The Shape of Antennas Yet to Come

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A Conundrum

A ham wants to make a wire antenna for 20-meter DX. It needs to have a lot of gain. More gain is better. He is blessed with an infinite spool of antenna wire but cursed with rusty, old wire cutters. He can make but two cuts. He cuts off two pieces of wire to drive one against the other. How much gain can his antenna have? In answering this simple question, Steve will lead us beyond dipoles into a world of 2D paths in 3D space. You will throw away your wire cutters after Steve shows how Texas longhorns and cowboy hats can beat beams.

Topics

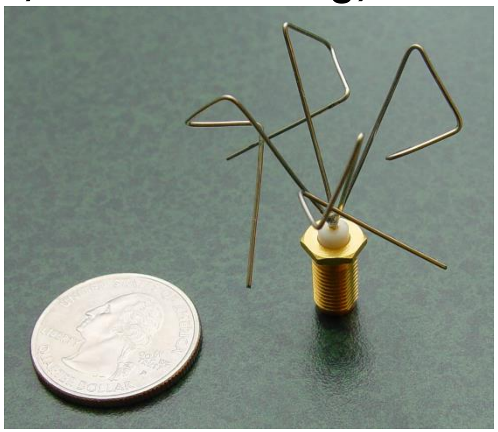
- **Wire antenna design choices**
- **What antenna optimizers can do**
- **Genetic evolved antennas**
- **Planar symmetric wire antennas**
  - Plane contains main lobe, max gain direction
  - Plane perpendicular to main lobe, max gain direction
- **The Landstorfer family**
  - Cowboy hats
  - Texas longhorns
- **How to Beat the Beam (Yagi-Uda)**

Wire Antenna Design Choices

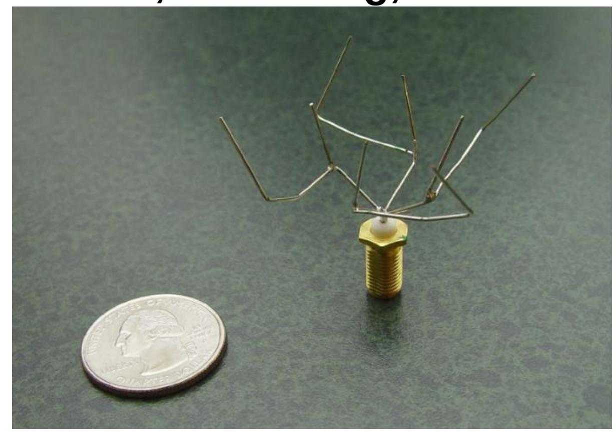
- **Traditional wire antenna variables**
  - Length
  - Diameter
- **Often unconsidered wire antenna variables**
  - Topology
    - Number of wire cuts (Can you “Name that Tune” in a single note?)
    - Connected and continuous vs Disconnected
    - Joints or junctions (To solder or not to solder, that is the question!)
  - Geometry
    - Size and shape

Genetic Evolved Antennas – “Crooked” Wires

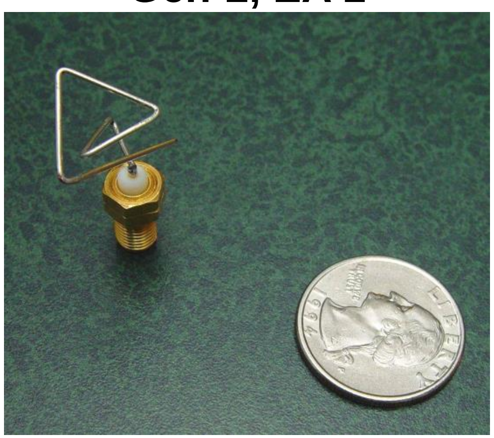
Gen-1, Non-Branching, ST5-4W-03



Gen-1, Branching, ST5-3-10



Gen-2, EA 1



Gen-2, EA 2

Dr. Jason D. Lohn, “Automated Antenna Design and Optimization,” Foothills Amateur Radio Society, June 17, 2011.

Antenna Optimizers

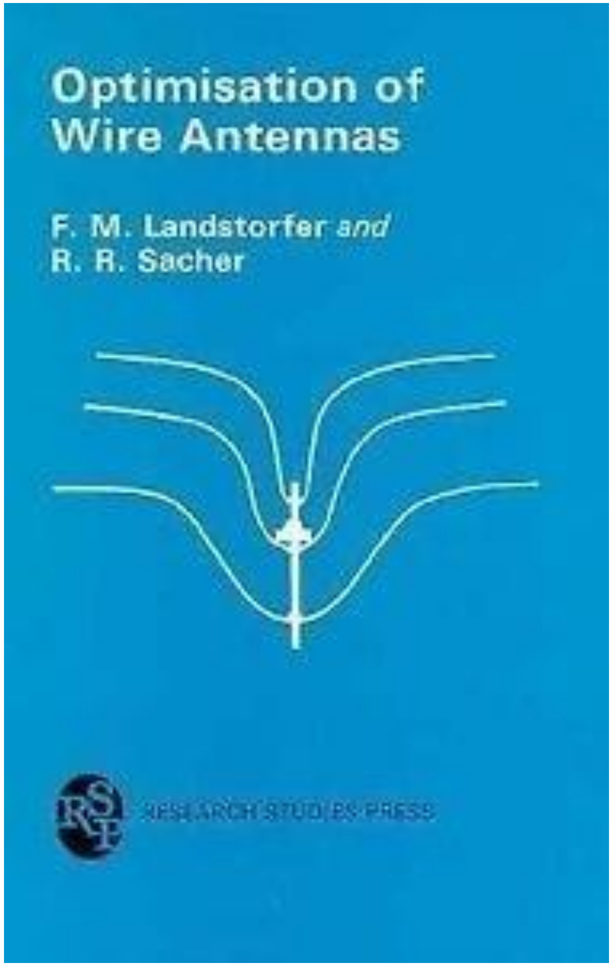
- **Featured in modern antenna modeling software**
- **Automatic optimization of antenna variables**
- **Three-part specification**
  - Antenna model specified by variables
  - Optimization algorithm
    - Gradient descent
    - Random search
    - Nelder-Mead (AKA amoeba or nonlinear simplex)
    - Genetic /evolutionary
    - Particle swarm
  - Goal
    - Simple or Compound
    - Desired impedance, far field pattern, or near field values
    - Limits on variable values

Optimizers are great for "fine tuning" a design.
Not good as blind substitute for design.

Optimization Specification

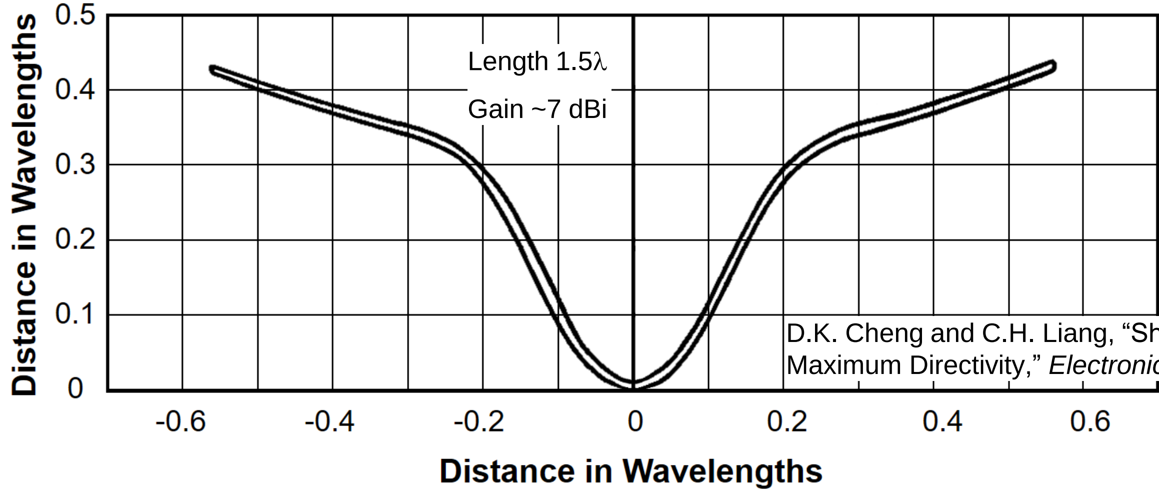
- **Antenna model**
  - Planar wire antenna
  - Plane contains main lobe, max gain direction
  - Wire is topologically connected
  - No cuts except feedpoint
  - Mirror symmetry about feedpoint
- **Optimization variables and constraints**
  - Segment end points
  - Segment length fixed at $< \lambda/20$
  - Total wire length (sum of segment lengths) is fixed
- **Optimizer algorithm**
  - Nelder-Mead (slow but reliable)
- **Simple goal**
  - Unidirectional with maximum gain in any direction in plane of antenna
  - For given total wire length and diameter

An Old Book Inspired Me

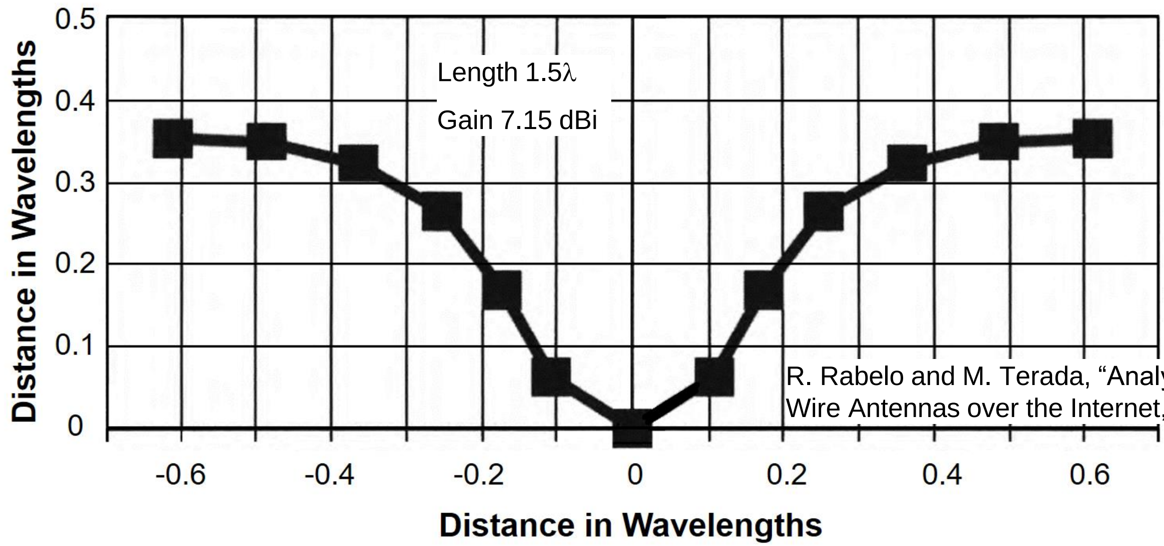


F.M. Landsdorfer and R.R. Sacher, *Optimisation of Wire Antennas*, Research Studies Press/Wiley, 1985.

Prior Results Using Different Optimizers and Variables

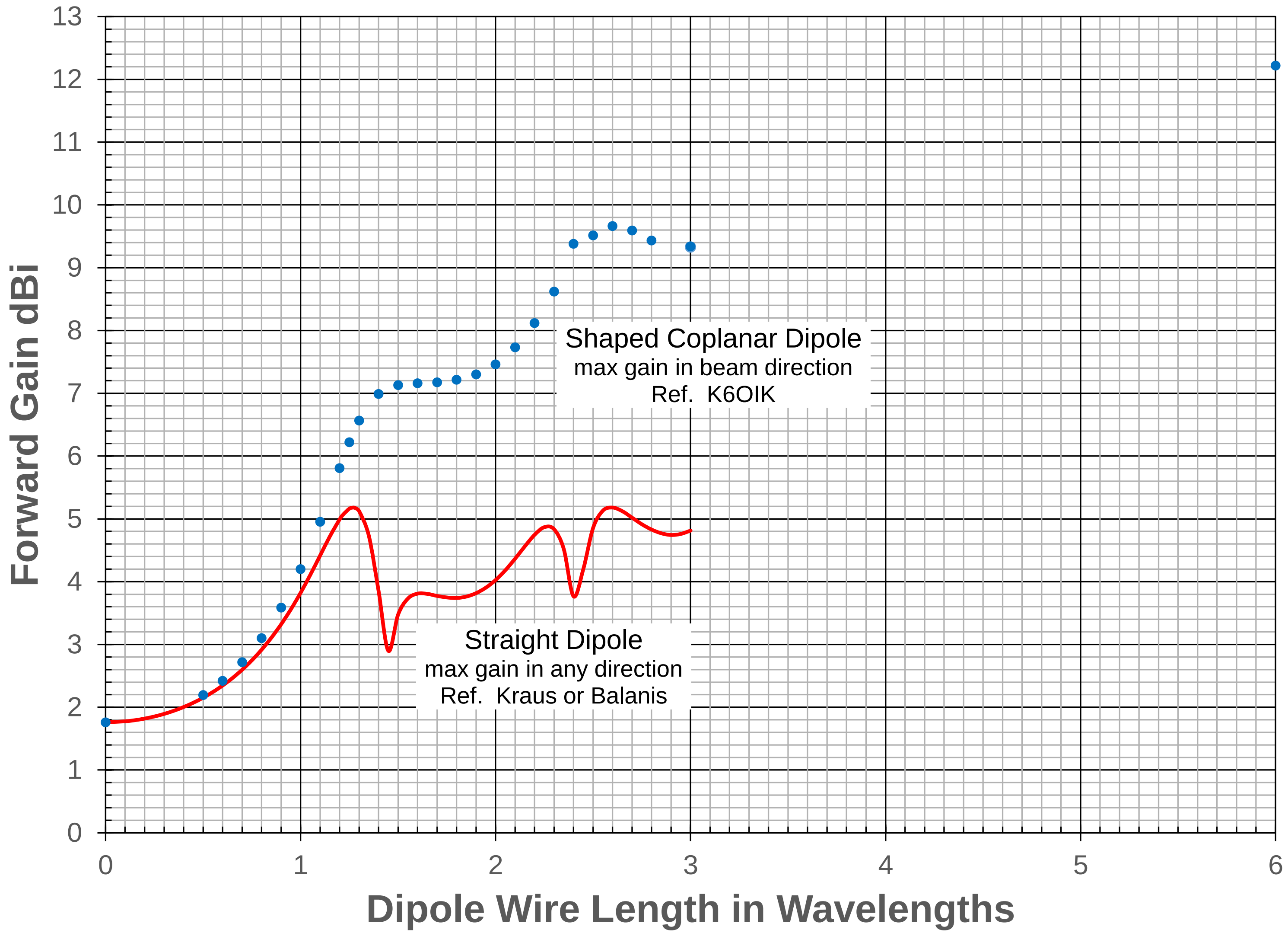


D.K. Cheng and C.H. Liang, “Shaped Wire Antennas with Maximum Directivity,” *Electronics Letters*, Sept 1982.

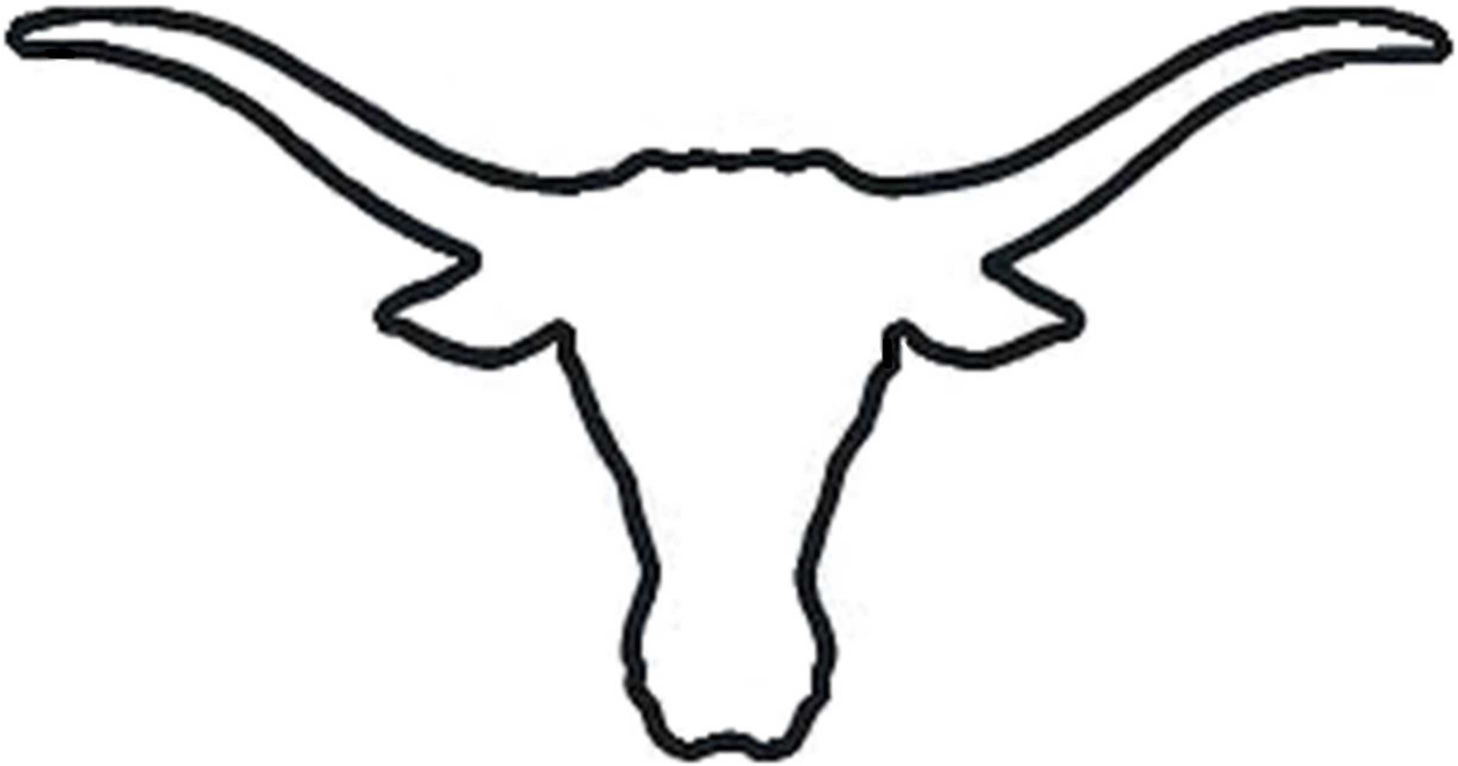


R. Rabelo and M. Terada, “Analysis and Optimization of Wire Antennas over the Internet,” *IEEE AP Mag*, Feb 2010.

Results of 26 Optimization Runs by HOBBIES

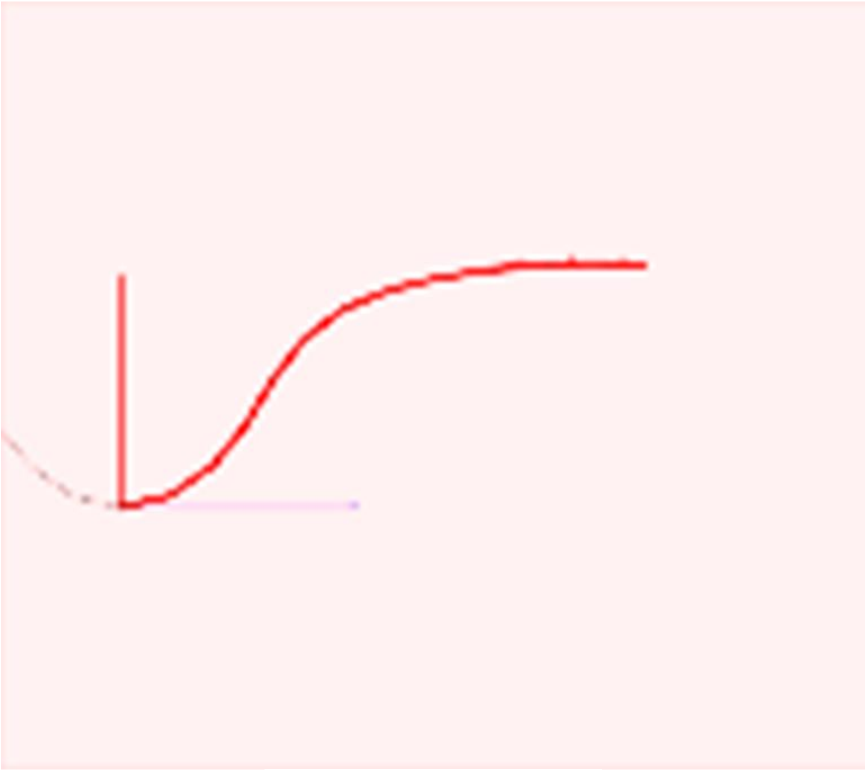


The Texas Longhorn Profile

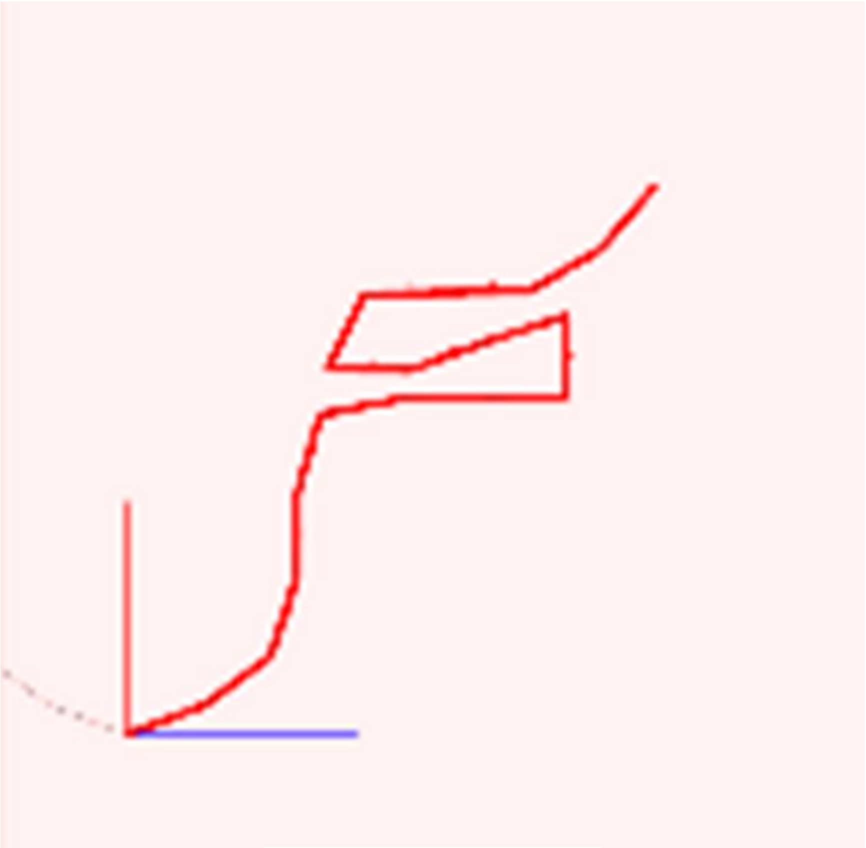


Texas Longhorn Antenna Profile

Transition From Cowboy Hats to Cows

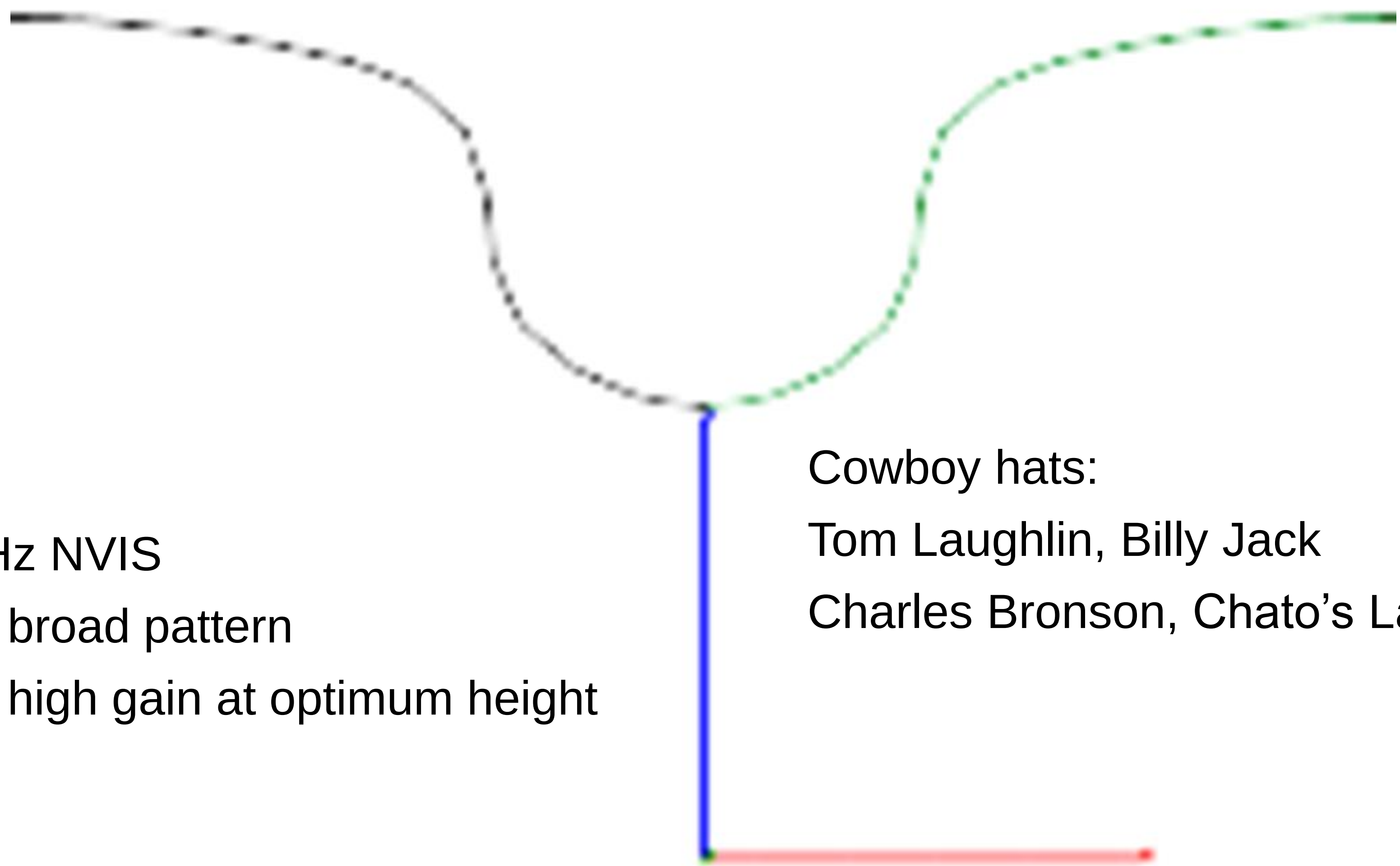


Length 1.4 λ



Length 2.4 λ

Upward Firing NVIS Using Ground as Reflector



4 MHz NVIS

Very broad pattern

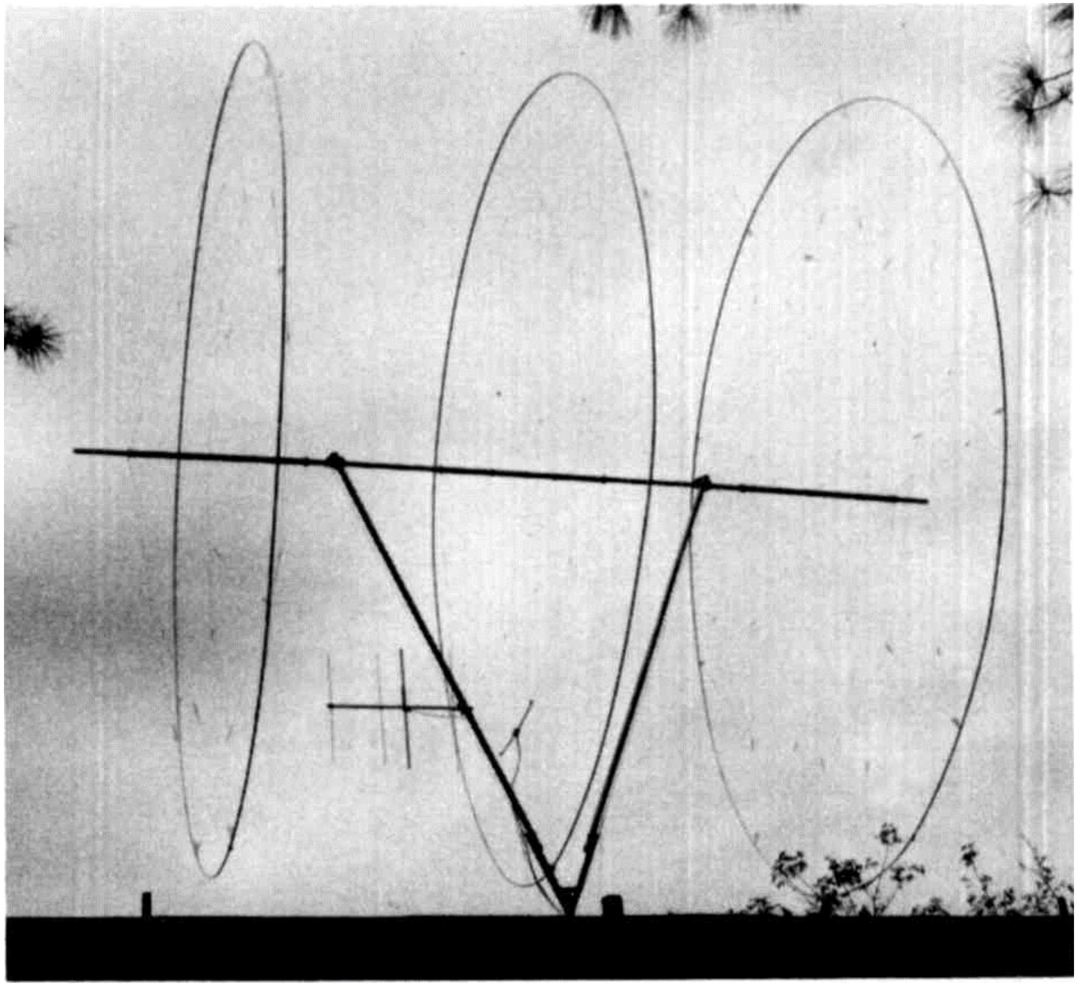
Very high gain at optimum height

Cowboy hats:

Tom Laughlin, Billy Jack

Charles Bronson, Chato's Land

Amateur Ingenuity: W4OVO 3-Element HF Loop Array

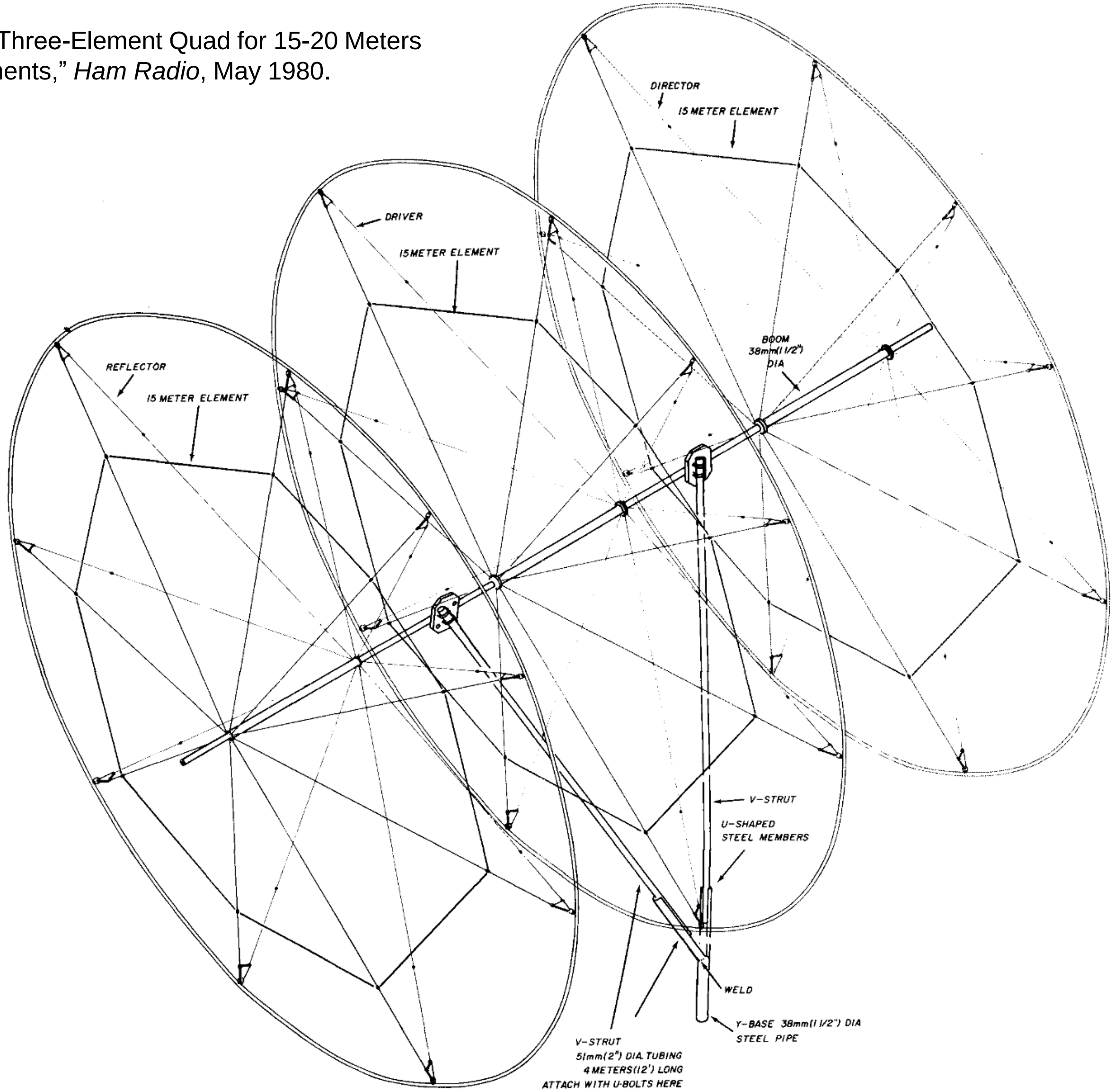


J.W. Kennicott W4OVO, "Three-Element Quad for 15-20 Meters Which Uses Circular Elements," *Ham Radio*, May 1980.

- 2 dB more gain
- Circular loop arrays have more gain than Yagi-Uda arrays per boom length
- But aren't circles hard to construct?

W4OVO's Solution – Three Jumbo Bicycle Wheels

J.W. Kennicott W4OVO, "Three-Element Quad for 15-20 Meters Which Uses Circular Elements," *Ham Radio*, May 1980.



A Two-Element Super-Directive Yagi-Uda Antenna

Element Plane Perpendicular to Main Lobe

(For the Guiness Book of Records)

Objective

- **Answer the simple question: What is the maximum possible gain for a 2-element Yagi-Uda antenna?**
- **Assume no other constraints**
  - No constraints on F/B ratio
  - No constraints on sidelobe levels
  - No constraints on impedance
  - No constraints on boom length or element shape
- **Assumptions**
  - Two elements
  - Free space
  - PEC metal

2-Element Yagi Targets to Beat

- **ARRL: 6 to 6.5 dBi**
- **Anecdotal: 7 to 7.5 dBi**
- **Less than a 3-element Landstorfer yagi, i.e. < 11.5 dBi**
- **Hansen and Woodyard (1938): -1.59 dBi**

$$\text{Gain} \simeq 4.83 \frac{\text{boom length}}{\lambda} \simeq 4.83 \times 0.144 = 0.694 \quad (-1.59 \text{ dBi})$$

- **Reid (1946): (formula not evaluated)**
  - D.G. Reid, "The Gain of an Idealized Yagi Array," *J IEE*, Pt IIIA, 1946
- **Walkinshaw (1946): 5.05 to 5.35 dBi**
  - 1 director: 2.4 to 3.2 dBd
- **Ehrenspeck and Poehler (1959): 7.78 dBi**

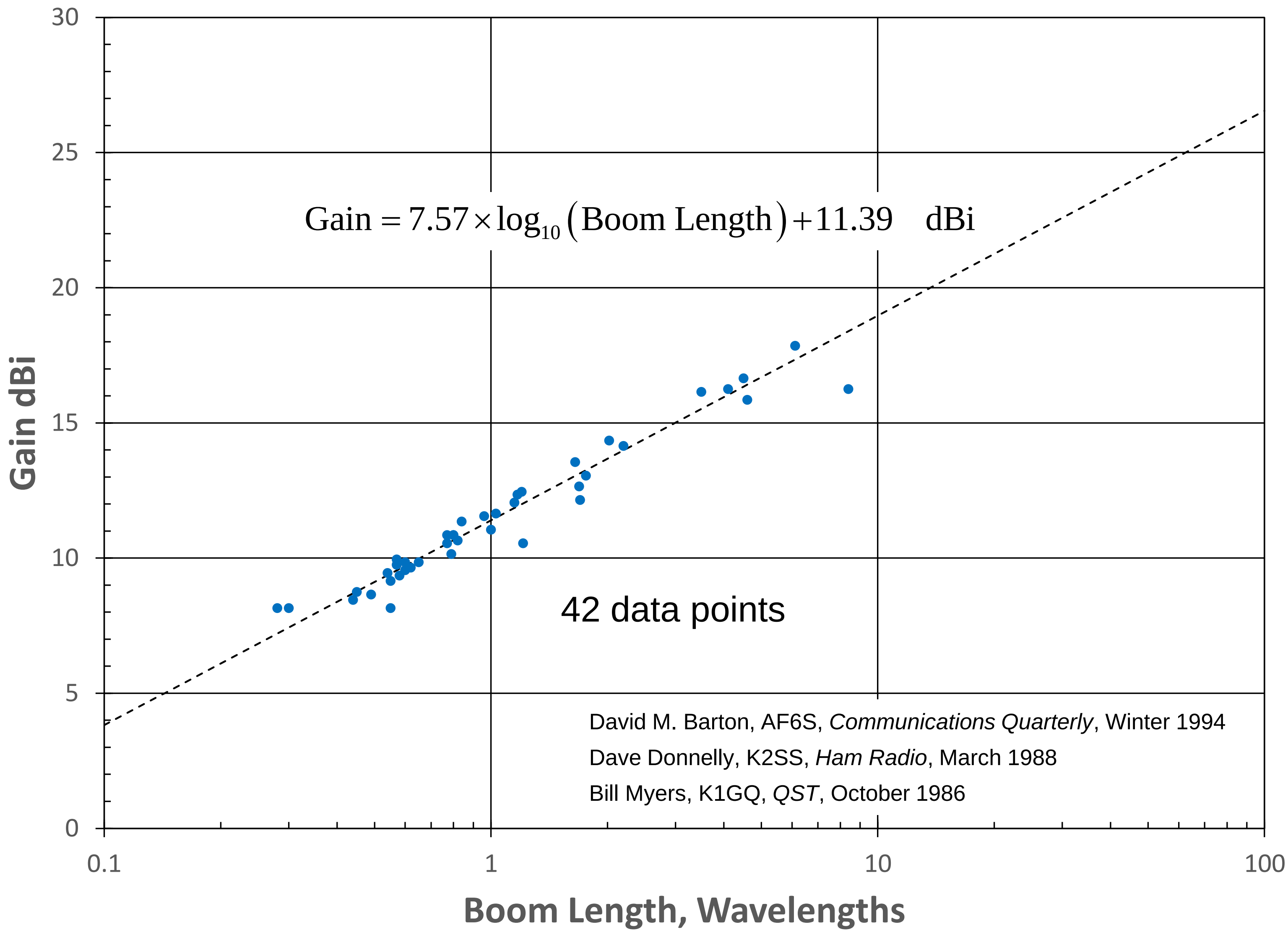
$$\text{Gain} \simeq 5.5 + 3.5 \frac{\text{boom length}}{\lambda} \simeq 5.5 + 3.5 \times 0.144 = 6.00 \quad (7.78 \text{ dBi})$$

- **Bojsen, et al. (1971): 6.03 to 6.88 dBi**

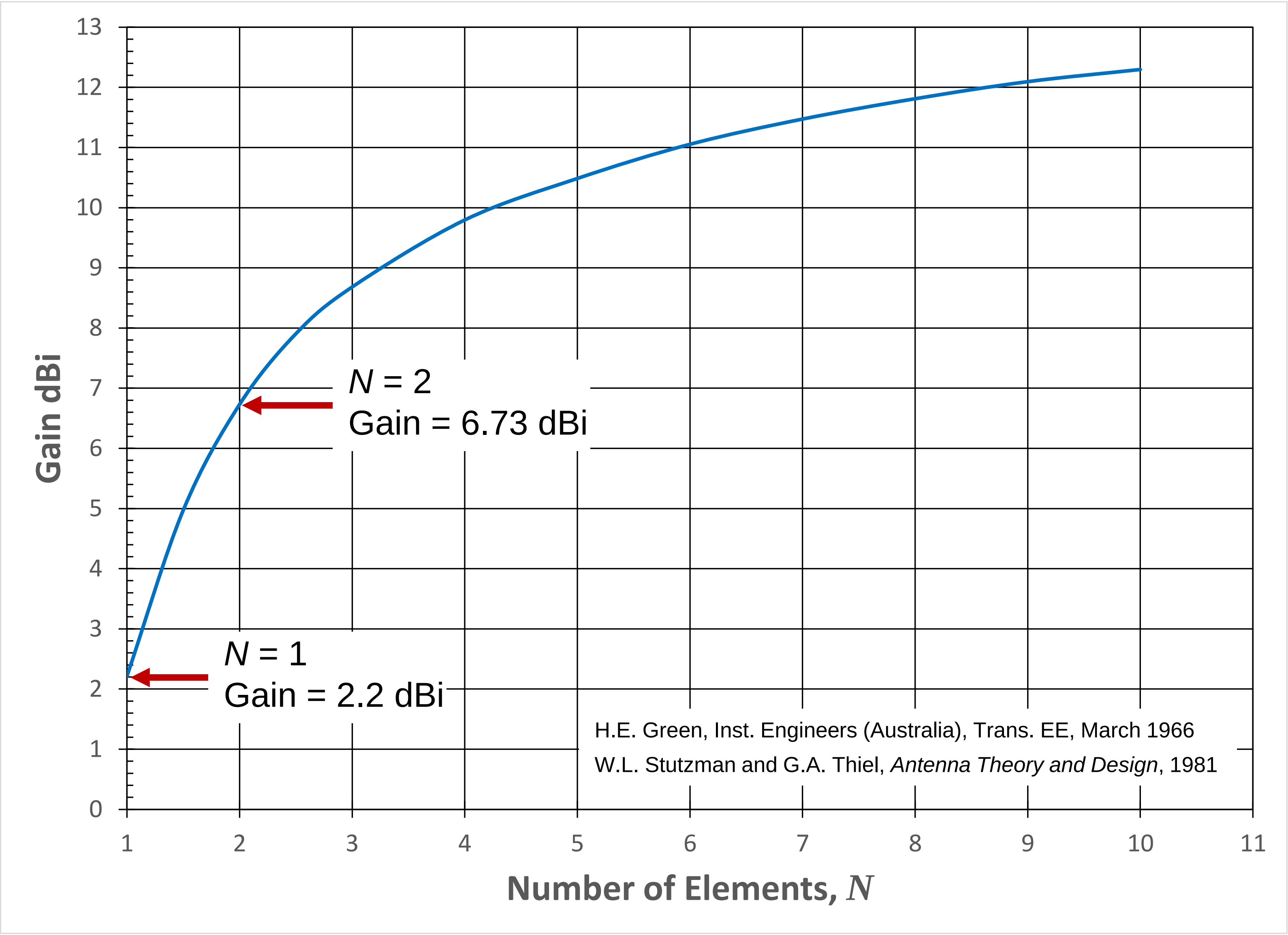
$$\text{Gain} \simeq 4.1 + 5.4 \frac{\text{boom length}}{\lambda} \simeq 4.1 + 5.4 \times 0.144 = 4.88 \quad (6.88 \text{ dBi})$$

$$\text{Gain} \simeq 3.0 + 7.0 \frac{\text{boom length}}{\lambda} \simeq 3.0 + 7.0 \times 0.144 = 4.01 \quad (6.03 \text{ dBi})$$

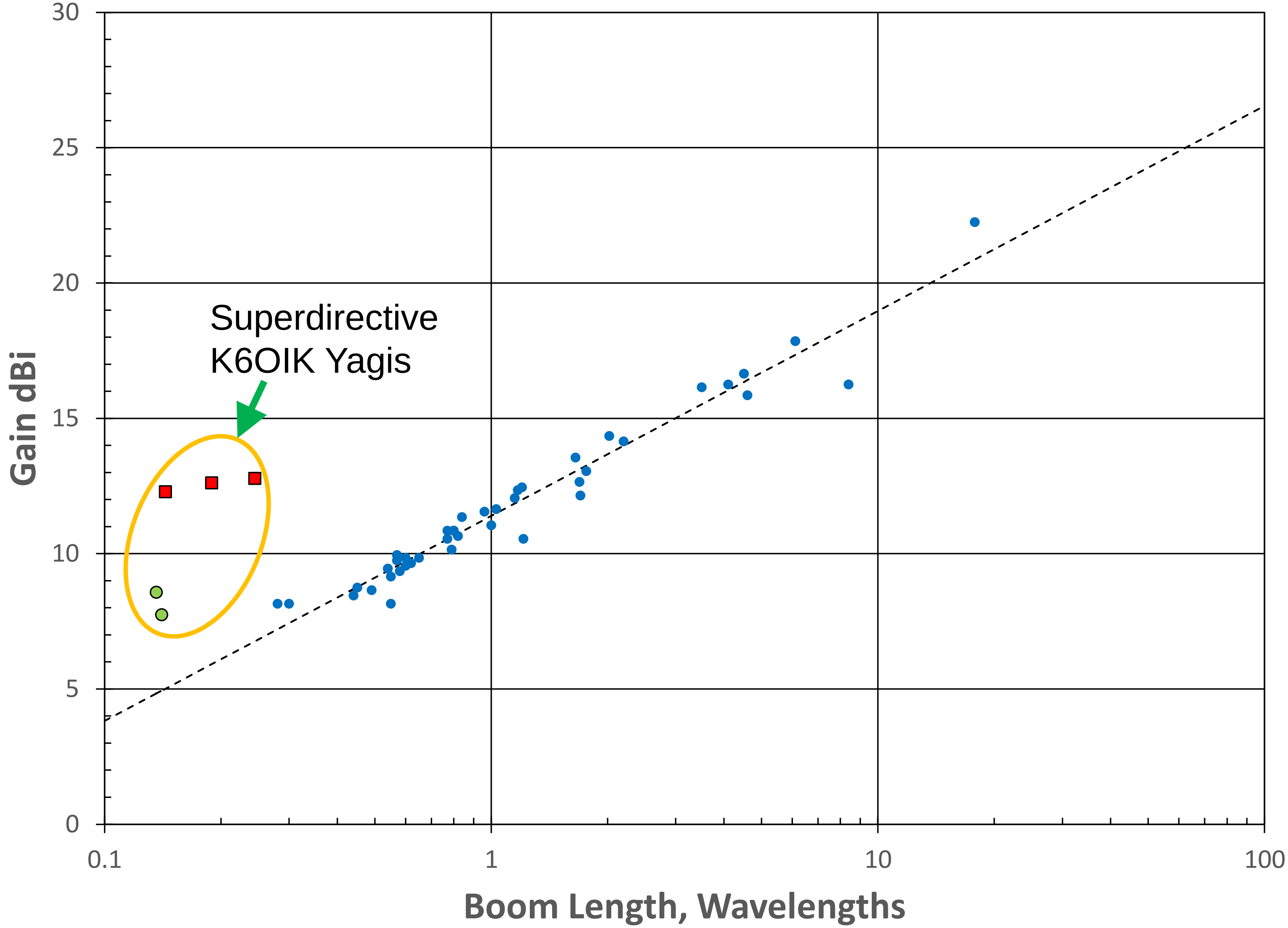
Yagi Gain versus Boom Length



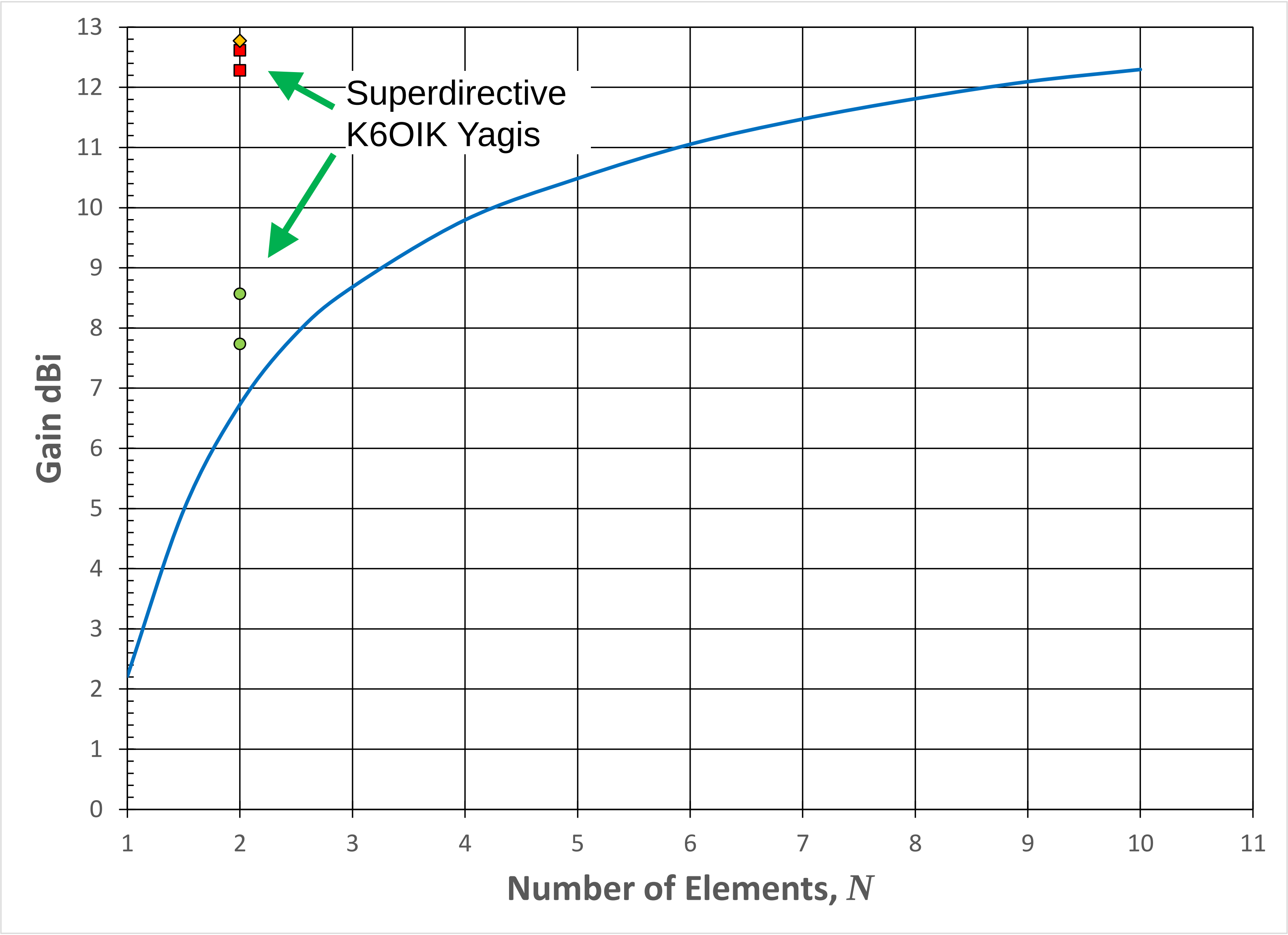
Typical Yagi Gain versus Number of Elements



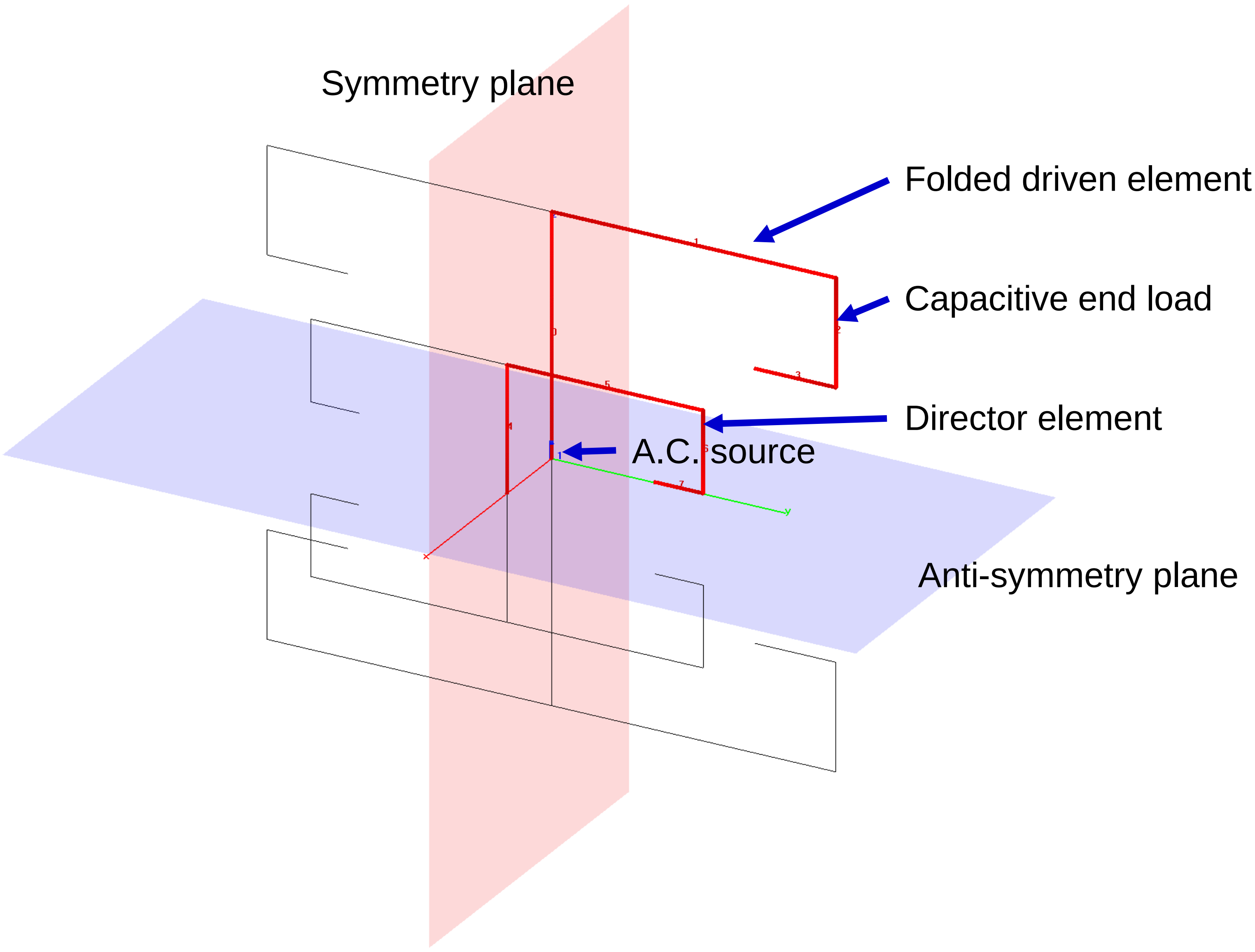
Exceptions to the Boom Length Rule



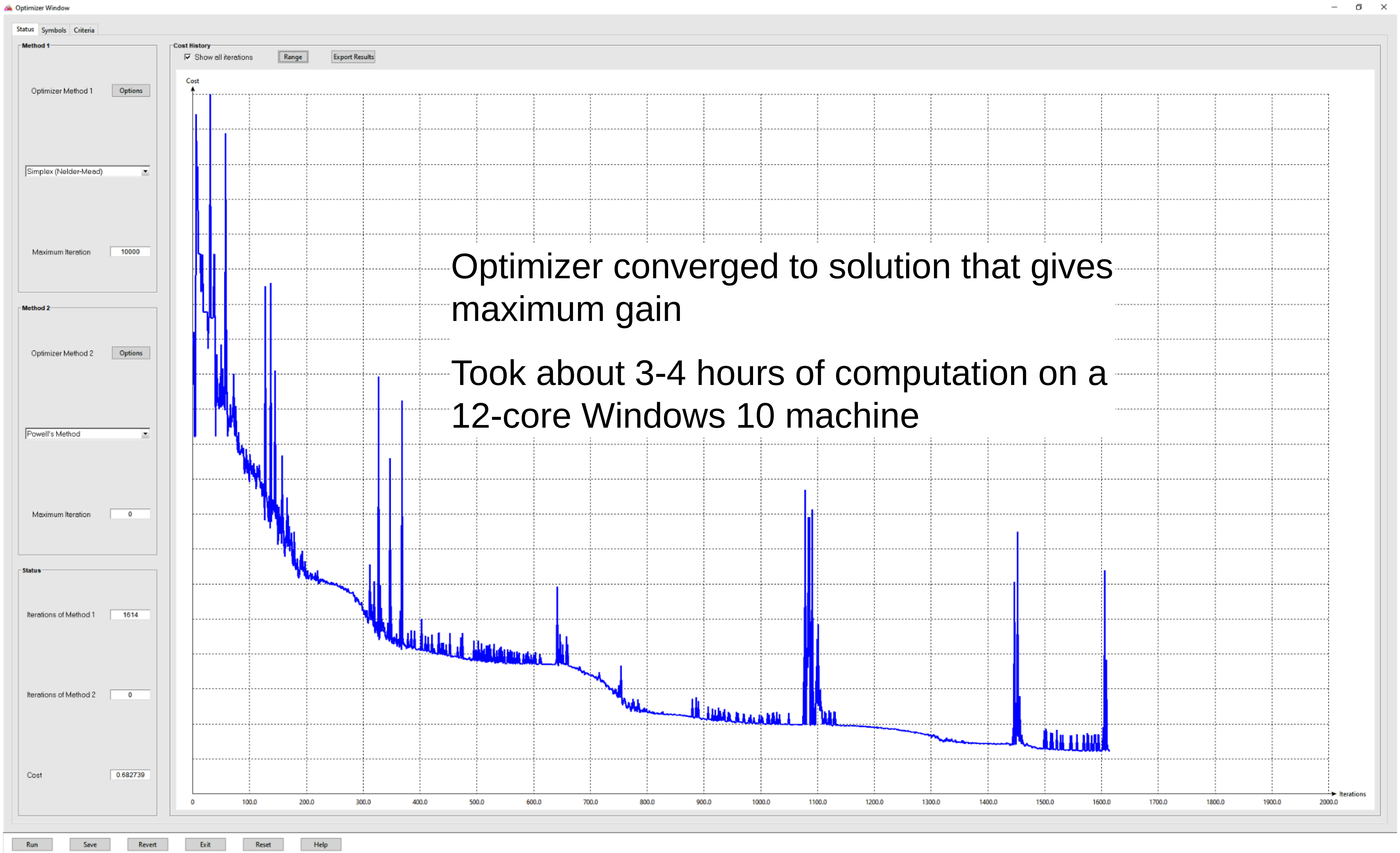
Exceptions to the Number of Elements Rule



Antenna Geometry



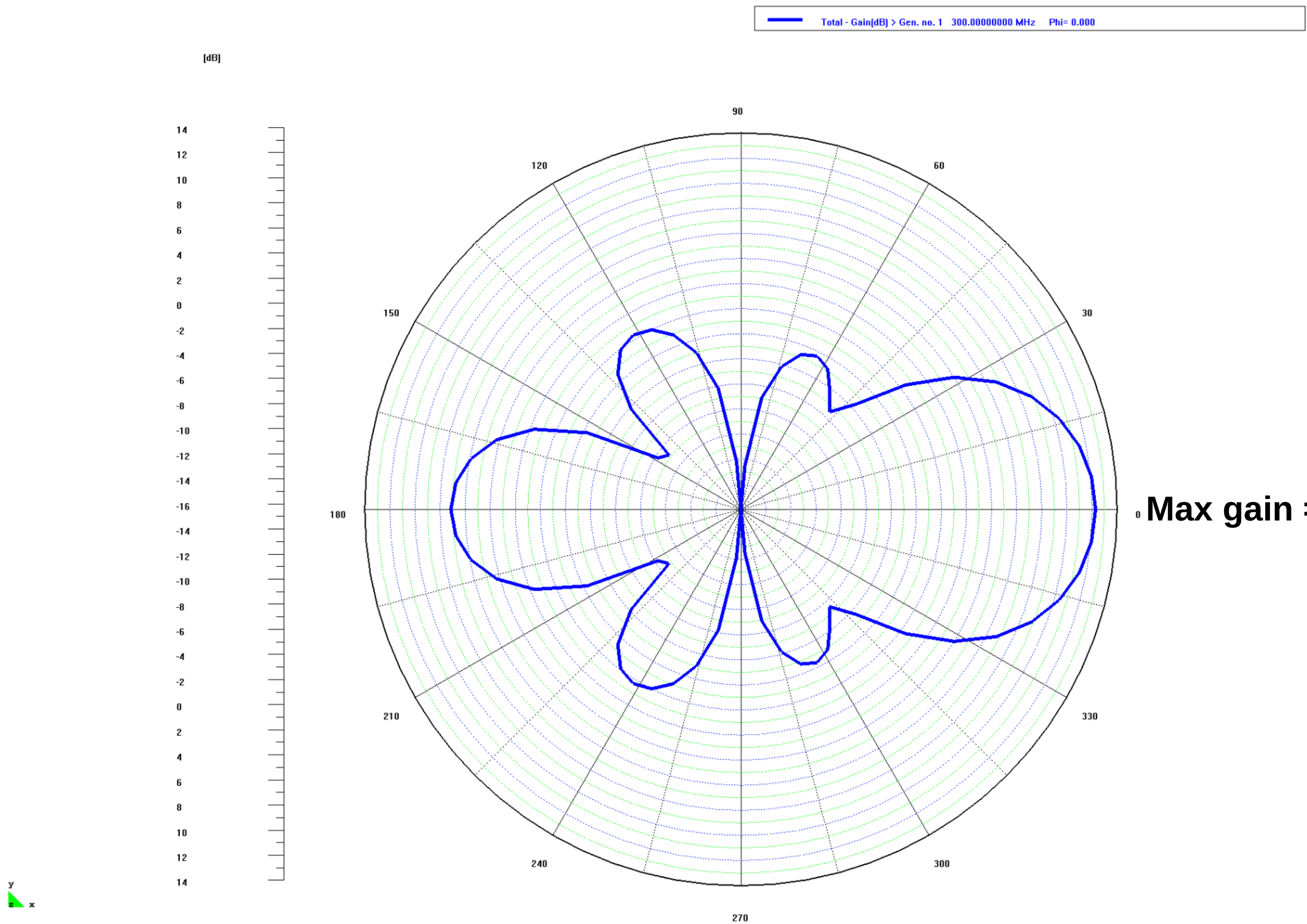
9-Variable Electromagnetic Fields Optimization



Optimizer converged to solution that gives maximum gain

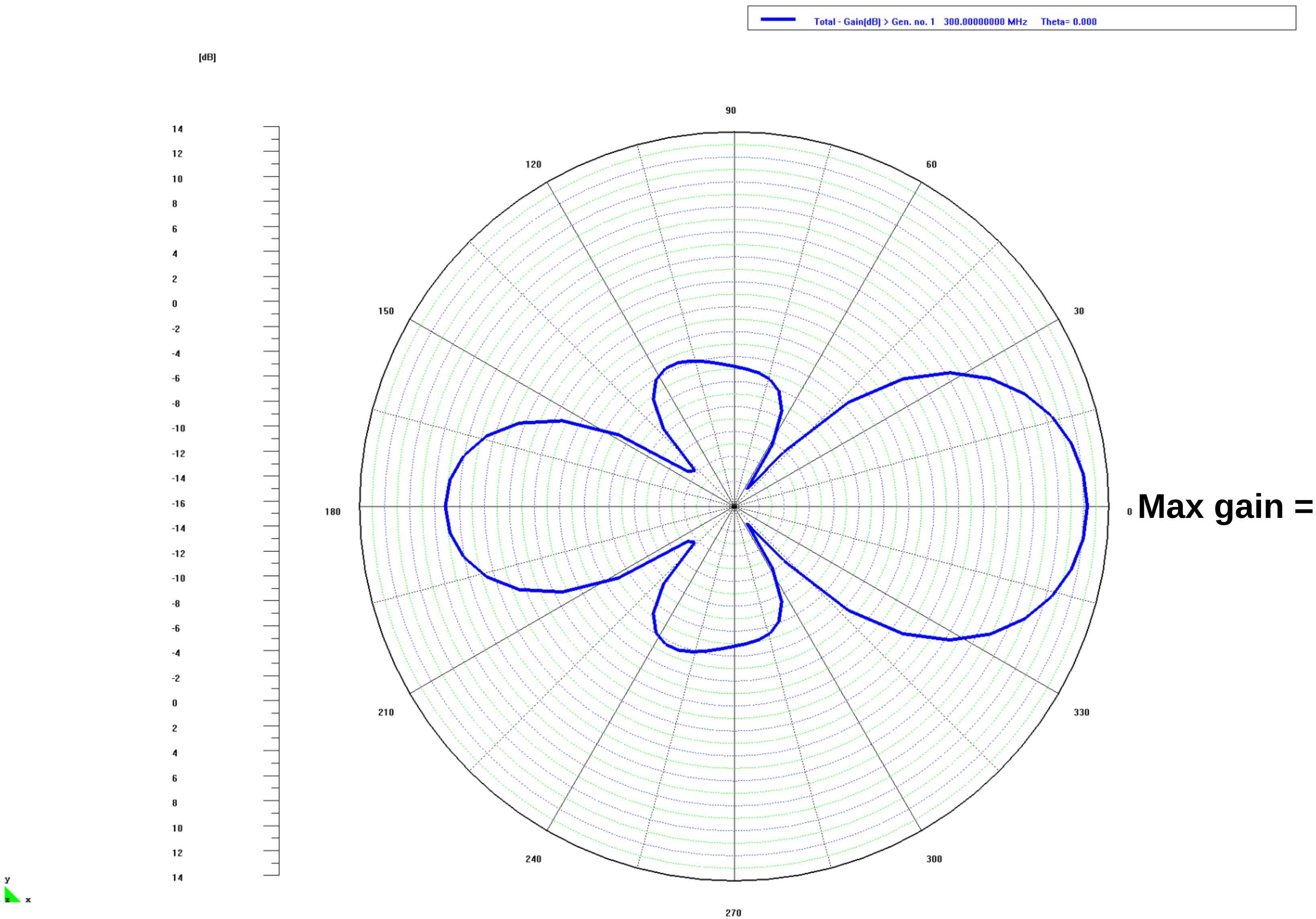
Took about 3-4 hours of computation on a 12-core Windows 10 machine

E-Plane Pattern ($\phi = 0$)



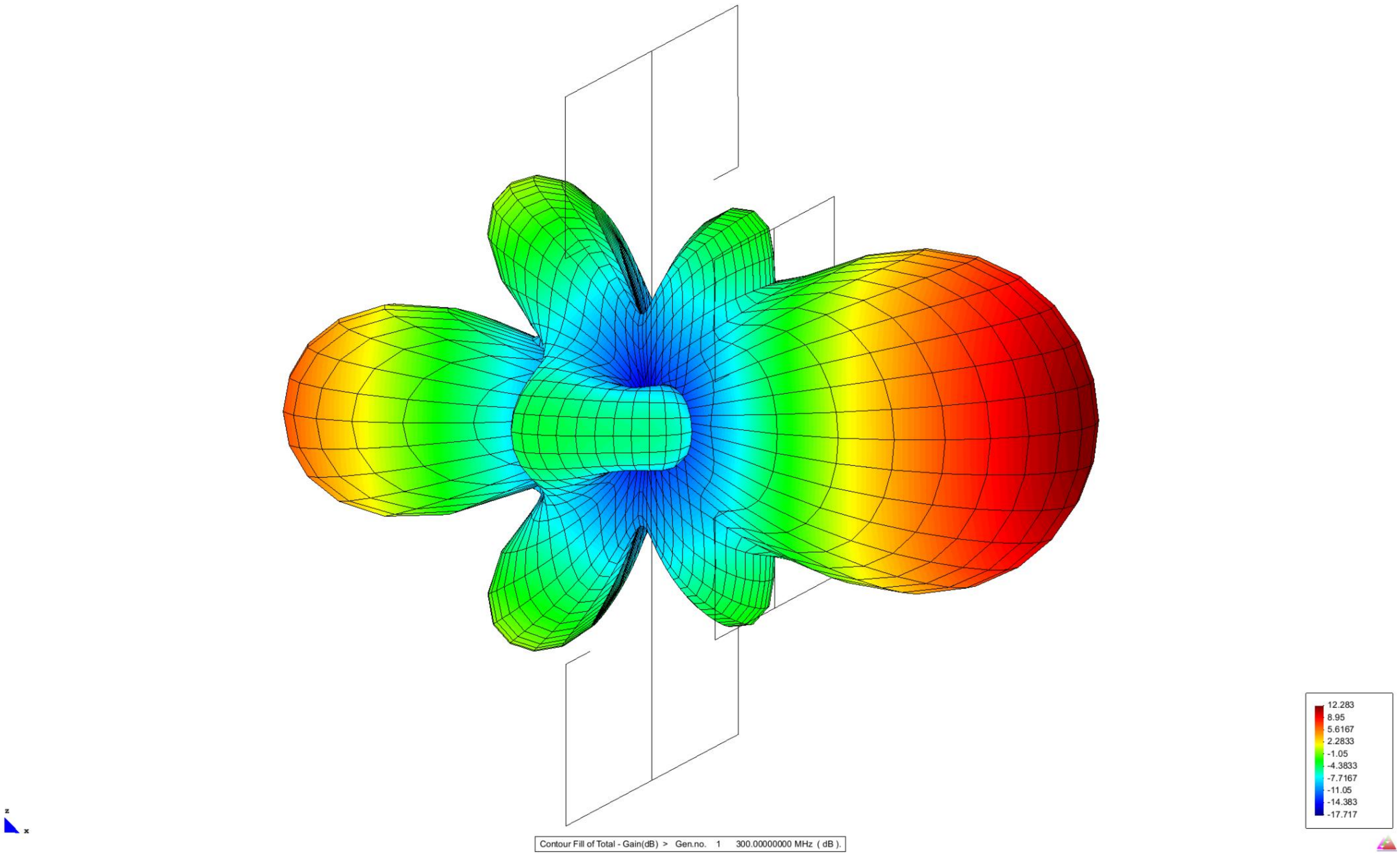
Max gain = 12.28 dBi

H-Plane Pattern ($\theta = 0$)

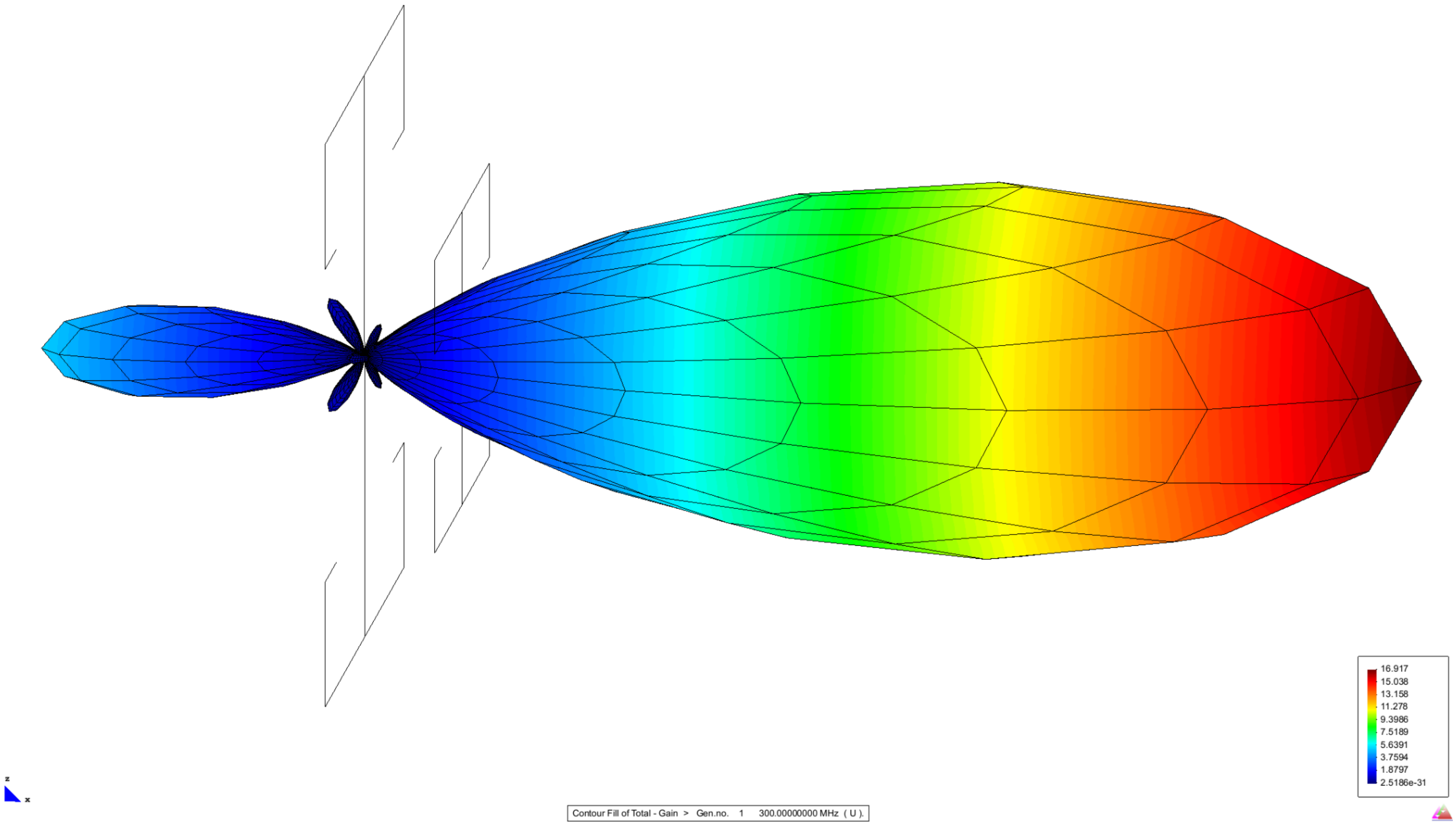


Max gain = 12.28 dBi

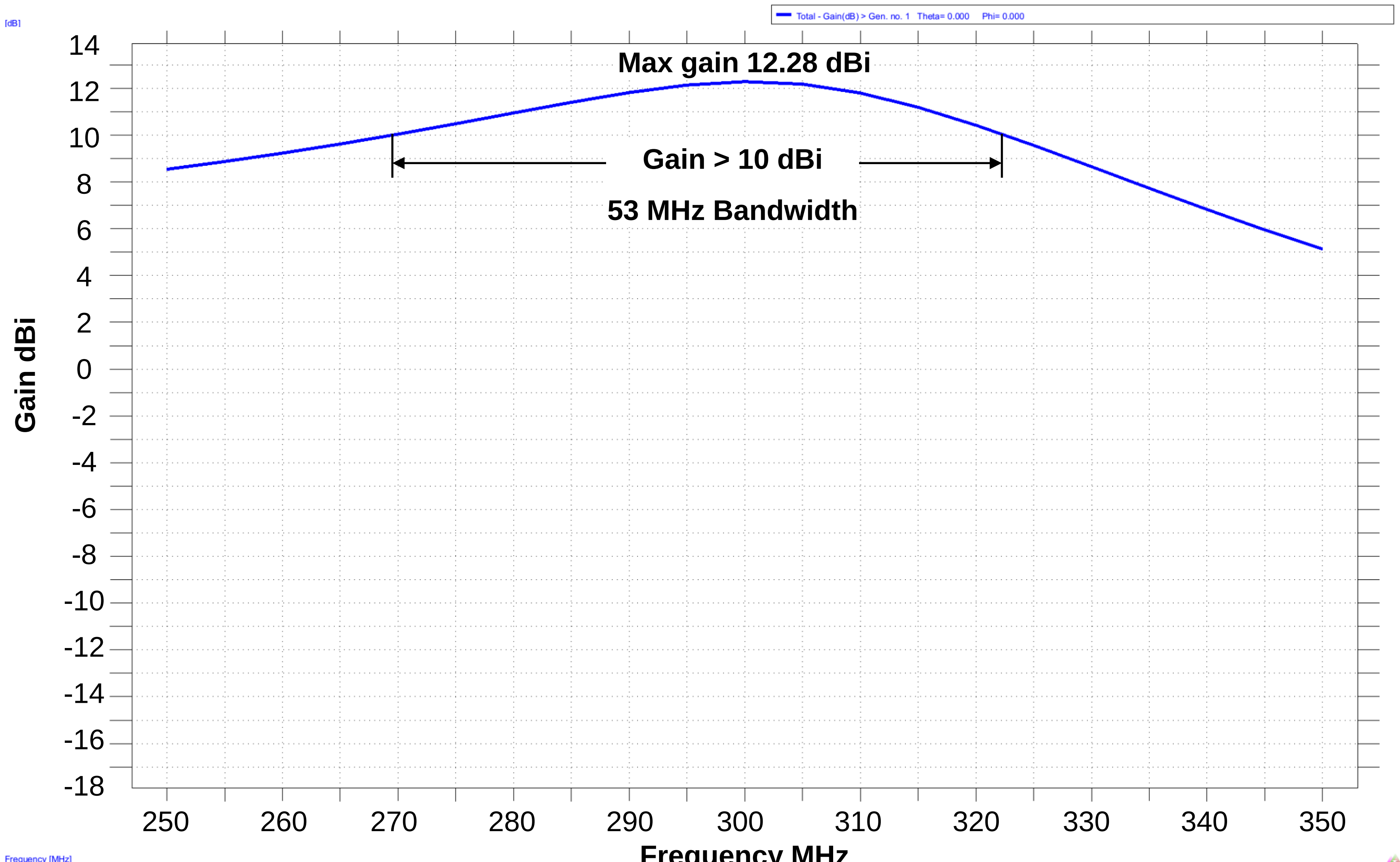
3D Pattern in dBi Units



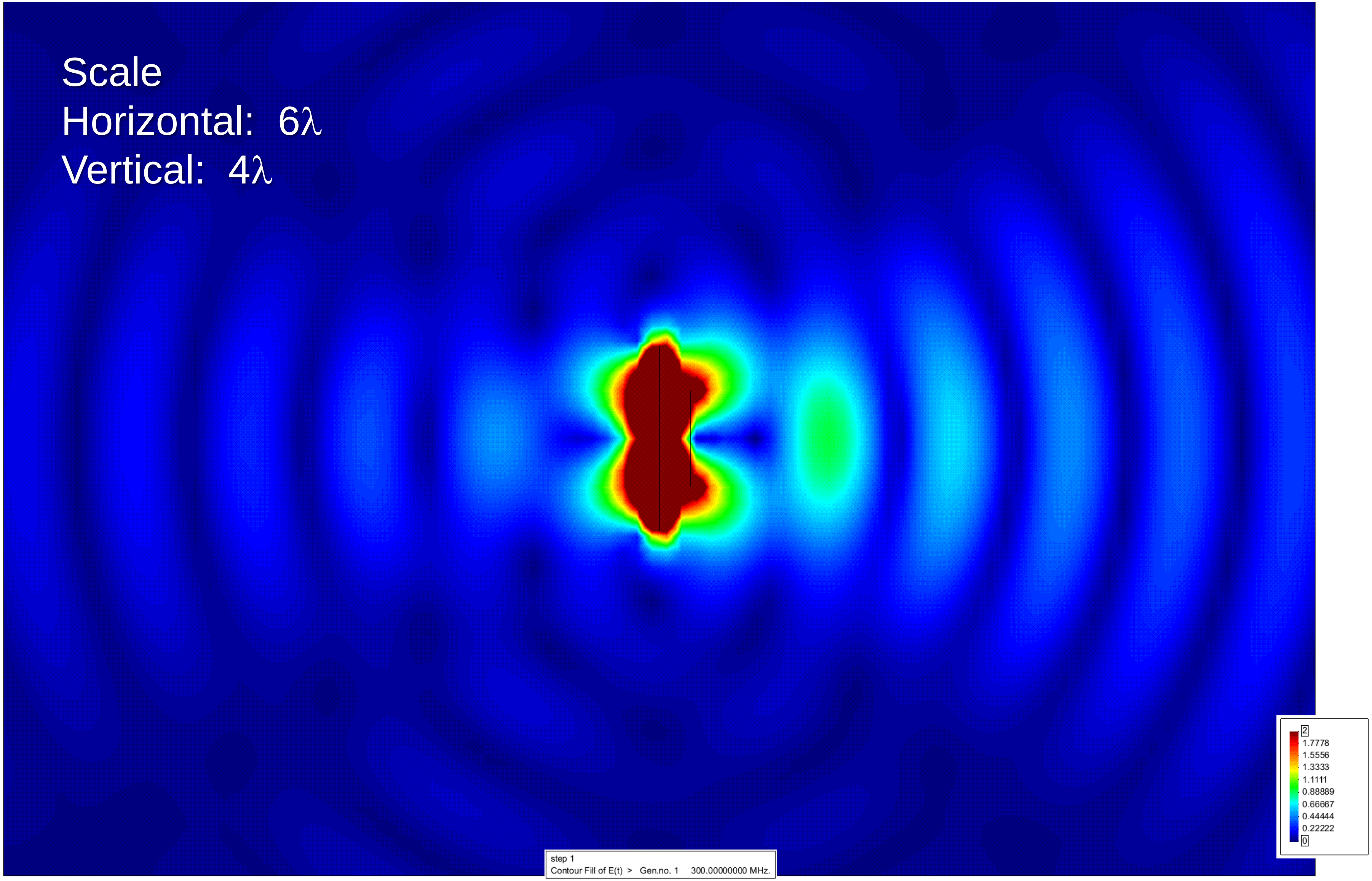
3D Pattern – Linear Scale



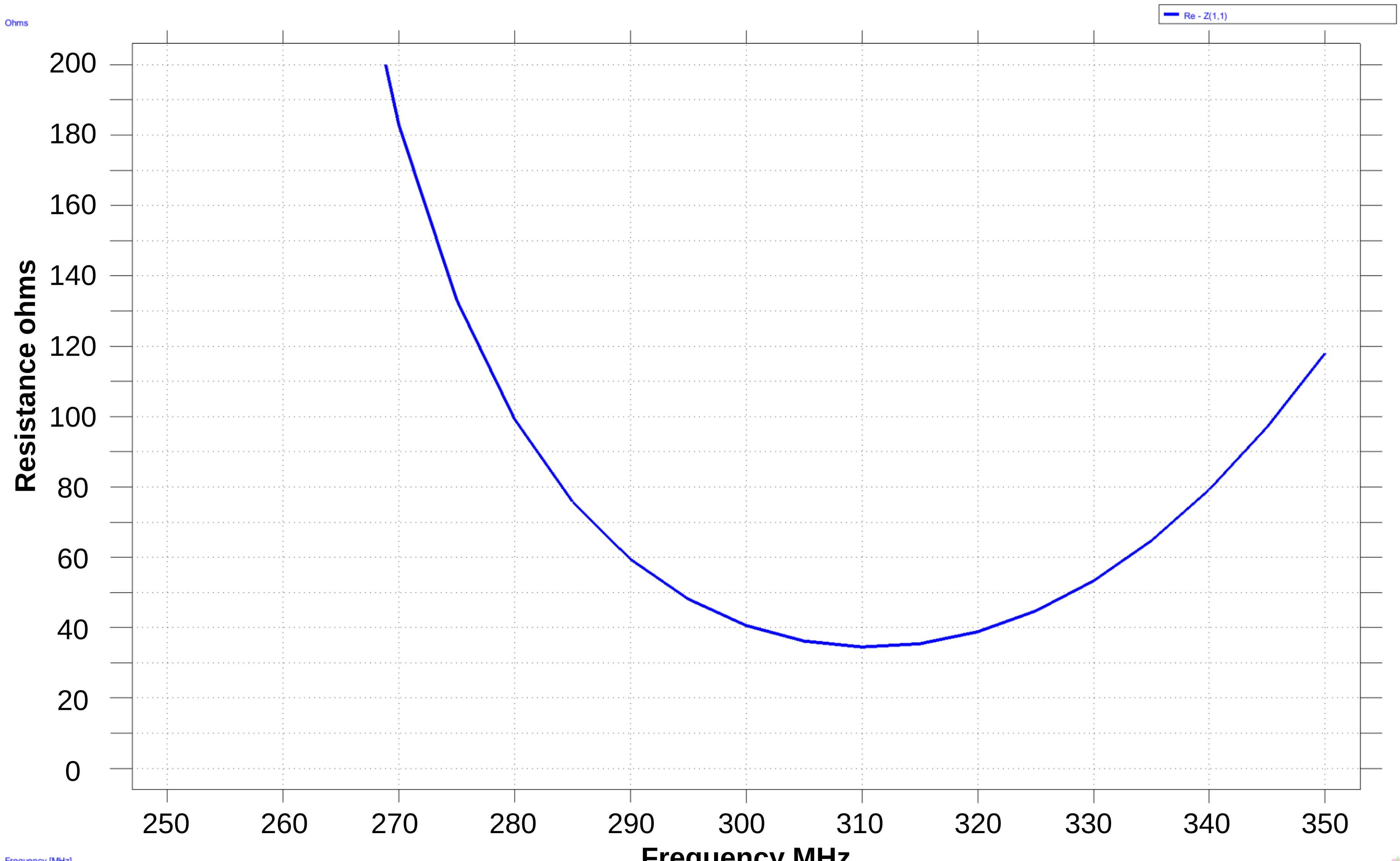
Gain versus Frequency



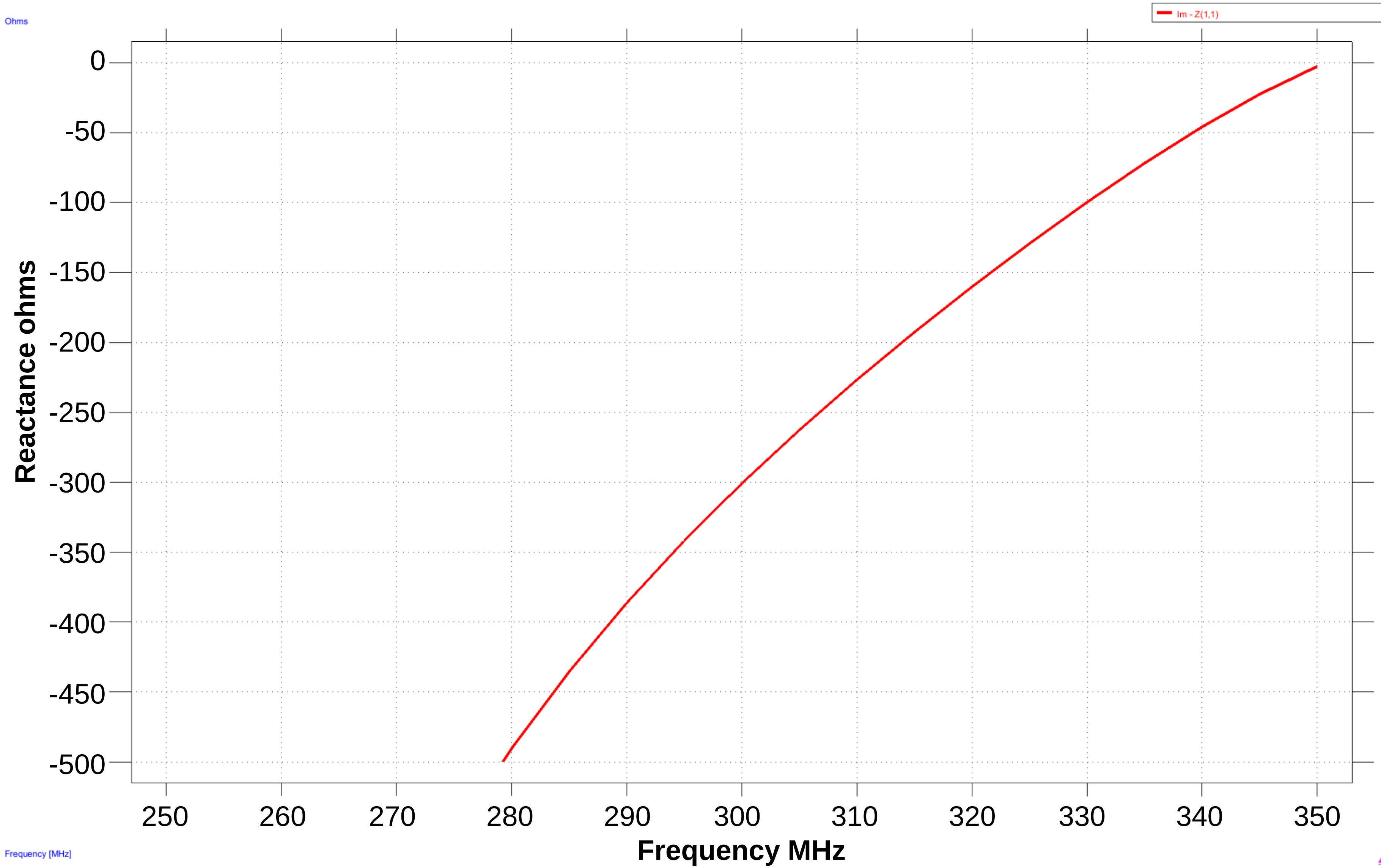
|E| Field in E-Plane (y = 0)



Impedance – Real Part



Impedance – Reactance



Lessons Learned

- **Design antennas first for radiation; impedance is second;**
  - Pattern: gain, efficiency, beamwidth, polarization, pattern bandwidth
- **Never design for resonance! Resonance is not a requirement**
  - Resonant antennas can have lousy patterns, low gain, or worse
  - Non resonant antennas can be excellent radiators
  - Tuners that merely resonate can have lousy impedance match and poor power transfer
- **Start with a good approximate design – within reach of all goals**
- **Use an optimizer for fine tuning, not for blind design**
- **Use a fast computer**
  - Multi-core, hyperthreaded CPU
  - High speed memory (Intel Optane)
  - Reliable fans
- **Consider impedance matching last. Make design adjustments if needed.**

Optimizers are great for “fine tuning” a design.
Not good as blind substitute for design.

The End