INTRODUCTION

CST Microwave Studio

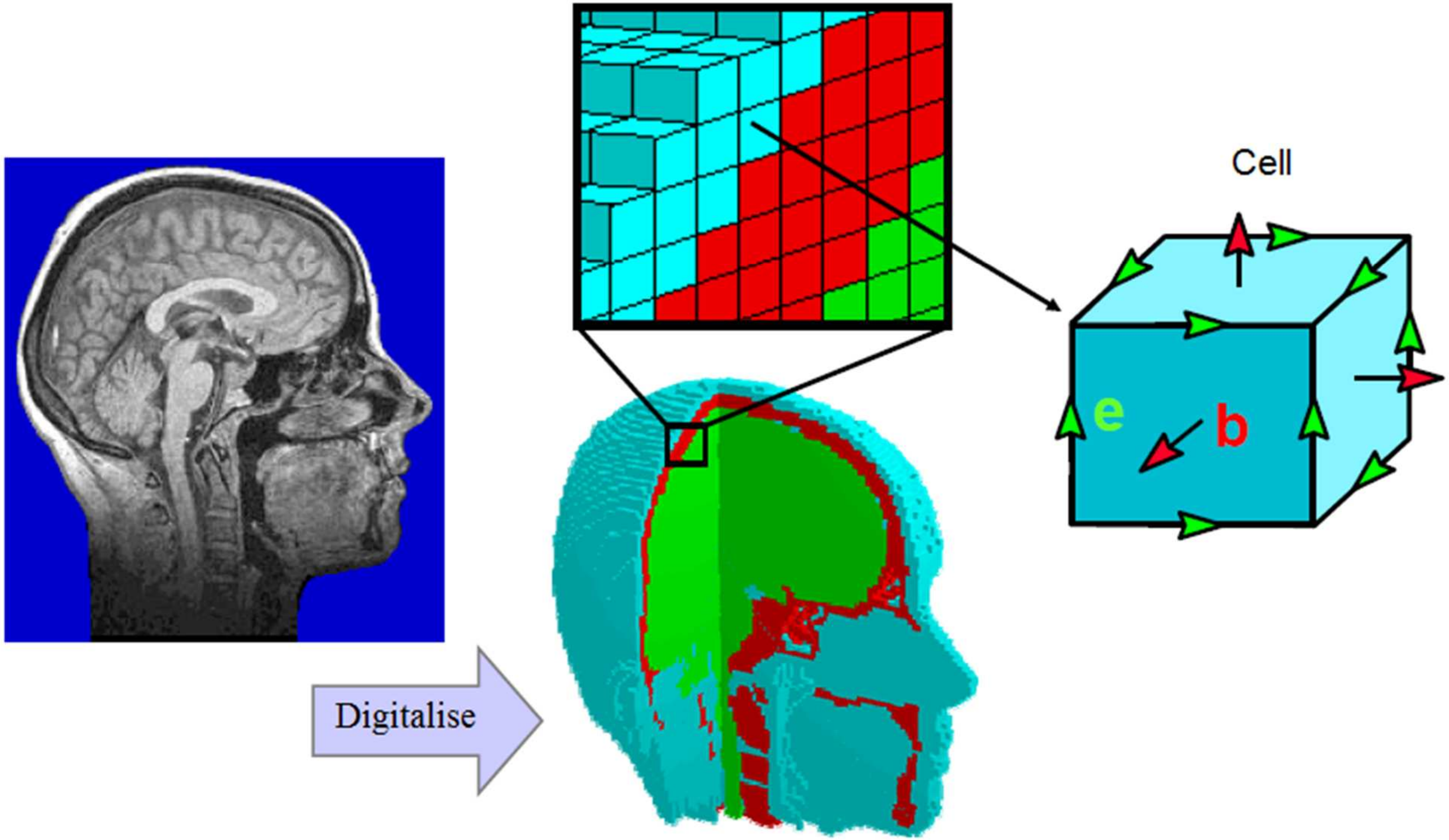
Background of the simulation method

- Finite Integration Technique (FIT)
    - First proposed by Weiland in 1976/1977.
    - Originated from FDTD (Finite Difference Time Domain) method, which was proposed by Yee in 1966.
  - A spatial discretisation scheme to numerically solve electromagnetic field problems in time domain.
  - Since it is a time-domain method, solutions can cover a wide frequency range with a single simulation run.
  - Unlike FDTD, FIT discretises the following integral form of Maxwell's equations rather than the differential one

$$\oint_{\partial A} \vec{E} \cdot d\vec{s} = -\int_A \frac{\partial \vec{B}}{\partial t} \cdot d\vec{A} \qquad \oint_{\partial A} \vec{H} \cdot d\vec{s} = \int_A \left(\frac{\partial \vec{D}}{\partial t} + \vec{J} \right) \cdot d\vec{A}$$

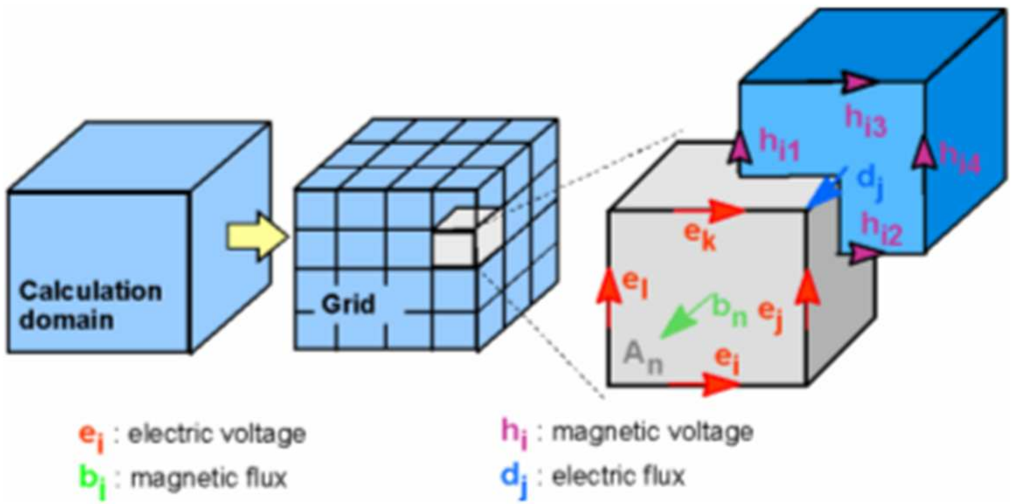
$$\oint_{\partial V} \vec{D} \cdot d\vec{A} = \int_V \rho \, dV \qquad \oint_{\partial V} \vec{B} \cdot d\vec{A} = 0$$

Grid, meshcell



Grid, meshcell

- 1. Splitting the studying domain up into many small grid cells (orthogonal, hexahedral).
  - The electric grid voltages **e** and magnetic facet fluxes **b** are allocated on the primary grid.
  - In addition, the dielectric facet fluxes **d** as well as the magnetic grid voltages **h** are defined on the dual grid.

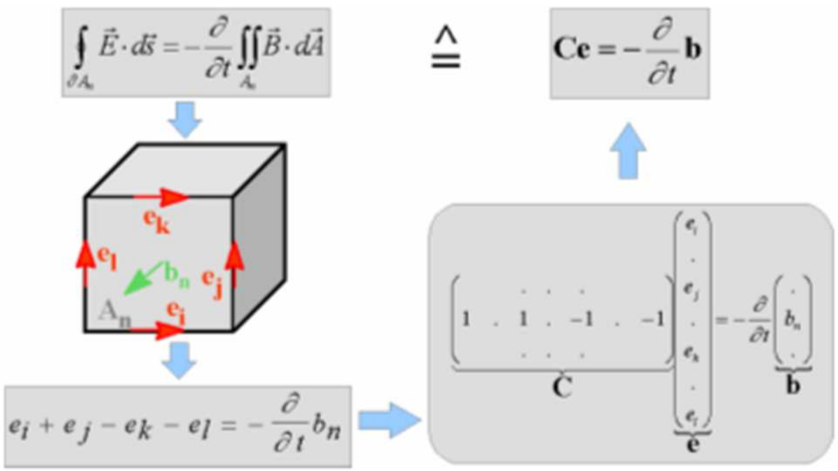


Yee cell:

Each grid has its own dielectric properties

Discretisation of Maxwell's equations

- 2. Maxwell's equations are formulated for each of the cell facets separately.
  - Faraday's Law
    - Left hand: the closed integral on the equation's left side can be rewritten as a sum of four grid voltages.
    - Right hand: the time derivative of the magnetic flux defined on the enclosed primary cell facet
    - Repeating this procedure for all available cell facets
    - Summarizes the calculation rule in a matrix formulation and introducing the topological matrix **C** as the ***"discrete curl operator"***



Discretisation of Maxwell's equations

– Ampère's law

- Introduce the definition of a corresponding dual discrete curl operator Ĉ

$$\tilde{\mathbf{C}}\mathbf{h} = \frac{d}{dt}\mathbf{d} + \mathbf{j} \ ,$$

- Similarly the discretisation of the remaining divergence equations introduces discrete divergence operators S and Ŝ

$$\tilde{\mathbf{S}}\mathbf{d} = \mathbf{q} \ , \qquad \mathbf{S}\mathbf{b} = \mathbf{0} \ .$$

- Finally, we got the complete discretised set of Maxwell's Grid Equations (MGEs):

$$\mathbf{C}\mathbf{e} = -\frac{d}{dt}\mathbf{b} \ , \qquad \tilde{\mathbf{C}}\mathbf{h} = \frac{d}{dt}\mathbf{d} + \mathbf{j} \ ,$$

$$\tilde{\mathbf{S}}\mathbf{d} = \mathbf{q} \ , \qquad \mathbf{S}\mathbf{b} = \mathbf{0} \ .$$

Discretisation of Maxwell's equations

– Material relations:
  - Introduce inevitable numerical inaccuracy due to spatial discretisation.
  - The coefficients depend on the averaged material parameters as well as on the spatial resolution of the grid

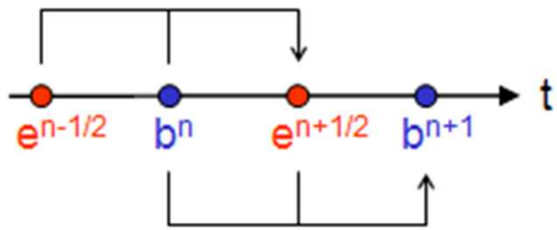
$$\vec{D} = \varepsilon \vec{E} \qquad\qquad \mathbf{d} = \mathbf{M}_{\varepsilon}\mathbf{e}$$
$$\vec{B} = \mu \vec{H} \qquad \Rightarrow \qquad \mathbf{b} = \mathbf{M}_{\mu}\mathbf{h}$$
$$\vec{J} = \sigma \vec{E} + \vec{J}_S \qquad\qquad \mathbf{j} = \mathbf{M}_{\sigma}\mathbf{e} + \mathbf{j}_S$$

Leap-frog scheme

- The transient solver (time domain) is based on the solution of the discretised set of Maxwell's Grid Equations.
- Substituting the time derivatives by central differences yields explicit update formulation for the loss-free case:

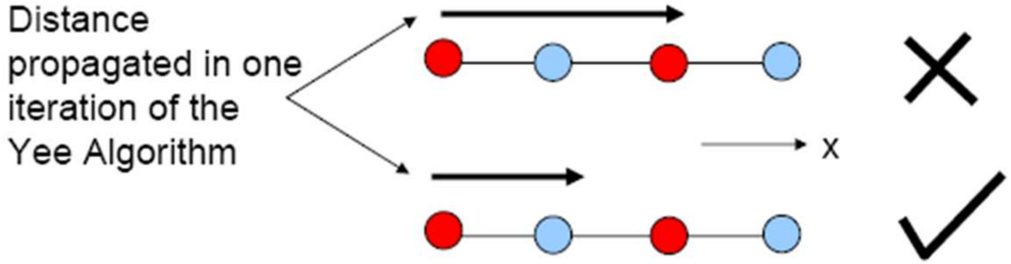
$$\mathbf{e}^{n+1/2} = \mathbf{e}^{n-1/2} + \Delta t \mathbf{M}_{\varepsilon}^{-1} \left[\widetilde{\mathbf{C}} \mathbf{M}_{\mu}^{-1} \mathbf{b}^{n} + \mathbf{j}_S^n \right],$$
$$\mathbf{b}^{n+1} = \mathbf{b}^{n} - \Delta t \, \mathbf{C} \, \mathbf{e}^{n+1/2} \; .$$

- Calculation variables are given by **e** and **b**. Both types of unknowns are located alternately in time.
  - For example, the magnetic flux at t = (n+1) Δt is computed from the magnetic flux at the previous time step t = n Δt and from the electric voltage at half a time step before, at t = (n+1/2) Δt .



Stability criterion

- Definition of stability: "A bounded input produces a bounded output, as the iteration time progresses".
- For stability to be maintained, the field must not change significantly from one point to another and a wave must not propagate more than one spatial field point in any one iteration of the algorithm.

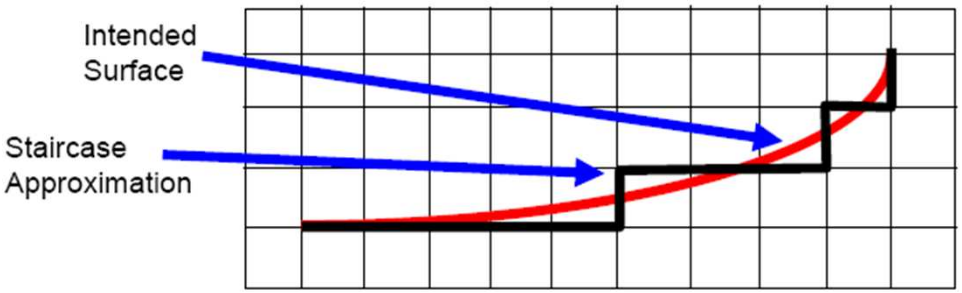


- Explicit time integration schemes are conditionally stable. The stability limit for the time step Δt is given by the Courant-Friedrichs-Levy (CFL) criterion

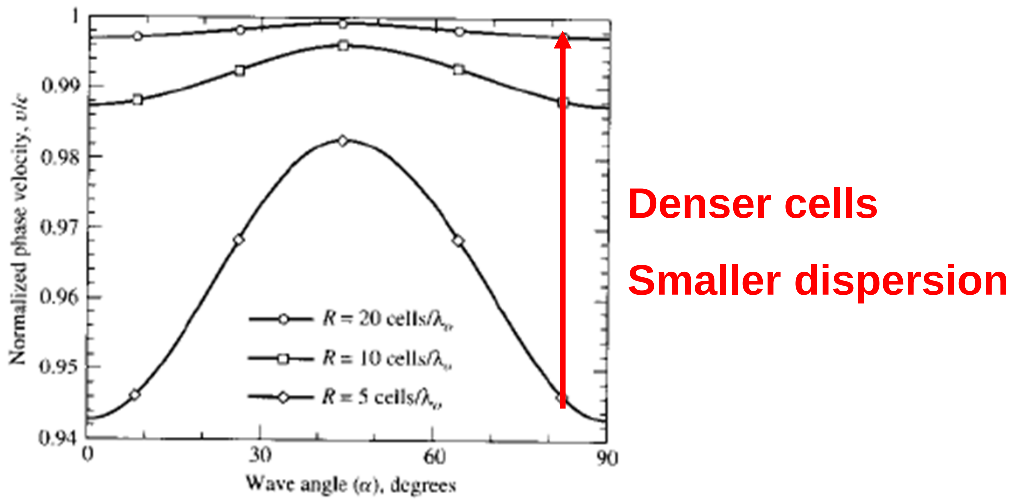
$$\Delta t \leq \frac{\sqrt{\varepsilon\mu}}{\sqrt{\left(\frac{1}{\Delta x}\right)^2+\left(\frac{1}{\Delta y}\right)^2+\left(\frac{1}{\Delta z}\right)^2}}$$

Stability criterion

- How to model a curved structure using the Yee cell arrangement?
  - Can not model a curved surface exactly
  - Must approximate it as a series of discrete steps
  - Technique known as the STAIRCASE APPROXIMATION

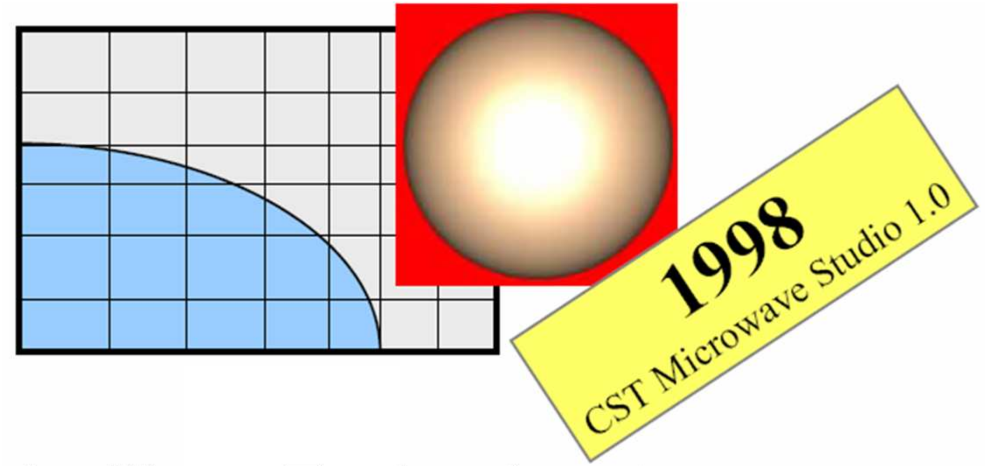


In the discrete domain, the velocity of propagation is a function of the spatial discretisation used. This effect is called ***numerical dispersion*** of the grids.

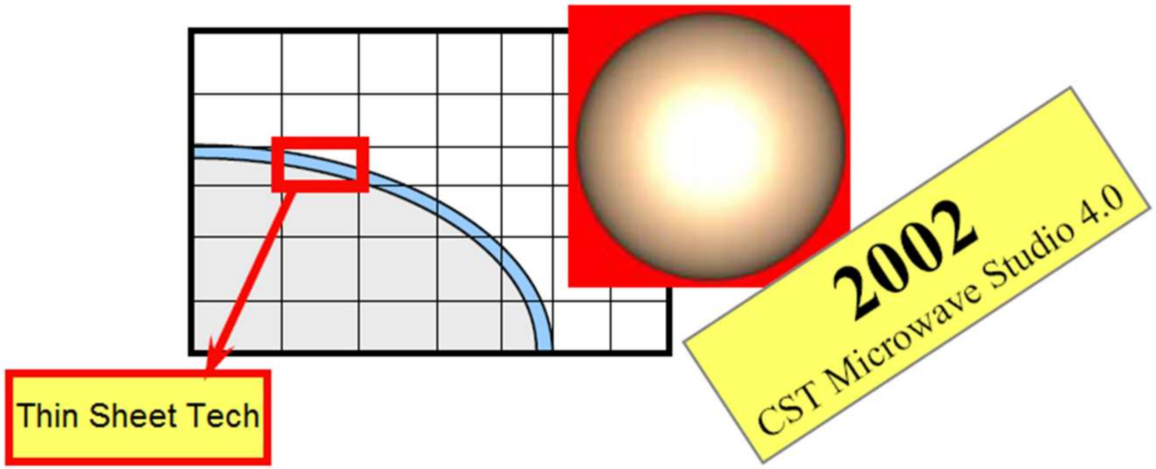


Novel techniques on mesh discretisation

- PBA (Perfect Boundary Approximation)



- TST (Thin Sheet Technology)

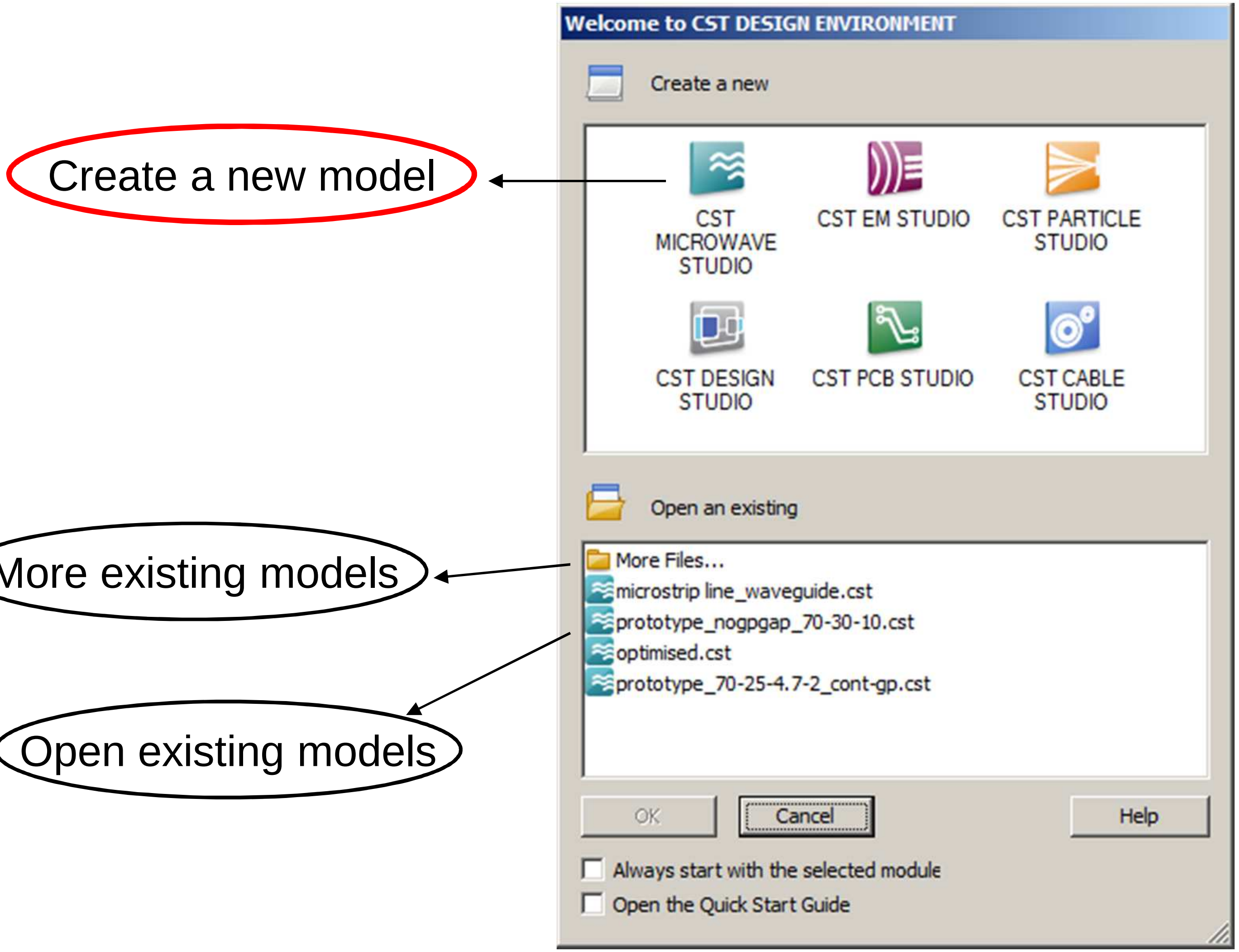


CST STUDIO SUITE ™

CST MICROWAVE STUDIO®	CST MICROWAVE STUDIO® is a specialized tool for the fast and accurate 3D EM simulation of high frequency problems. Along with a broad application range, CST MICROWAVE STUDIO® offers considerable product-to-market advantages: shorter development cycles; virtual prototyping before physical trials; optimization instead of experimentation.
CST EM STUDIO®	CST EM STUDIO® is an easy-to-use tool for the analysis and design of static and low frequency structures. Applications include: actuators, brakes, EMC, generators, measurement, motors, sensors and shielding.
CST PARTICLE STUDIO®	CST PARTICLE STUDIO® is a specialized tool for the fast and accurate design and analysis of 3D electron guns. This new software is based on the multi-purpose electromagnetic solvers of the CST STUDIO family and incorporates their powerful modelling capabilities in addition to successful algorithms of the MAFIA-TS simulators.
CST DESIGN STUDIO™	CST DESIGN STUDIO™ represents a universal platform to manage the entire design process of a complex system beginning with a first layout and closing with the final solution. By constructing elementary sub-systems, the user can analyze the behavior of the complete system in small segments.
CST PCB STUDIO™	CST PCB STUDIO™ is a tool for the investigation of Signal and Power Integrity and the simulation of EMC and EMI effects on Printed Circuit Boards (PCB).
CST CABLE STUDIO™	CST CABLE STUDIO™ is a tool for the analysis of SI, EMC and EMI effects in cable systems including single wires, twisted pairs as well as complex cable harnesses.

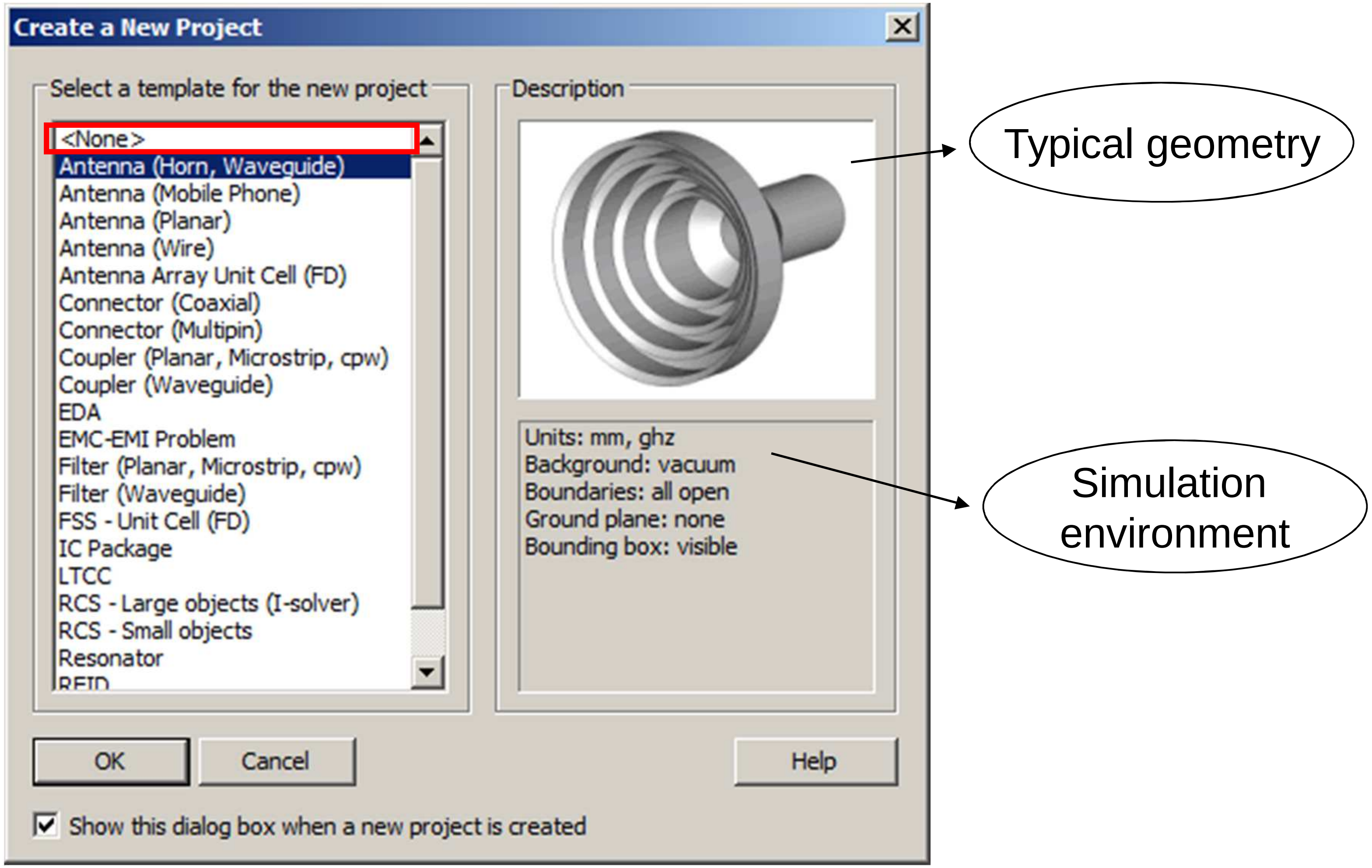
Start CST

- CST Design Environment



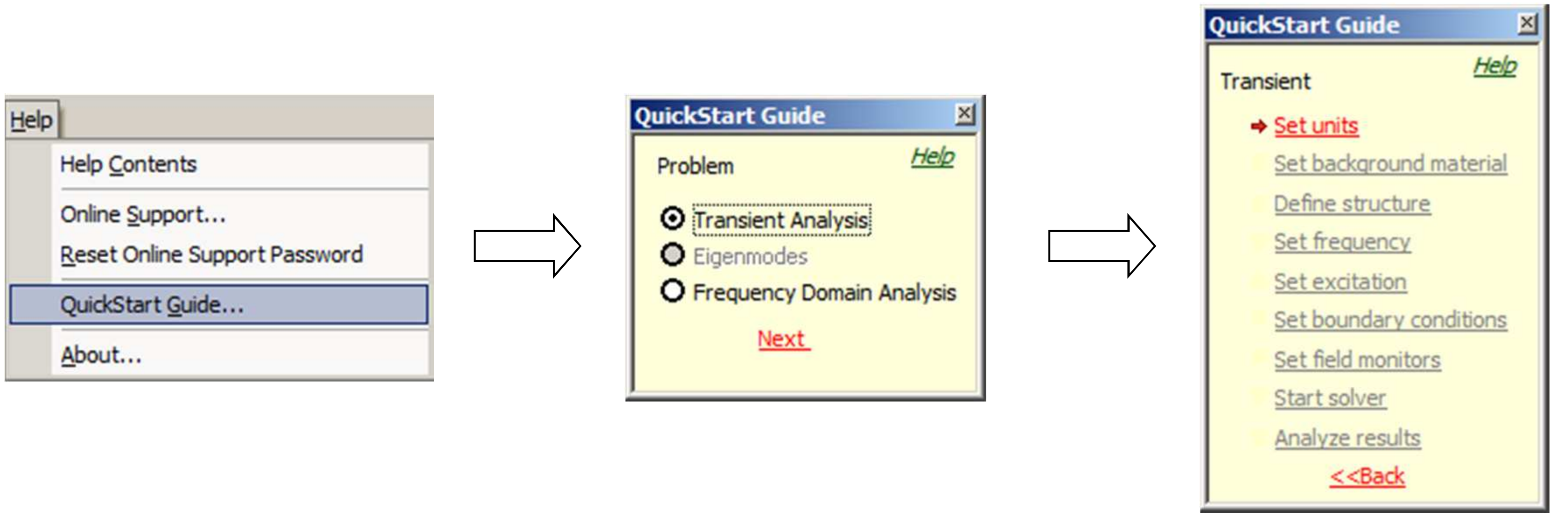
Start CST

- Template for the new project



The first model with QuickStart Guide

- Help -> QuickStart Guide…

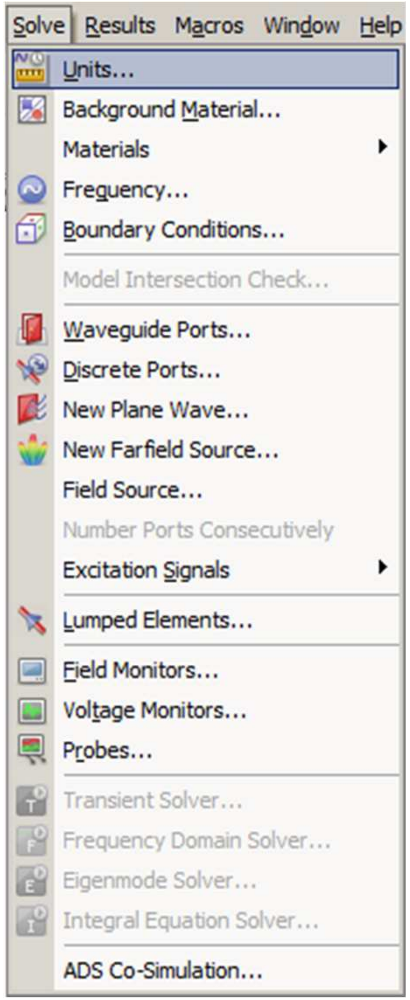


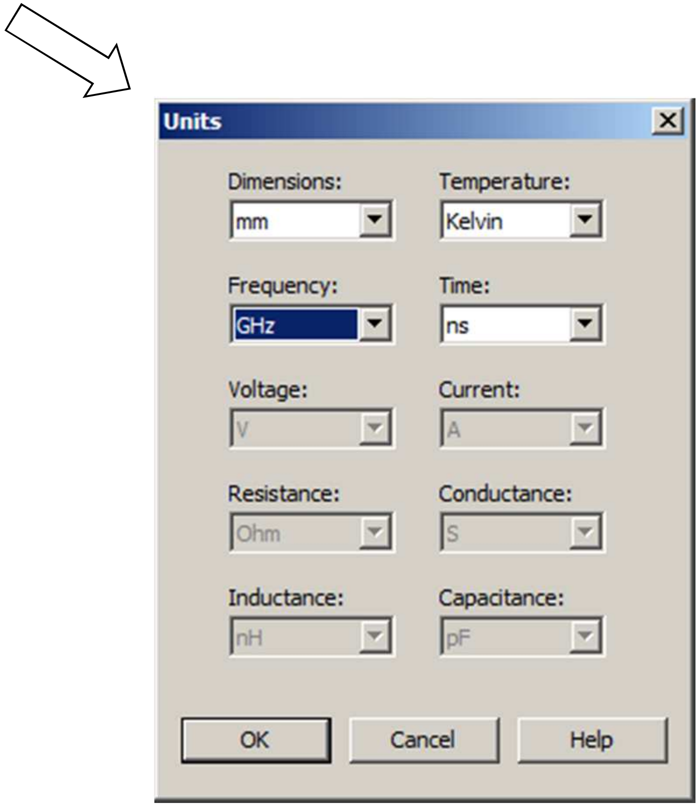
Procedures of a simulation

- 1. Set units (mm, ns, GHz)
- 2. Set background material (normal)
- 3. Define structure (draw the geometry)
- 4. Set frequency (range)
- 5. Set excitation (port and signal)
- 6. Set boundary condition (open add space)
- *. Set mesh properties
- 7. Set field monitors (E-field, H-field and far-field)
- 8. Start solver (T-solver)
- 9. Analyse results
  - S-parameters (return loss s_{11}, transmission coefficient s_{21})
  - Radiation patterns (far-field)
  - Current distribution & current flow

First simulation model – microstrip line

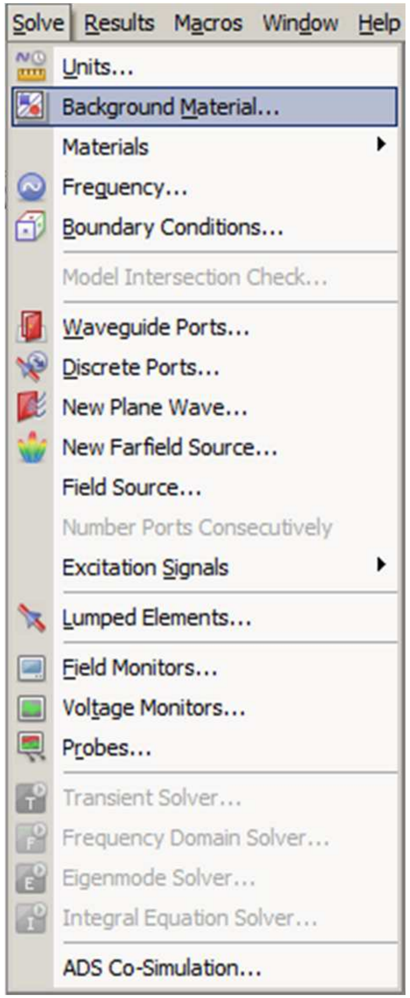
– 1. Set units (mm, ns, GHz)

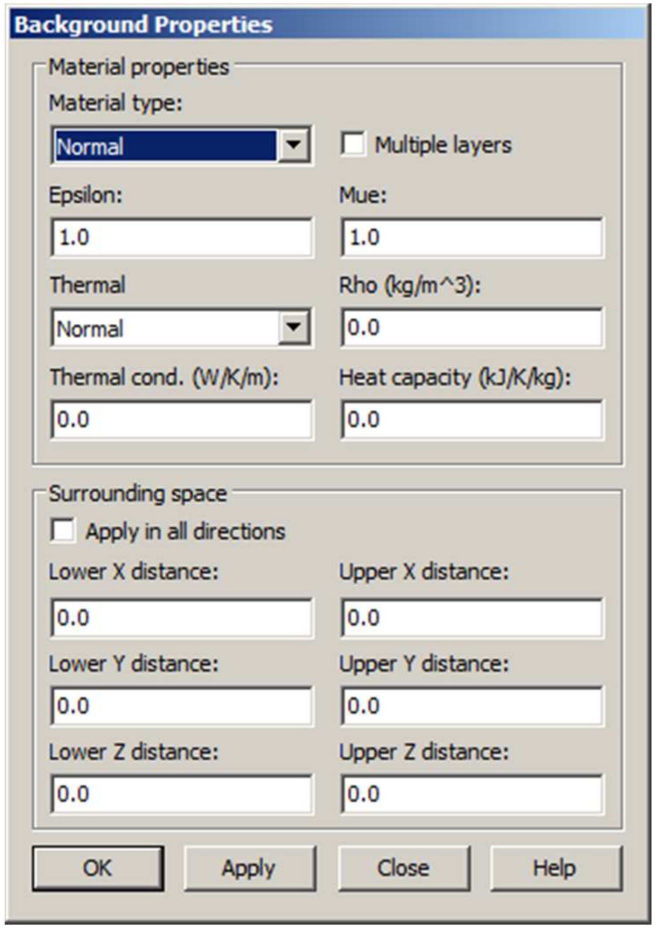




First simulation model – microstrip line

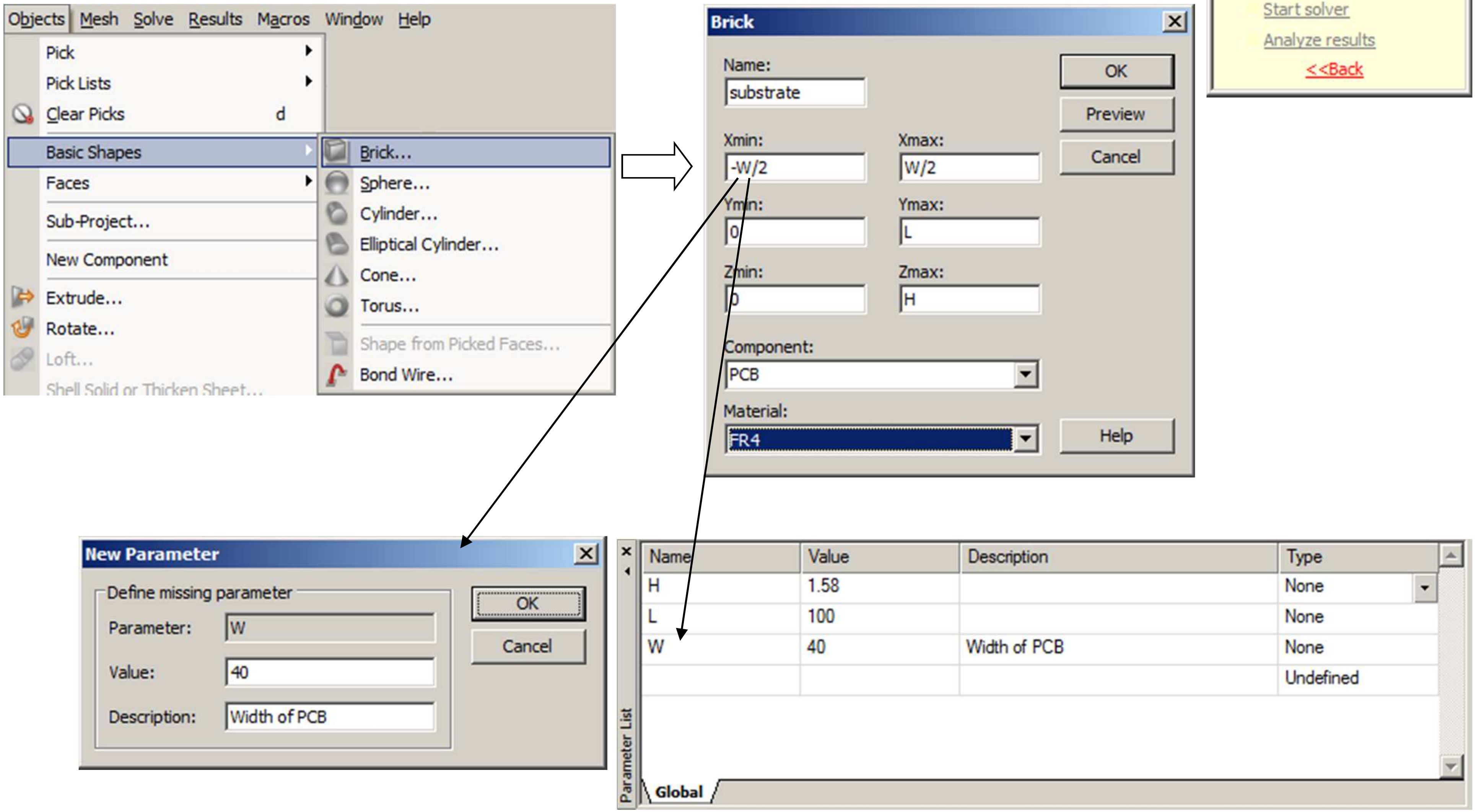
– 2. Set background material (normal)





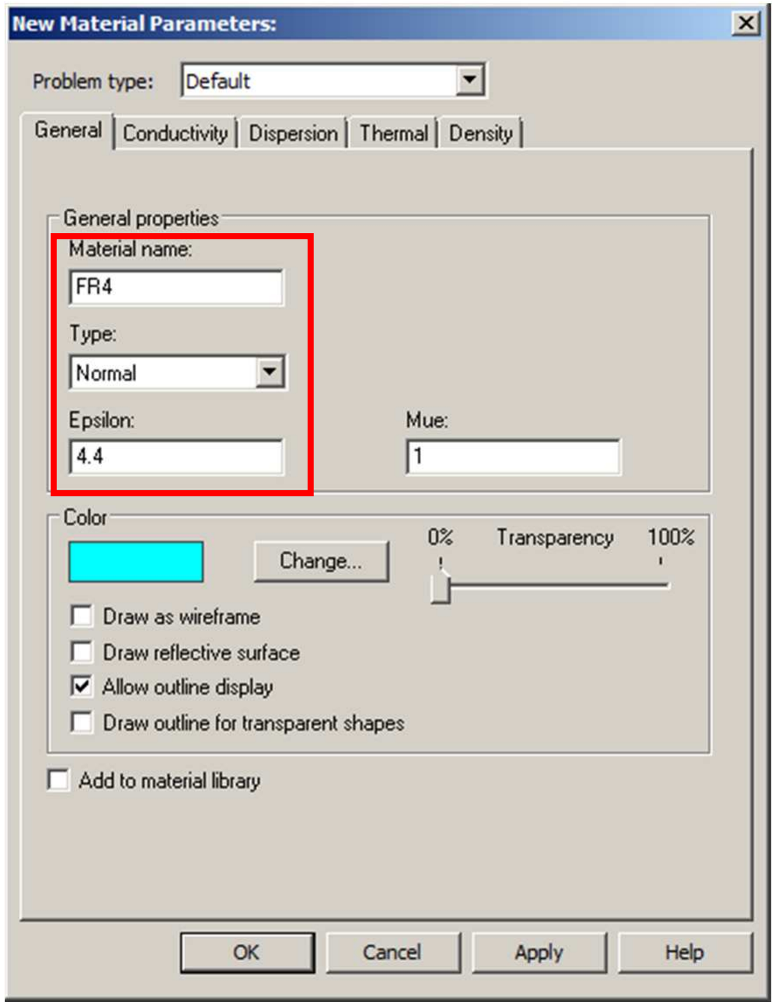
First simulation model – microstrip line

– 3. Define structure (draw the geometry)



First simulation model – microstrip line

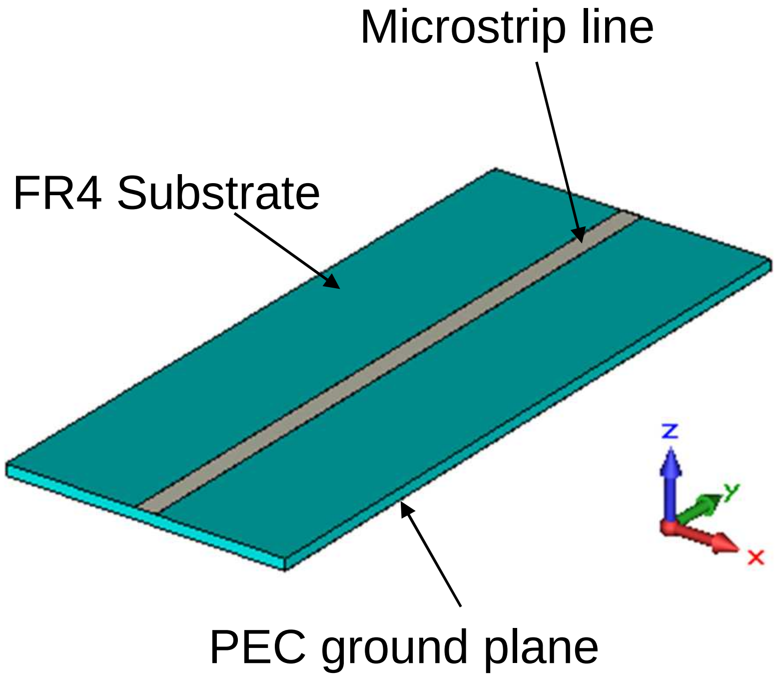
- Define the material (if needed)



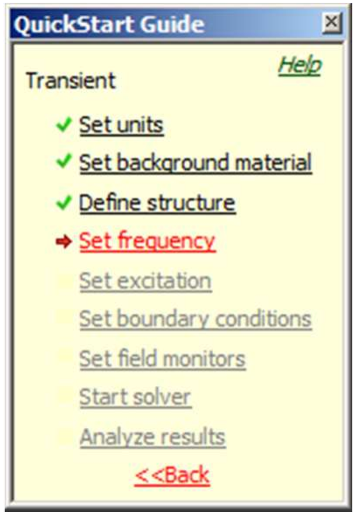
First simulation model – microstrip line

- Draw the ground plane
  - A metal (PEC – Perfect Electric Conductor) block with very thin thickness (t=0.035mm)
  - Same W and L as substrate layer

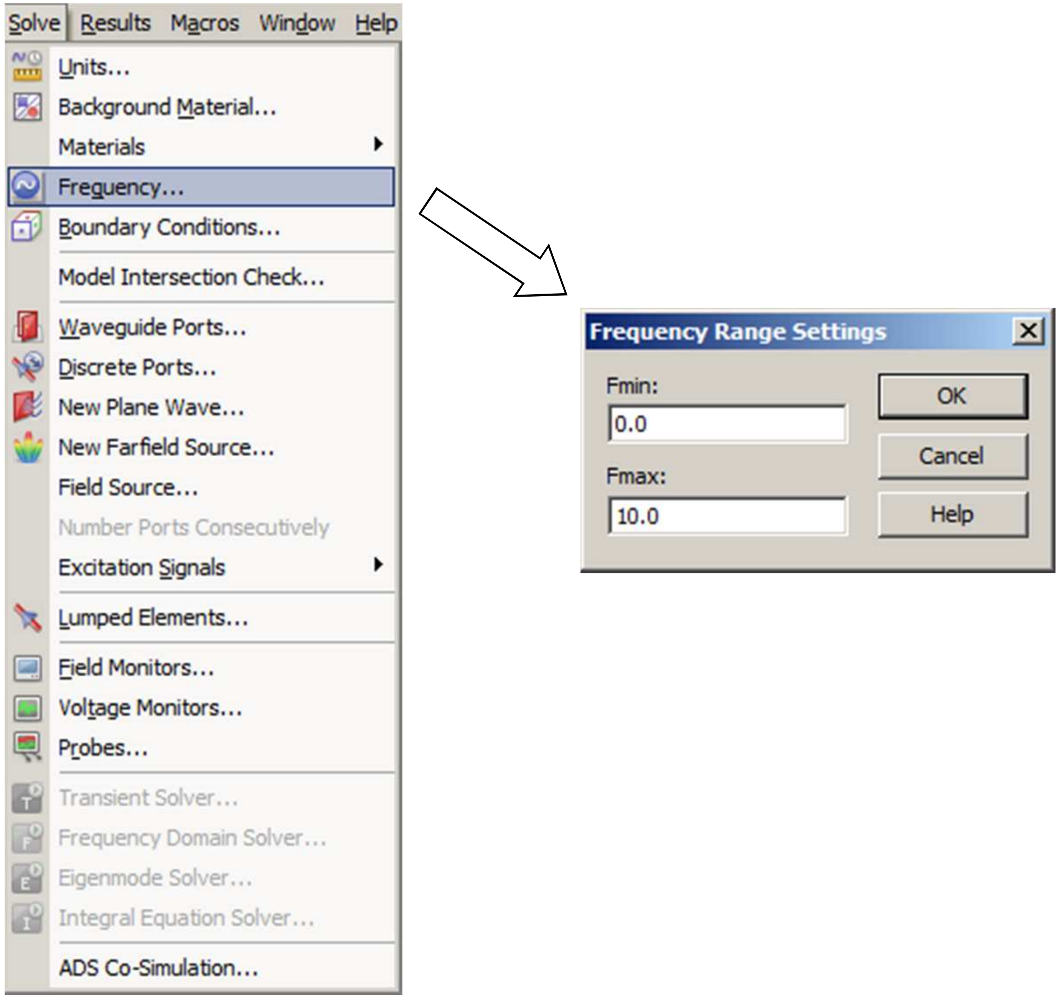
- Draw the microstrip line
  - A narrower metal block with the same thickness and length as ground plane
  - The width is the value you calculated: ms_w



First simulation model – microstrip line

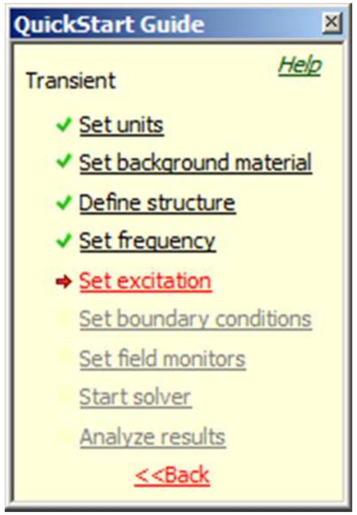


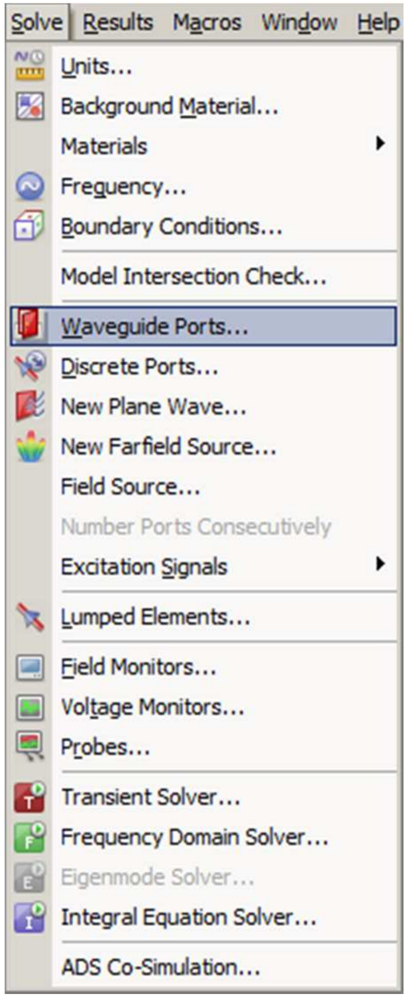
– 4. Set frequency (range)

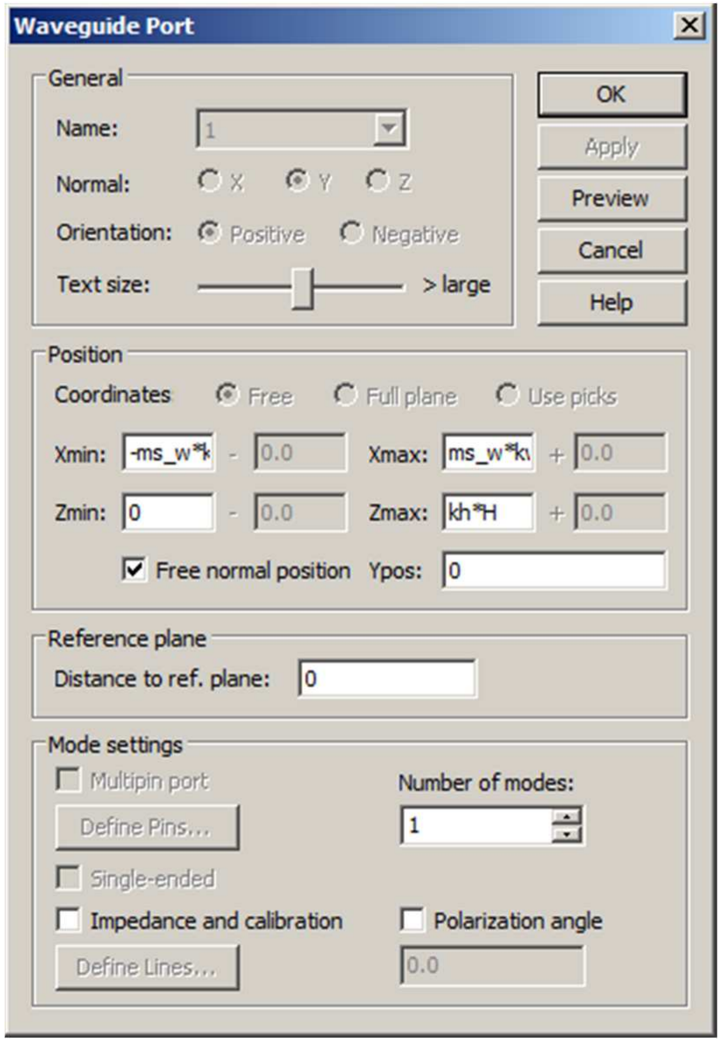


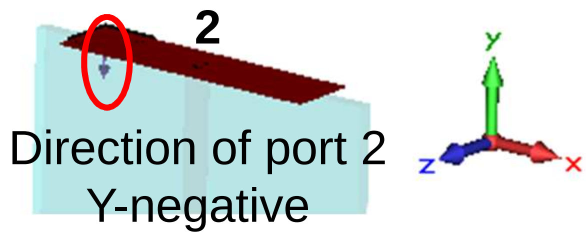
First simulation model – microstrip line

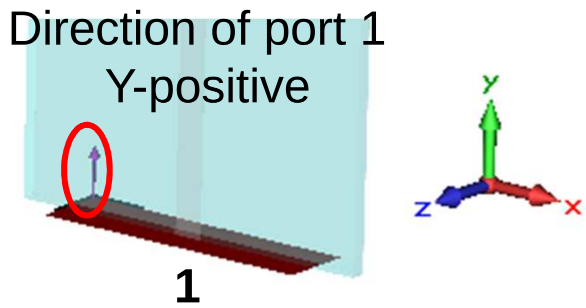
– 5. Set excitation (port and signal)







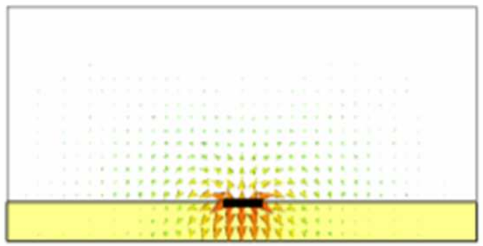




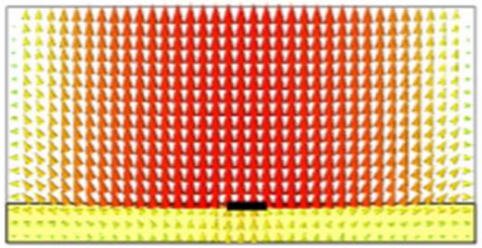
Microstrip line

The microstrip line => transmission lines

- Size of the port
  - On one hand, the port needs to be large enough to enclose the significant part of the microstrip line’s fundamental quasi-TEM mode.
  - On the other hand, the port size should not be chosen unnecessarily large because this may cause higher order waveguide modes to propagate in the port.



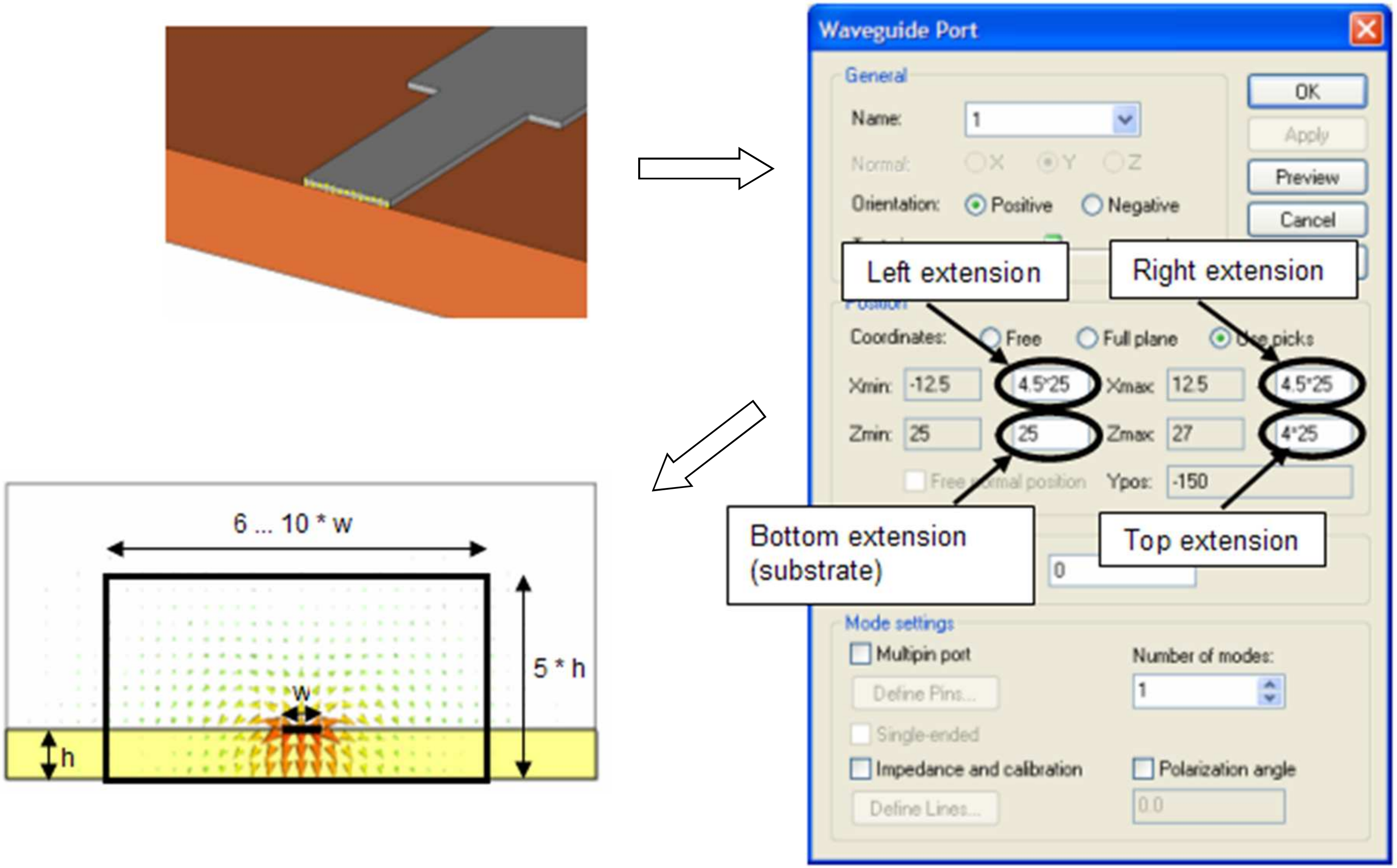
Fundamental mode



Higher order mode

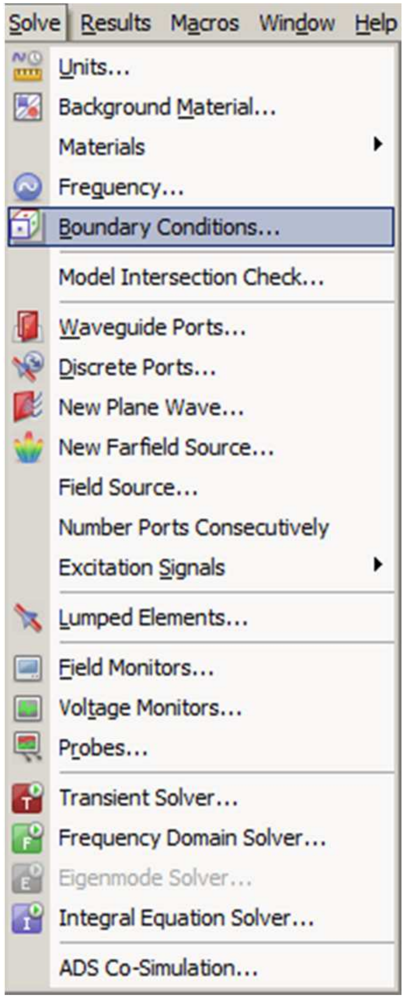
Microstrip line

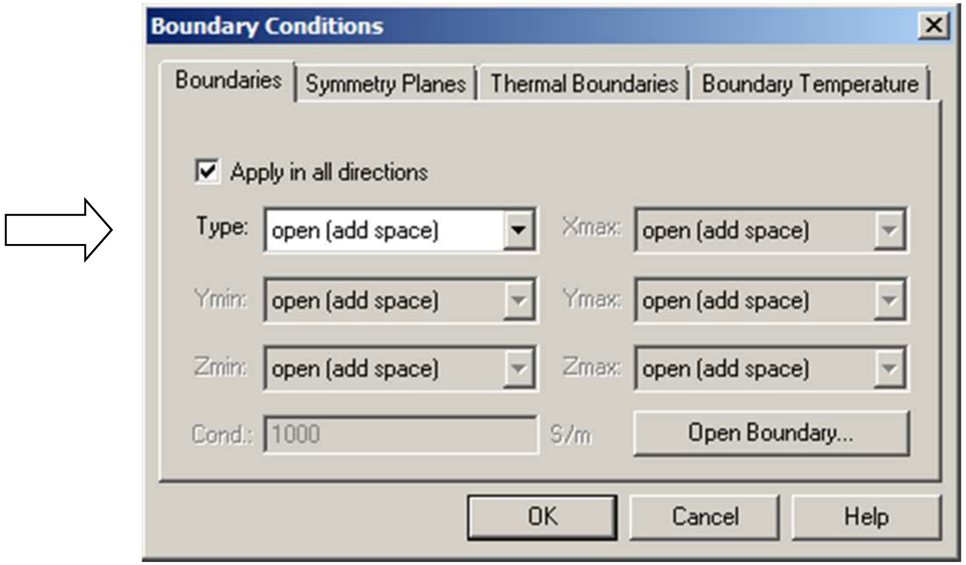
- Solve -> Waveguide port

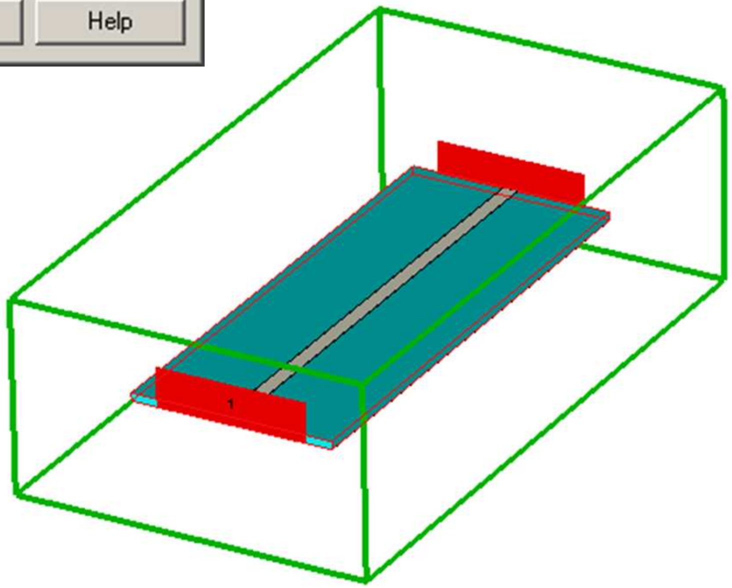


First simulation model – microstrip line

– 6. Set boundary condition (open add space)

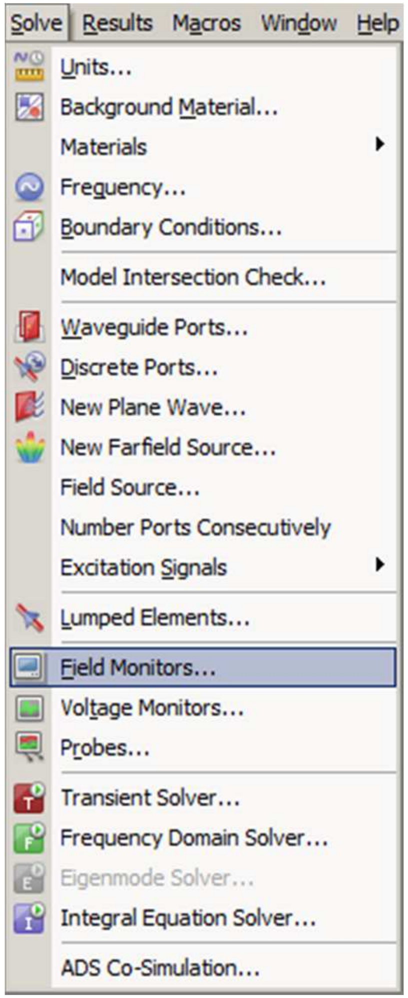


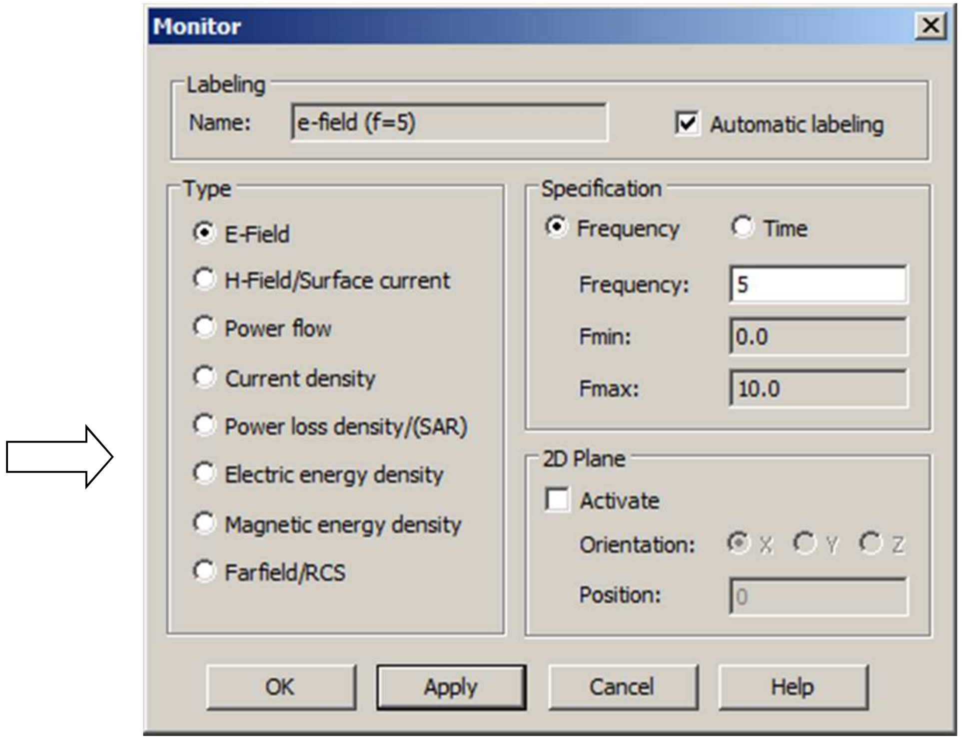




First simulation model – microstrip line

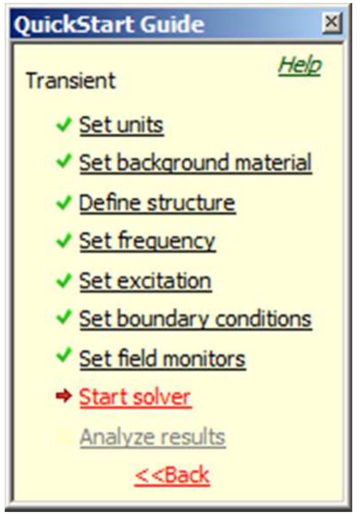
– 7. Set field monitors

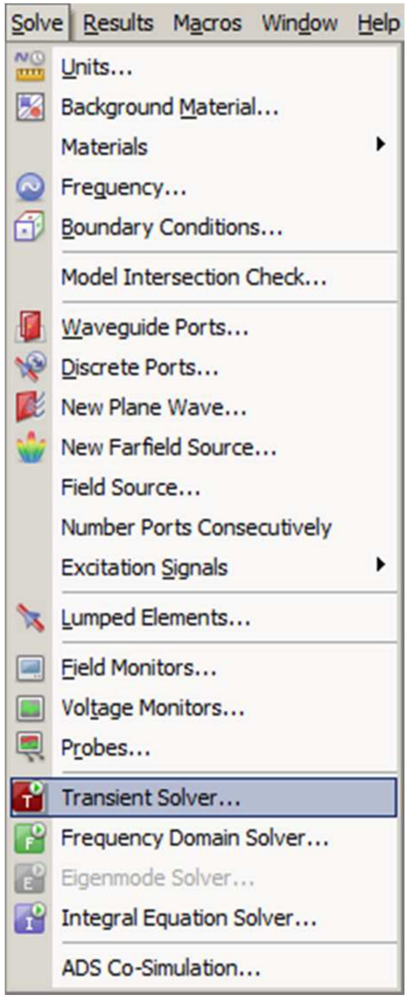


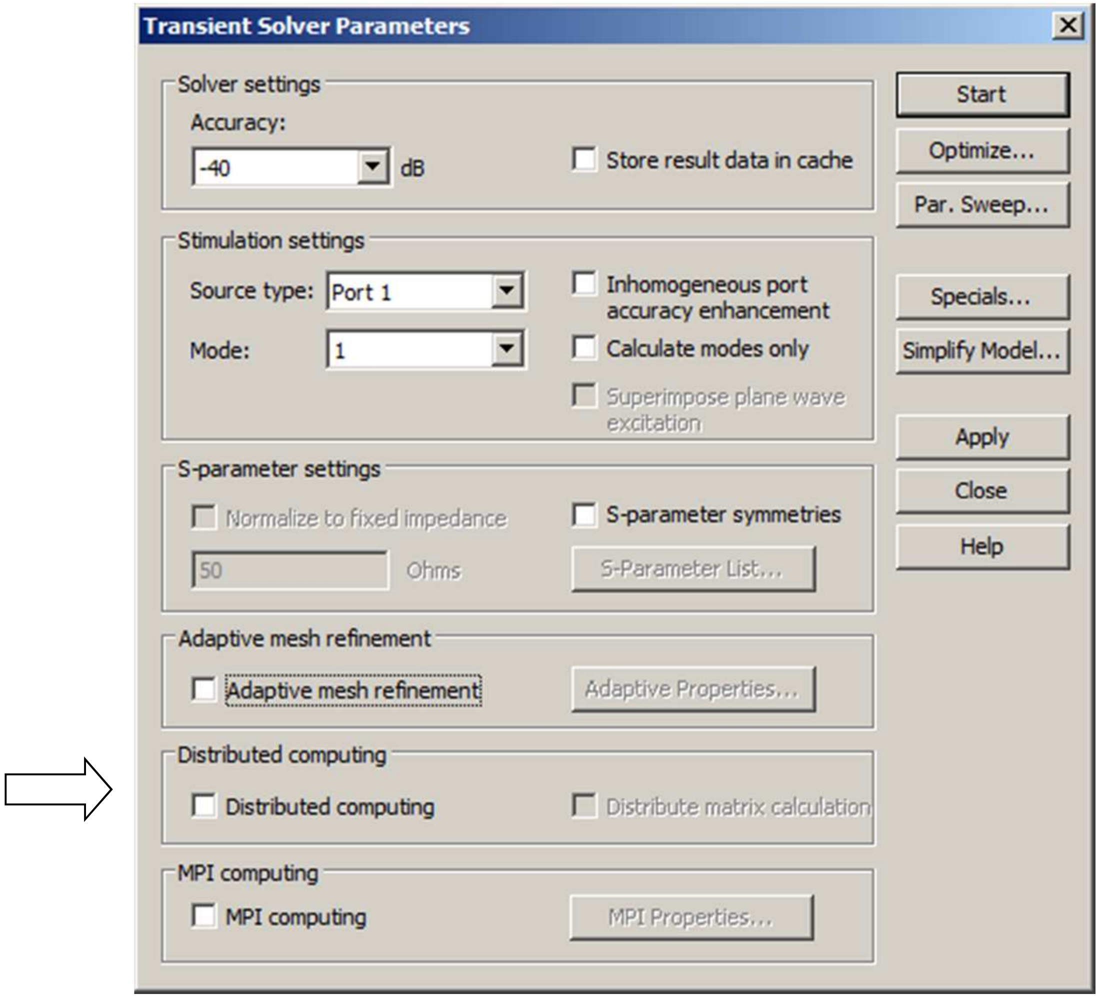


First simulation model – microstrip line

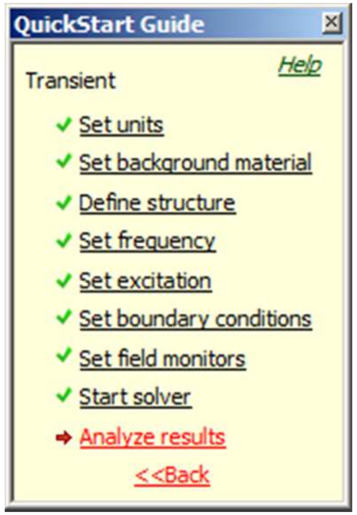
– 8. Start solver (T-solver)



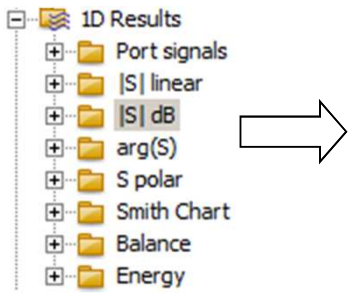


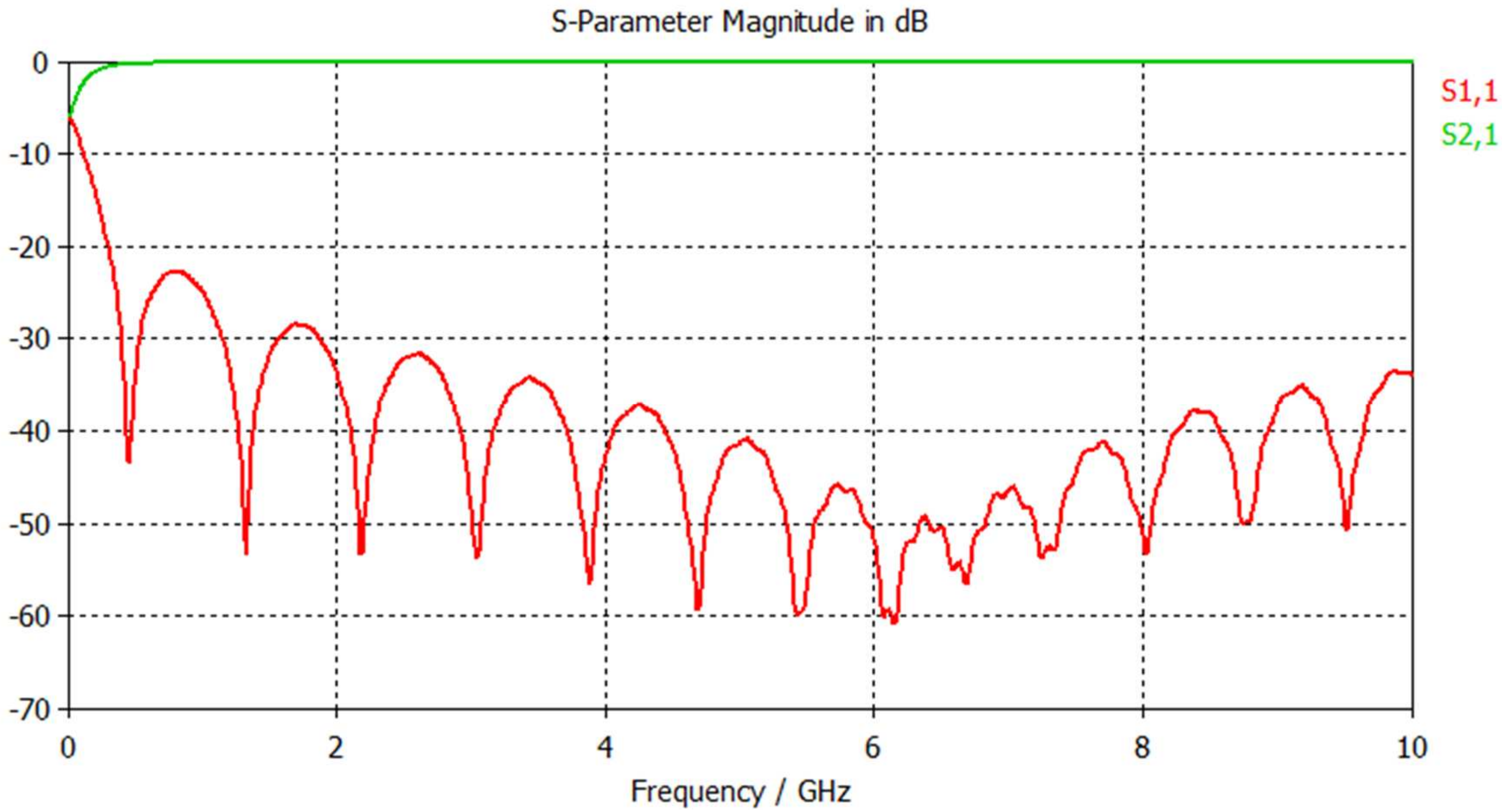


First simulation model – microstrip line



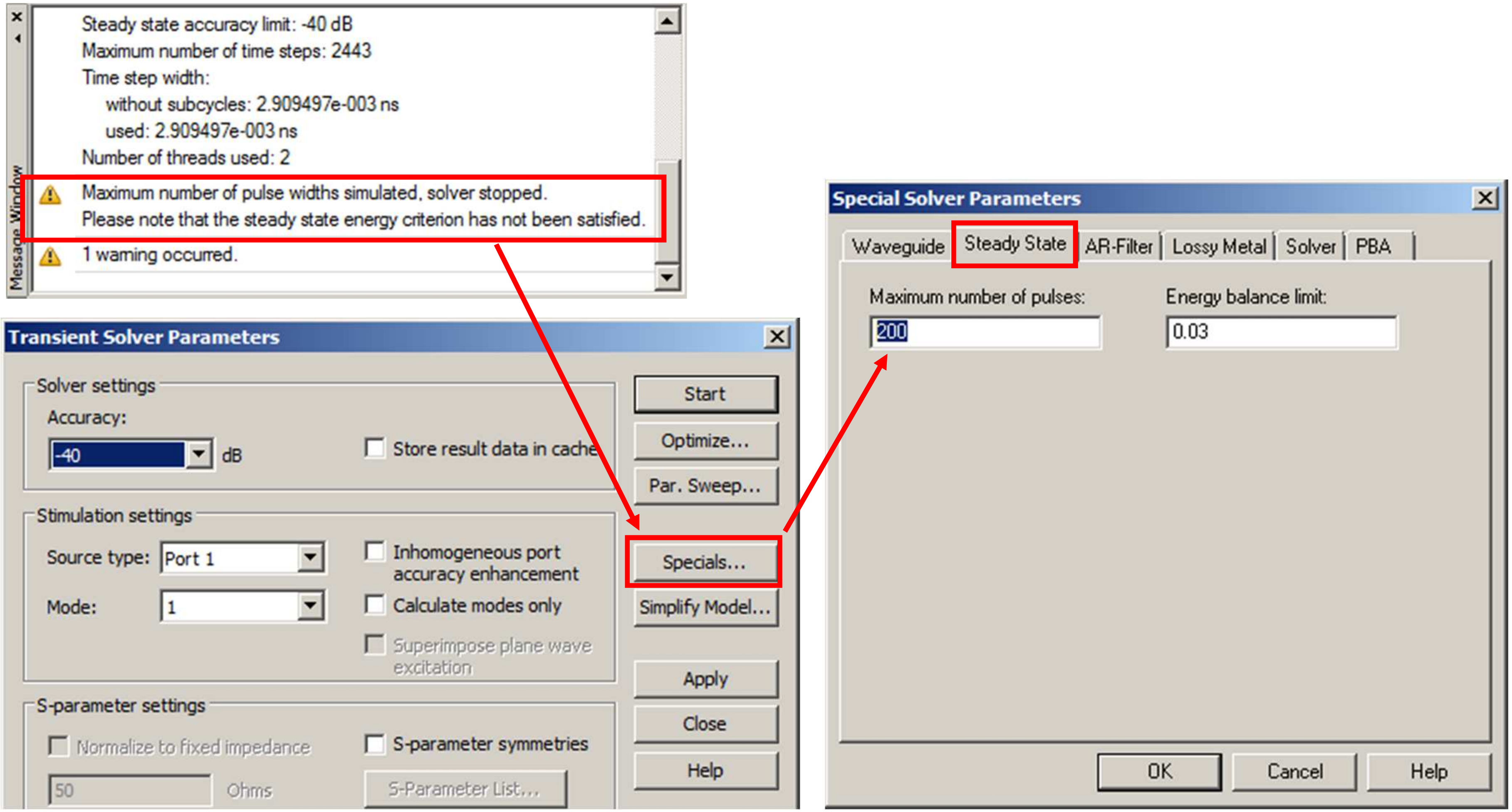
- 9. Analyse results
  - S-parameters
    - return loss s_{11}
    - transmission coefficient s_{21}





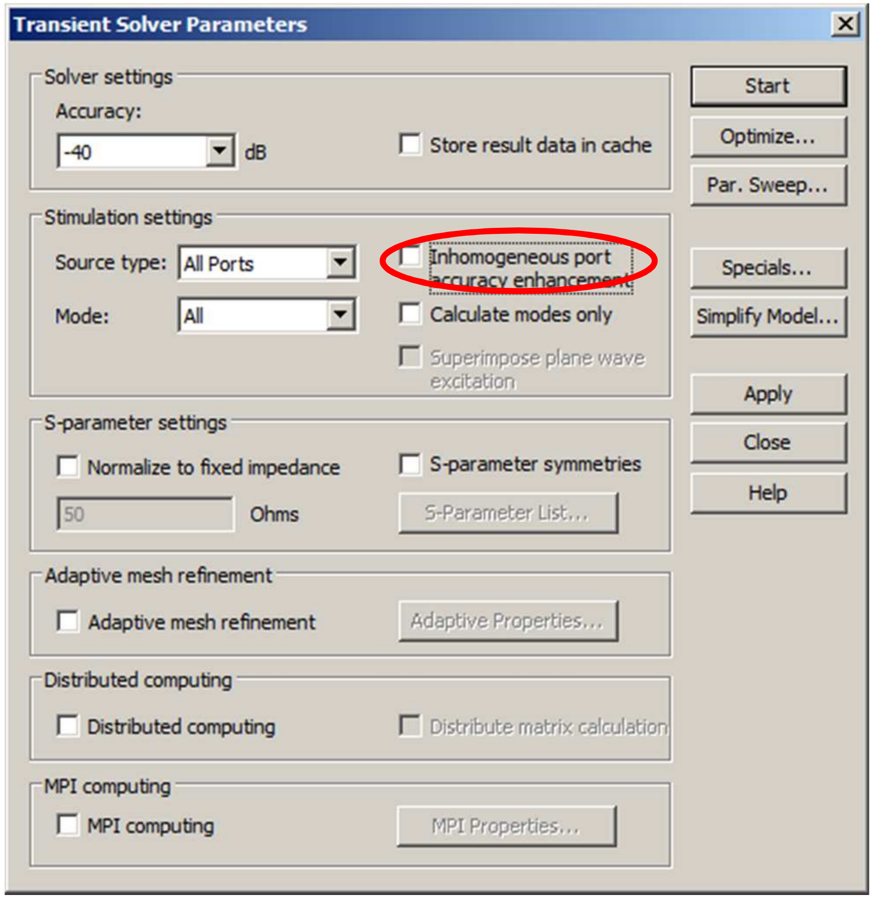
First simulation model – microstrip line

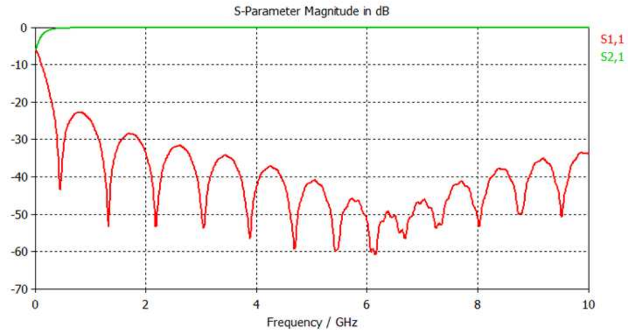
- Warning: Maximum number of pulse widths simulated, solver stopped.



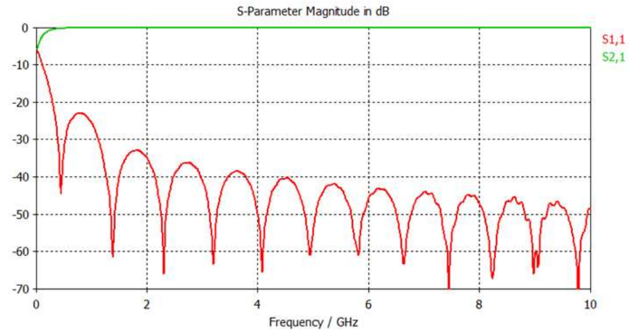
First simulation model – microstrip line

- Accuracy enhancement over the wide frequency band
  - *Inhomogeneous port accuracy enhancement* (Solve -> Transient solver)





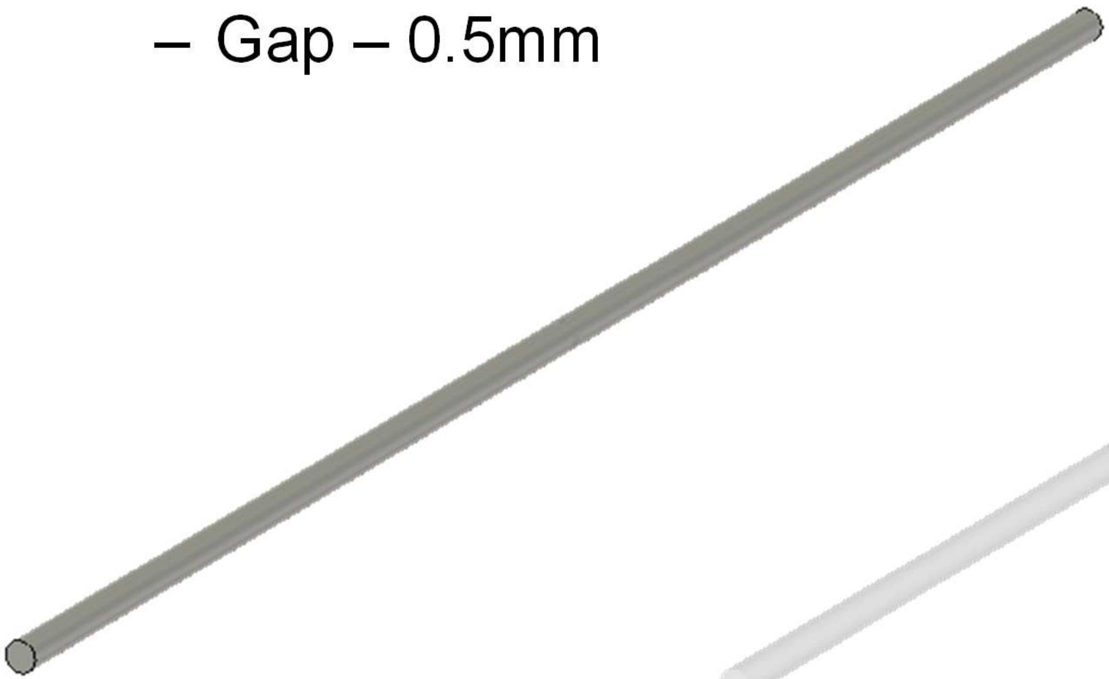
Without IPAE

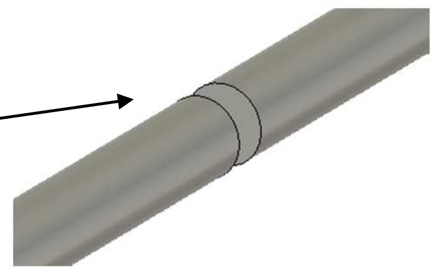


With IPAE

Dipole antenna

- Drawing the geometry of dipole antenna
  - A cylindrical rod with a gap
  - Radius – 0.5mm
  - Gap – 0.5mm

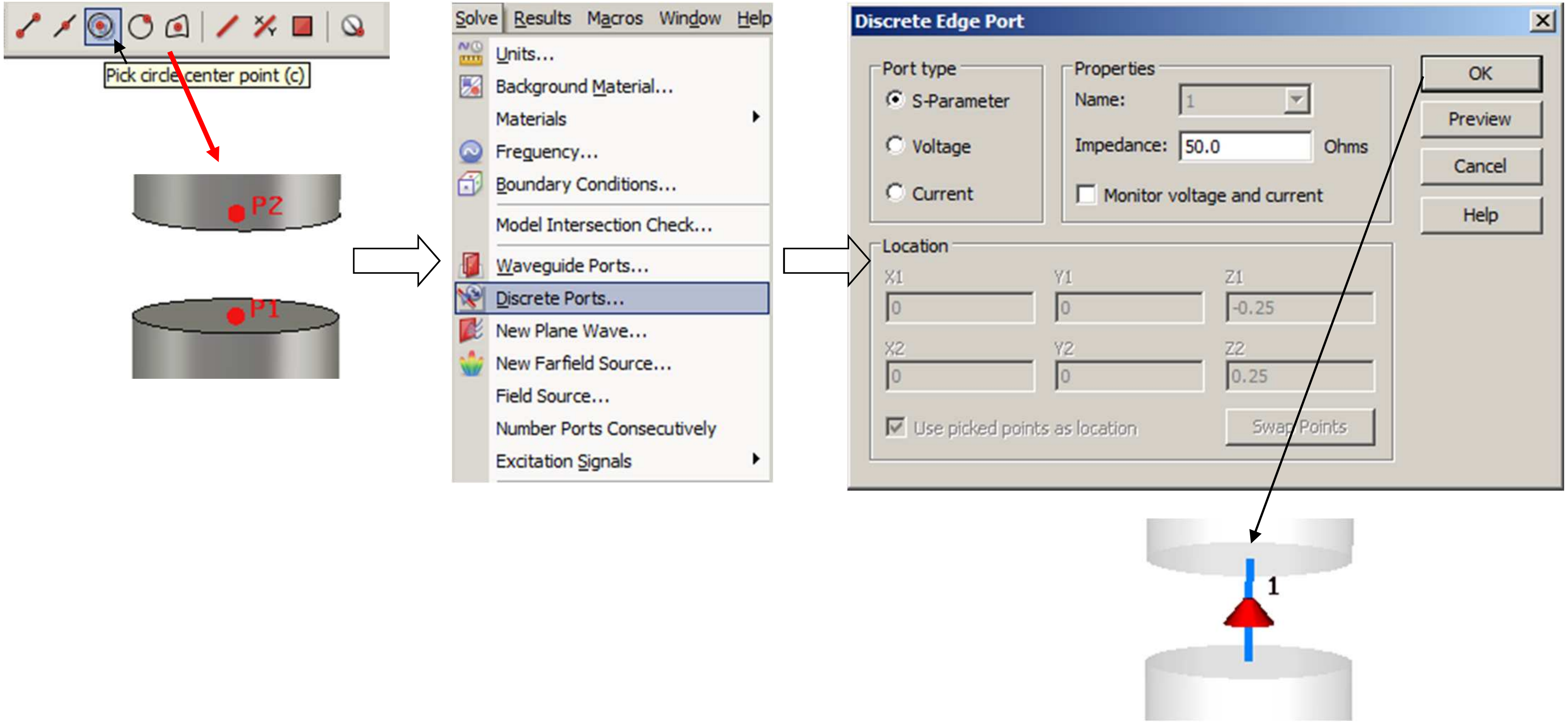




Dipole rod **-** **Gap rod**

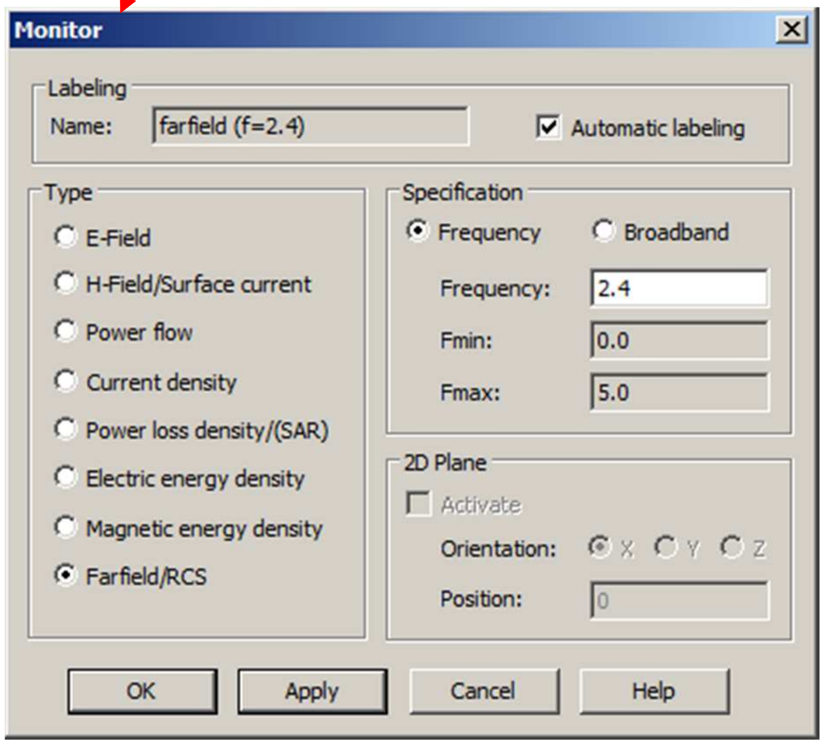
Dipole antenna

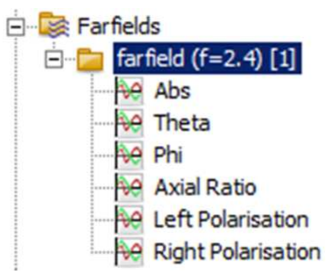
- Set up the port – discrete port
  - Select the circle centre points P1 and P2
  - Define the discrete port 1 (P1 point to P2)

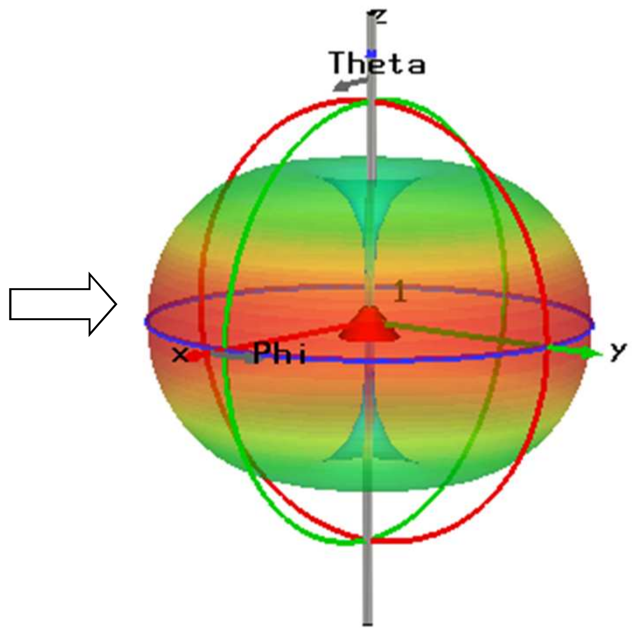


Dipole antenna

- Analyse the far-field (Radiation pattern)
  - Setup the observation in Monitor
  - After simulation, check the result in the navigation tree -> Farfields -> farfield (f=2.4)

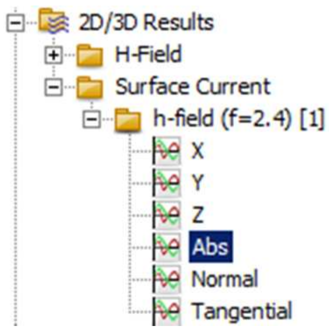






Rectangular patch antenna

- Calculate the parameters values
- Model the antenna with
  - Insert feeding
  - Quarter-wave Transformer matching feeding
- Analyse the results
  - Return loss
  - Radiation pattern
  - Surface current distribution
    - Before simulation
      - Monitor – H-Field / Surface current: f=2.4GHz
    - After simulation
      - 2D/3D Results -> Surface Current -> h-field (f=2.4) -> Abs



Tutorials in CST help

- Press F1, or select Help -> Help content in the main menu at the top of the interface.

Online resources

- CST website:
  - http://www.cst.com/
  - http://www.cst-china.cn/

- Forums
  - http://bbs.rfeda.cn/
  - http://www.mwtee.com/forum.php

- Any other good resources, please share with me ☺