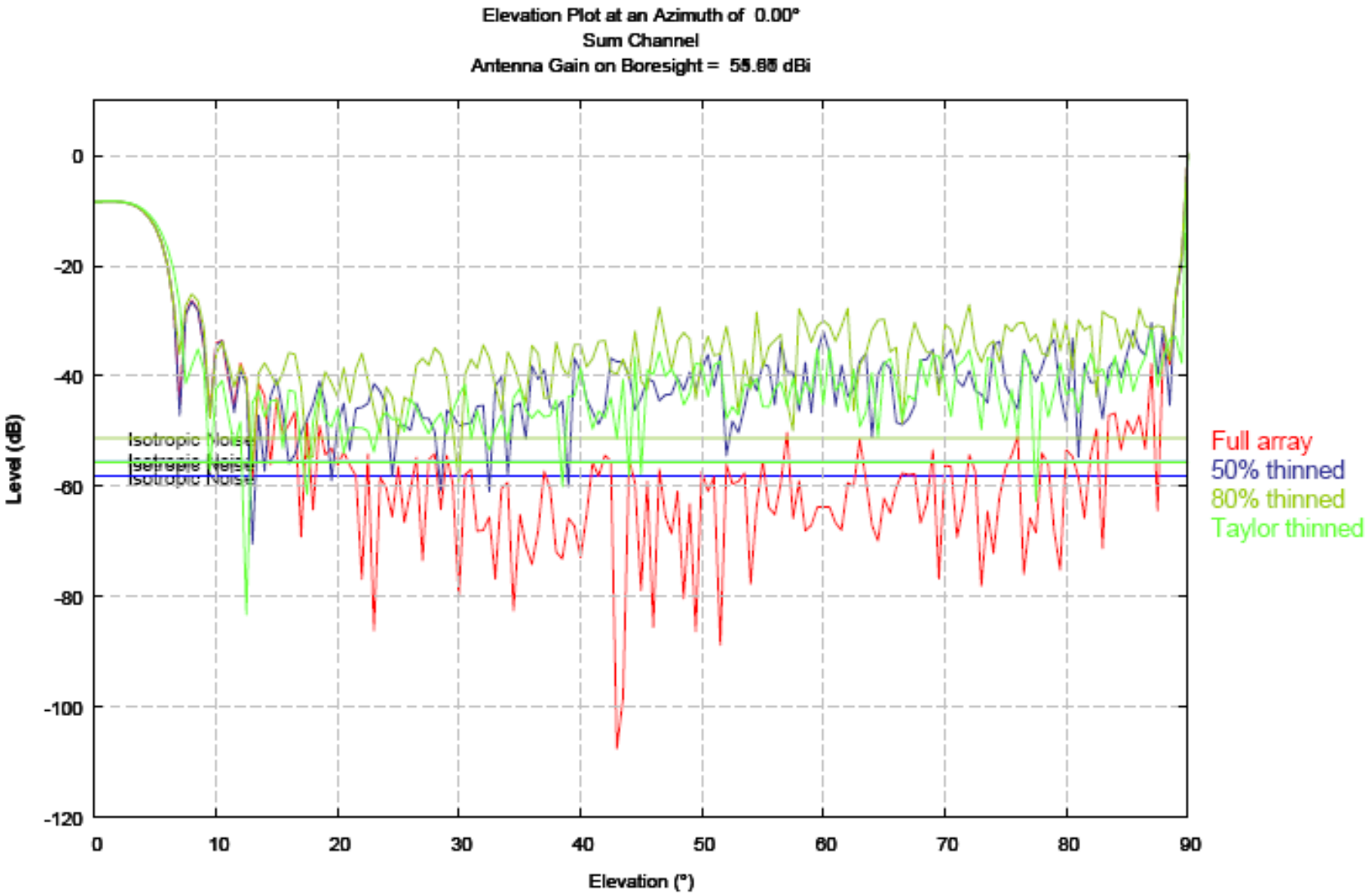
TYPICAL TAPERED TAYLOR APERTURE WEIGHTING FUNCTIONS



Effect of different amplitude tapers

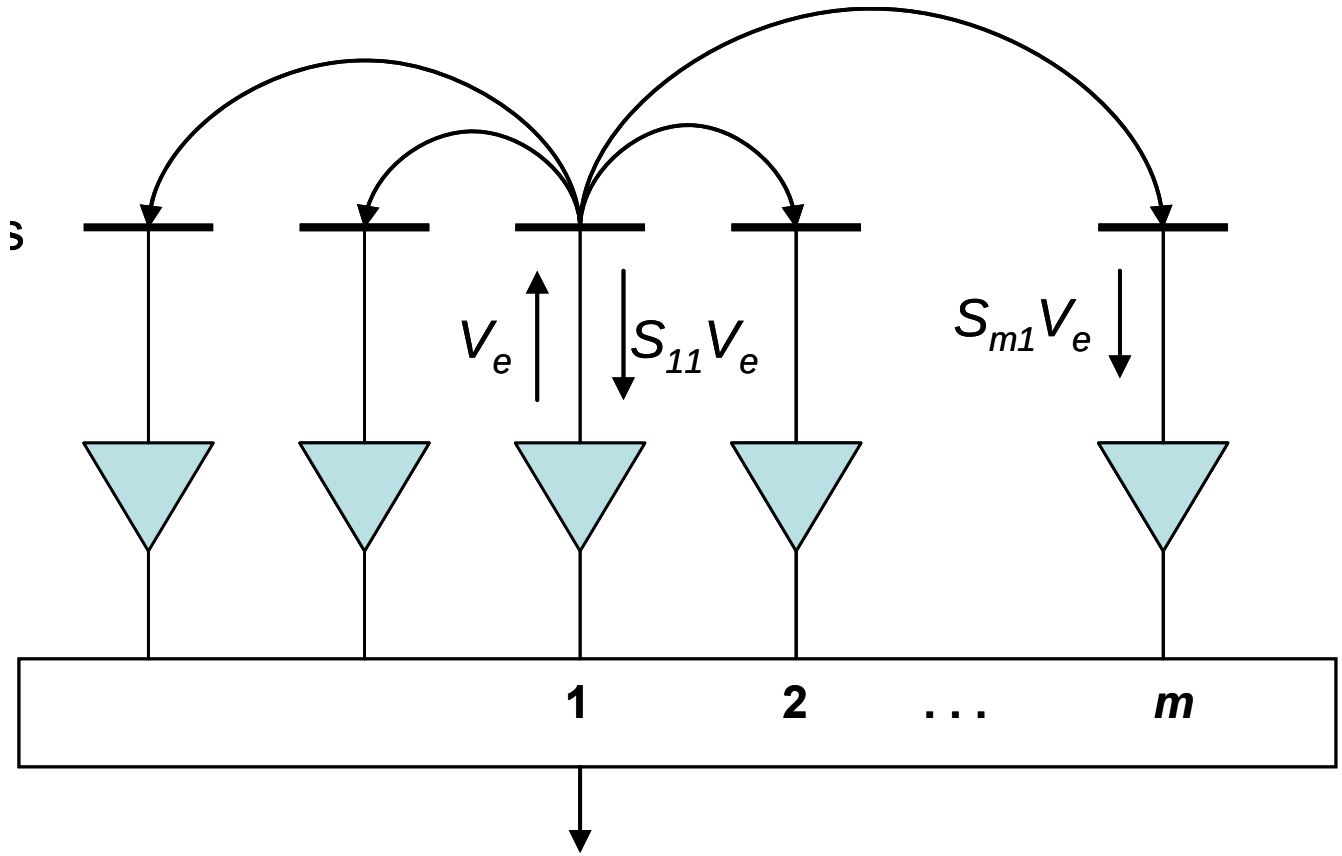



30000
20000
10000
0
-10000
-20000
-30000
y (mm)
-30000
-20000
-10000
0
10000
20000
x (mm)


Elevation Plot at an Azimuth of 0.00°
Sum Channel
Antenna Gain on Boresight = 55.85 dBi
Level (dB)
0
-20
-40
-60
-80
-100
-120
0
10
20
30
40
50
60
70
80
90
Elevation (°)
Isotropic Noise
Isotropic Noise
Isotropic Noise
Full array
50% thinned
80% thinned
Taylor thinned

- Sparse arrays allow array spacing optimised to give low frequency performance to be used at high frequencies without production of grating lobes
- Sparse arrays need random geometries
  - (although it may be possible to apply random phase weight-not yet looked at)
- The N*effective element area guideline has to be treated with care
- Beamwidth reduction leads to more beams at high frequencies than dense aray (or smaller FOV)
- High peak sidelobes which may occur at wide angles.

Mutual Coupling



- Coupling coefficients depend on element type and separation
- Compact wideband elements can use on the coupling to give low end extension to impedence bandwidth- gives problems with certain geometries, also getting good impedence match- sometimes element separation is set by this criteria so is sub optimal
- Larger elements need more space- appropriate to sparse arrays . Coupling lower but cannot be ignored

Summary

- By controlling the array geometry we can effect trade-off between numbers of elements, effective area and sidelobe levels
- Narrow band arrays can produce more effective area than just N x effective area of one element.
- Broad band arrays are a compromise- either oversampled at the low end so elements not contributing in a cost efficient manner or else we undersample at the top end and have gating lobes (or use sparse array)
- Triangular grids use less elements than square grids for same performance

- The element design and array geometry are linked by the mutual coupling in the array- strongly so in close packed grids