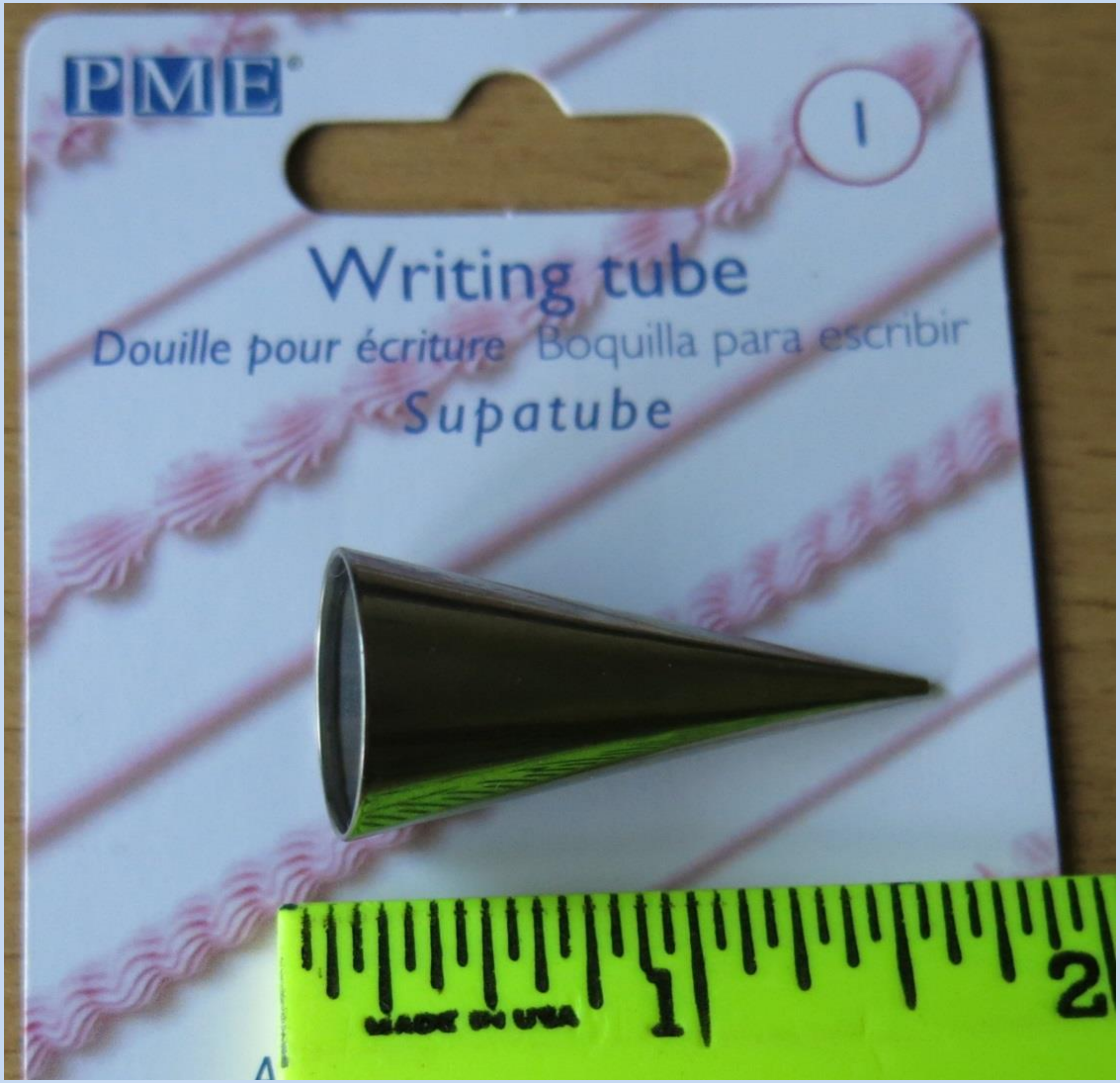
Martlesham 2017

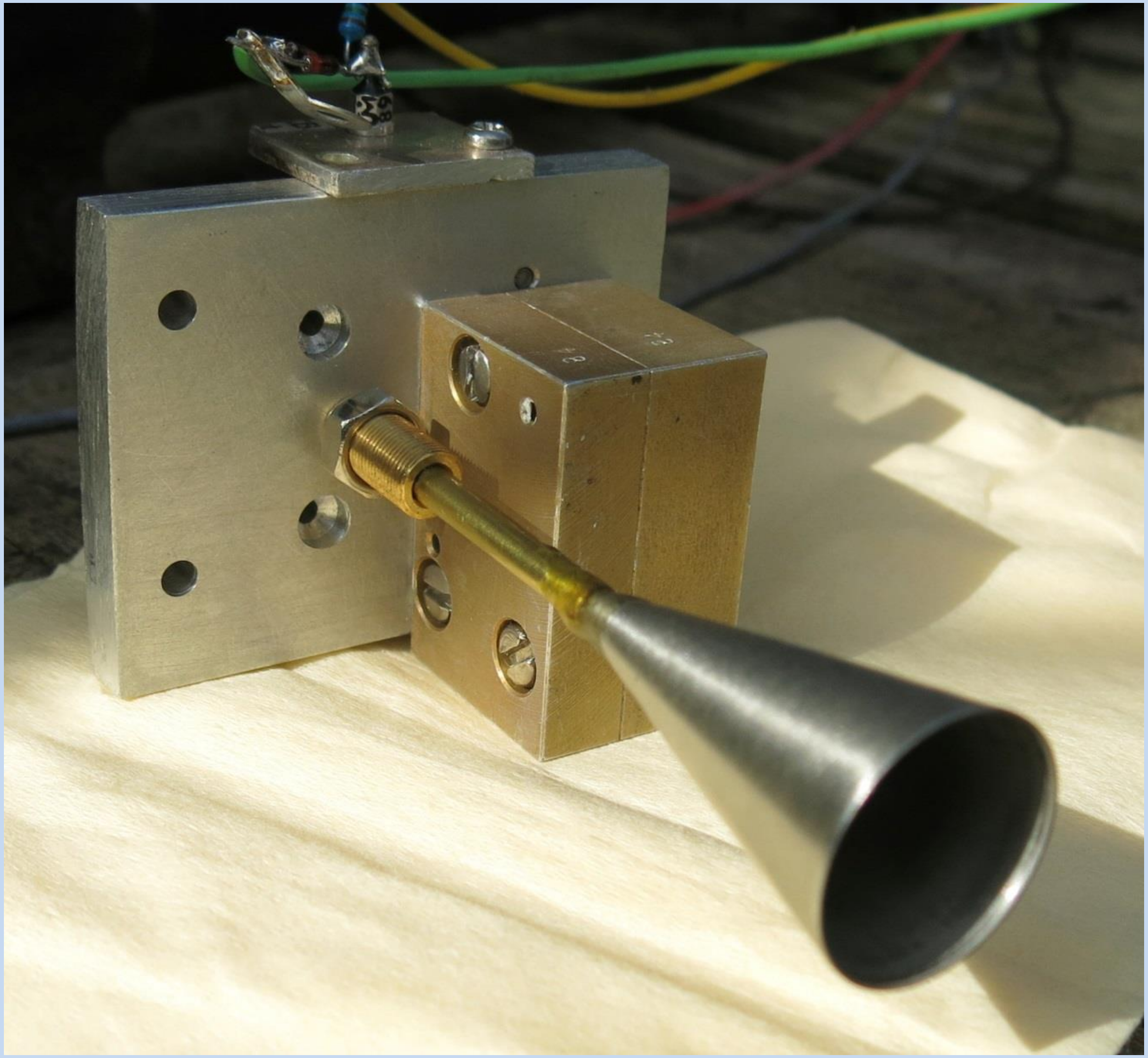
Antenna modelling at 122,134 and 241 GHz using openEMS

Barry Chambers, G8AGN

Cake-icing nozzle

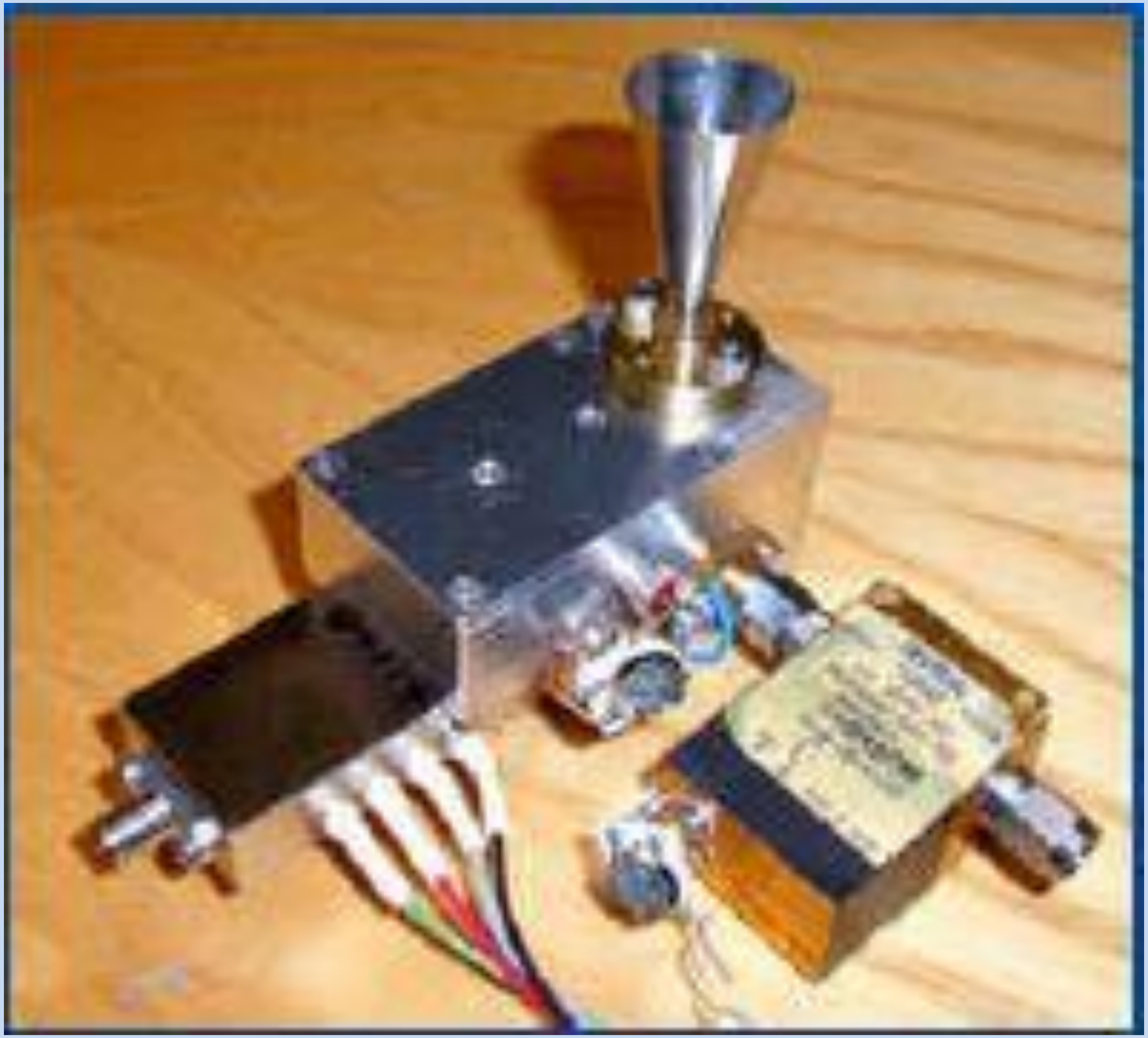


Icing nozzle antenna for 134 GHz



Source: G0EWN

Icing nozzle antenna for 241GHz



Source: G8CUB

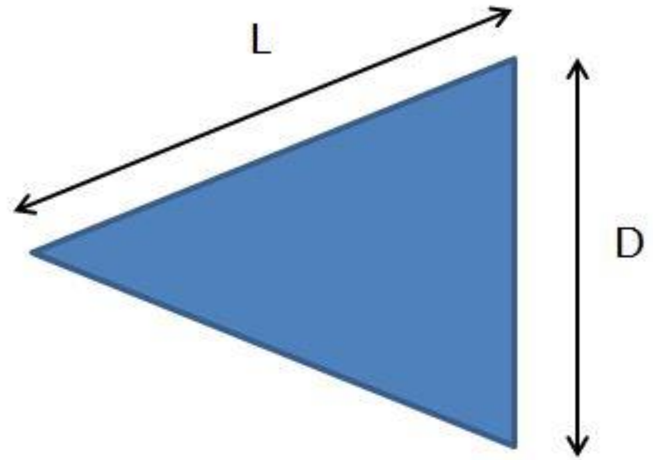
Aperture antennas

$$Gain(dB) = 10log_{10}\frac{4\pi\ \times effective\ aperture}{\lambda^2}$$

$$effective\ aperture = aperture\ area\ \times aperture\ efficiency$$
$$= \frac{\pi D^2 \eta}{4}$$

Antenna type	Aperture efficiency %
Optimum pyramidal horn	50
Optimum conical horn	52.2
Lensed conical horn	~ 80
Dish with feed	20 – 80 depending on f/D and feed

Simple design of conical horns



Gain is optimum when $D = \sqrt{3L\lambda}$

$$Gain = 20\, log_{10} \frac{\pi D}{\lambda} - 2.82\ \ dB$$

The gain loss of 2.82 dB is equivalent to an aperture efficiency $\eta = 52.2\ \%$

Maxwell's equations

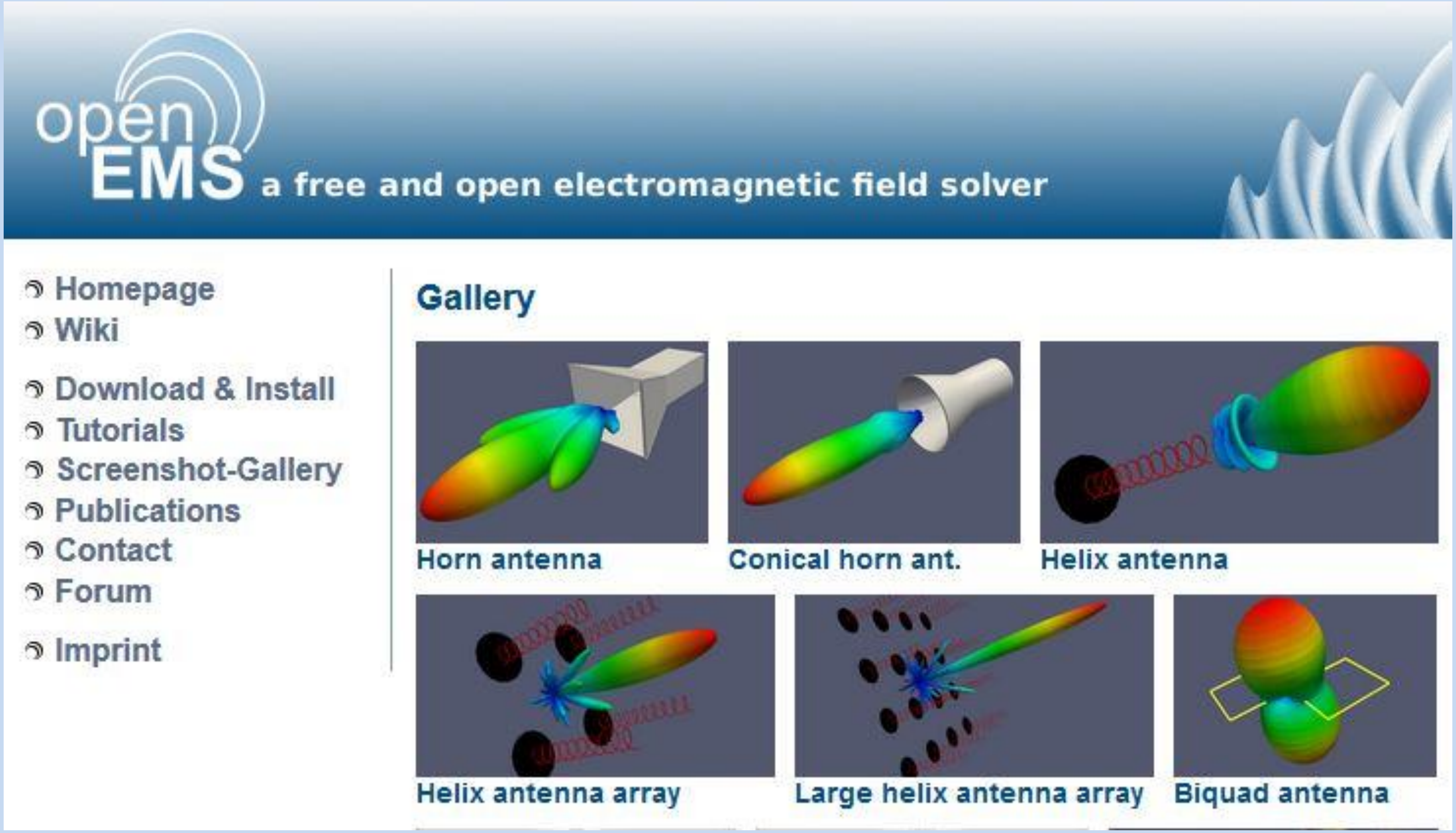
$$\nabla \cdot \mathbf{E} = \frac{\rho_v}{\varepsilon} \qquad \text{(Gauss' Law)}$$

$$\nabla \cdot \mathbf{H} = 0 \qquad \text{(Gauss' Law for Magnetism)}$$

$$\nabla \times \mathbf{E} = -\mu \frac{\partial \mathbf{H}}{\partial t} \qquad \text{(Faraday's Law)}$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \varepsilon \frac{\partial \mathbf{E}}{\partial t} \qquad \text{(Ampere's Law)}$$

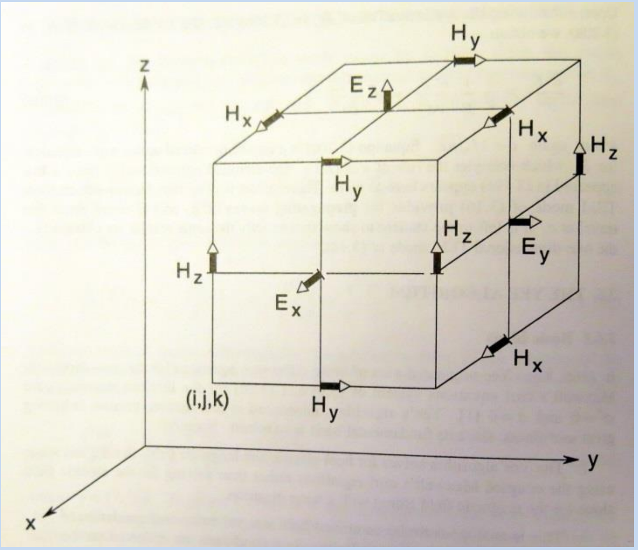
Analytical solutions only available for simple geometries, e.g. rectangular waveguide.
For more complicated and 'open' geometries, need to use numerical techniques.



Freeware
Needs MATLAB or Octave (freeware) front-end
Runs under Windows or Linux

Needs at least an i5 processor with 8 or 16 GB RAM
Poor documentation but lots of examples which can be customised by the user

Finite Difference Time Domain



The source wave is allowed to propagate through the model in a series of very small time-steps. After each time step, new values of the E and H fields in each cell are obtained.
After solution convergence, the antenna radiation pattern, gain and input match are computed.

- Maxwell's equations are approximated by finite-difference representations

- The object to be modelled is assembled from a large number of 3D blocks or 'cells'

- Each cell has defined electrical properties such as conductivity, dielectric constant etc.

- For antennas, a wave source must be included. On Tx this might come from a waveguide etc. On Rx this could be an incident plane wave. The source wave may be CW or pulsed.

- Because the antenna model is finite, the free-space around it must be terminated by an absorbing boundary to prevent reflections

Influence of mesh sampling

As an example, consider the design of a conical horn having a desired gain of 23dB at 134.4GHz

From the above formulae and using a circular waveguide feed 1.6mm in diameter, we get

Horn aperture diameter = 13.88mm

Flare length = 28.77mm

Axial length = 24.70mm

Flare angle = 13.95^{0}

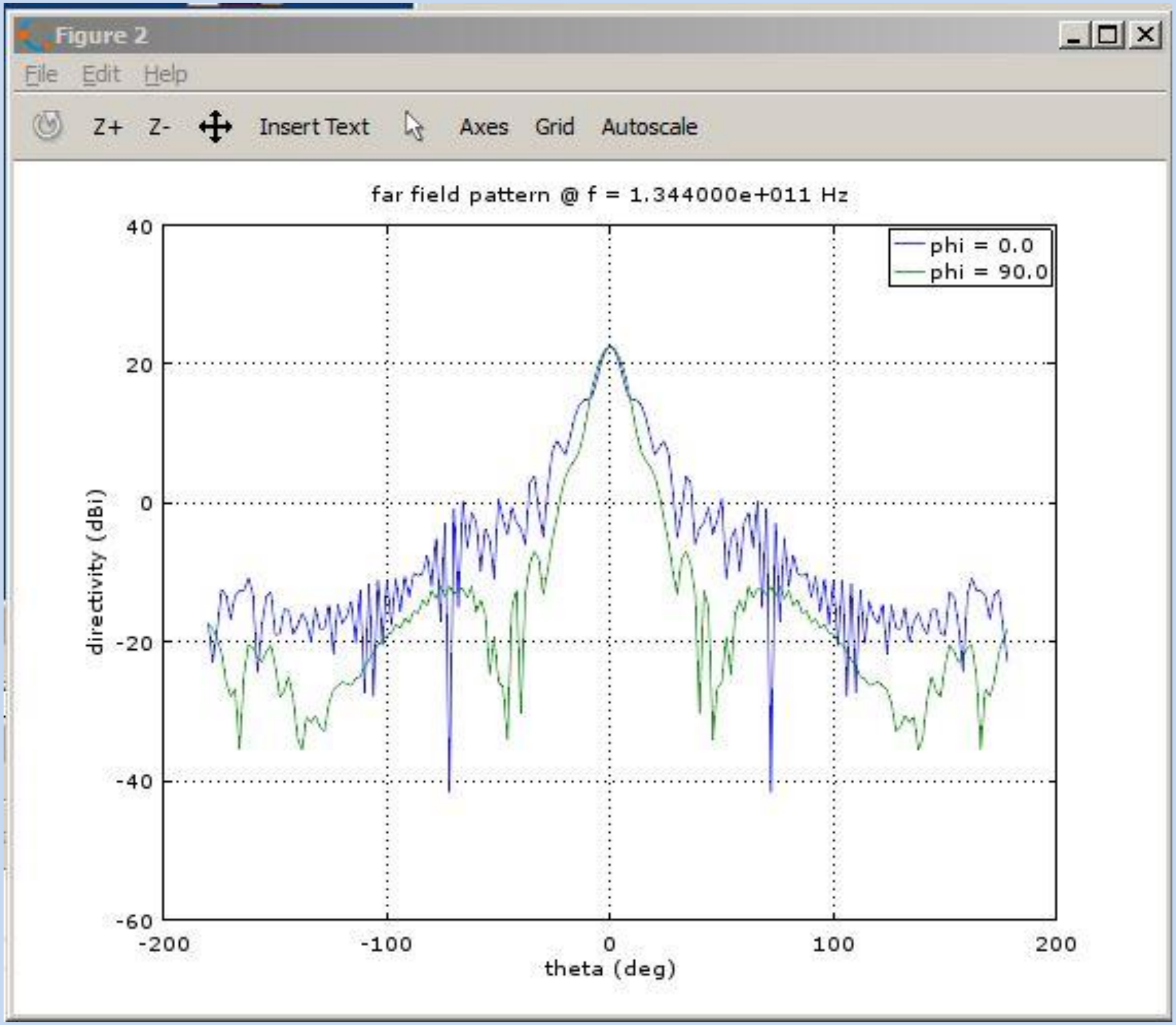
Results from openEMS

Horn conductivity $= 5.8 \times 10^7\ S/m$ *(copper)*

Wall thickness = 0.25mm.

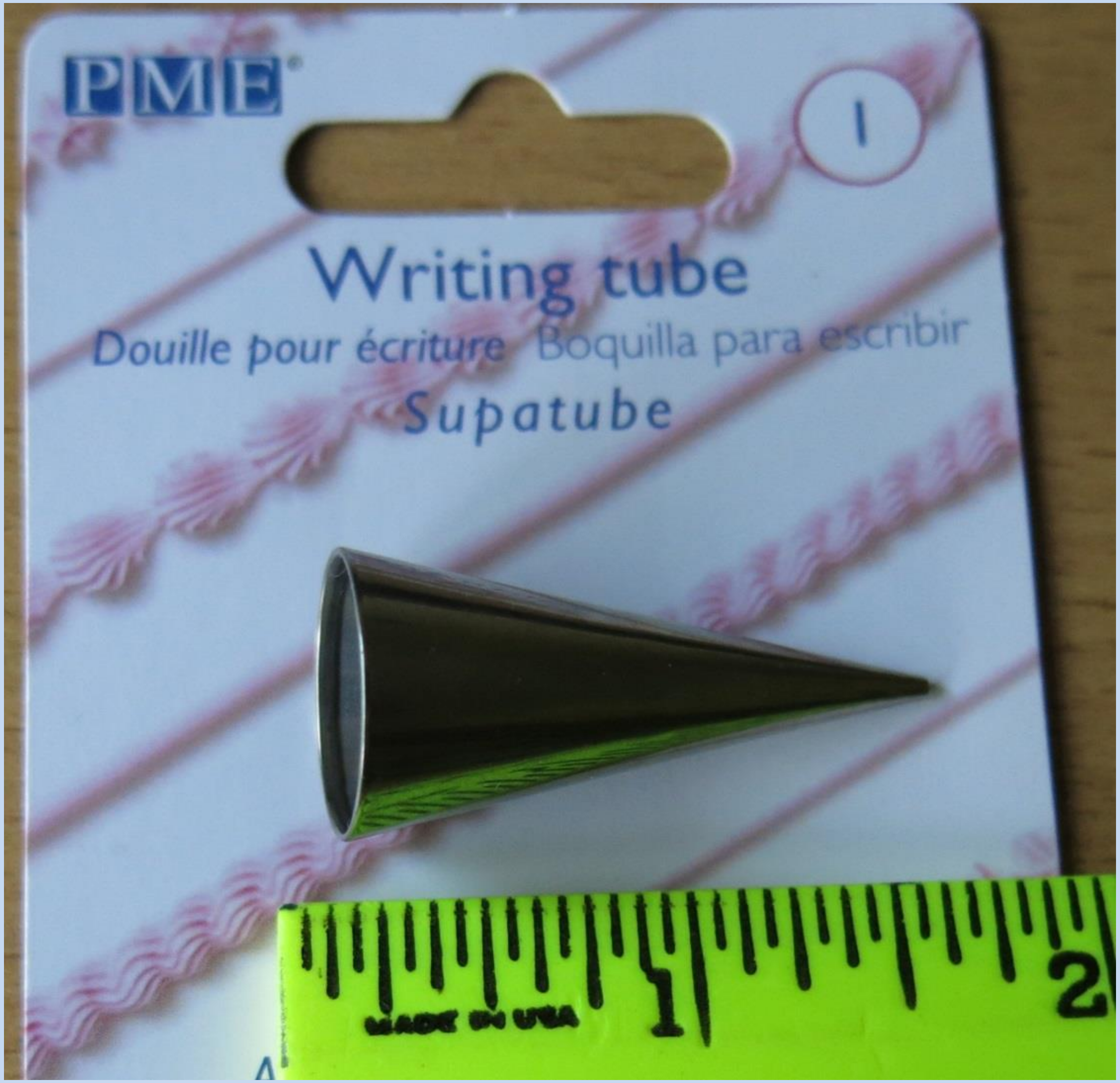
FDTD mesh interval (no of cells per wavelength)	Calculated gain (dBi)	Aperture efficiency (%)	No of cells in FDTD mesh
10	17.00	12.2	1.08 e 6
15	21.56	34.94	3.64 e 6
20	21.91	37.88	8.37 e 6
25	22.18	40.26	1.64 e 7
30	22.56 23.0	44.02 52.2	2.83 e 7

Horn far-field patterns with $\lambda/_{30}$ meshing



Blue: E plane
Green: H plane

Conical horn using cake-icing nozzle



PME 1.5 icing nozzle guesstimate

Nozzle dimensions are L = 40 mm, D = 16.0 mm

At f = 134.4 GHz, λ = 2.23 mm

Predicted maximum gain (η = 0.522) = 24.2 dB

Optimum aperture diameter for given slant length of 40 mm is 16.36 mm.

This is close to PME 1.5 value of 16.0 mm.

PME 1.5 nozzle should be close to optimum at 134 GHz

and acceptable at 122 GHz ($D_{opt} = 17.2mm$)

Validity of the guesstimate

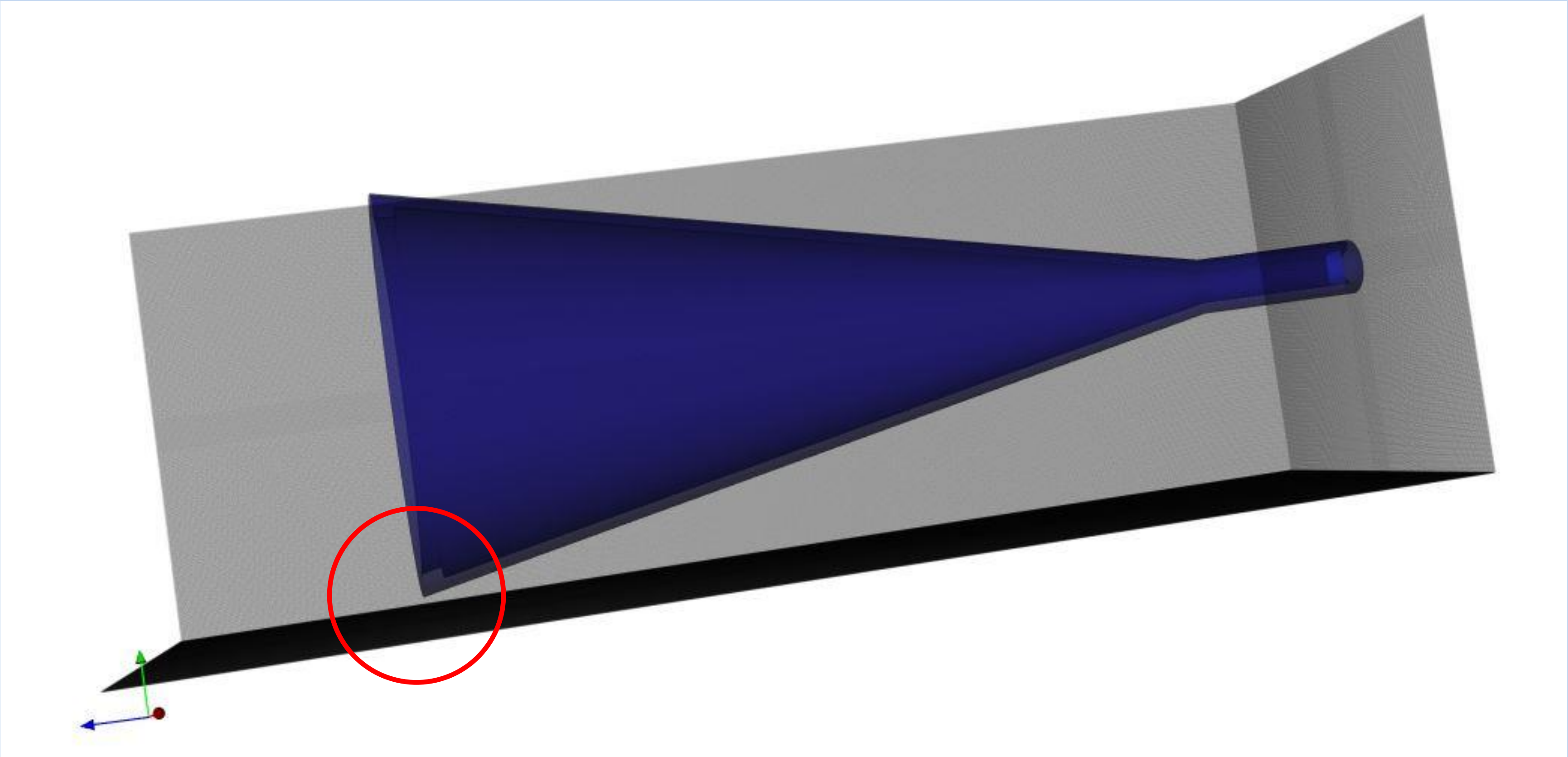
The guesstimate takes no account of

- the actual horn feed geometry
- the horn construction
- the horn conductivity

These factors will affect

- the gain
- the impedance match
- the E and H plane radiation patterns

openEMS model for PME 1.5 nozzle at 134 GHz



Horn material: stainless steel. Circular waveguide feed, 1.6 mm ID

Modelling data and results (PME 1.5)

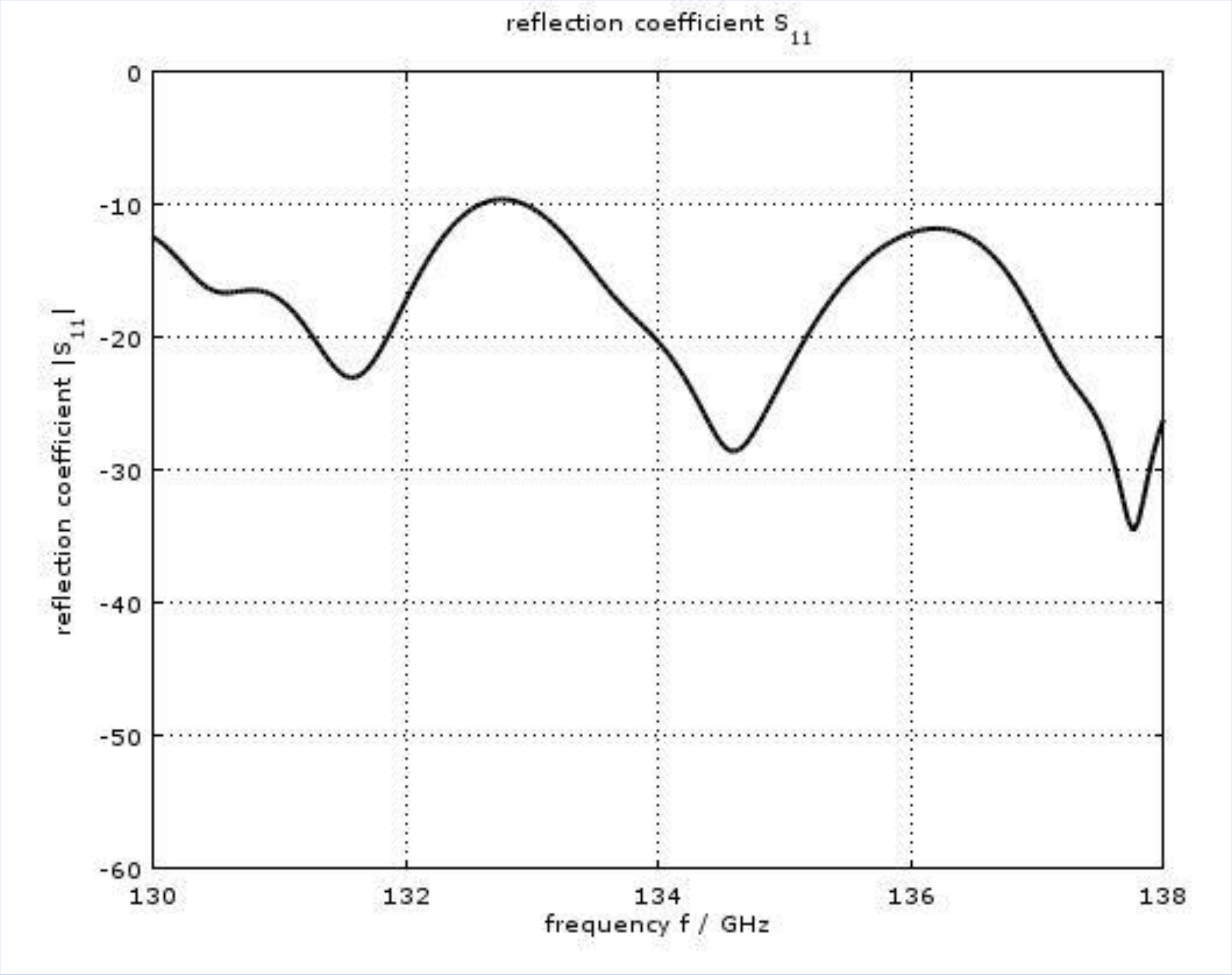
Calculated horn gain = **24.3 dBi** (24.2 dBi)
Calculated aperture efficiency = 42 % (52.2 %)
Calculated S11 at 134.4 GHz = –29 dB

36.2 million cells in 3D model with a $\lambda/25$ resolution.
λ = 2.23 mm at 134.4 GHz

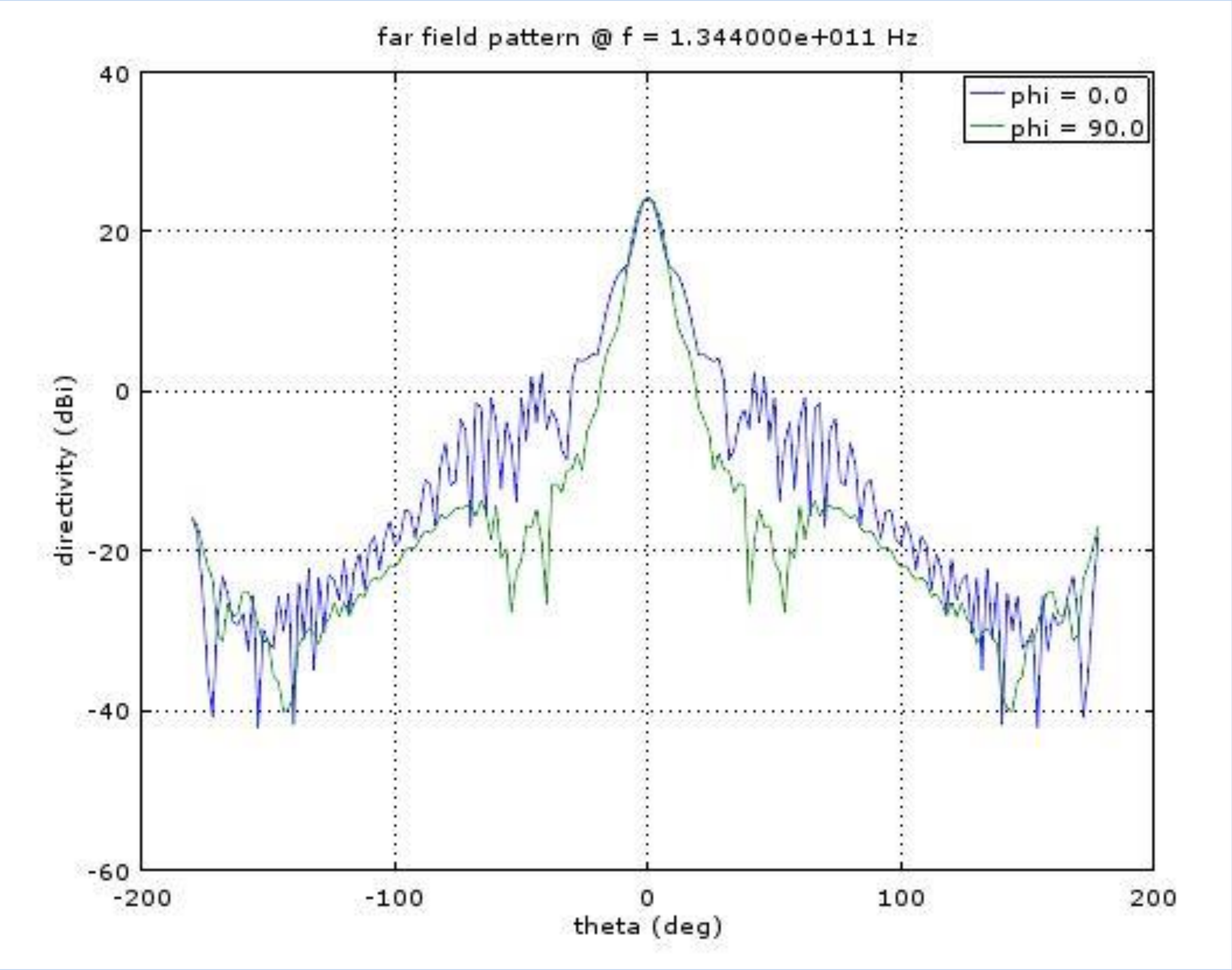
Solution time for mesh
i5, 8 GB RAM = 1 hr 15 min
I7, 16 GB RAM = 50 min

- **openEMS model includes wall thickness, edge diffraction etc.**
- **Simple theory does not**

PME 1.5 match at 134.4 GHz

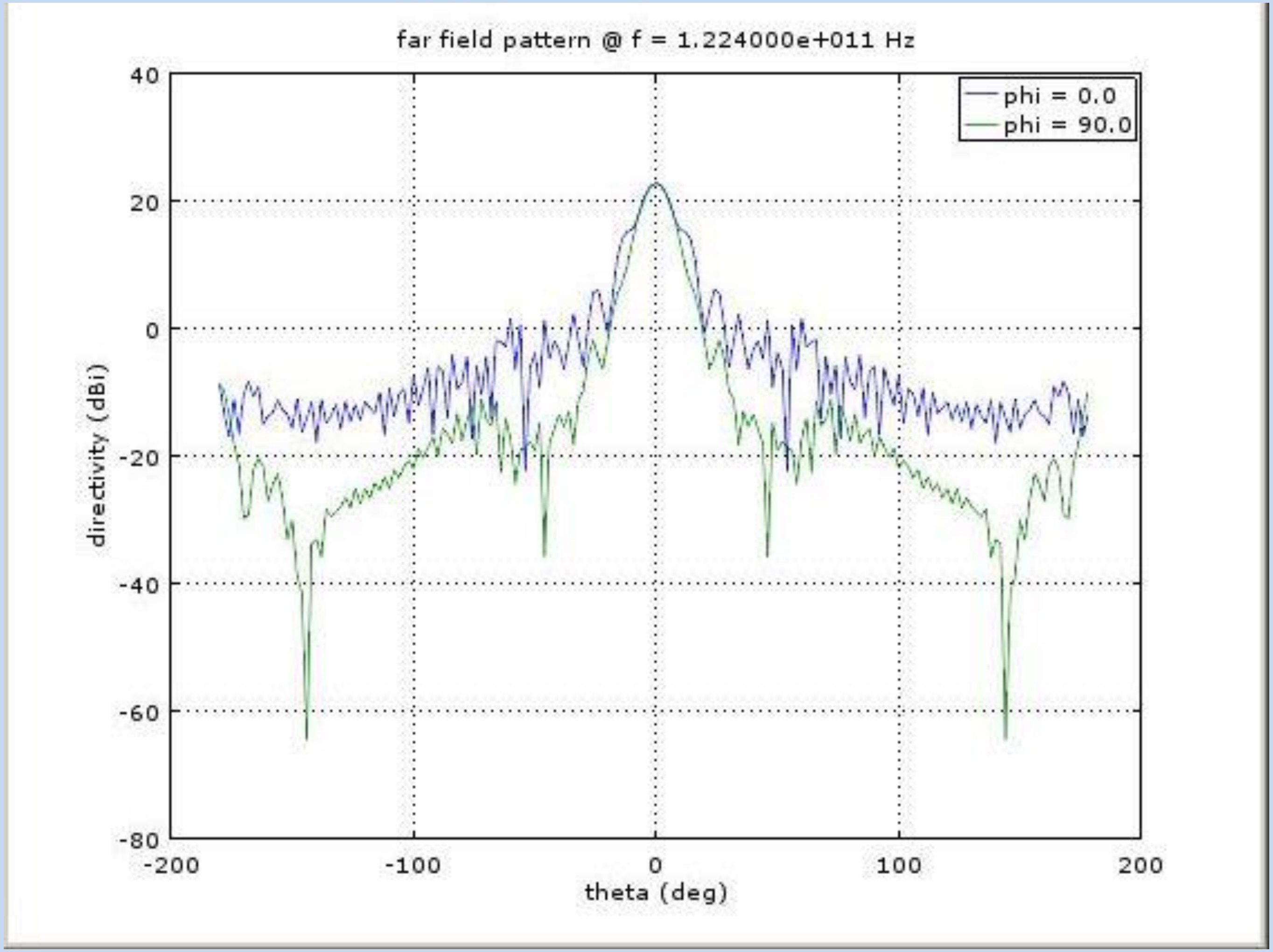


PME 1.5 far-field patterns at 134.4 GHz



Blue: E plane, Green: H plane

PME 1.5 far-field patterns at 122.4 GHz



Blue: E plane, Green: H plane

PME 1.0 icing nozzle guesstimate

Nozzle dimensions are $L = 40$ mm, $D = 16.0$ mm

At $f = 241.02$ GHz, $\lambda = 1.24$ mm

Predicted optimum gain ($\eta = 0.522$) = 29.3 dB

Optimum aperture diameter for given slant length of 40 mm is 12.2 mm.

This is smaller than the PME value of 16.5 mm.

PME nozzle is not optimum at 241 GHz

For D = 16.5 mm, optimum L should be 73 mm

Modelling data and results (PME 1.0)

Calculated horn gain = 23.8 dBi (29.3 dBi)

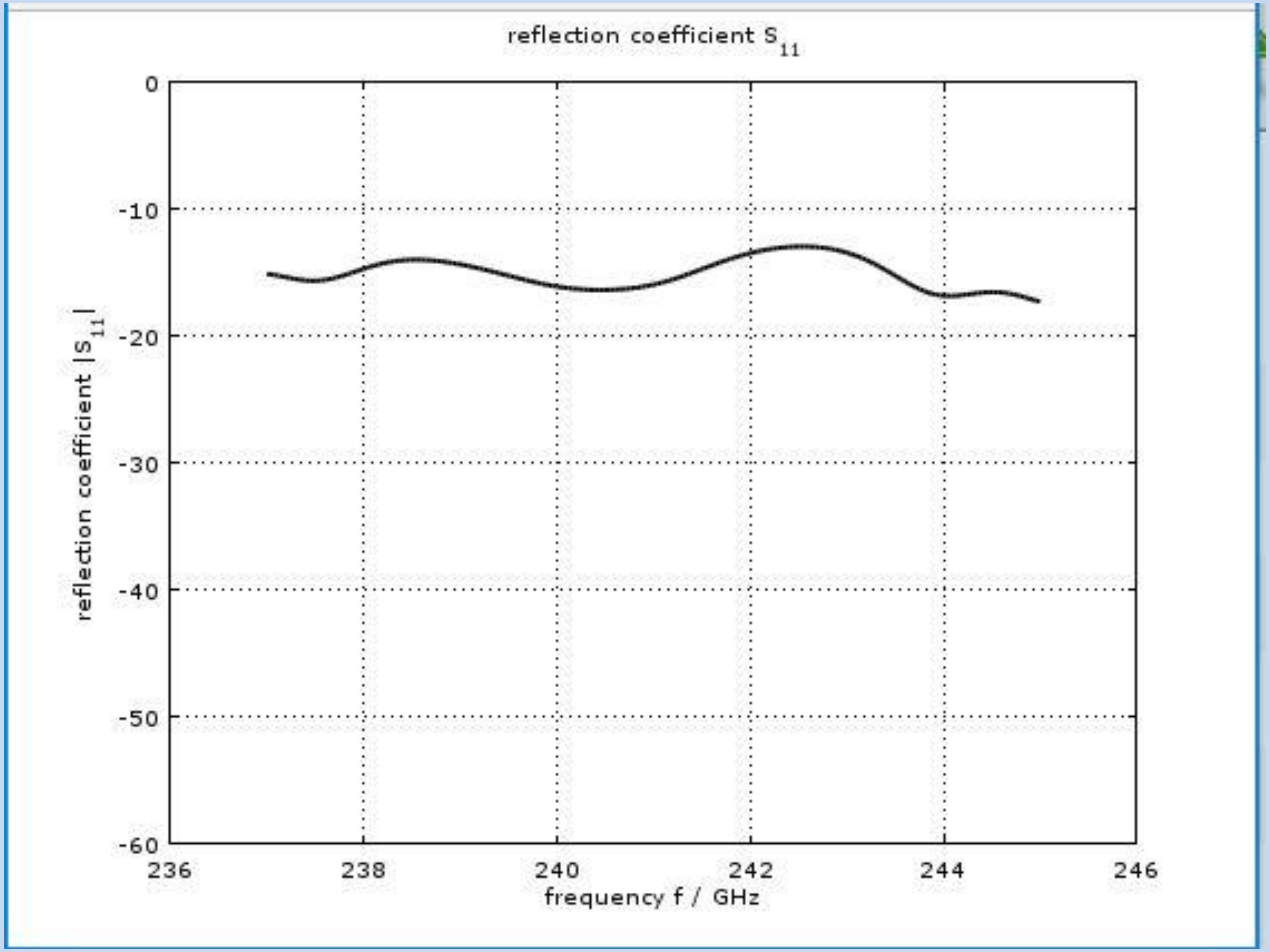
Calculated aperture efficiency = 11.6 % (52.2 %)

Calculated S11 at 241 GHz = – 15 dB

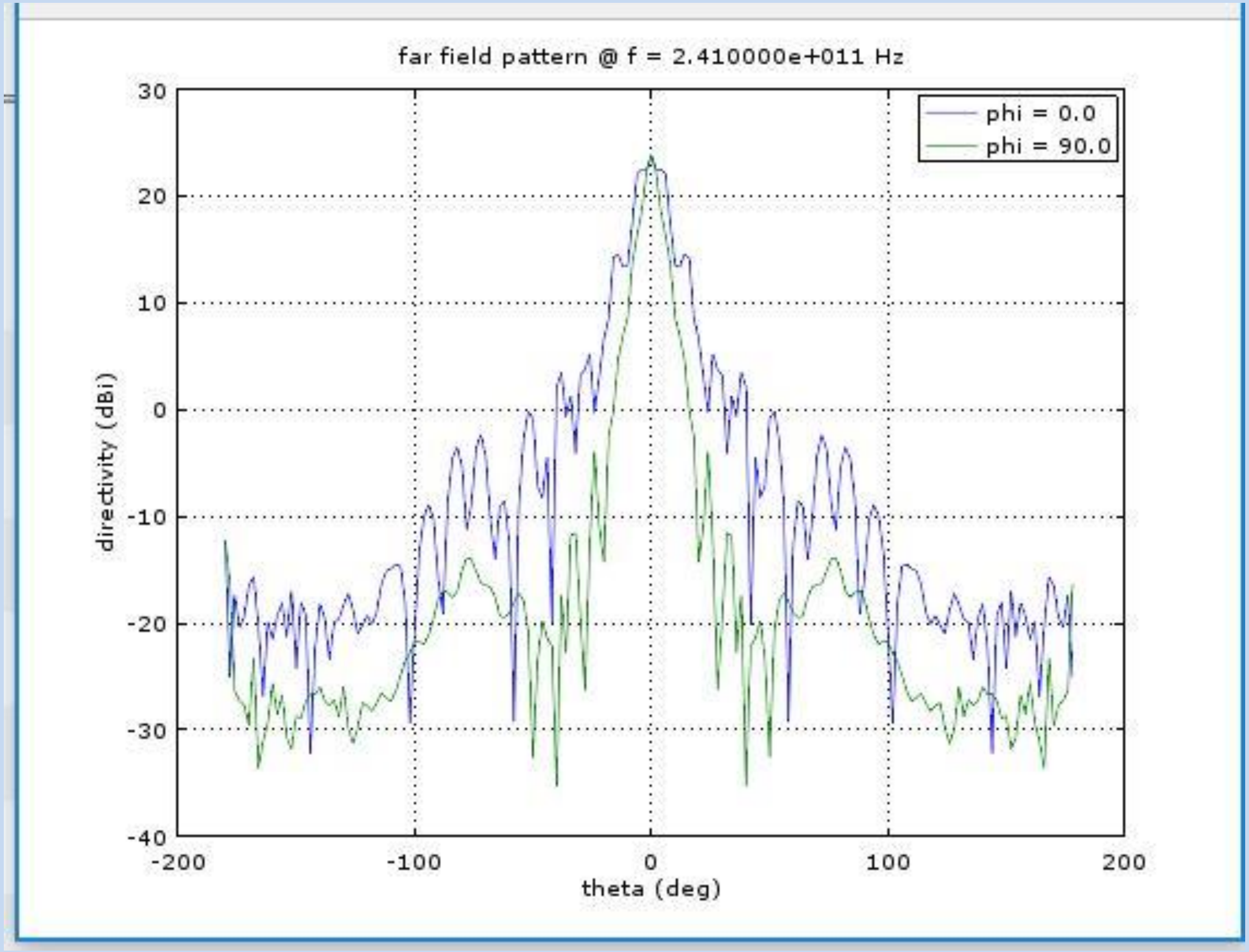
187 million cells in 3D model with a $\lambda/25$ resolution.
λ = 1.24 mm at 241 GHz

Solution time for mesh
i7, 16 GB RAM = 5 hr 4 min

PME 1.0 match at 241 GHz

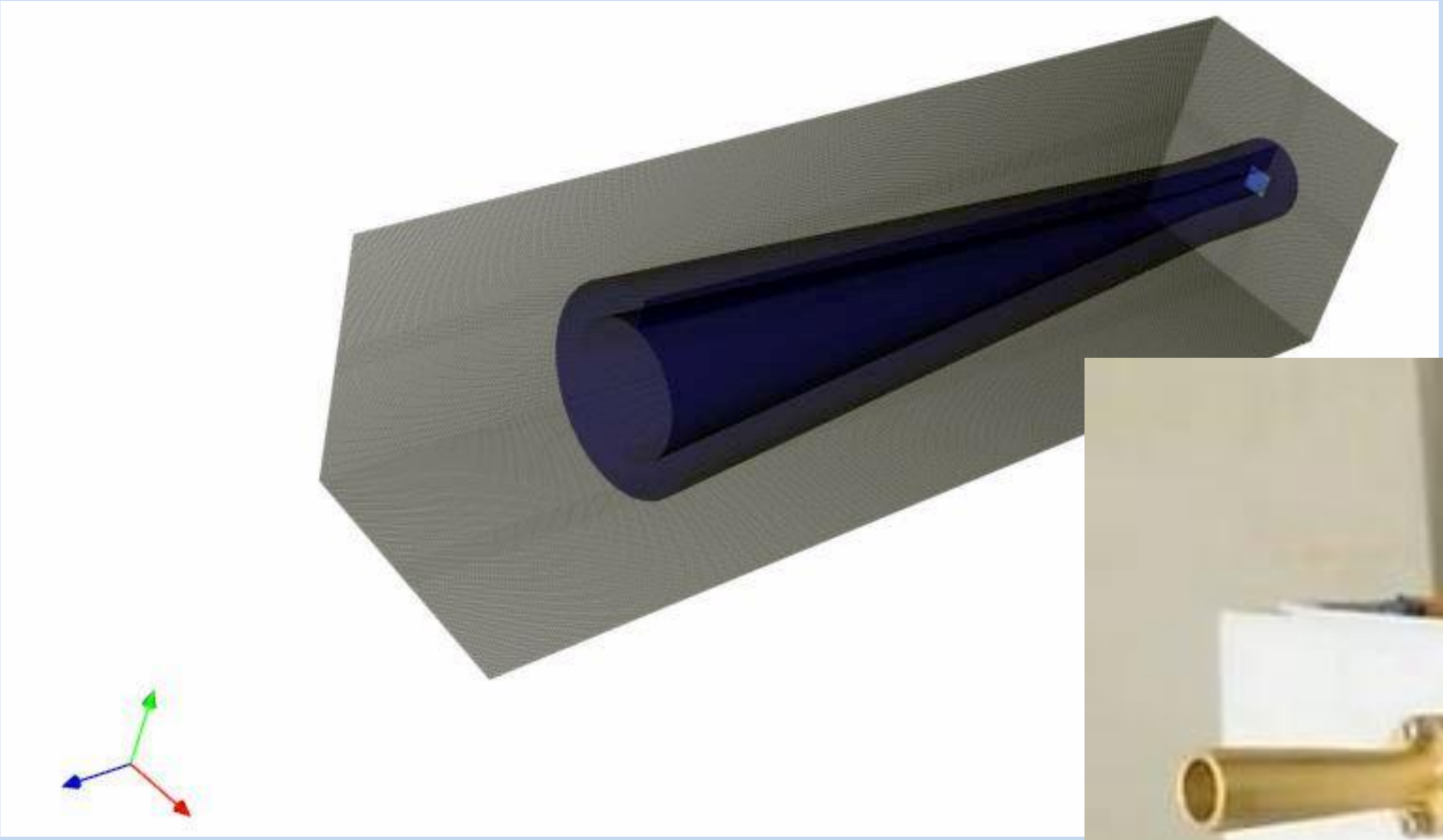


PME 1.0 far-field patterns at 241 GHz

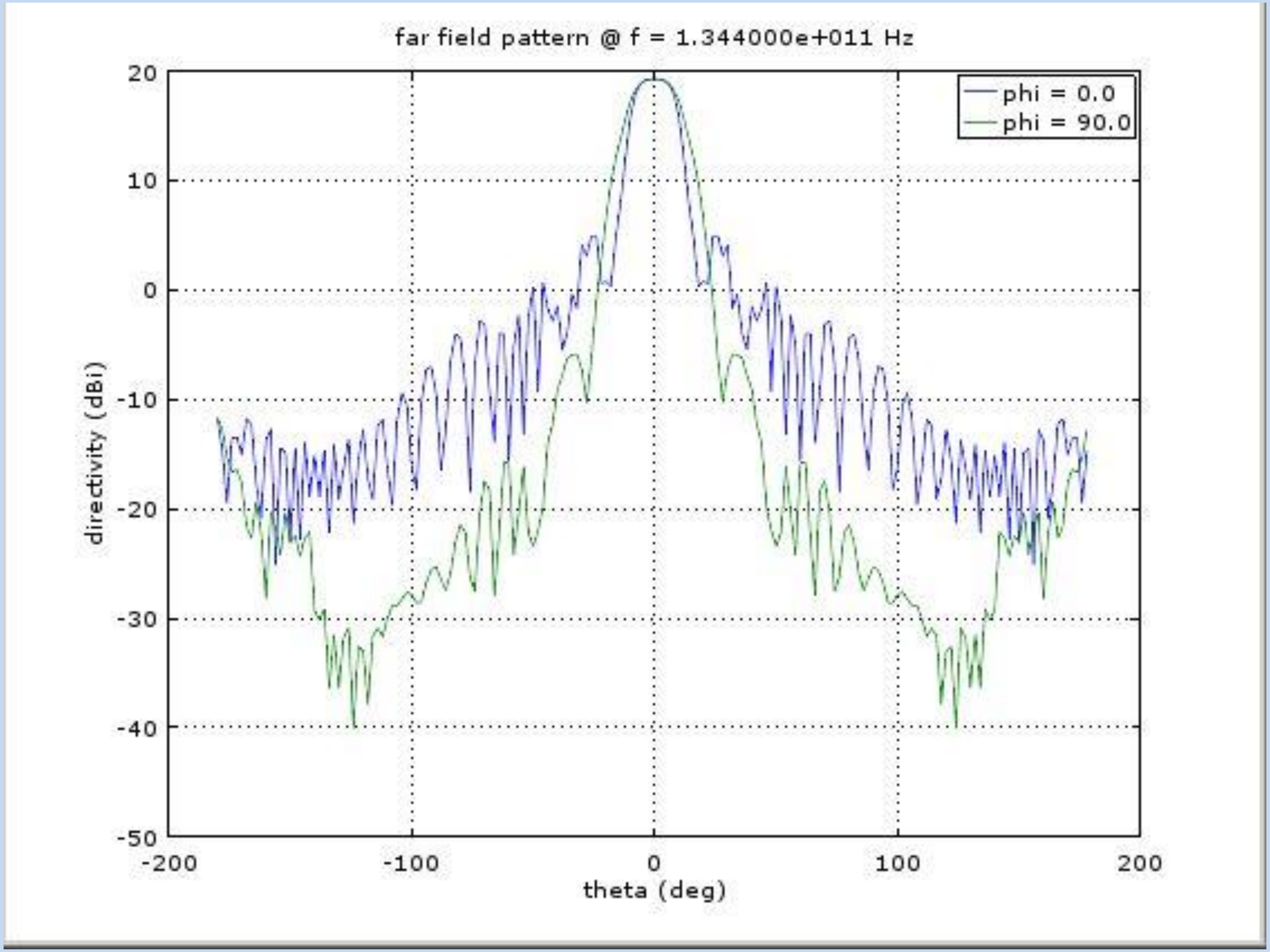


Blue: E plane, Green: H plane

G8ACE conical horn dish-feed at 134 GHz

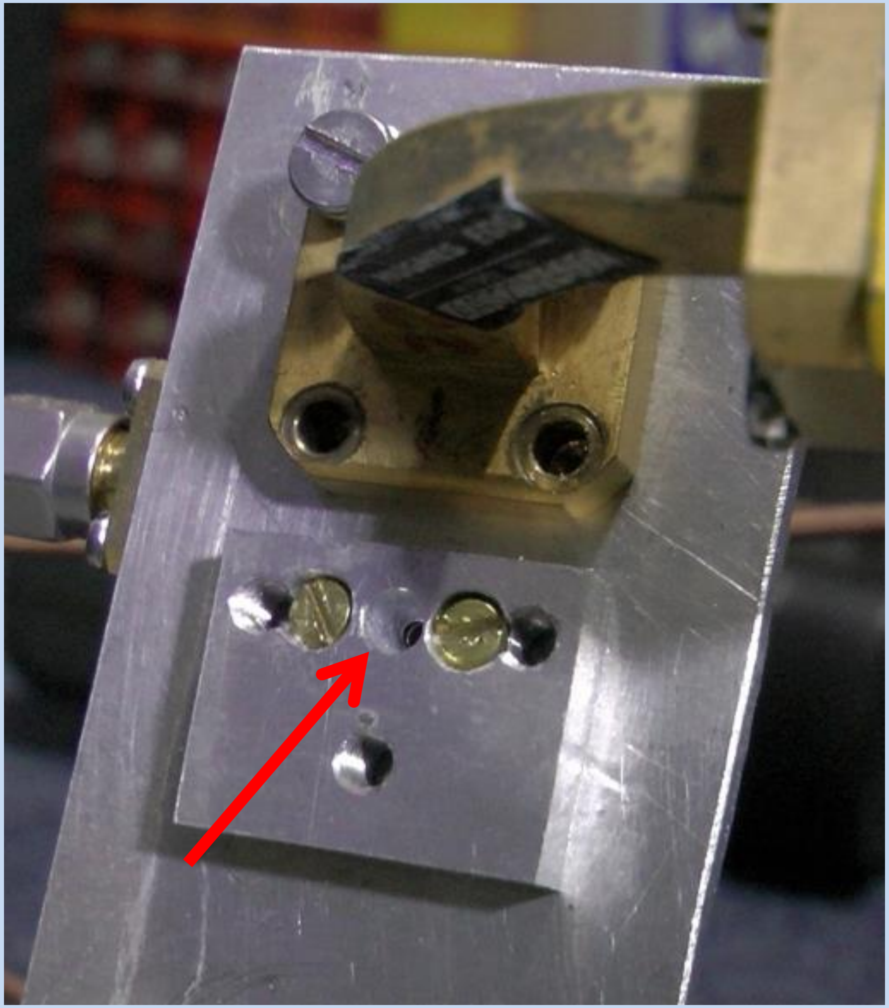


G8ACE conical horn dish-feed at 134 GHz

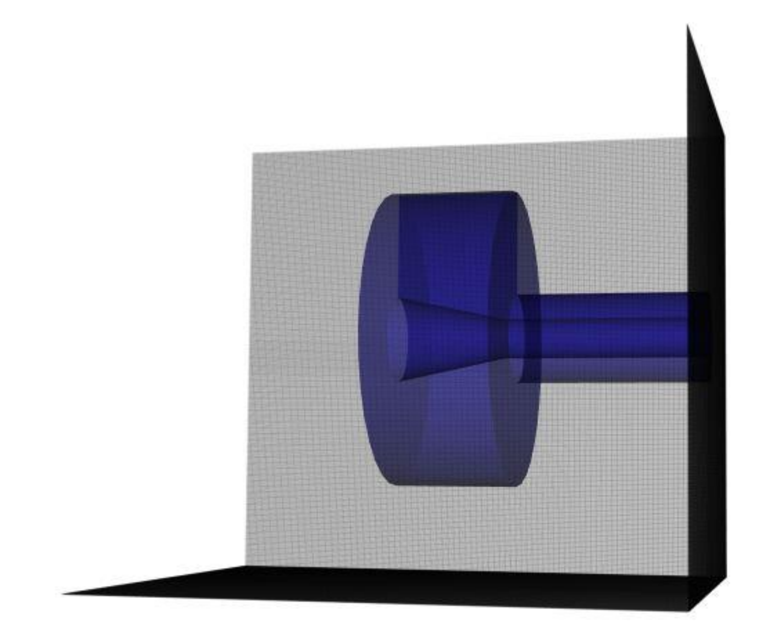


Gain = 19.3 dBi, Blue: E plane, Green: H plane

134 GHz block with integrated horn



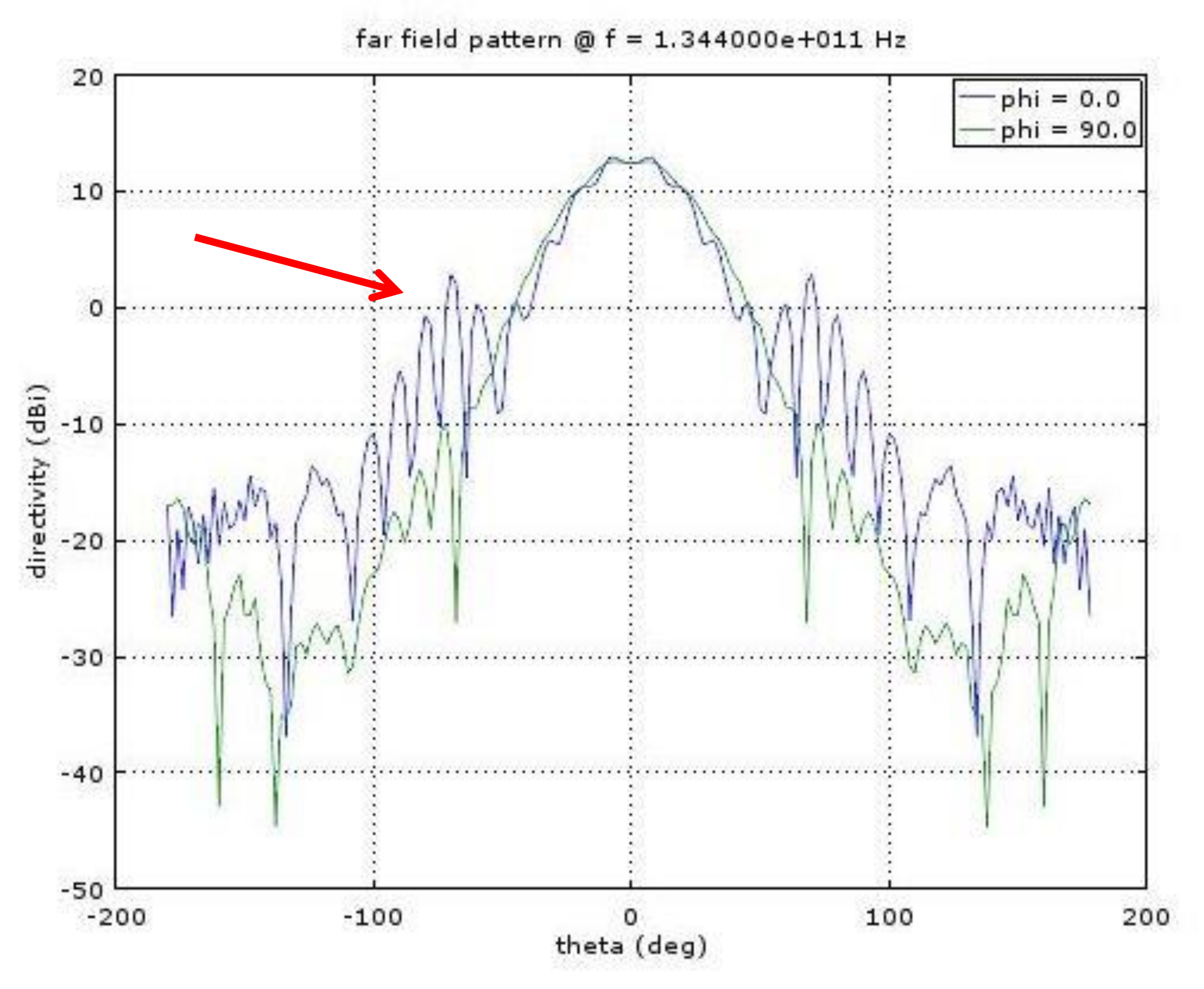
Source: M0DTS



openEMS model

Dish f/D = 0.6
Horn aperture = 3.5 mm
Horn length = 4.5 mm
Waveguide = 1.6mm ID

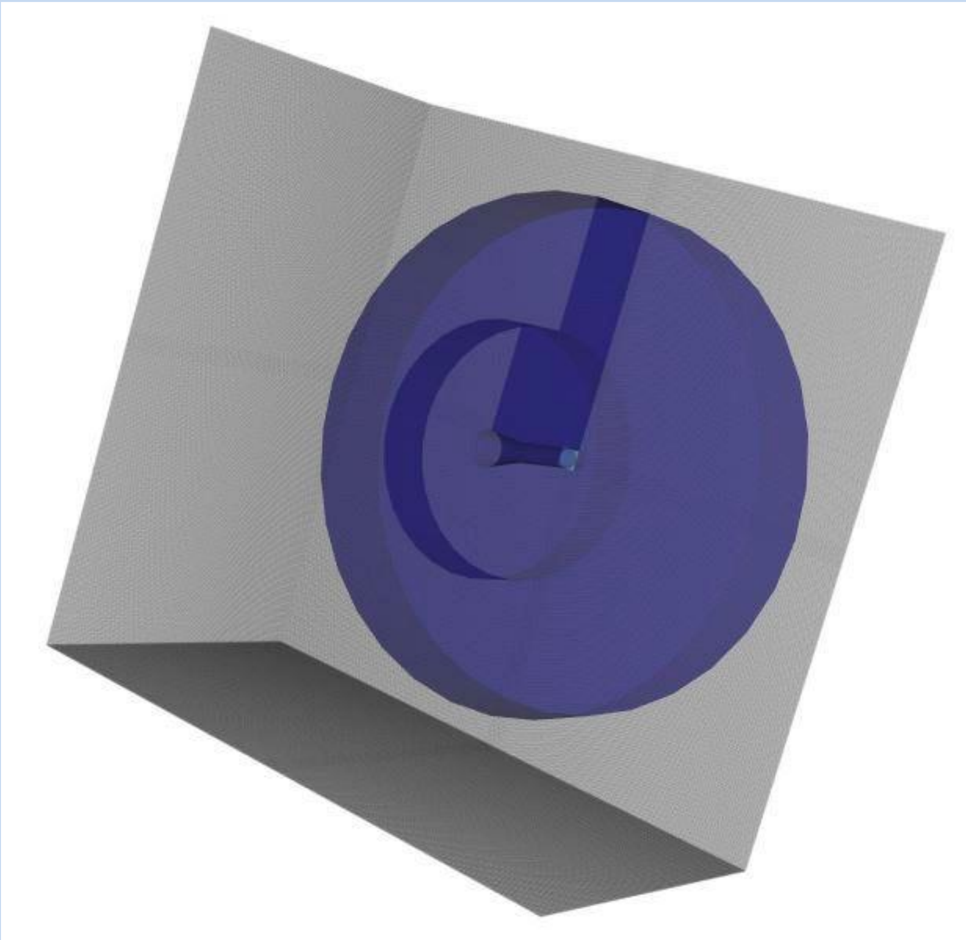
M0DTS 134 GHz mixer-block horn



For f/D = 0.6, optimum $\theta_{10dB} = \pm 48.5°$

Blue: E plane, Green: H plane

G8AGN 134GHz mixer block horn



Horn aperture = 1.3λ = 2.9mm

Horn length = 1.13mm

Horn flare angle = 30^0

Waveguide diameter = 1.6mm

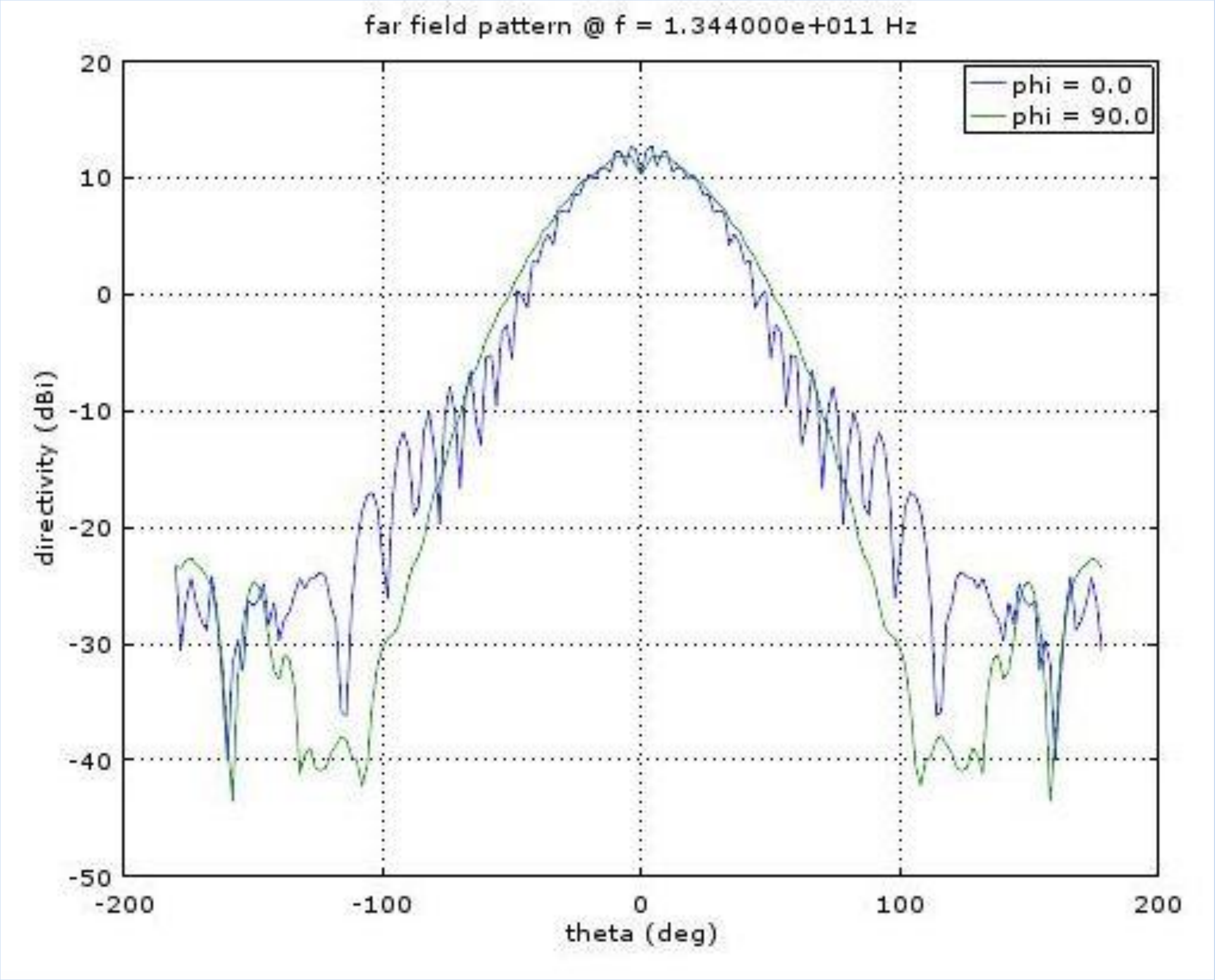
M0DTS design

Horn aperture = 3.5mm

Horn length = 4.5mm

Flare angle = 11.9°

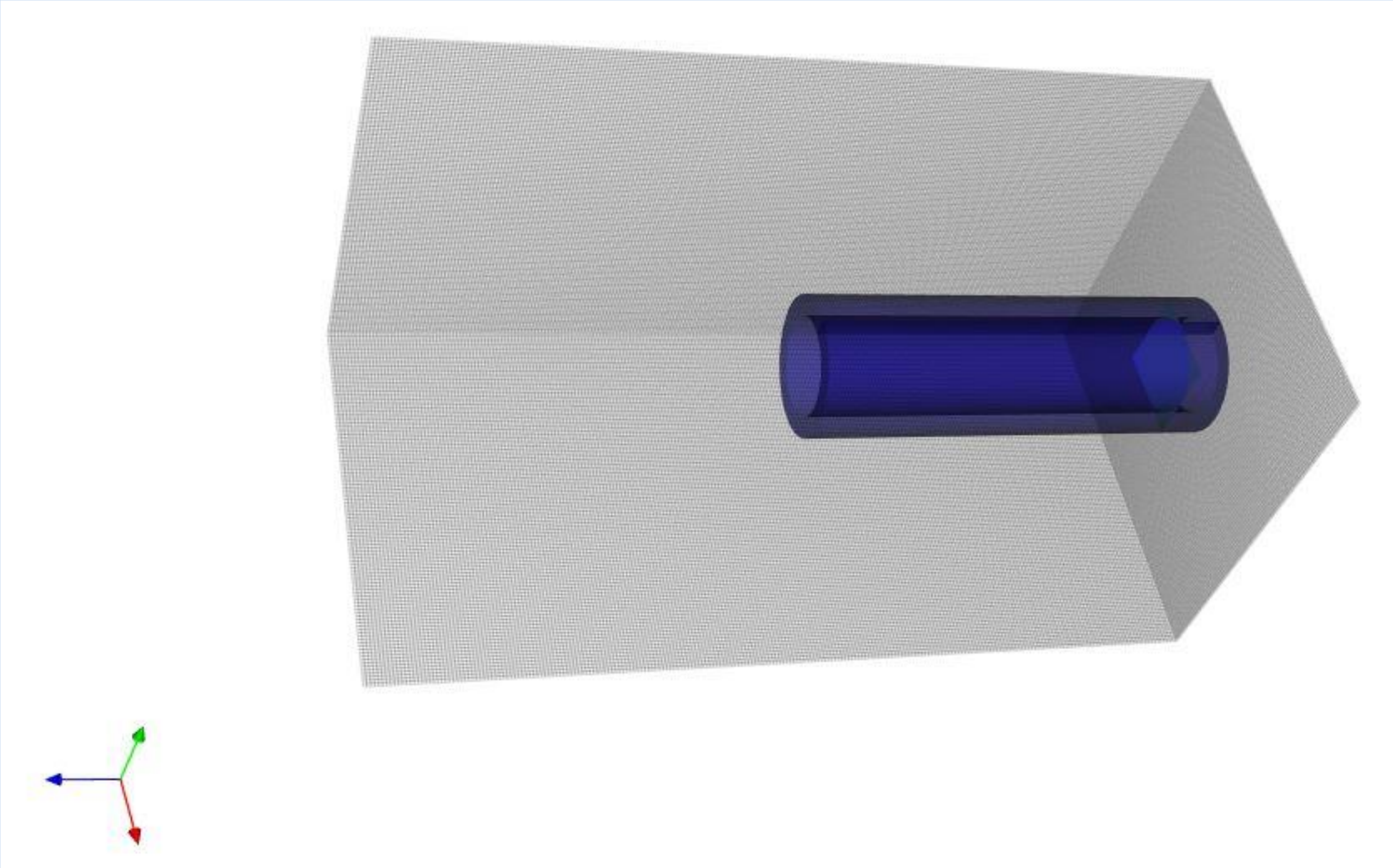
G8AGN horn far-field pattern at 134.4GHz



For f/D = 0.6, optimum $\theta_{10dB} = \pm 48.5°$

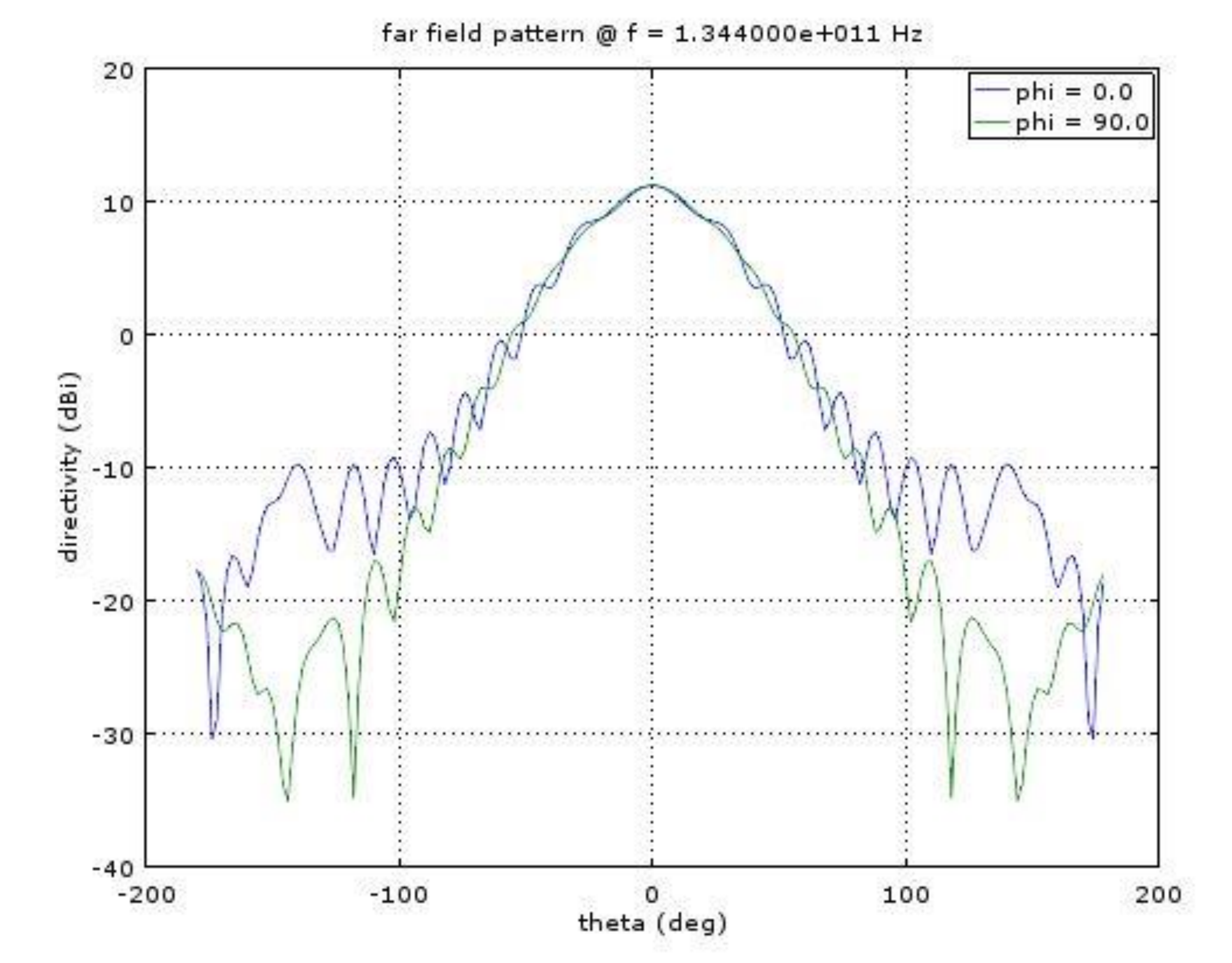
Blue: E plane, Green: H plane

openEMS model of circular waveguide feed



f = 134.4 GHz, waveguide ID = 3/32 inch, 3.2 million cells, λ/25 resolution

3/32'' circular waveguide far-field pattern at 134 GHz

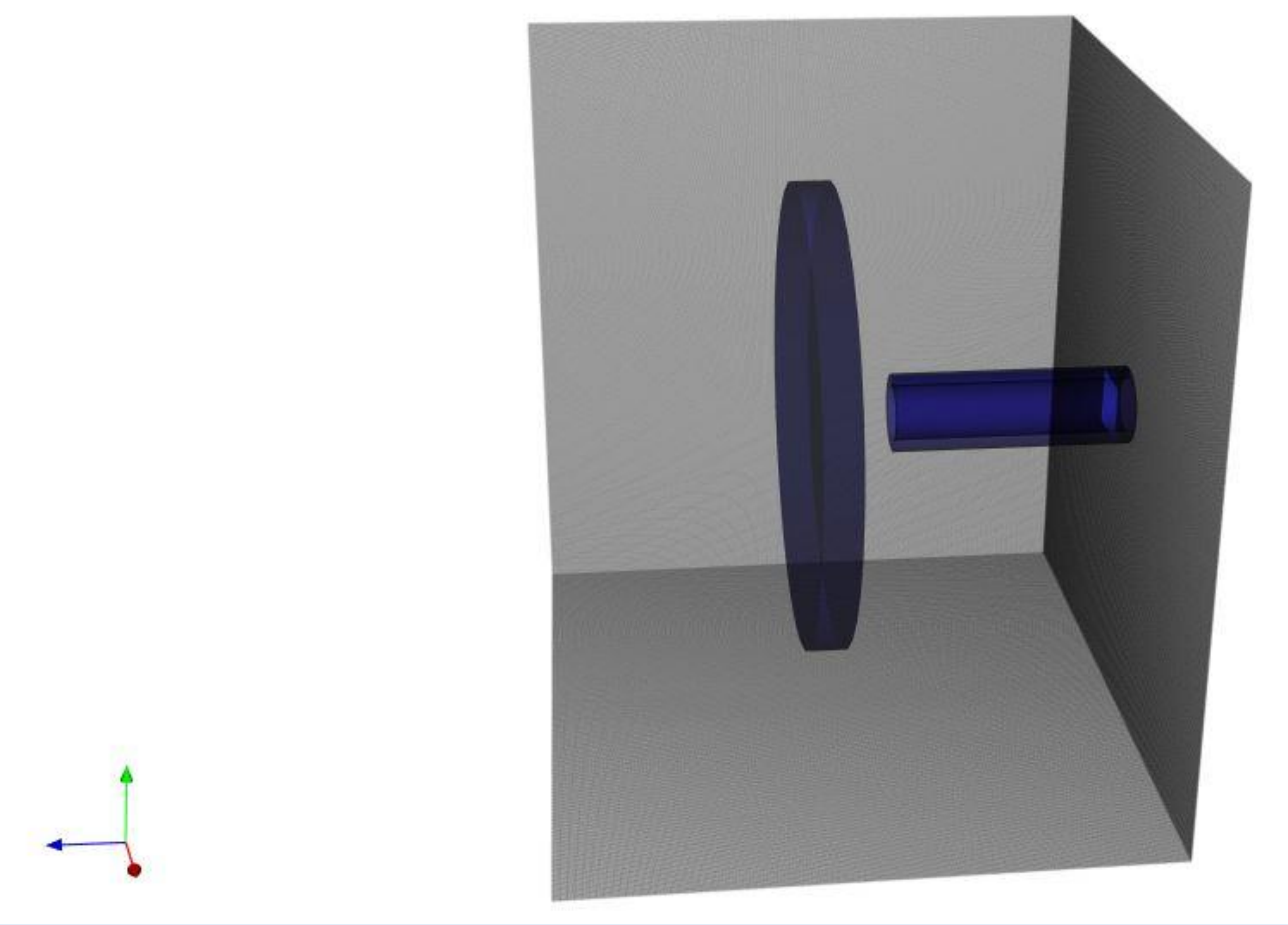


Gain = 11.2 dBi, Blue: E plane, Green: H plane

“New penny” splash-plate feed for 134 GHz

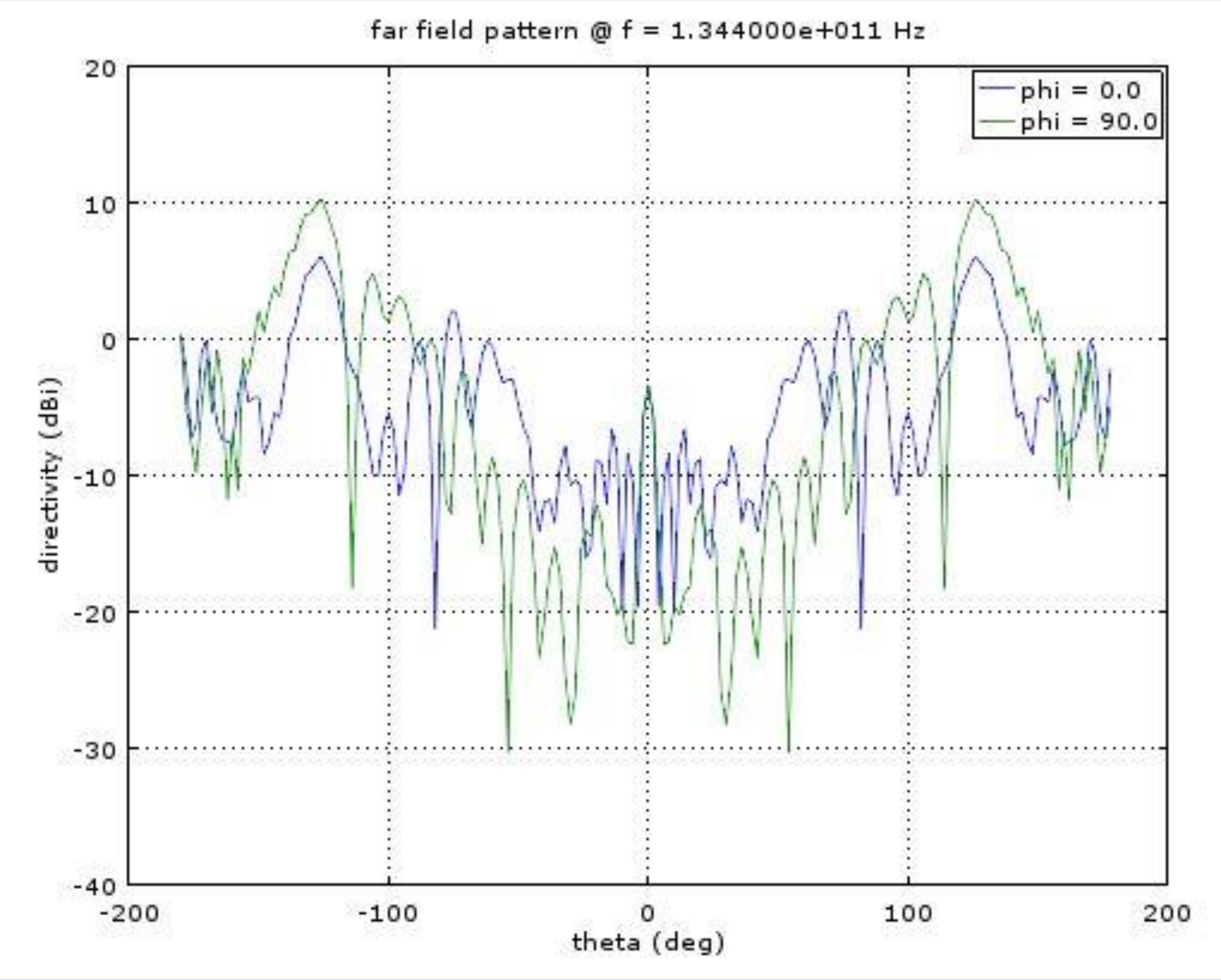
Waveguide ID = 3/32 inch, disc diameter = 20 mm, spacing = 2.5 mm

openEMS model of splash-plate feed



Including the dish would require a huge increase in computer RAM and processing power

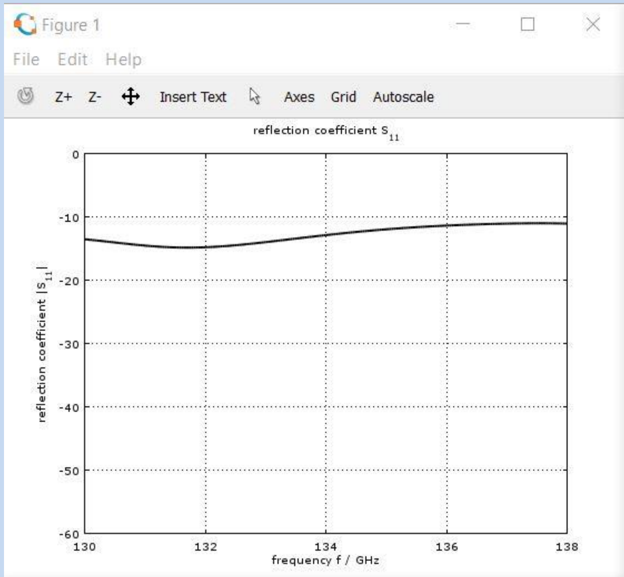
Splash-plate feed far-field pattern at 134 GHz

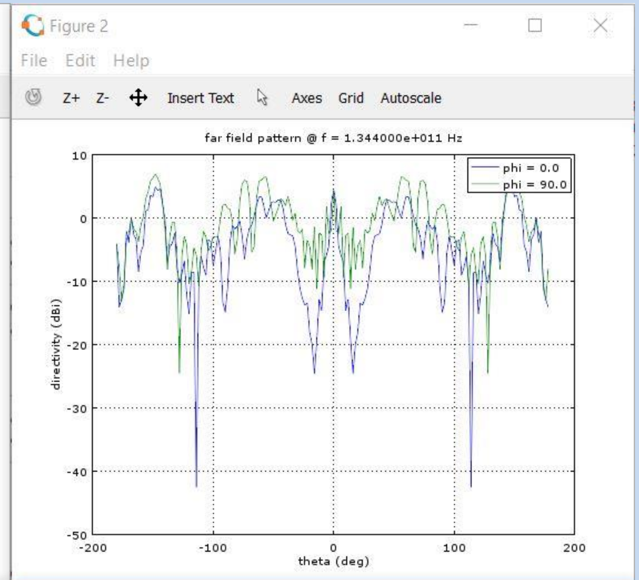


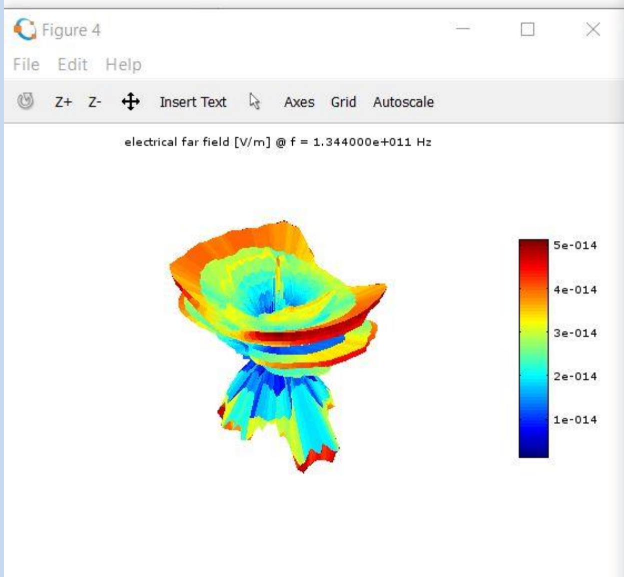
Blue: E plane, Green: H plane

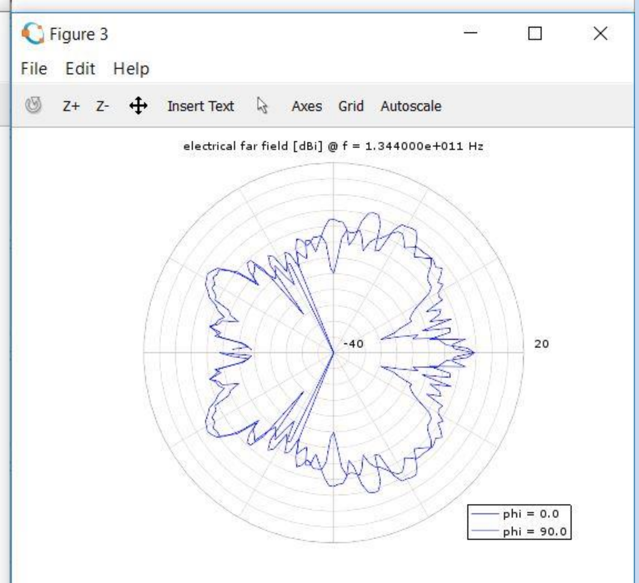
NOT OPTIMUM

Procom PRO-145-001dish feed (as supplied)



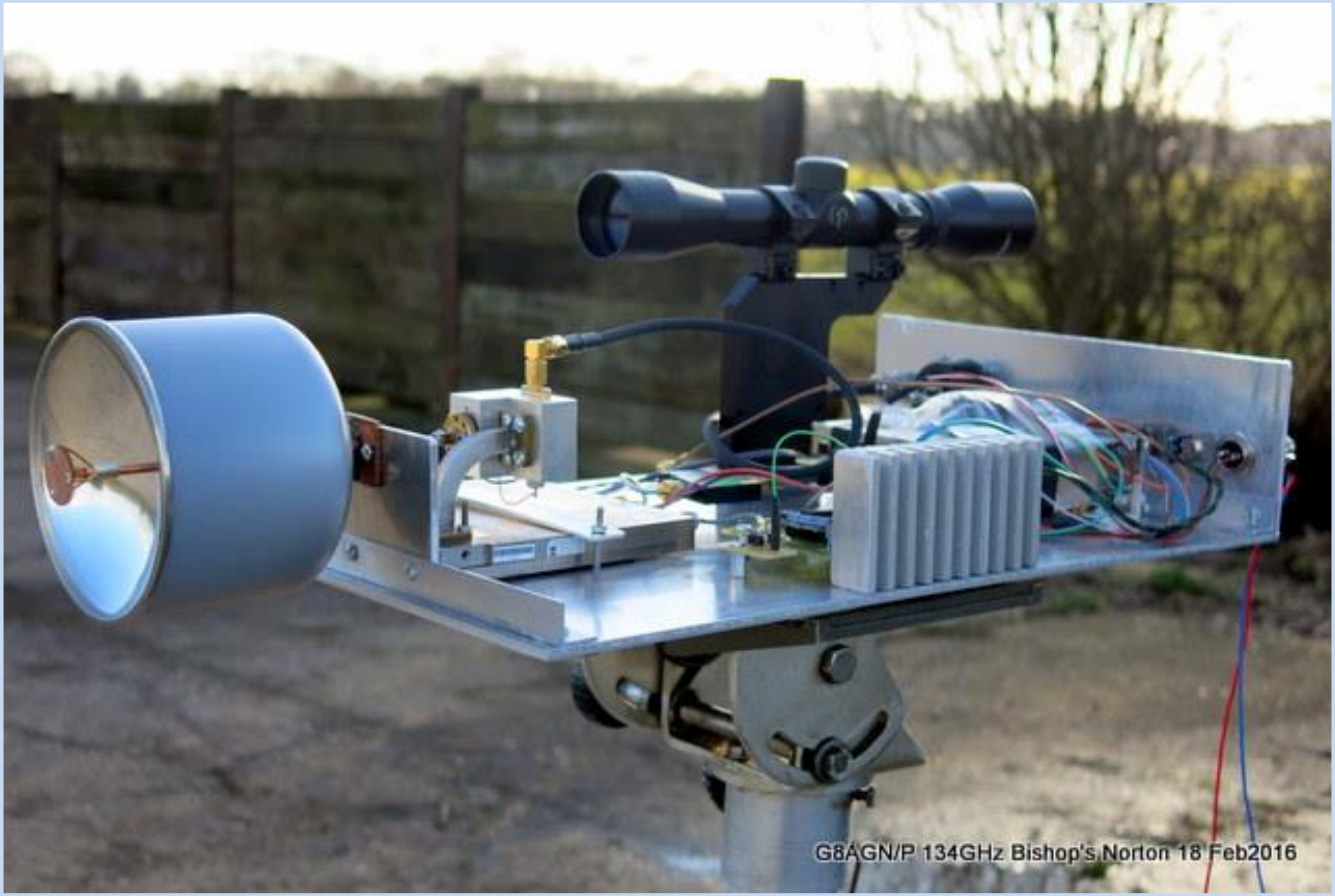






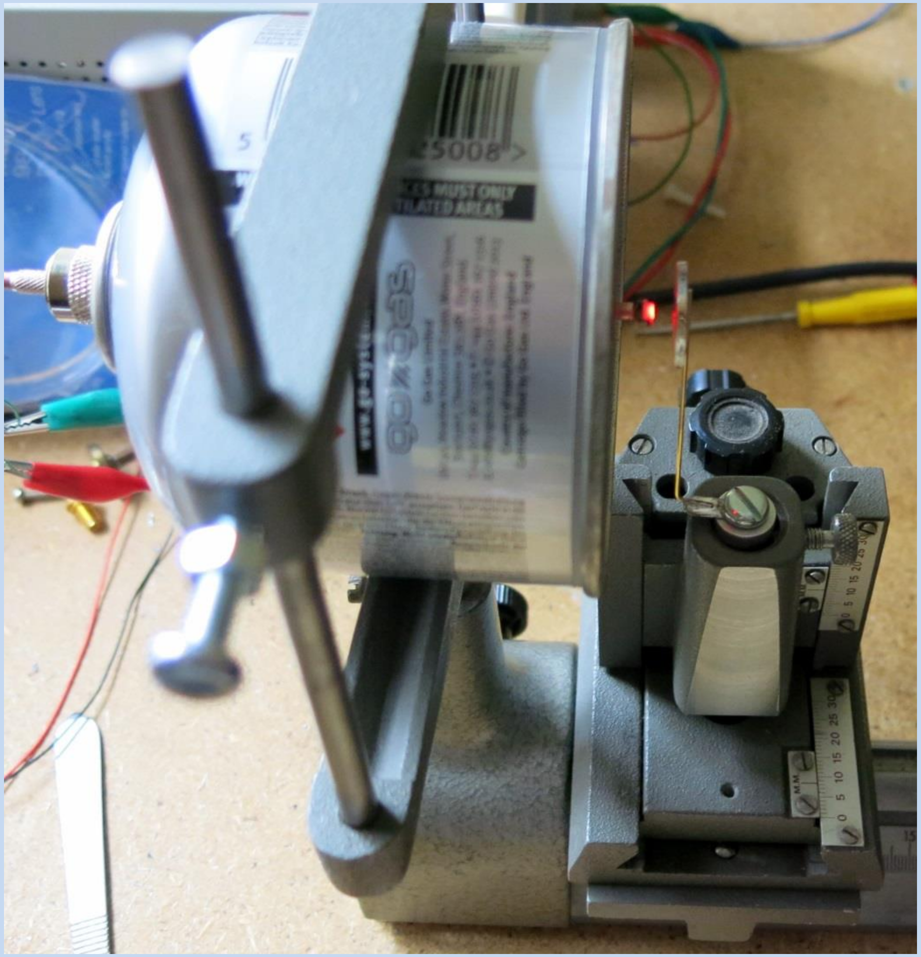
250mm diameter
f/D = 0.4
WR7 waveguide
26.5mm disc
Disc to wg = 6mm

Gas canister antenna for 134 GHz

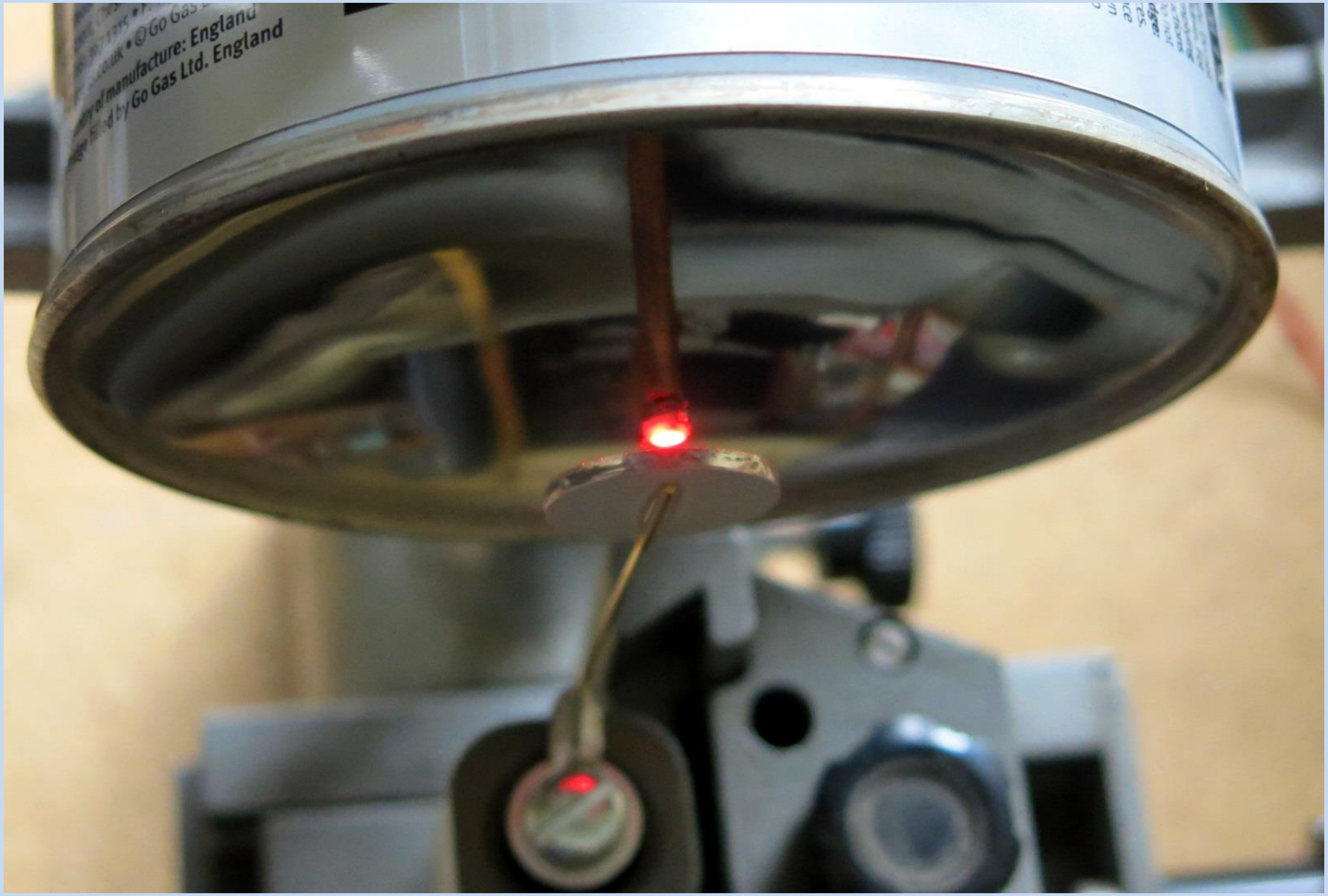


"New penny" splash-plate feed for 134 GHz

Optical testing of gas canister antenna



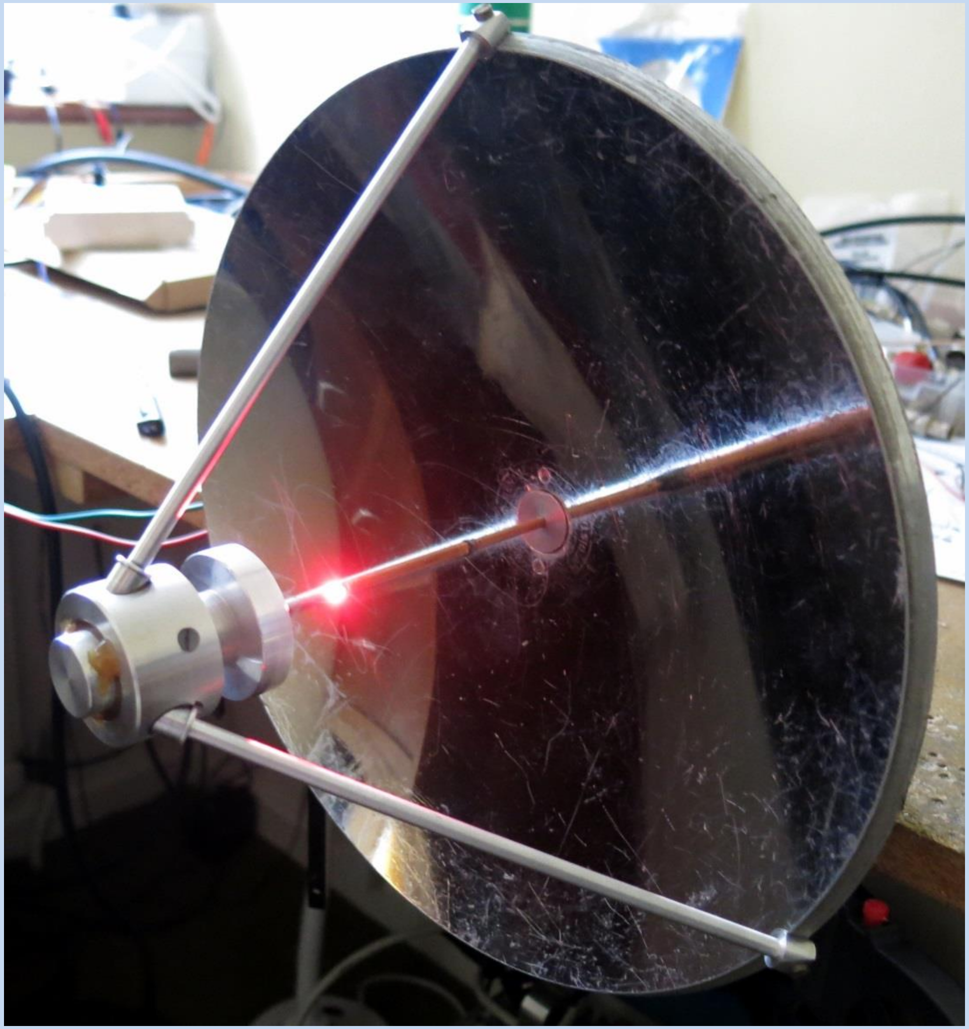
LED source for optical testing



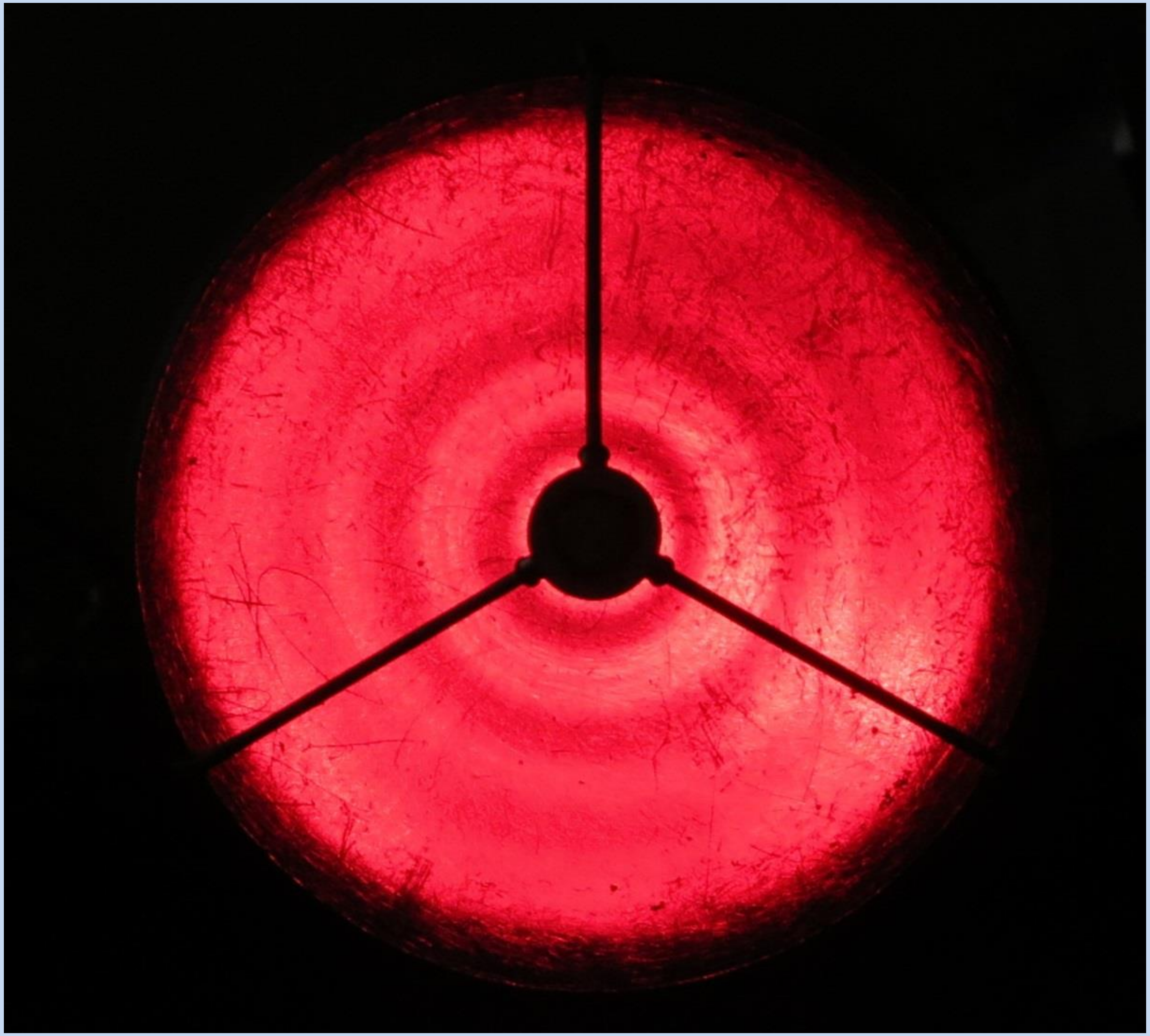
Aperture illumination of gas canister

134 GHz Cassegrain antenna

Optical testing of Cassegrain feed



Aperture illumination using Cassegrain feed



Conclusions

- openEMS offers the amateur a realistic technique for assessing the performance of microwave antennas of modest electrical dimensions when measurements cannot be made.

- openEMS results seem to compare favourably with those measured by G8CUB on icing nozzle horns at 134 GHz (see also SP-1511).

- optical testing may offer an alternative way for optimising reflector antennas whose electrical dimensions are too large for amateurs to model using openEMS.