Simbeor Application Note #2015_01, May 2015

Currents in microstrip line

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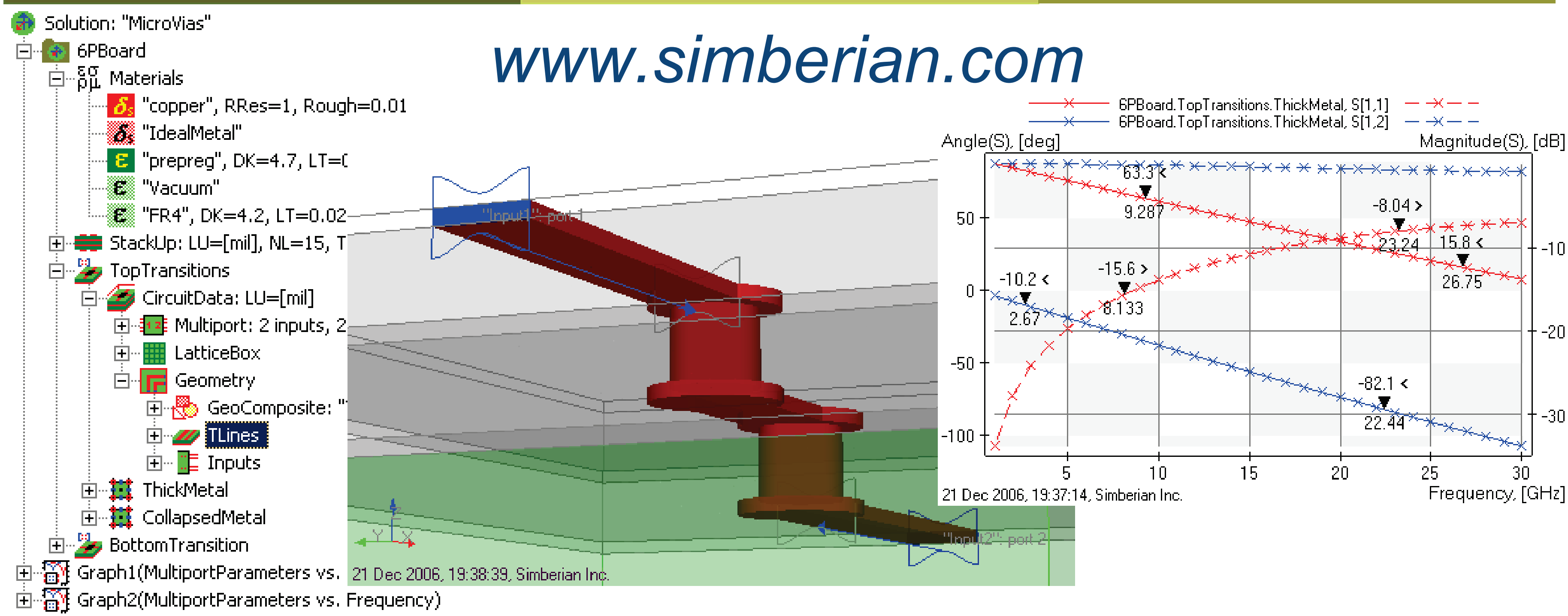

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Introduction

- This is investigation of current density distribution in microstrip line with Simbeor 3DTF solver (from Simbeor THz release)
- Simbeor 3DTF is frequency-domain solver with the simulation technology based solely on the Trefftz Finite Element (TFE) method
  - TFE method is the finite element method based on the wave expansion of electromagnetic fields inside elements and either scattering or admittance matrix formulation
  - Electromagnetic field computed within the element is always exact solution of the Maxwell's equations
  - The solution is an approximation of the boundary value problems (problem with all boundary conditions imposed)
  - Any type of dielectric, conductor and semi-conductor are meshed and solved in the same way
  - Trefftz element size within dielectrics and conductors may be comparable or even greater than wavelength or skin depth without the loss of accuracy in many problems
  - Trefftz elements within conductive and semi-conductive materials provide asymptotically correct solution at low and high frequencies as well as at the frequencies of transition to skin-effect
- **TFE method makes possible to solve problems over 6-8 decades of frequency bandwidth with the same mesh in one frequency sweep as demonstrated here**

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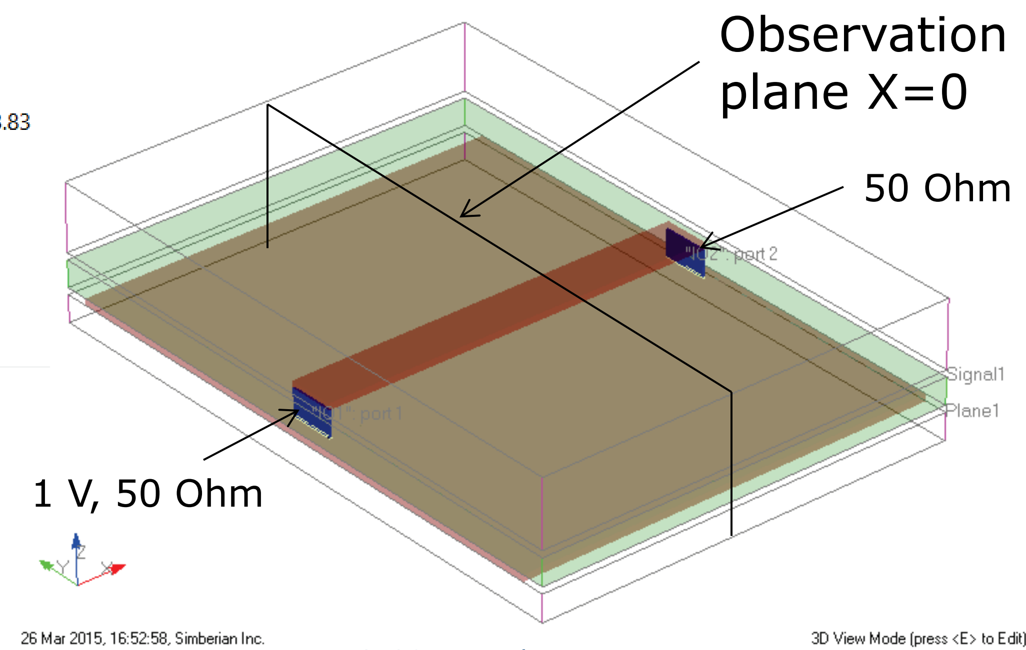
Microstrip segment

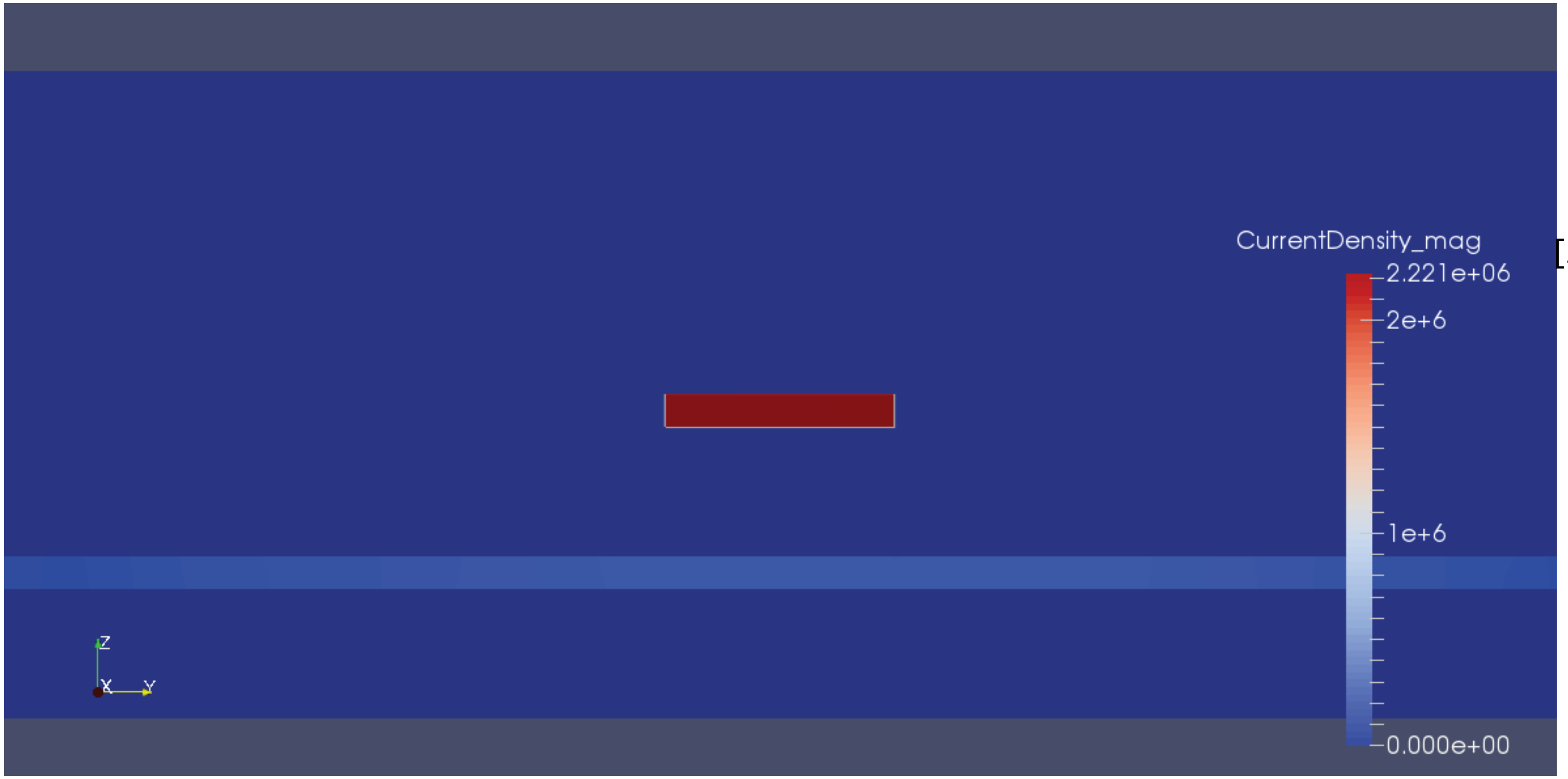
- 7-mil wide microstrip line segment 60 mil long in 1 mil thick layer Signal1 with two ports with the reference conductor in Plane1 (1 mil thick); conductor is copper – no roughness;
- PMC boundary conditions as external wall to prevent current flow on the simulation box walls
- Currents are computed at the X=0 plane (middle of the segment) – cross section is Y=104 mil by Z=20 mil ; plane size along Y is 84 mil;
- Port 1 has 1 V voltage source in series with 50 Ohm resistor, port 2 is terminated with 50 Ohm (current in strip and plane is 0.01 A)
- Current density in A/m^2 is computed and shown on all pictures

Project(1)
- Materials: T=20[°C],...
  - "Copper", RR=1
  - "FR4", Dk=4.2, LT=0.02, PLM=WD, Dk(0)=5.06, Dk(inf)=3.83
  - "Air"
- StackUp: LU=[mil], NL=2, T=20[mil]
  - 1| Medium: T=10, Ins="Air"
  - 2| Signal: "Signal1", T=1, Ins="Air", Cond="Copper"
  - 3| Medium: T=4, Ins="FR4"
  - 4| Plane: "Plane1", Cond="Copper", T=1, Ins="Air"
  - 5| Medium: T=4, Ins="Air"



Peak conduction current 1 KHz

Uniform distribution in both strip and plane

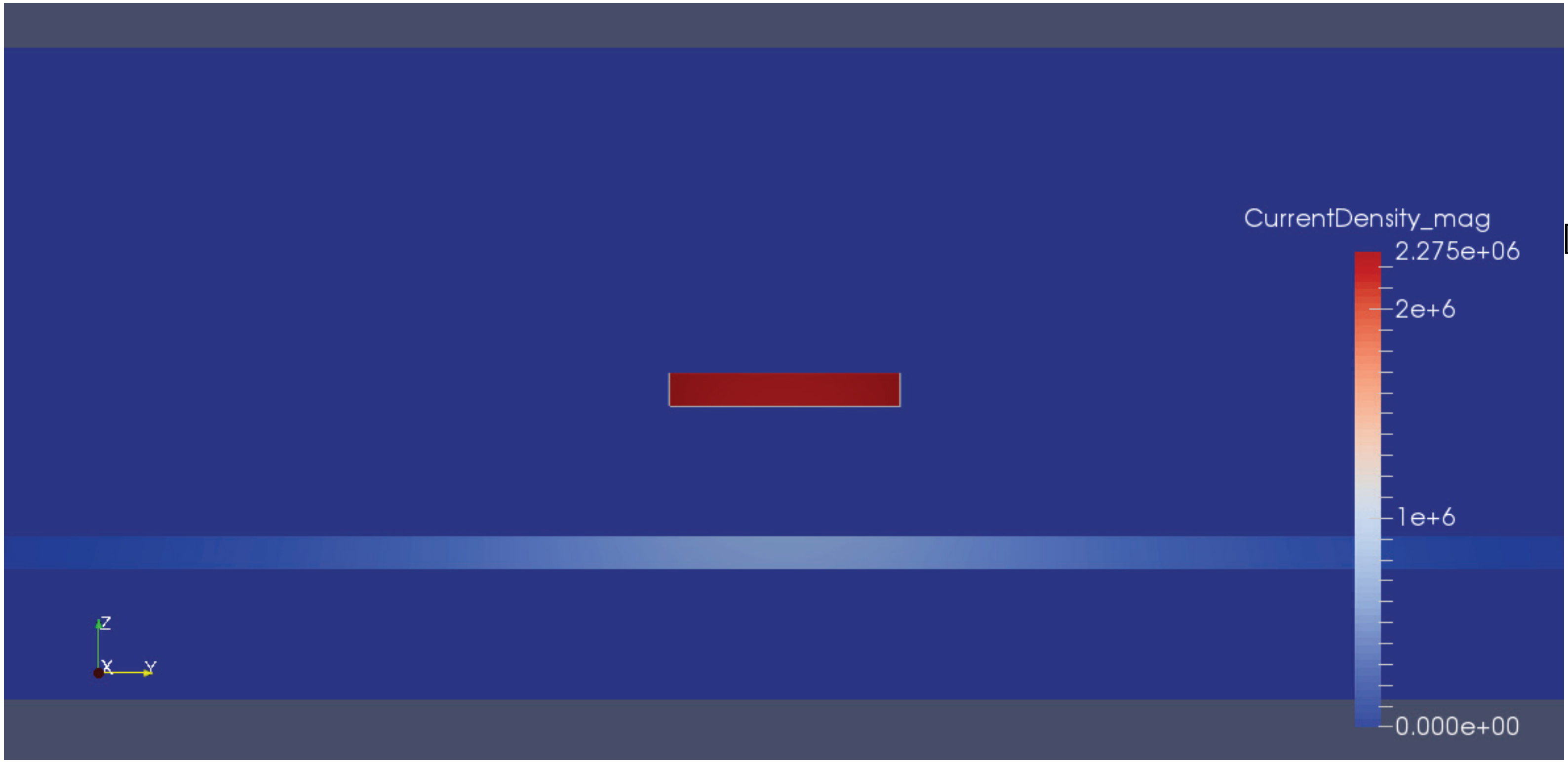


[A/m^2]

Skin Depth 82 mil (conductor thickness is 0.012 of SD)
Current density on strip 2.22e6 A/m^2, on plane 1.85e5 A/m^2 – 0.01 A total current on plane and strip in opposite directions

Peak conduction current 1 MHz

Uniform current distribution in strip, crowding in plane

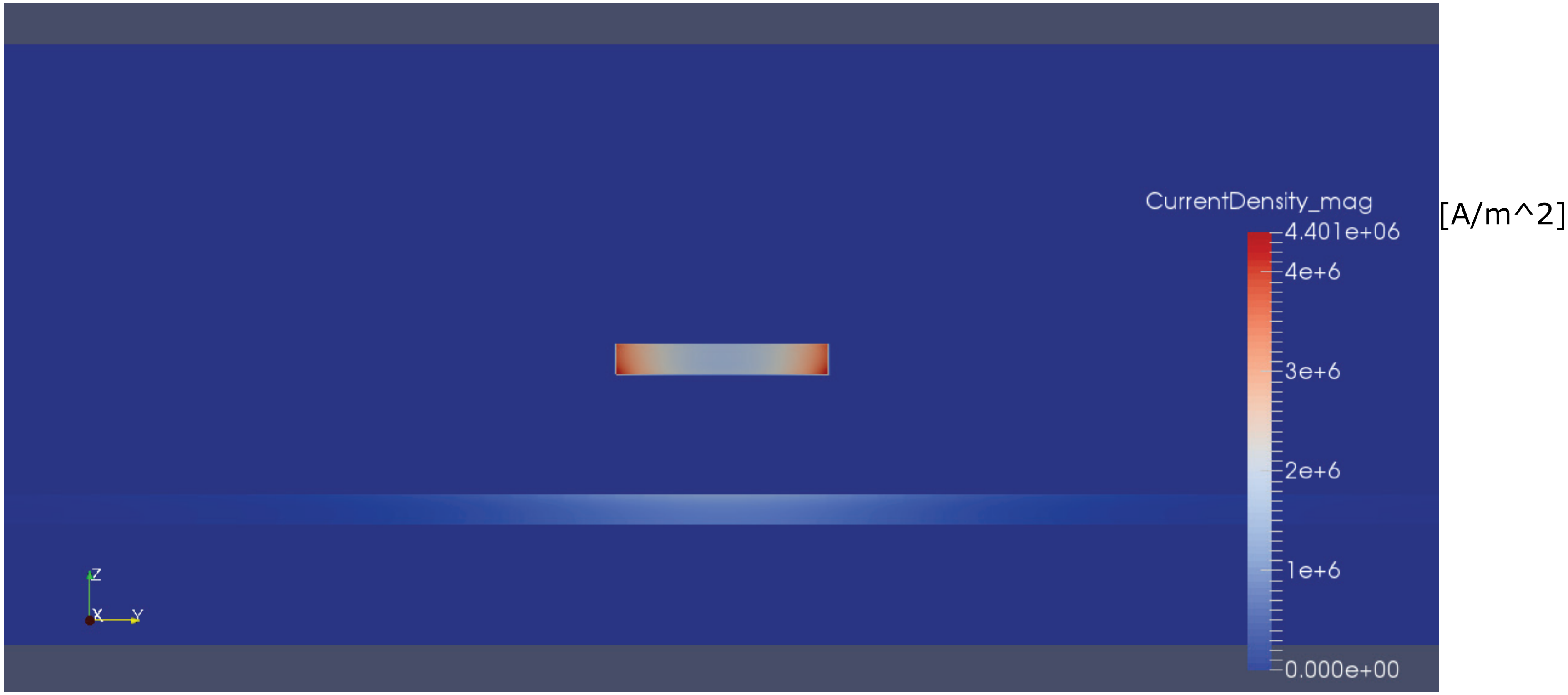


[A/m^2]

Skin Depth 2.6 mil (conductor thickness is 0.38 of SD)

Peak conduction current 10 MHz

Higher currents at the strip edges, further crowding in plane



Skin Depth 0.82 mil (conductor thickness is 1.22 of SD)

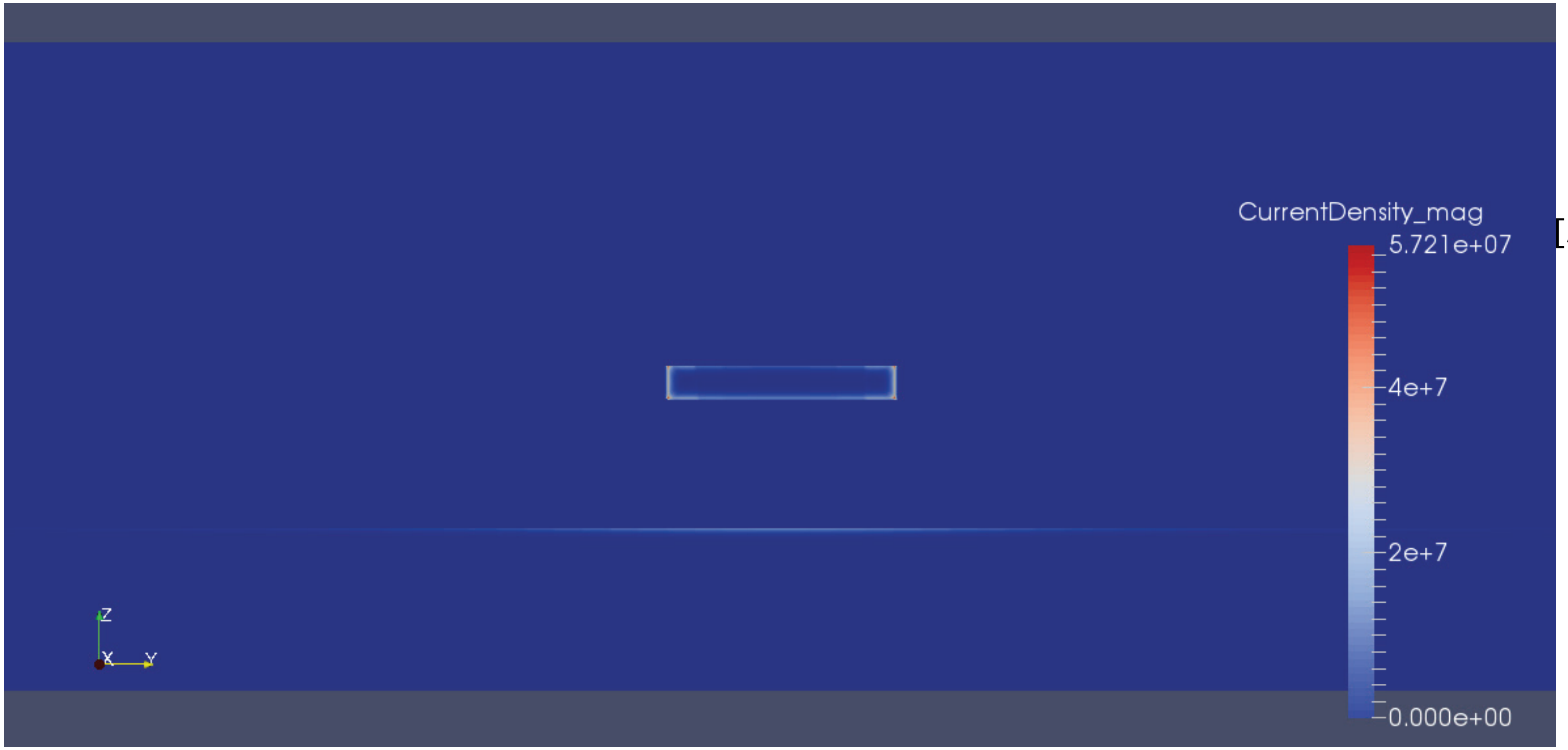
Peak conduction current 100 MHz

Further concentration at strip edges and in plane below the strip

Skin Depth 0.26 mil (conductor thickness is 3.84 of SD)

Peak conduction current 1 GHz

Well developed skin effect in both strip and plane

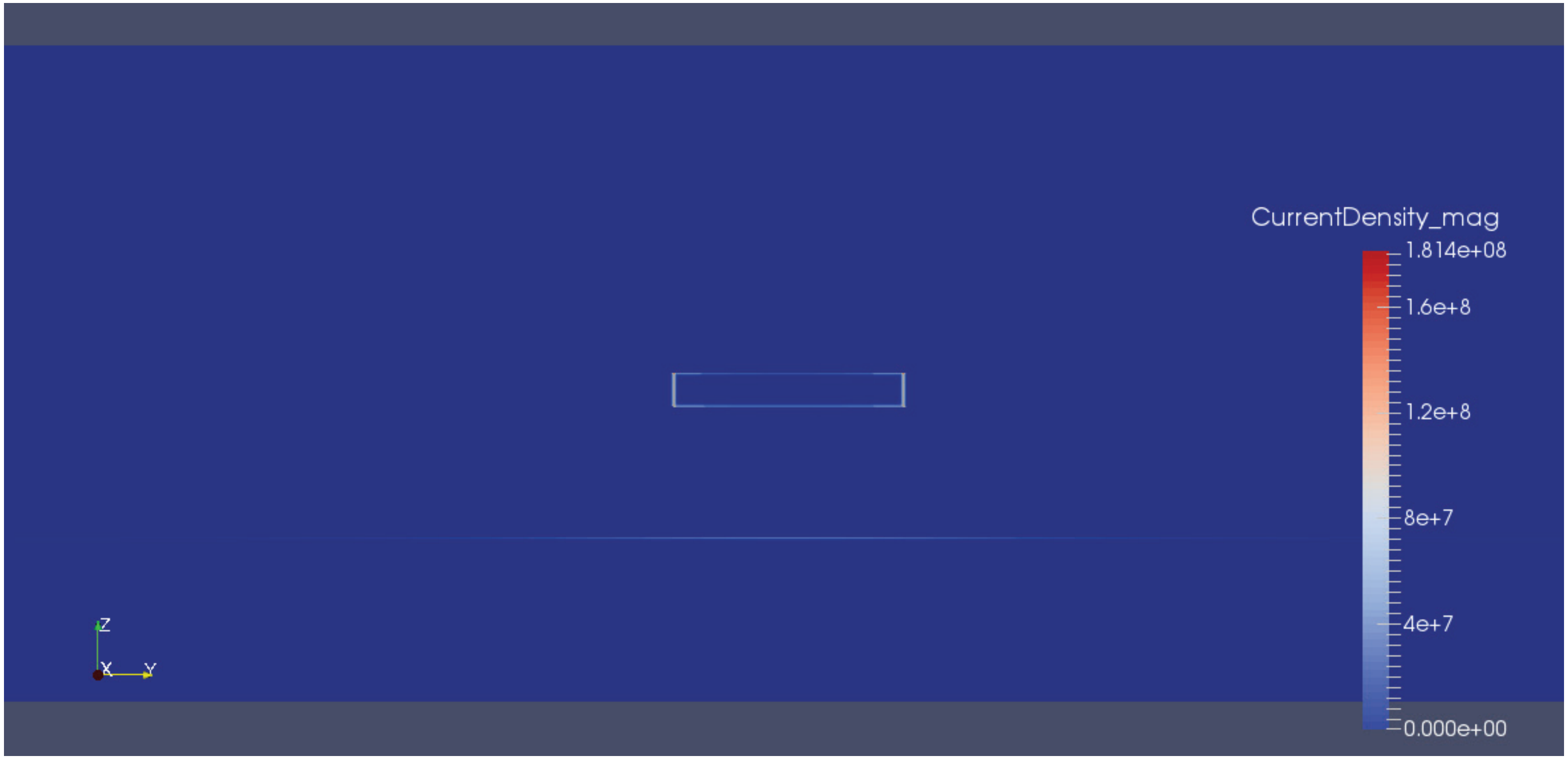


[A/m^2]

Skin Depth 0.082 mil (conductor thickness is 12.2 of SD)

Peak conduction current 10 GHz

Higher current density in thinner layer



[A/m^2]

Skin Depth 0.026 mil (conductor thickness is 38.5 of SD)

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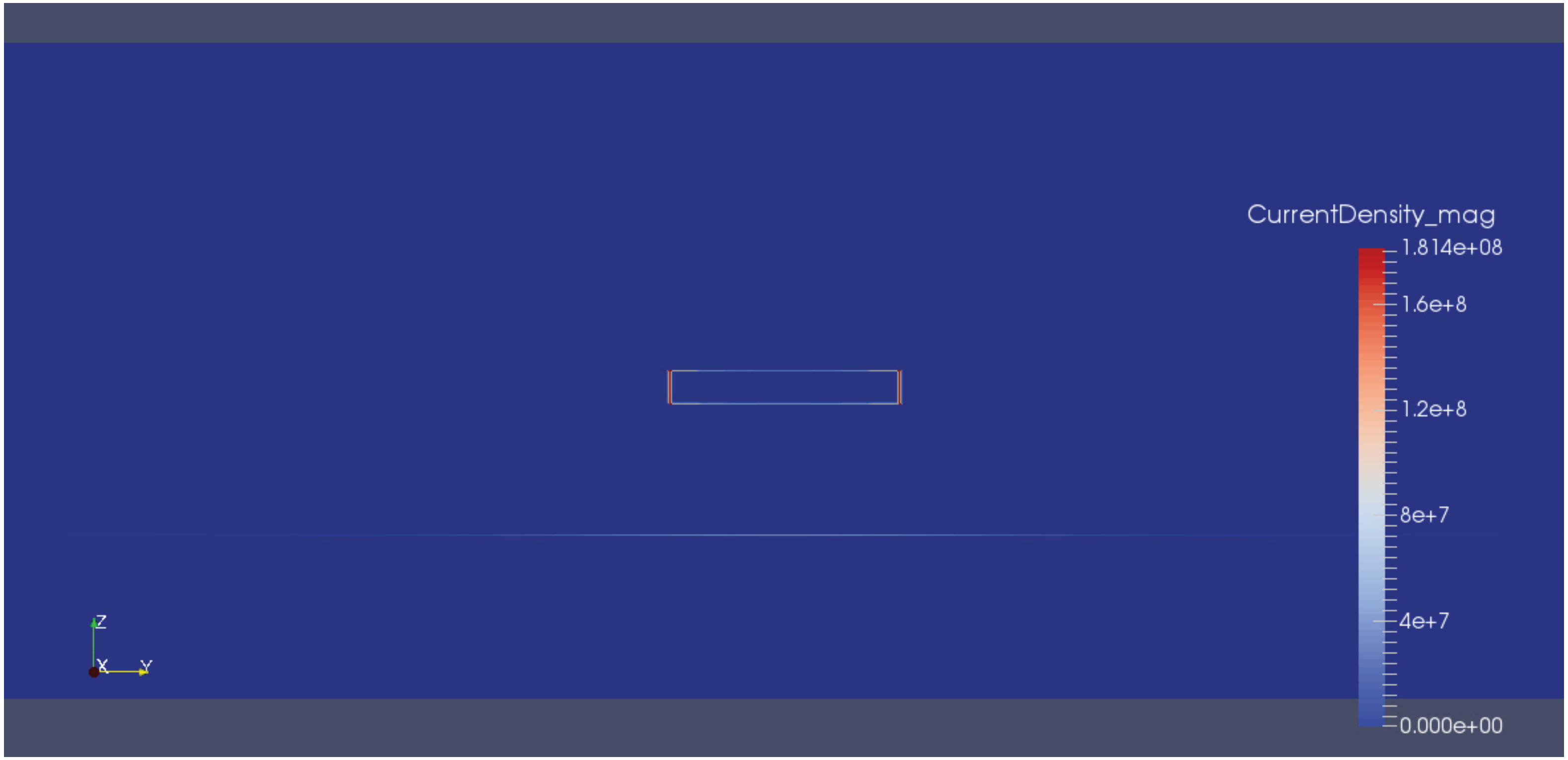
Peak conduction current 50 GHz

Higher current density in thinner layer



[A/m^2]

Skin Depth 0.012 mil (conductor thickness is 83.3 of SD)
Plot is on the same scale as 10 GHz

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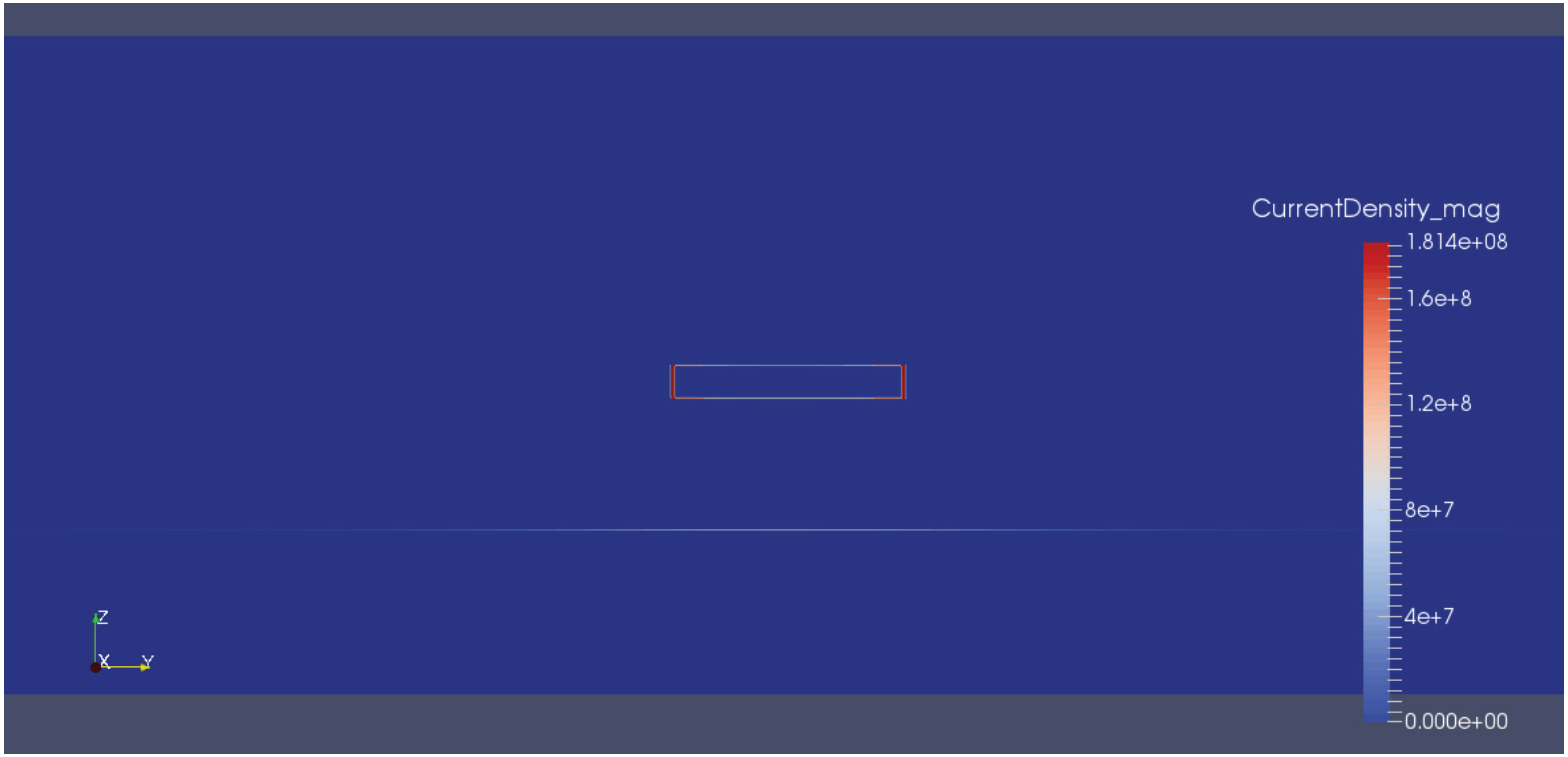
Peak conduction current 100 GHz

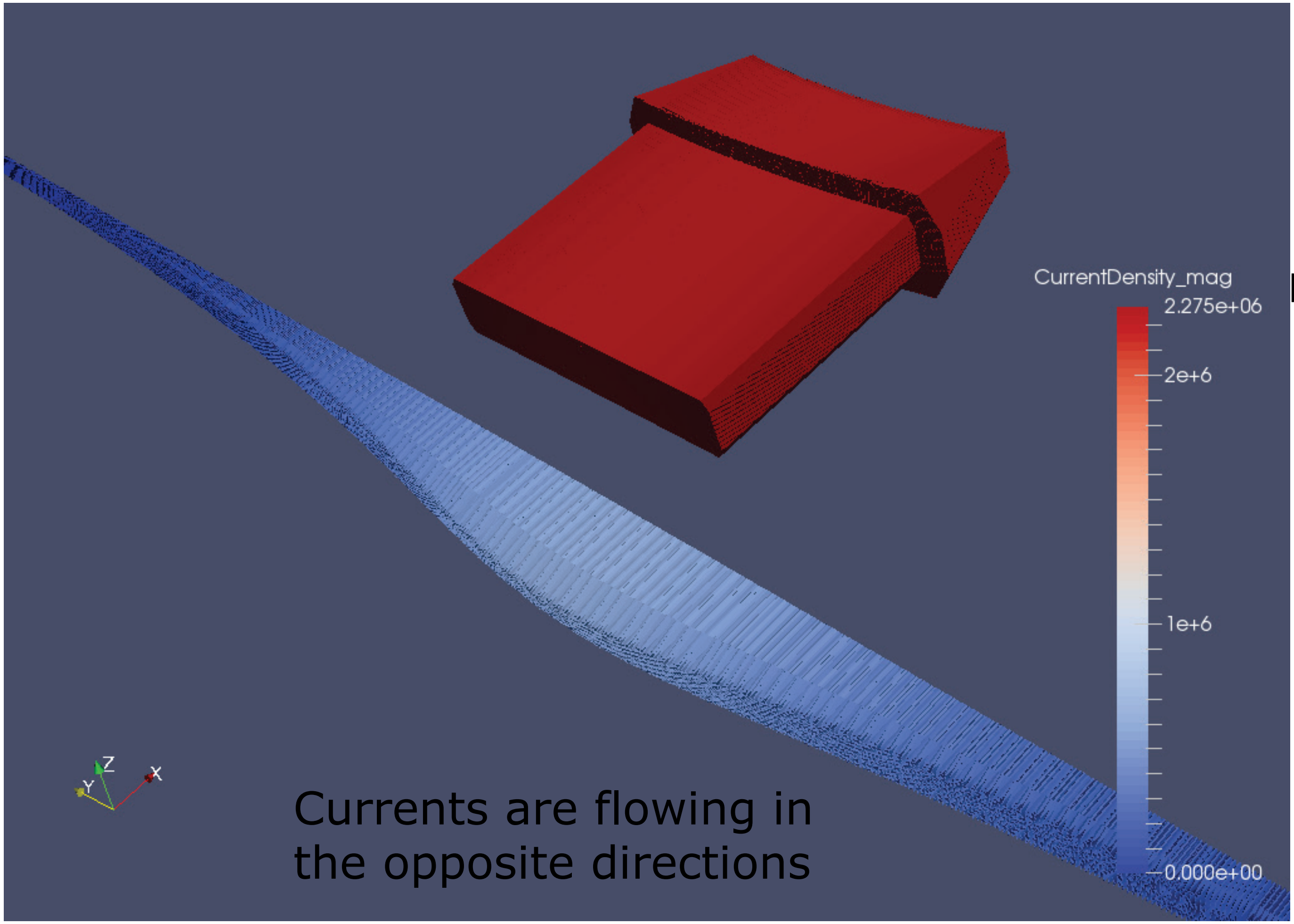
Higher current density in thinner layer



[A/m^2]

Skin Depth 0.0082 mil (conductor thickness is 122 of SD)
Plot is on the same scale as 10 GHz

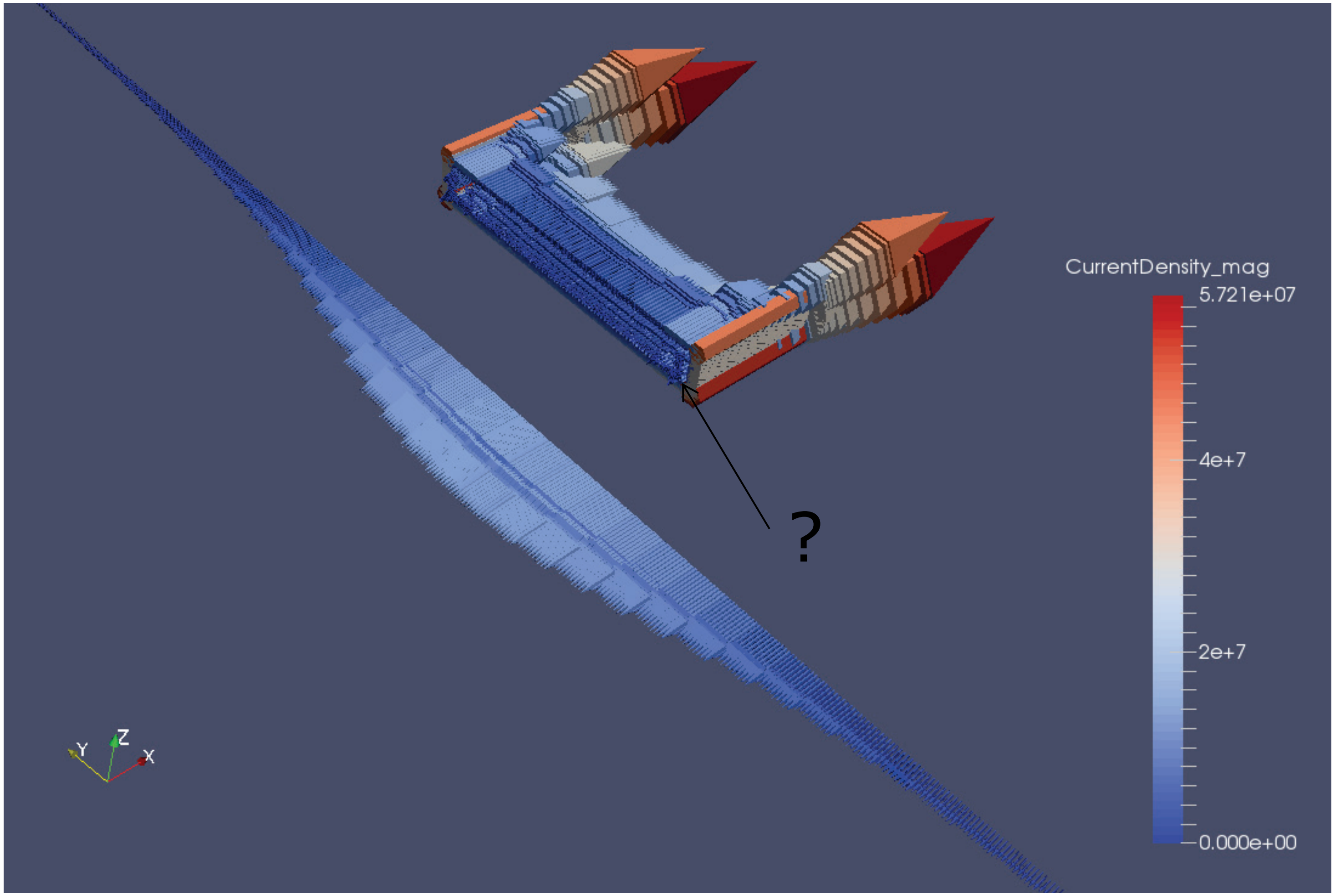
Instantaneous current 1 MHz (t=0)



[A/m^2]

Skin Depth 2.6 mil (conductor thickness is 0.38 of SD)

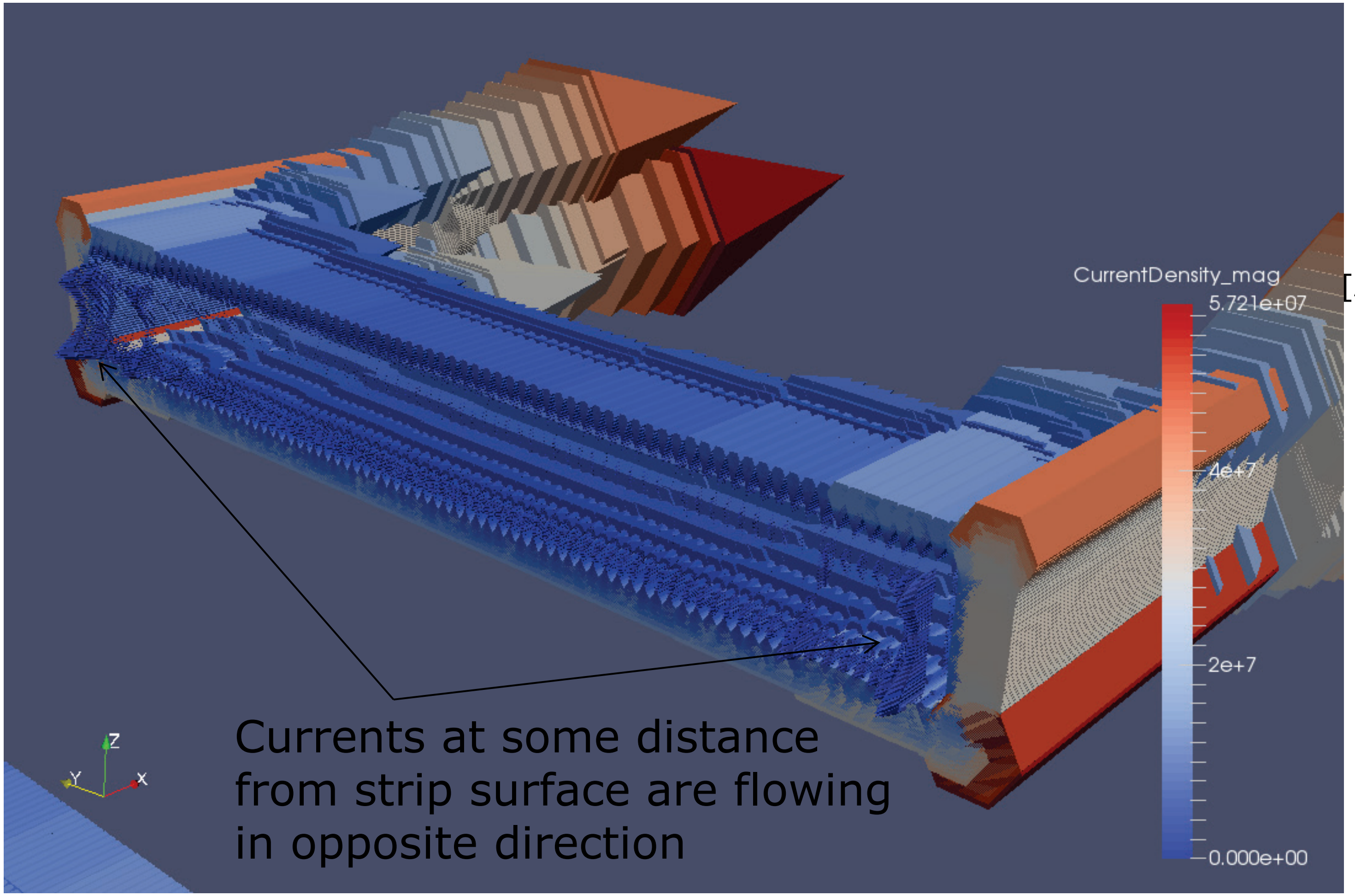
Instantaneous current 1 GHz (t=0)



[A/m^2]

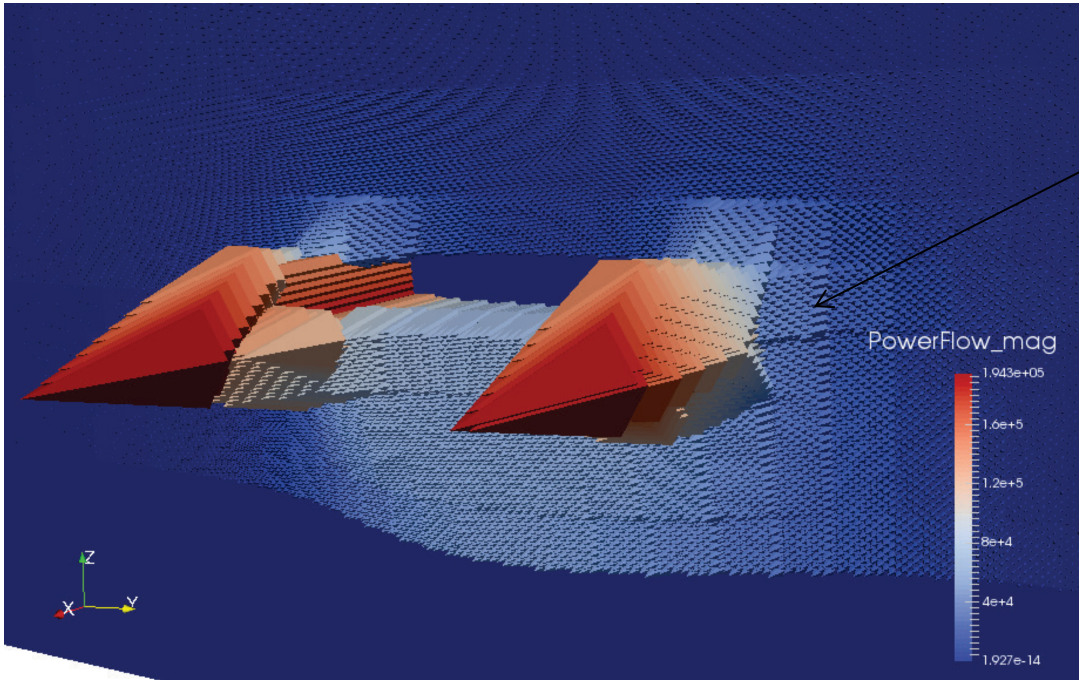
Skin Depth 0.082 mil (conductor thickness is 12.2 of SD)

Instantaneous current 1 GHz - strip

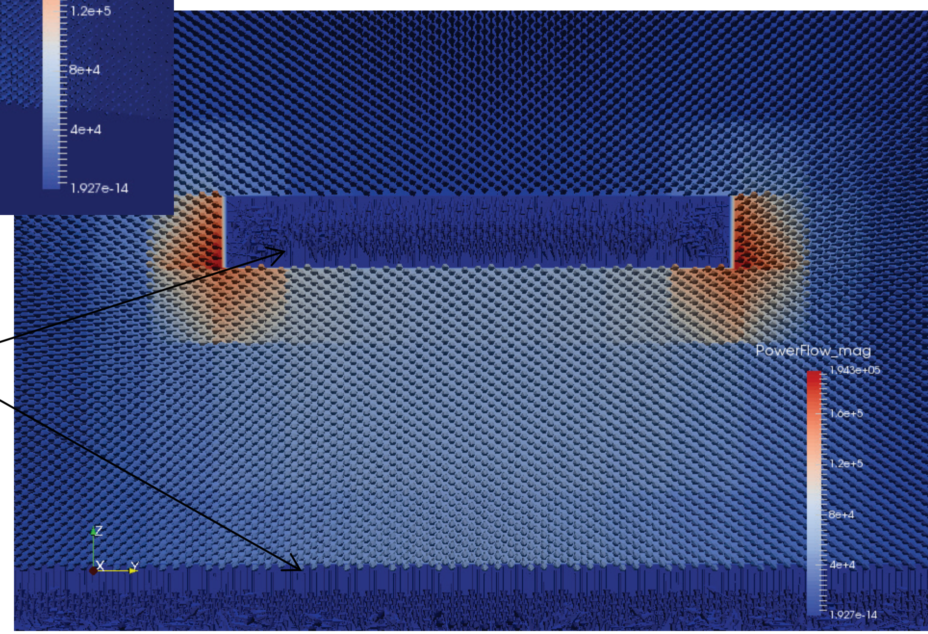


Skin Depth 0.082 mil (conductor thickness is 12.2 of SD)

Peak power flow at 1 GHz [W/m^2]



Poynting vector outside the conductors is directed along the TEM wave propagation direction



Poynting vector in the conductors is perpendicular to the conductor surface and points into the conductor! Though, it is considerably smaller.

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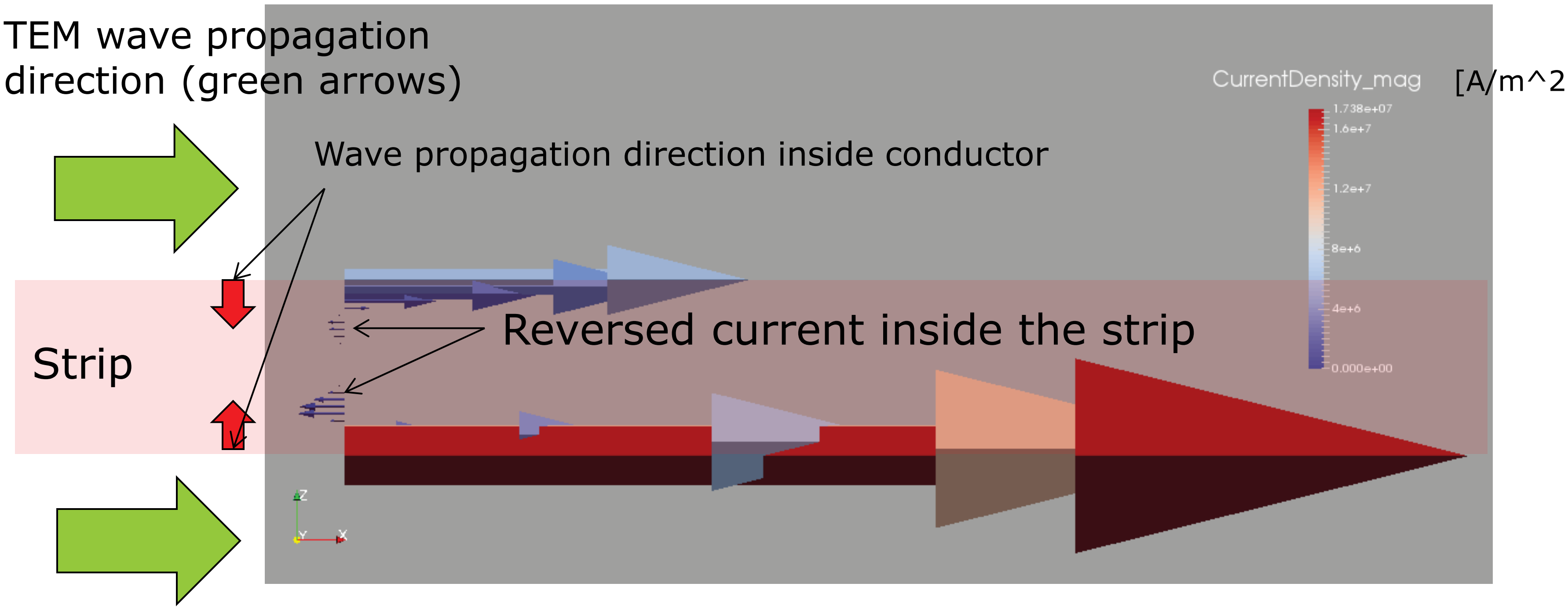
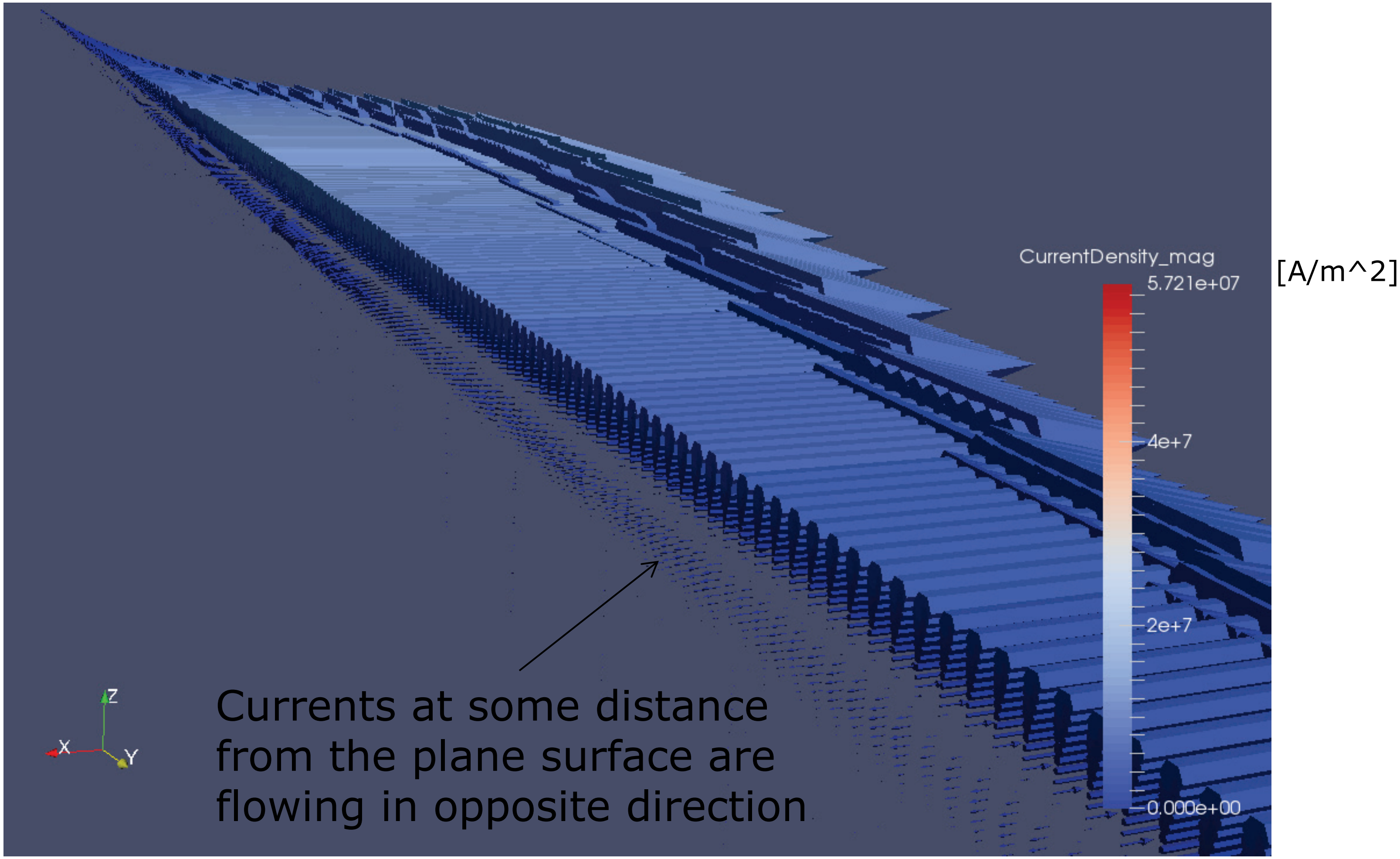
Instantaneous current 1 GHz - strip

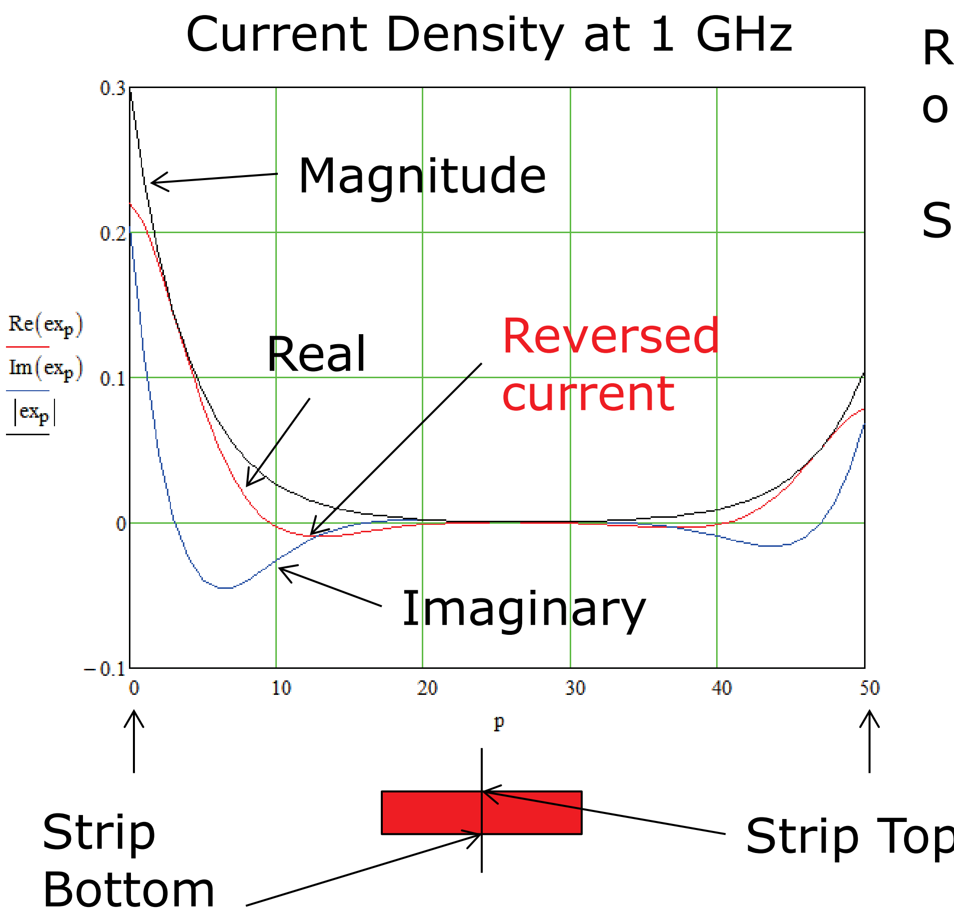


Delay of the wave propagating into the strip explain the current reverse and the internal inductance
Skin Depth 0.082 mil (conductor thickness is 12.2 of SD)

Instantaneous current 1 GHz - plane

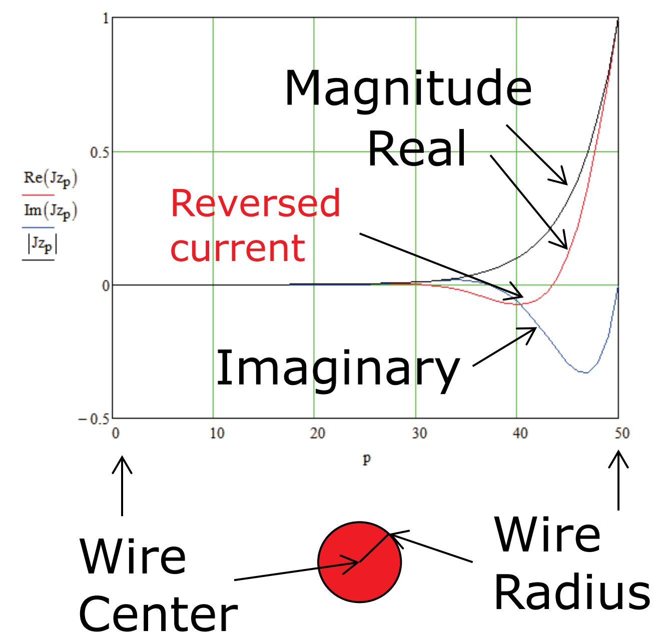


Analytical solution for current density

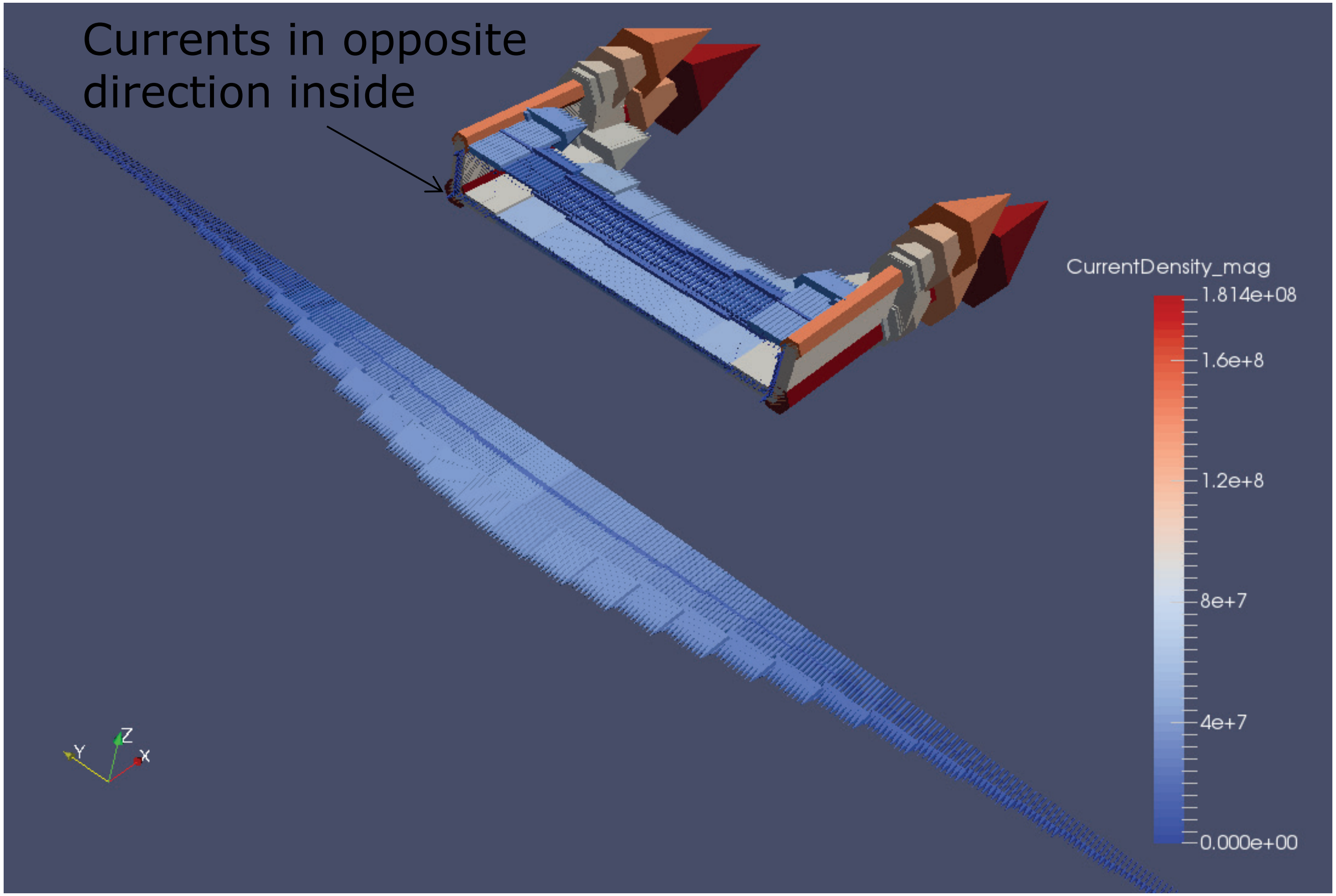


Real negative part means direction opposite to the surface currents!

Similar to the current in round wire



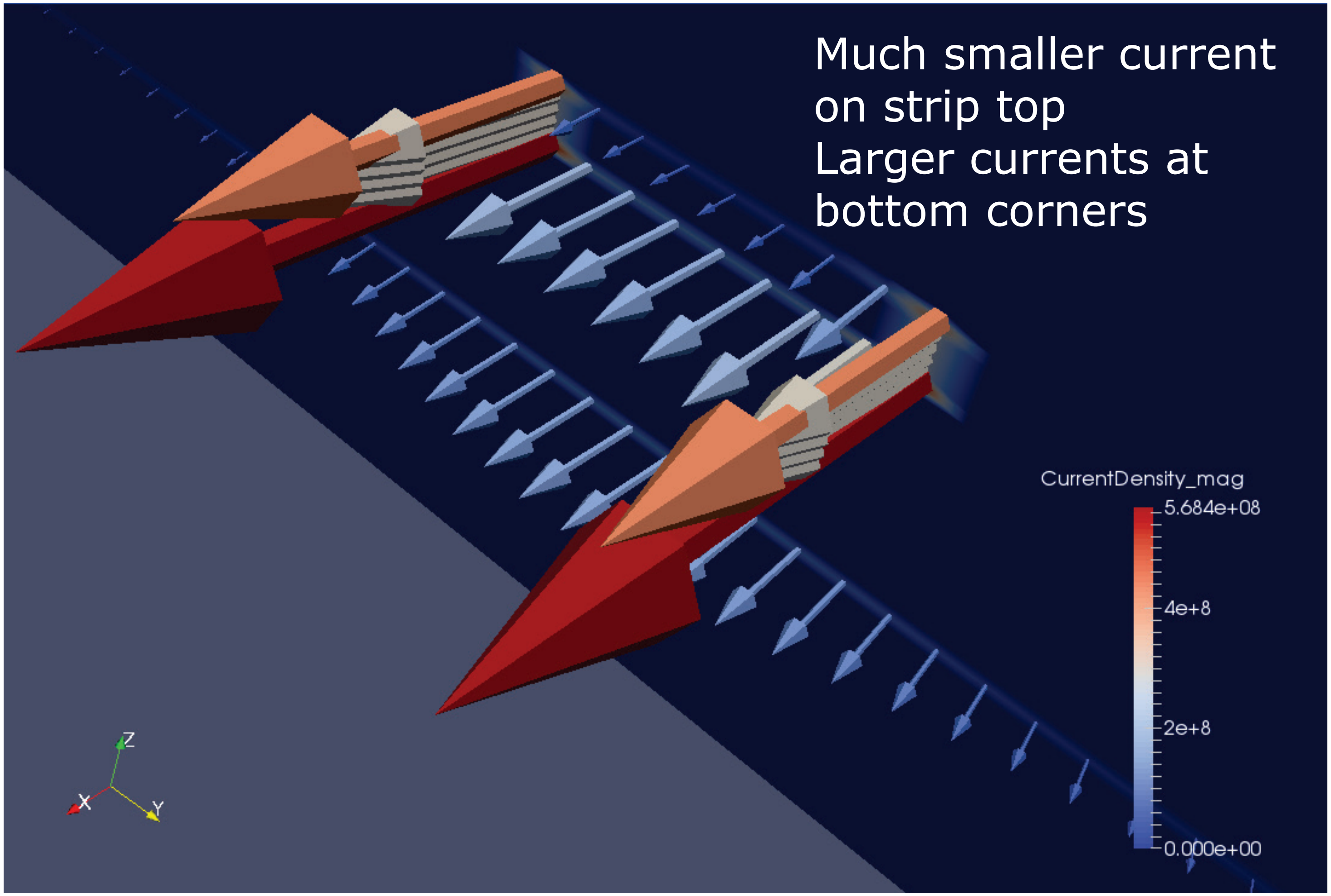
Instantaneous current 10 GHz



[A/m^2]

Skin Depth 0.026 mil (conductor thickness is 38.5 of SD)

Peak conduction currents at 100 GHz

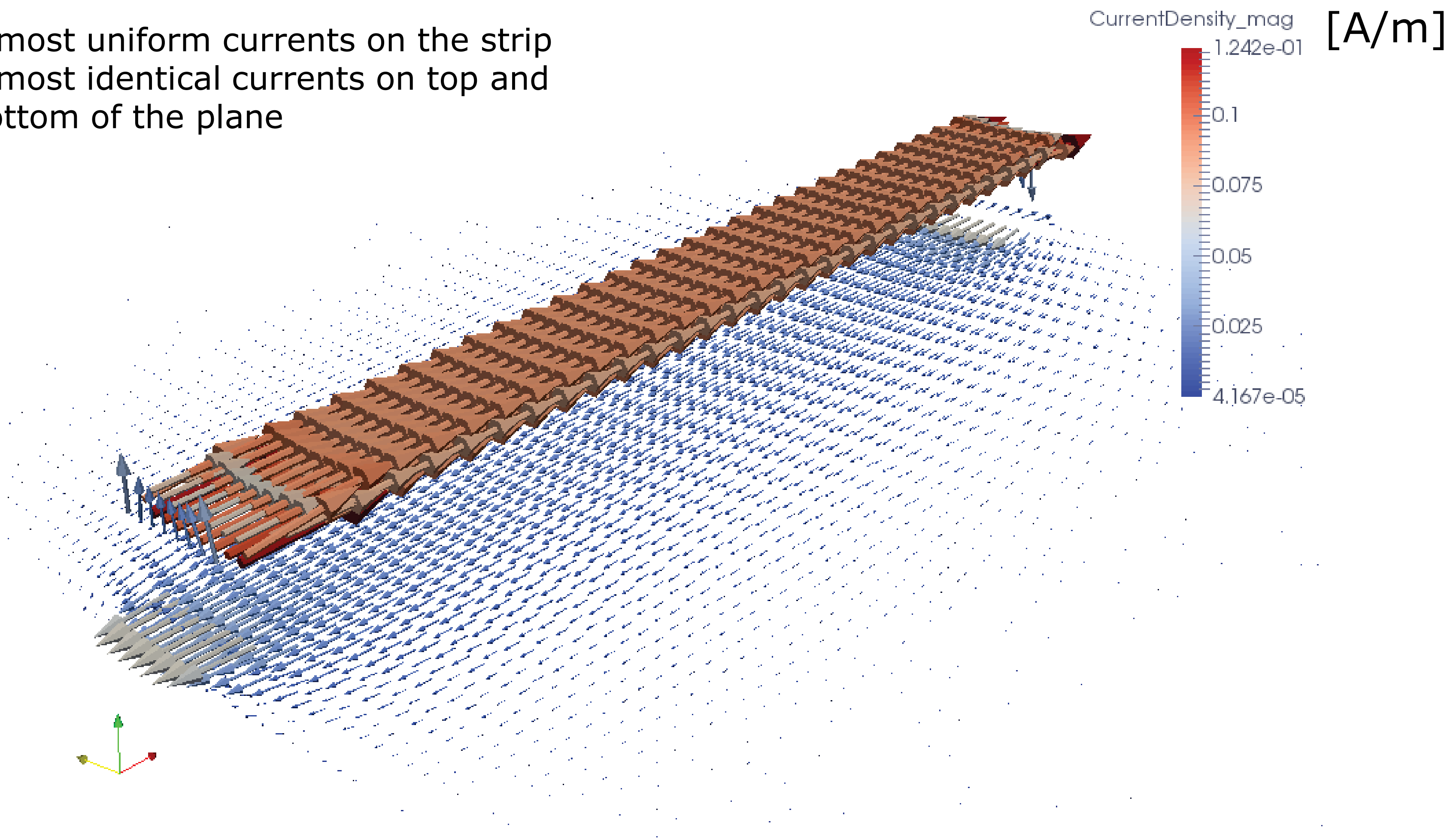


[A/m^2]

Skin Depth 0.0082 mil (conductor thickness is 122 of SD)

Instantaneous surface current 1 MHz

Almost uniform currents on the strip
Almost identical currents on top and bottom of the plane



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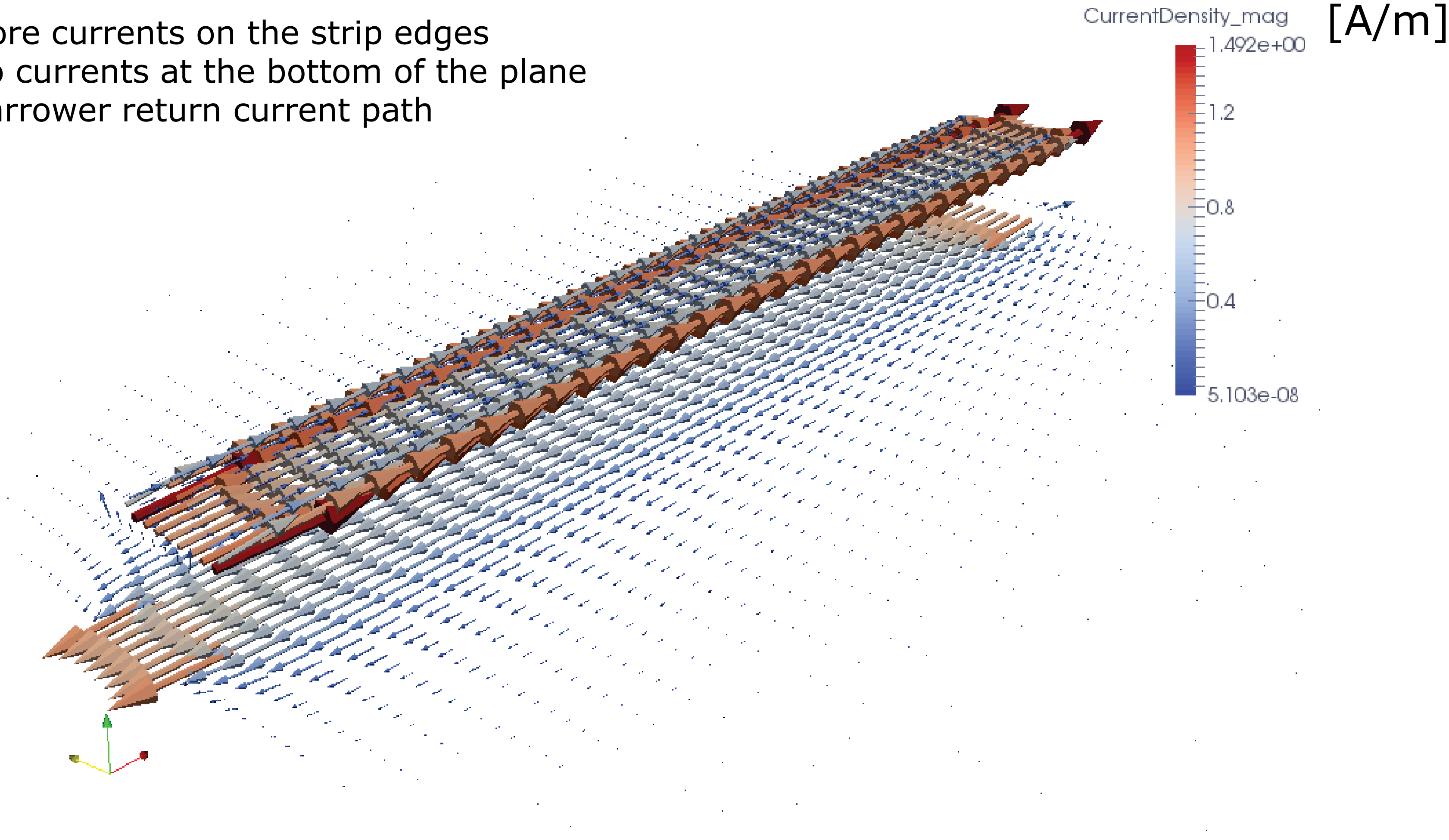
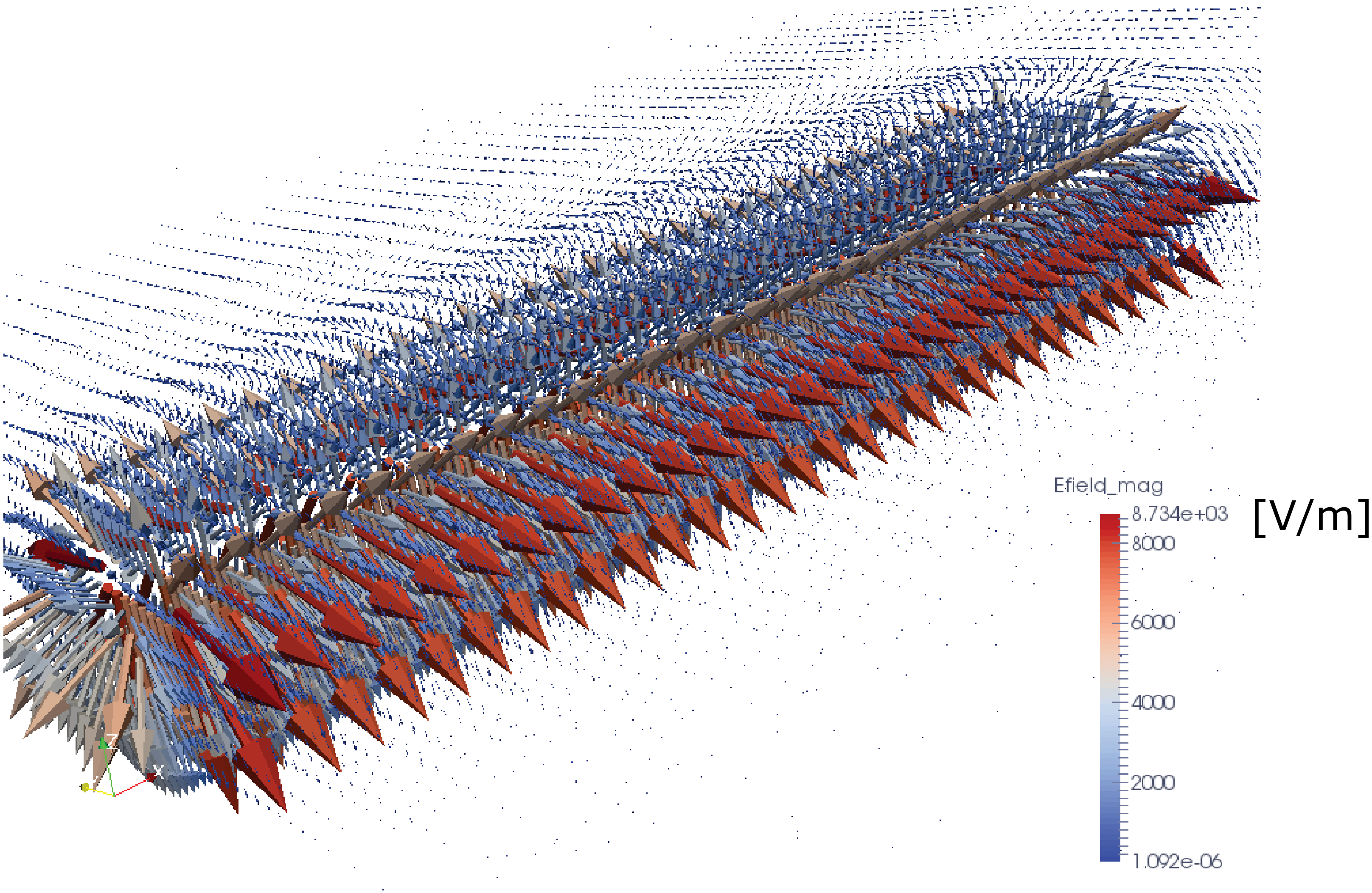
Instantaneous surface current 1 GHz

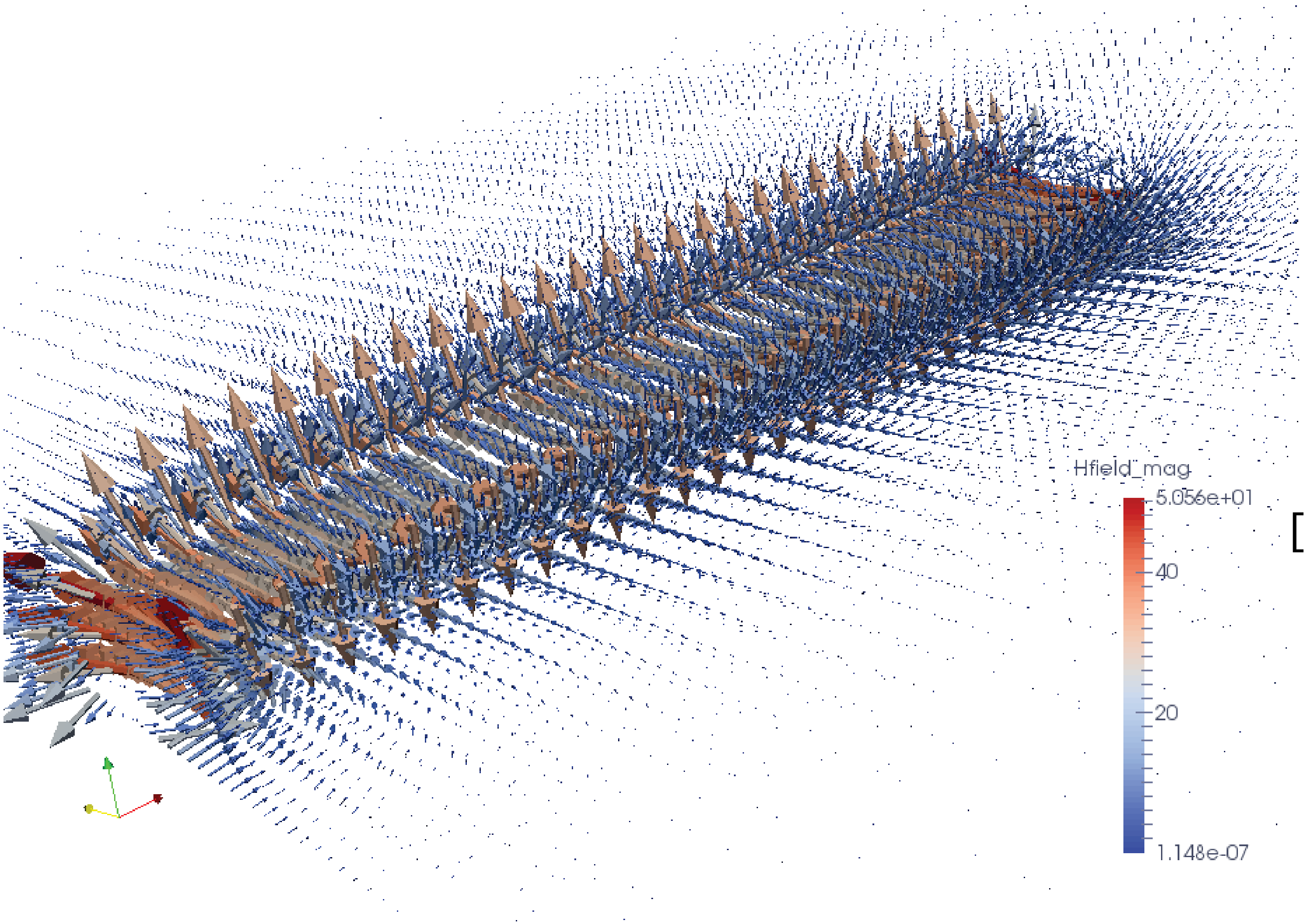
More currents on the strip edges
No currents at the bottom of the plane
Narrower return current path



Instantaneous electric field at 1 GHz

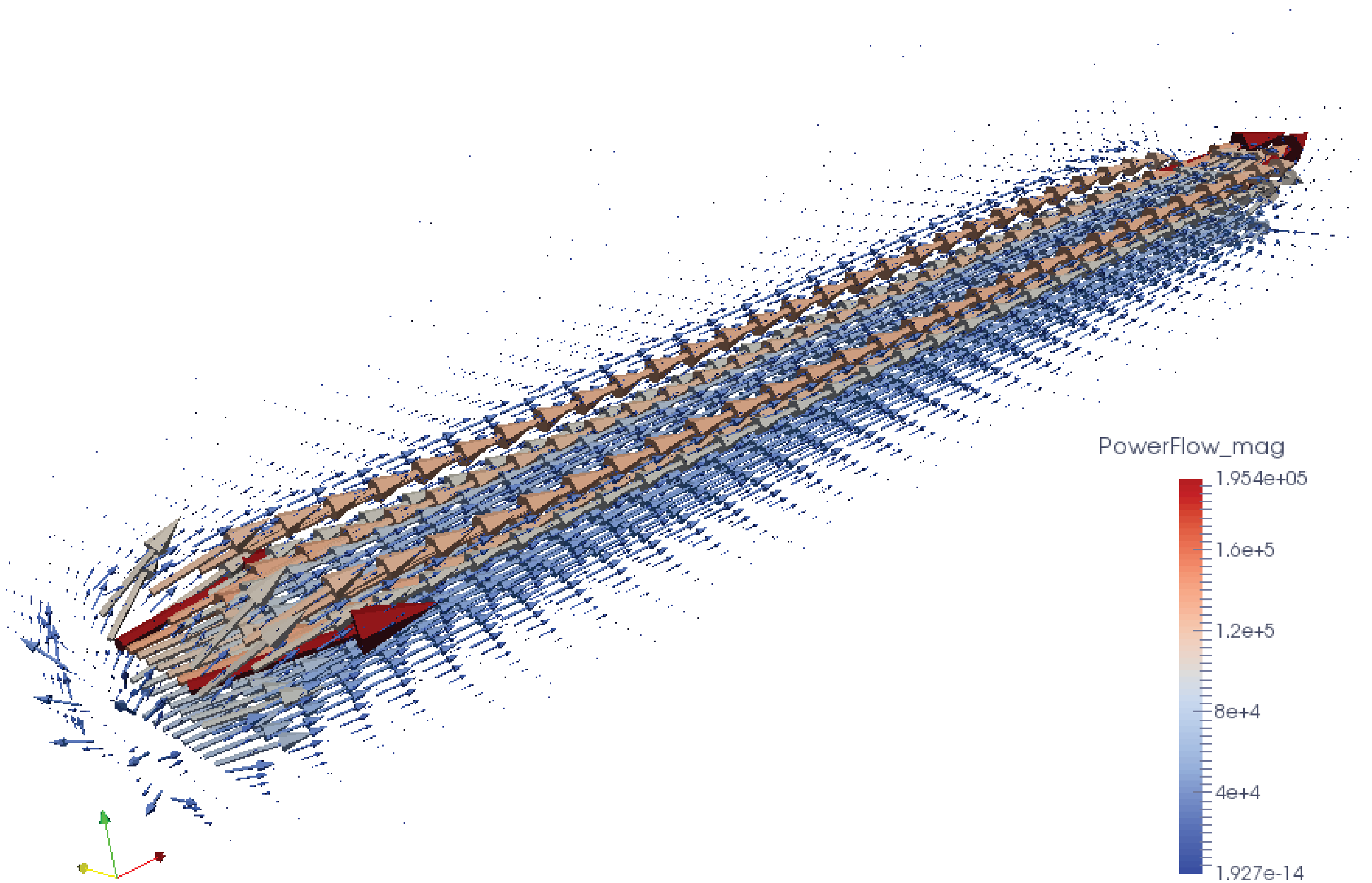


Instantaneous magnetic field at 1 GHz



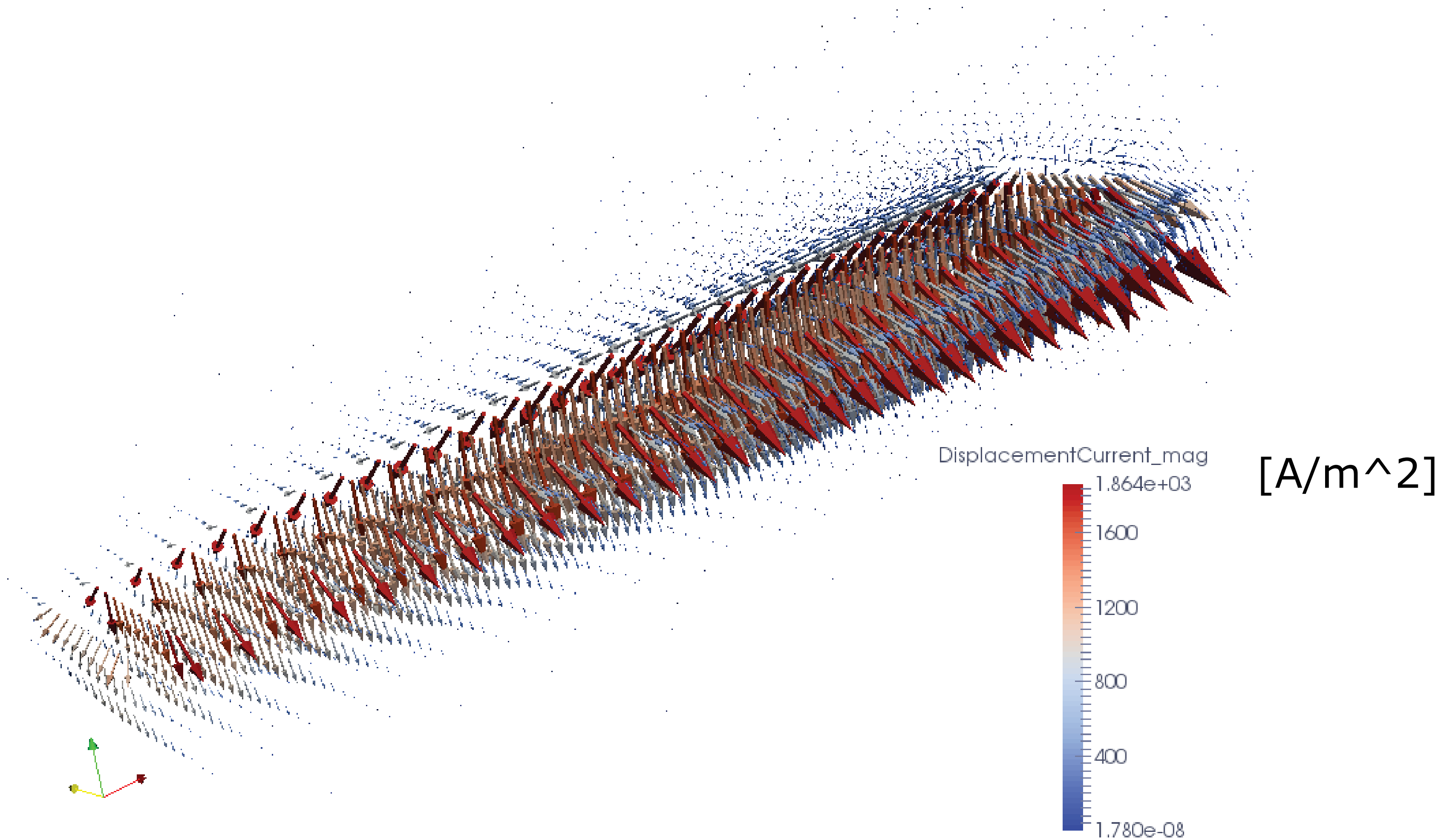
[A/m]

Instantaneous power flow at 1 GHz



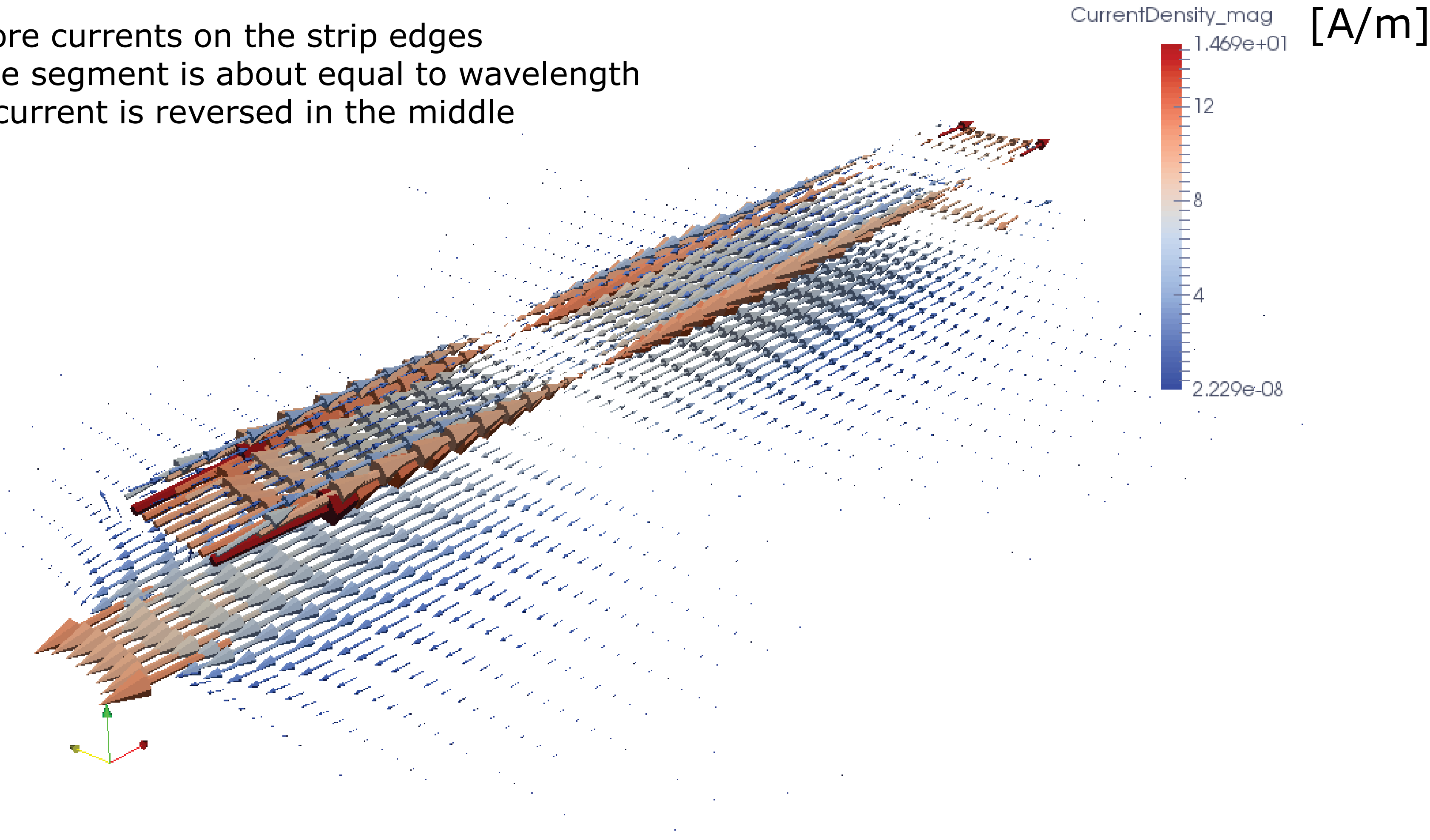
[W/m^2]

Instantaneous displacement current at 1 GHz

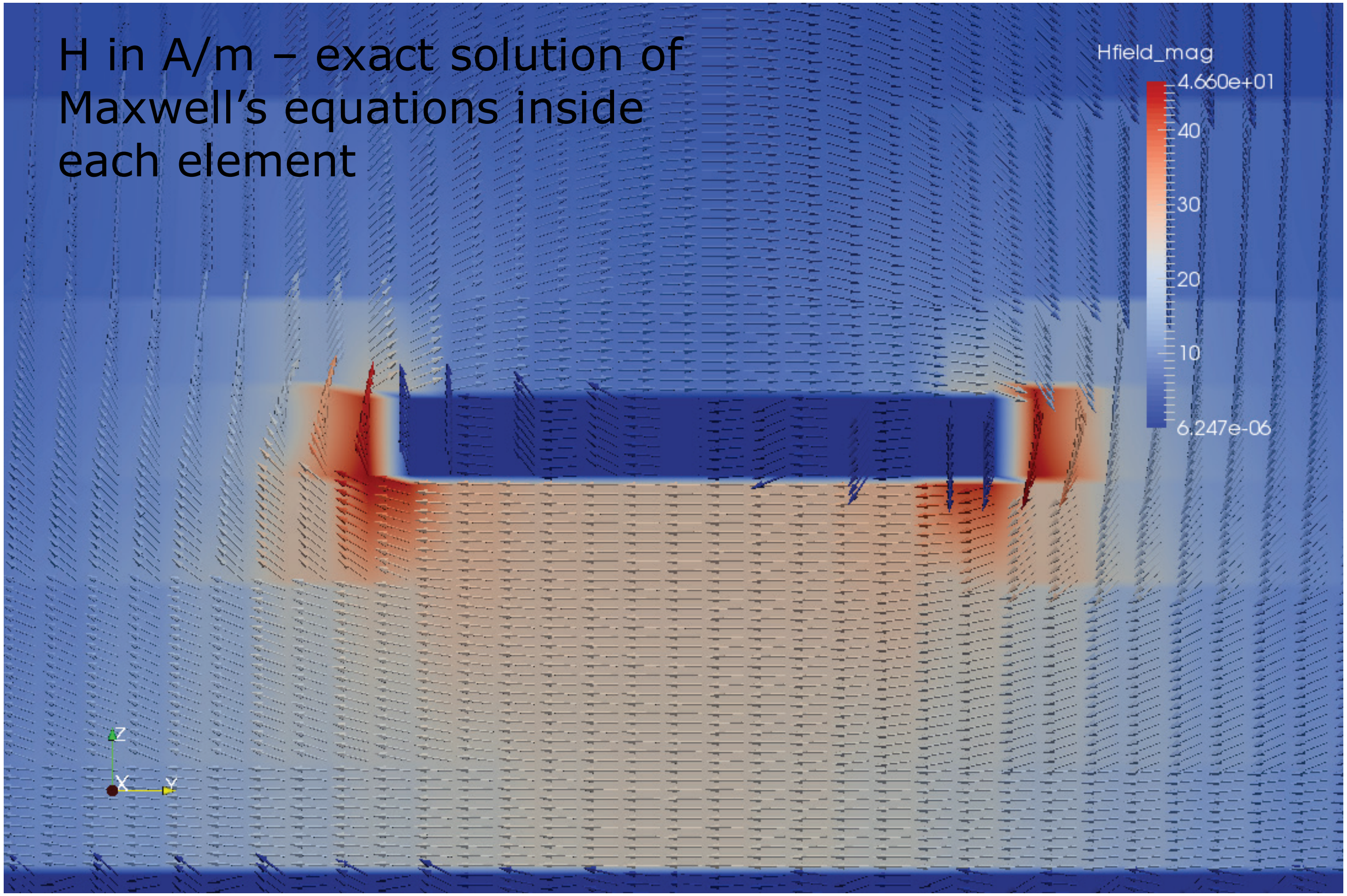


Instantaneous surface current 100 GHz

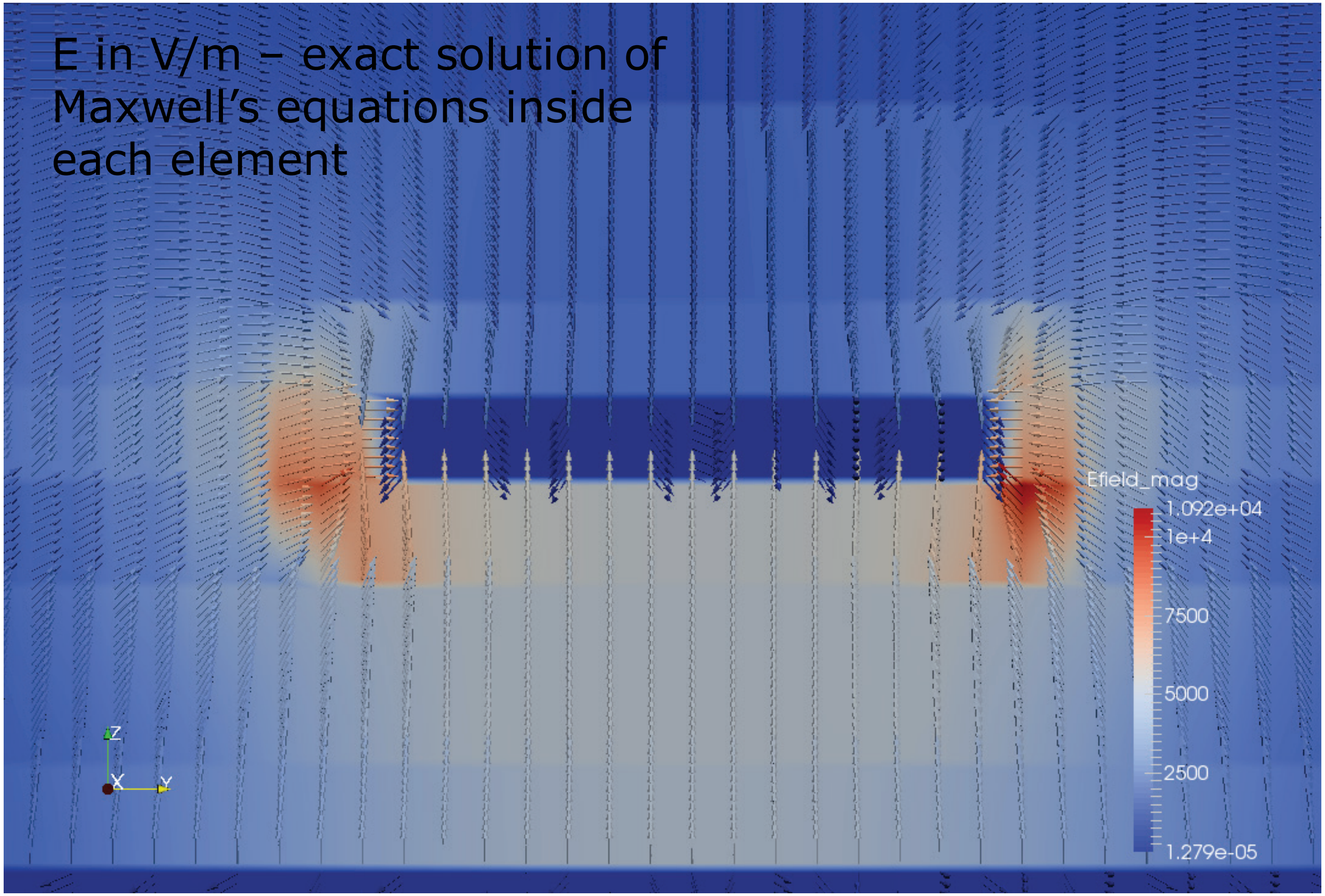
More currents on the strip edges
The segment is about equal to wavelength
– current is reversed in the middle



Instantaneous magnetic field 100 GHz, t=0

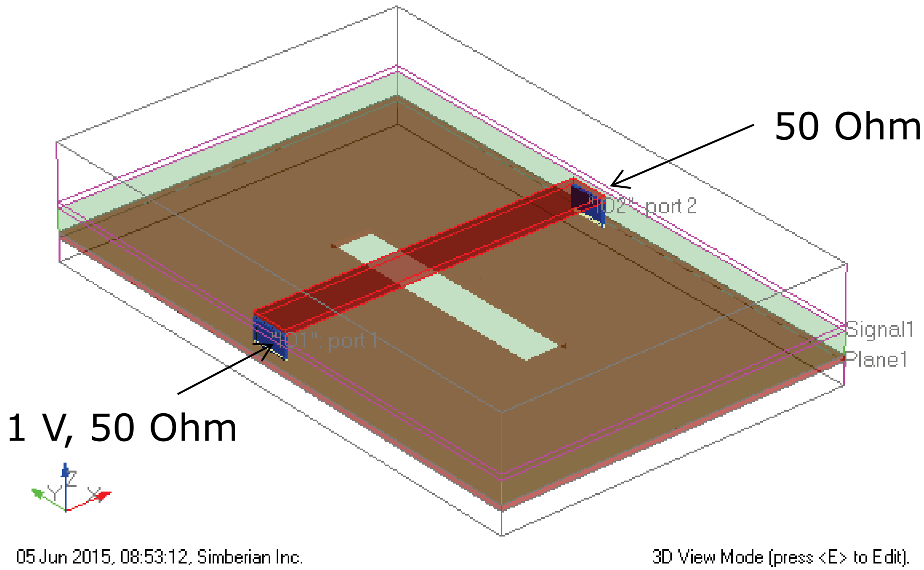


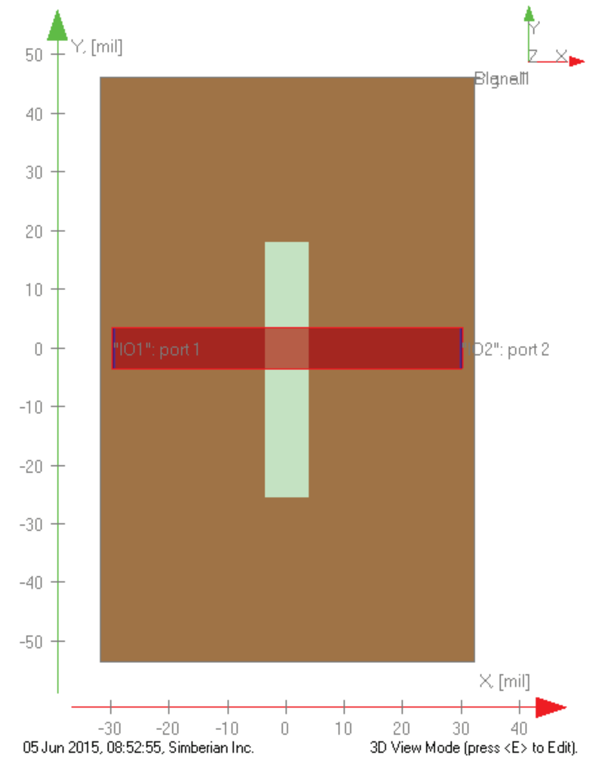
Instantaneous electric field 100 GHz, t=0



What if we cut the plane?

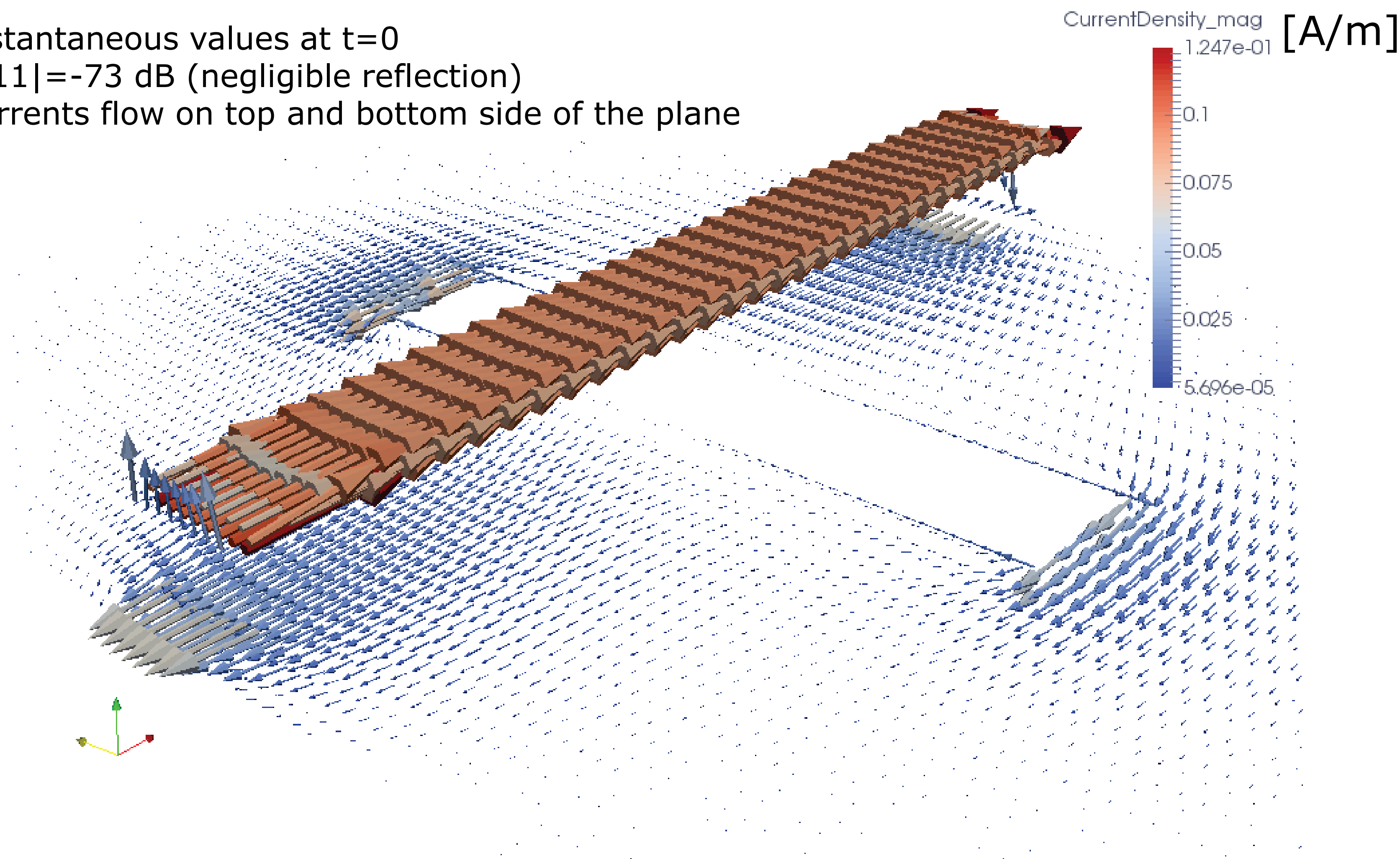
- Same strip line segment, 7.5 mil by 43.5 mil cut in the plane





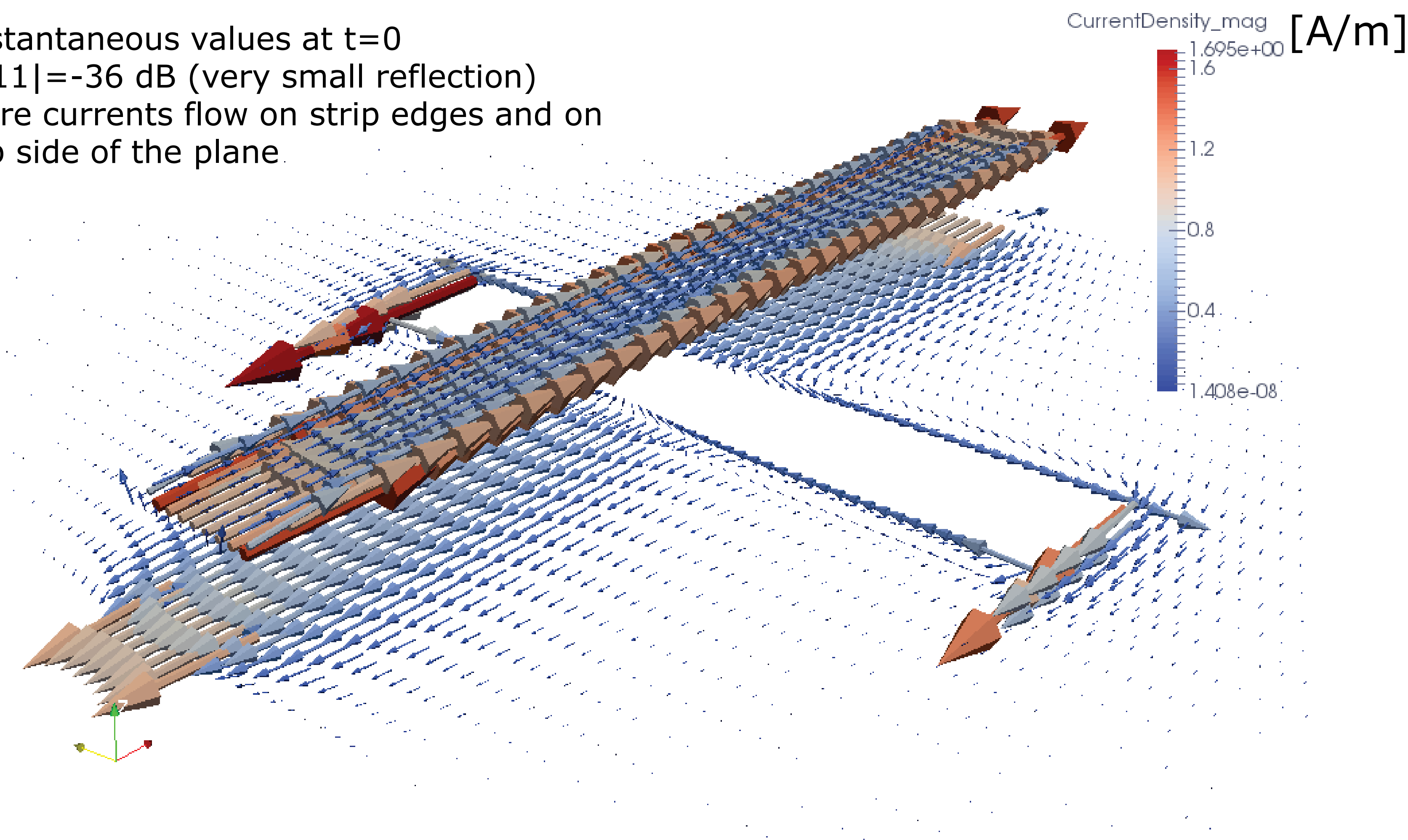
Surface current density at 1 MHz

Instantaneous values at t=0
|S11|=-73 dB (negligible reflection)
Currents flow on top and bottom side of the plane



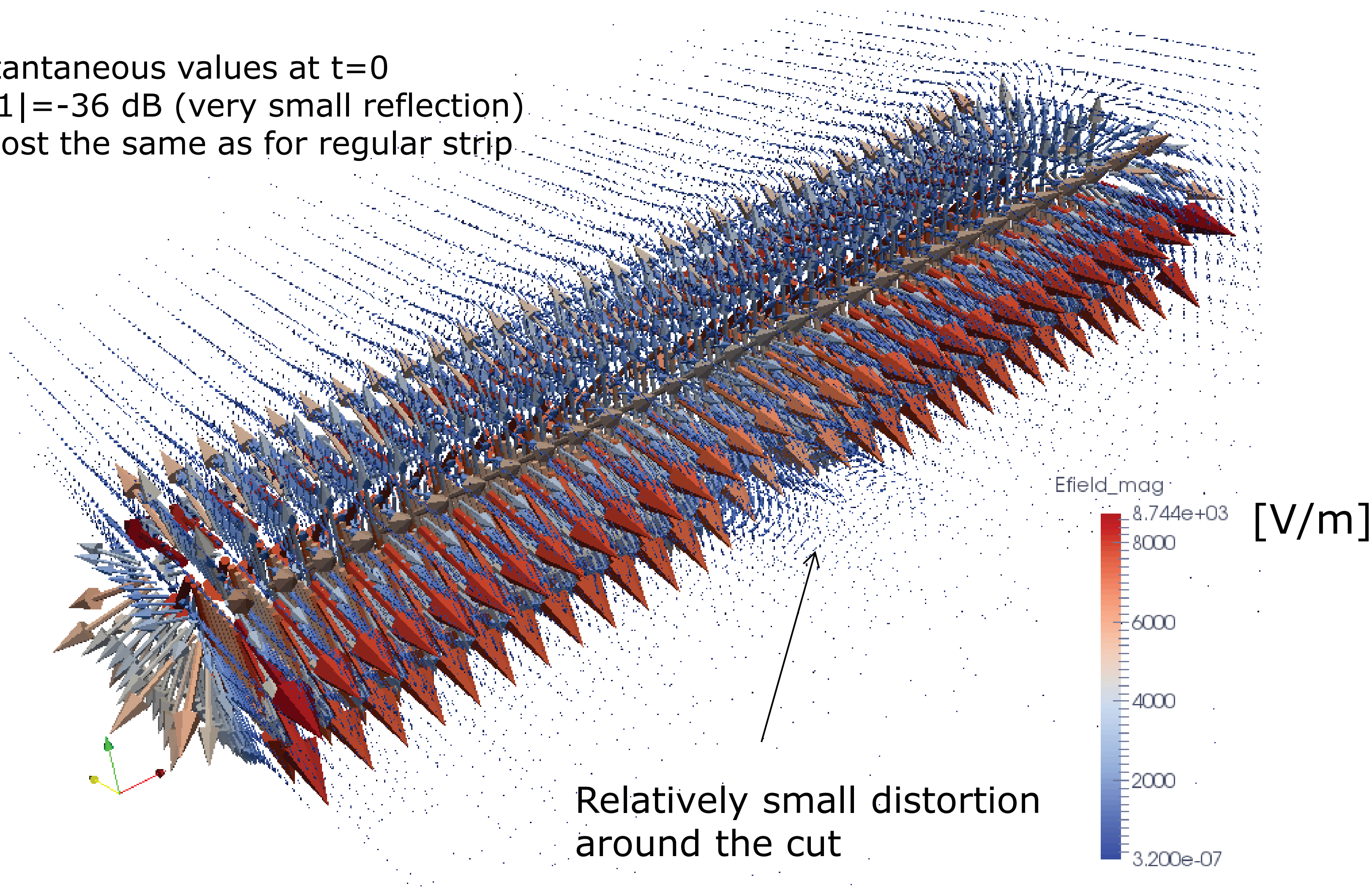
Surface current density at 1 GHz

Instantaneous values at t=0
|S11|=-36 dB (very small reflection)
More currents flow on strip edges and on top side of the plane



Electric field at 1 GHz

Instantaneous values at t=0
|S11|=-36 dB (very small reflection)
Almost the same as for regular strip



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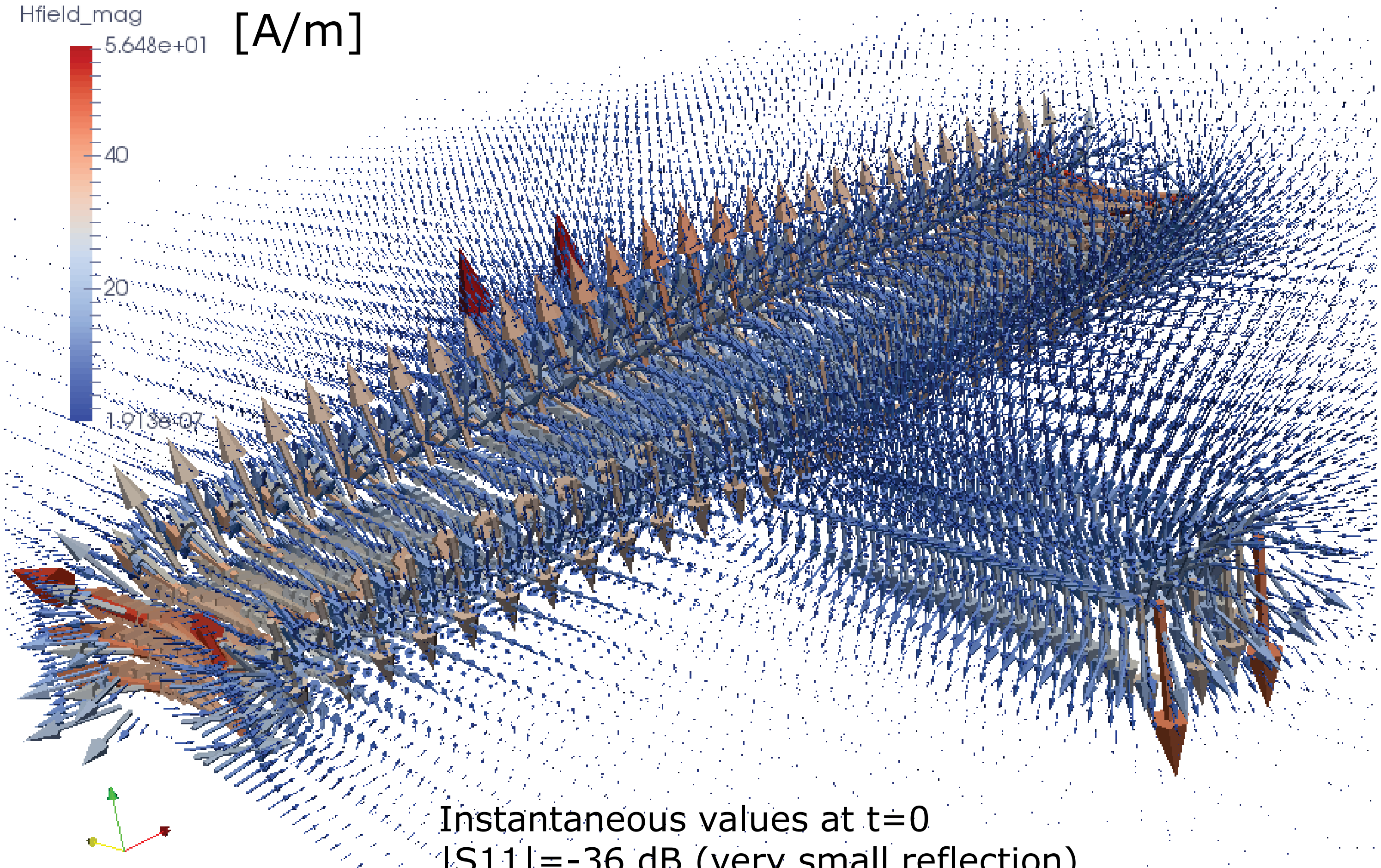
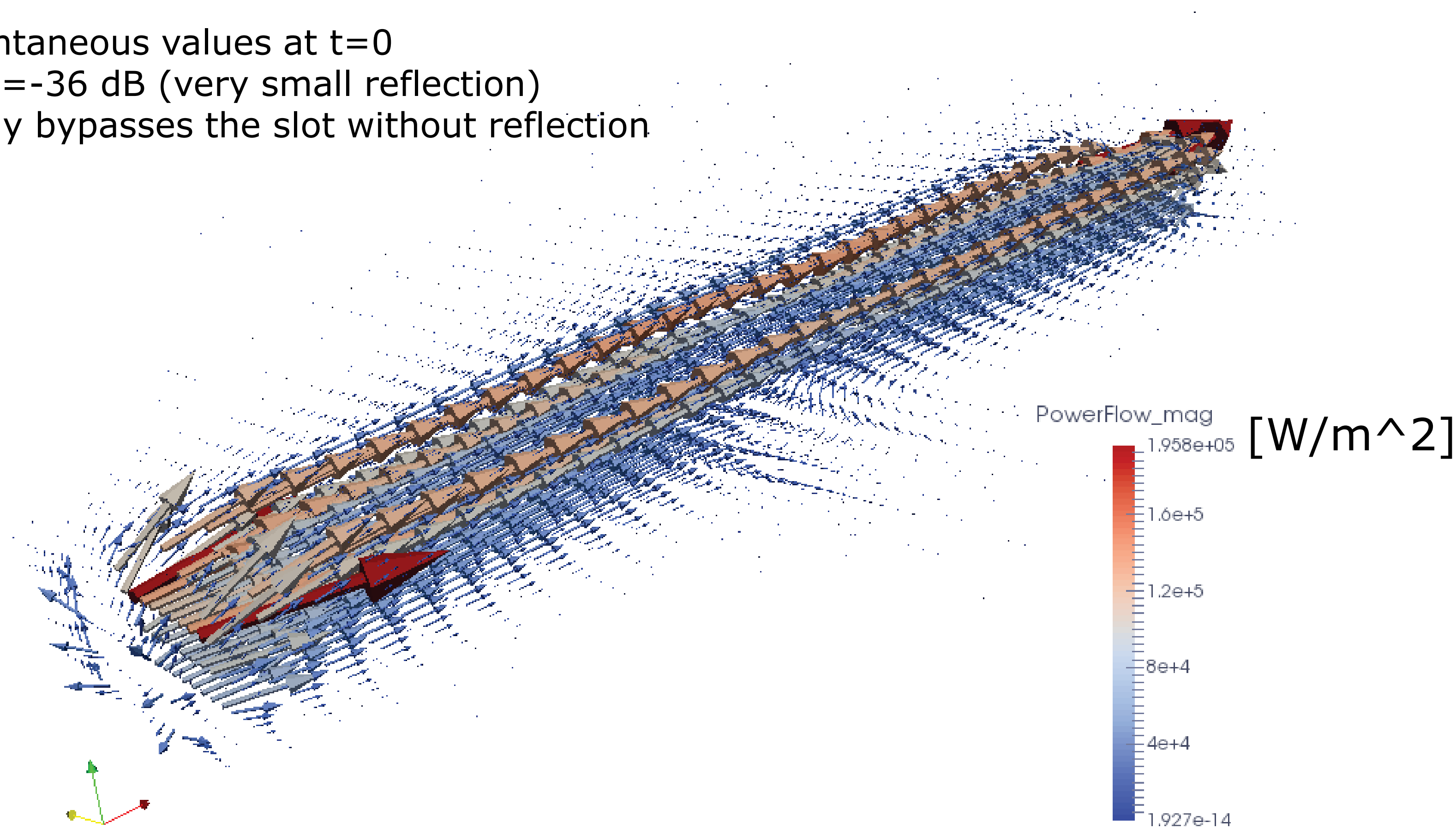
Magnetic field at 1 GHz



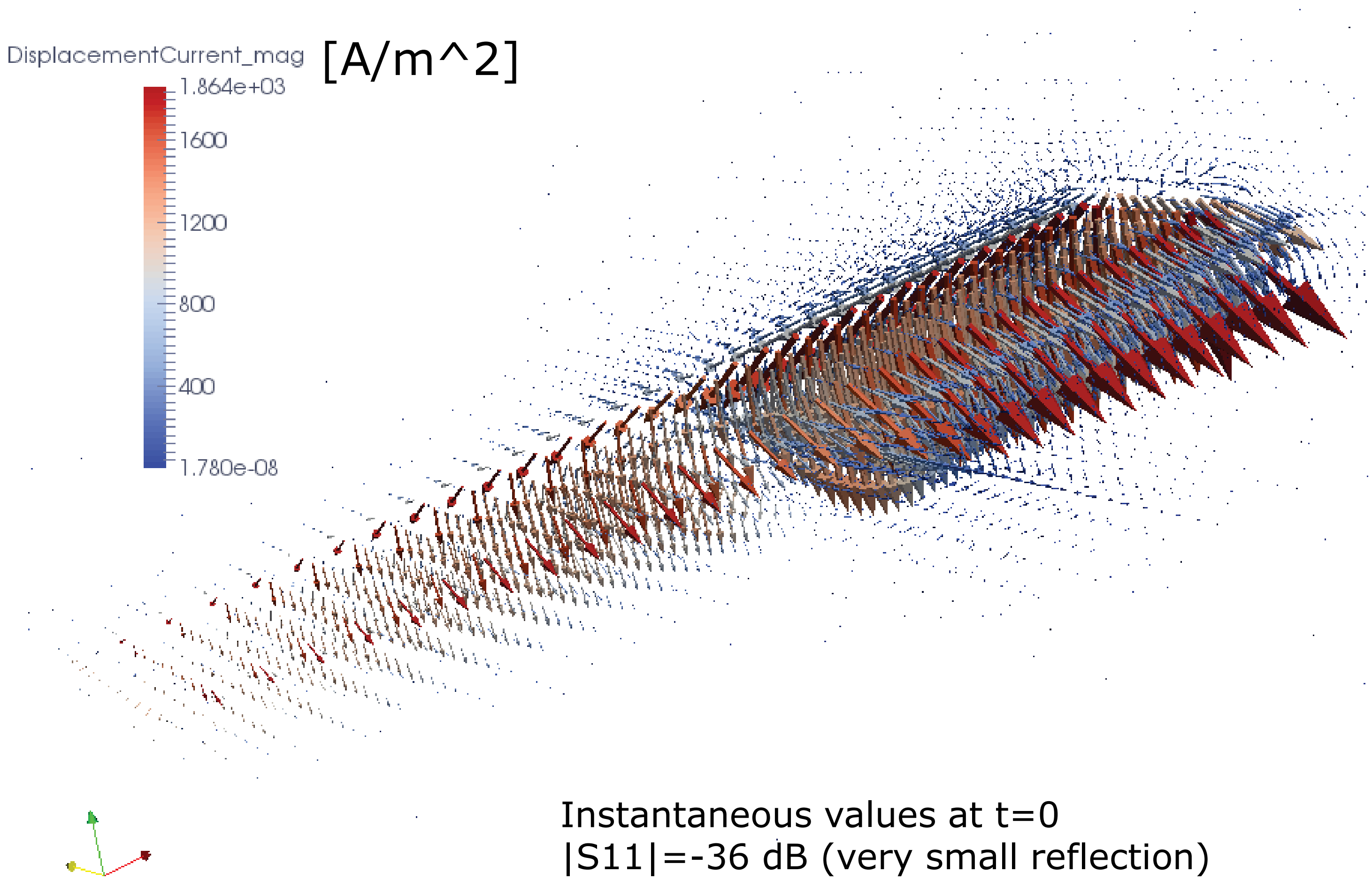
Instantaneous values at t=0
|S11|=-36 dB (very small reflection)
H is getting through the slot

Power flow at 1 GHz

Instantaneous values at t=0
|S11|=-36 dB (very small reflection)
Energy bypasses the slot without reflection



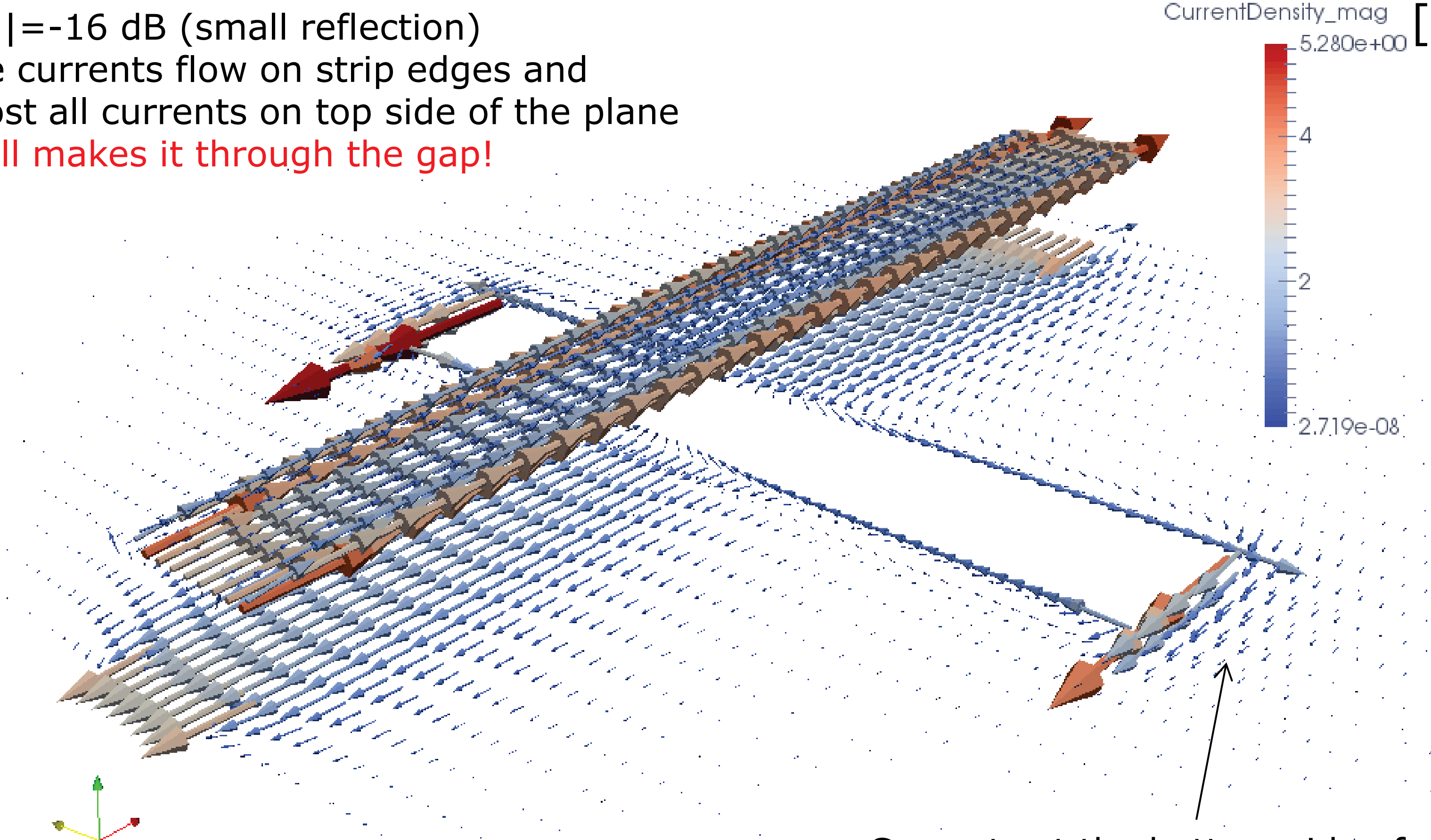
Displacement current at 1 GHz



Instantaneous values at t=0
|S11|=-36 dB (very small reflection)
Much larger on the other side of the slot

Surface current density at 10 GHz

Instantaneous values at t=0
|S11|=-16 dB (small reflection)
More currents flow on strip edges and almost all currents on top side of the plane
It still makes it through the gap!

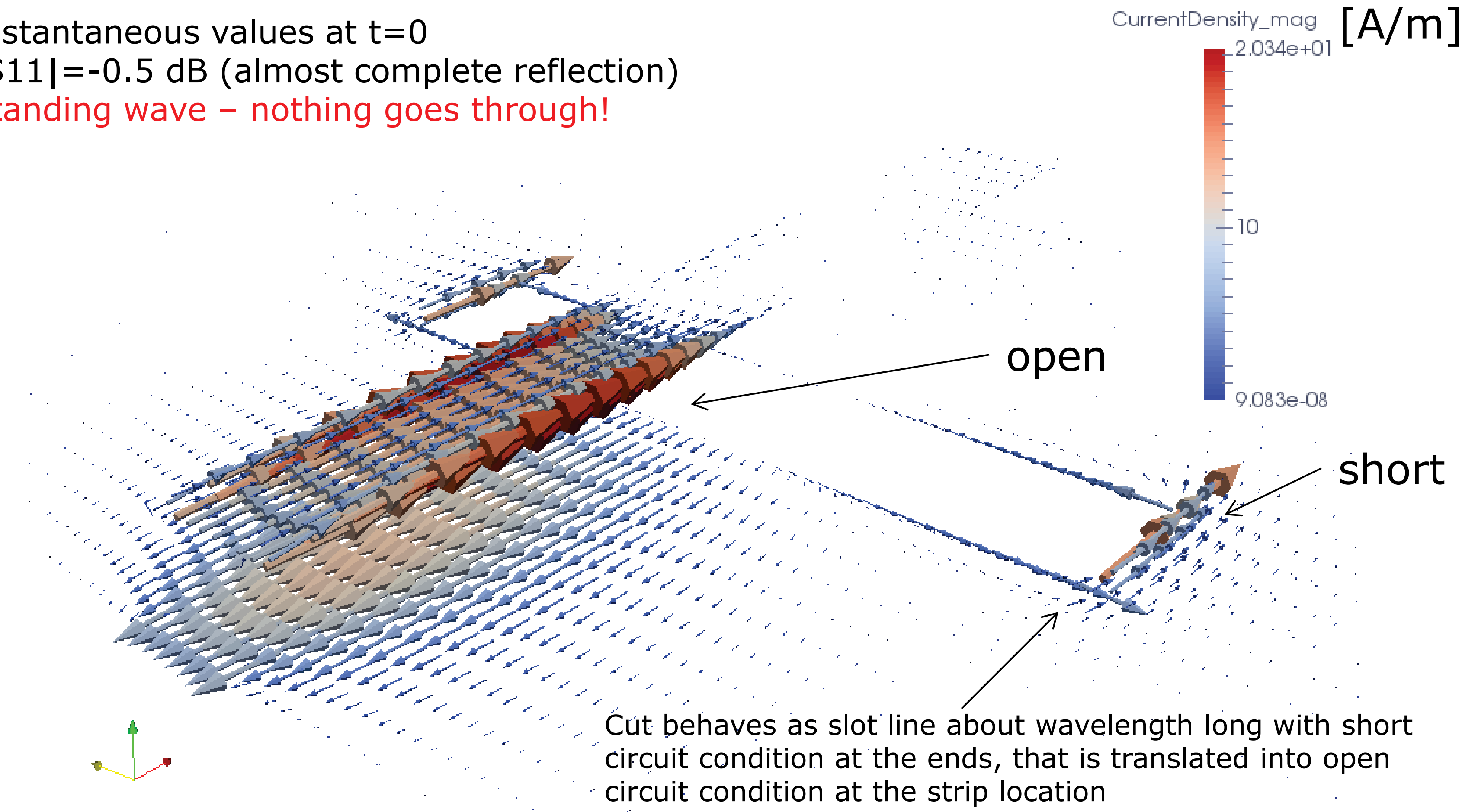


[A/m]

Currents at the bottom side of planes only in the gap bypass area

Surface current density at 100 GHz

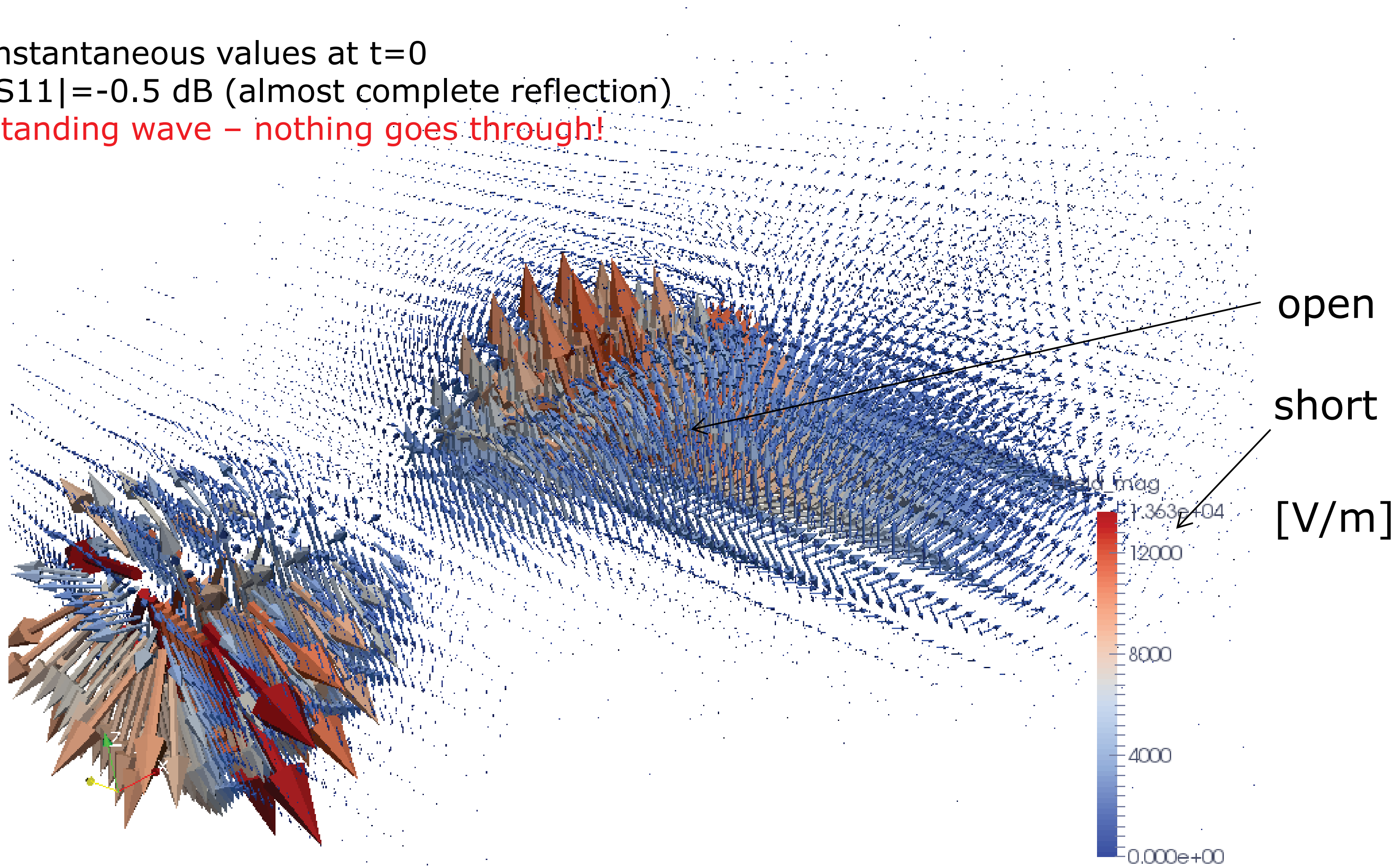
Instantaneous values at t=0
|S11|=-0.5 dB (almost complete reflection)
Standing wave – nothing goes through!



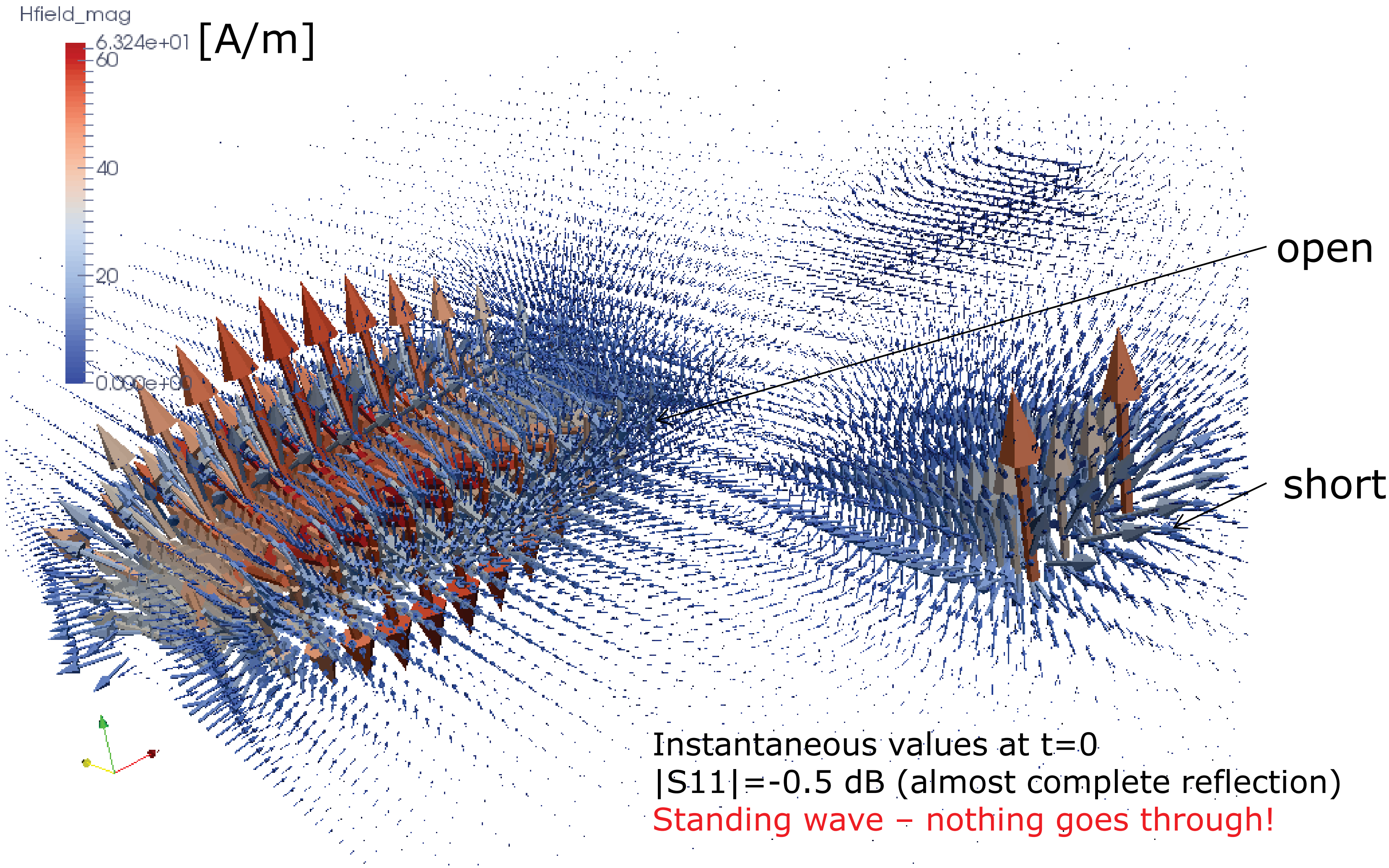
Cut behaves as slot line about wavelength long with short circuit condition at the ends, that is translated into open circuit condition at the strip location
See more at H.J. Liaw, H. Merkelo, Signal integrity issues at split ground and power planes, ECTC 1996, p. 752-755.

Electric field at 100 GHz

Instantaneous values at t=0
|S11|=-0.5 dB (almost complete reflection)
Standing wave – nothing goes through!



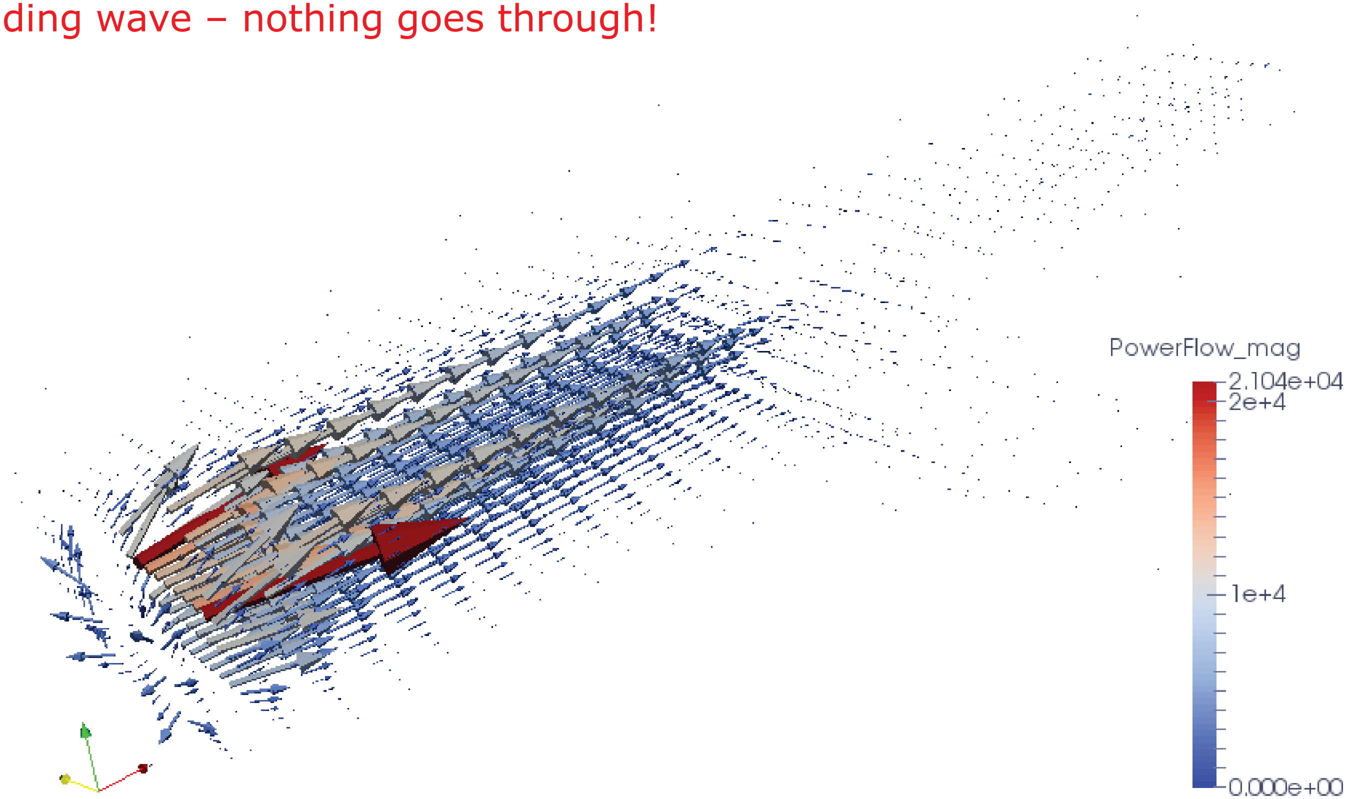
Magnetic field at 100 GHz



Instantaneous values at t=0
|S11|=-0.5 dB (almost complete reflection)
Standing wave – nothing goes through!

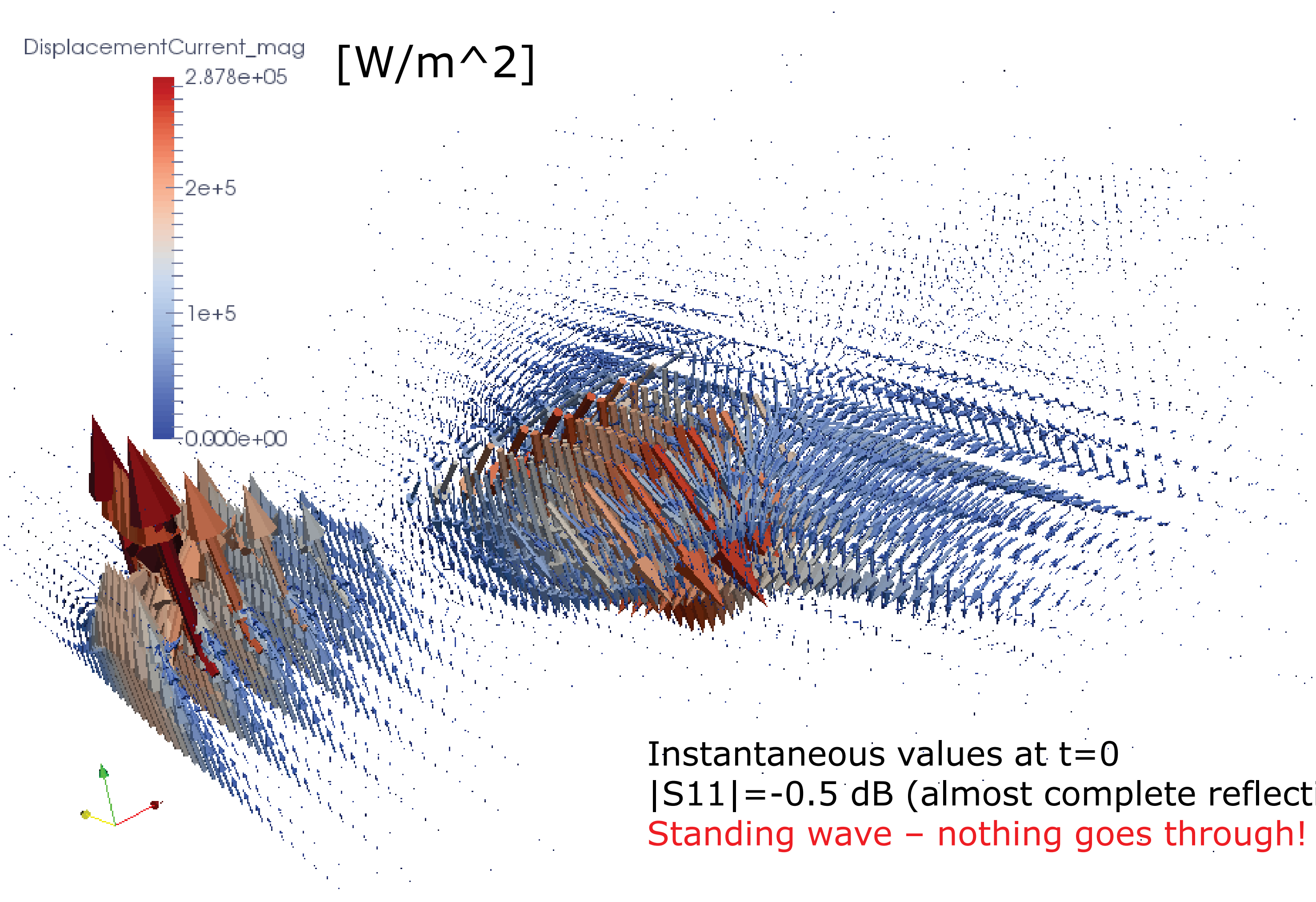
Power flow at 100 GHz

Instantaneous values at t=0
|S11|=-0.5 dB (almost complete reflection)
Standing wave – nothing goes through!



[W/m^2]

Displacement current at 100 GHz



[W/m^2]

Instantaneous values at t=0
|S11|=-0.5 dB (almost complete reflection)
Standing wave – nothing goes through!

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Observations

- Current and field distribution of microstrip line segment is analyzed from 1 KHz to 100 GHz with TFE-elements on the same hexahedral mesh in one frequency sweep
- Different stages of current distribution are observed
  - Uniform at very low frequency
  - Current crowding in the reference plane at low frequencies
  - Current crowding at the surface and edges at higher frequencies
- At high frequencies:
  - The largest current density is at the strip edges (theoretically infinite value, complicates estimates of conductive losses)
  - Currents observed at the bottom surface of strip are over 2 times larger than on the top surface in the analyzed case
  - Currents have reversed direction at about 2 skin depths

Simberian Inc.

- Mission
  - Build accurate, easy-to-use, and cost-effective electromagnetic software for high-speed electronic design automation
- Incorporated in USA on February 28, 2006
  - Founder and President Yuriy Shlepnev
    - PhD in in computational electromagnetics
    - 25-years experience in building electromagnetic software
- Development in Las Vegas, USA, St. Petersburg and Voronezh Russia
- Location and contacts
  - Corporate office: 3030 S Torrey Pines Dr., Las Vegas, NV 89146, USA Tel/Fax +1-702-876-2882, skype *simberian*
  - Web: www.simberian.com
  - Support knowledge base www.kb.simberian.com