A Wideband Dipole Array for Directed Energy Applications and Digital TV Reception

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Outline

- **Problem and motivation**
- **The “ribcage” dipole antenna**
- **Comparisons with classic configurations**
- **Ribcage dipole antenna for communications**
  - Optimized ribcage dipole with balun
  - Simulations and laboratory measurements
- **Antenna array for Directed Energy applications**
  - Optimized unit cell with balun
  - Customized power dividers
  - 8x8 array of ribcages: simulations and preliminary laboratory tests
  - Composite array model for antenna array pattern modeling
- **Conclusions and future work**

Compact High Performance RF Communications

Motivation #1

Whip antennas for HF communications

- Simple classic design
- Narrow bandwidth
- High visibility
- Needs assembly for portability

Ribcage dipole antenna

- Low profile
- Excellent performance over a ground plane
- Wide impedance bandwidth
- Uniform antenna pattern over the bandwidth
- Needs further development and funds

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Compact Portable Focused Beam Antenna

Motivation #2

Parabolic dish antennas

- Wide band
- High gain
- Focused beam
- Simple feeding

- Complex position control
- Large volume
- Not easily portable
- Highly visible

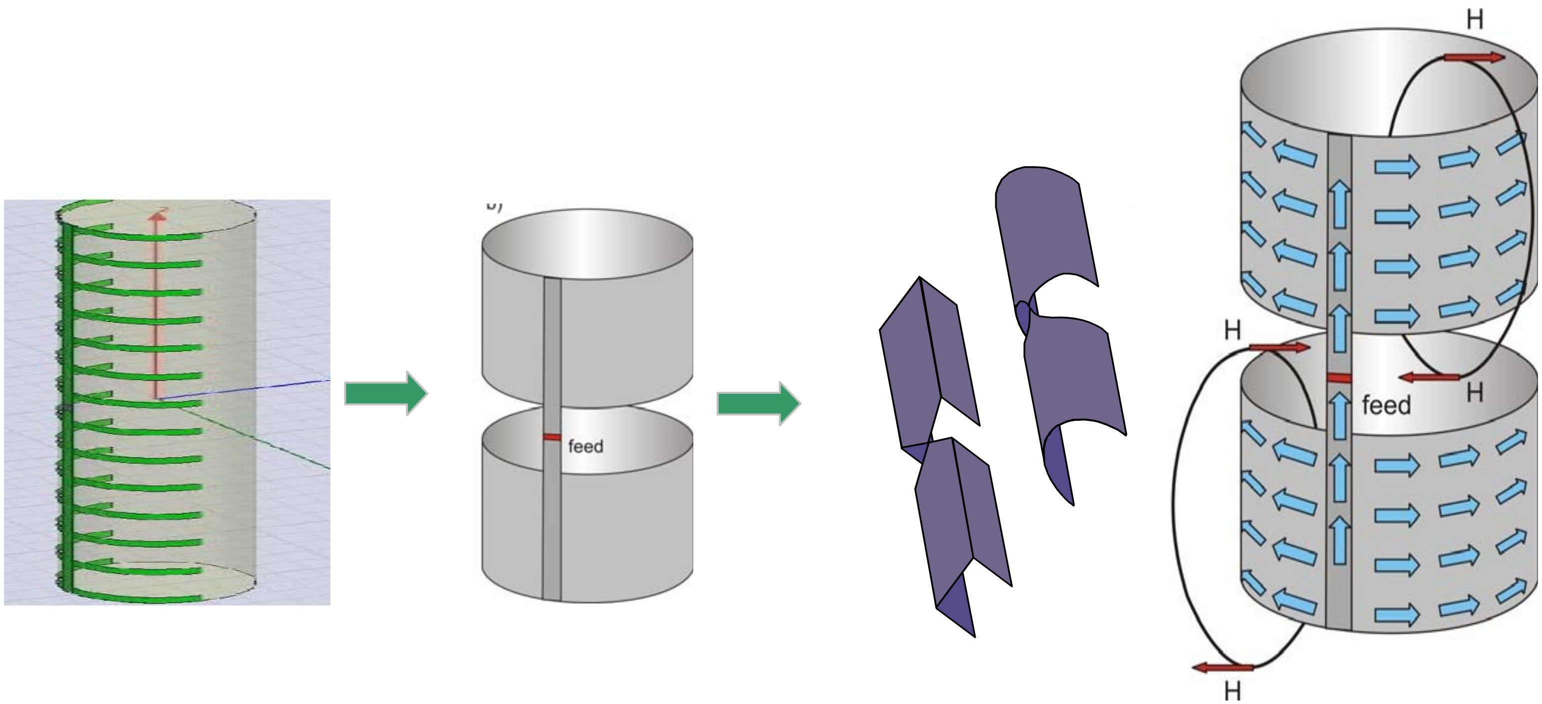
Antenna array of ribcage elements

- Wide-band, high gain, narrow beam
- Possibility of electronic scanning
- Compact, low-profile, easily portable
- Can be stowed in sub-array modules

- More complex feeding network

The Origins of the “Ribcage” Dipole

- **Volumetric dipole antenna with ribs, wings, or sleeves**
- **Closed ring or open sleeve**
- **Intrinsic additional magnetic field**



Wideband Volumetric Antenna: Dipole With Sleeves

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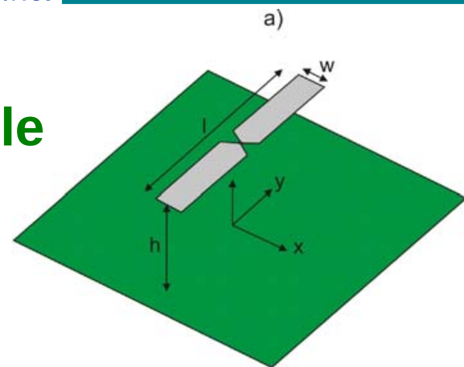
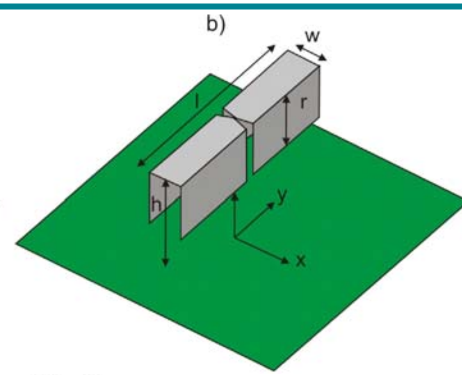
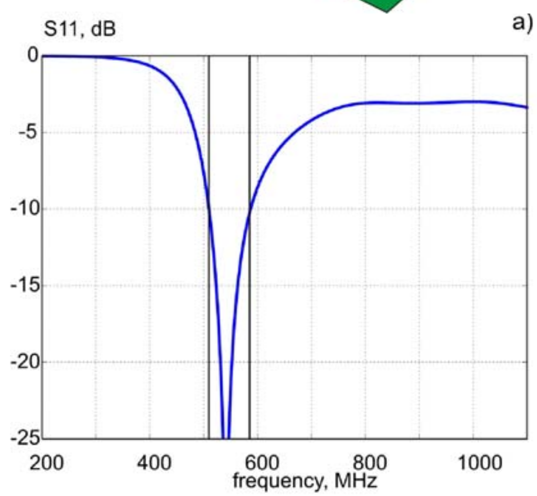
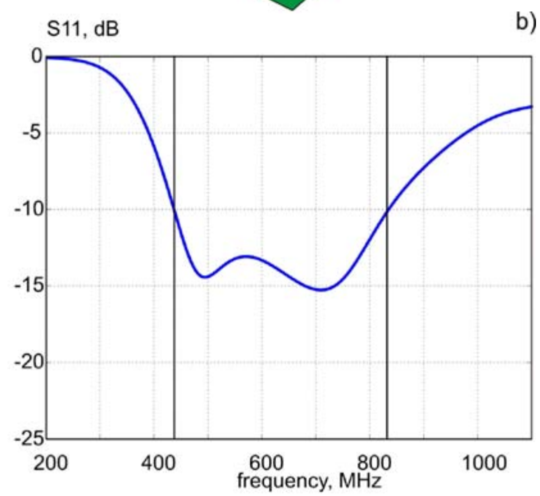
Blade Dipole



Ribcage Dipole







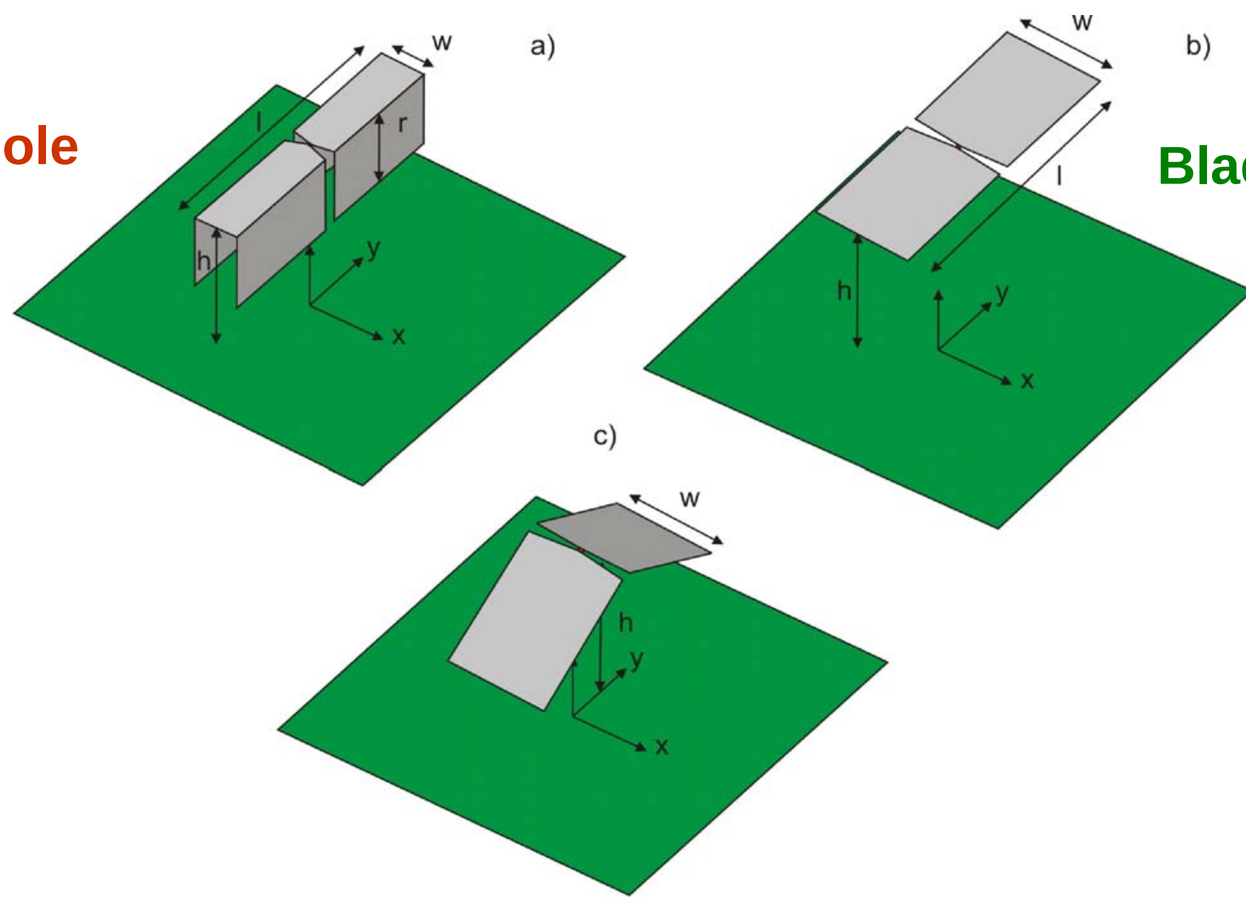
The ribcage dipole has wider bandwidth than blade dipole of same width and length.

Antenna	Height above Ground Plane	Width	Total Length	(Sleeve) Depth	Ground Plane
Blade dipole	**h=105 mm**	w=30 mm	**l=220 mm**	NA	300×300 mm
Ribcage dipole	**h=160 mm**	w=30 mm	**l=220 mm**	r = 70 mm	300×300 mm

Comparison of Dipoles Over Ground Plane

Ribcage Dipole

Blade Dipole



Droopy Dipole

Optimized Droopy Dipole and Blade Dipole

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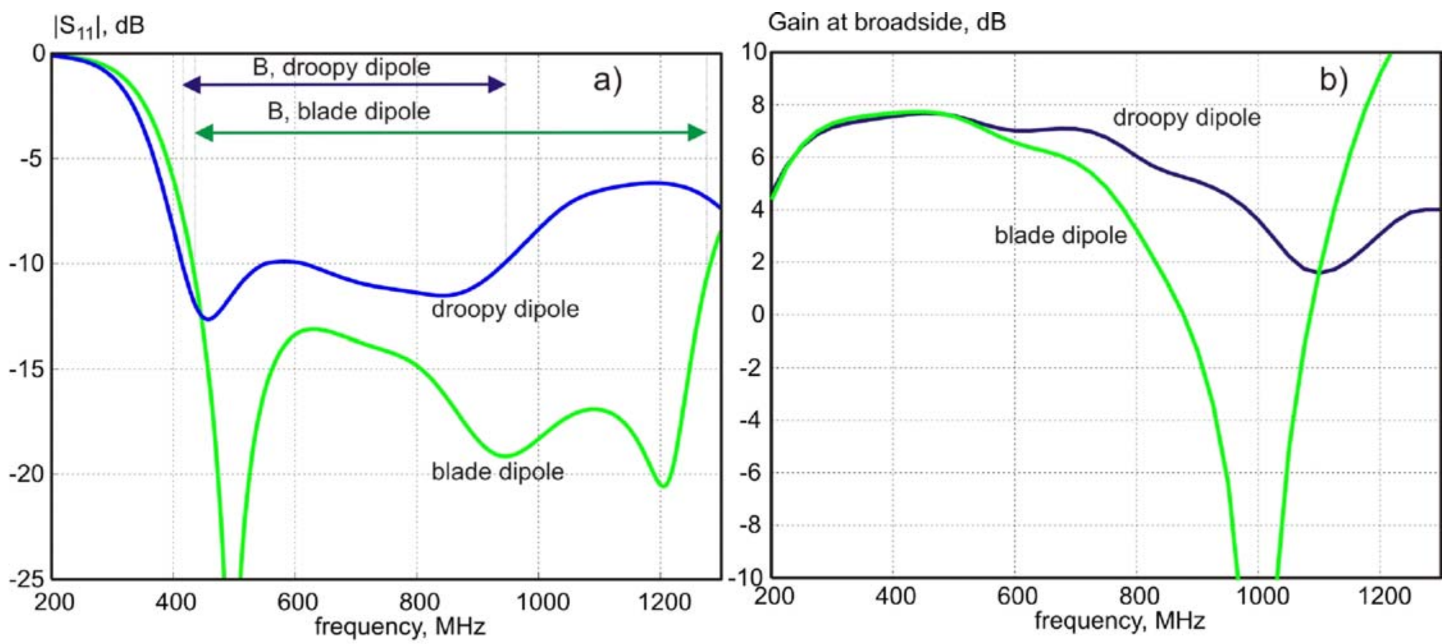
Antenna	Height over Ground Plane	Width	Total Length	Sleeve Depth	GP
Blade dipole	**h=150 mm**	**w=120 mm**	**l=220 mm**	NA	**300×300 mm**
Droopy dipole	**h=150 mm**	**w=140 mm**	**l=220 mm**	NA	**300×300 mm**



- **The blade dipole has a wider impedance bandwidth**
- **The droopy dipole has a more uniform gain over the bandwidth**

Ribcage Dipole and Droopy Dipole

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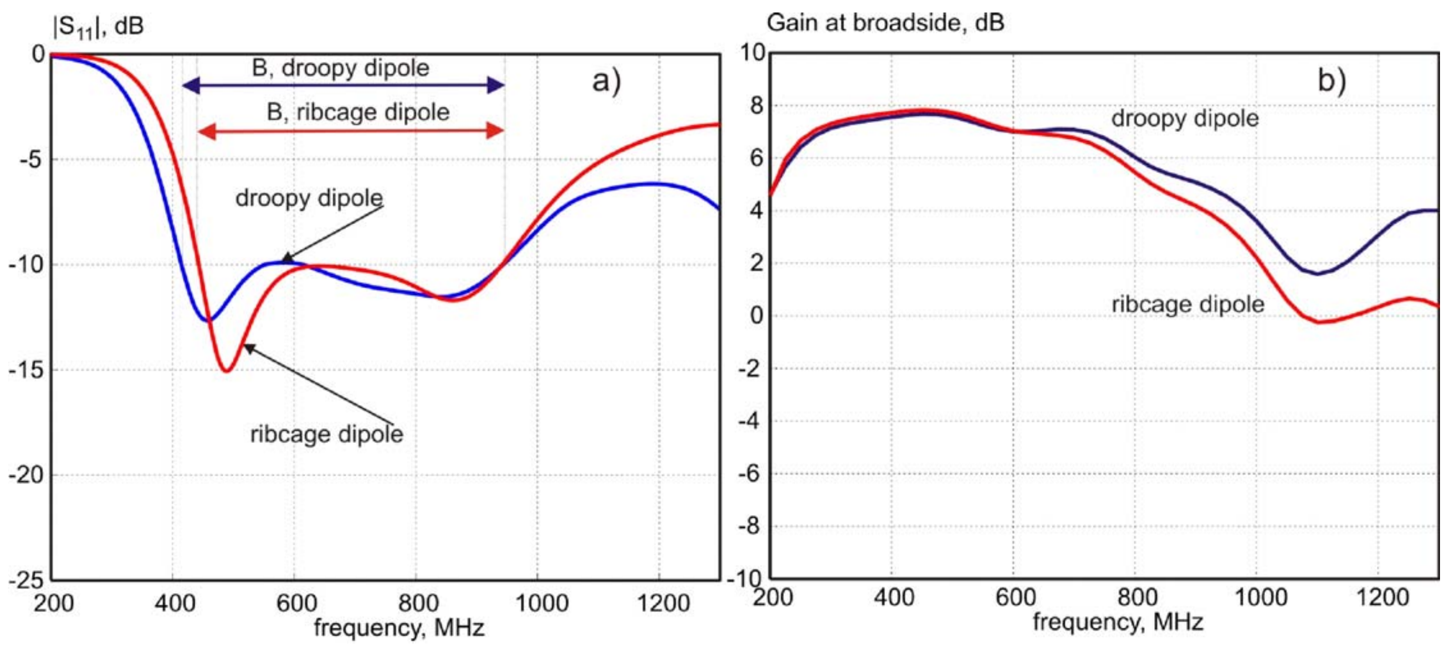
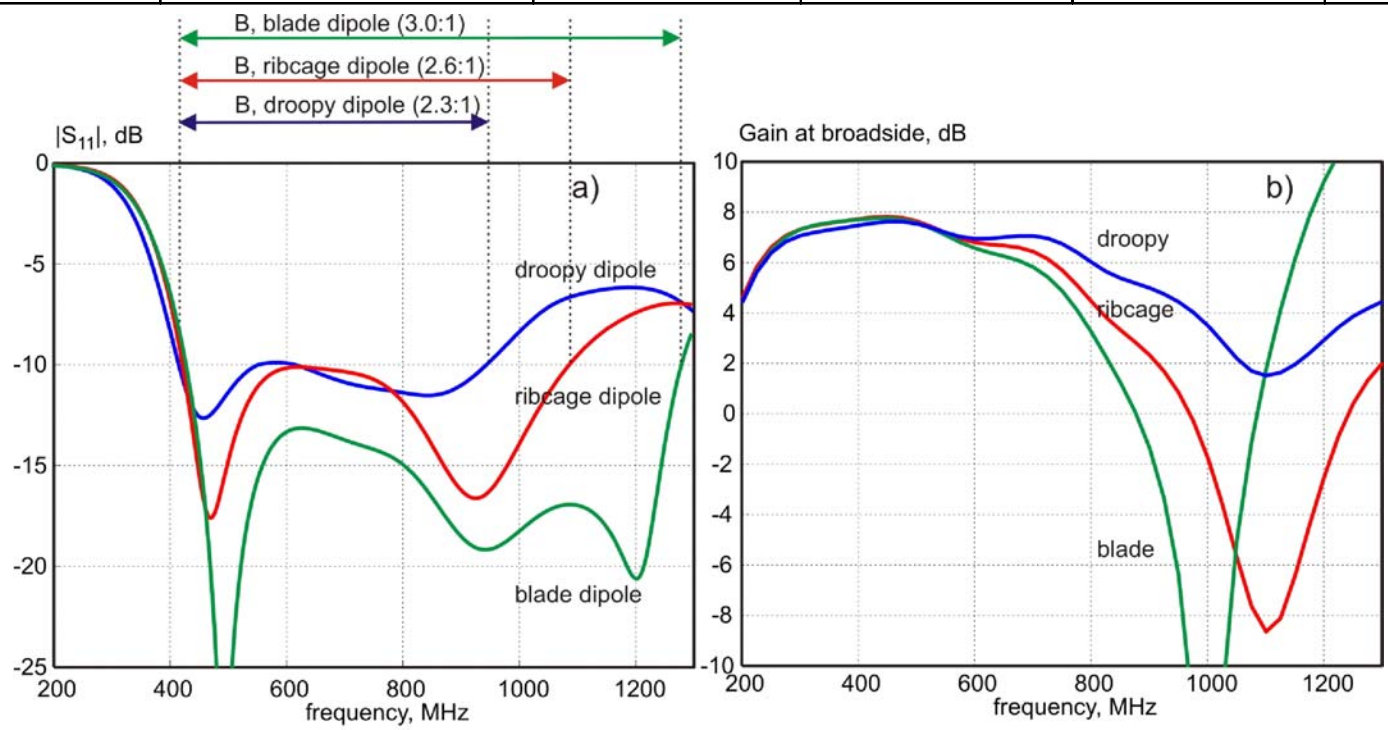
Antenna	Height from Ground Plane	Width	Length	Sleeve Depth	GP
Ribcage dipole	h=150 mm	w=25 mm	l=220 mm	60mm	300×300 mm
Droopy dipole	h=150 mm	w=140 mm	l=220 mm	NA	300×300 mm



- **The ribcage dipole can be designed to have similar performance than the droopy dipole**

Ribcage Dipole:
Between Droopy Dipole and Blade Dipole

Antenna	Height From Ground Plane	Width	Length	Sleeve Depth	GP
Ribcage dipole	**h=150 mm**	**w=55 mm**	**l=220 mm**	**40 mm**	**300×300 mm**
Droopy dipole	**h=150 mm**	**w=140 mm**	**l=220 mm**	NA	**300×300 mm**
Blade dipole	**h=150 mm**	**w=120 mm**	**l=220 mm**	NA	**300×300 mm**



- **The ribcage dipole can be designed to combine advantages of both droopy dipole and blade dipole (its extreme cases).**

Optimized Ribcage Dipole

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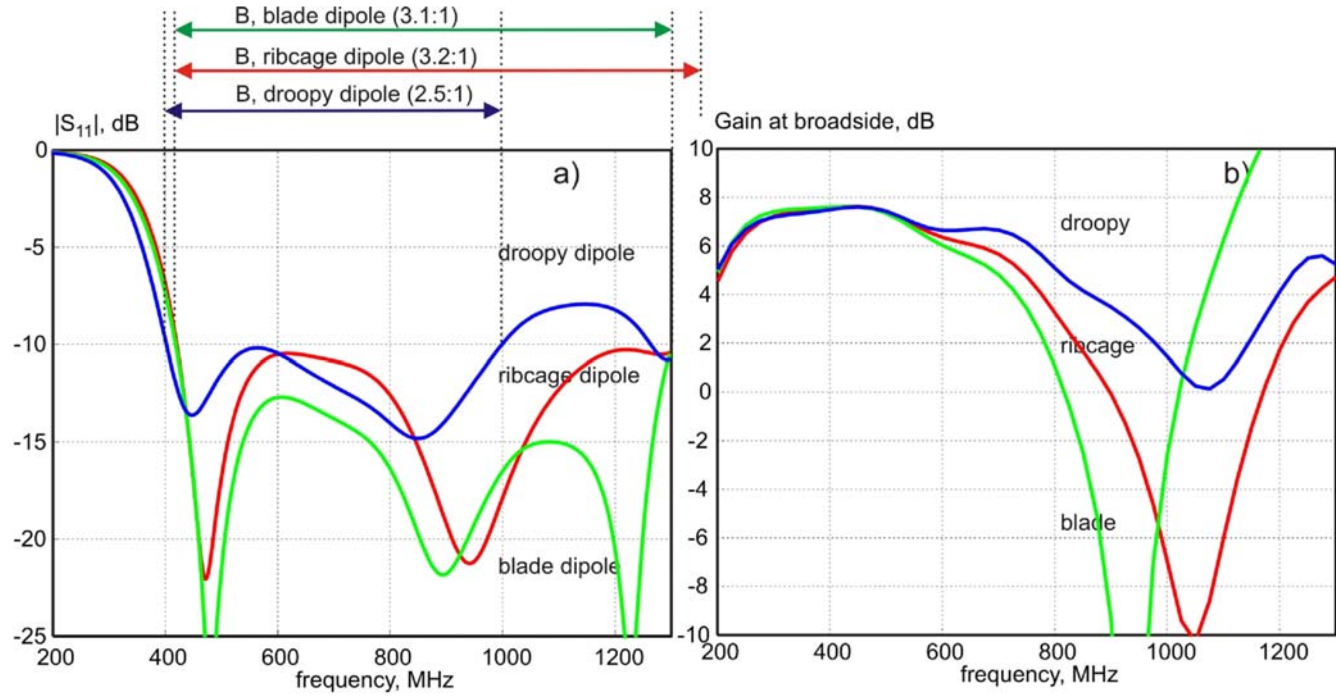
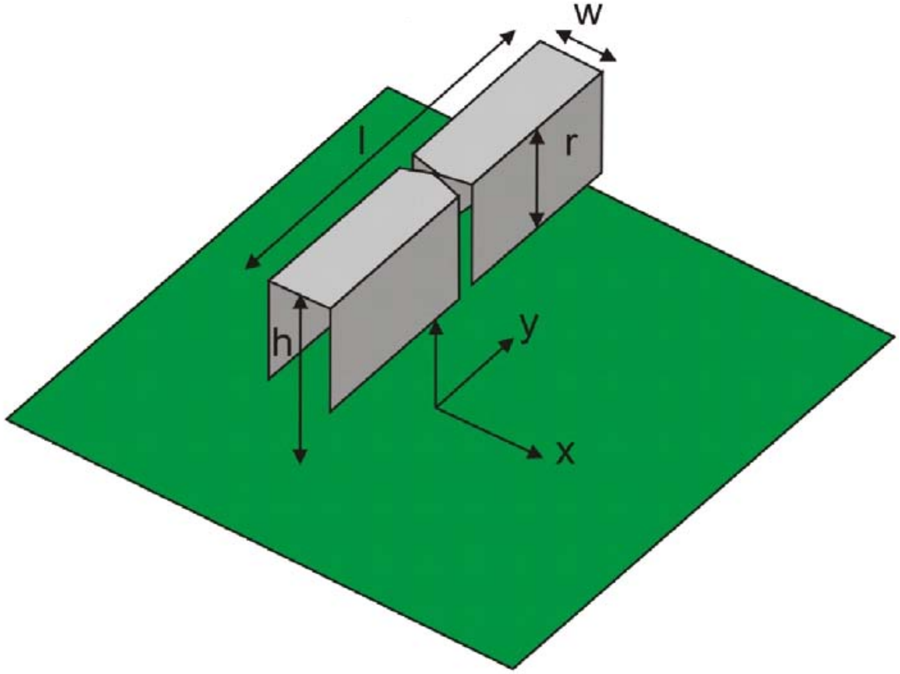
Antenna	Height from Ground Plane	Width	Length	Sleeve Depth	GP
Ribcage dipole	h=160mm	w=50mm	l=220mm	40mm	300×300mm
Droopy-blade dipole	h=160mm	w=140mm	l=220mm	NA	300×300mm
Wide-Blade dipole	h=160mm	w=120mm	l=220mm	NA	300×300mm



- A **ribcage dipole** can be optimized to have wider impedance bandwidth than a **droopy dipole** and better gain bandwidth than a **blade dipole**

Advantages of Ribcage Dipoles

- **Space optimization**
- **Design flexibility (more parameters)**
- **Wide impedance bandwidth**
- **Wide gain bandwidth**



Ribcage Antenna With Tapered Balun

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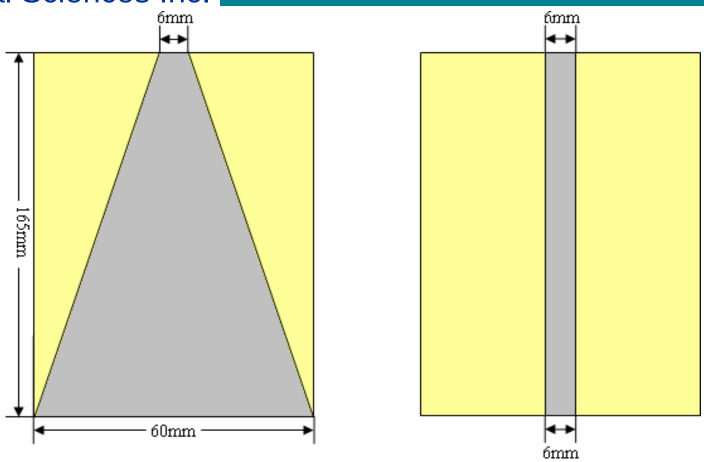
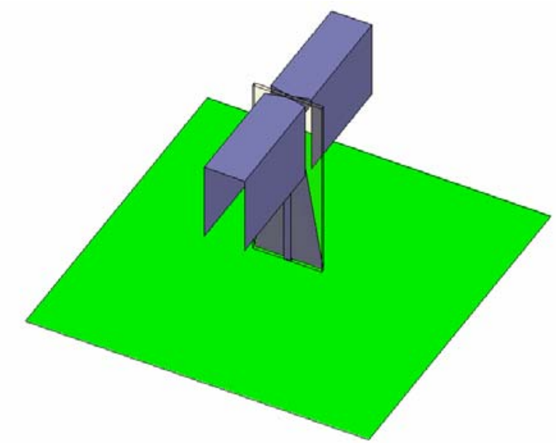
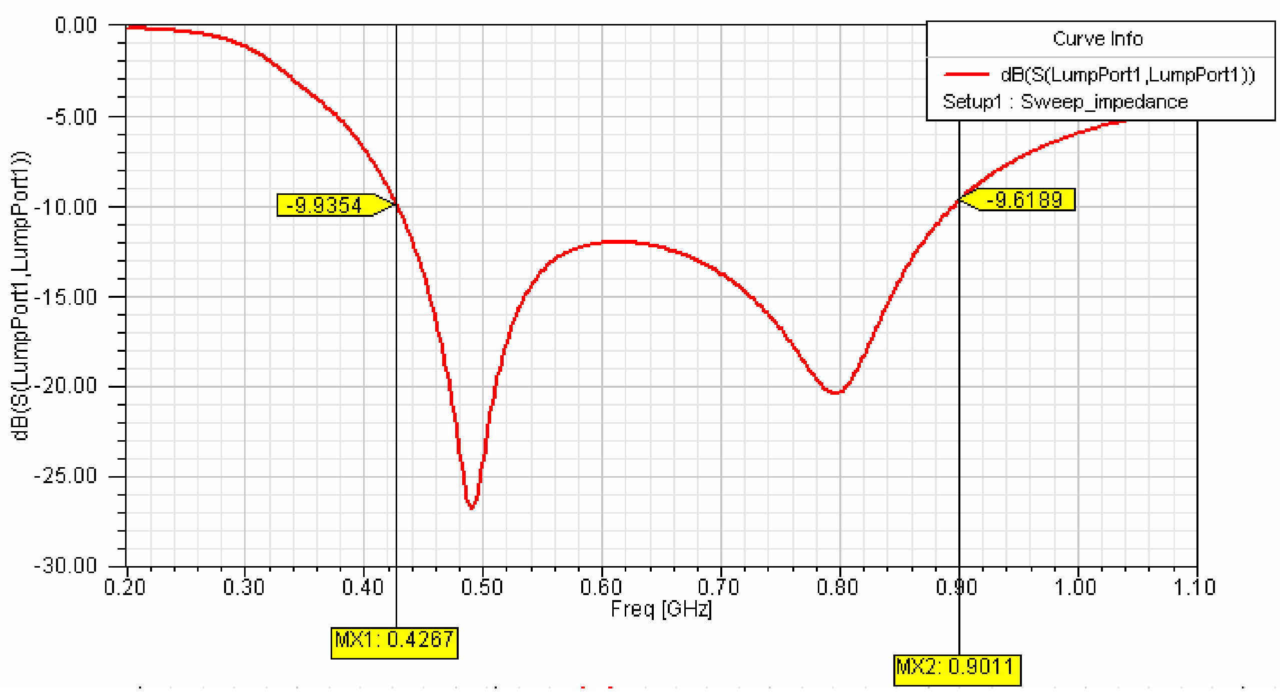
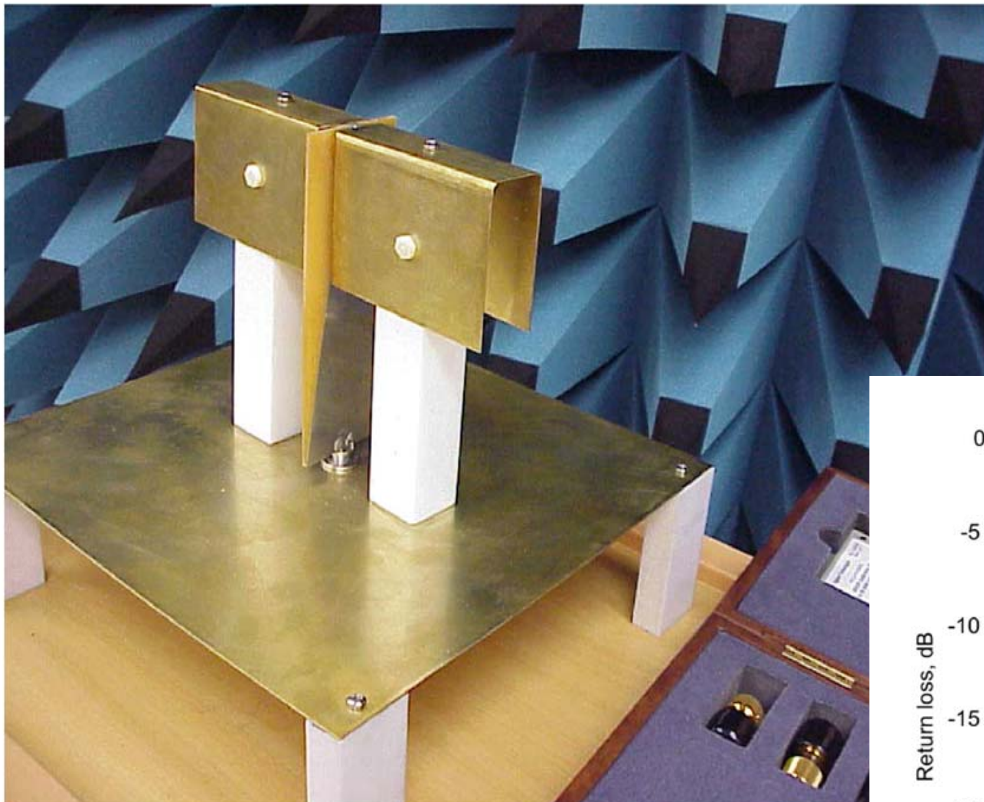
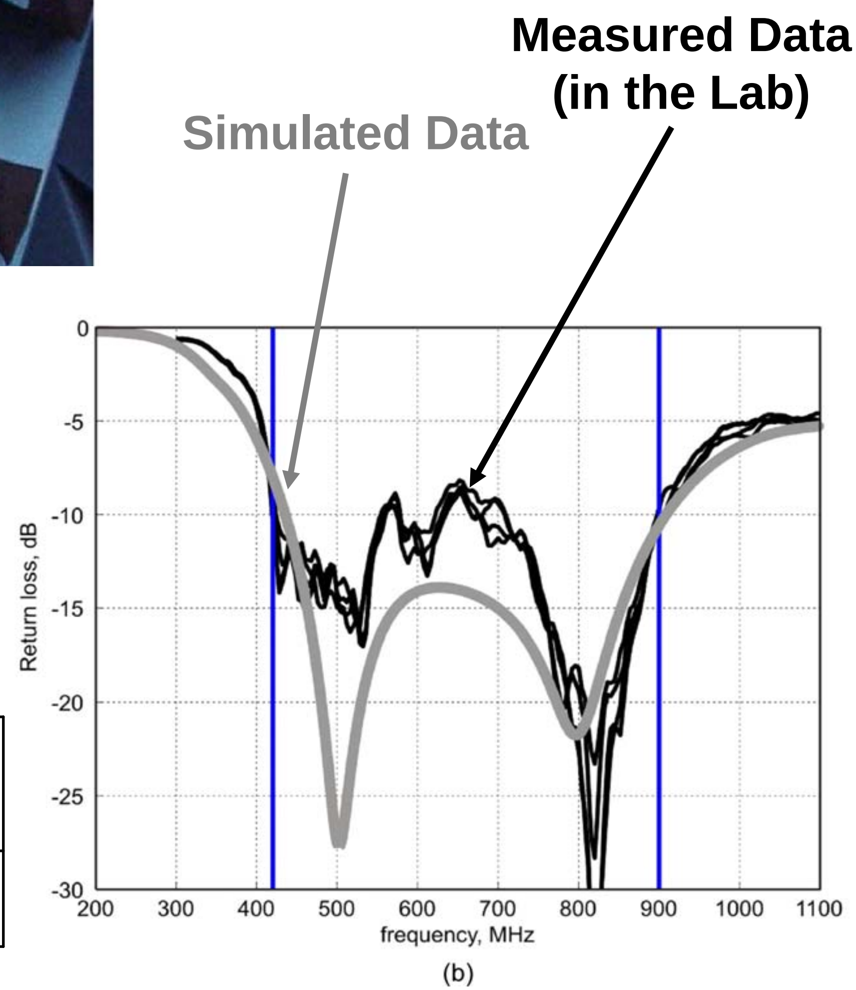






Ribcage Antenna With Balun and Teflon Support

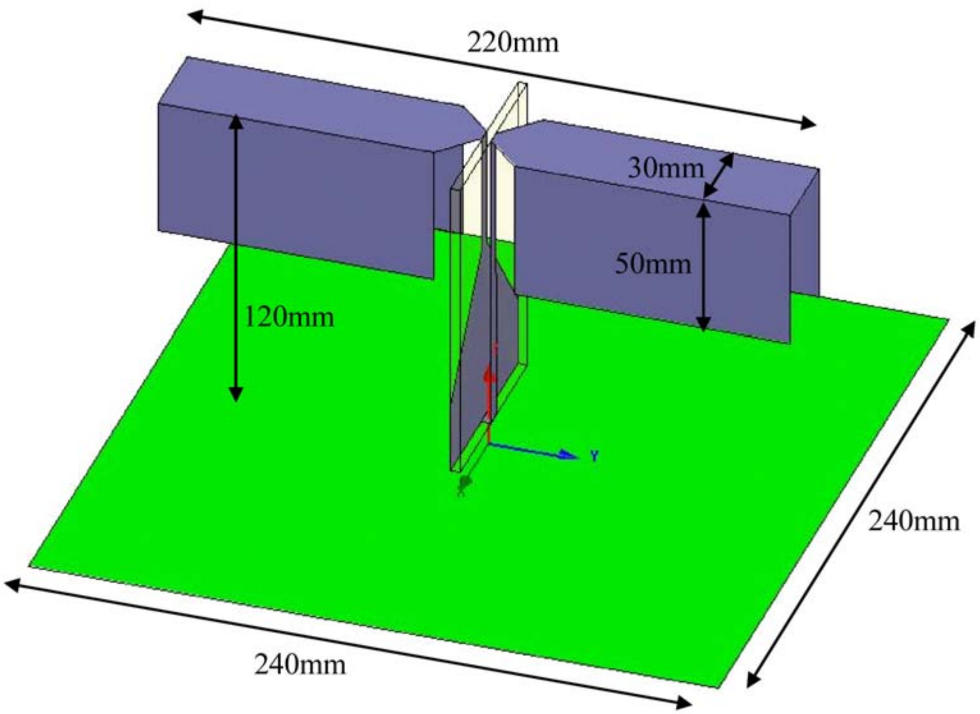


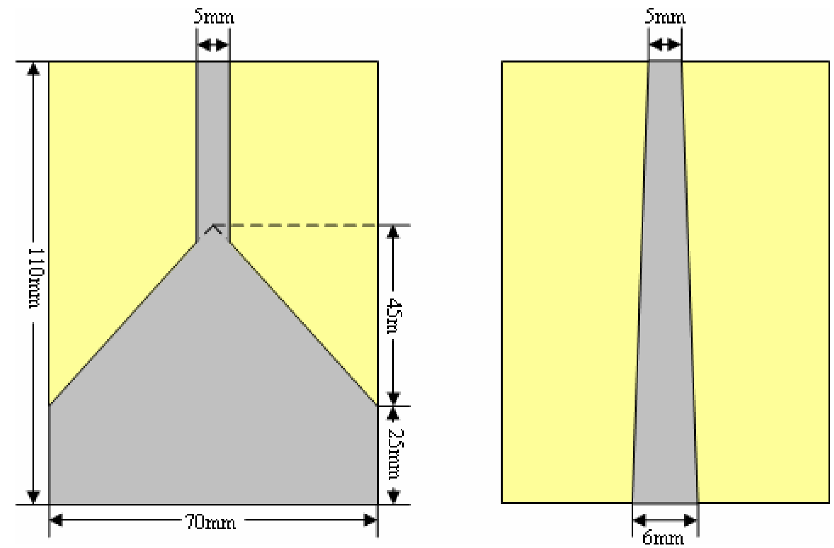


Height from Ground Plane	Width	Total Length	Sleeve Depth	GP
h=175 mm	w=35 mm	L=210 mm	r=70 mm	300×300 mm

Optimized Unit Cell With Balun

- **Optimized single radiating element for the array**





- **Optimized tapered balun for the array configuration**

Simulated Antenna Array Return Loss

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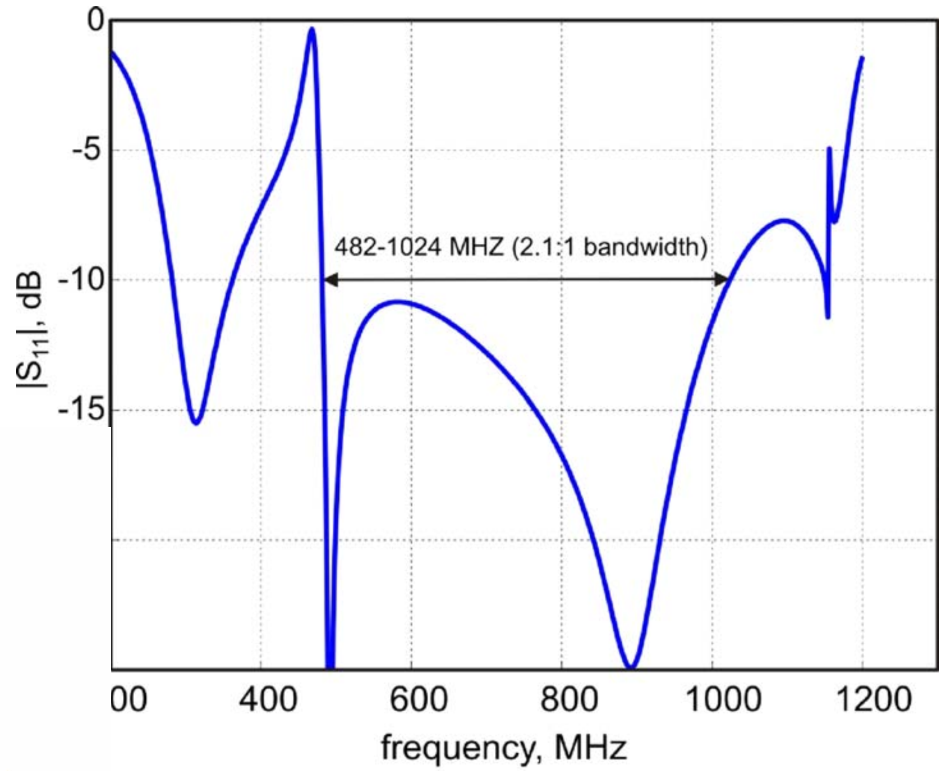
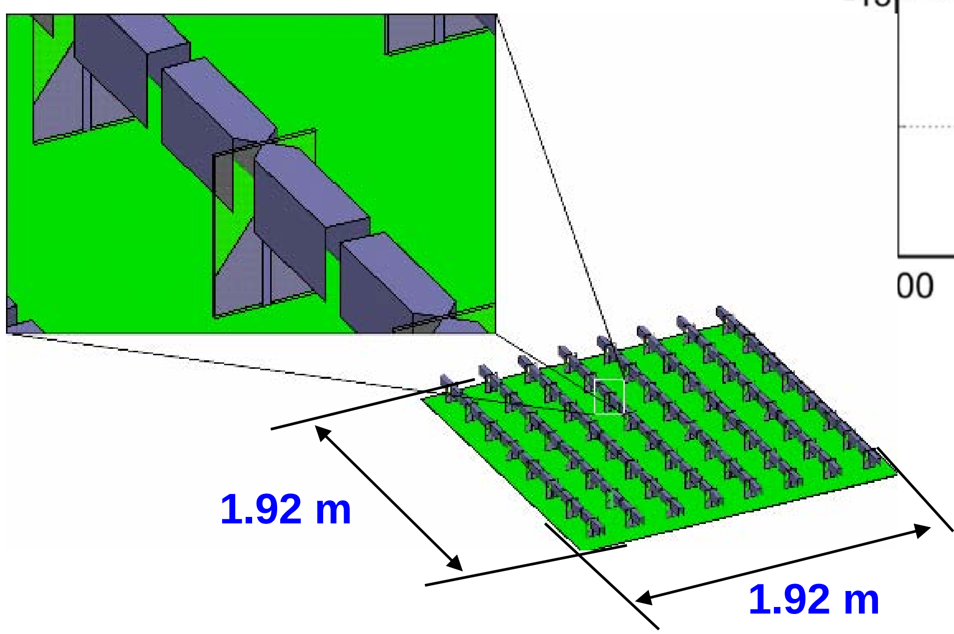
- **Return Loss for an infinite antenna array of ribcages with tapered balun**





- **1.92 x 1.92 m (8x8) array**
- **Equivalent to a 3 m parabolic reflector antenna**

Optimized Power Dividers

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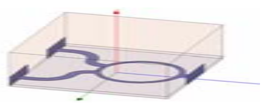

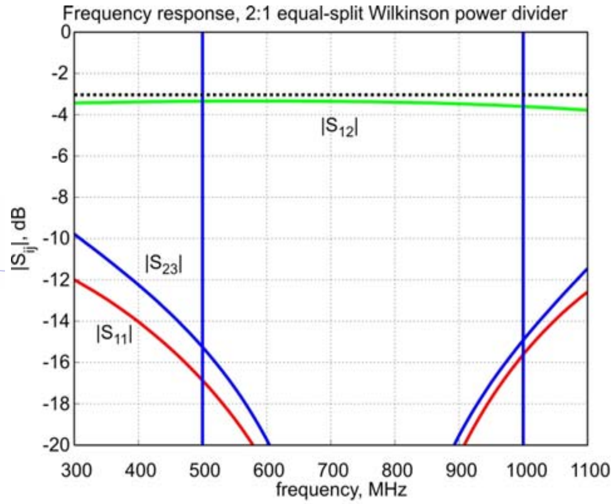

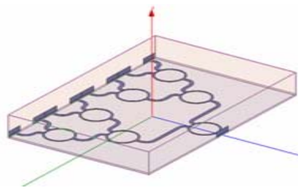

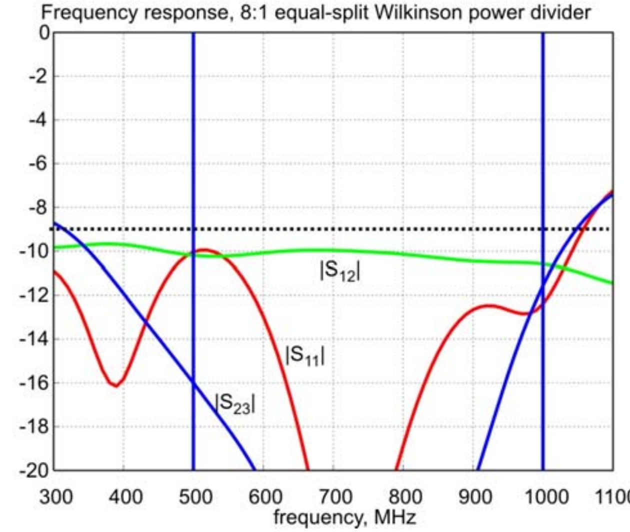

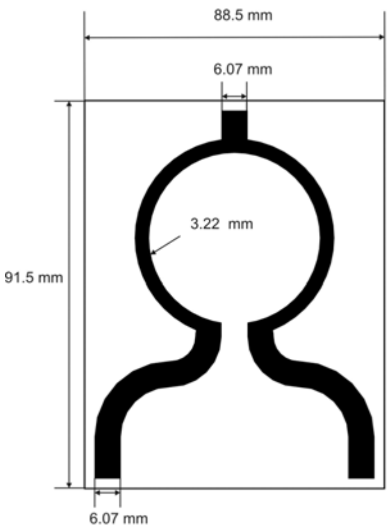

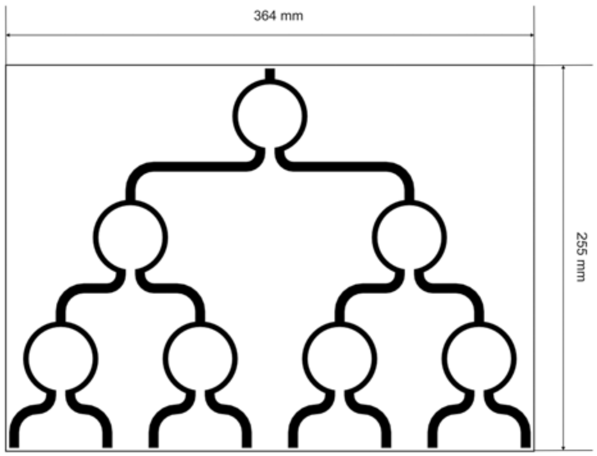

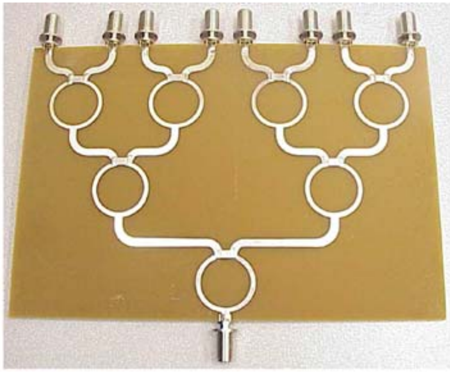

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Feeding Network for 8x8 Array of Ribcages

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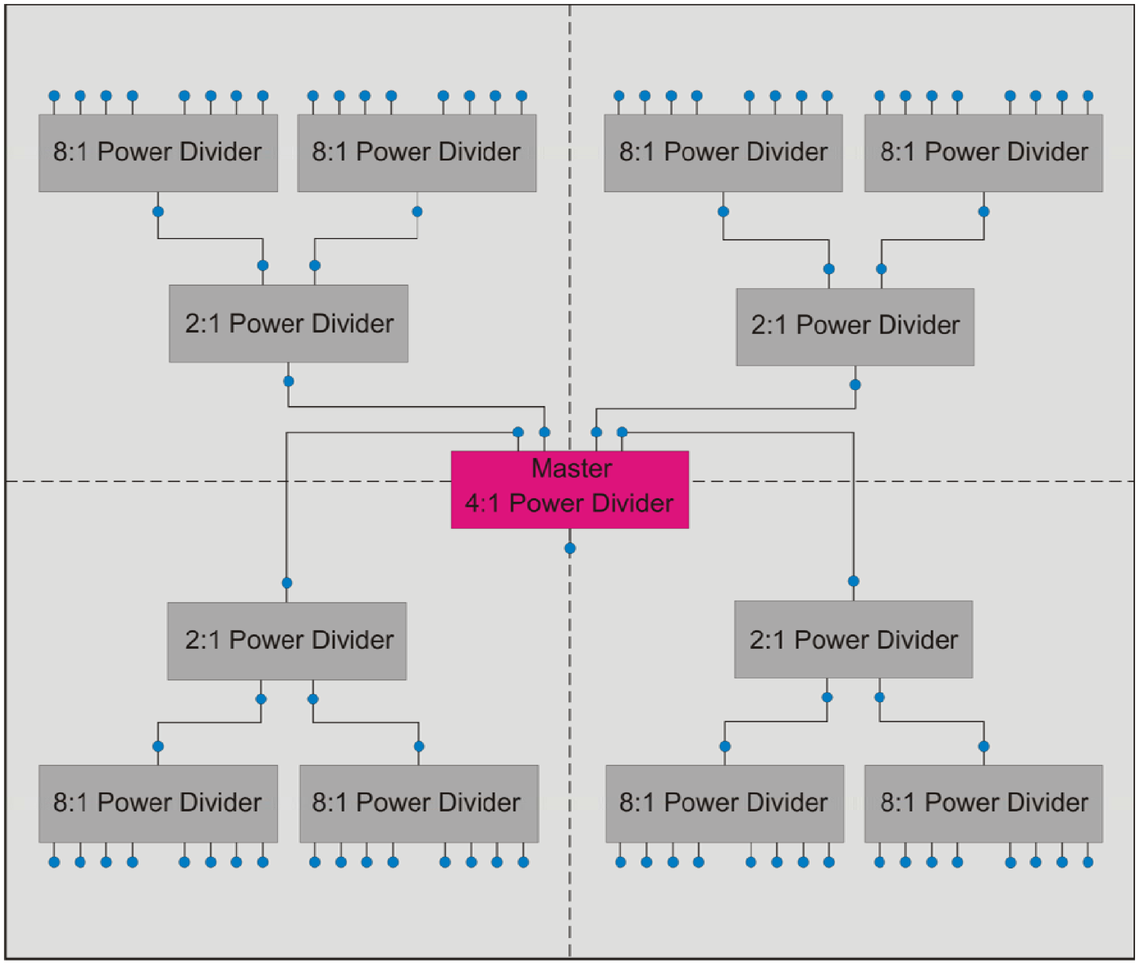

Measured Return Loss for the 4x4 Sub-Array Module

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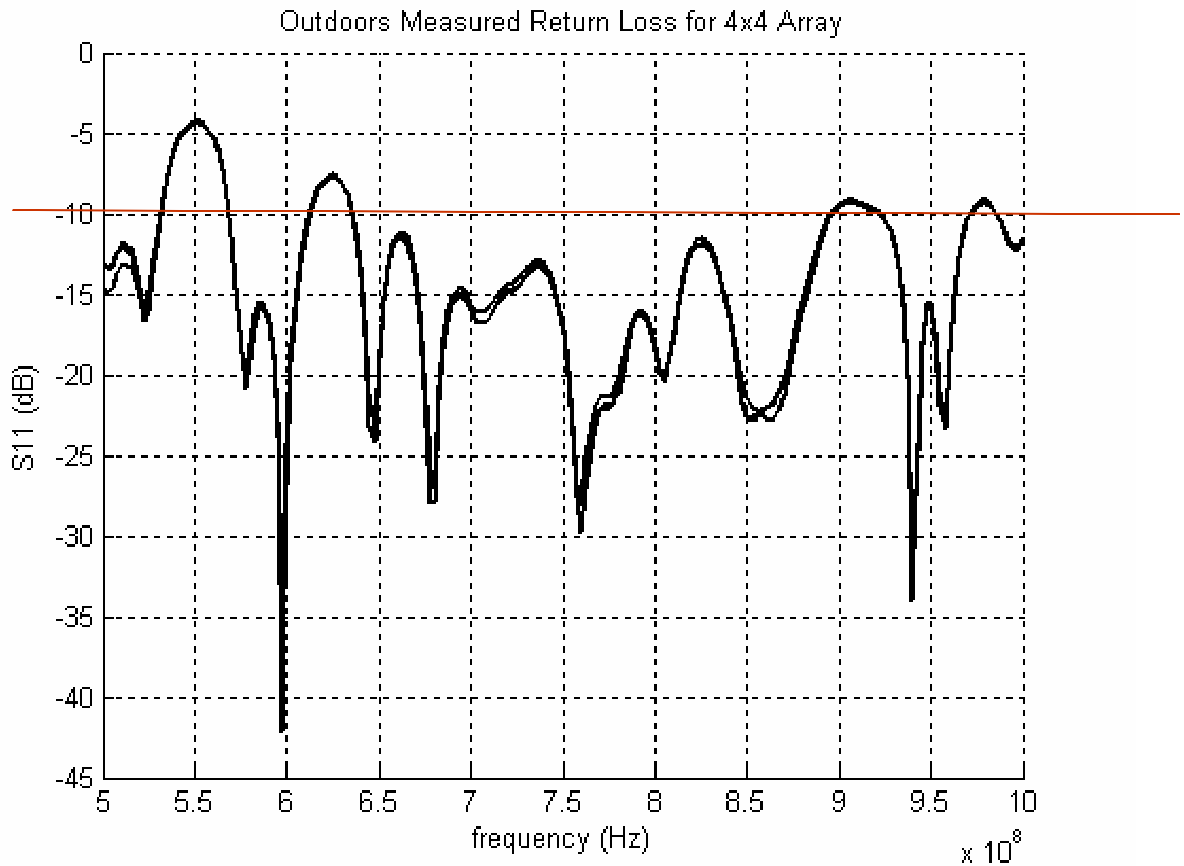
- **Replacement for conventional Digital TV antennas**



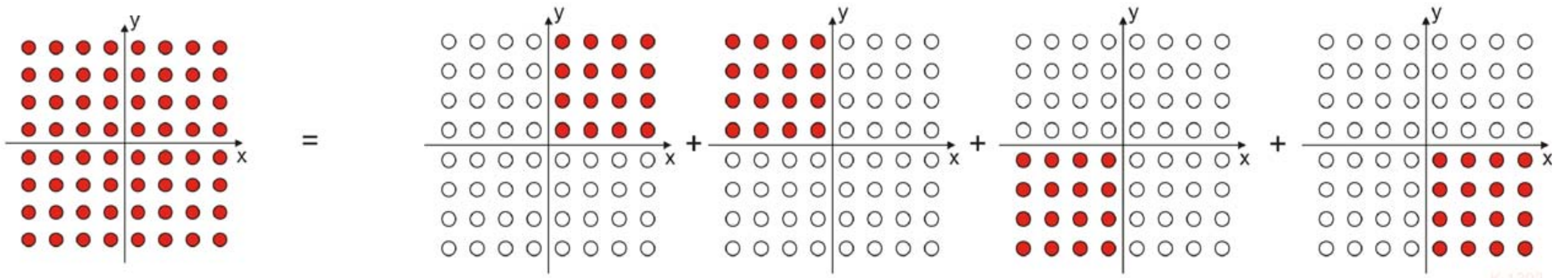
- **S_{11} for a 4x4 array of ribcage dipoles**
- **It can be used for Digital TV reception in the UHF band: 400-900 MHz**

Simplified 8x8 Antenna Array Pattern Modeling

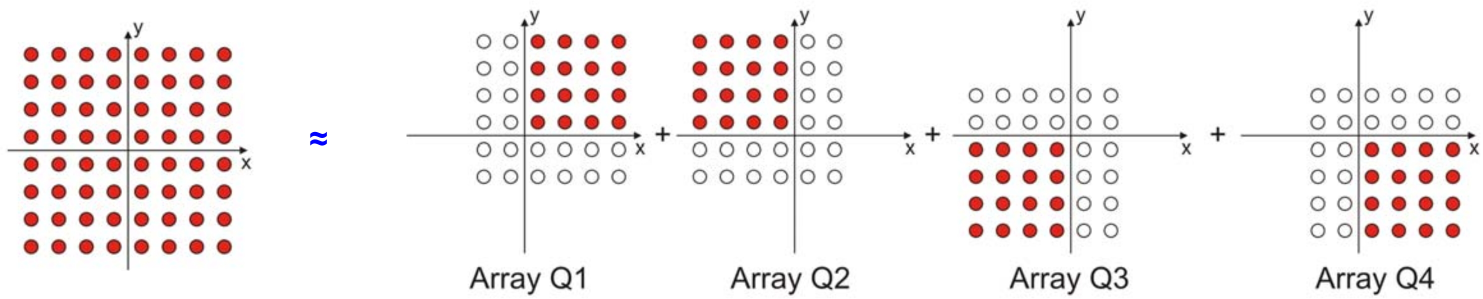
- **Modeling a finite 8x8 antenna array of ribcage dipoles with balun in Ansoft HFSS requires**
  - ~ 21 hours
  - 70 GB of memory on a
  - 64-bit Windows machine
- **We have developed a simplified methodology that exploits the symmetry of the array and array excitations**
- **We have implemented an algorithm that allows to compute the total field pattern for the 8x8 antenna array from the analysis of one 6x6 sub-array**
- **Modeling a finite 6x6 sub-array of ribcage dipoles with balun in Ansoft HFSS requires**
  - ~ 6 hours
  - 20 GB of memory on a
  - 64-bit Windows machine

Simplified Composite Array Model

- **The total array field pattern can be expressed as superposition of four array field patterns, when the quadrants Q1, Q2, Q3, and Q4 are excited**
- **Only 16 elements are excited at any one time, while the remaining elements are passive and match-terminated (50 Ω)**



- **Approximation: truncate the passive arrays by removing the two outermost rows and columns.**
- **Now there are four 6x6 arrays, which can be analyzed/simulated separately**



Further Simplification of the Composite Array Model

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- **When the array excitation is symmetric with respect to the x- and y-axes:**

$$\overline{E}_{Q3}(\theta,\varphi) = -\overline{E}_{Q1}(\theta,\varphi)$$

- **Q2 and Q4 are mirror images of Q1 and Q2:**

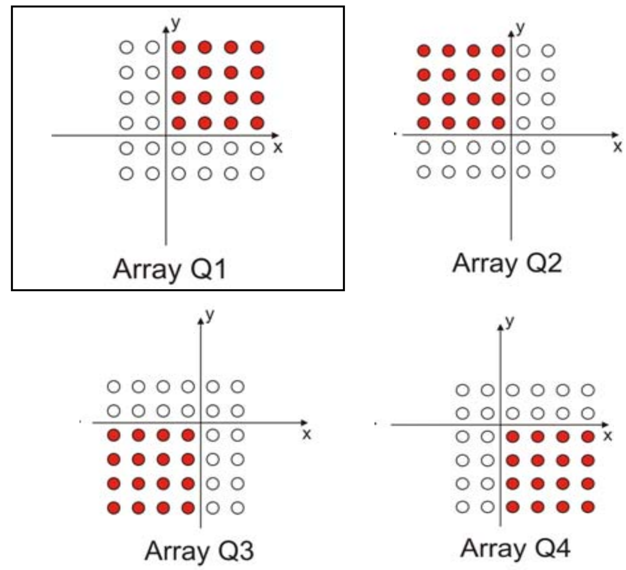
$$\overline{E}_{Q2,\theta}(\theta,\varphi) = -\overline{E}_{Q1,\theta}(\theta,\pi-\varphi)$$

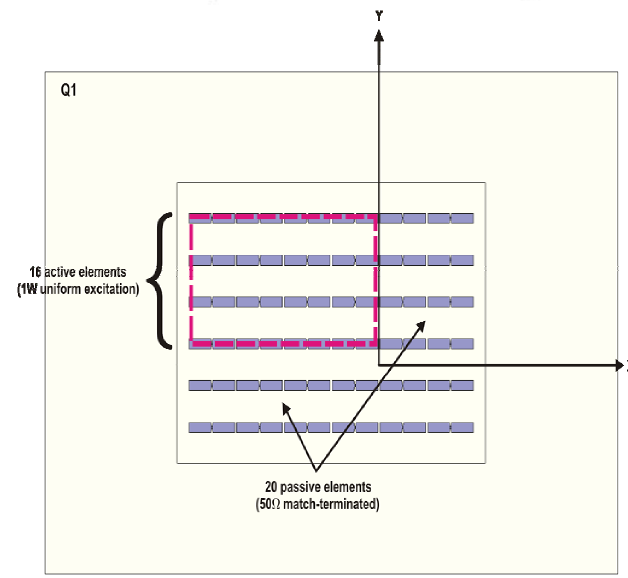
$$\overline{E}_{Q2,\varphi}(\theta,\varphi) = \overline{E}_{Q1,\varphi}(\theta,\pi-\varphi)$$

$$\overline{E}_{Q4,\theta}(\theta,\varphi) = \overline{E}_{Q1,\theta}(\theta,-\varphi)$$

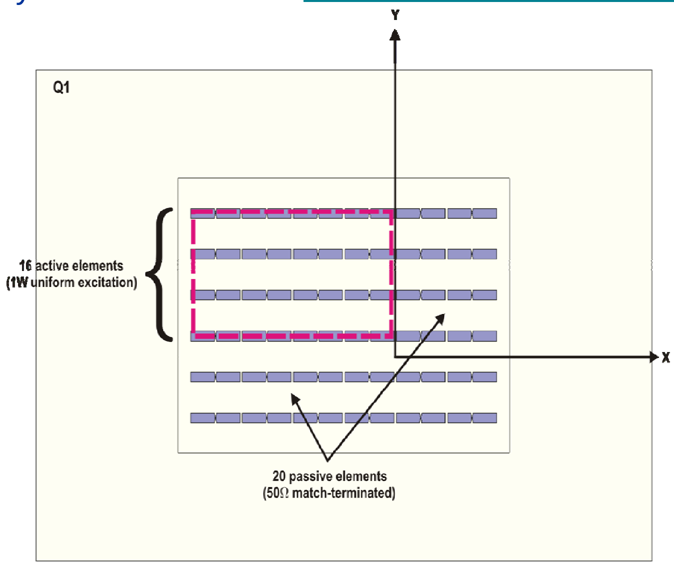
$$\overline{E}_{Q4,\varphi}(\theta,\varphi) = -\overline{E}_{Q1,\varphi}(\theta,-\varphi)$$

- **A highly accurate representation for the far filed of the 8x8 array can be obtain from the computation of a single 6x6 array (Q1)**

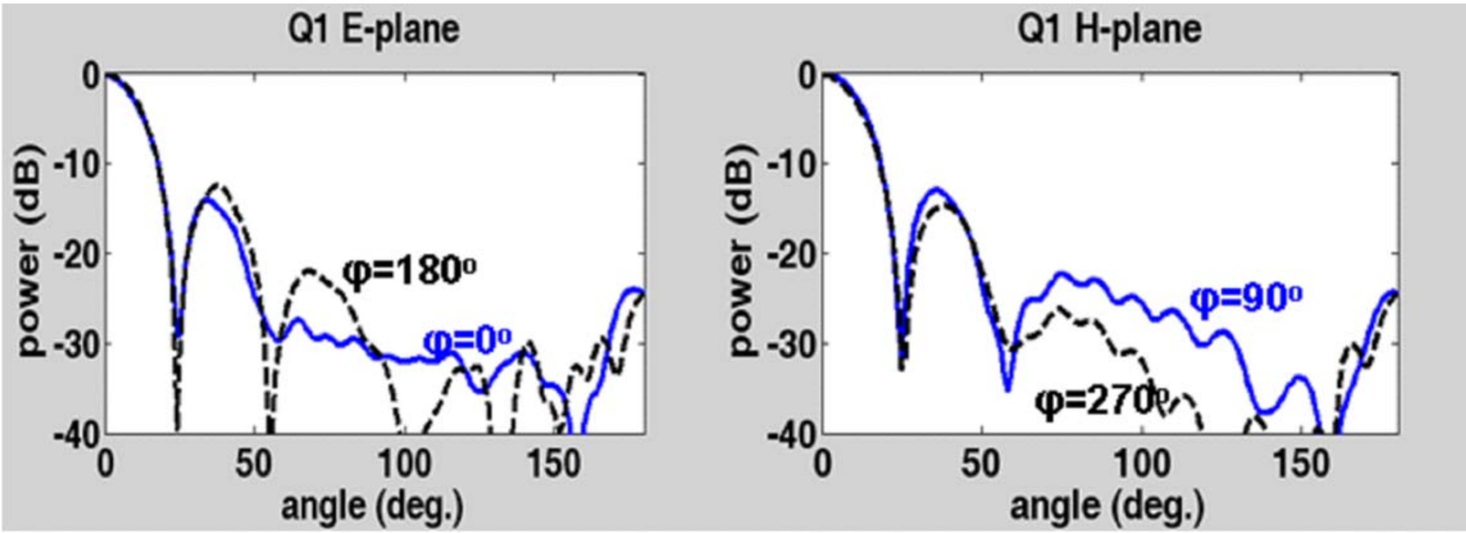




Q1 Sub-Array Pattern



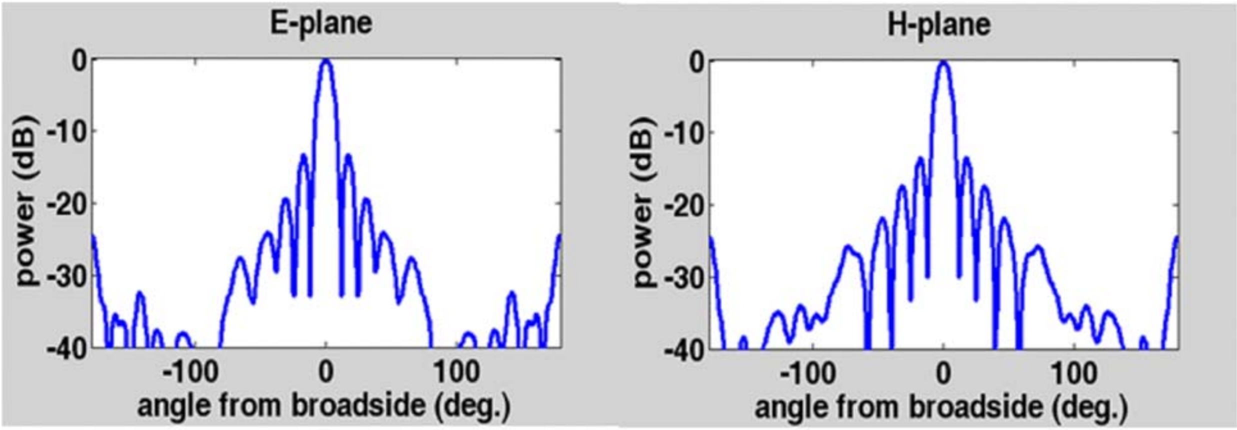
Q1 sub-array pattern at 750 MHz: E-plane and H-plane



8x8 array Gain From Simplified Composite Array Model

The array directivity D is obtained by simple integration:

$$D = \frac{|E_{\max}|^2}{\int\int |E_{\max}|^2 \sin\theta \, d\theta d\varphi}$$



Frequency	Aperture Gain	Gain Computed from Composite Array Model	Total Gain (array gain - net loss in feeding network)
500 MHz	21.1 dB	21.5 dB	19.0 dB
750 MHz	24.6 dB	24.7 dB	22.2 dB
1000 MHz	27.1 dB	26.4 dB	23.9 dB

Conclusions

- **Wideband ribcage dipole as a single radiator:**
  - Combines advantages of blade dipole and droopy dipole
  - Achieves wide impedance bandwidth up to 3.2:1 while maintaining good pattern stability
  - Has low profile when mounted parallel to a ground or air vehicle

- **Array of ribcage elements:**
  - Has performance similar to a parabolic antenna while occupying less volume (e.g. 3 m diameter vs 1.92x1.92 m)
  - Can be stowed and transported in smaller sub-array modules (e.g. four 4x4 sub-arrays for an 8x8 array)
  - Its gain pattern was computed using a Simplified Composite Array Model

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