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Subsurface fluid flow

|  |  |
| --- | --- |
| Report date | Jun 7, 2025, 8:25:34 AM |

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1. Global Definitions

|  |  |
| --- | --- |
| Date | Jun 4, 2025, 11:44:57 PM |

Global settings

|  |  |
| --- | --- |
| Name | Final.mph |
| Path | C:\Users\shrut\Downloads\final.mph |
| Version | COMSOL Multiphysics 6.1 (Build: 252) |
| Unit system | SI |

Used products

|  |
| --- |
| Battery Design Module |
| COMSOL Multiphysics |

Computer information

|  |  |
| --- | --- |
| CPU | Intel64 Family 6 Model 154 Stepping 4, 12 cores, 7.69 GB RAM |
| Operating system | Windows 10 |

* 1. Parameters

Parameters 1

| **Name** | **Expression** | **Value** | **Description** |
| --- | --- | --- | --- |
| rho\_f | 1000 | 1000 |  |
| eta\_f | 1.14E-3 | 0.00114 |  |
| phi | 0.33 | 0.33 |  |
| K | 8E-5 | 8E−5 |  |
| sigma\_sat | 0.012 | 0.012 |  |
| Qv | 0.48 [C/m^3] | 0.48 C/m³ |  |
| g | 9.82 [m/s^2] | 9.82 m/s² |  |

* 1. Shared Properties
     1. Default Model Inputs

|  |  |
| --- | --- |
| Tag | cminpt |

1. Component 1

|  |  |
| --- | --- |
| Date | May 13, 2025, 3:46:24 PM |

Settings

| **Description** | **Value** |
| --- | --- |
| Unit system | Same as global system (SI) |
| Geometry shape function | Automatic |

Spatial frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| x | y | z |

Material frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| X | Y | Z |

Geometry frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xg | Yg | Zg |

Mesh frame coordinates

| **First** | **Second** | **Third** |
| --- | --- | --- |
| Xm | Ym | Zm |

* 1. Definitions
     1. Variables

#### Variables 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Entire model |

| **Name** | **Expression** | **Unit** | **Description** |
| --- | --- | --- | --- |
| js\_x | Qv \* dl.UX + eps | A/m² |  |
| js\_y | Qv \* dl.UY + eps | A/m² |  |

* + 1. Coordinate Systems

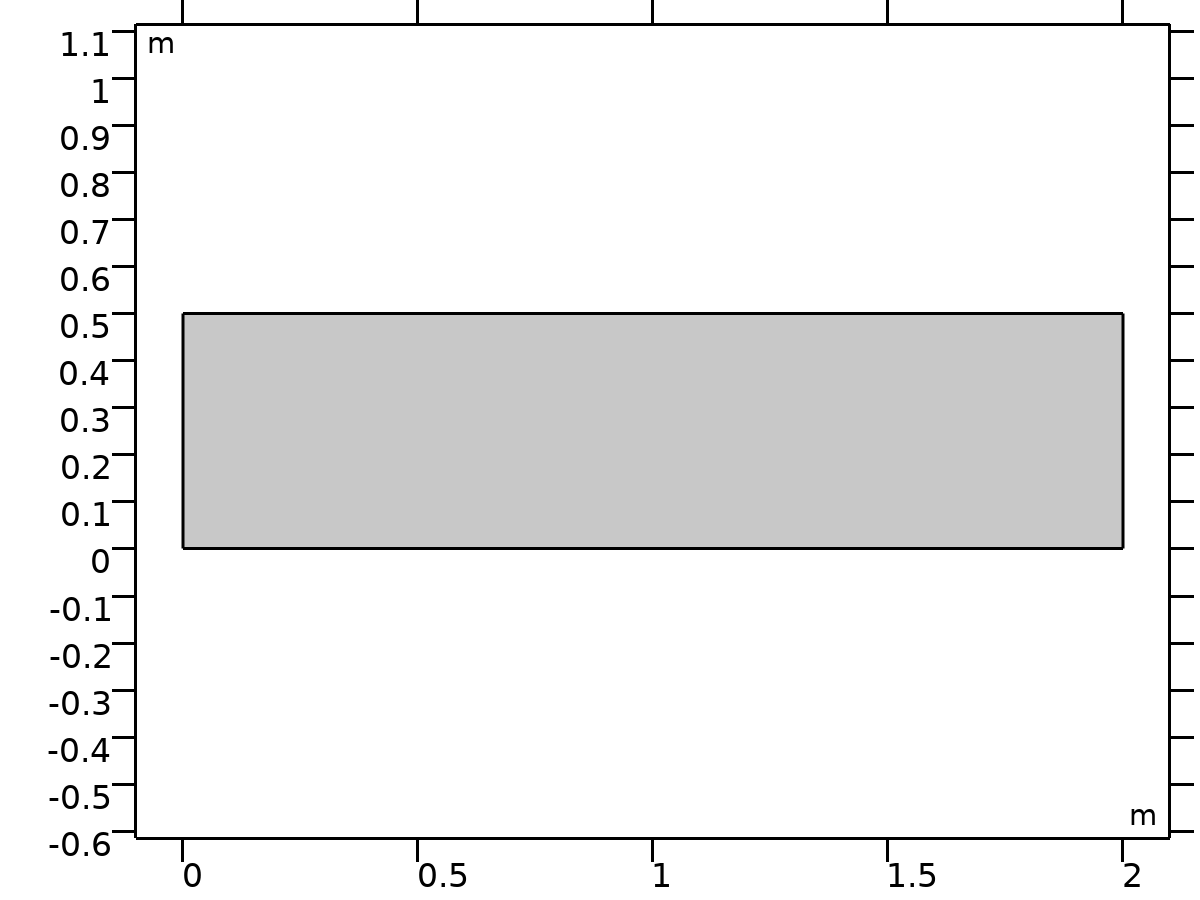
#### Boundary System 1

|  |  |
| --- | --- |
| Coordinate system type | Boundary system |
| Tag | sys1 |

Coordinate names

| **First** | **Second** | **Third** |
| --- | --- | --- |
| t1 | n | to |

* 1. Geometry 1



Geometry 1

Units

|  |  |
| --- | --- |
| Length unit | m |
| Angular unit | deg |

Geometry statistics

| **Description** | **Value** |
| --- | --- |
| Space dimension | 2 |
| Number of domains | 1 |
| Number of boundaries | 4 |
| Number of vertices | 4 |

* + 1. Rectangle 1 (r1)

Position

| **Description** | **Value** |
| --- | --- |
| Position | {0, 0} |

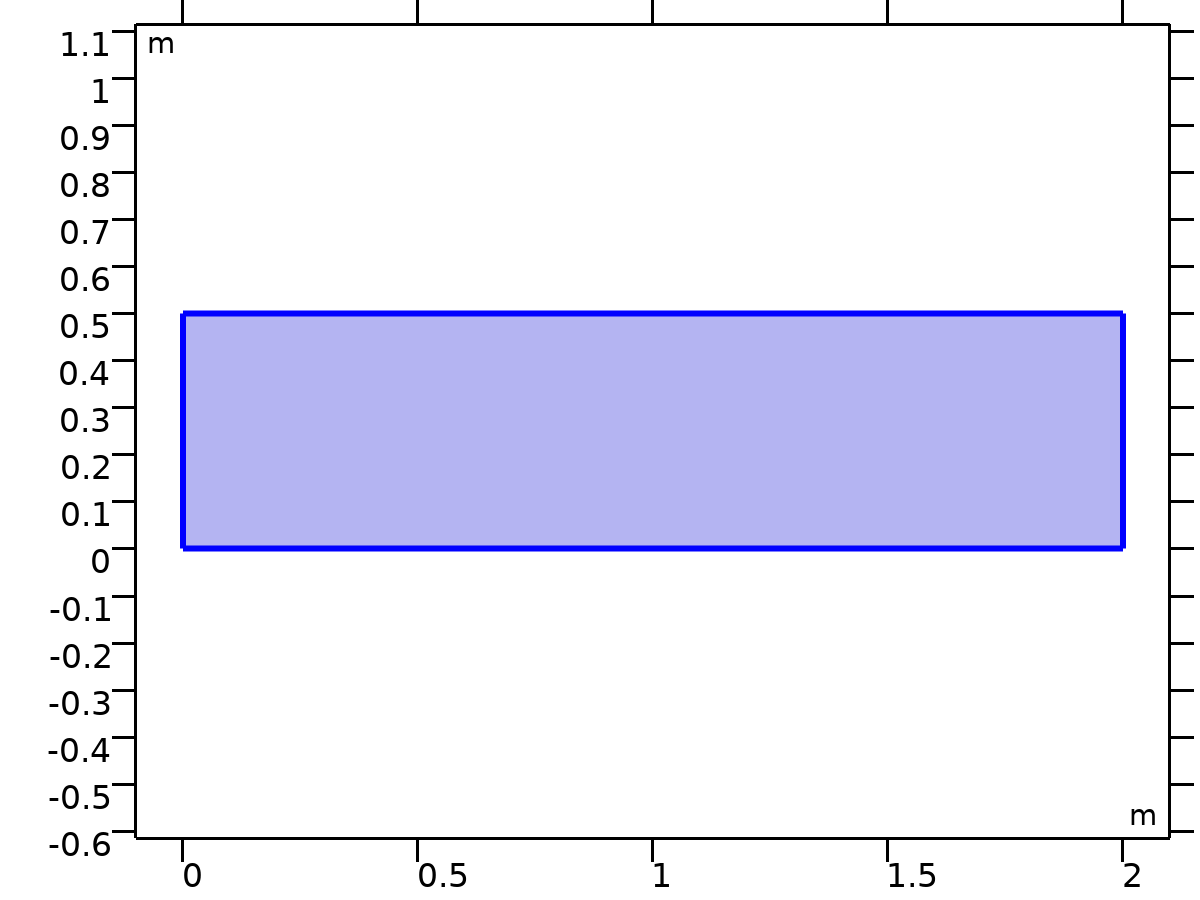
Size

| **Description** | **Value** |
| --- | --- |
| Width | 2 |
| Height | 0.5 |

* 1. Darcy's Law

Used products

|  |
| --- |
| Battery Design Module |
| COMSOL Multiphysics |

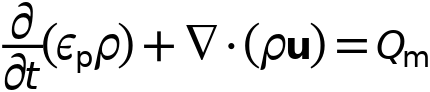


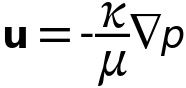
Darcy's Law

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations





* + 1. Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Pressure | Quadratic |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

#### Physical Model

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Thickness | 1 | m |
| Reference pressure level | 1.0133E5 | Pa |

#### Gravity Effects

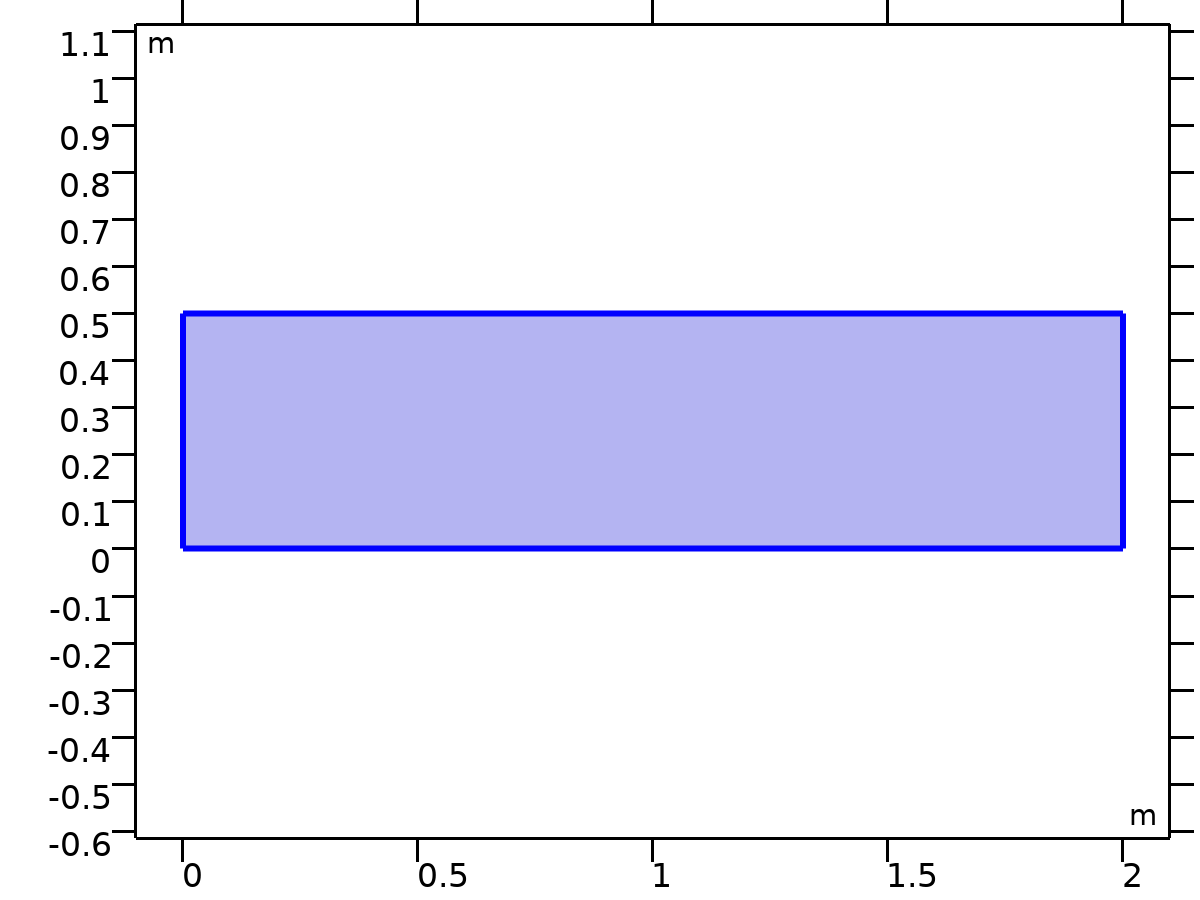
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Include gravity | Off |  |
| Acceleration of gravity | g\_const | m/s² |

* + 1. Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** |
| --- | --- | --- | --- | --- |
| dl.dz | 1[m] | m | Thickness | Domain 1 |
| dl.pref | 1[atm] | Pa | Reference pressure level | Domain 1 |
| dl.pA | p+dl.pref | Pa | Absolute pressure | Domain 1 |
| dl.d | dl.dz | m | Thickness | Domain 1 |
| dl.nX | dnX | 1 | Normal vector, X-component | Boundaries 1–4 |
| dl.nY | dnY | 1 | Normal vector, Y-component | Boundaries 1–4 |
| dl.nZ | 0 | 1 | Normal vector, Z-component | Boundaries 1–4 |
| dl.g | g\_const | m/s² | Acceleration of gravity | Domain 1 |
| dl.H | p/(dl.g\*dl.rho)+dl.D | m | Hydraulic head | Domain 1 |
| dl.Hp | p/(dl.g\*dl.rho) | m | Pressure head | Domain 1 |
| dl.dHpdt | d(dl.Hp,t) | m/s | Time change in pressure head | Domain 1 |
| dl.D | 0 | m | Elevation | Domain 1 |
| dl.gvect1 | 0 | m/s² | Gravity acceleration vector, 1-component | Domain 1 |
| dl.gvect2 | 0 | m/s² | Gravity acceleration vector, 2-component | Domain 1 |
| dl.gvect3 | 0 | m/s² | Gravity acceleration vector, 3-component | Domain 1 |
| dl.ag1 | 0 | m/s² | Help variable, 1-component | Domain 1 |
| dl.ag2 | 0 | m/s² | Help variable, 2-component | Domain 1 |
| dl.ag3 | 0 | m/s² | Help variable, 3-component | Domain 1 |
| dl.rrefX | 0 | m | Reference position, X-component | Domain 1 |
| dl.rrefY | 0 | m | Reference position, Y-component | Domain 1 |
| dl.rrefZ | 0 | m | Reference position, Z-component | Domain 1 |

* + 1. Porous Medium 1

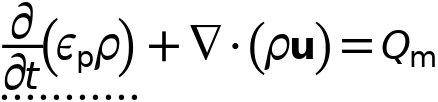


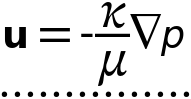
Porous Medium 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations





#### Porous Medium

Settings

| **Description** | **Value** |
| --- | --- |
| Flow model | Darcian flow |
| Storage model | From density and porosity |

#### Coordinate System Selection

Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| domflux.pX | dl.rho\*dl.UX | kg/(m²·s) | Domain flux, X-component | Domain 1 |  |
| domflux.pY | dl.rho\*dl.UY | kg/(m²·s) | Domain flux, Y-component | Domain 1 |  |
| dl.rho | dl.porous.fluid.rho | kg/m³ | Density | Domain 1 |  |
| dl.kappaXX | dl.porous.pm.kappaXX | m² | Permeability, XX-component | Domain 1 |  |
| dl.kappaYX | dl.porous.pm.kappaYX | m² | Permeability, YX-component | Domain 1 |  |
| dl.kappaZX | dl.porous.pm.kappaZX | m² | Permeability, ZX-component | Domain 1 |  |
| dl.kappaXY | dl.porous.pm.kappaXY | m² | Permeability, XY-component | Domain 1 |  |
| dl.kappaYY | dl.porous.pm.kappaYY | m² | Permeability, YY-component | Domain 1 |  |
| dl.kappaZY | dl.porous.pm.kappaZY | m² | Permeability, ZY-component | Domain 1 |  |
| dl.kappaXZ | dl.porous.pm.kappaXZ | m² | Permeability, XZ-component | Domain 1 |  |
| dl.kappaYZ | dl.porous.pm.kappaYZ | m² | Permeability, YZ-component | Domain 1 |  |
| dl.kappaZZ | dl.porous.pm.kappaZZ | m² | Permeability, ZZ-component | Domain 1 |  |
| dl.mu | dl.porous.fluid.mu | Pa·s | Dynamic viscosity | Domain 1 |  |
| dl.nu | dl.mu/dl.rho | m²/s | Kinematic viscosity | Domain 1 |  |
| dl.Sp | 0 | 1/Pa | Storage | Domain 1 | + operation |
| dl.TraXX | dl.kappaXX/dl.mu | m³·s/kg | Transmissibility, XX-component | Domain 1 |  |
| dl.TraYX | dl.kappaYX/dl.mu | m³·s/kg | Transmissibility, YX-component | Domain 1 |  |
| dl.TraZX | dl.kappaZX/dl.mu | m³·s/kg | Transmissibility, ZX-component | Domain 1 |  |
| dl.TraXY | dl.kappaXY/dl.mu | m³·s/kg | Transmissibility, XY-component | Domain 1 |  |
| dl.TraYY | dl.kappaYY/dl.mu | m³·s/kg | Transmissibility, YY-component | Domain 1 |  |
| dl.TraZY | dl.kappaZY/dl.mu | m³·s/kg | Transmissibility, ZY-component | Domain 1 |  |
| dl.TraXZ | dl.kappaXZ/dl.mu | m³·s/kg | Transmissibility, XZ-component | Domain 1 |  |
| dl.TraYZ | dl.kappaYZ/dl.mu | m³·s/kg | Transmissibility, YZ-component | Domain 1 |  |
| dl.TraZZ | dl.kappaZZ/dl.mu | m³·s/kg | Transmissibility, ZZ-component | Domain 1 |  |
| dl.gradp\_mag | sqrt(eps+pX^2+pY^2) | N/m³ | Pressure gradient, magnitude | Domain 1 |  |
| dl.epsilon | dl.porous.pm.epsilon | 1 | Porosity | Domain 1 | + operation |
| dl.kappa\_mean | 0.5\*(dl.porous.pm.kappaXX+dl.porous.pm.kappaYY) | m² | Mean effective permeability | Domain 1 |  |
| dl.chif | dl.porous.fluid.chif | 1/Pa | Compressibility of fluid | Domain 1 |  |
| dl.dp | dl.porous.pm.dp | m | Particle diameter | Domain 1 |  |
| dl.cf | dl.porous.pm.cf | 1 | Forchheimer parameter | Domain 1 |  |
| dl.u | spatial.F11\*dl.UX+spatial.F21\*dl.UY | m/s | Darcy's velocity field, x-component | Domain 1 |  |
| dl.v | spatial.F12\*dl.UX+spatial.F22\*dl.UY | m/s | Darcy's velocity field, y-component | Domain 1 |  |
| dl.w | dl.UZ | m/s | Darcy's velocity field, z-component | Domain 1 |  |
| dl.UX | -dl.TraXX\*pX-dl.TraXY\*pY+dl.ugX | m/s | Darcy's velocity field, X-component | Domain 1 | + operation |
| dl.UY | -dl.TraYX\*pX-dl.TraYY\*pY+dl.ugY | m/s | Darcy's velocity field, Y-component | Domain 1 | + operation |
| dl.UZ | -dl.TraZX\*pX-dl.TraZY\*pY+dl.ugZ | m/s | Darcy's velocity field, Z-component | Domain 1 | + operation |
| dl.ugX | dl.rho\*(dl.TraXX\*dl.ag1+dl.TraXY\*dl.ag2+dl.TraXZ\*dl.ag3) | m/s | Gravity contribution to Darcy velocity field, X-component | Domain 1 |  |
| dl.ugY | dl.rho\*(dl.TraYX\*dl.ag1+dl.TraYY\*dl.ag2+dl.TraYZ\*dl.ag3) | m/s | Gravity contribution to Darcy velocity field, Y-component | Domain 1 |  |
| dl.ugZ | dl.rho\*(dl.TraZX\*dl.ag1+dl.TraZY\*dl.ag2+dl.TraZZ\*dl.ag3) | m/s | Gravity contribution to Darcy velocity field, Z-component | Domain 1 |  |
| dl.U | sqrt(dl.u^2+dl.v^2+dl.w^2) | m/s | Darcy's velocity magnitude | Domain 1 |  |
| dl.ul1 | spatial.invF11\*dl.u+spatial.invF21\*dl.v | m/s | Darcy's velocity field, local coordinate system, X-component | Domain 1 |  |
| dl.ul2 | spatial.invF12\*dl.u+spatial.invF22\*dl.v | m/s | Darcy's velocity field, local coordinate system, Y-component | Domain 1 |  |
| dl.ul3 | dl.w | m/s | Darcy's velocity field, local coordinate system, Z-component | Domain 1 |  |
| dl.bndflux | -dflux\_material(p) | kg/(m²·s) | Boundary flux | Boundaries 1–4 |  |
| dl.Qvd | dl.mu\*(dl.UX\*((dl.kappaYY\*dl.kappaZZ-dl.kappaYZ\*dl.kappaZY)\*dl.UX+(dl.kappaXZ\*dl.kappaZY-dl.kappaXY\*dl.kappaZZ)\*dl.UY+(dl.kappaXY\*dl.kappaYZ-dl.kappaXZ\*dl.kappaYY)\*dl.UZ)+dl.UY\*((dl.kappaYZ\*dl.kappaZX-dl.kappaYX\*dl.kappaZZ)\*dl.UX+(dl.kappaXX\*dl.kappaZZ-dl.kappaXZ\*dl.kappaZX)\*dl.UY+(dl.kappaXZ\*dl.kappaYX-dl.kappaXX\*dl.kappaYZ)\*dl.UZ)+dl.UZ\*((dl.kappaYX\*dl.kappaZY-dl.kappaYY\*dl.kappaZX)\*dl.UX+(dl.kappaXY\*dl.kappaZX-dl.kappaXX\*dl.kappaZY)\*dl.UY+(dl.kappaXX\*dl.kappaYY-dl.kappaXY\*dl.kappaYX)\*dl.UZ))/(dl.kappaXX\*dl.kappaYY\*dl.kappaZZ+dl.kappaXY\*dl.kappaYZ\*dl.kappaZX+dl.kappaXZ\*dl.kappaYX\*dl.kappaZY-dl.kappaXX\*dl.kappaYZ\*dl.kappaZY-dl.kappaXY\*dl.kappaYX\*dl.kappaZZ-dl.kappaXZ\*dl.kappaYY\*dl.kappaZX) | W/m³ | Viscous dissipation | Domain 1 |  |
| dl.Qm | d(dl.epsilon\*dl.rho,t)-dl.rho\*dl.Sp\*pt | kg/(m³·s) | Mass source | Domain 1 | + operation |

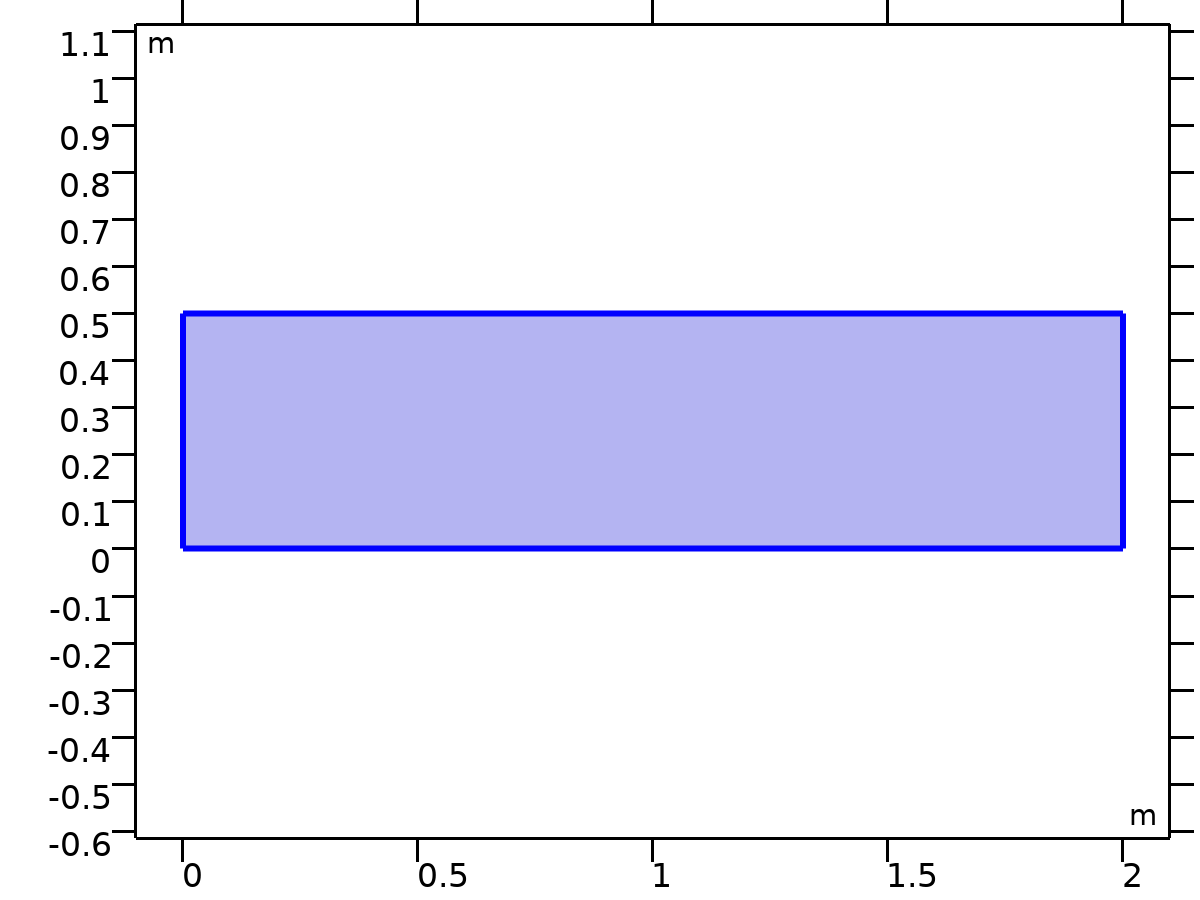
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| p | Lagrange (Quadratic) | Pa | Pressure | Material | Domain 1 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| dl.rho\*(dl.UX\*test(pX)+dl.UY\*test(pY))\*dl.d | 4 | Material | Domain 1 |
| -d(dl.epsilon\*dl.rho,t)\*test(p)\*dl.d | 4 | Material | Domain 1 |

#### Fluid 1

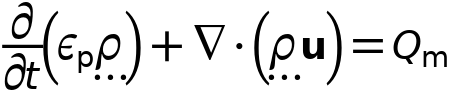


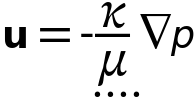
Fluid 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations





##### Fluid Properties

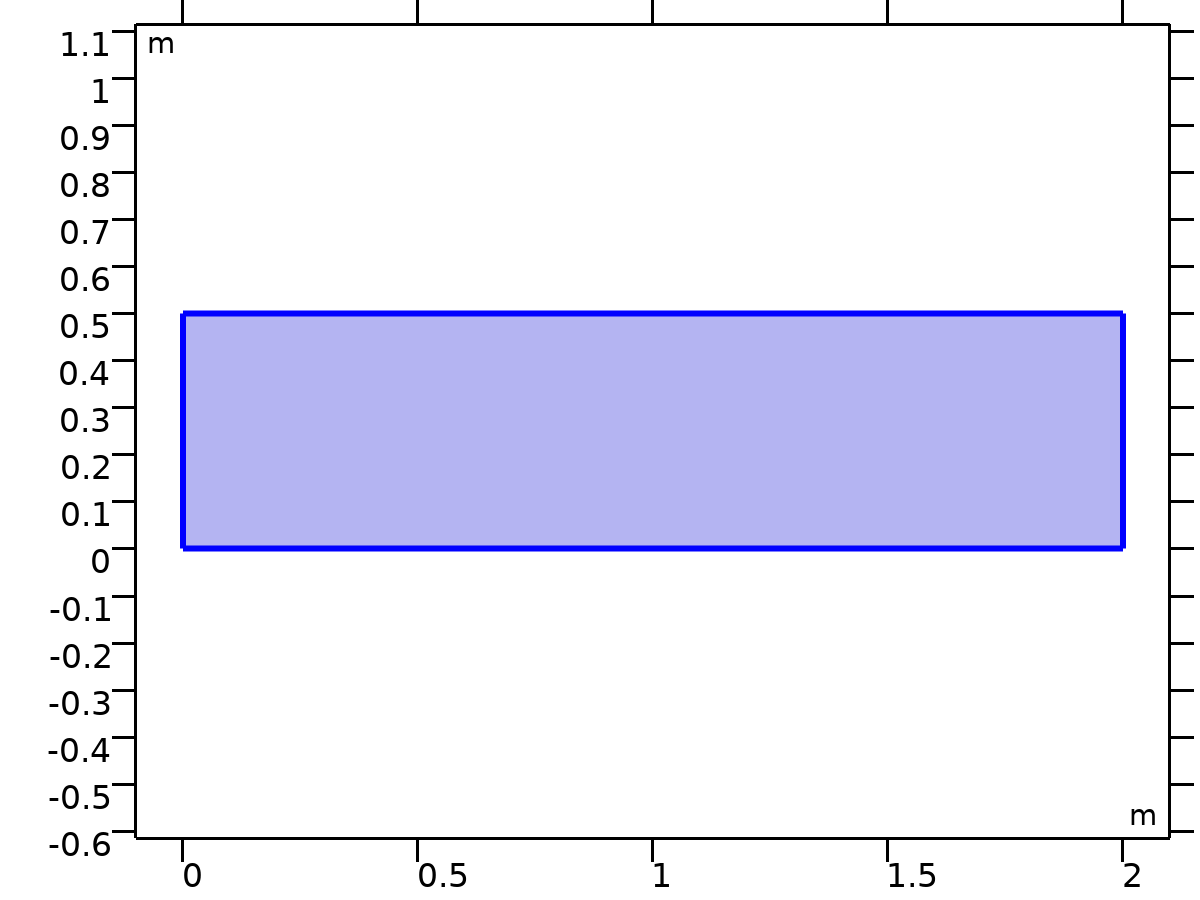
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Fluid type | Gas/Liquid |  |
| Density | User defined |  |
| Density | rho\_f | kg/m³ |
| Dynamic viscosity | User defined |  |
| Dynamic viscosity | eta\_f | Pa·s |

##### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| dl.porous.fluid.rho | dl.porous.fluid.rhomat | kg/m³ | Density | Domain 1 |  |
| dl.porous.fluid.rhomat | material.rho | kg/m³ | Density | Domain 1 | Meta |
| dl.porous.fluid.mu | material.mu | Pa·s | Dynamic viscosity | Domain 1 | Meta |
| dl.porous.fluid.chif | material.chif | 1/Pa | Compressibility of fluid | Domain 1 | Meta |
| dl.porous.fluid.prho | dl.porous1.fluid1.minput\_pressure | Pa | Pressure for the evaluation of density | Domain 1 |  |
| dl.porous.fluid.Trho | dl.porous1.fluid1.minput\_temperature | K | Temperature for density evaluation | Domain 1 |  |

#### Porous Matrix 1

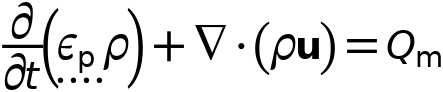


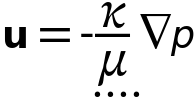
Porous Matrix 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations





##### Matrix Properties

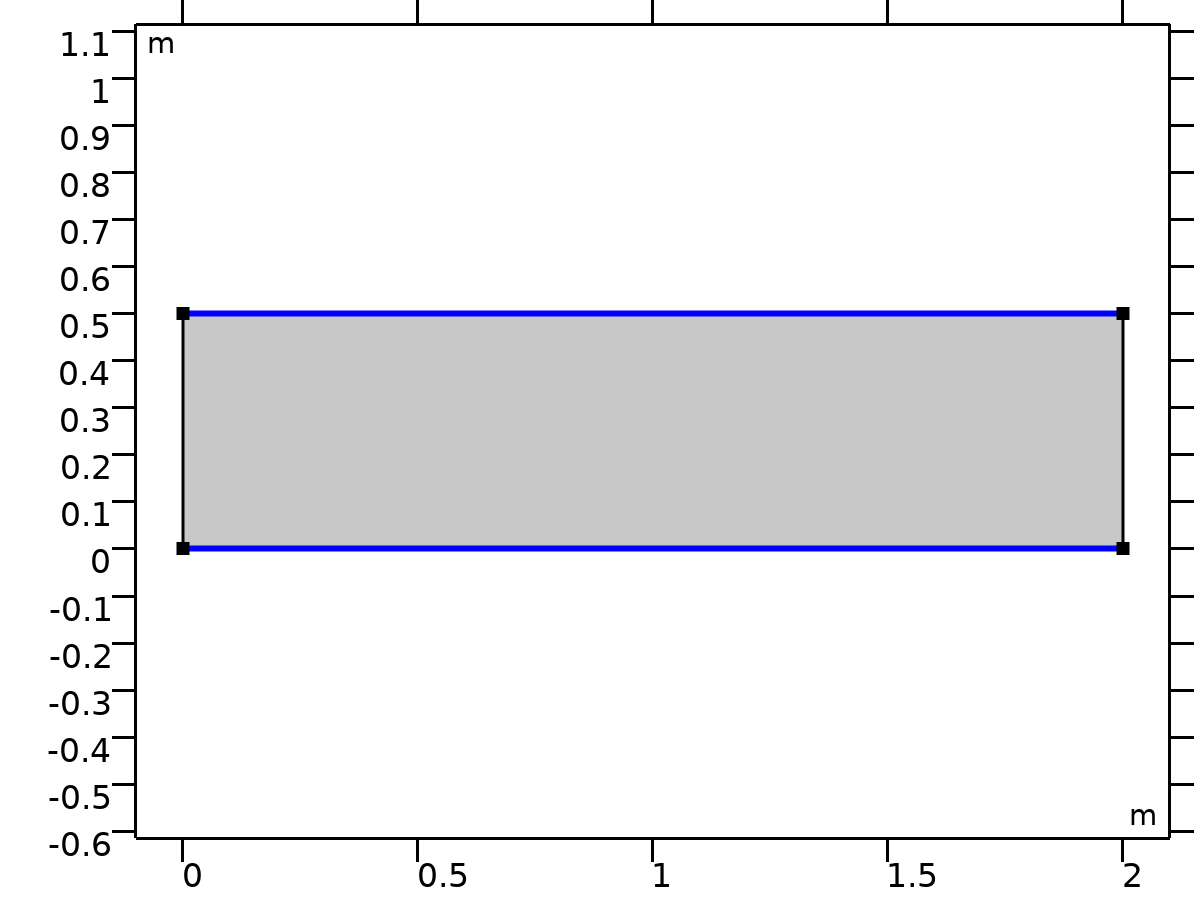
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Porosity | User defined |  |
| Porosity | phi | 1 |
| Permeability model | Permeability |  |
| Permeability | User defined |  |
| Permeability | K | m² |

##### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| dl.porous.pm.epsilon | phi | 1 | Porosity | Domain 1 | + operation |
| dl.porous.pm.kappaXX | K | m² | Permeability, XX-component | Domain 1 |  |
| dl.porous.pm.kappaYX | 0 | m² | Permeability, YX-component | Domain 1 |  |
| dl.porous.pm.kappaZX | 0 | m² | Permeability, ZX-component | Domain 1 |  |
| dl.porous.pm.kappaXY | 0 | m² | Permeability, XY-component | Domain 1 |  |
| dl.porous.pm.kappaYY | K | m² | Permeability, YY-component | Domain 1 |  |
| dl.porous.pm.kappaZY | 0 | m² | Permeability, ZY-component | Domain 1 |  |
| dl.porous.pm.kappaXZ | 0 | m² | Permeability, XZ-component | Domain 1 |  |
| dl.porous.pm.kappaYZ | 0 | m² | Permeability, YZ-component | Domain 1 |  |
| dl.porous.pm.kappaZZ | K | m² | Permeability, ZZ-component | Domain 1 |  |
| dl.porous.pm.alpha | 1[1/m] | 1/m | Constitutive relation constant | Domain 1 |  |
| dl.porous.pm.l | 0.5 | 1 | Constitutive relation constant | Domain 1 |  |
| dl.porous.pm.n | 2 | 1 | Constitutive relation constant | Domain 1 |  |
| dl.porous.pm.m | 0.5 | 1 | Constitutive relation constant | Domain 1 |  |
| dl.porous.pm.theta\_r | 0 | 1 | Residual liquid volume fraction | Domain 1 |  |

* + 1. No Flow 1



No Flow 1

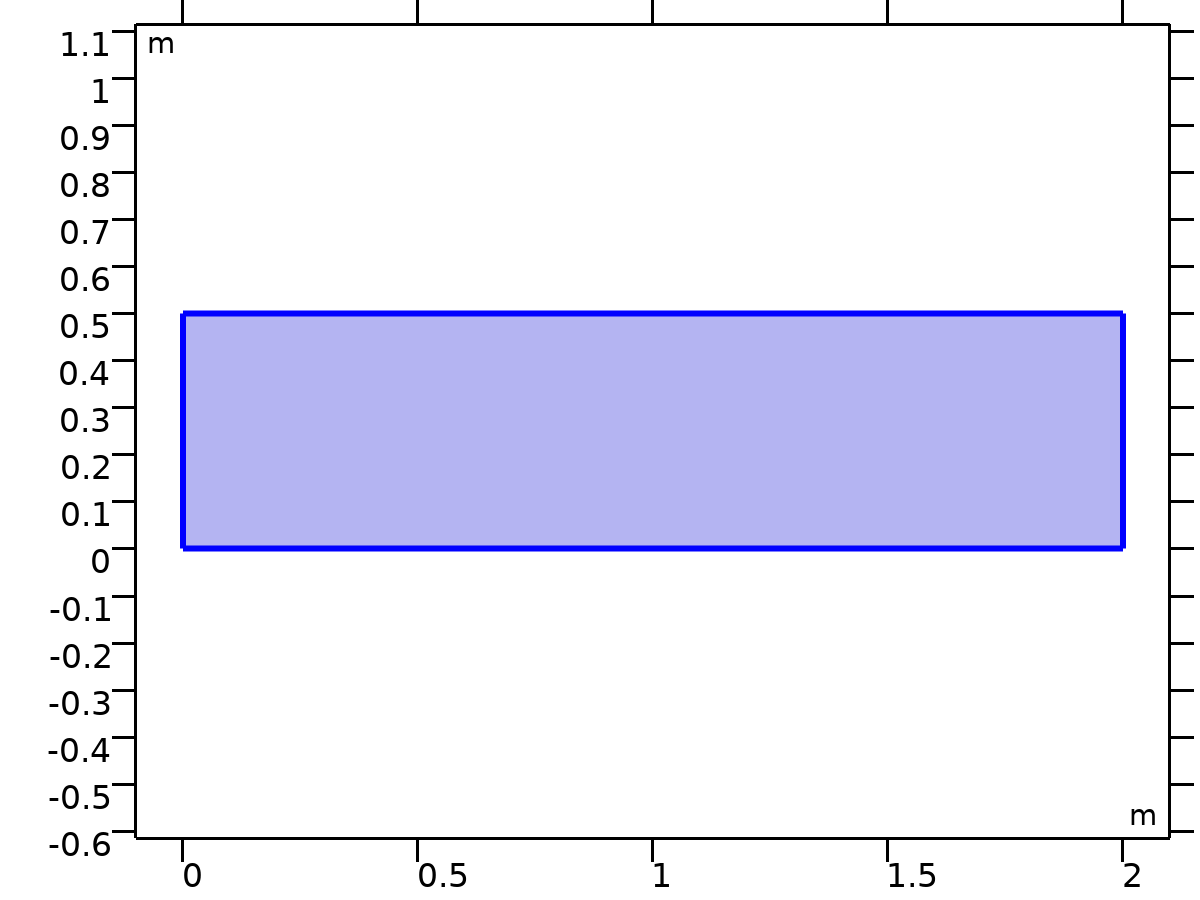
Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 1: All boundaries |

Equations



* + 1. Initial Values 1



Initial Values 1

Selection

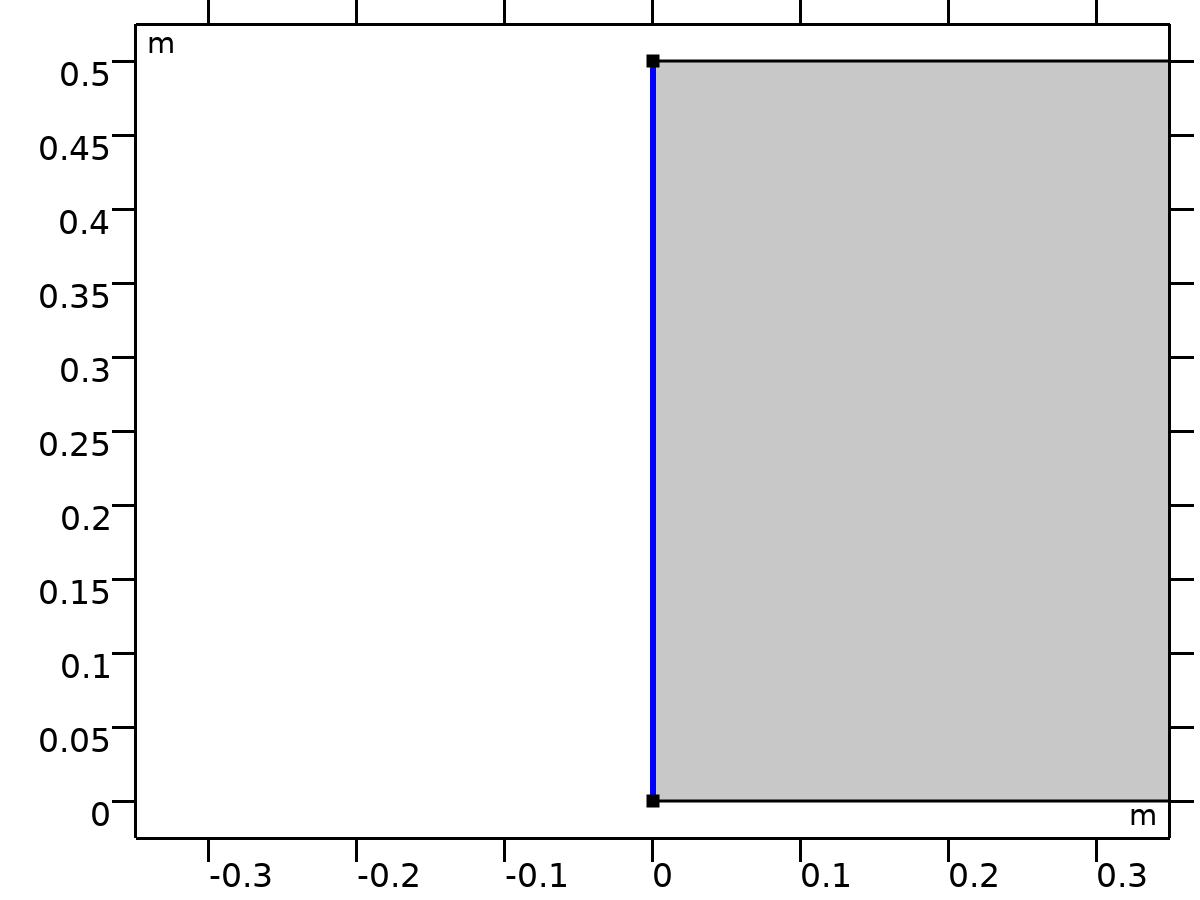
|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

#### Initial Values

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
|  | Pressure |  |
| Pressure | 1000 | Pa |
| Pressure | 1000 | Pa |

* + 1. Pressure 1



Pressure 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 1: Boundary 1 |

Equations



#### Pressure

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Pressure | 1000 | Pa |

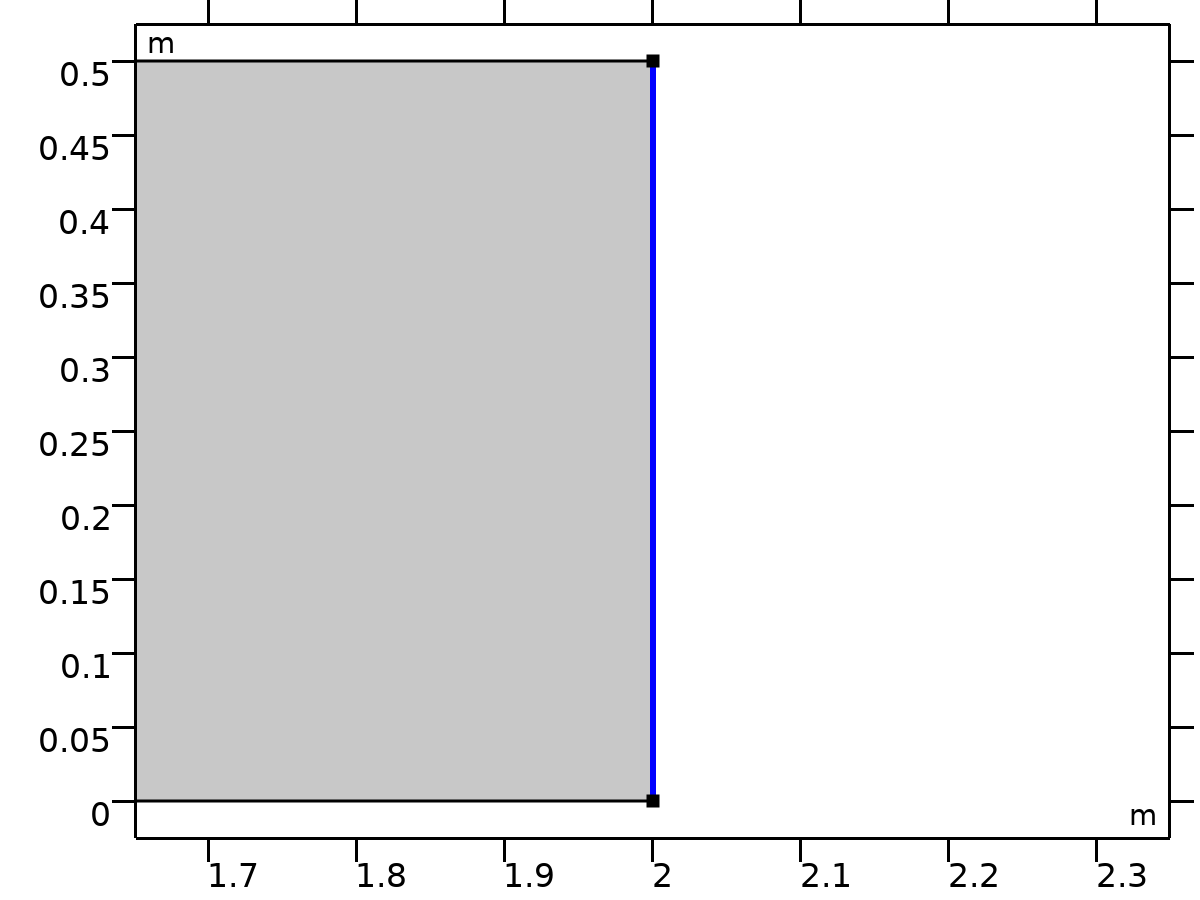
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| dl.p0 | 1000 | Pa | Pressure | Boundary 1 |  |
| dl.pr1.varInt | dl.d | m | Intermediate variable | Boundary 1 | Meta |
| dl.pr1.Mflow | dl.pr1.intExtBnd(dl.bndflux\*dl.pr1.varInt) | kg/s | Mass flow | Global |  |
| dl.pr1.Mflow\_u | dl.pr1.intIntBnd(dl.bndflux\_u\*dl.pr1.varInt) | kg/s | Mass flow, upside | Global |  |
| dl.pr1.Mflow\_d | dl.pr1.intIntBnd(dl.bndflux\_d\*dl.pr1.varInt) | kg/s | Mass flow, downside | Global |  |

#### Constraints

| **Constraint** | **Constraint force** | **Shape function** | **Selection** | **Details** |
| --- | --- | --- | --- | --- |
| p-dl.p0 | test(p-dl.p0) | Lagrange (Quadratic) | Boundary 1 | Elemental |

* + 1. Pressure 2



Pressure 2

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 1: Boundary 4 |

Equations



#### Pressure

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Pressure | 0 | Pa |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| dl.p0 | 0 | Pa | Pressure | Boundary 4 |  |
| dl.pr2.varInt | dl.d | m | Intermediate variable | Boundary 4 | Meta |
| dl.pr2.Mflow | dl.pr2.intExtBnd(dl.bndflux\*dl.pr2.varInt) | kg/s | Mass flow | Global |  |
| dl.pr2.Mflow\_u | dl.pr2.intIntBnd(dl.bndflux\_u\*dl.pr2.varInt) | kg/s | Mass flow, upside | Global |  |
| dl.pr2.Mflow\_d | dl.pr2.intIntBnd(dl.bndflux\_d\*dl.pr2.varInt) | kg/s | Mass flow, downside | Global |  |

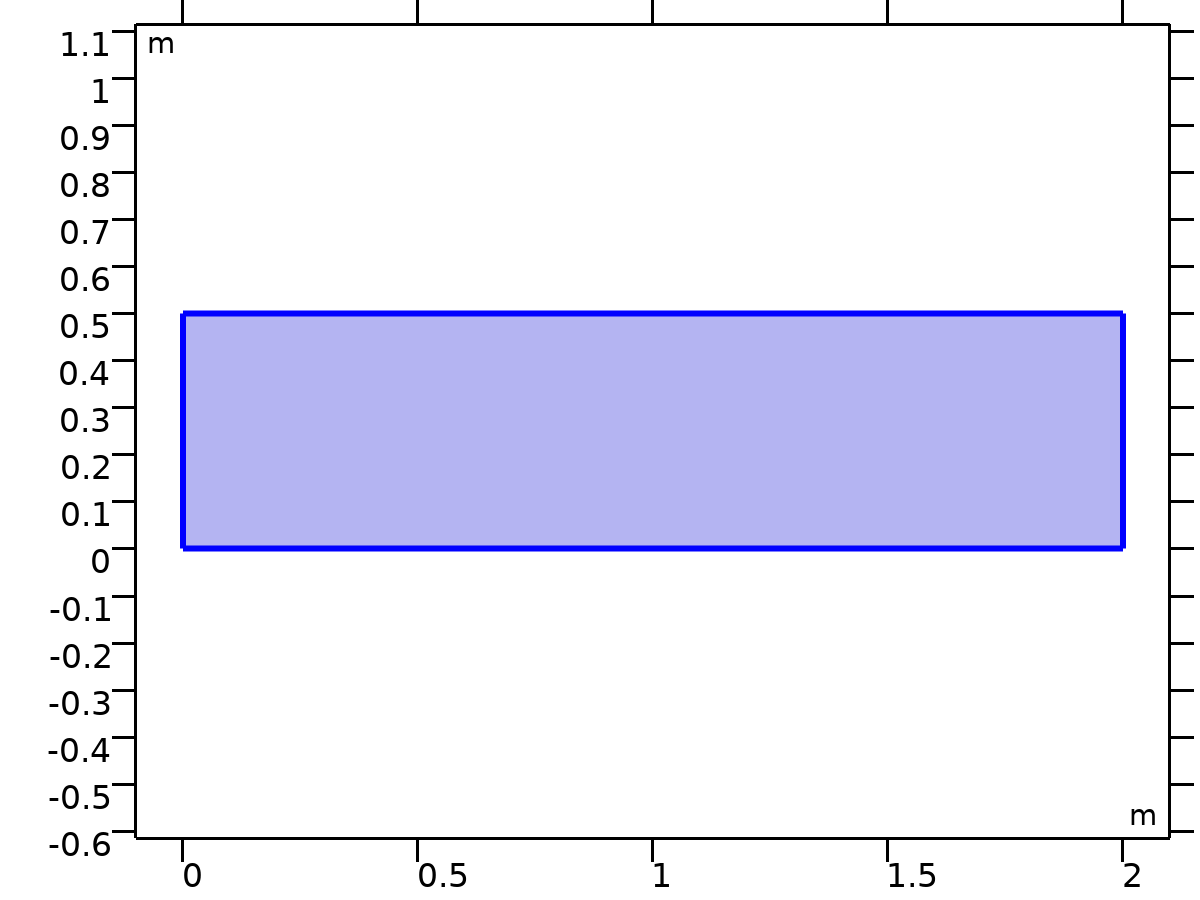
#### Constraints

| **Constraint** | **Constraint force** | **Shape function** | **Selection** | **Details** |
| --- | --- | --- | --- | --- |
| p-dl.p0 | test(p-dl.p0) | Lagrange (Quadratic) | Boundary 4 | Elemental |

* 1. Electric Currents

Used products

|  |
| --- |
| COMSOL Multiphysics |



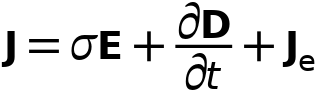
Electric Currents

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations







* + 1. Interface Settings

#### Discretization

Settings

| **Description** | **Value** |
| --- | --- |
| Electric potential | Quadratic |

Settings

| **Description** | **Value** |
| --- | --- |
| Equation form | Study controlled |

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Out-of-plane thickness | 1 | m |

#### Manual Terminal Sweep Settings

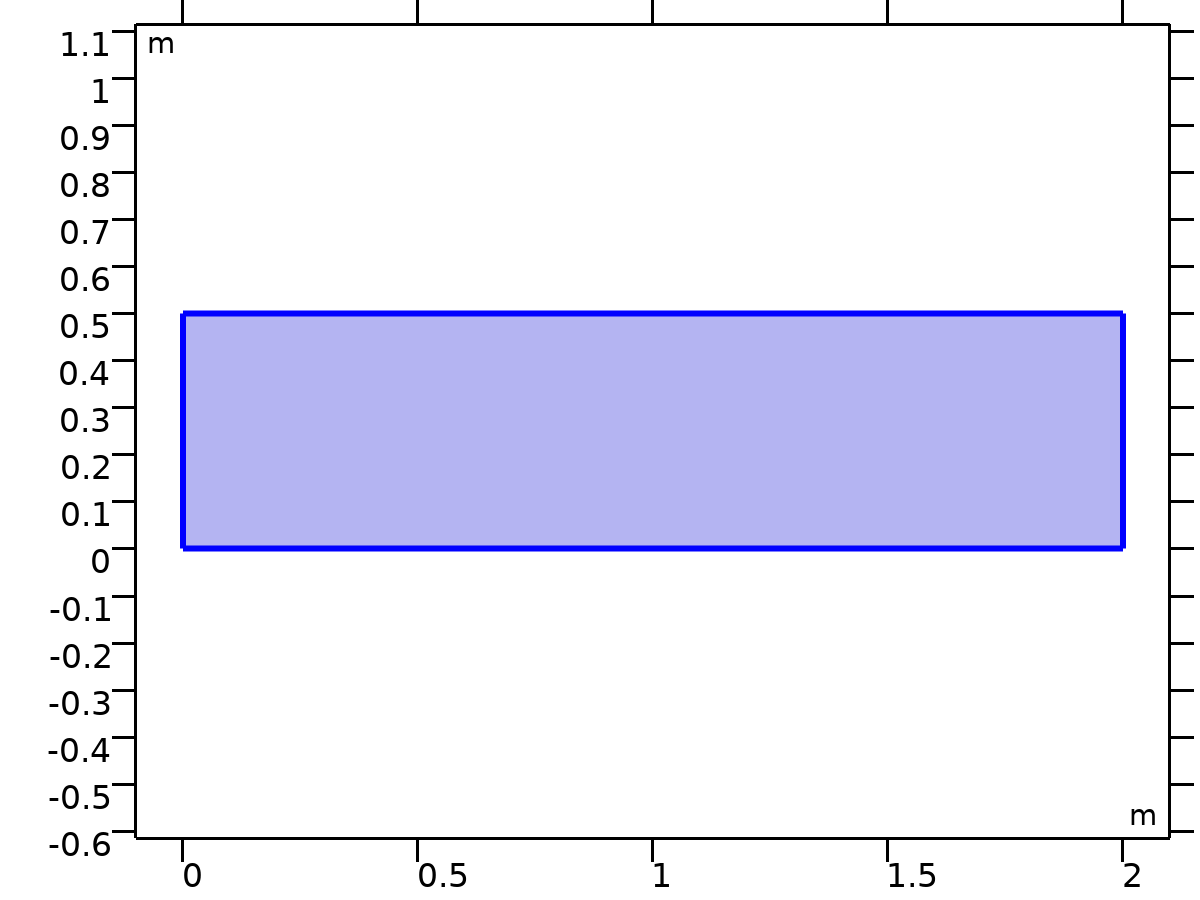
Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Use manual terminal sweep | Off |  |
| Reference impedance | 50 | Ω |

* + 1. Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ec.d | 1 | m | Out-of-plane thickness | Domain 1 |  |
| ec.I\_sXX | (spatial.invF11\*(spatial.invF11\*ec.I\_sxx+spatial.invF21\*ec.I\_syx)+spatial.invF21\*(spatial.invF11\*ec.I\_sxy+spatial.invF21\*ec.I\_syy))\*spatial.detF | 1 | Spatial identity matrix, material frame, XX-component | Domain 1 |  |
| ec.I\_sYX | (spatial.invF11\*(spatial.invF12\*ec.I\_sxx+spatial.invF22\*ec.I\_syx)+spatial.invF21\*(spatial.invF12\*ec.I\_sxy+spatial.invF22\*ec.I\_syy))\*spatial.detF | 1 | Spatial identity matrix, material frame, YX-component | Domain 1 |  |
| ec.I\_sZX | (spatial.invF11\*ec.I\_szx+spatial.invF21\*ec.I\_szy)\*spatial.detF | 1 | Spatial identity matrix, material frame, ZX-component | Domain 1 |  |
| ec.I\_sXY | (spatial.invF12\*(spatial.invF11\*ec.I\_sxx+spatial.invF21\*ec.I\_syx)+spatial.invF22\*(spatial.invF11\*ec.I\_sxy+spatial.invF21\*ec.I\_syy))\*spatial.detF | 1 | Spatial identity matrix, material frame, XY-component | Domain 1 |  |
| ec.I\_sYY | (spatial.invF12\*(spatial.invF12\*ec.I\_sxx+spatial.invF22\*ec.I\_syx)+spatial.invF22\*(spatial.invF12\*ec.I\_sxy+spatial.invF22\*ec.I\_syy))\*spatial.detF | 1 | Spatial identity matrix, material frame, YY-component | Domain 1 |  |
| ec.I\_sZY | (spatial.invF12\*ec.I\_szx+spatial.invF22\*ec.I\_szy)\*spatial.detF | 1 | Spatial identity matrix, material frame, ZY-component | Domain 1 |  |
| ec.I\_sXZ | (spatial.invF11\*ec.I\_sxz+spatial.invF21\*ec.I\_syz)\*spatial.detF | 1 | Spatial identity matrix, material frame, XZ-component | Domain 1 |  |
| ec.I\_sYZ | (spatial.invF12\*ec.I\_sxz+spatial.invF22\*ec.I\_syz)\*spatial.detF | 1 | Spatial identity matrix, material frame, YZ-component | Domain 1 |  |
| ec.I\_sZZ | ec.I\_szz\*spatial.detF | 1 | Spatial identity matrix, material frame, ZZ-component | Domain 1 |  |
| ec.I\_sxx | 1 | 1 | Spatial identity matrix, xx-component | Domain 1 |  |
| ec.I\_syx | 0 | 1 | Spatial identity matrix, yx-component | Domain 1 |  |
| ec.I\_szx | 0 | 1 | Spatial identity matrix, zx-component | Domain 1 |  |
| ec.I\_sxy | 0 | 1 | Spatial identity matrix, xy-component | Domain 1 |  |
| ec.I\_syy | 1 | 1 | Spatial identity matrix, yy-component | Domain 1 |  |
| ec.I\_szy | 0 | 1 | Spatial identity matrix, zy-component | Domain 1 |  |
| ec.I\_sxz | 0 | 1 | Spatial identity matrix, xz-component | Domain 1 |  |
| ec.I\_syz | 0 | 1 | Spatial identity matrix, yz-component | Domain 1 |  |
| ec.I\_szz | 1 | 1 | Spatial identity matrix, zz-component | Domain 1 |  |
| ec.nx | dnx |  | Normal vector, x-component | Boundaries 1–4 |  |
| ec.ny | dny |  | Normal vector, y-component | Boundaries 1–4 |  |
| ec.nz | 0 |  | Normal vector, z-component | Boundaries 1–4 |  |
| ec.nmeshx | dnxmesh |  | Mesh normal vector, x-component | Boundaries 1–4 |  |
| ec.nmeshy | dnymesh |  | Mesh normal vector, y-component | Boundaries 1–4 |  |
| ec.nmeshz | 0 |  | Mesh normal vector, z-component | Boundaries 1–4 |  |
| ec.unmeshx | unxmesh |  | Mesh normal vector, upside, x-component | Boundaries 1–4 |  |
| ec.unmeshy | unymesh |  | Mesh normal vector, upside, y-component | Boundaries 1–4 |  |
| ec.unmeshz | 0 |  | Mesh normal vector, upside, z-component | Boundaries 1–4 |  |
| ec.dnmeshx | dnxmesh |  | Mesh normal vector, downside, x-component | Boundaries 1–4 |  |
| ec.dnmeshy | dnymesh |  | Mesh normal vector, downside, y-component | Boundaries 1–4 |  |
| ec.dnmeshz | 0 |  | Mesh normal vector, downside, z-component | Boundaries 1–4 |  |
| ec.unTx | ec.unTex | Pa | Maxwell upward surface stress tensor, x-component | Boundaries 1–4 |  |
| ec.unTy | ec.unTey | Pa | Maxwell upward surface stress tensor, y-component | Boundaries 1–4 |  |
| ec.unTz | ec.unTez | Pa | Maxwell upward surface stress tensor, z-component | Boundaries 1–4 |  |
| ec.dnTx | ec.dnTex | Pa | Maxwell downward surface stress tensor, x-component | Boundaries 1–4 |  |
| ec.dnTy | ec.dnTey | Pa | Maxwell downward surface stress tensor, y-component | Boundaries 1–4 |  |
| ec.dnTz | ec.dnTez | Pa | Maxwell downward surface stress tensor, z-component | Boundaries 1–4 |  |
| ec.unx | unx |  | Normal vector up direction, x-component | Boundaries 1–4 |  |
| ec.uny | uny |  | Normal vector up direction, y-component | Boundaries 1–4 |  |
| ec.unz | 0 |  | Normal vector up direction, z-component | Boundaries 1–4 |  |
| ec.dnx | dnx |  | Normal vector down direction, x-component | Boundaries 1–4 |  |
| ec.dny | dny |  | Normal vector down direction, y-component | Boundaries 1–4 |  |
| ec.dnz | 0 |  | Normal vector down direction, z-component | Boundaries 1–4 |  |
| ec.unTex | 0 | Pa | Maxwell upward electric surface stress tensor, x-component | Boundaries 1–4 |  |
| ec.unTey | 0 | Pa | Maxwell upward electric surface stress tensor, y-component | Boundaries 1–4 |  |
| ec.unTez | 0 | Pa | Maxwell upward electric surface stress tensor, z-component | Boundaries 1–4 |  |
| ec.dnTex | -0.5\*ec.unx\*(real(down(ec.Dx))\*real(down(ec.Ex))+real(down(ec.Dy))\*real(down(ec.Ey))+real(down(ec.Dz))\*real(down(ec.Ez)))+real(down(ec.Dx))\*(real(down(ec.Ex))\*ec.unx+real(down(ec.Ey))\*ec.uny+real(down(ec.Ez))\*ec.unz) | Pa | Maxwell downward electric surface stress tensor, x-component | Boundaries 1–4 |  |
| ec.dnTey | -0.5\*ec.uny\*(real(down(ec.Dx))\*real(down(ec.Ex))+real(down(ec.Dy))\*real(down(ec.Ey))+real(down(ec.Dz))\*real(down(ec.Ez)))+real(down(ec.Dy))\*(real(down(ec.Ex))\*ec.unx+real(down(ec.Ey))\*ec.uny+real(down(ec.Ez))\*ec.unz) | Pa | Maxwell downward electric surface stress tensor, y-component | Boundaries 1–4 |  |
| ec.dnTez | -0.5\*ec.unz\*(real(down(ec.Dx))\*real(down(ec.Ex))+real(down(ec.Dy))\*real(down(ec.Ey))+real(down(ec.Dz))\*real(down(ec.Ez)))+real(down(ec.Dz))\*(real(down(ec.Ex))\*ec.unx+real(down(ec.Ey))\*ec.uny+real(down(ec.Ez))\*ec.unz) | Pa | Maxwell downward electric surface stress tensor, z-component | Boundaries 1–4 |  |
| ec.intWe | ec.int\_We(ec.d\*ec.dWe) | J | Total electric energy | Global | + operation |
| ec.Qh | 0 | W/m³ | Volumetric loss density, electromagnetic | Domain 1 |  |
| ec.Qsh | 0 | W/m² | Surface loss density, electromagnetic | Boundaries 1–4 |  |
| ec.Qlh | 0 | W/m | Line loss density, electromagnetic | Boundaries 1–4 |  |
| ec.zref | 50[ohm] | Ω | Reference impedance | Global |  |

* + 1. Current Conservation 1



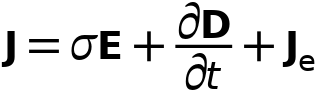
Current Conservation 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Equations







#### Constitutive Relation Jc-E

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Conduction model | Electrical conductivity |  |
| Electrical conductivity | User defined |  |
| Electrical conductivity | sigma\_sat | S/m |

#### Constitutive Relation D-E

Settings

| **Description** | **Value** |
| --- | --- |
| Dielectric model | Relative permittivity |
| Relative permittivity | User defined |
| Relative permittivity | 1 |

#### Coordinate System Selection

Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ec.Qh | ec.Qrh | W/m³ | Volumetric loss density, electromagnetic | Domain 1 |  |
| ec.Jex | 0 | A/m² | External current density, x-component | Domain 1 | + operation |
| ec.Jey | 0 | A/m² | External current density, y-component | Domain 1 | + operation |
| ec.Jez | 0 | A/m² | External current density, z-component | Domain 1 | + operation |
| ec.Jix | ec.sigmaxx\*ec.Ex+ec.sigmaxy\*ec.Ey+ec.sigmaxz\*ec.Ez | A/m² | Conduction current density, x-component | Domain 1 |  |
| ec.Jiy | ec.sigmayx\*ec.Ex+ec.sigmayy\*ec.Ey+ec.sigmayz\*ec.Ez | A/m² | Conduction current density, y-component | Domain 1 |  |
| ec.Jiz | ec.sigmazx\*ec.Ex+ec.sigmazy\*ec.Ey+ec.sigmazz\*ec.Ez | A/m² | Conduction current density, z-component | Domain 1 |  |
| ec.Jdx | d(ec.Dx,t) | A/m² | Displacement current density, x-component | Domain 1 |  |
| ec.Jdy | d(ec.Dy,t) | A/m² | Displacement current density, y-component | Domain 1 |  |
| ec.Jdz | d(ec.Dz,t) | A/m² | Displacement current density, z-component | Domain 1 |  |
| ec.Jx | ec.Jix+ec.Jdx+ec.Jex | A/m² | Current density, x-component | Domain 1 |  |
| ec.Jy | ec.Jiy+ec.Jdy+ec.Jey | A/m² | Current density, y-component | Domain 1 |  |
| ec.Jz | ec.Jiz+ec.Jdz+ec.Jez | A/m² | Current density, z-component | Domain 1 |  |
| ec.normJ | sqrt(realdot(ec.Jx,ec.Jx)+realdot(ec.Jy,ec.Jy)+realdot(ec.Jz,ec.Jz)) | A/m² | Current density norm | Domain 1 |  |
| ec.rhoq | ppr(d(ec.Dx,x)+d(ec.Dy,y)) | C/m³ | Space charge density | Domain 1 |  |
| ec.sigmaxx | material.sigma11 | S/m | Electrical conductivity, xx-component | Domain 1 | Meta |
| ec.sigmayx | material.sigma21 | S/m | Electrical conductivity, yx-component | Domain 1 | Meta |
| ec.sigmazx | material.sigma31 | S/m | Electrical conductivity, zx-component | Domain 1 | Meta |
| ec.sigmaxy | material.sigma12 | S/m | Electrical conductivity, xy-component | Domain 1 | Meta |
| ec.sigmayy | material.sigma22 | S/m | Electrical conductivity, yy-component | Domain 1 | Meta |
| ec.sigmazy | material.sigma32 | S/m | Electrical conductivity, zy-component | Domain 1 | Meta |
| ec.sigmaxz | material.sigma13 | S/m | Electrical conductivity, xz-component | Domain 1 | Meta |
| ec.sigmayz | material.sigma23 | S/m | Electrical conductivity, yz-component | Domain 1 | Meta |
| ec.sigmazz | material.sigma33 | S/m | Electrical conductivity, zz-component | Domain 1 | Meta |
| ec.sigma\_iso | material.sigma\_iso | S/m | Electrical conductivity, isotropic value | Domain 1 | Meta |
| ec.epsilonrxx | 1 | 1 | Relative permittivity, xx-component | Domain 1 |  |
| ec.epsilonryx | 0 | 1 | Relative permittivity, yx-component | Domain 1 |  |
| ec.epsilonrzx | 0 | 1 | Relative permittivity, zx-component | Domain 1 |  |
| ec.epsilonrxy | 0 | 1 | Relative permittivity, xy-component | Domain 1 |  |
| ec.epsilonryy | 1 | 1 | Relative permittivity, yy-component | Domain 1 |  |
| ec.epsilonrzy | 0 | 1 | Relative permittivity, zy-component | Domain 1 |  |
| ec.epsilonrxz | 0 | 1 | Relative permittivity, xz-component | Domain 1 |  |
| ec.epsilonryz | 0 | 1 | Relative permittivity, yz-component | Domain 1 |  |
| ec.epsilonrzz | 1 | 1 | Relative permittivity, zz-component | Domain 1 |  |
| ec.epsilonr\_iso | 1 | 1 | Relative permittivity, isotropic value | Domain 1 |  |
| ec.Dx | epsilon0\_const\*ec.I\_sxx\*ec.Ex+epsilon0\_const\*ec.I\_sxy\*ec.Ey+epsilon0\_const\*ec.I\_sxz\*ec.Ez+ec.Px+ec.Pex+ec.Phx | C/m² | Electric displacement field, x-component | Domain 1 |  |
| ec.Dy | epsilon0\_const\*ec.I\_syx\*ec.Ex+epsilon0\_const\*ec.I\_syy\*ec.Ey+epsilon0\_const\*ec.I\_syz\*ec.Ez+ec.Py+ec.Pey+ec.Phy | C/m² | Electric displacement field, y-component | Domain 1 |  |
| ec.Dz | epsilon0\_const\*ec.I\_szx\*ec.Ex+epsilon0\_const\*ec.I\_szy\*ec.Ey+epsilon0\_const\*ec.I\_szz\*ec.Ez+ec.Pz+ec.Pez+ec.Phz | C/m² | Electric displacement field, z-component | Domain 1 |  |
| ec.Px | epsilon0\_const\*(ec.chixx\*ec.Ex+ec.chixy\*ec.Ey+ec.chixz\*ec.Ez) | C/m² | Polarization, x-component | Domain 1 |  |
| ec.Py | epsilon0\_const\*(ec.chiyx\*ec.Ex+ec.chiyy\*ec.Ey+ec.chiyz\*ec.Ez) | C/m² | Polarization, y-component | Domain 1 |  |
| ec.Pz | epsilon0\_const\*(ec.chizx\*ec.Ex+ec.chizy\*ec.Ey+ec.chizz\*ec.Ez) | C/m² | Polarization, z-component | Domain 1 |  |
| ec.normD | sqrt(realdot(ec.Dx,ec.Dx)+realdot(ec.Dy,ec.Dy)+realdot(ec.Dz,ec.Dz)) | C/m² | Electric displacement field norm | Domain 1 |  |
| ec.normP | sqrt(realdot(ec.Px,ec.Px)+realdot(ec.Py,ec.Py)+realdot(ec.Pz,ec.Pz)) | C/m² | Polarization norm | Domain 1 |  |
| ec.Pex | 0 | C/m² | Polarization contribution, x-component | Domain 1 | + operation |
| ec.Pey | 0 | C/m² | Polarization contribution, y-component | Domain 1 | + operation |
| ec.Pez | 0 | C/m² | Polarization contribution, z-component | Domain 1 | + operation |
| ec.Phx | 0 | C/m² | Polarization contribution, x-component | Domain 1 | + operation |
| ec.Phy | 0 | C/m² | Polarization contribution, y-component | Domain 1 | + operation |
| ec.Phz | 0 | C/m² | Polarization contribution, z-component | Domain 1 | + operation |
| ec.chixx | -1+ec.epsilonrxx | 1 | Electric susceptibility, xx-component | Domain 1 |  |
| ec.chiyx | ec.epsilonryx | 1 | Electric susceptibility, yx-component | Domain 1 |  |
| ec.chizx | ec.epsilonrzx | 1 | Electric susceptibility, zx-component | Domain 1 |  |
| ec.chixy | ec.epsilonrxy | 1 | Electric susceptibility, xy-component | Domain 1 |  |
| ec.chiyy | -1+ec.epsilonryy | 1 | Electric susceptibility, yy-component | Domain 1 |  |
| ec.chizy | ec.epsilonrzy | 1 | Electric susceptibility, zy-component | Domain 1 |  |
| ec.chixz | ec.epsilonrxz | 1 | Electric susceptibility, xz-component | Domain 1 |  |
| ec.chiyz | ec.epsilonryz | 1 | Electric susceptibility, yz-component | Domain 1 |  |
| ec.chizz | -1+ec.epsilonrzz | 1 | Electric susceptibility, zz-component | Domain 1 |  |
| ec.Ex | -Vx | V/m | Electric field, x-component | Domain 1 |  |
| ec.Ey | -Vy | V/m | Electric field, y-component | Domain 1 |  |
| ec.Ez | 0 | V/m | Electric field, z-component | Domain 1 |  |
| ec.tEx | -VTx | V/m | Tangential electric field, x-component | Boundaries 1–4 |  |
| ec.tEy | -VTy | V/m | Tangential electric field, y-component | Boundaries 1–4 |  |
| ec.tEz | 0 | V/m | Tangential electric field, z-component | Boundaries 1–4 |  |
| ec.normE | sqrt(realdot(ec.Ex,ec.Ex)+realdot(ec.Ey,ec.Ey)+realdot(ec.Ez,ec.Ez)) | V/m | Electric field norm | Domain 1 |  |
| ec.Qrh | (ec.Jix+ec.Jex)\*ec.Ex+(ec.Jiy+ec.Jey)\*ec.Ey+(ec.Jiz+ec.Jez)\*ec.Ez | W/m³ | Volumetric loss density, electric | Domain 1 | + operation |
| ec.W | ec.We | J/m³ | Energy density | Domain 1 | + operation |
| ec.dWe | ec.We | J/m³ | Integrand for total electric energy | Domain 1 | Meta |
| ec.We | 0.5\*epsilon0\_const\*(((ec.I\_sxx+ec.chixx)\*ec.Ex+(ec.I\_sxy+ec.chixy)\*ec.Ey+(ec.I\_sxz+ec.chixz)\*ec.Ez)\*ec.Ex+((ec.I\_syx+ec.chiyx)\*ec.Ex+(ec.I\_syy+ec.chiyy)\*ec.Ey+(ec.I\_syz+ec.chiyz)\*ec.Ez)\*ec.Ey+((ec.I\_szx+ec.chizx)\*ec.Ex+(ec.I\_szy+ec.chizy)\*ec.Ey+(ec.I\_szz+ec.chizz)\*ec.Ez)\*ec.Ez) | J/m³ | Electric energy density | Domain 1 |  |
| ec.rhoqs | -ec.dnx\*down(ec.Dx)-ec.dny\*down(ec.Dy)-ec.dnz\*down(ec.Dz) | C/m² | Surface charge density | Boundaries 1–4 |  |

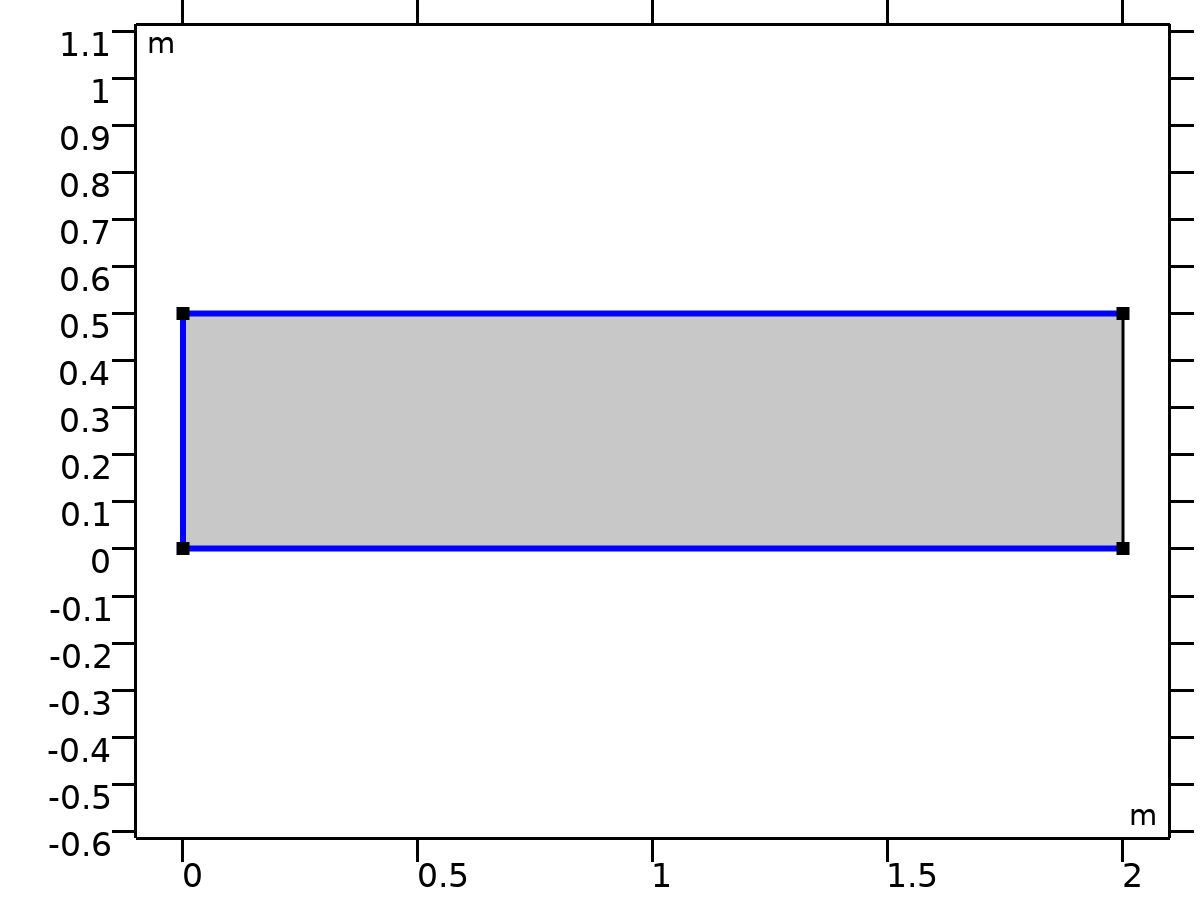
#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** |
| --- | --- | --- | --- | --- | --- |
| V | Lagrange (Quadratic) | V | Electric potential | Spatial | Domain 1 |
| V | Lagrange (Quadratic) | V | Electric potential | Material | Domain 1 |
| V | Lagrange (Quadratic) | V | Electric potential | Geometry | Domain 1 |
| V | Lagrange (Quadratic) | V | Electric potential | Mesh | Domain 1 |

#### Weak Expressions

| **Weak expression** | **Integration order** | **Integration frame** | **Selection** |
| --- | --- | --- | --- |
| (ec.Jx\*test(Vx)+ec.Jy\*test(Vy))\*ec.d | 4 | Spatial | Domain 1 |

* + 1. Electric Insulation 1



Electric Insulation 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 1: All boundaries |

Equations



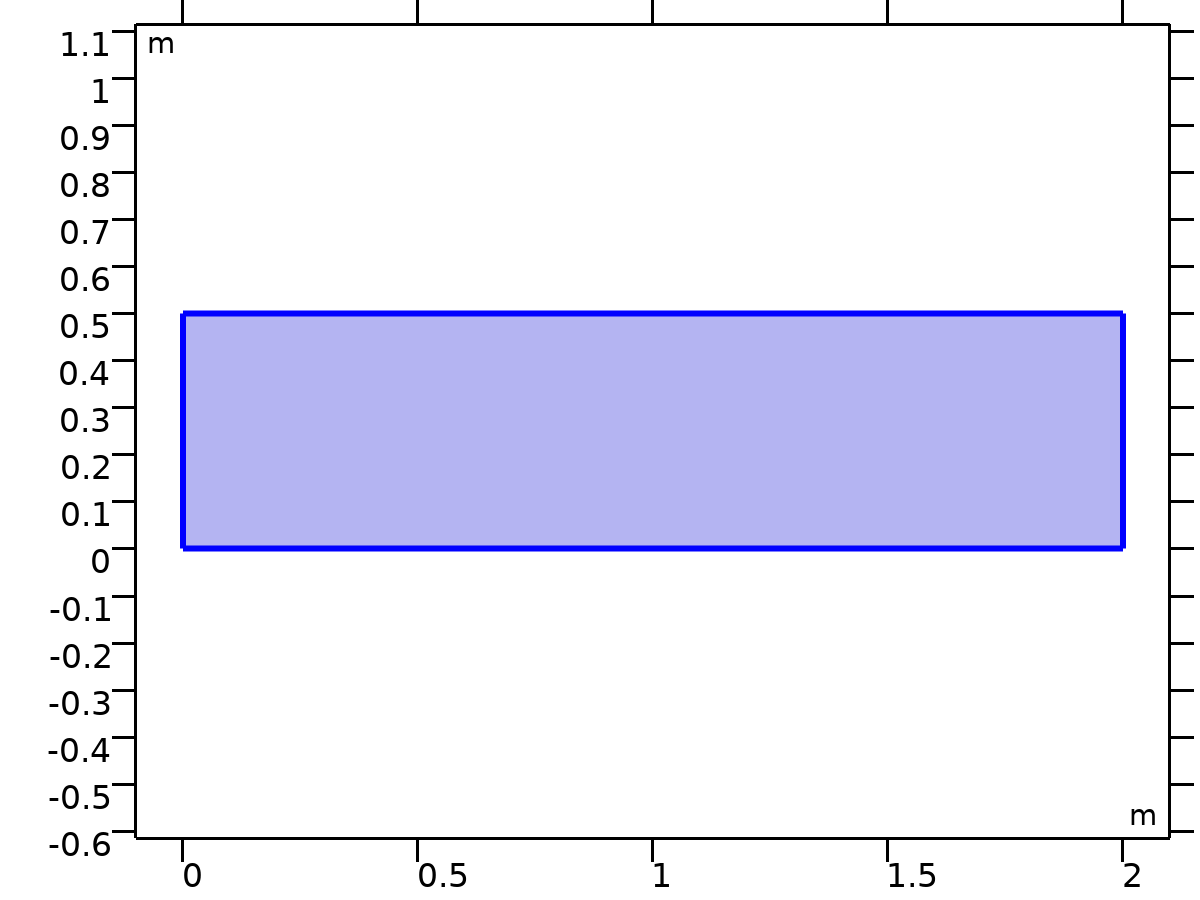
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ec.nJ | 0 | A/m² | Normal current density | Boundaries 1–3 | + operation |

#### Shape functions

| **Name** | **Shape function** | **Unit** | **Description** | **Shape frame** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- | --- |
| V | Lagrange (Quadratic) | V | Electric potential | Spatial | No boundaries | Slit |
| V | Lagrange (Quadratic) | V | Electric potential | Material | No boundaries | Slit |
| V | Lagrange (Quadratic) | V | Electric potential | Geometry | No boundaries | Slit |
| V | Lagrange (Quadratic) | V | Electric potential | Mesh | No boundaries | Slit |

* + 1. Initial Values 1



Initial Values 1

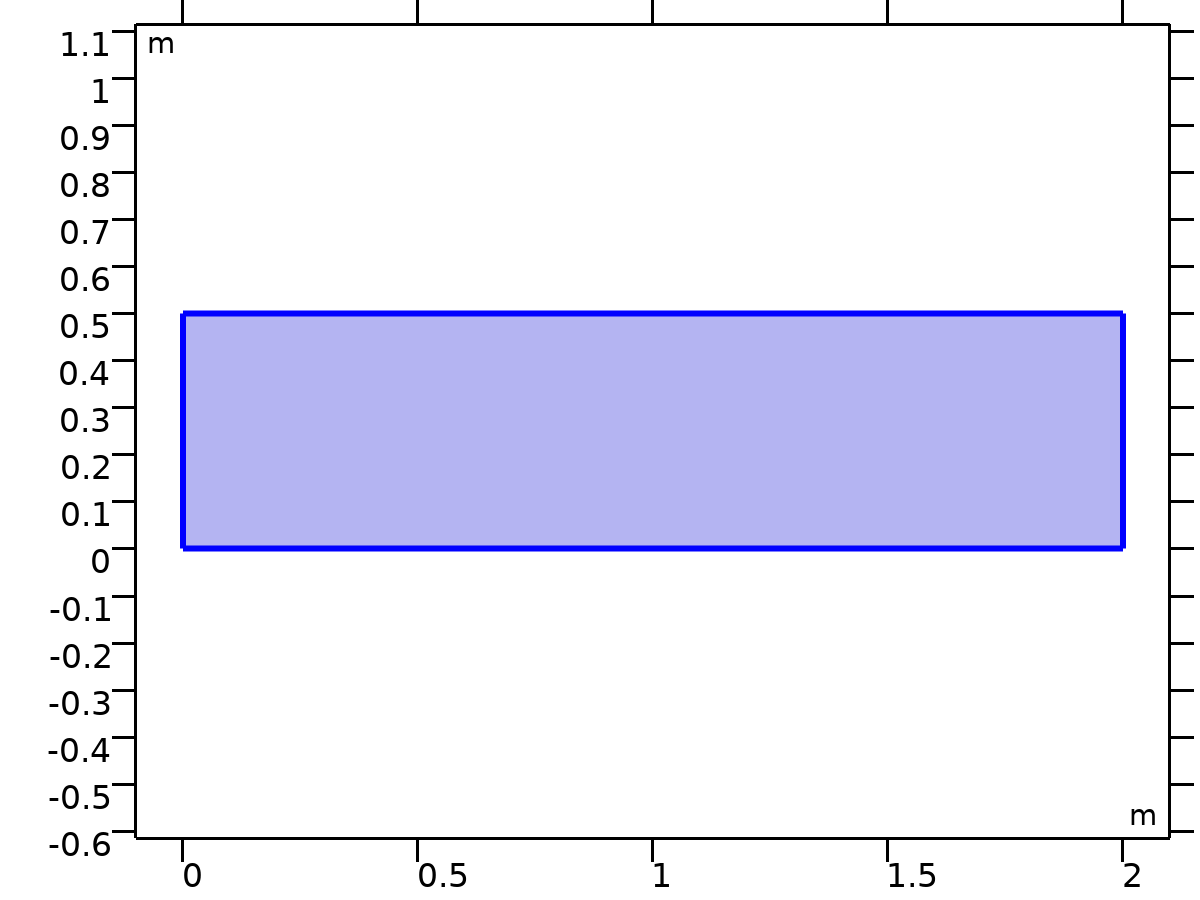
Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: All domains |

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| Electric potential | 0 | V |

* + 1. External Current Density 1



External Current Density 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Geometry geom1: Dimension 2: Domain 1 |

Equations



#### External Current Density

Settings

| **Description** | **Value** | **Unit** |
| --- | --- | --- |
| External current density, x-component | js\_x | A/m² |
| External current density, y-component | js\_y | A/m² |
| External current density, z-component | 0 | A/m² |
| Add contribution of the external current density to the losses | Off |  |

#### Coordinate System Selection

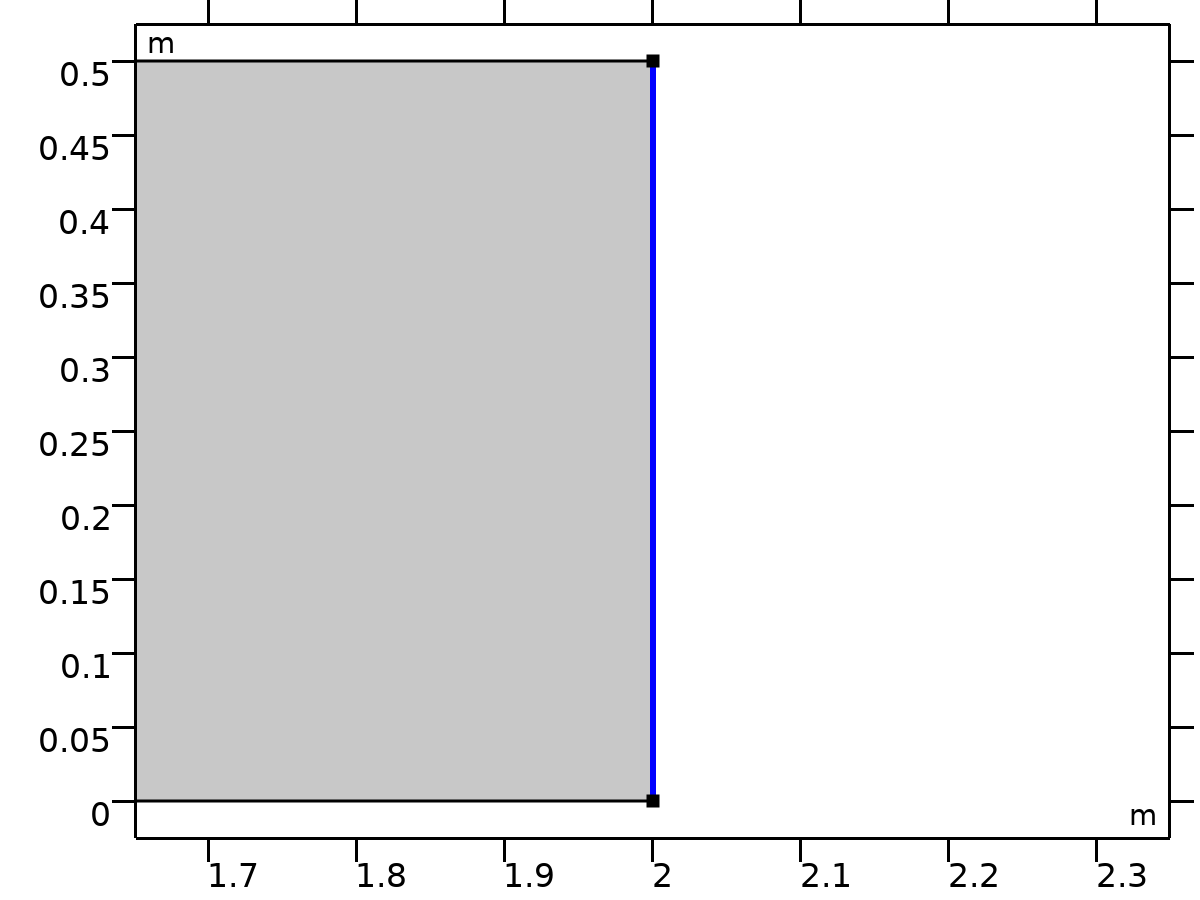
Settings

| **Description** | **Value** |
| --- | --- |
| Coordinate system | Global coordinate system |

#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ec.Jex | ec.ecd1.Jex | A/m² | External current density, x-component | Domain 1 | + operation |
| ec.Jey | ec.ecd1.Jey | A/m² | External current density, y-component | Domain 1 | + operation |
| ec.Jez | ec.ecd1.Jez | A/m² | External current density, z-component | Domain 1 | + operation |
| ec.ecd1.Jex | js\_x | A/m² | External current density, x-component | Domain 1 |  |
| ec.ecd1.Jey | js\_y | A/m² | External current density, y-component | Domain 1 |  |
| ec.ecd1.Jez | 0 | A/m² | External current density, z-component | Domain 1 |  |

* + 1. Ground 1



Ground 1

Selection

|  |  |
| --- | --- |
| Geometric entity level | Boundary |
| Selection | Geometry geom1: Dimension 1: Boundary 4 |

Equations



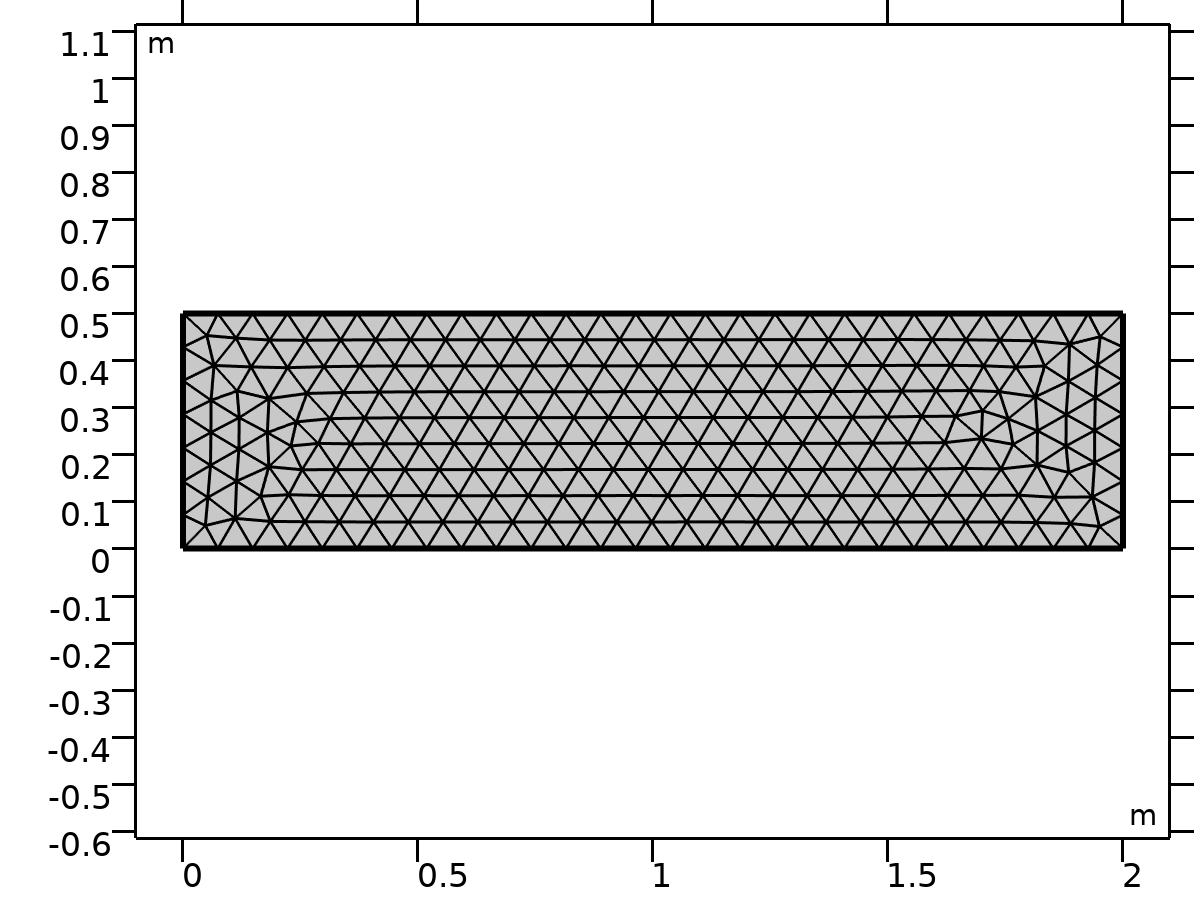
#### Variables

| **Name** | **Expression** | **Unit** | **Description** | **Selection** | **Details** |
| --- | --- | --- | --- | --- | --- |
| ec.nJ | ec.unx\*down(ec.Jx)+ec.uny\*down(ec.Jy)+ec.unz\*down(ec.Jz) | A/m² | Normal current density | Boundary 4 | + operation |
| ec.V0 | 0 | V | Electric potential | Boundary 4 |  |

#### Constraints

| **Constraint** | **Constraint force** | **Shape function** | **Selection** | **Details** |
| --- | --- | --- | --- | --- |
| ec.V0-V | test(ec.V0-V) | Lagrange (Quadratic) | Boundary 4 | Elemental |

* 1. Mesh 1



Mesh 1

Mesh statistics

| **Description** | **Value** |
| --- | --- |
| Status | Complete mesh |
| Mesh vertices | 280 |
| Triangles | 490 |
| Edge elements | 68 |
| Vertex elements | 4 |
| Number of elements | 490 |
| Minimum element quality | 0.7136 |
| Average element quality | 0.8905 |
| Element area ratio | 0.51159 |
| Mesh area | 1 m² |

* + 1. Size (size)

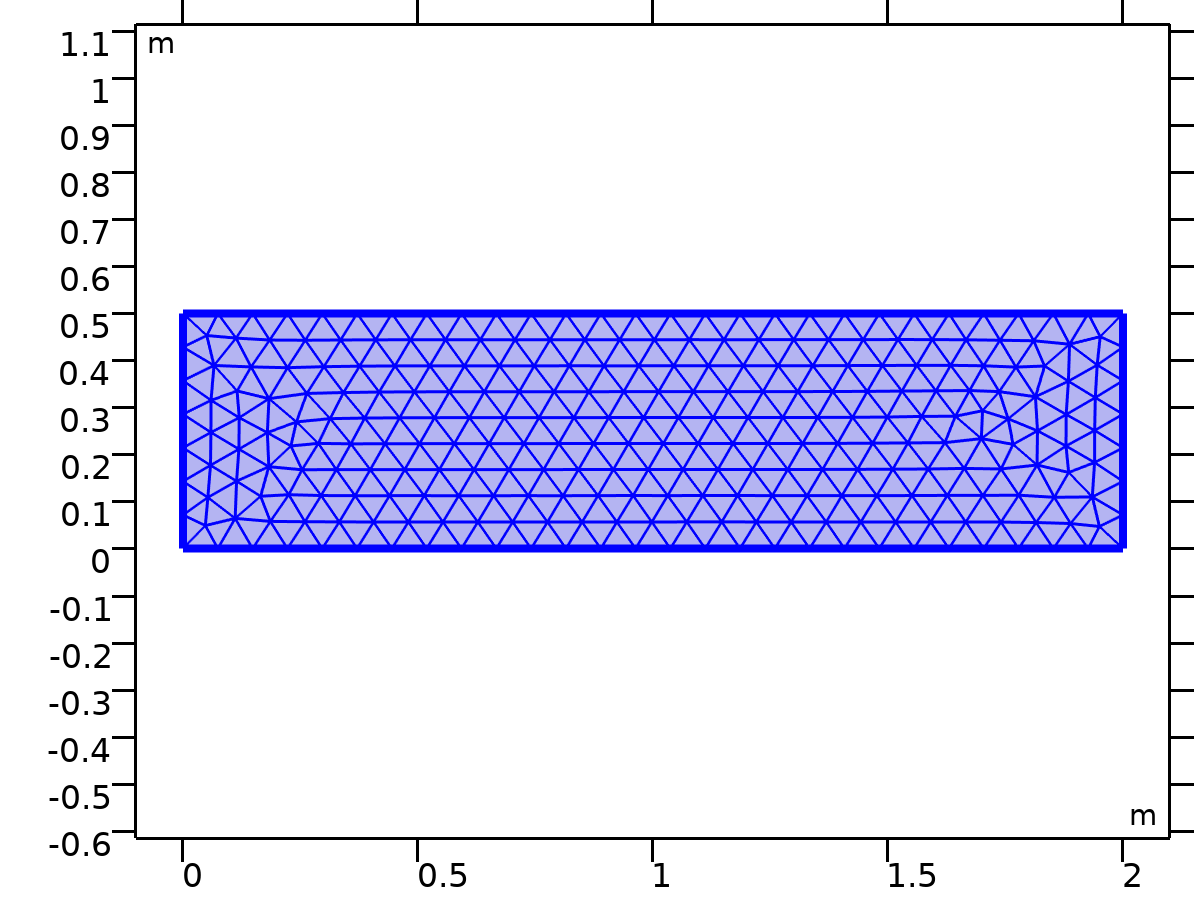
Settings

| **Description** | **Value** |
| --- | --- |
| Maximum element size | 0.074 |
| Minimum element size | 2.5E-4 |
| Curvature factor | 0.25 |
| Maximum element growth rate | 1.25 |
| Predefined size | Finer |

* + 1. Free Triangular 1 (ftri1)

Selection

|  |  |
| --- | --- |
| Geometric entity level | Domain |
| Selection | Remaining |



Free Triangular 1

Settings

| **Description** | **Value** |
| --- | --- |
| Number of iterations | 4 |
| Maximum element depth to process | 4 |
| Last build time | 0 |
| Built with | COMSOL 6.1.0.252 (win64)|2025 - 05 - 13T17:43:09.749886400 |

1. Study 1

Computation information

|  |  |
| --- | --- |
| Computation time | 2 s |

* 1. Time Dependent

| **Times** | **Unit** |
| --- | --- |
| range(0, 10, 300) | s |

Study settings

| **Description** | **Value** |
| --- | --- |
| Include geometric nonlinearity | Off |

Study settings

| **Description** | **Value** |
| --- | --- |
| Output times | {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300} |

Physics and variables selection

| **Physics interface** | **Discretization** |
| --- | --- |
| Darcy's Law (dl) | physics |
| Electric Currents (ec) | physics |

Mesh selection

| **Geometry** | **Mesh** |
| --- | --- |
| Geometry 1 (geom1) | mesh1 |

* 1. Solver Configurations
     1. Solution 1

#### Compile Equations: Time Dependent (st1)

Study and step

| **Description** | **Value** |
| --- | --- |
| Use study | [Study 1](#cs7430628) |
| Use study step | Time Dependent |

Log

<---- Compile Equations: Time Dependent in Study 1/Solution 1 (sol1) -----------

Started at May 13, 2025, 5:44:08 PM.

Geometry shape function: Quadratic Lagrange

Running on Intel64 Family 6 Model 154 Stepping 4, GenuineIntel.

Using 1 socket with 12 cores in total on DELL\_12.

Available memory: 7.88 GB.

Time: 1 s.

Physical memory: 1.17 GB

Virtual memory: 1.33 GB

Ended at May 13, 2025, 5:44:09 PM.

----- Compile Equations: Time Dependent in Study 1/Solution 1 (sol1) ---------->

#### Dependent Variables 1 (v1)

General

| **Description** | **Value** |
| --- | --- |
| Defined by study step | [Time Dependent](#cs3347200) |

Residual scaling

| **Description** | **Value** |
| --- | --- |
| Method | Manual |

Initial value calculation constants

| **Constant name** | **Initial value source** |
| --- | --- |
| t | range(0, 10, 300) |
| timestep | 0.3[s] |

Log

<---- Dependent Variables 1 in Study 1/Solution 1 (sol1) -----------------------

Started at May 13, 2025, 5:44:09 PM.

Solution time: 0 s.

Physical memory: 1.18 GB

Virtual memory: 1.33 GB

Ended at May 13, 2025, 5:44:09 PM.

----- Dependent Variables 1 in Study 1/Solution 1 (sol1) ---------------------->

##### Pressure (comp1.p) (comp1\_p)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.p |

##### Electric potential (comp1.V) (comp1\_V)

General

| **Description** | **Value** |
| --- | --- |
| Field components | comp1.V |

#### Time-Dependent Solver 1 (t1)

General

| **Description** | **Value** |
| --- | --- |
| Defined by study step | [Time Dependent](#cs3347200) |
| Output times | {0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280, 290, 300} |
| Relative tolerance | 0.005 |

Time stepping

| **Description** | **Value** |
| --- | --- |
| Maximum BDF order | 2 |
| Nonlinear controller | On |

Log

<---- Time-Dependent Solver 1 in Study 1/Solution 1 (sol1) ---------------------

Started at May 13, 2025, 5:44:09 PM.

Time-dependent solver (BDF)

Number of degrees of freedom solved for: 2098.

Nonsymmetric matrix found.

Scales for dependent variables:

Pressure (comp1.p): 1e+03

Electric potential (comp1.V): 7.6e+04

Step        Time    Stepsize      Res  Jac  Sol Order Tfail NLfail   LinErr   LinRes

   0           0           - out    4    3    4                  0  4.4e-14  3.5e-14

   1         0.3         0.3        6    4    6     1     0      0  3.3e-14  7.5e-15

   2         0.6         0.3        7    5    7     1     0      0  3.4e-14  6.1e-14

   3         1.2         0.6        8    6    8     2     0      0  3.3e-14    6e-14

   4         2.4         1.2        9    7    9     1     0      0  2.6e-14  3.5e-15

   5         4.8         2.4       10    8   10     1     0      0  3.7e-14  5.3e-15

   6         9.6         4.8       11    9   11     1     0      0  4.5e-14    1e-14

   -          10           - out

   7        19.2         9.6       12   10   12     1     0      0  4.4e-14  8.8e-15

   -          20           - out

   -          30           - out

   8        38.4        19.2       13   11   13     1     0      0  2.5e-14  1.6e-15

   -          40           - out

   -          50           - out

   -          60           - out

   9        68.4          30       14   12   14     1     0      0  3.3e-14  3.5e-15

   -          70           - out

   -          80           - out

   -          90           - out

  10        98.4          30       15   13   15     1     0      0  4.2e-14  2.8e-15

   -         100           - out

   -         110           - out

   -         120           - out

  11       128.4          30       16   14   16     1     0      0  4.7e-14  3.6e-15

   -         130           - out

   -         140           - out

   -         150           - out

  12       158.4          30       17   15   17     1     0      0  4.8e-14  8.1e-15

   -         160           - out

   -         170           - out

   -         180           - out

  13       188.4          30       18   16   18     1     0      0  4.8e-14  9.1e-15

   -         190           - out

   -         200           - out

   -         210           - out

  14       218.4          30       19   17   19     1     0      0  4.7e-14    1e-14

   -         220           - out

   -         230           - out

   -         240           - out

  15       248.4          30       20   18   20     1     0      0    3e-14  1.5e-14

   -         250           - out

   -         260           - out

   -         270           - out

  16       278.4          30       21   19   21     1     0      0    4e-14  1.1e-14

   -         280           - out

   -         290           - out

   -         300           - out

  17       308.4          30       22   20   22     1     0      0  3.7e-14  5.1e-15

Time-stepping completed.

Solution time: 1 s.

Physical memory: 1.2 GB

Virtual memory: 1.35 GB

Ended at May 13, 2025, 5:44:10 PM.

----- Time-Dependent Solver 1 in Study 1/Solution 1 (sol1) -------------------->

##### Advanced (aDef)

Assembly settings

| **Description** | **Value** |
| --- | --- |
| Reuse sparsity pattern | On |

##### Fully Coupled 1 (fc1)

General

| **Description** | **Value** |
| --- | --- |
| Linear solver | [Direct, pressure (dl) (merged)](#cs7123162) |

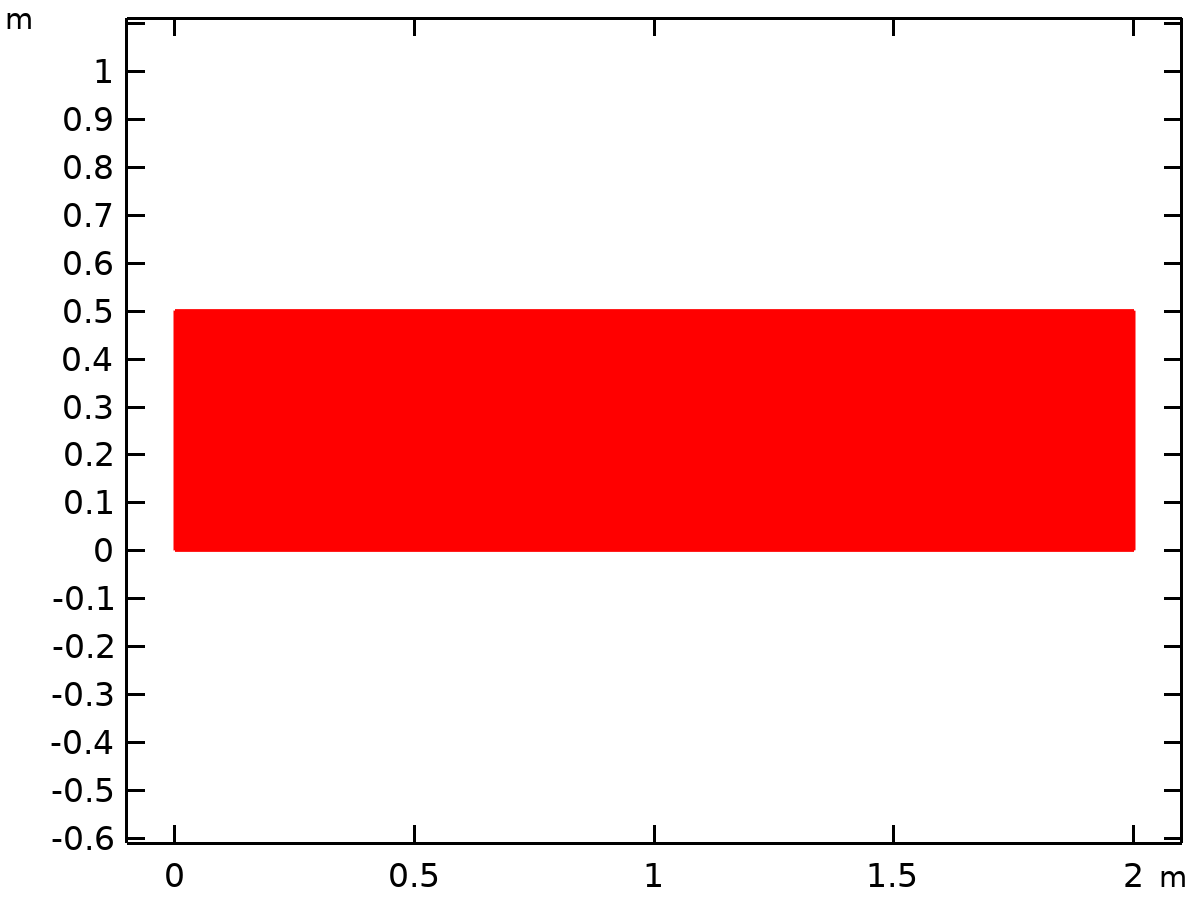
Method and termination

| **Description** | **Value** |
| --- | --- |
| Jacobian update | Once per time step |
| Maximum number of iterations | 8 |
| Stabilization and acceleration | Anderson acceleration |
| Dimension of iteration space | 5 |
| Mixing parameter | 0.9 |

1. Results
   1. Datasets
      1. Study 1/Solution 1

Solution

| **Description** | **Value** |
| --- | --- |
| Solution | [Solution 1](#cs5890210) |
| Component | Component 1 (comp1) |



Dataset: Study 1/Solution 1

* 1. Plot Groups
     1. Pressure (dl)

[COMSOLlink[]]

Surface: Pressure (Pa) Streamline: Darcy's velocity field

* + 1. Electric Potential (ec)

[COMSOLlink[]]

Surface: Electric potential (V)

* + 1. Electric Field Norm (ec)

[COMSOLlink[]]

Surface: Electric field norm (V/m)