Advanced Simulation Summit

cadmicro

DASSAULT SYSTEMES

CST STUDIO SUITE

Talal Azfar

Nov 17 2022

cadmicro

DASSAULT SYSTEMES

Agenda

Introduction to CST Studio Suite

3D Experience Role: Electromagnetics Engineer

Applications of CST

Project Templates

High Frequency Design

Antenna & Microwave Device Examples

Multi-Physics Simulations

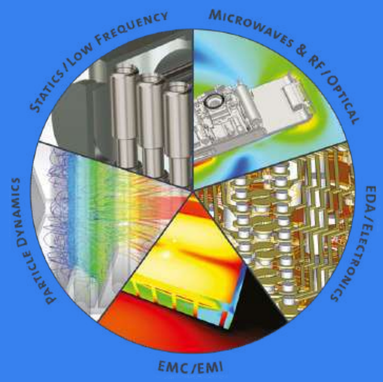
Low Frequency Design

Permanent Magnet Synchronous Motor Example

Q&A

cadmicro

Why Do I Need Electro-Magnetic Simulation ?



1. Do I really need a Simulation Software?

2. How will it help me in my Prototype Development ?

3. Will it be cost effective to have such a Simulation Software ?

4. Can it really simulate what I need ?

Example: Design & Test a Patch Antenna

cadmicro

Cost of Design & Test of a Prototype Patch Antenna?

1. First Design of Antenna. 3-4 Sample Designs: 1 week of design engineer time.

2. Send these samples for manufacturing: Turn around 1 week.

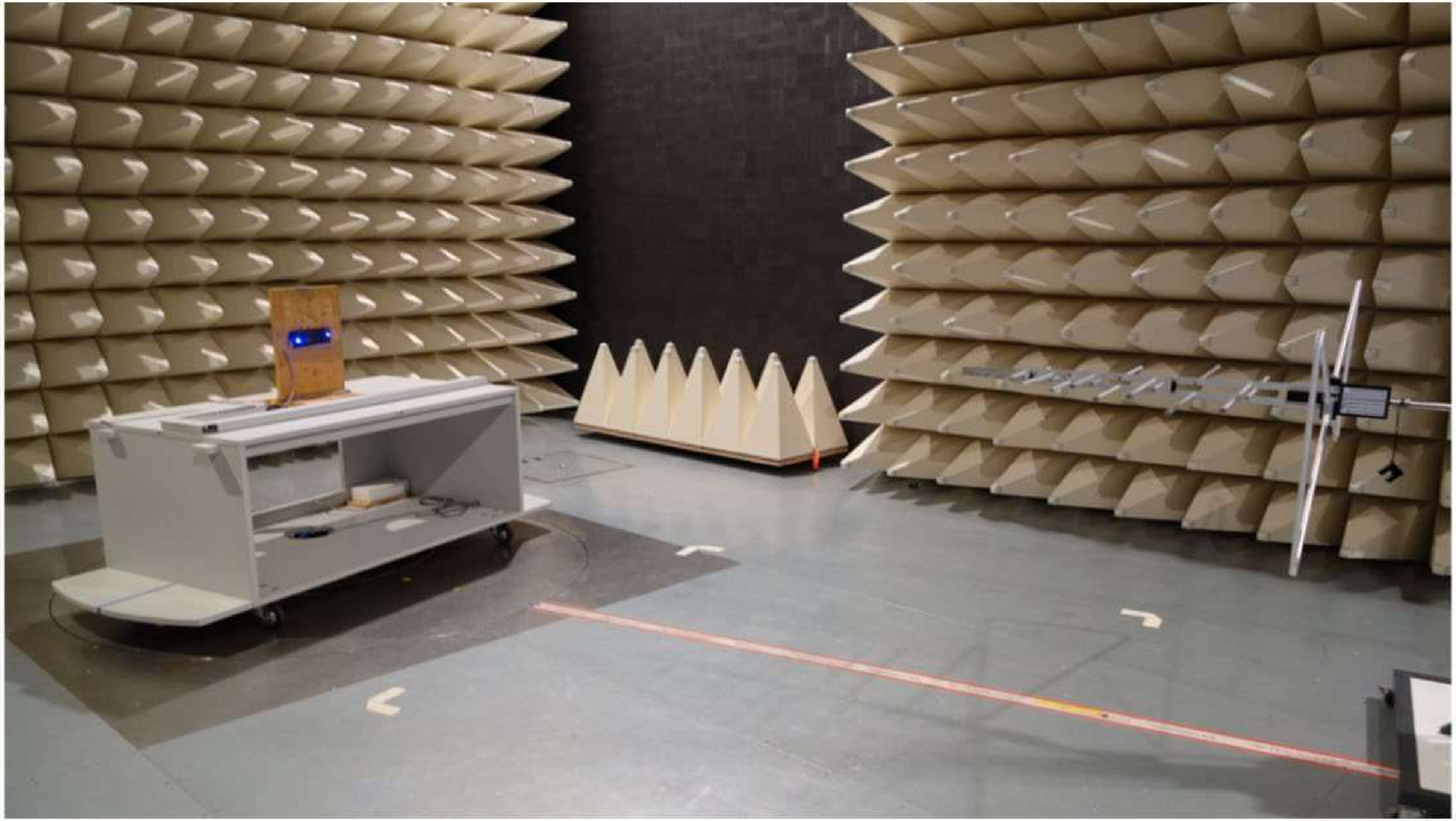
3. Test and Result Analysis of each sample. 1 week of 2-3 microwave engineer's time.

4. Total Cost ~ 10 - 20 K USD

cadmicro

Cost of Design & Test of a Prototype Patch Antenna?

Radiated Emissions Test Setup for Electromagnetic Compatibility (EMC)



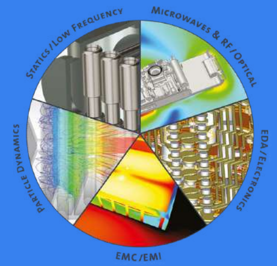
Test Equipment for Antenna Testing

- Isolated Room with no EM feedbacks or interference.
- Network Analyzer
- Signal Analyzer
- Spectrum Analyzer
- High Bandwidth Oscilloscopes
- Microwave connectors, cables, probes etc.
- Total Cost ~ 100 K USD

cadmicro

Cost of Design & Test of a Prototype Patch Antenna?

- Second Round of Design based on first results. 1-2 week of Design Engineer's time.
- Second Batch of Test antennas to manufacture: 1 week
- Second Round of Testing: 1-2 weeks
- Final Design, manufacturing and testing 1-2 week.



cadmicro

Cost of Design & Test of a Prototype Patch Antenna?

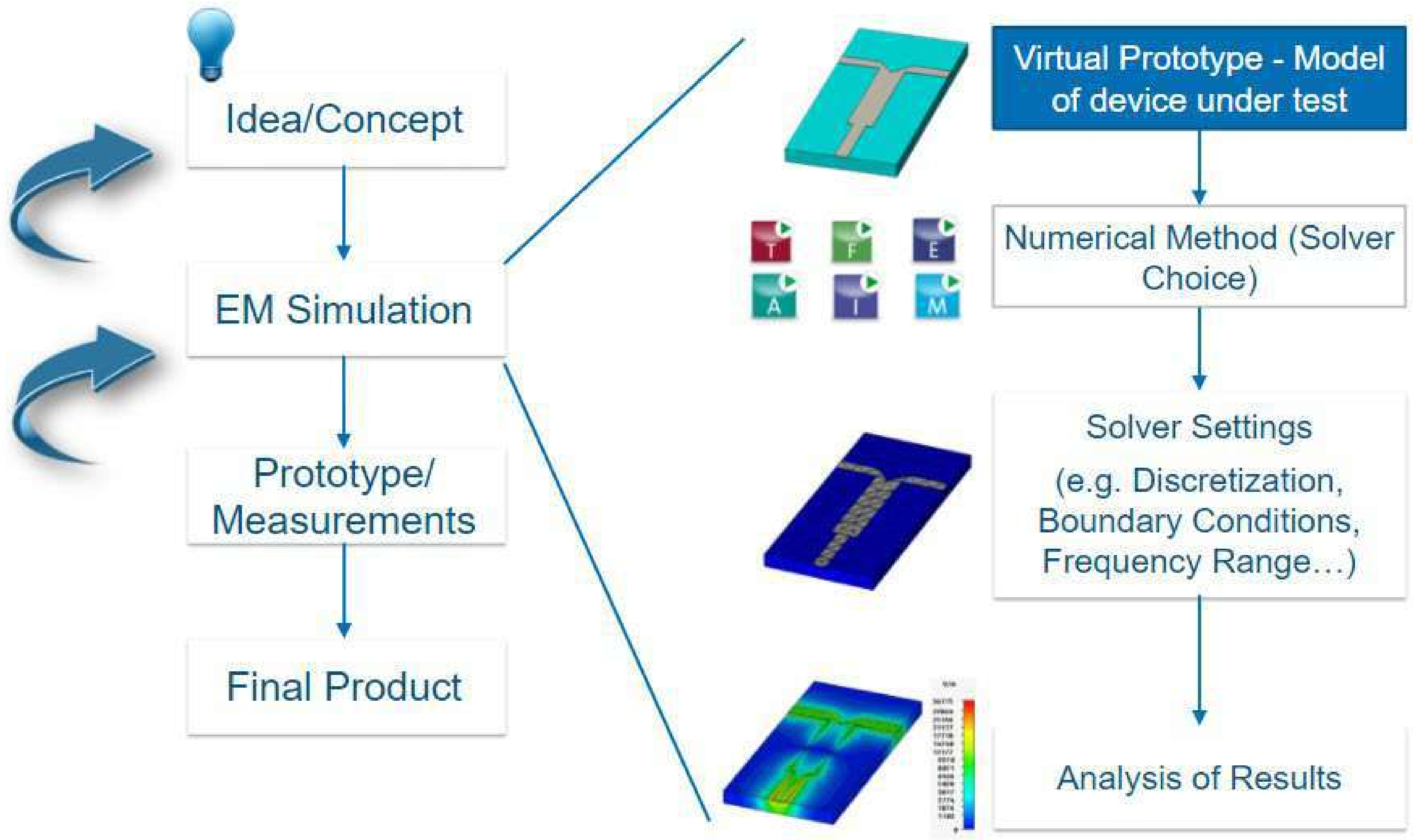
- Biological Effect and Safety Tests: Probably outsource to specialized testing company.
- Must pass Government Safety Protocols and Test. If not then repeat the whole process !
- **<u>Total Cost ~ 150 – 200 K USD</u>**

cadmicro

A *capable* EM Simulation Software is much cheaper than trial/error product design-development process !

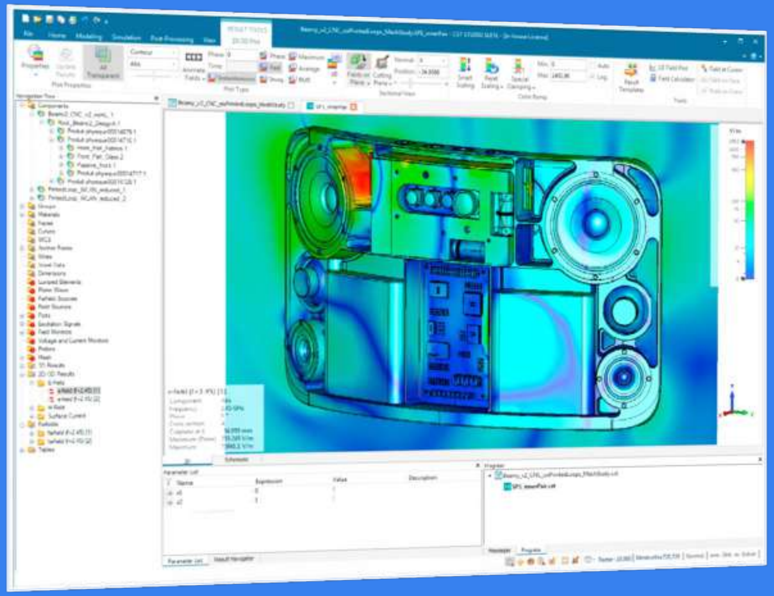
cadmicro

CST Microwave Studio Workflow



ro

CST Studio Suite | Key Features

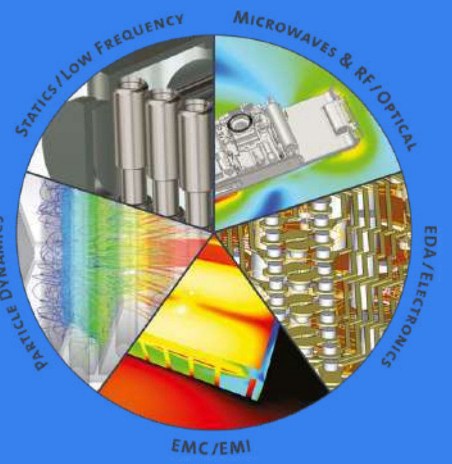


- Electromagnetic (EM) field solvers for applications across the EM spectrum are contained within a single user interface
- Well known & proven solution among leading technology and engineering companies around the world
- Offers end-to-end solution for designing, analyzing, and optimizing electromagnetic components and systems

cadmicro

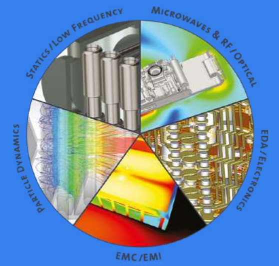
CST Studio Suite | Key Features

- Leading market solution for high frequency and low frequency electromagnetic simulation
- Optimize antenna and microwave devices
- Prevents and minimize electromagnetic interference (EMI) and electromagnetic compatibility (EMC) issues
- Coupled simulations: system-level, hybrid, multi-physics & EM/circuit co-simulation

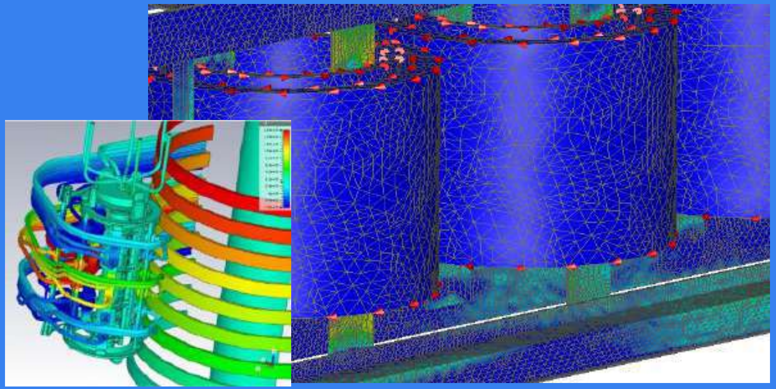


cadmicro

Applications of CST Studio Suite

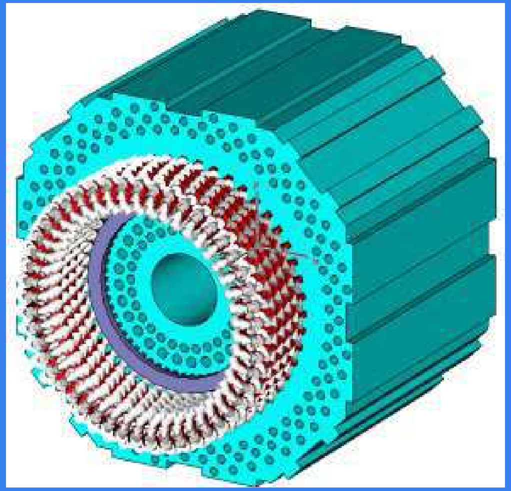


Energy, Process and Utilities

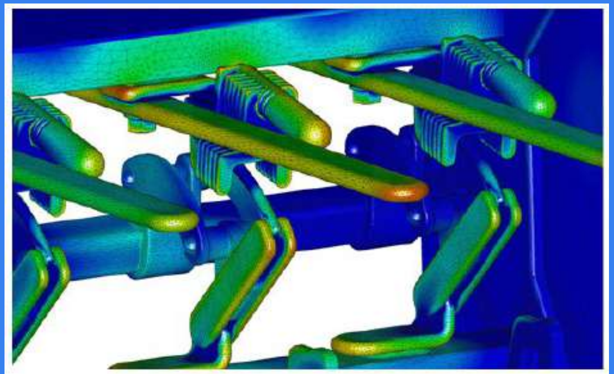


Power transformers

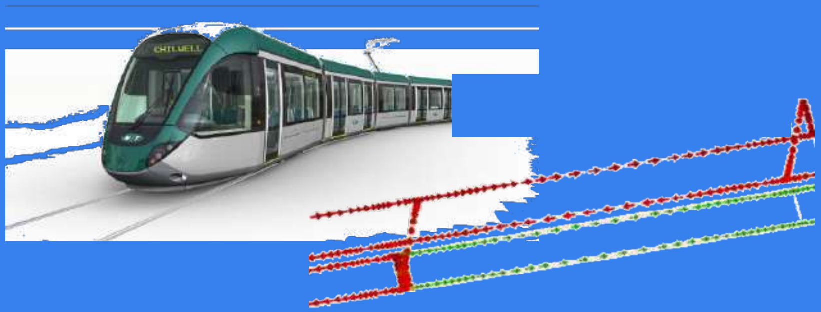
Insulators



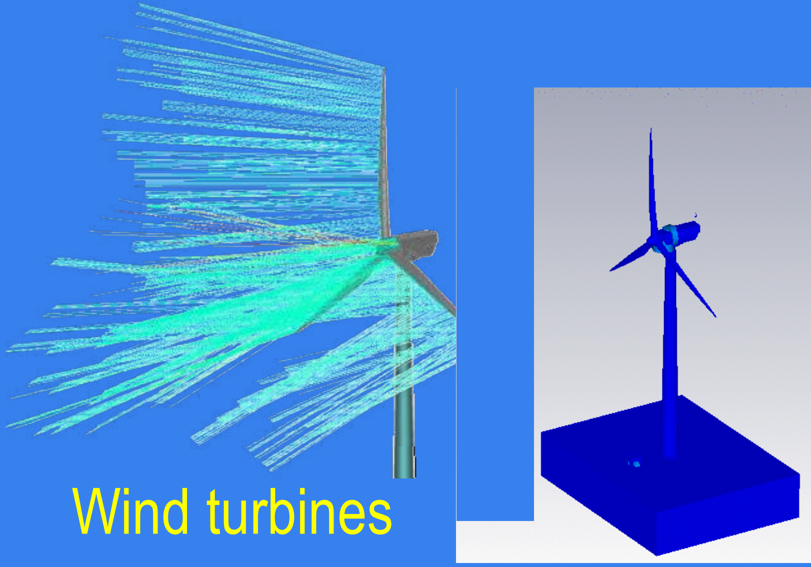
Generators



High voltage components



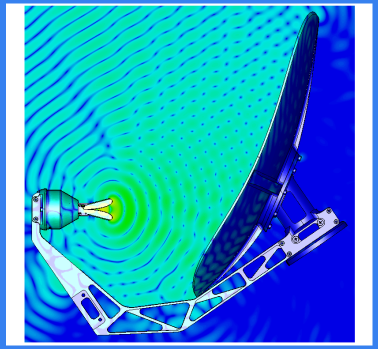
Power transmission



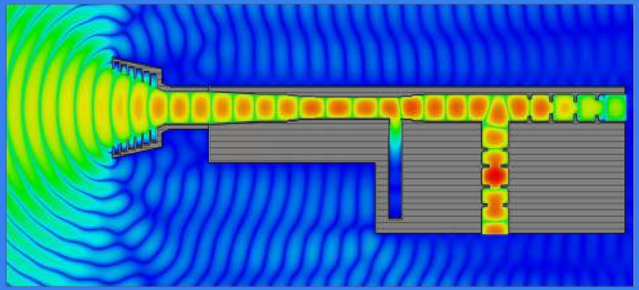
Wind turbines

cadmicro

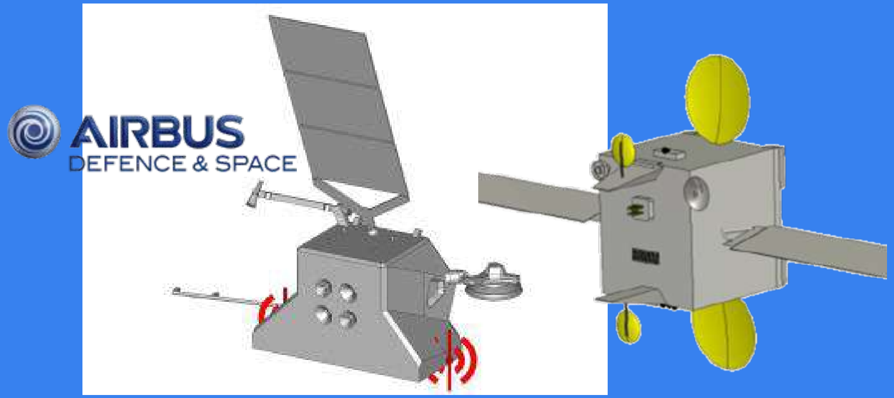
Aerospace and Defense



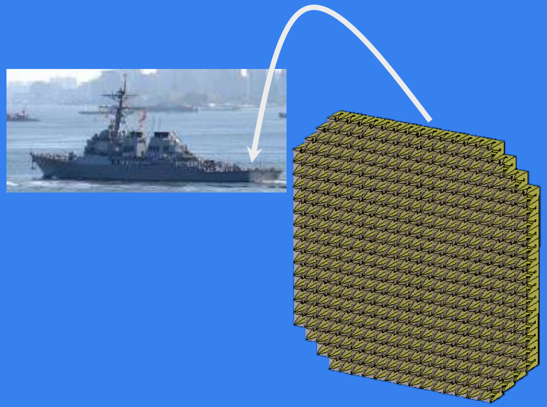
Reflector antenna



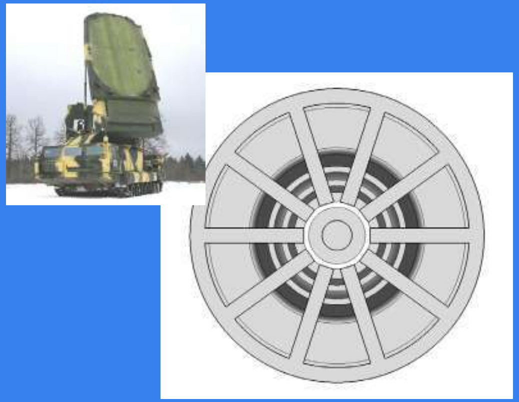
Antenna feed



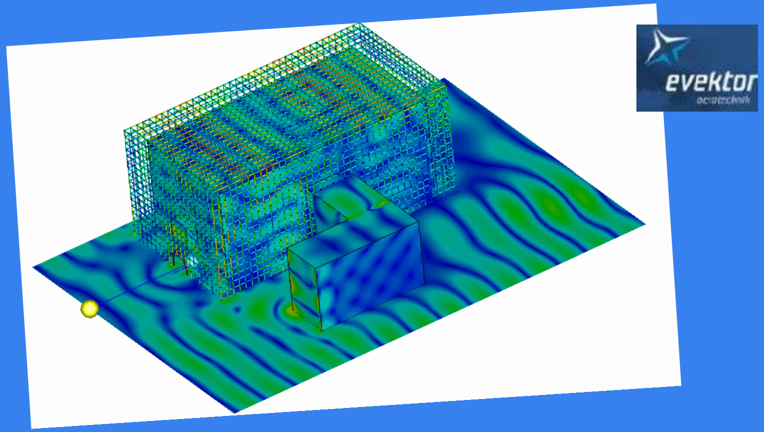
Interference analysis



Antenna arrays



Radar Sources

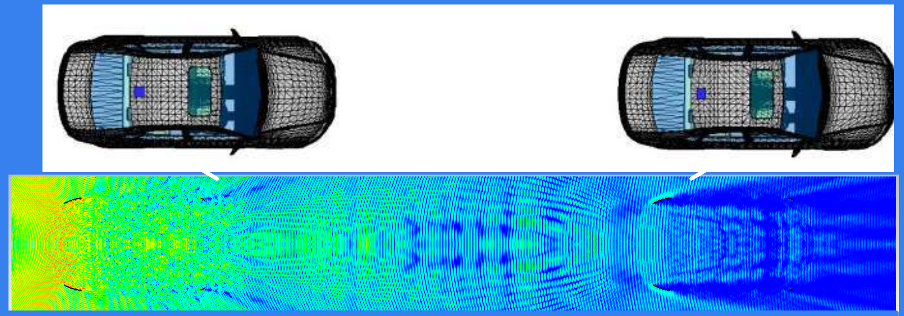


EM immunity

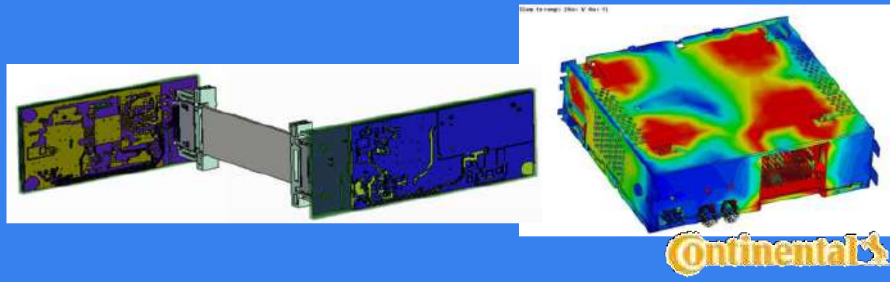
cadmicro

Transportation & Mobility

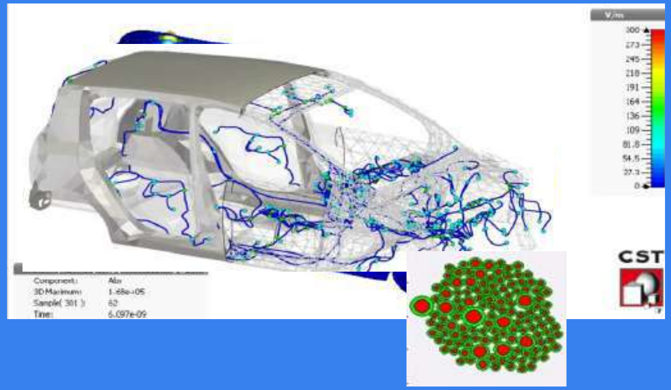
Antennas



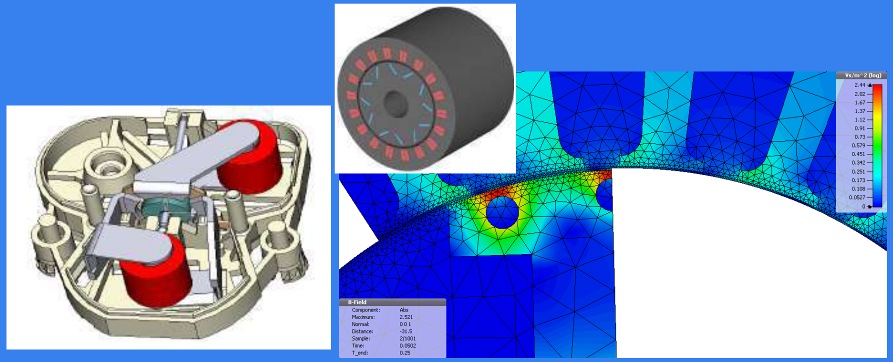
V2V Communication & Self Driving Cars



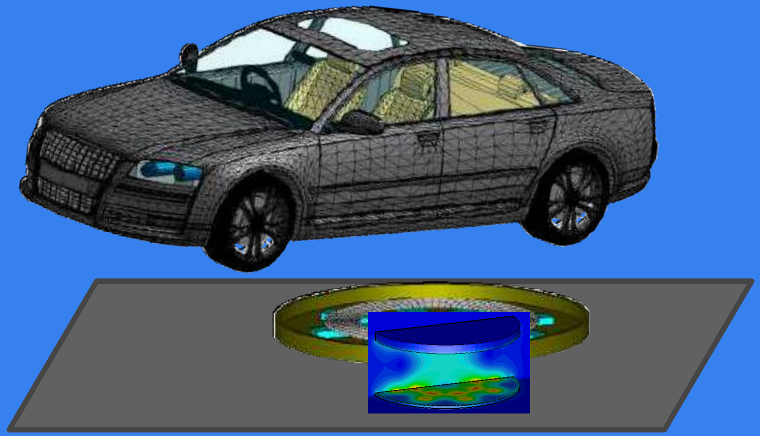
On-board electronics



Cabling EM behavior



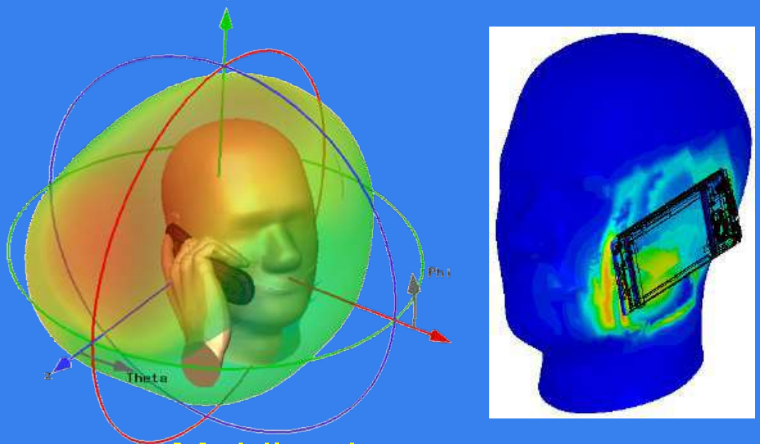
Electric motors

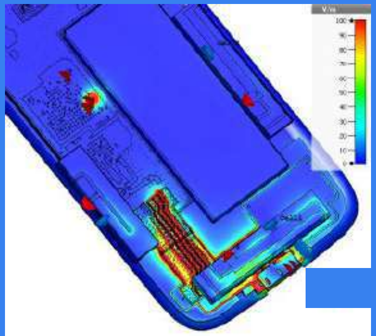


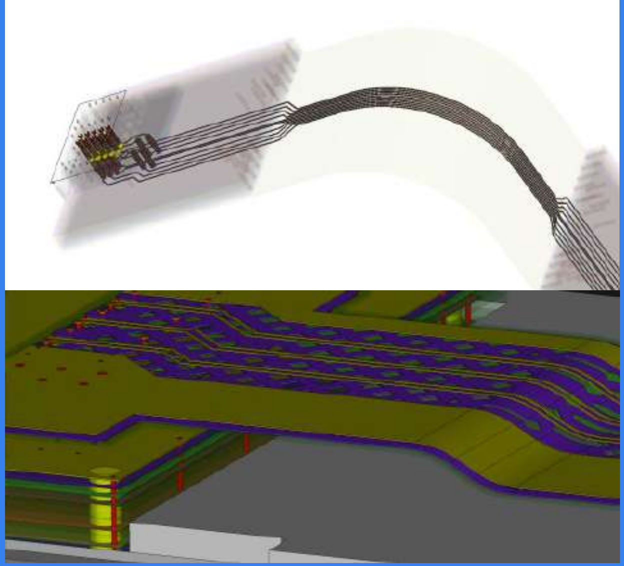
E-mobility, Wireless charging

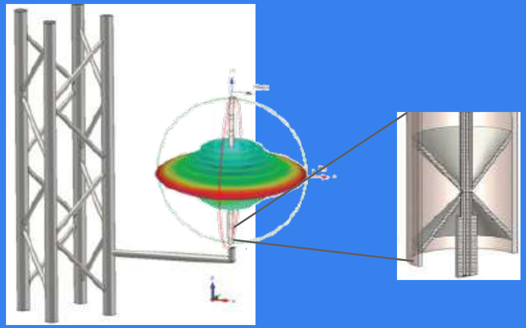
cadmicro

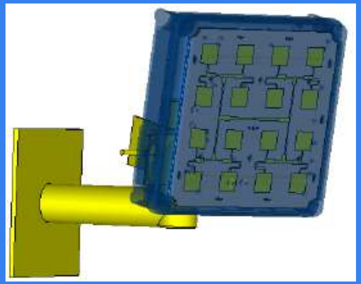
High Tech: Communication/IOT

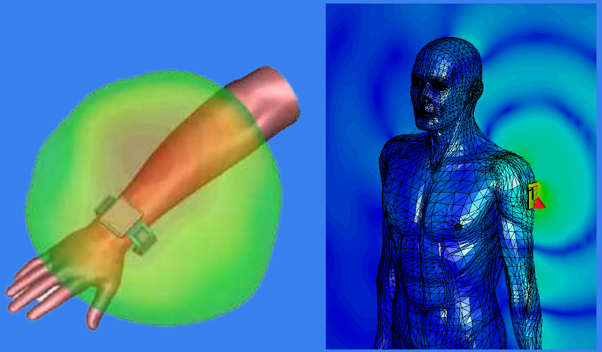

Mobile phones


Emissions and Interference


Flexible electronics

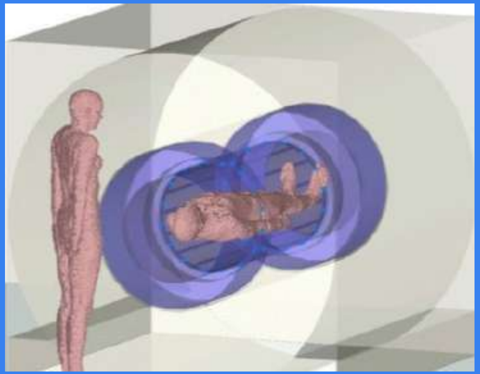

Base station

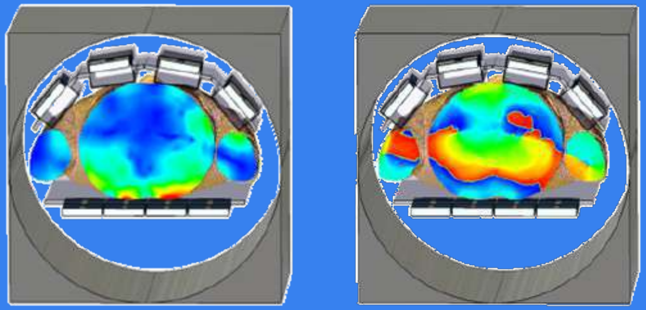

WiFi access point

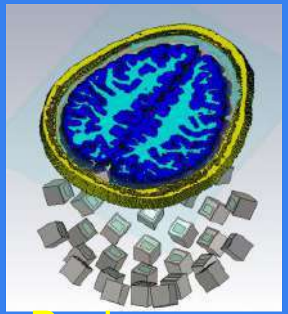

Wearable devices

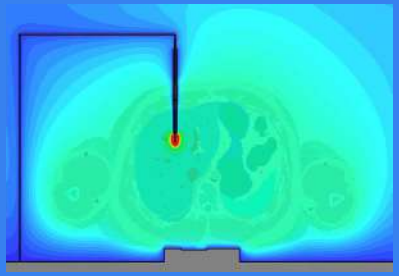
cadmicro

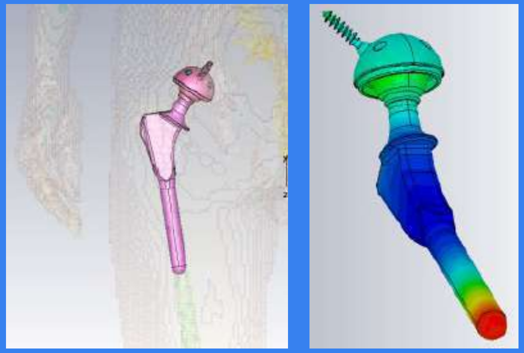
Life Sciences:

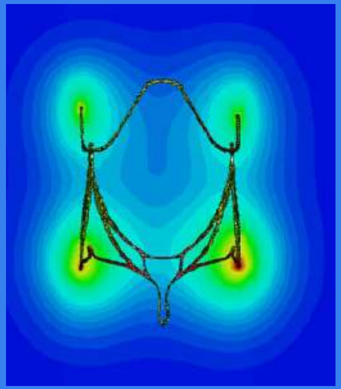

Imaging and diagnostics

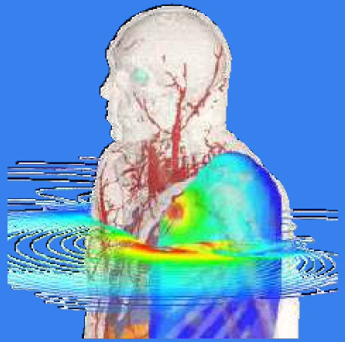

Highfield MRI

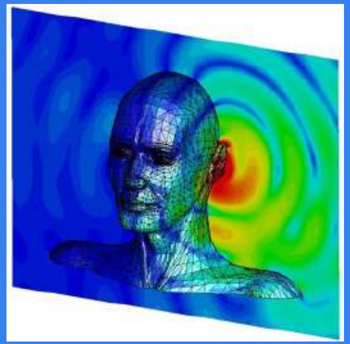

Brain cancer detection


Thermal cancer treatment


Implant Safety

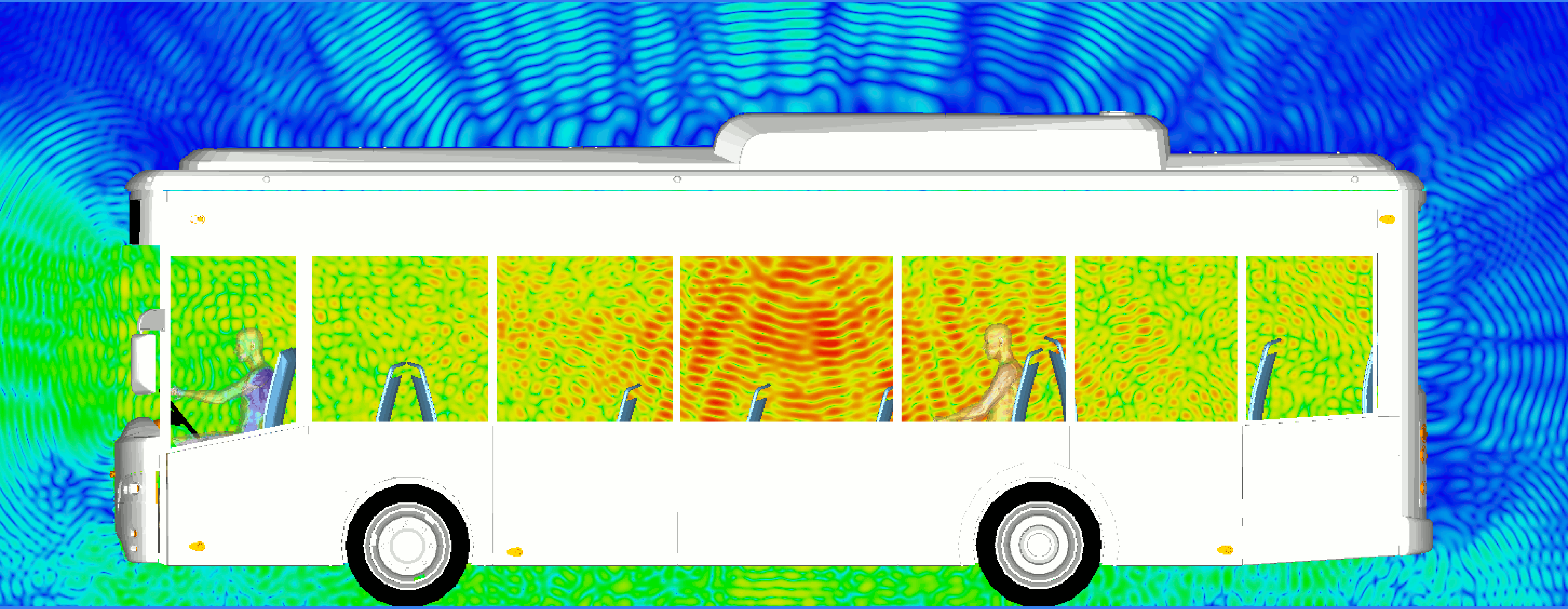

Heart Valve


Pacemaker


Hearing Aids

cadmicro

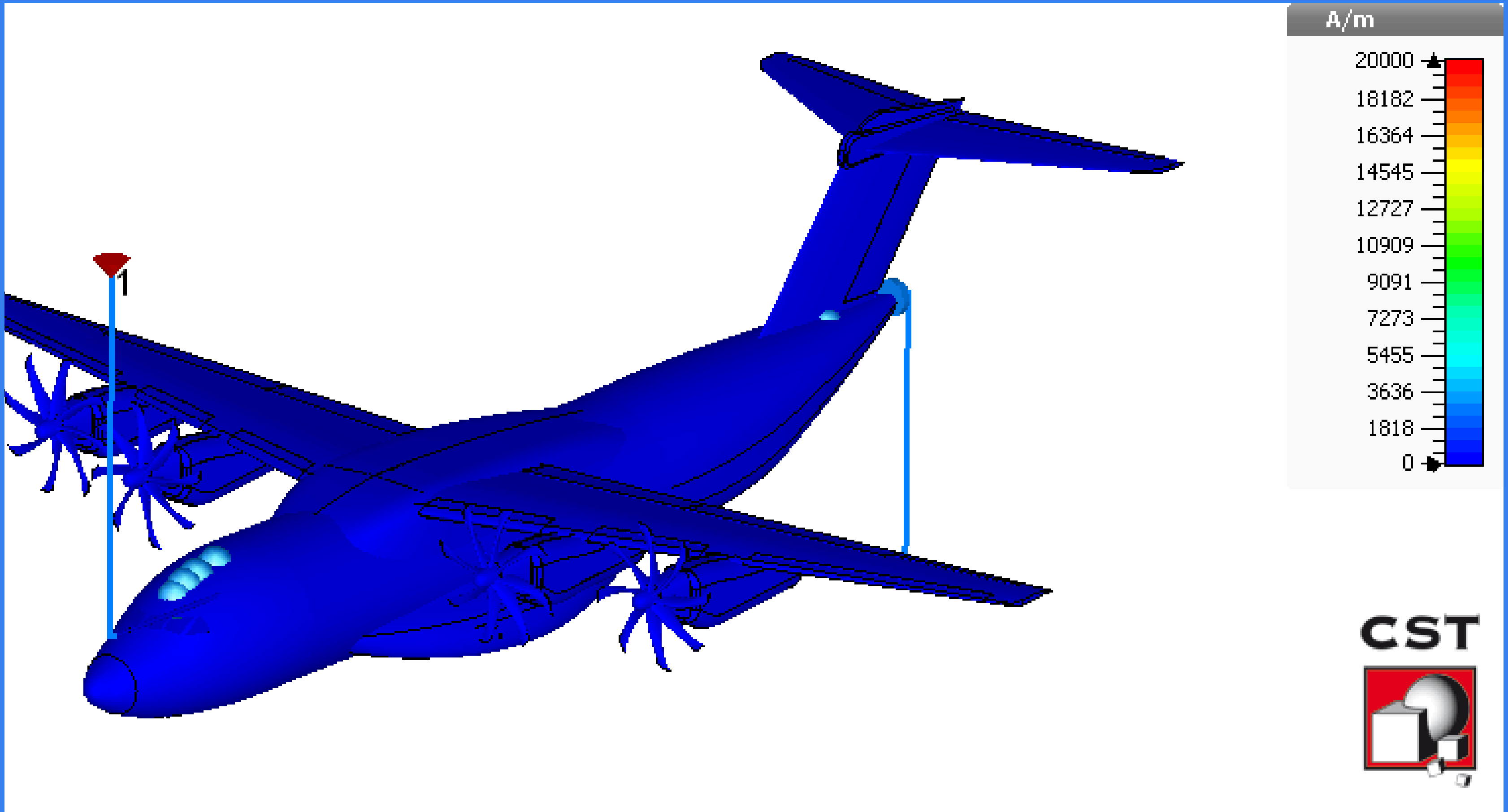
Large Vehicles (Buses, Trains, Planes, etc.)



cadmicro

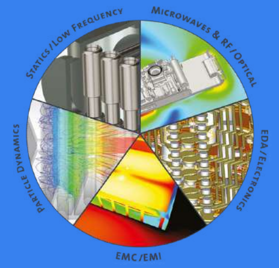
Large Vehicles (Buses, Trains, Planes, etc.)

- Lightning Strike (Fast Transient EM Fields)
- High Voltage/Current
- Large Physical Size to Mesh
- Various Wavelengths (Wideband)



cadmicro

What is CST Studio Suite ?



cadmicro

SIMULIA Electromagnetics Product Portfolio

CST Studio Suite

Antenna Magus
An expert system for antenna design

Opera
2D and/or 3D low frequency simulation

Filter Designer 3D
Simulation of passive microwave components

Chip Interface
Generation of complex 3D chip models from 2D layout

FEST 3D
Design and analysis of filters and other waveguide components

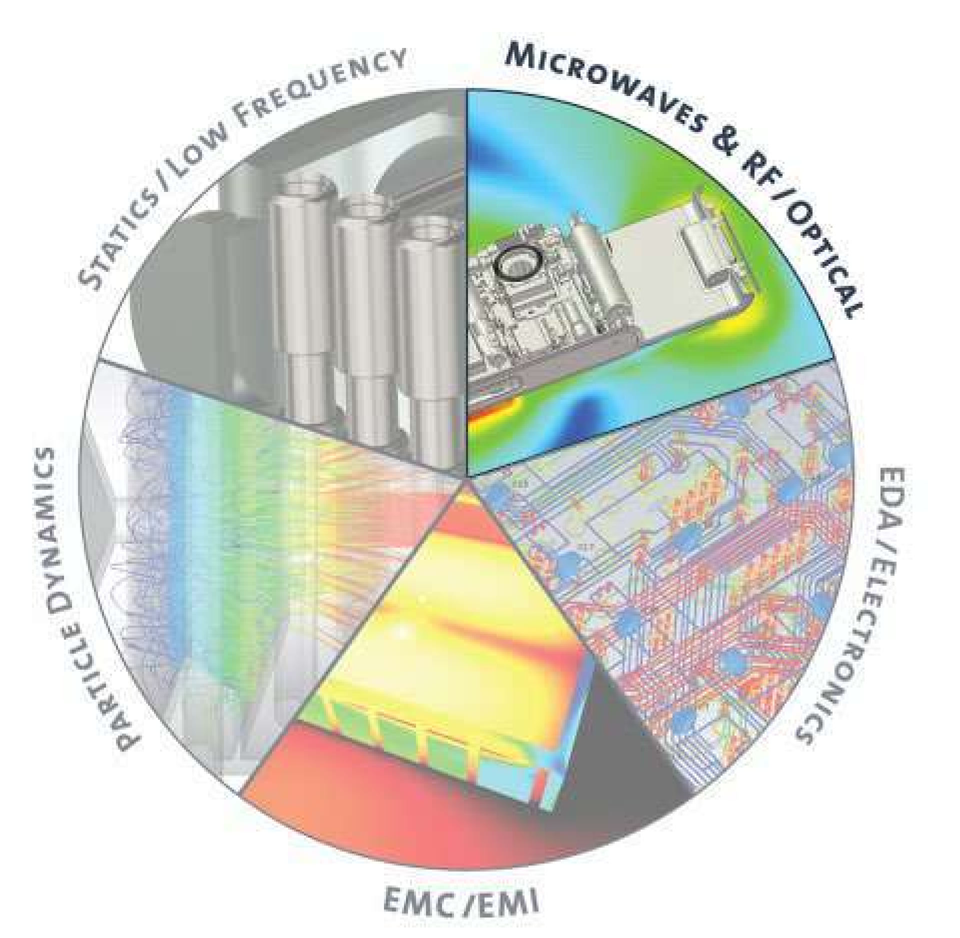
IDEM Works
Best-in-class tool for generation of broadband macromodels

SPARK 3D
Multipactor and gas discharge breakdown analysis

System Simulator
Design of electromechanical components

CST Studio Suite | Main Components

1. Microwave, RF & Optical (High Frequency)
2. EDA – Electronics: PCB, Signal Integrity etc.
3. EMI-EMC: EM Interference
4. Particle Dynamics
5. Statics-Low Frequency: Generators/Motors. Permanent Magnets
6. Multi-Physics: Thermal and Structural



cadmicro

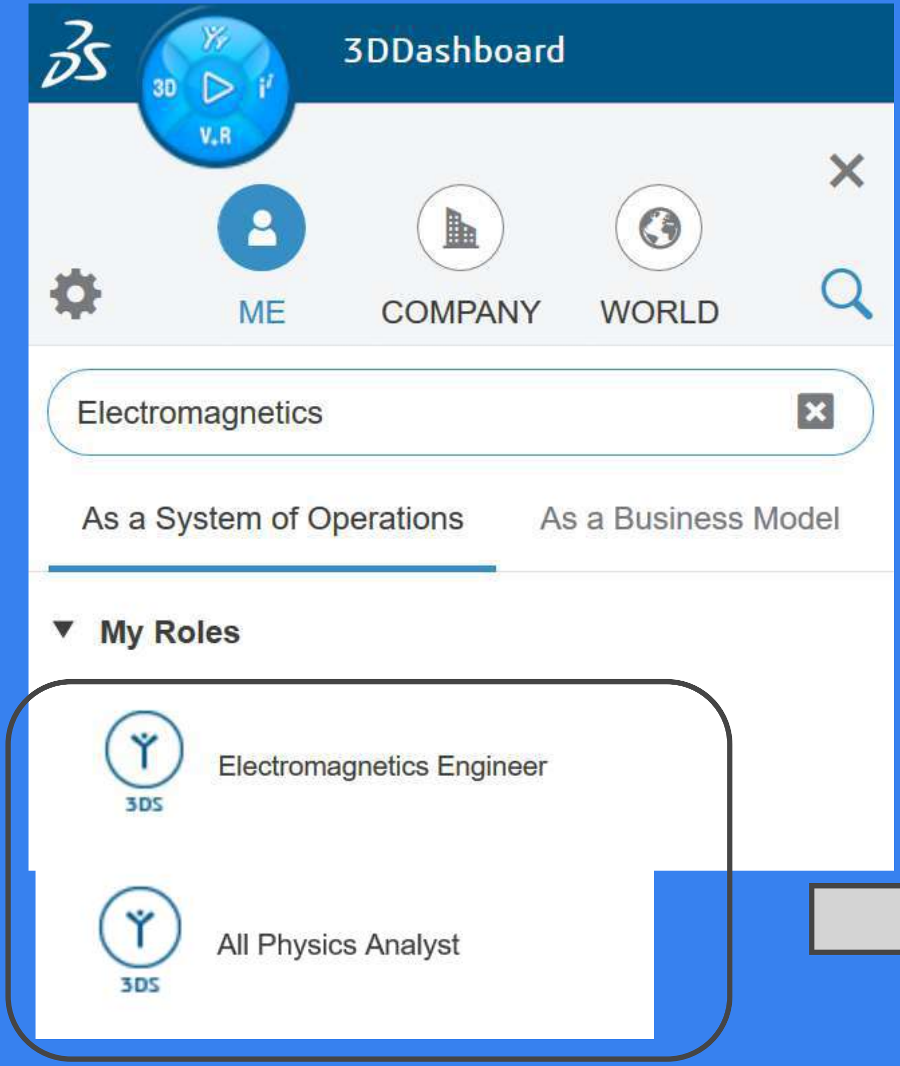
CST on Cloud| 3D Experience Platform

Electromagnetics Engineer | Connected Role

CST Studio Suite is installed (locally), licensed and launched from the platform (similar to 3DEXPERIENCE SOLIDWORKS)

- More capabilities and features than just a connector
- Combines the best of both products to provide a unique EM simulation solution

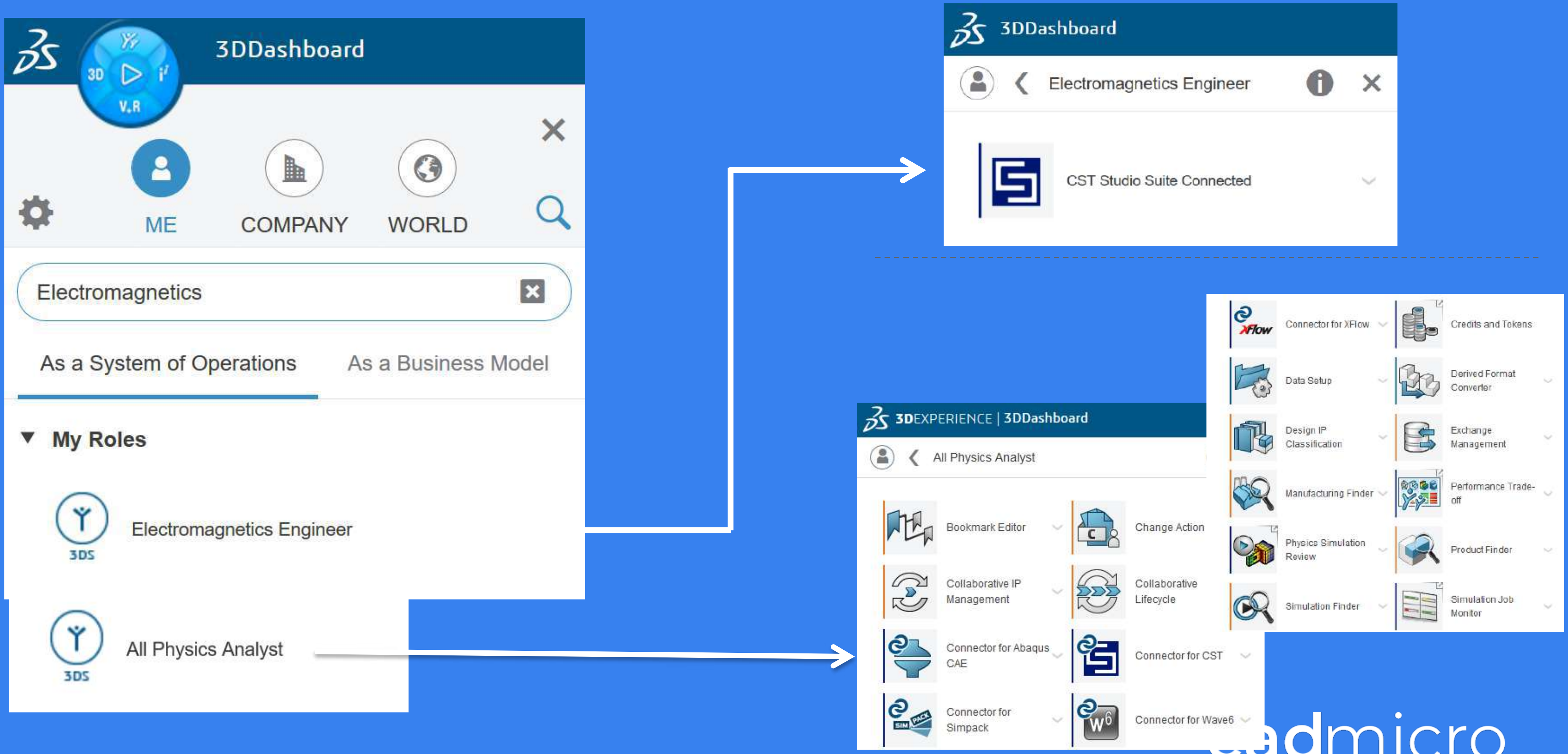
Electromagnetics Engineer | Packaged with two roles



Package contains both roles to provide users a seamless experience

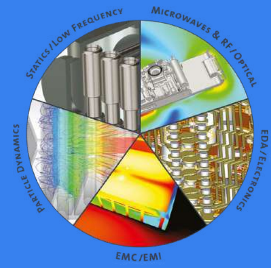
cadmicro

Apps included for both roles



CST Studio Suite: Main Functionality

A. Modeling a Device
B. Meshing the Models
C. Choose a Solver: Time / Frequency
D. HPC or Local Computing
E. Example: Coaxial Connector

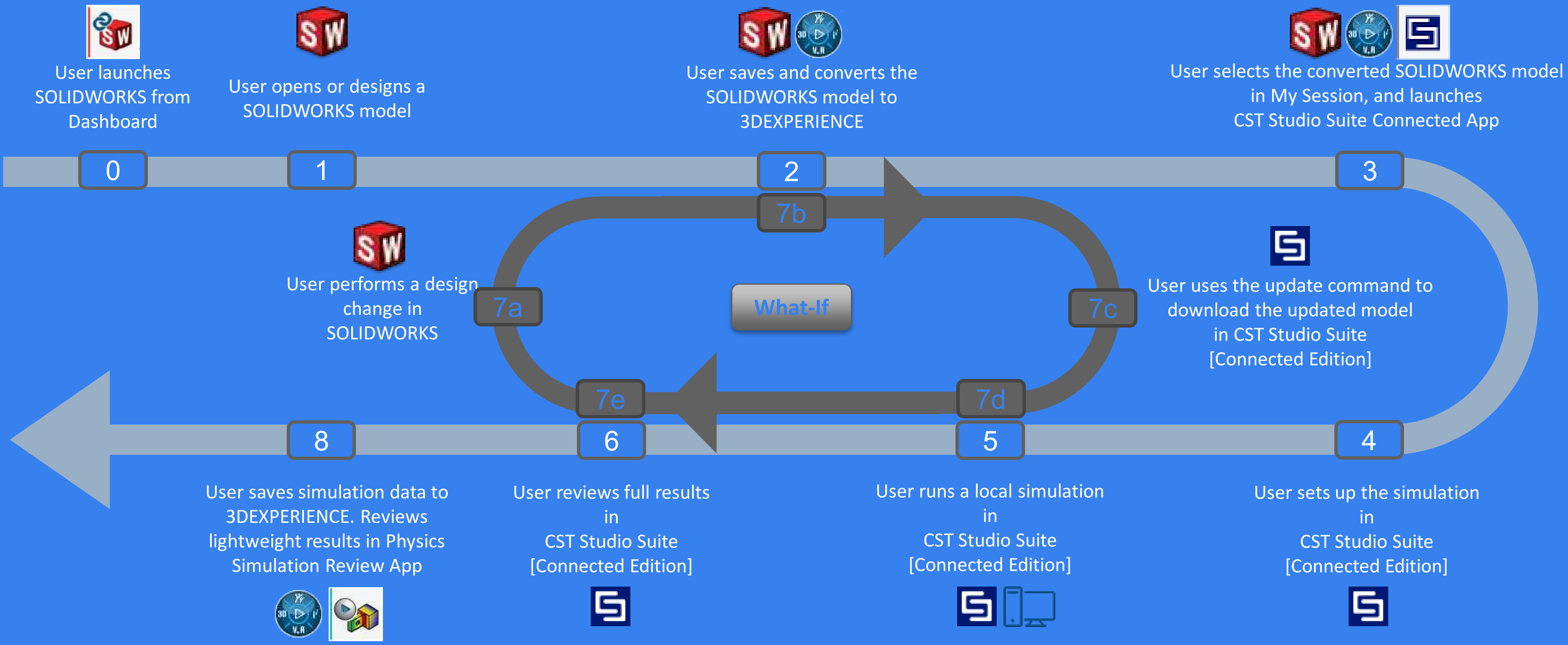


cadmicro

Creating a Model in CST Studio

CAD Import Handling

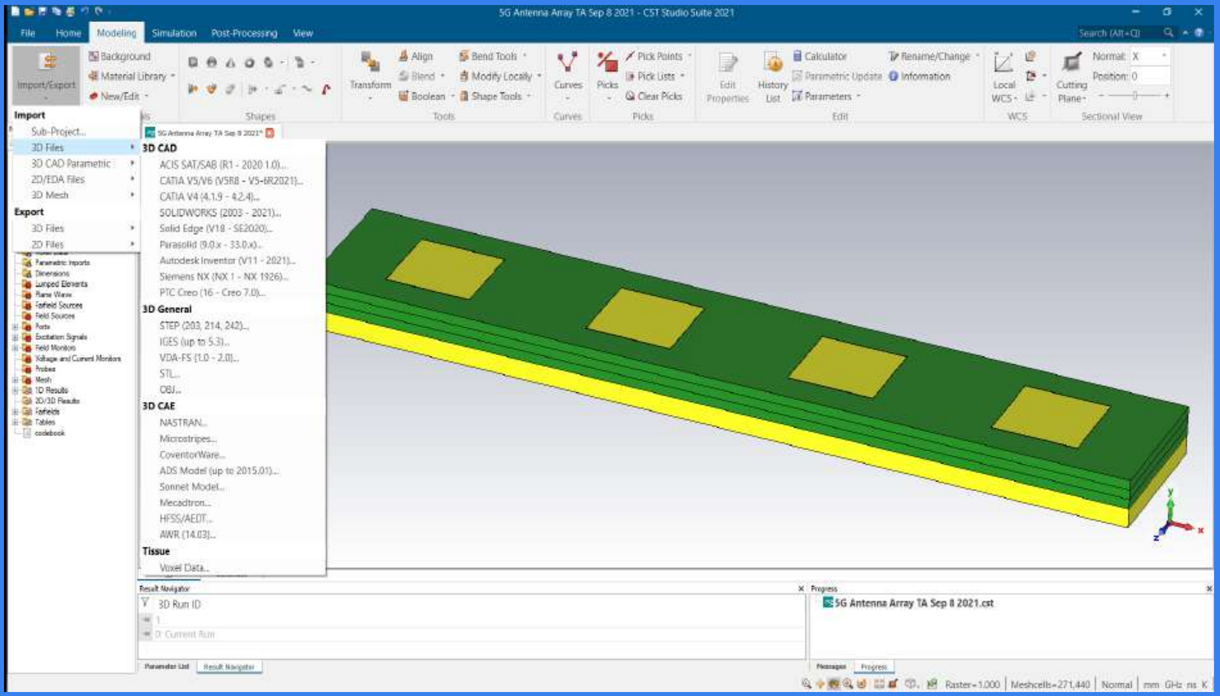
Electromagnetics Engineer | Workflow



cadmicro

Creating a Model in CST Studio

- A complete 3D Model can be created in CST Studio itself.
- It has a built-in Library of materials
- Includes non-homogenous and non-linear materials
- Electro-Magnetic, Thermal and Structural Properties can be defined for each (Multi-Physics)



cadmicro

Component Library

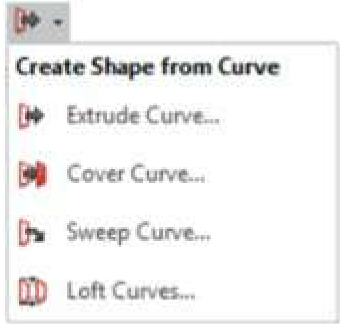
- The Component Library offers a way to collect reusable components and to easily collaborate with other users sharing the same library path.
- View all of the available components in the specified global libraries.
- Each component can be downloaded into the user's local directory for editing.
- CST Studio Suite includes pre-built models available for download in the library.

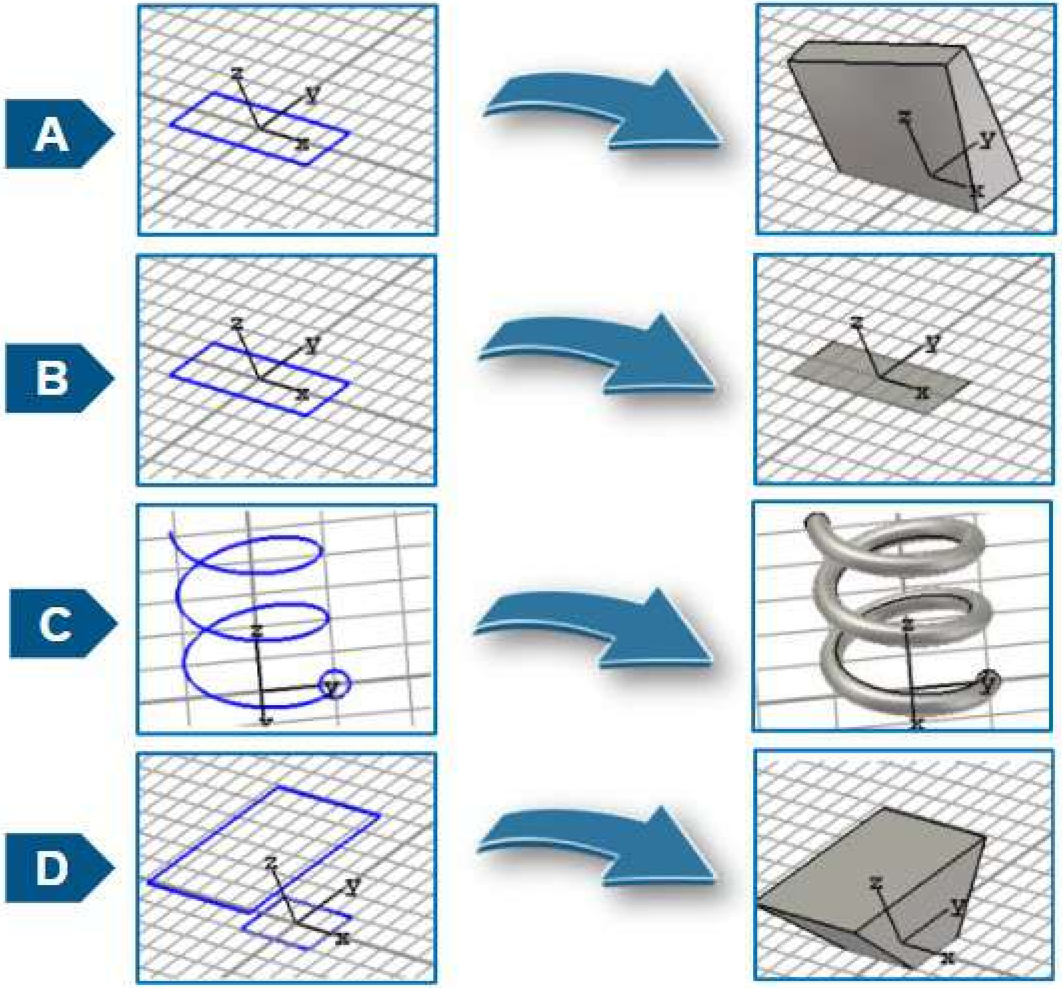
cadmicro

Curves

Curve Tools

Solids can be created from curves using the **Create Shape from Curve** options under the **Modeling** ribbon



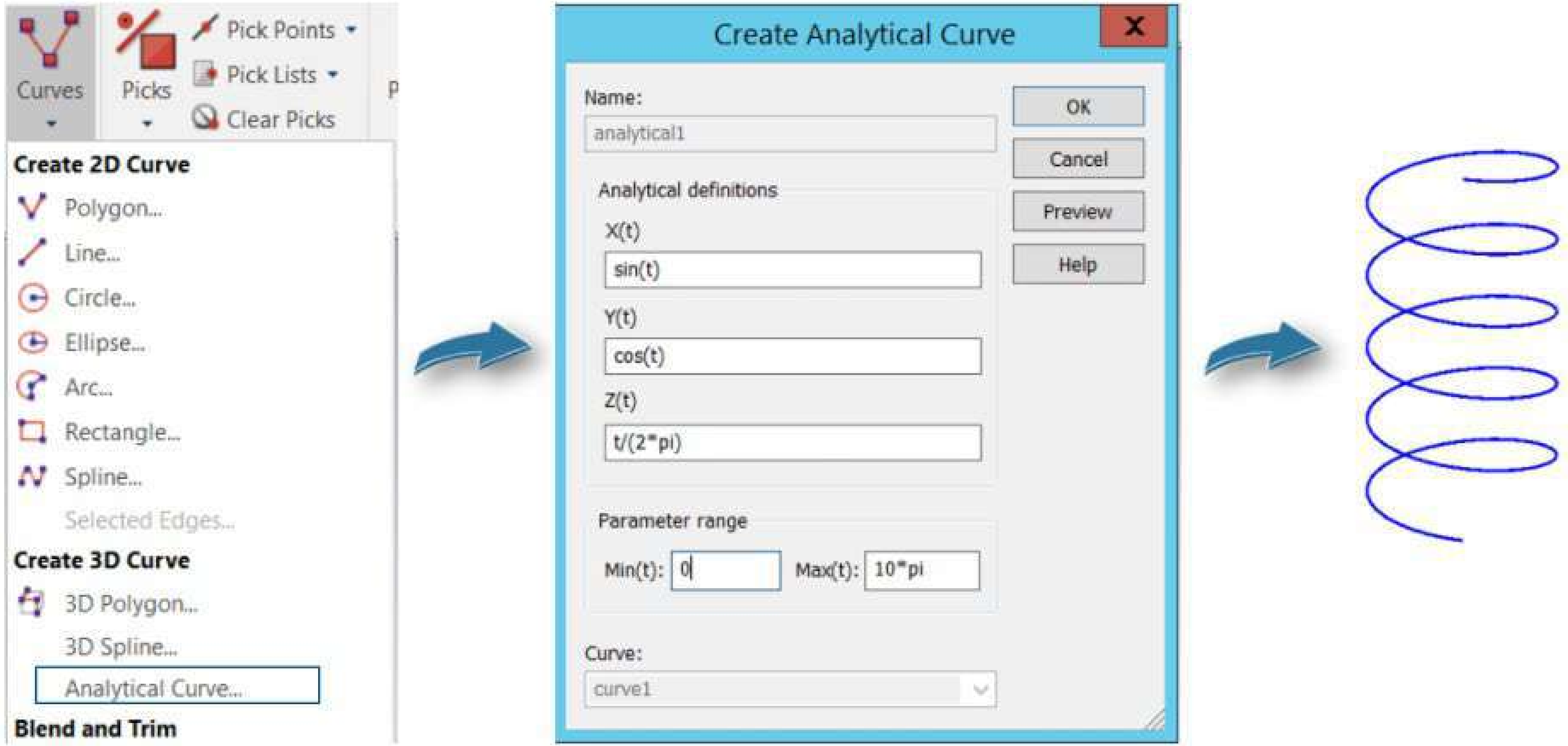


A. **Extrude Curve**: Extrusion of a planar curve
B. **Cover Curve**: Creation of a sheet from a planar curve
C. **Sweep Curve:** Sweep a 2D profile along a path
D. **Loft Curves:** Lofting of two curves together

Curves

Analytical Curves

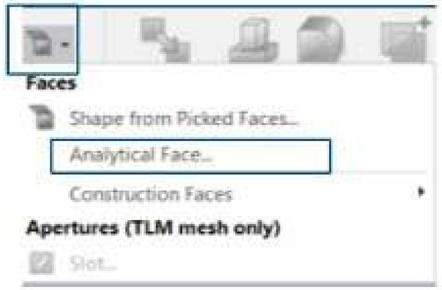
- 3D curves and faces can be created using analytical expressions.
- The **Analytical Curve** feature can be accessed from **Curves** under the **Modeling** ribbon.

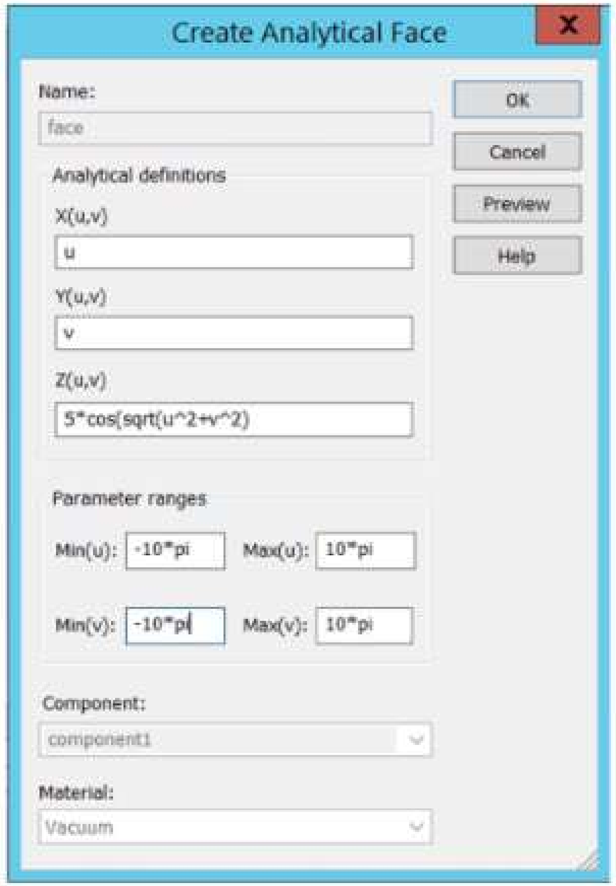


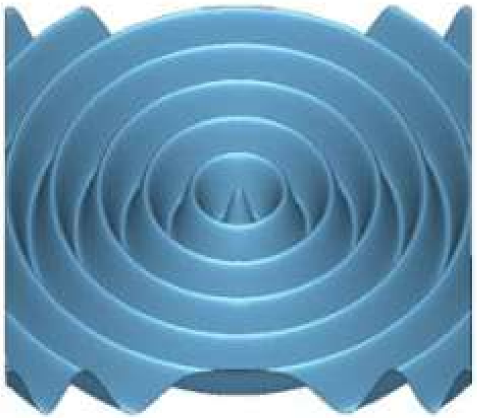
Curves

Analytical Face

- 3D curves and faces can be created using analytical expressions.
- The **Analytical Face** feature can be used from **Faces** under the **Modeling** ribbon for this.





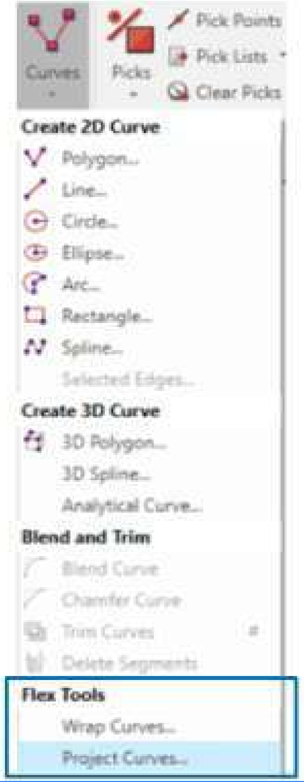


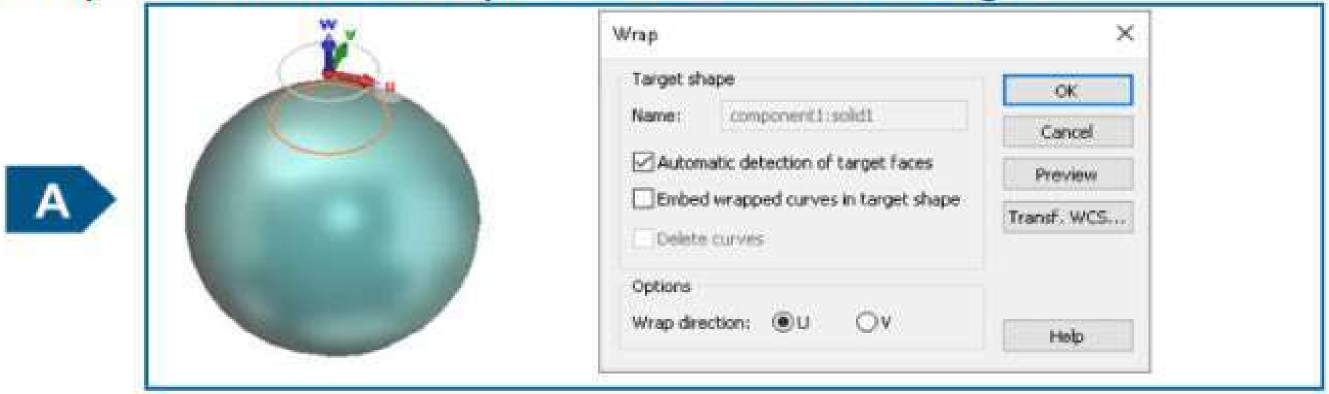
Curves

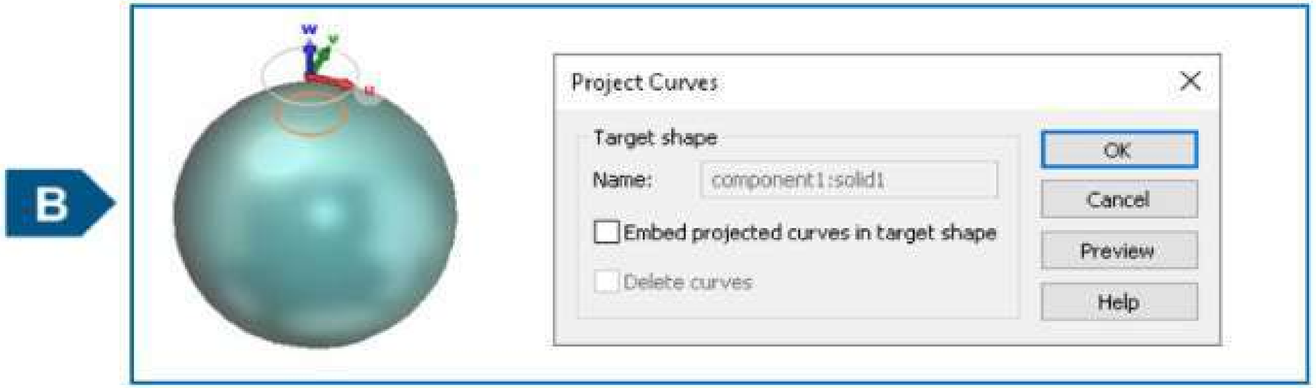
Flex Tools

A. Wrap Curves: Wrap previously selected curves toward a shape. The wrap operation preserves the length of the curves.

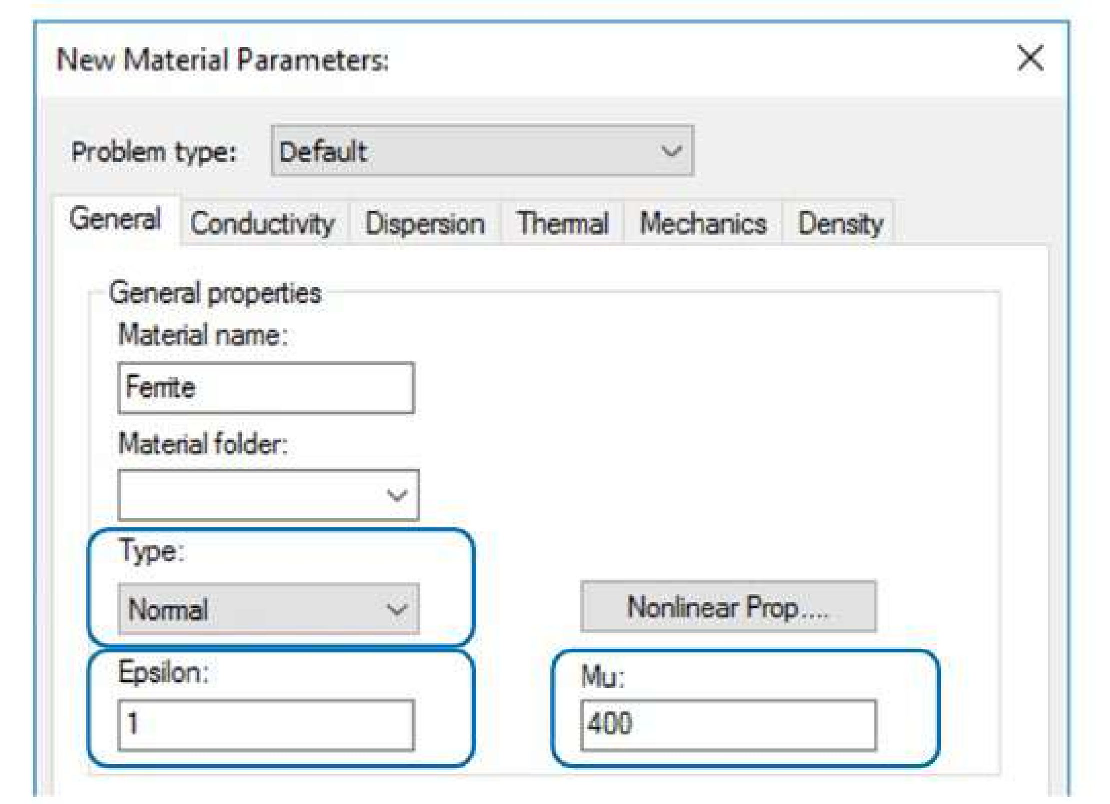
B. Project Curves: Project previously selected curves toward a shape along the surface normal of the target shape. The projection operation does not preserve the curve length.

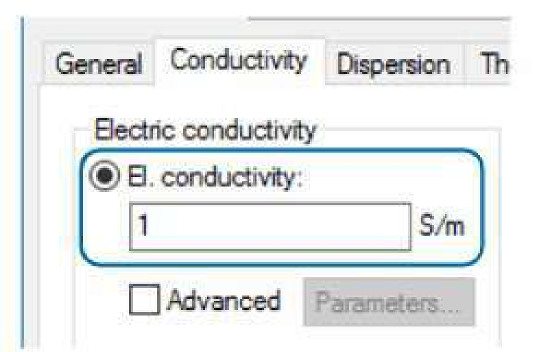






Materials in CST



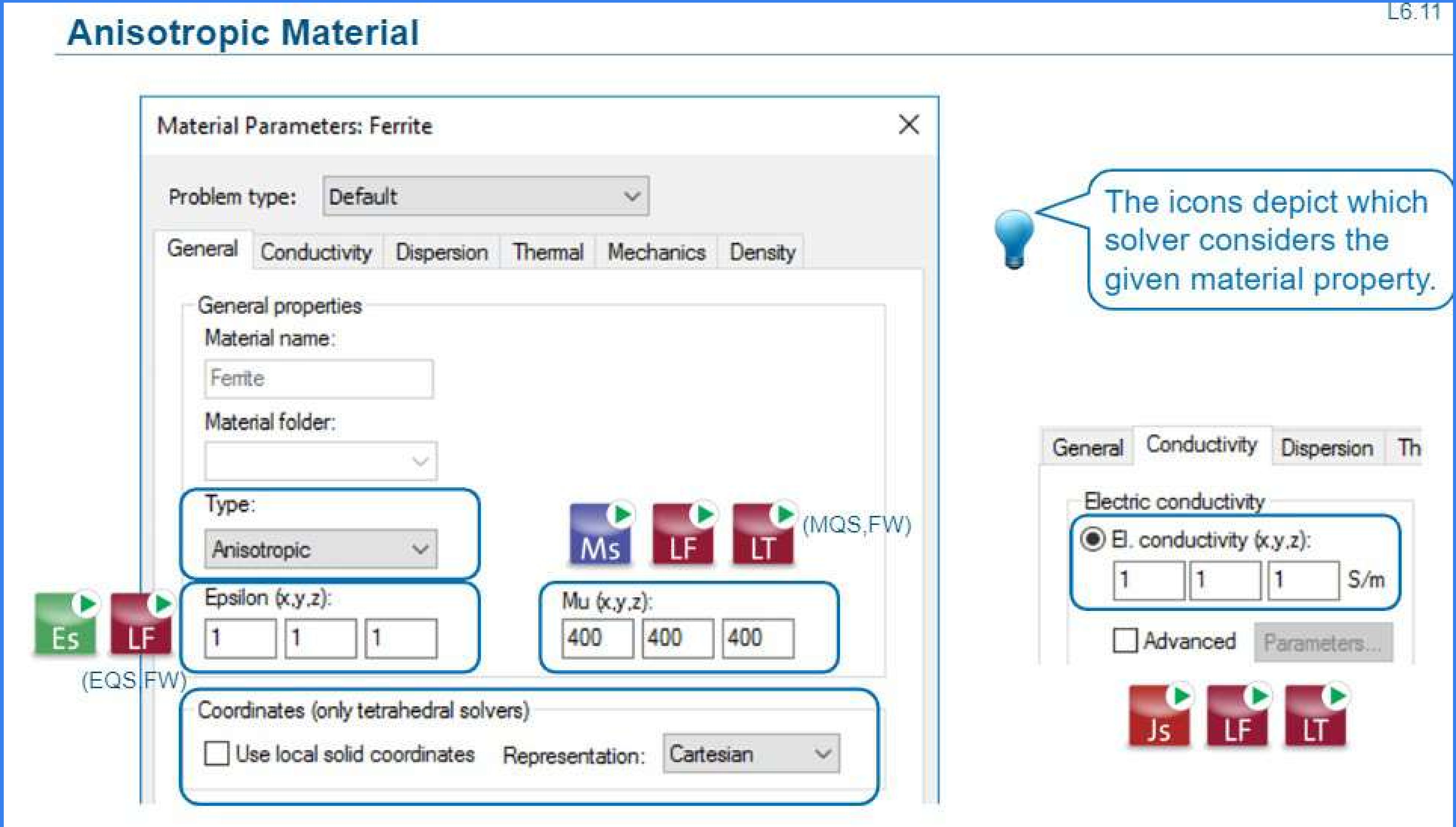


- Define Electrical permittivity and Magnetic permeability
- Can be An-isotropic
- Thermal Conductivity, Specific Heat etc.

Metals

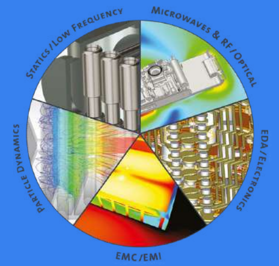
Material	Description
PEC ($\sigma \to \infty$)	▸ Perfect electric conductor
Lossy metal ($\sigma \neq \infty$)	▸ Recommended for the simulation of materials with a high but finite conductivity, e.g., copper, aluminum. ▸ Skin effect is taken into account. The skin depth must be much smaller than the material thickness, i.e., fields cannot penetrate objects made of "lossy metal"

Materials in CST



Meshing in CST Studio

Volumetric & Surface Mesh
Tetrahedral & Hexahedral Mesh

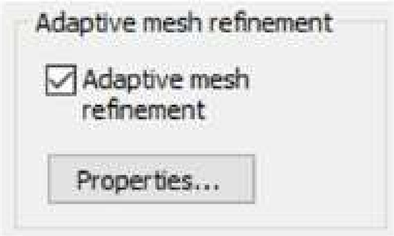


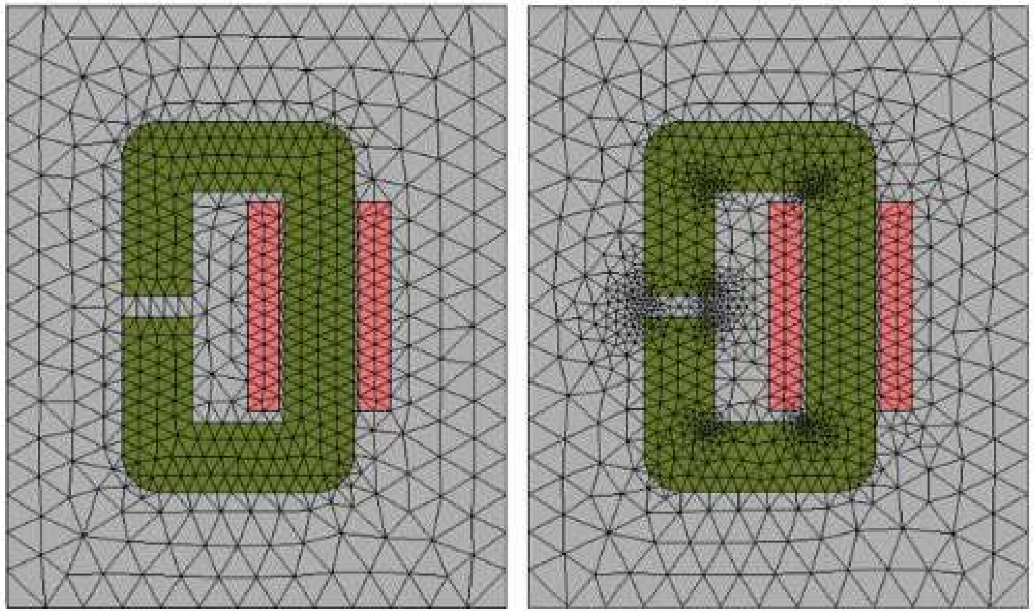
cadmicro

Meshing in CST

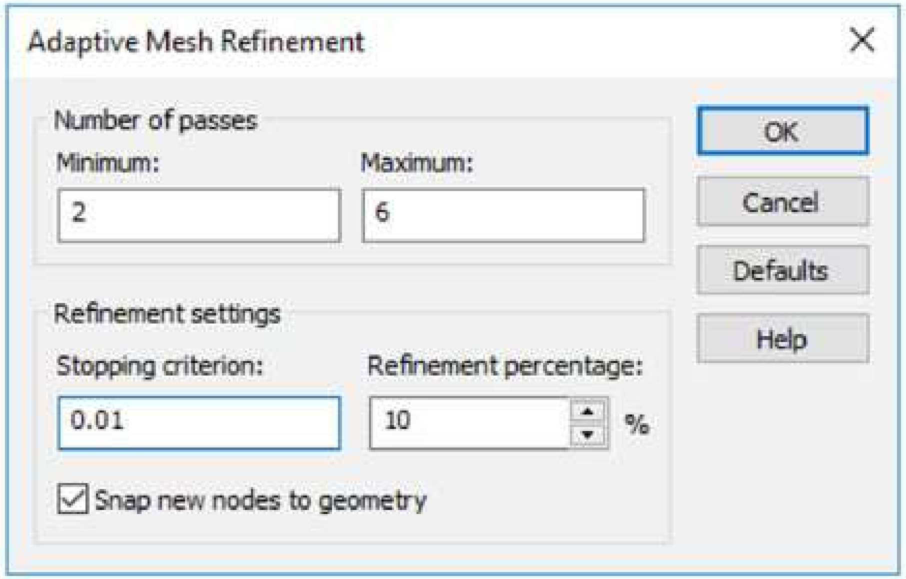
Adaptive Mesh Refinement

- Enabled by default.
- Automatic mesh refinement in CST Studio Suite tries to refine the initial mesh in a clever way such that the results are accurate.





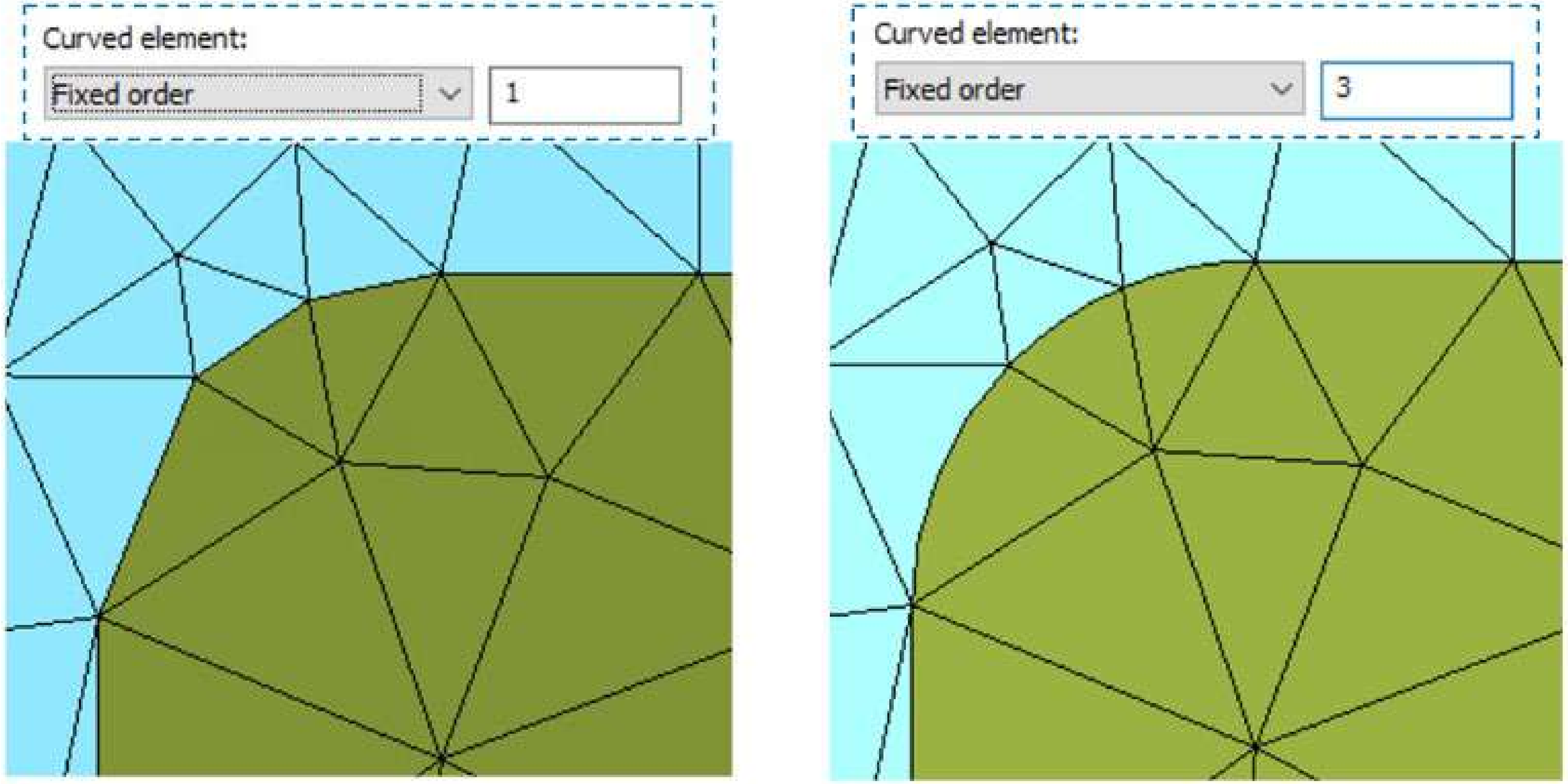
Initial Mesh   Adapted Mesh



Meshing in CST

Curved Elements

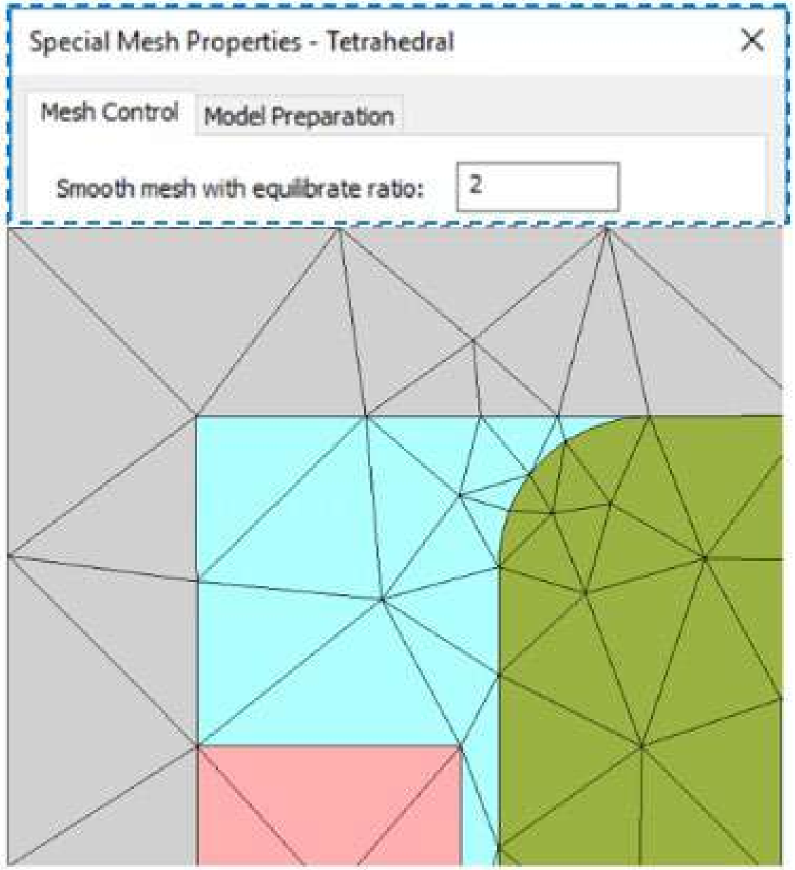
- Improve the numerical representation of the structure.
- Supported by Tetrahedral and Surface meshes.

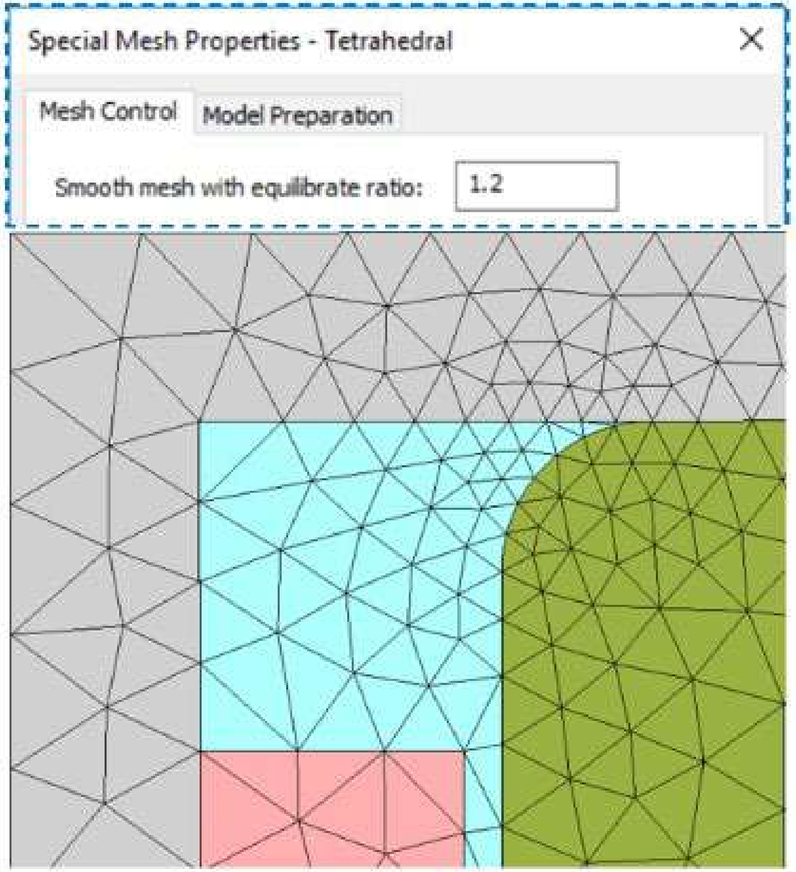


Meshing in CST

Smooth Mesh

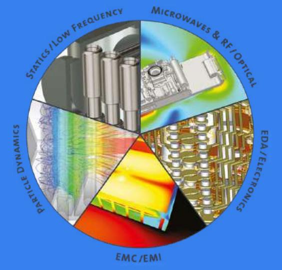
- Controls the ratio of the edge lengths between adjacent elements.





cadmicro

Various Solvers in CST Studio



cadmicro

CST Microwave Studio Solver Overview

Volumetric Mesh			Surface Mesh	
Full Wave				Ray Tracing
T	TLM	F	I	A
Time Domain	**Time Domain**	**Frequency Domain**	**Integral Equation**	**Asymptotic**
FIT	*TLM*	*FEM*	*MOM, MLFMM*	*SBR*
Hexahedral mesh	Hexahedral mesh	Tetrahedral mesh	Surface mesh	Surface mesh
Conformal (PBA)	Conformal (PBA cell warping) with octree lumping	Curved	Curved	Curved

Finite Integration Technique (FIT)

Transmission Line Matrix (TLM)

Method of Moments (MoM)

Multi Level Fast Multipole Method (MLFMM)

CST Microwave Studio Solver Overview

Special Solvers

A

- Electrically very large structure
- Farfield and RCS calculation
- Nearfield/farfield source for antenna placement calculations

E

- Eigenmode calculation
- Hexahedral/tetrahedral mesh
- External Q-factor calculation

I

- Electrically large structure
- Characteristic mode analysis (CMA)
- Scattering parameter matrices

M

- Planar multilayer structure
- Characteristic mode analysis (CMA)
- Method of Moment (MoM) based

Low Frequency-Static Solvers

- **Static Solvers**
  - Electrostatic, Stationary Current and Magnetostatic Solvers:
    Do not take time-dependent effects into account. Presume a stationary state: $d/dt = 0$.

Es Js Ms

- **Dynamic Solvers**
  - Consider time dependency, either in the frequency domain (electroquasistatic, magneto-quasistatic and full wave) or in the time domain (electroquasistatic, magnetoquasistatic).

LF LT

Multi-Physics Solvers

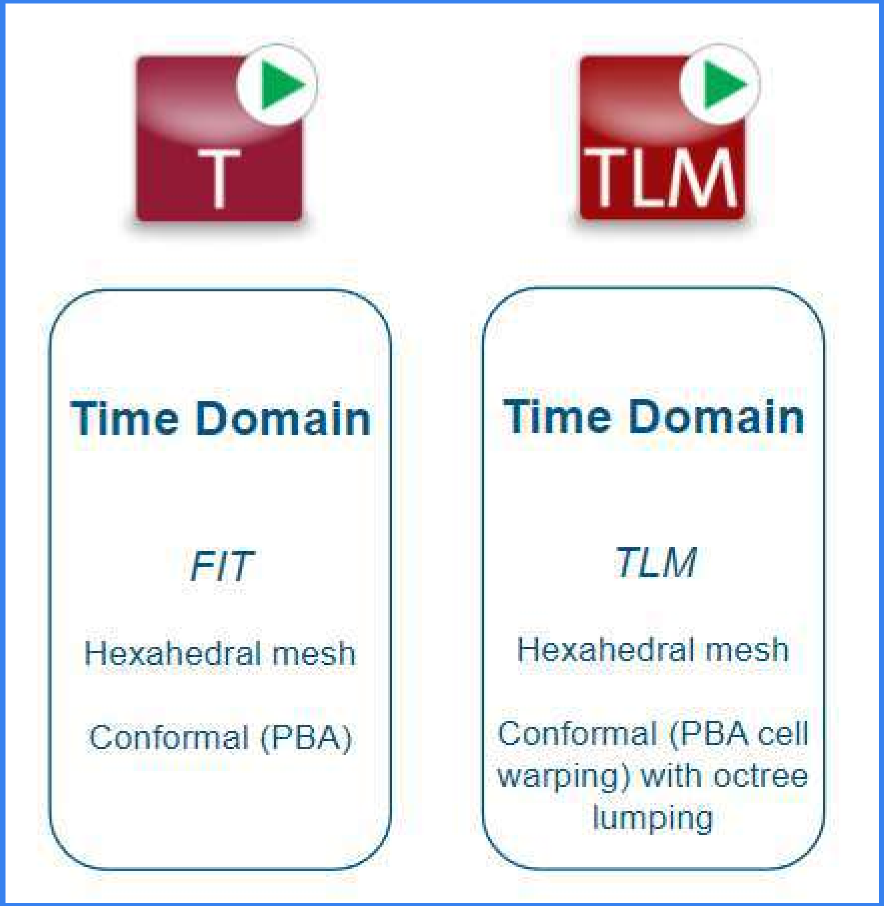
Thermal Solvers	Conduction	Convection	Radiation	Mesh
Steady-State & Transient THs THt	Yes	Approximated using ***Thermal Surface Properties***	Surface-to-Ambient only	Tetrahedral Hexahedral
Conjugate Heat Transfer (Steady-State & Transient) CHT	Yes	Yes	Yes Surface-to-Surface	Octree-Hexahedral

Mechanical Solver	Elastic Deformation	Thermal Stress	Nonlinear Properties	Mesh
Structural Mechanics ST	Yes	Yes	Temperature-Dep. Young's Modulus	Tetrahedral only

Time vs. Frequency Domain Solvers

cadmicro

Time Domain Solver



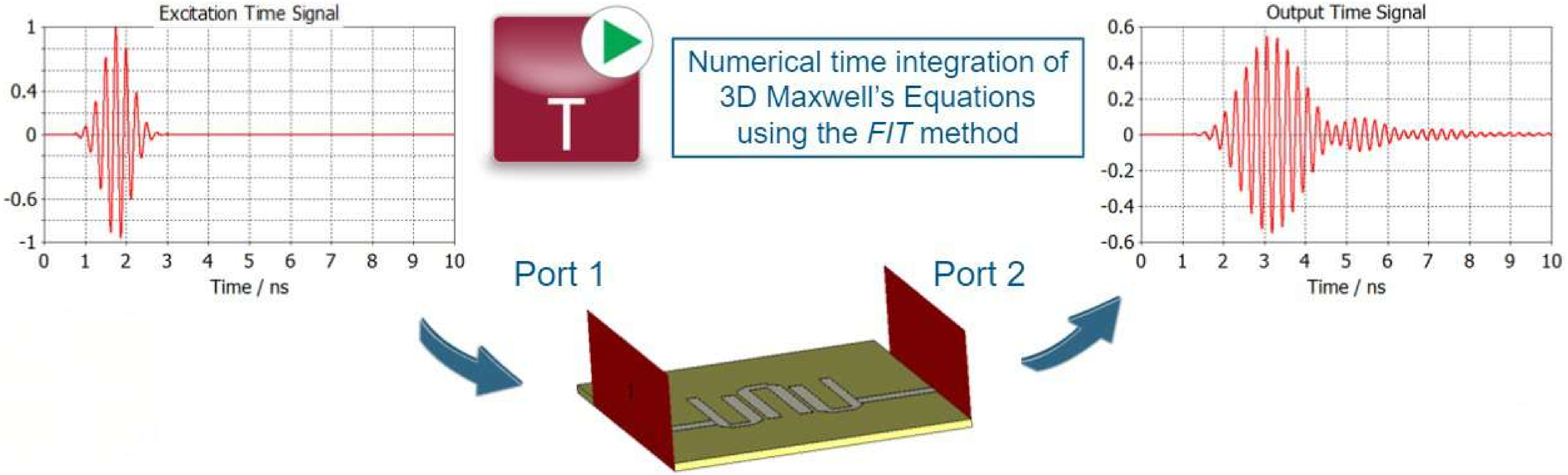
- The largest simulation flexibility is offered by the **time domain solvers**, which can obtain the entire broadband frequency behavior of the simulated device from a single calculation run.
- These solvers are remarkably efficient for many high frequency applications such as connectors, transmission lines, waveguide components, and antennas, amongst others.
- Two time domain solvers are available, both using a hexahedral mesh, either based on the Finite Integration Technique (FIT) or on the Transmission-Line Matrix (TLM) method. The latter is especially well suited to EMC/EMI/E3 applications

cadmicro

Time Domain Solver

Behind the Scenes

1. The model is excited with a broadband signal (Gaussian pulse).
2. The response of the model is monitored in the time domain (output time signals).
3. A discrete Fourier Transform is applied automatically to the time signals to obtain the broadband behavior of the model in the frequency domain (broadband S-parameters).



cadmicro

Time Domain Solver

T TLM

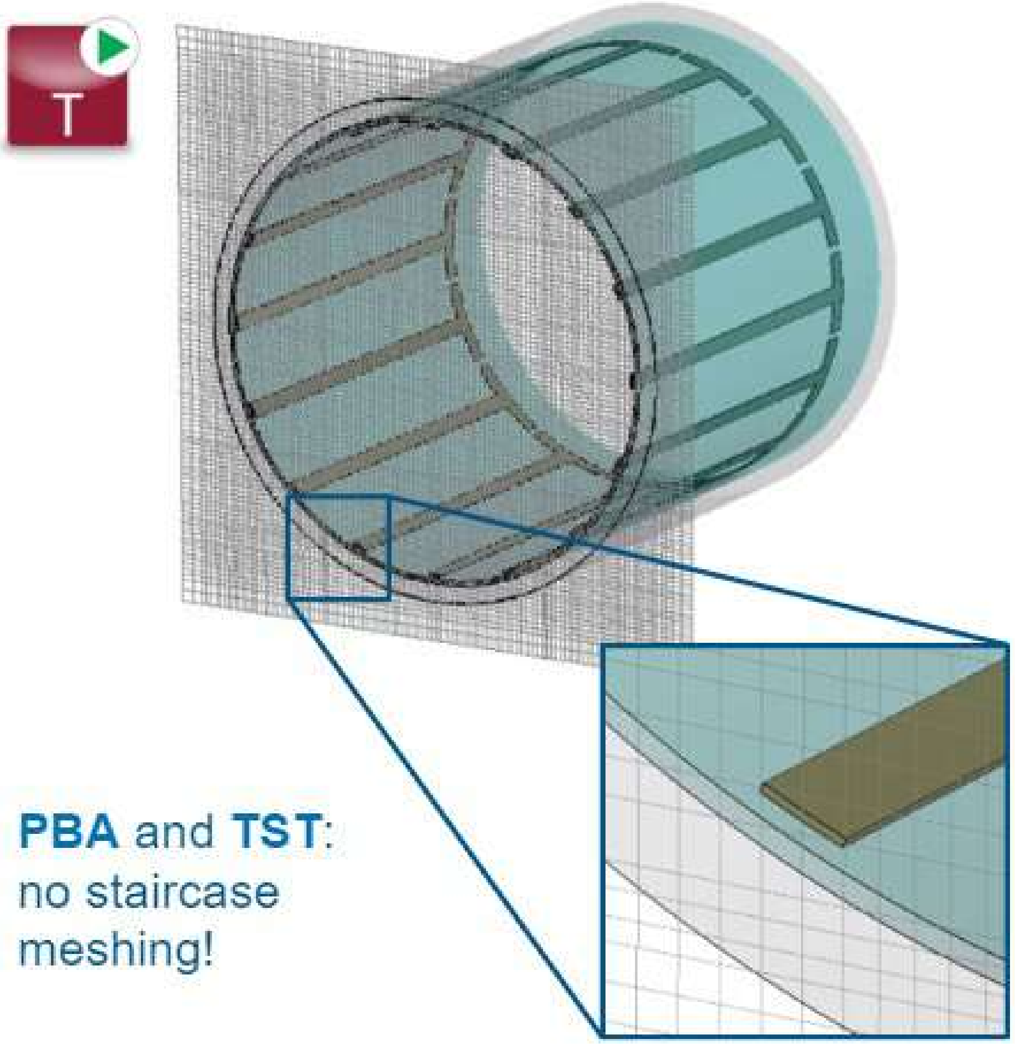
Mesh Type
Hexahedral
✓ Hexahedral TLM

- Ports sequentially processed (simultaneous excitation of a combination possible)
- Broadband
- Very efficient for high level of geometric complexity
- Slows down at low frequencies
- High Q structures require long simulation time
- Able to handle large model
- Great speedup with GPU

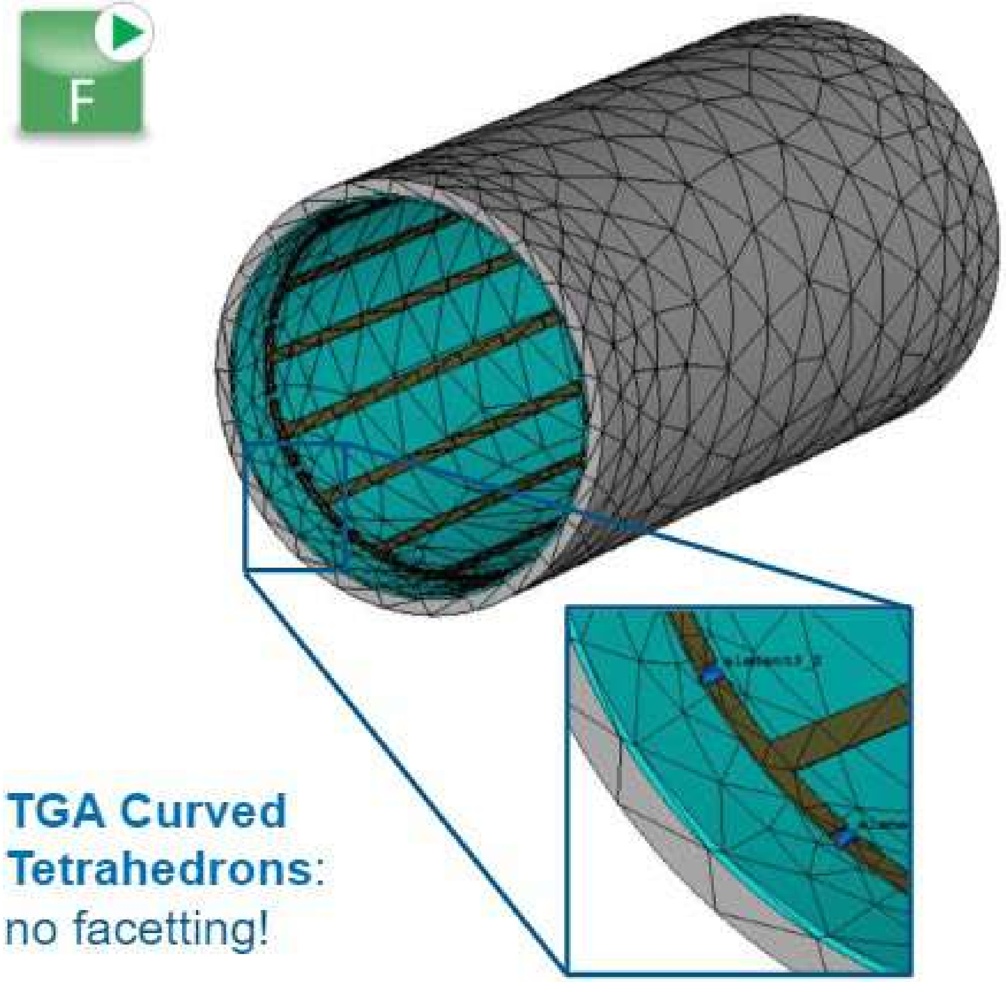
F

- Frequency samples processed sequentially, additional ports not time demanding (direct solver)
- Mesh generation can be difficult for highly complex geometries
- Works well below 1 MHz
- Can handle high Q structures
- Small to medium models
- Great speedup with multi-core CPU

Hexahedral and Tetrahedral Mesh



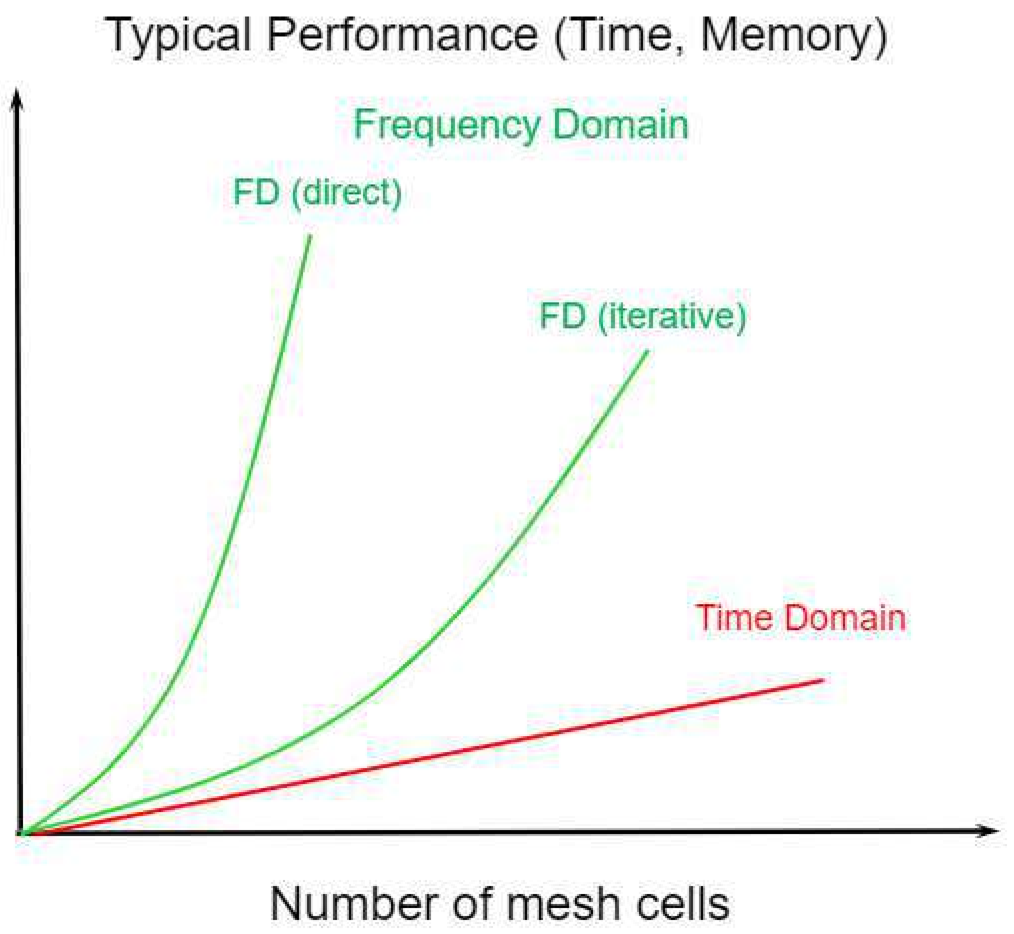
PBA and **TST**:
no staircase
meshing!



TGA Curved Tetrahedrons:
no facetting!

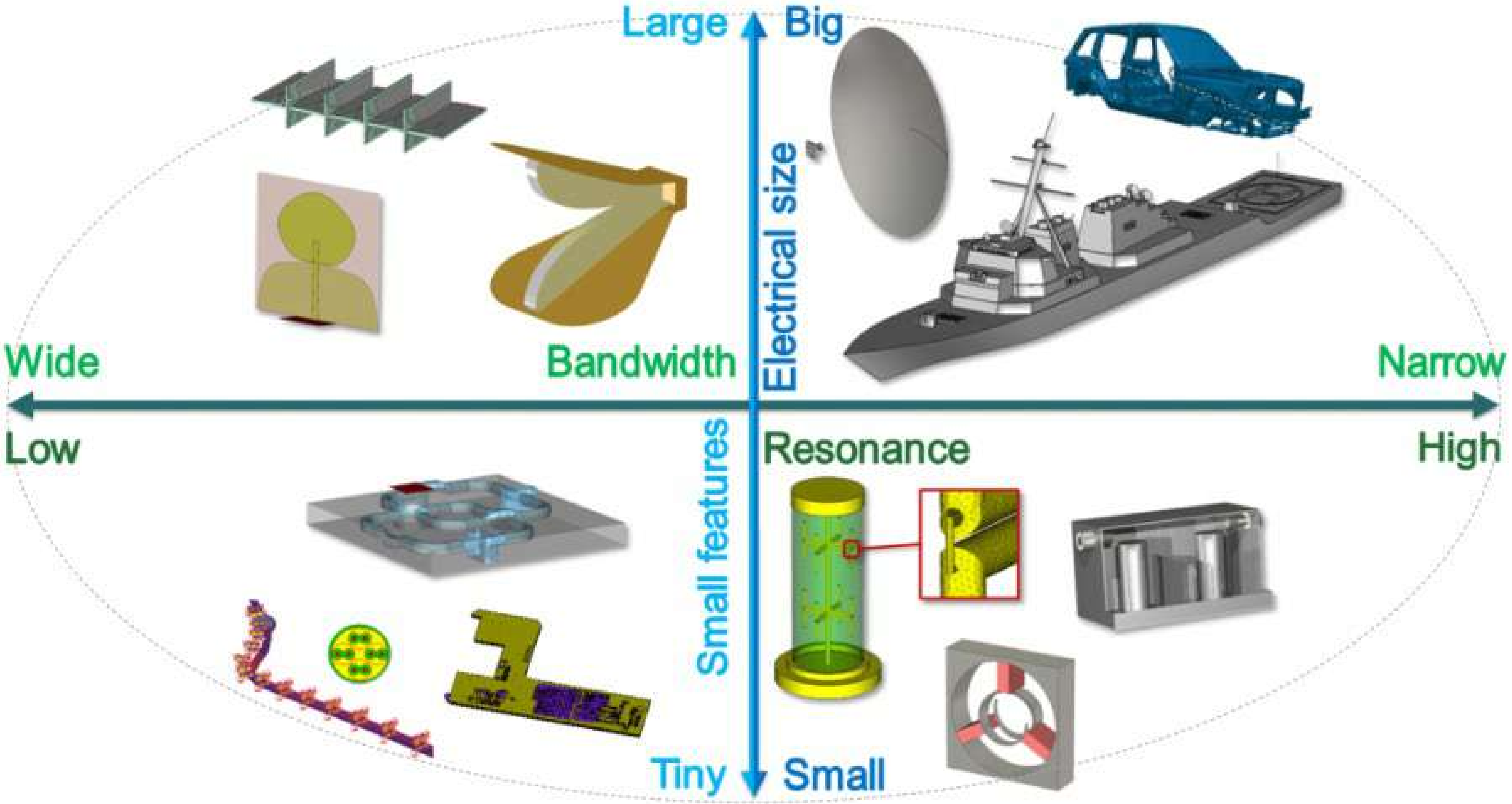
Memory and Time

- Time Domain solver –
  - Memory efficient
  - Scales linearly with no. of mesh cells
  - Approx. estimate for CPU RAM – 1GB per 4 million cells*
  - Approx. estimate for GPU RAM – 1GB per 10 million cells*
- Frequency Domain solver –
  - Memory hungry for larger models
  - Iterative solver consumes less memory than direct solver
  - Memory requirement is solver order dependent (default is 2^{nd} order)



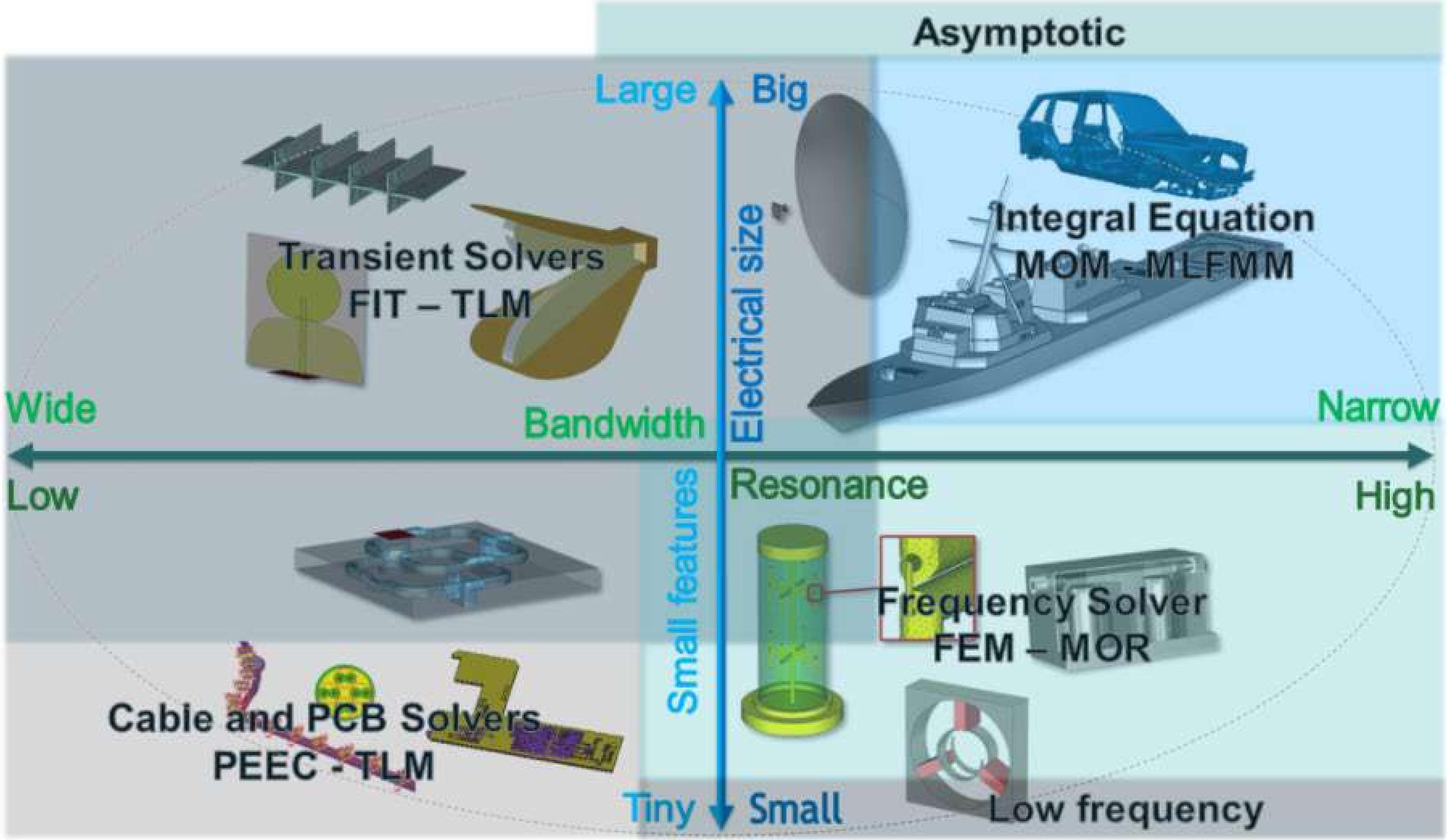
* These estimates depend on several factors including material type (lossy, dispersive dielectrics may consume more memory), boundary conditions, etc.

Selecting the Most Appropriate Solver



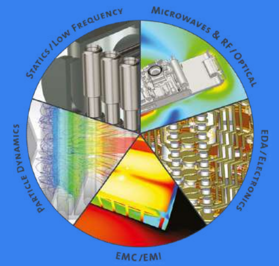
cadmicro

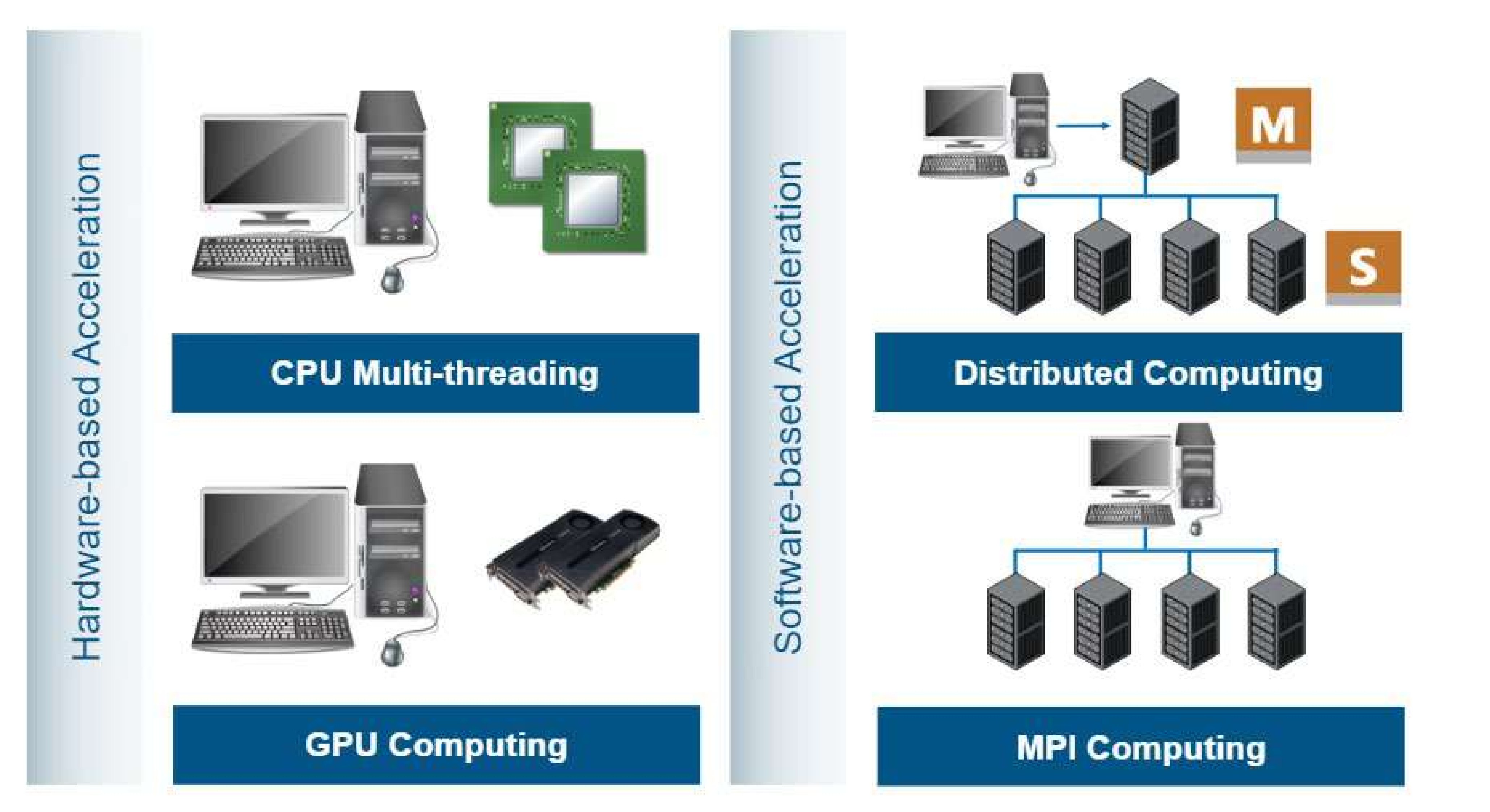
Selecting the Most Appropriate Solver



cadmicro

HPC & Cloud Computing





Hardware-based Acceleration
CPU Multi-threading
GPU Computing
Software-based Acceleration
M
S
Distributed Computing
MPI Computing

cadmicro

Supported Acceleration Methods by Solver

Solver	Multithreading	GPU Computing	Distributed Computing	MPI Computing
T	✓	✓	✓	✓
F	✓		✓	✓
I	✓	✓	✓	✓
A	✓	✓	✓	
Pic	✓	✓	✓	
WAK	✓		✓	✓

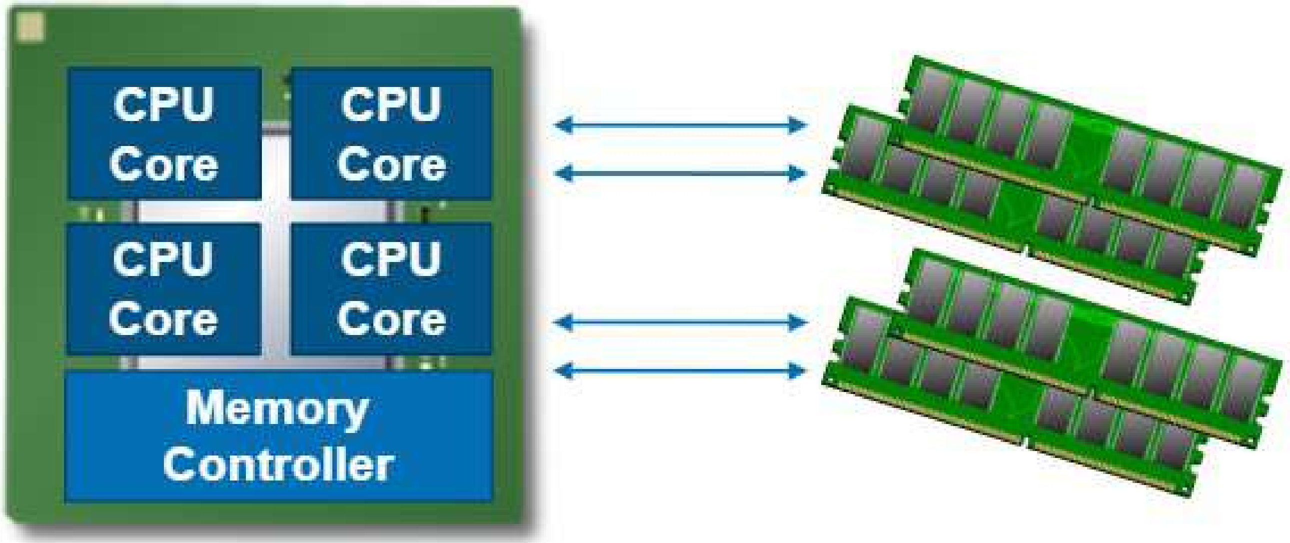
Note: The F-Solver supports MPI with the DDM solver. Please refer to the MPI Computing Guide for supported solvers, features and limitations.

Multithreading Scalability

- The bottleneck which limits the performance of the Transient Solver is the memory bandwidth of the system (i.e. the Transient Solver algorithm is memory bound)

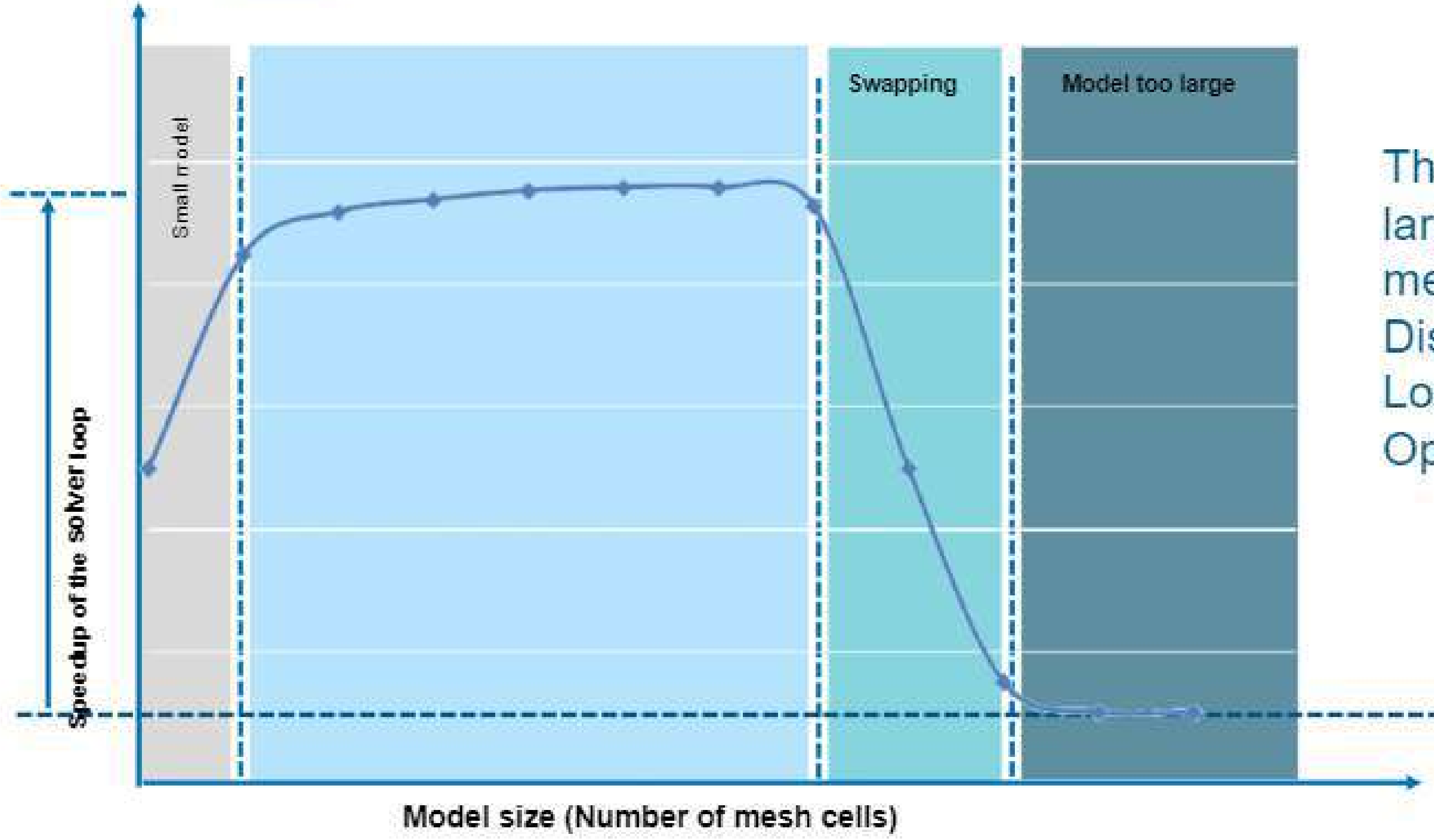
- Many CPU cores are competing for memory access.

Solution → *Hardware Acceleration*



GPU Computing — Typical Performance

GPU Computing — Typical Performance

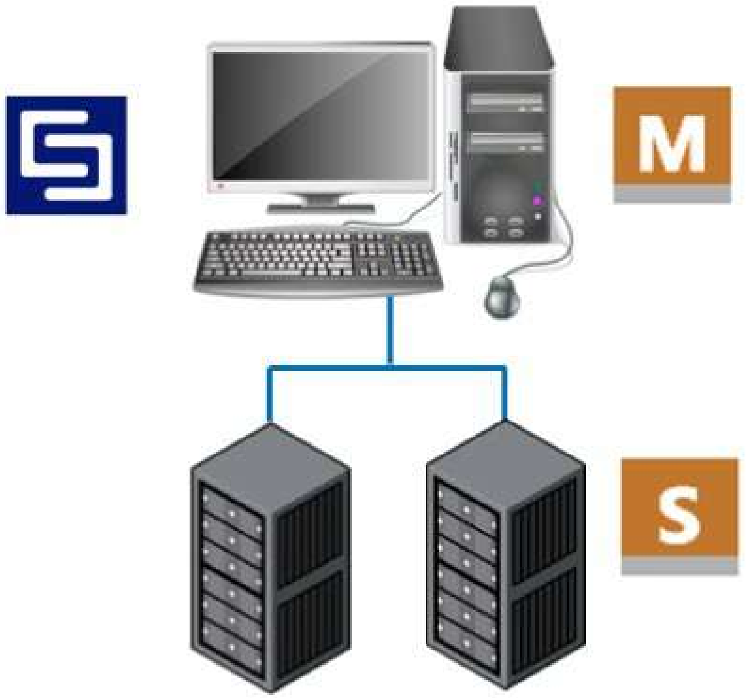


The features which require the largest amount of GPU memory:
Dispersive materials
Lossy metals
Open boundaries

Distributed Computing (1/2)

Overview

- Some parts of the simulation tasks are independent of each other:
  - Computation of different frequency samples for F-solver and I-solver
  - Simulations performed during a parameter sweep or optimization
  - Excitations from multiple sequential ports
- DC allows the distribution of independent simulation tasks, from a single project, on various systems within the same network.
- Hardware resources can be shared.

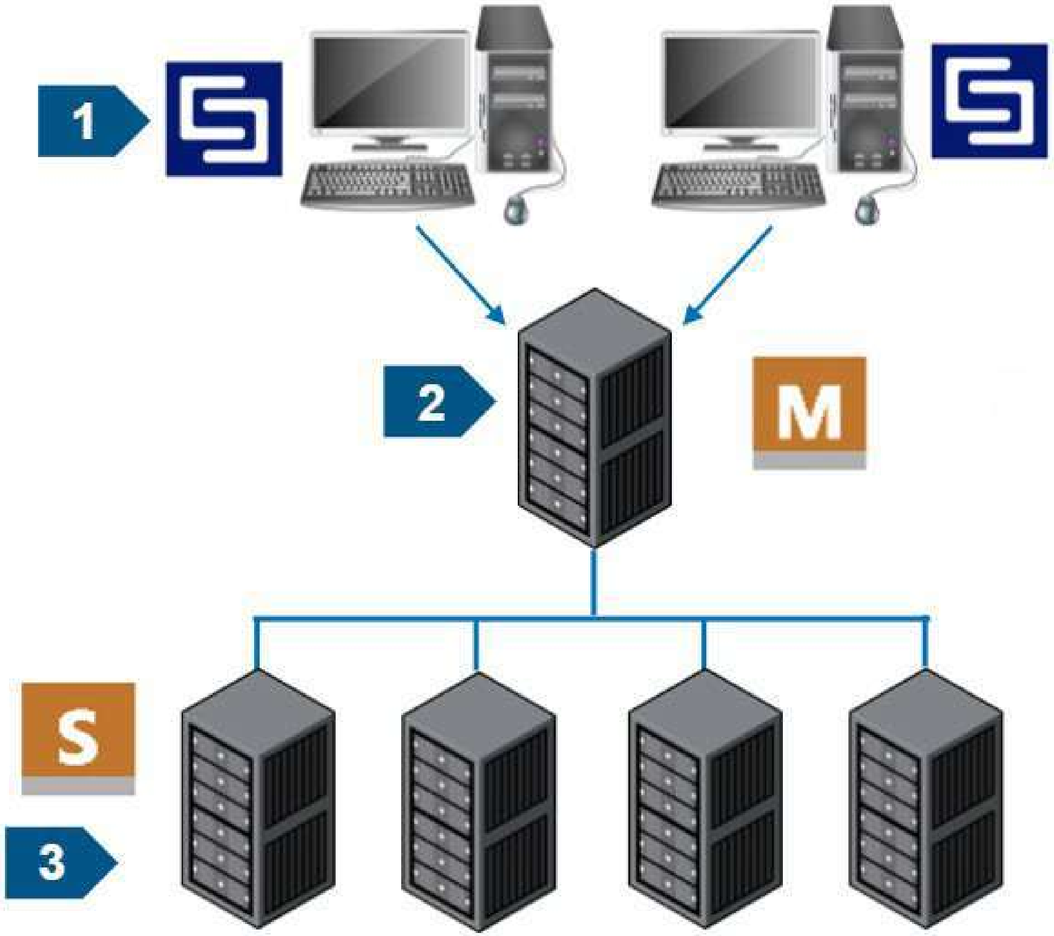


The DC functionality is part of each standard license, for up to two CPU devices/sockets.

Distributed Computing (2/2)

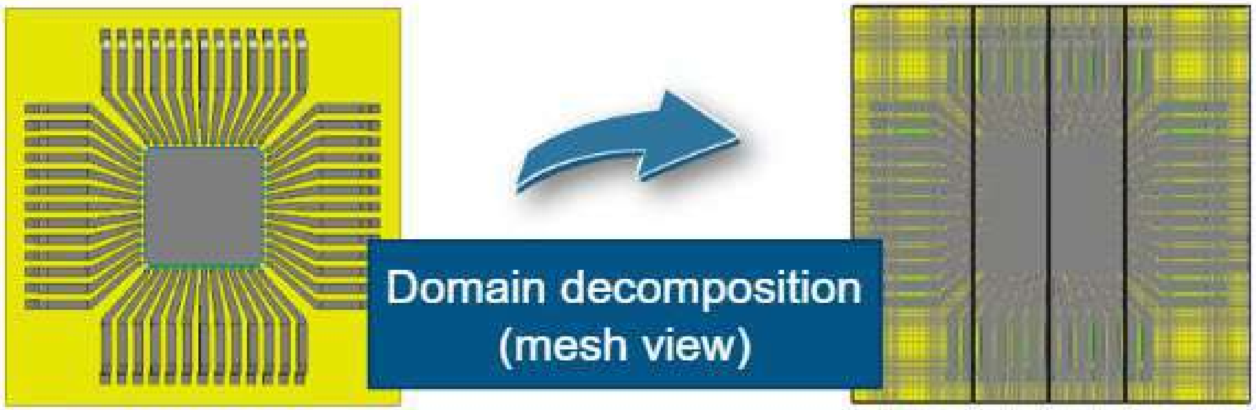
Working Principle

1. Users submit simulation jobs from their front end to the DC Main Controller
2. The DC Main Controller acts as a queuing system which selects solver servers based on the criteria entered in the solver setup.
3. The DC Main Controller then sends the simulation tasks over the network to the selected Solver Servers when they are available. Tasks are submitted on a “first come, first serve” basis.
4. Once the job is complete on the Solver Server, the job is sent back to the Main Controller to queue for the final transfer back to the corresponding front end.



MPI Computing

- MPI computing splits the computational workload for a simulation among computational resources either in a shared memory or distributed memory environment.
- MPI differs from Distributed Computing in that it can assign computational tasks which are not independent of each other to computational resources, such that these resources work on the tasks in parallel (e.g., field computations in different areas of a 3D model).
- MPI Computing provides an option for solving very large models, which might otherwise not fit in the resources available on a single workstation or server.
- Some appropriate applications for use with MPI Computing:
  - Electrically very large structures (e.g., RCS or lightning strike simulation on aircraft)
  - Extremely complex structures (e.g., SI simulation for full package)

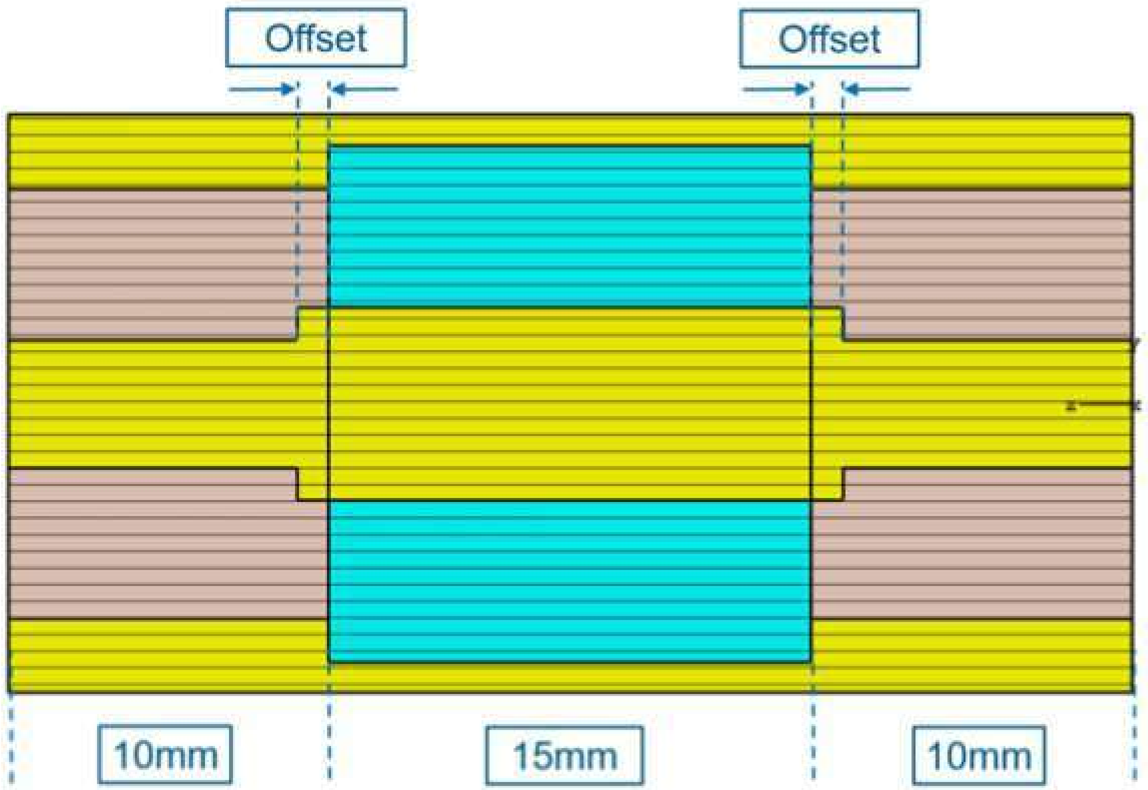


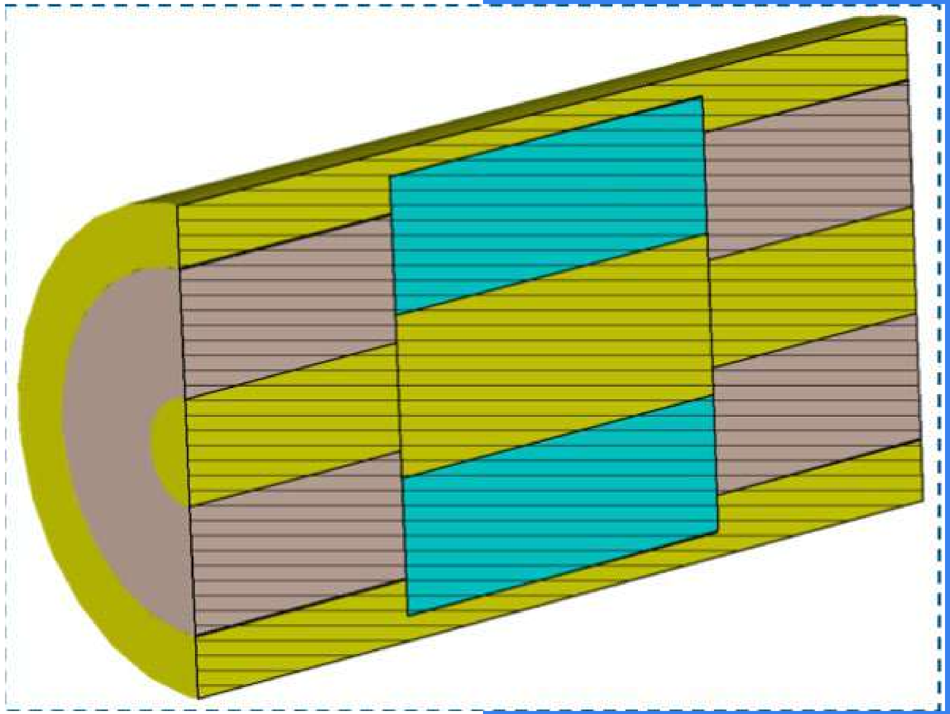
Example: Coax Connector

cadmicro

Example: Coax Connector

Perform an optimization to reduce reflections by parameterizing the offset parameter





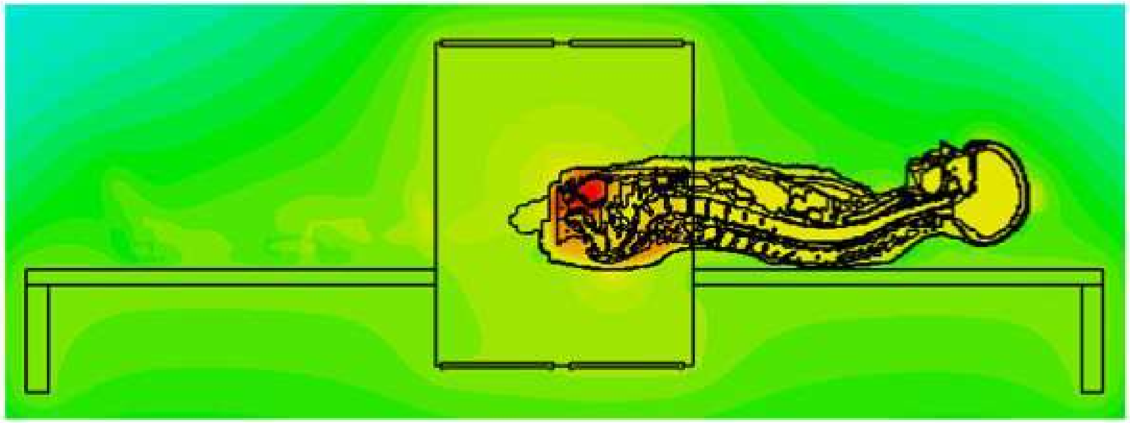
cadmicro

Multi-Physics

What is CST Multi-Physics Studio?

- CST MPhysics Studio is a software package from the CST Studio Suite family which allows thermal and mechanical simulations.
- It is based on the ACIS modeling kernel.
- Full parameterization of the structure modeler enables the use of variables in the definition of your component. In combination with the built-in optimizer and parameter sweep tools, CST MPhysics Studio is capable of analyzing and designing thermal and mechanical aspects of devices.
- After the component has been modeled, a fully automatic meshing procedure is applied before a simulation engine is started.
- A key feature of CST MPhysics Studio is its tight integration with the other CST Studio products. This allows a workflow for coupled EM-Multiphysics simulations.

Stationary Thermal Solver

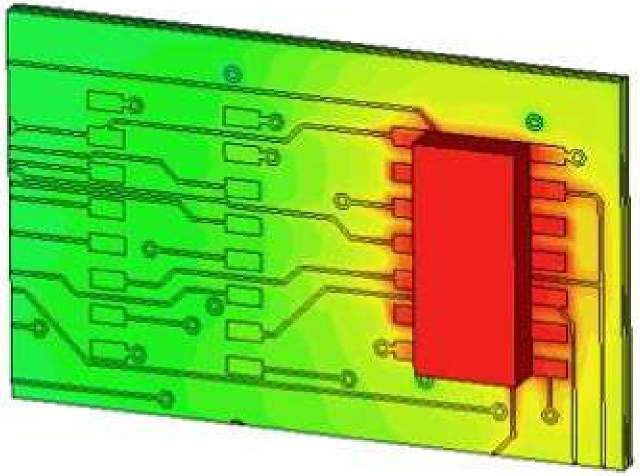


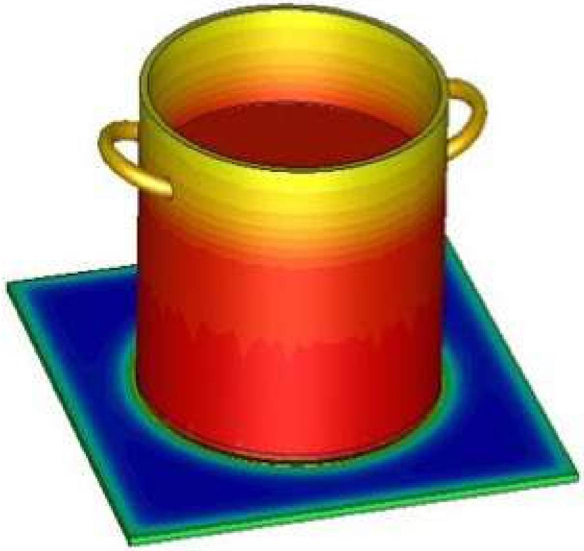
Key Features

- Steady-state solver
- Supports hexahedral and tetrahedral grids
- Uni- and bidirectional coupling with EM solvers
- Moving Media
- Bio-heat transfer

Typical Applications

- Heat distribution in PCB
- Induction heating
- Hyperthermia treatment

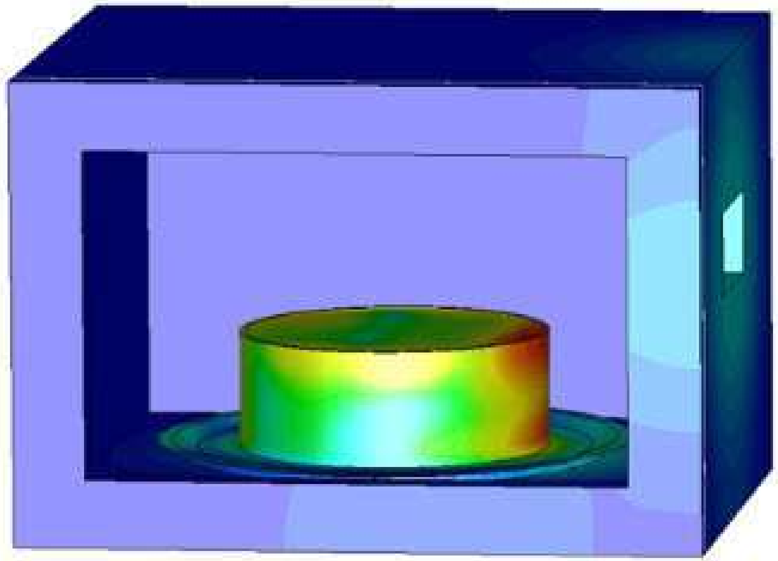




Transient Thermal Solver

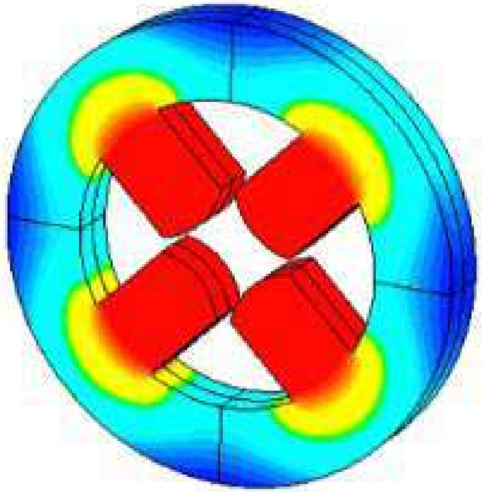
Key Features

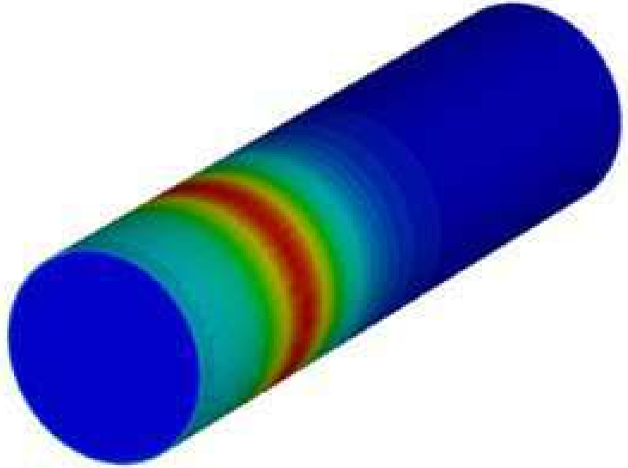
- Transient simulation with arbitrary time signals for sources
- Supports hexahedral and tetrahedral grids
- Uni- and bidirectional coupling with EM solvers
- Moving Media
- Bio-heat transfer



Typical Applications

- Microwave heating
- Induction hardening
- Temperature-dependent materials





- When accurate convection and radiation calculations are needed, the **Conjugate Heat Transfer** (CHT) solver is more appropriate to use.

- The CHT solver uses the **Computational Fluid Dynamics** (CFD) technique to solve 3D mass, momentum and energy conservation equations, collectively known as the Navier-Stokes equations. Written in a general form:

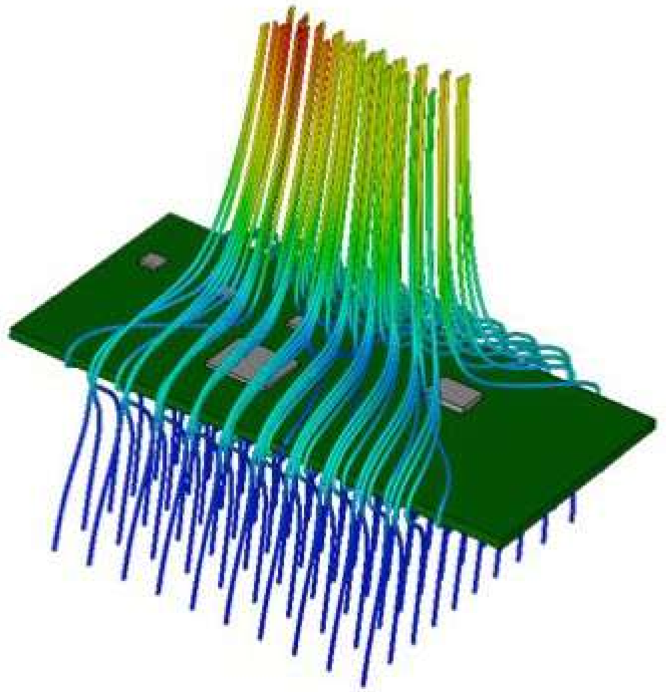
$$\frac{\partial \rho \phi}{\partial t} + \nabla \cdot (\rho \boldsymbol{U} \phi) = \nabla \cdot \left(\Gamma_\phi \nabla \phi \right) + S_\phi$$

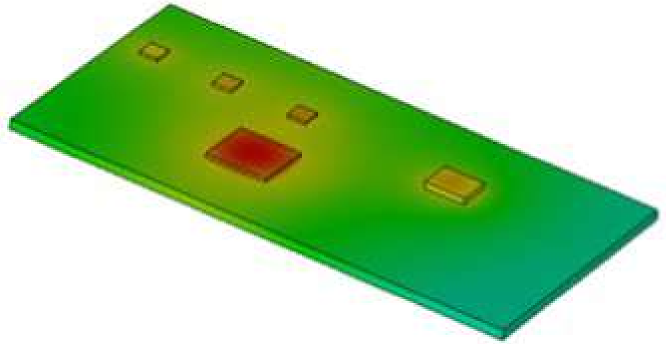
where ρ, t, $\boldsymbol{U}$, Γ_ϕ, S_ϕ are fluid density, time, velocity vector, diffusion coefficient, source respectively, and ϕ is a general variable, representing velocity components, temperature, mass, etc.

- The CHT solver employs octree-based hexahedral meshing, which can be very tolerant of geometric issues often accompanying complex CAD geometries.

Modeling Flow

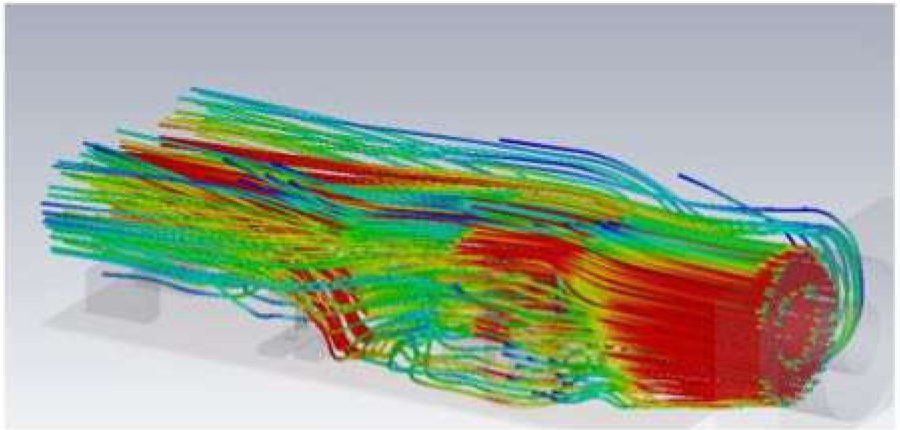
- Natural Convection
  - Typical scenario: The object is sitting in a seemingly “still” environment
  - The environment is actually not very still: the background air is usually being heated by the object and becomes lighter. The buoyancy force drives hotter air upwards. This is called Natural Convection.
  - Thermal radiation also plays an important role in Natural Convection.





Modeling Flow

- Forced Convection
  - Very often a mechanical device (e.g., certain types of fans) is used to enhance the cooling by exerting forces on the background fluid. This is called Forced Convection.
  - To model Forced Convection, three mechanisms can be used
    - Flow boundary
    - Fan
    - Opening
  - Usually under Forced Convection, thermal radiation, although still present, plays a minor role in dissipating heat, and can often be ignored.



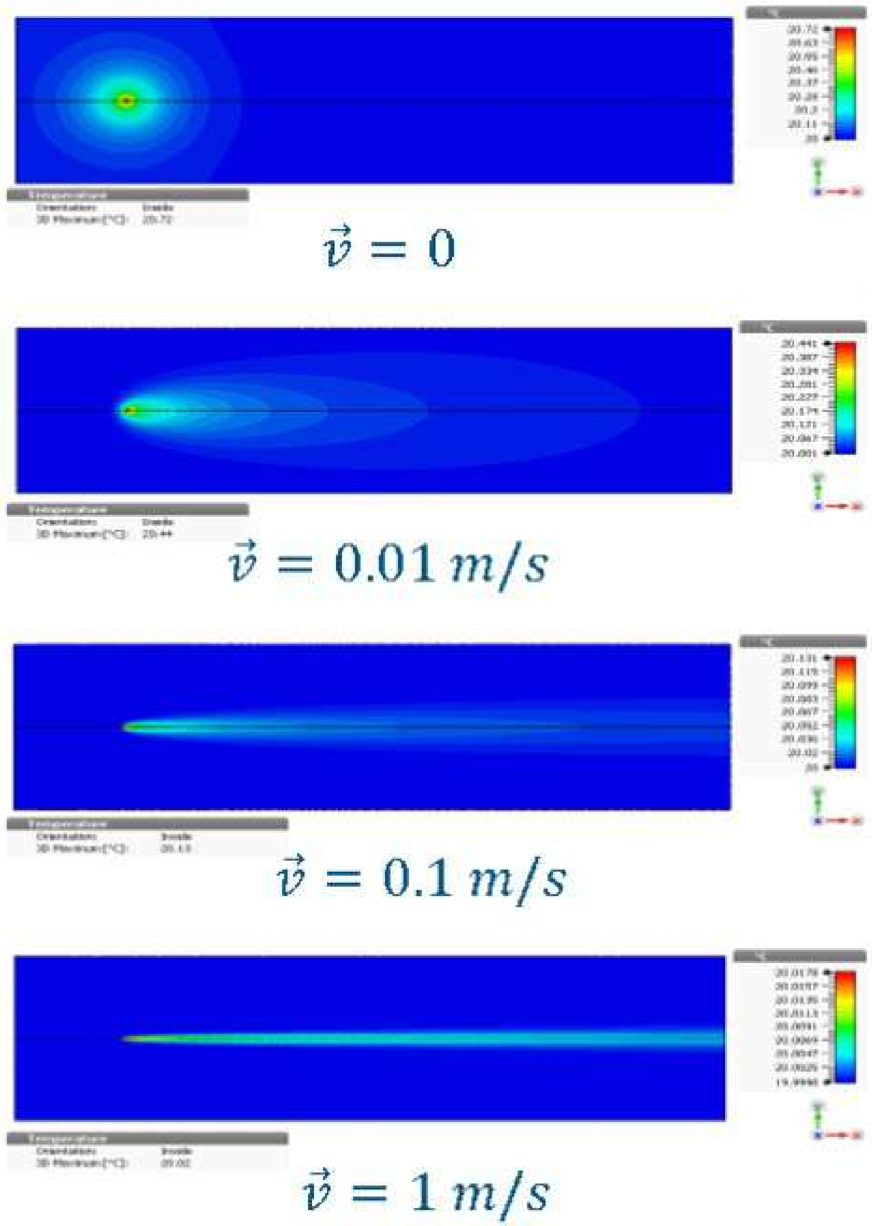
Moving Media

- When the material moves, the spot of heating moves relative to the material.
  - Usually a 'heating' trace can be seen from the solution
- A non-dimensionless number called the *Peclet number*, which is defined as

$$Pe = c\rho \frac{\mathbf{L} \cdot \mathbf{v}}{\lambda},$$

where
c : specific heat (heat capacity),
ρ : density
λ : thermal conductivity
$\mathbf{v}$: velocity of moving media
$\mathbf{L}$: characteristic (cell) length

can be used as a guidance of mesh size.



> The Peclet number usually needs to be <1; therefore, higher speeds require a finer mesh.

Coupled Simulations with Thermal or Mechanical Solvers: EM-Multiphysics couplings:

- Field monitor results from a high frequency transient, eigenmode or frequency domain solver can be used as heat sources for thermal simulations.

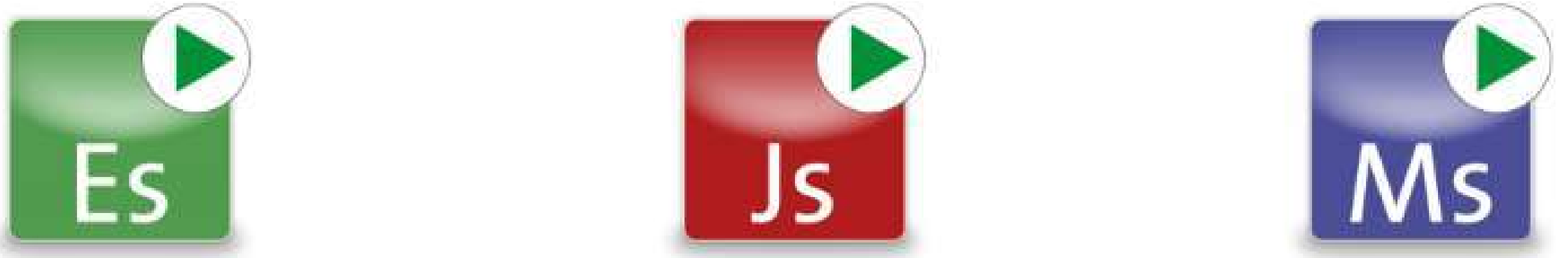
- Based on the thermal results a subsequent stress simulation can be performed, and the impact of the stress on the EM simulation can then be considered when performing a sensitivity analysis with the frequency domain or eigenmode solver with a tetrahedral mesh.

- Temperature fields calculated by the thermal solvers can be imported by the high frequency time and frequency domain solvers to simulate the effects of temperature dependent materials.

Low Frequency Simulation

CST EM Studio Solvers Overview

- **Static Solvers**
  - Electrostatic, Stationary Current and Magnetostatic Solvers:
    Do not take time-dependent effects into account. Presume a stationary state: $d/dt = 0$.



- **Dynamic Solvers**
  - Consider time dependency, either in the frequency domain (electroquasistatic, magneto-quasistatic and full wave) or in the time domain (electroquasistatic, magnetoquasistatic).

- Due to different mathematical formulations, each solver class has its own sources.

Ms LF LT

- Magneto(quasi)static and Fullwave solvers:
  - Coils and coil segments
  - Current paths
  - Voltage paths (LF, LT)
  - Current density distribution from Js (Ms)
  - Permanent magnets (Ms, LT)
  - Homogeneous magnetic source fields

Es LF LT

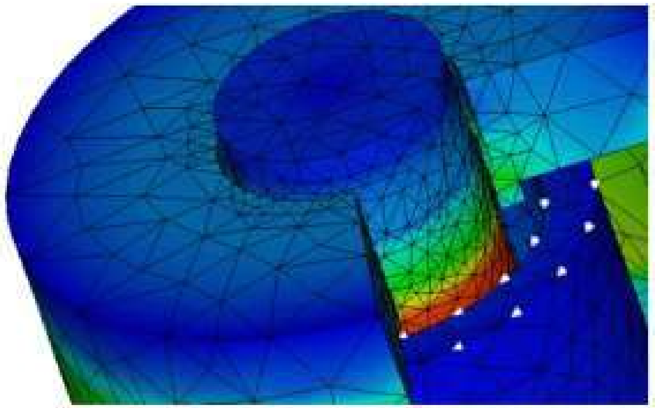
- Electro(quasi)static solvers:
  - Potentials
  - Field Grading Source
  - Charges

Source	Solver	Select?	Enter?
Electric potential	Es Js Ms LF LT	PEC Face	Potential Value (V)
Charge	Es	PEC Face	Charge Value (C)
Charge distribution	Es	Surface of "normal" Body	Total Charge (C) Charge Density (C/m³)
Permanent magnet	Ms LT	Surface of Body	Remanent Magnetization+ Permeability, J(H)-Curve
Current port	Js Ms LF LT	Face	Current
Current path	Js Ms LF LT	Curve	Current / Phase
Voltage path	LF LT	Curve	Voltage / Phase

Coil	Ms LF LT	1. Profile Curve or Face 2. Path Curve	Current/ Voltage, Phase, Number of Turns, Resistance
Coil segment	Js Ms LF LT	1. Profile Curve or Face 2. Path Curve or Pick Point	Current / Voltage, Phase, Number of Turns, Height (optional)
Magnetic source field	Ms LF LT		Field Vector
Stationary current field	Ms		Toggle on in Solver dialog box: ☑ Precompute stationary current field

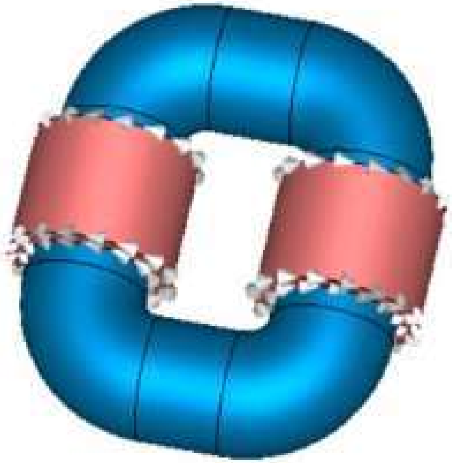
Magnetostatic Solver

- The main task for the solver is to calculate the flux density $\boldsymbol{B} = \nabla \times \boldsymbol{A}$ and the magnetic field strength $\boldsymbol{H} = \mu^{-1}(B)\boldsymbol{B} - \boldsymbol{M}_{PM}(B)$ with the magnetization $\boldsymbol{M}_{PM}(B)$ of permanent magnets under static conditions. The primary solution quantity is the magnetic vector potential $\boldsymbol{A}$.



- Flux linkage, force and torque can be calculated as well as inductance matrices.

- Planar meshes can be used for 2D simulations.



- Applications include transformers, permanent magnets, inductive sensors, coils, actuators and electric machines.

icro

Force and Torque Calculation

- After the field calculation, the forces/force density and torques on 3D objects such as solids, magnets and coils or on groups of 3D objects can be calculated as a postprocessing step.
- The algorithm implemented is discretely equivalent to the virtual work method.
- For time harmonic fields the force represents a quantity changing in time and will be characterized by three parameters in each vector component: the DC value F_{DC} and the complex AC amplitude F_{AC}

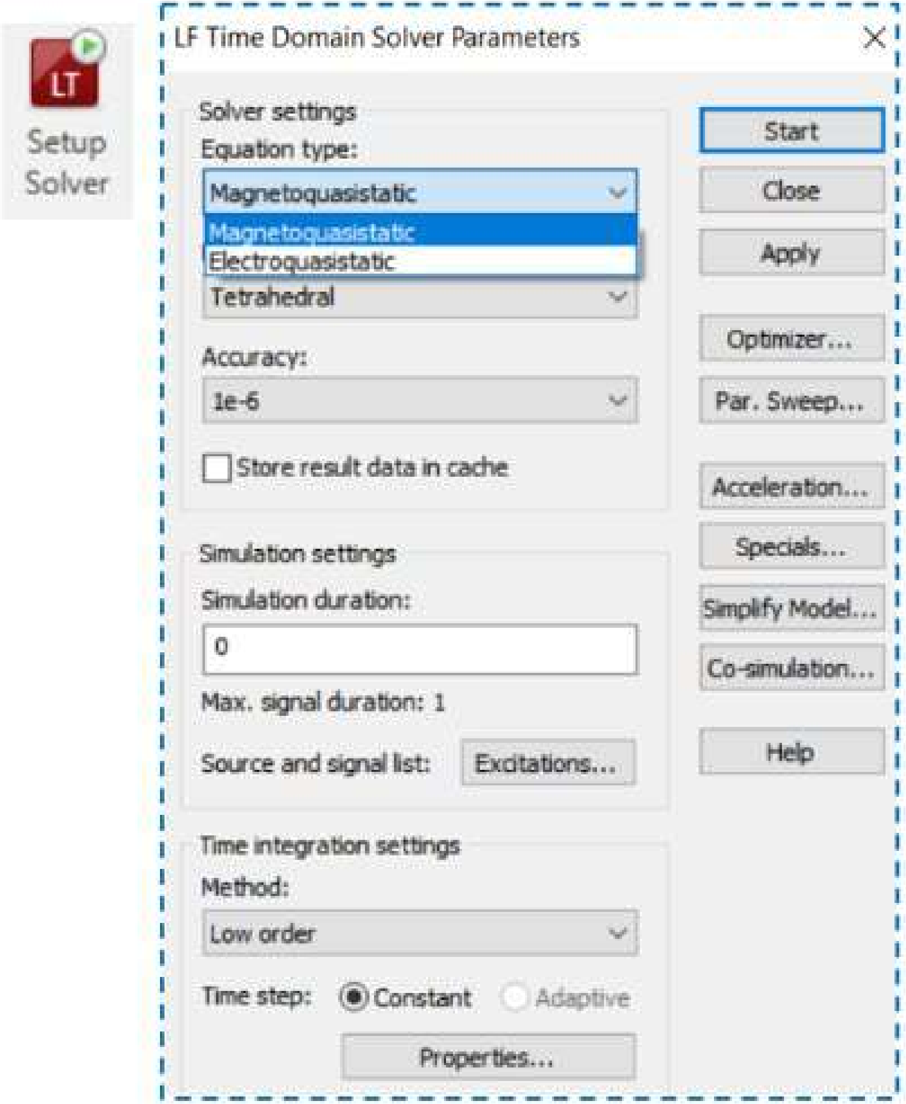
$$F(t) = F_{DC} + \mathrm{Re}\left(\mathrm{Re}(F_{AC}) + j \cdot \mathrm{Im}(F_{AC}) e^{j\omega t}\right)$$

- The force computation method requires objects which are completely surrounded by the background or by objects that are equivalent to the background.
- An object is considered equivalent to the background if
  - it has the same material coefficients (e.g., for electrostatics the same permittivity, or for magnetostatics the same permeability);
  - it is not occupied by a source.

cadmicro

LF Time Domain Solver

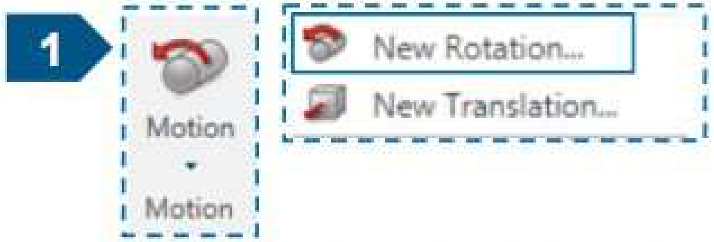
- The LF Time Domain Solver can be used to solve electromagnetic field transient problems in the time domain.
- The main task for the solver is to calculate the time evolution of losses and energies.
- Applications include transformers, coils, proximity sensors, iron loss calculations, wireless power transfer, electric machines, linear and rotational motion.
- Two equation types can be solved with the LF Time Domain Solver:
  - Magnetoquasistatic (MQS)
  - Electroquasistatic (EQS)

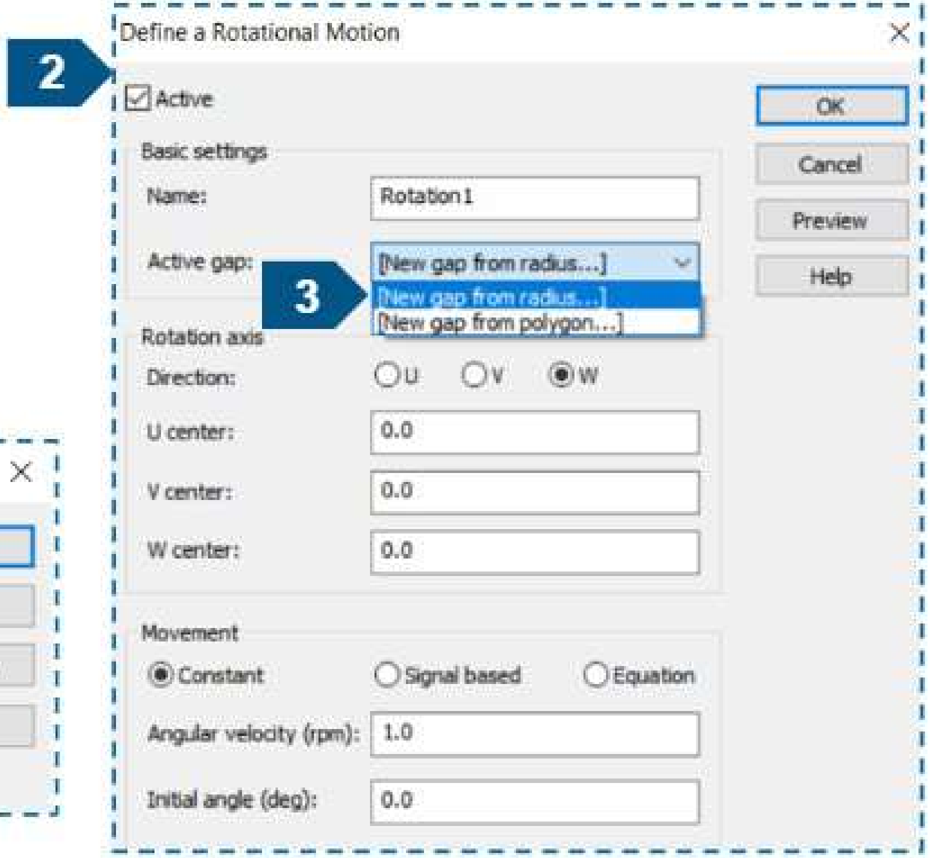


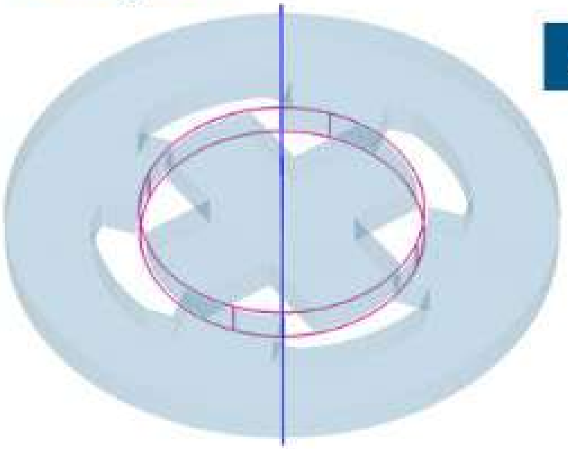
LF Time Domain Solver

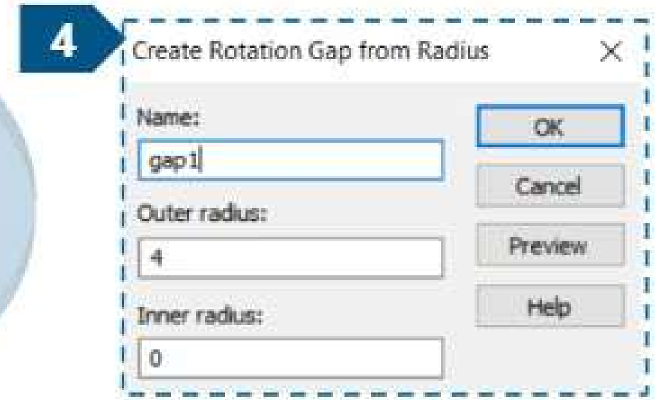
Define a Rotation

1. Select **Simulation: Motion > Motion > New Rotation**.
2. In the dialog box that appears, set the properties.
3. Select **New gap from radius** to define the rotor.
4. Double-click the outer radius/polygon in working plane or press **Esc** to show the dialog box.









Low Frequency Example

Permanent Magnet Synchronous Motor

cadmicro

Thank you!

cadmicro

Questions & Answers