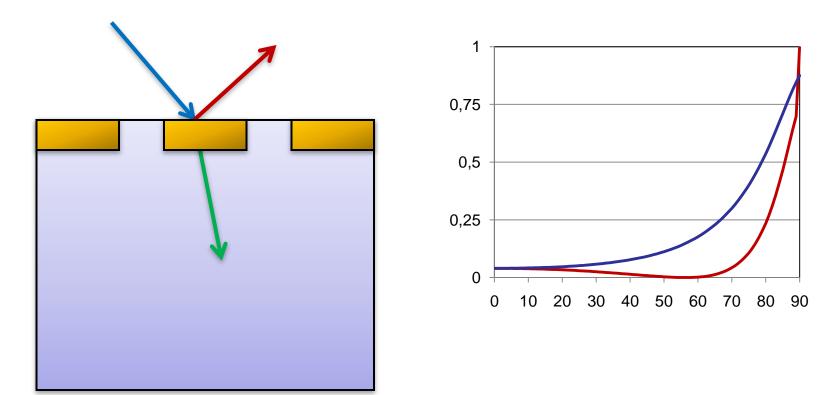
Introductory tutorial to the RF Module: Periodic Problems & Diffraction Gratings





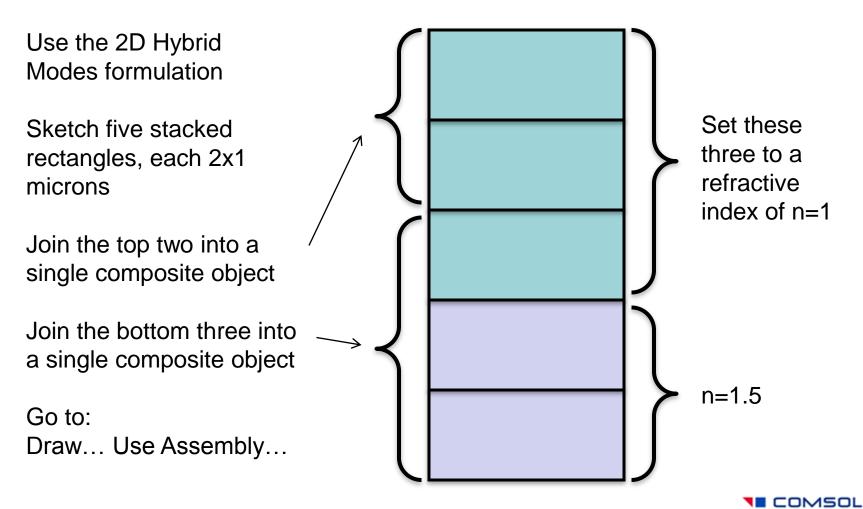
First exercise: Plane wave coming in at an angle

 $P_{incident}$ $P_{reflected}$ $P = \int \frac{1}{2} \mathbf{n} \cdot \operatorname{Re}(\mathbf{E} \times \mathbf{H}^*) \partial \Gamma$ boundary $R = \frac{P_{reflected}}{P_{incident}}$ Consider two polarizations of incident light: $T = \frac{P_{transmittel}}{P_{transmittel}}$ TE, Electric field is $P_{incident}$ $P_{transmitted}$ perpendicular to the plane R + T = 1TM, Magnetic field is perpendicular to the plane



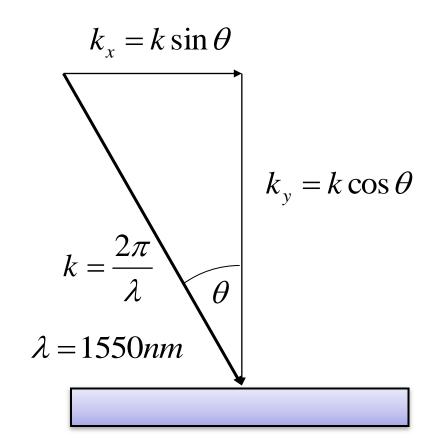


Sketch the domains



Set up a parametric study on incident angle

Set up global expressions for the k-vector and components as a function of incident angle





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Use Floquet boundary condition on the sides

PMC	Boundary Settings - In-Plane Hybrid-Mode Waves (rfwe) Image: Settings - In-Plane Hybrid-Mode Waves (rfwe) Equation Equation Edst = Escexp(-jk-(r_dst - r_sc))	<u>(</u>
	Boundaries Groups Pairs Conditions Material Properties Port Far-Field Color/Style Boundary sources and constraints Floquet Boundary condition: Periodic condition	
	PMC Type of periodicity: Floquet periodicity Periodicity Periodic pair index: 0	
PMC	Change source and destination order Quantity Value/Expression Unit Description k kx ky rad/m k-vector for Floquet periodicity	
PMC		
	Name: floquet Type: Boundaries New Delete	
	OK Cancel Apply Help	
с	Leave all interior boundaries at the default, cont	inuit
PMC	Set all other boundaries to PMC	

There is also a "Boundary Pair" at the boundaries between the two objects

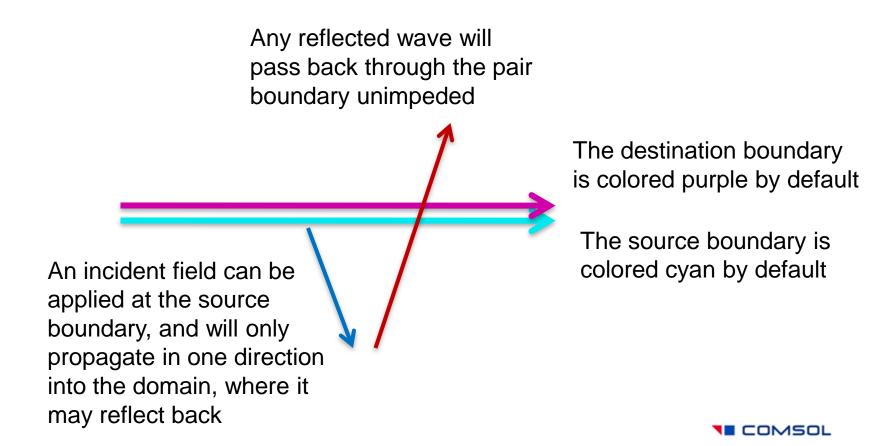
Equation	X
Boundaries Groups Pairs Conditions Material Properties Port Far-Field Color/Style Pair 1 (identity) Image: Condition Strate in the strate i	
Port phase Port phase Set the boundary pair to be the foundary condition, and set an indication.	
Active pair OK Cancel Apply Help	
	TE COMSOL
	Equation S = f(E - E ₁)E ₁ / fE ₁ E ₁ Boundaries Groups Pairs Pair selection Pair selection Pair 1 (identity) Pair vectation at this port Quantity Value/Expression Pin 1 Φ _p 0 V Port power level Port phase Set the boundary pair to be the F boundary condition, and set an in

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Use an analytic expression for a plane wave

Boundary Settings - In-Plane I	Hybrid-Mode Waves (rfwe)			×
Equation $S = \int (\mathbf{E} - \mathbf{E}_1) \cdot \mathbf{E}_1 / \int \mathbf{E}_1 \cdot \mathbf{E}_1$				
Boundaries Groups Pairs Pair selection Pair 1 (identity)	Mode type:	User defined Transverse electric (TE) E0*exp(-i*kx*x) Specify β	V/m Electric field Specify β ₀ and v ₀ rad/m Propagation constant	
Specify either a TE or TM mode, and use the analytic expression for a plane wave at an angle to a line: exp(-i*kx*x) Also, enter the propagation constant normal to the boundary: ky				
		ок	Cancel Apply Help	

The pair condition applies the incident field to only one side of the pair



When using Assembly mode, the mesh may be non-congruent, try to avoid this

Assembly meshing allows elements to be non-congruent.

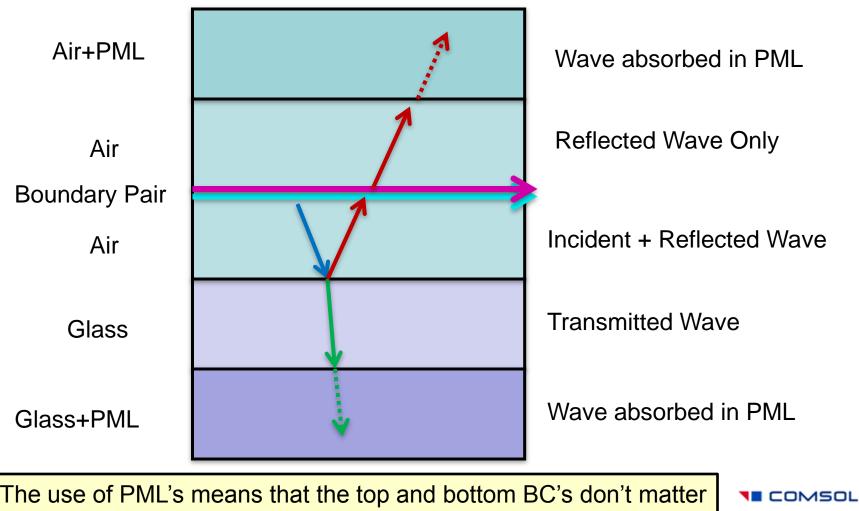
Assembly meshes add extra equations "behind the scenes" that balance the flux between the adjacent elements.

In 2D, you must have at least eight elements per wavelength in the media

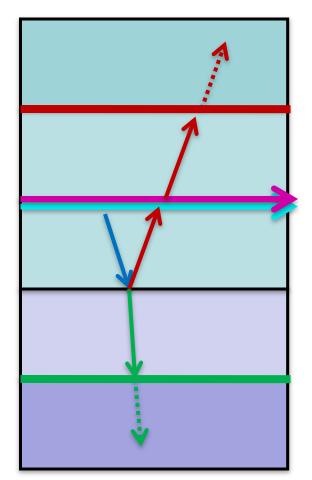
In 3D, use five elements per λ_{local}

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Using PML's absorbing in the y-direction to absorb the wave



We don't (generally) know the propagation constant of the reflected or transmitted wave, but with the PML, it doesn't matter



Integrate the reflected power across this boundary

Set up global expressions to compute the reflection and transmission coefficients

Integrate the transmitted power across this boundary, you may need to switch the sign to account for the non-unique normal vector

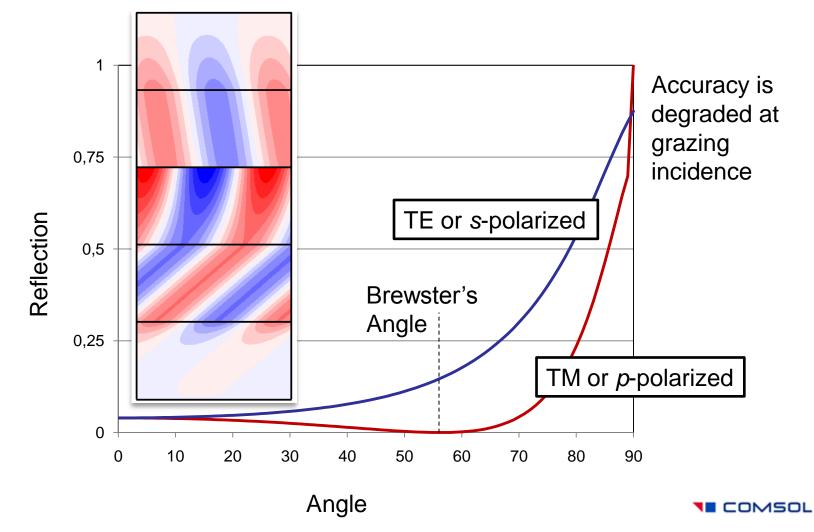
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When solving periodic problems, make sure to change the solver settings as shown:

Solver Parameters			×	
Solver Parameters Analysis: Harmonic propagation Auto select solver Solver: Stationary Time dependent Eigenvalue Parametric	Constraint handling method: Null-space function: Assembly block size:	Advanced Elimination Automatic S000 Instraint matrix and in symmetry detection al input		
Stationary segregated Parametric segregated	 Stop if error due to undefined Store solution on file Solution form: Scaling of variables Type of scaling: Manual scaling: Row equilibration: 	operation Automatic Automatic On		Solve for incident angles from 0-90° and for both TE and TM excitations,
	Manual control of reassembly Load constant Constraint constant	Jacobian constantConstraint Jacobian constant		which you have to switch on the Port tab
	Damping (mass) constant	Cancel Apply Help		TE COMSOL

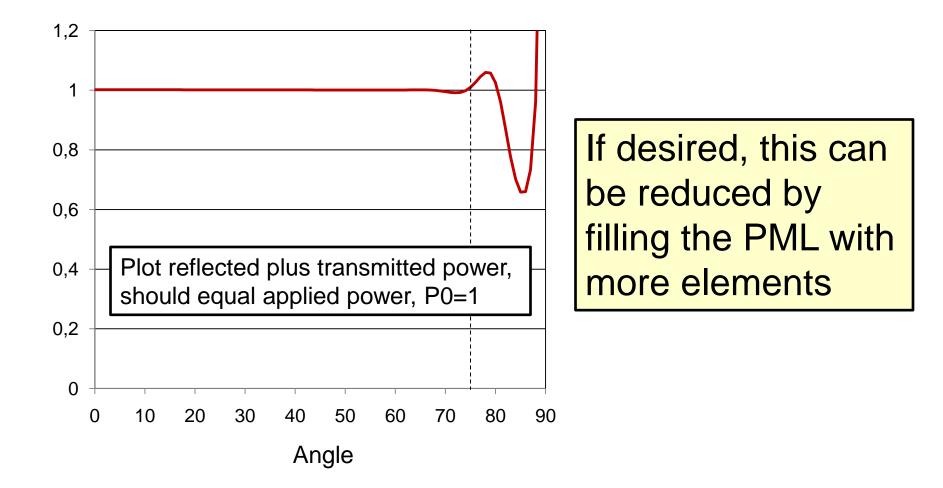


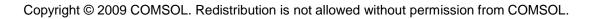
Results...



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At grazing incidence, accuracy is degraded







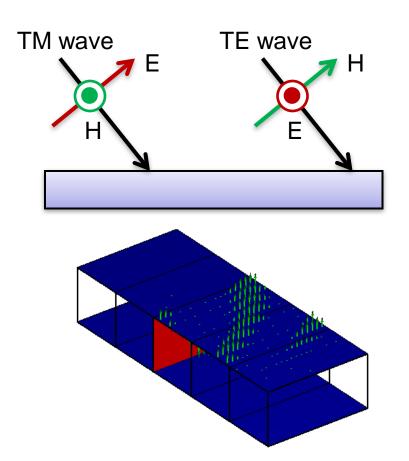
Modeling in 3D...

Same solver settings... Same material properties... Same PML's... Same periodic boundary conditions...

Easier to consider polarizations separately... Different Port excitations... New boundary conditions... Special meshing techniques...



Build two models, one TE, on TM



The TM case is when the H-field is parallel to the boundary at which the excitation is applied, the red face.

In the TM case, all the blue boundaries must be PMC, which represents symmetry.

The TE case is the opposite, when the E-field is parallel to the excitation boundary, in this case, the blue faces must all be PEC.



Port mode conditions for the TM case

undary Settings - Electromagnetic Waves (rfw)
Equation
$S = \int (\mathbf{E} - \mathbf{E}_1) \cdot \mathbf{E}_1 / \int \mathbf{E}_1 \cdot \mathbf{E}_1$
Boundaries Groups Pairs Conditions Material Properties Port Far-Field Color Pair selection Port definition Port definition Port Port Port
Pair 1 (identity) Mode specification: User defined
S-parameter output: Magnitude and phase
Mode type: Transverse magnetic (TM)
Incident field: Eigenmode given by H field H0 0 H0z*exp(- A/m Magnetic field
C Specify cutoff frequency • Specify β $\frac{Hoz exp(-i*kx*x)}{potenty p_0}$ and v_0
β ky rad/m Propagation constant
Active pair
OK Cancel Apply Help

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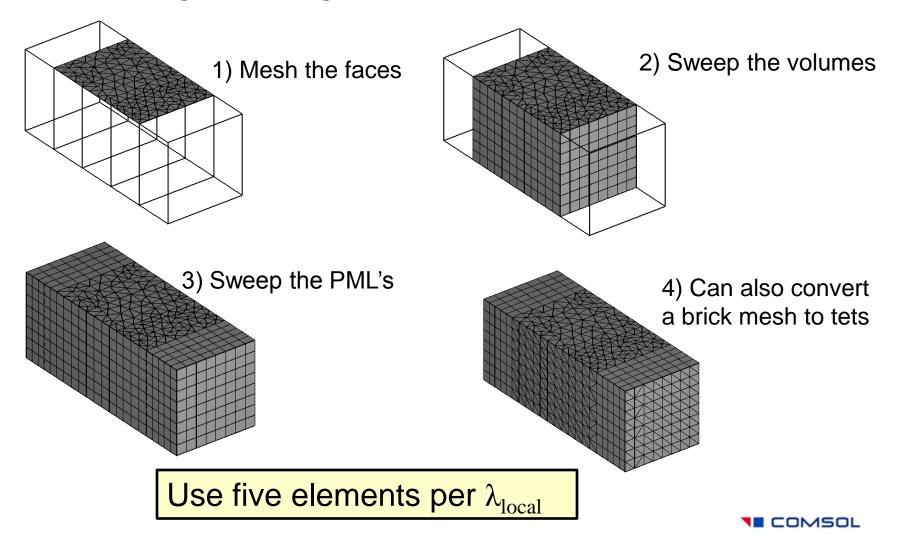
Port mode conditions for the TE case

Boundary Settings - Electromag	jnetic Waves (rfw)		×
Equation			
$S = f(E - E_1) \cdot E_1 / f E_1 \cdot E_1$			
Boundaries Groups Pairs Pair selection Pair 1 (identity)	Conditions Material Properties Port definition Mode specification: S-parameter output: Mode type: Incident field: E ₀ C Specify cutoff frequency β	Port Far-Field User defined Magnitude and phase Transverse electric (TE) Eigenmode given by E field 0 0 E0*exp(-i* V/m Electric field • Specify β E0*exp(-j*kx*x)/p and v_0 ky rad/m Propagation constant	
Active pair			
		OK Cancel Apply Help	

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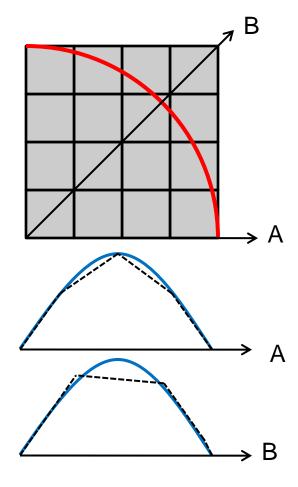


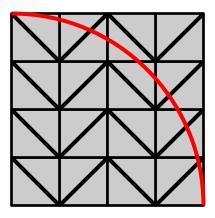
Meshing strategies...





When using brick elements, recall that error is governed by distance between the nodes

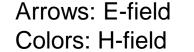


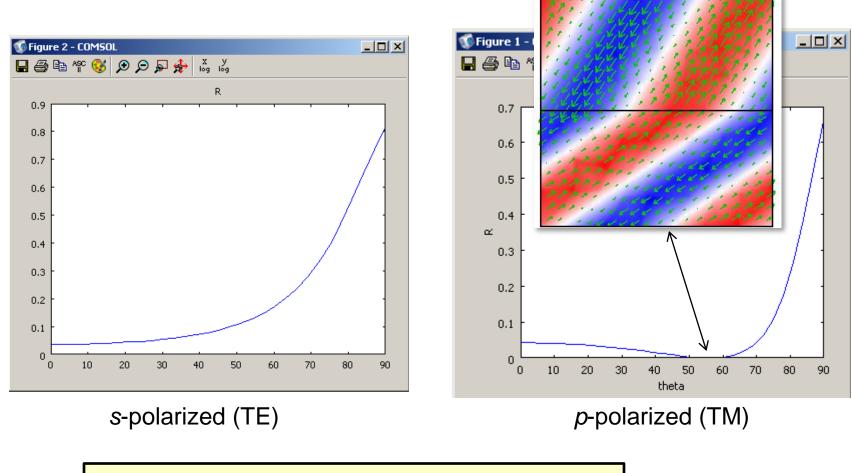


Triangular meshes require less memory and time, since there is less connectivity

In 3D, tetrahedral elements have better convergence properties using the iterative solvers, but this does not matter much for direct solvers.

Results...

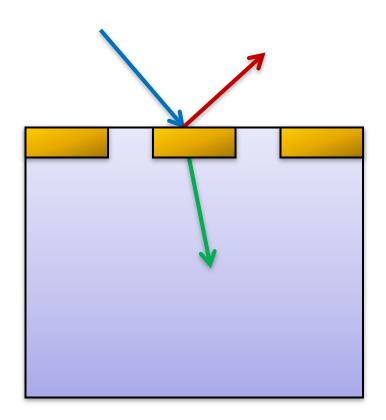




Again, accuracy is reduced at grazing incidence

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Diffraction gratings and periodic structures



Same solver settings... Same material properties... Same PML's... Same periodic boundary conditions... Same excitation...

Must use interactive meshing to get a good mesh on the part:

Copy the mesh for periodic faces Copy the mesh for identity pair faces Use about five elements per wavelength Use five elements through the PML Use swept meshing as much as possible Use Convert to Tet Mesh