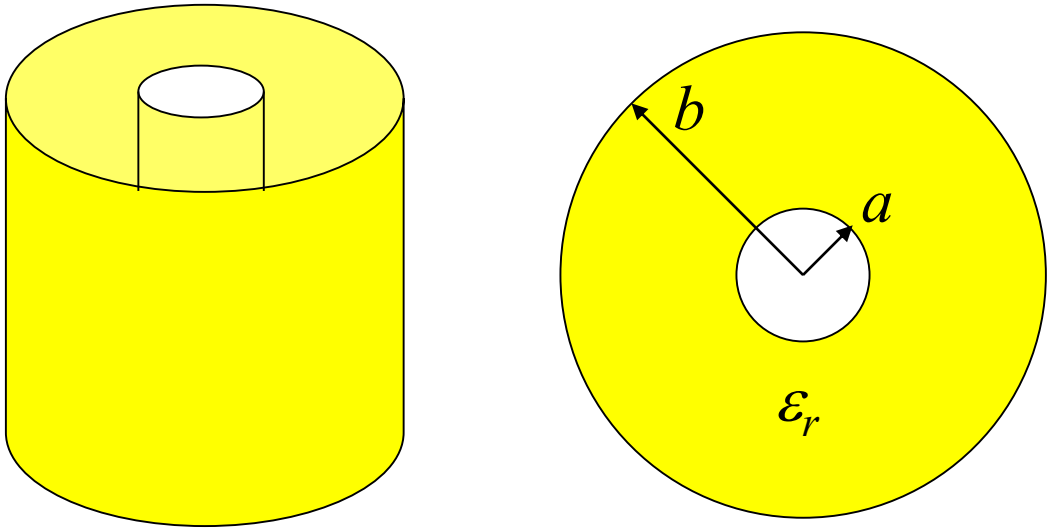
COMSOLによる同軸線路の解析
～ 数値ポート ～



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平野 拓一
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October 27, 2017

同軸ケーブル(TEMモード)

Cの計算

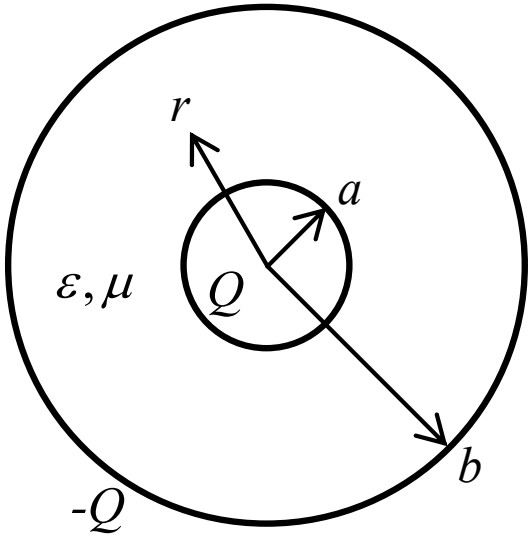
$$\oiint_S \mathbf{D}\cdot d\mathbf{S} = \iiint_V \rho dV \qquad \text{ガウスの法則}$$

$$\varepsilon E_r \cdot 2\pi r = Q$$

$$E_r = \frac{Q}{2\pi\varepsilon r}$$

$$V = \int_a^b E_r dr = \frac{Q}{2\pi\varepsilon}\left[\log r\right]_a^b = \frac{Q}{2\pi\varepsilon}\log\frac{b}{a}$$

$$C = \frac{Q}{V} = \frac{2\pi\varepsilon}{\log\dfrac{b}{a}}$$



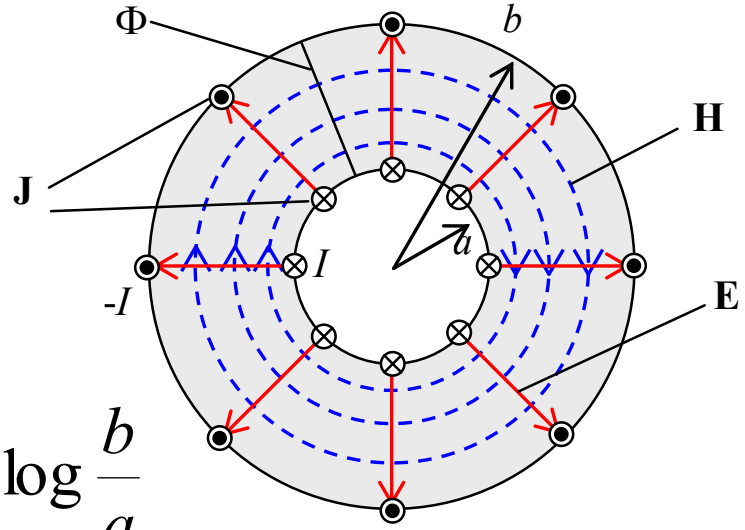
Lの計算

$$\oint_C \mathbf{H}\cdot d\mathbf{l} = \iint_S \mathbf{i}\cdot d\mathbf{S} + \iint_S \frac{d\mathbf{D}}{dt}\cdot d\mathbf{S} \qquad \text{アンペアの法則}$$

$$H_\varphi \cdot 2\pi r = I \quad H_\varphi = \frac{I}{2\pi r}$$

$$\frac{\Phi}{\mu} = \int_a^b H_\varphi dr = \frac{I}{2\pi}\log\frac{b}{a}$$

$$L = \frac{\Phi}{I} = \frac{\mu}{2\pi}\log\frac{b}{a}$$

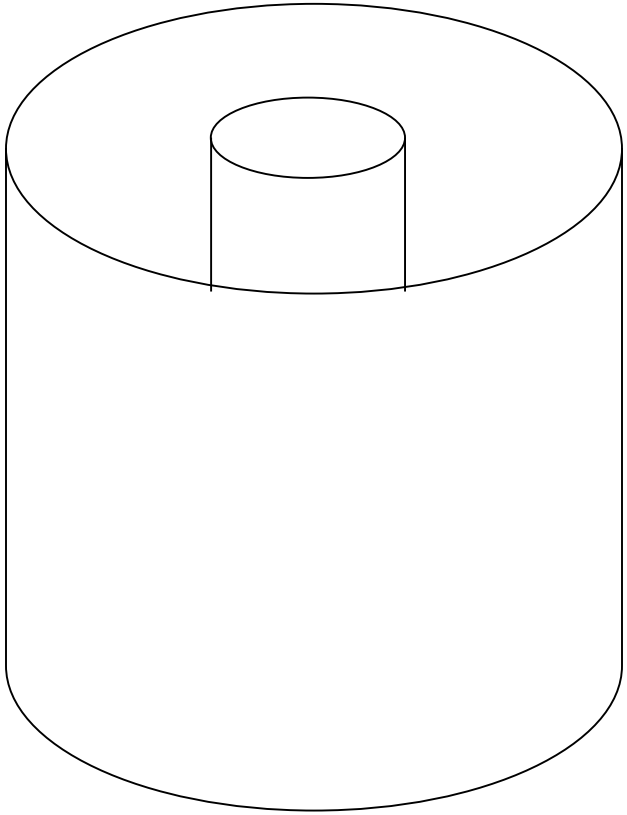


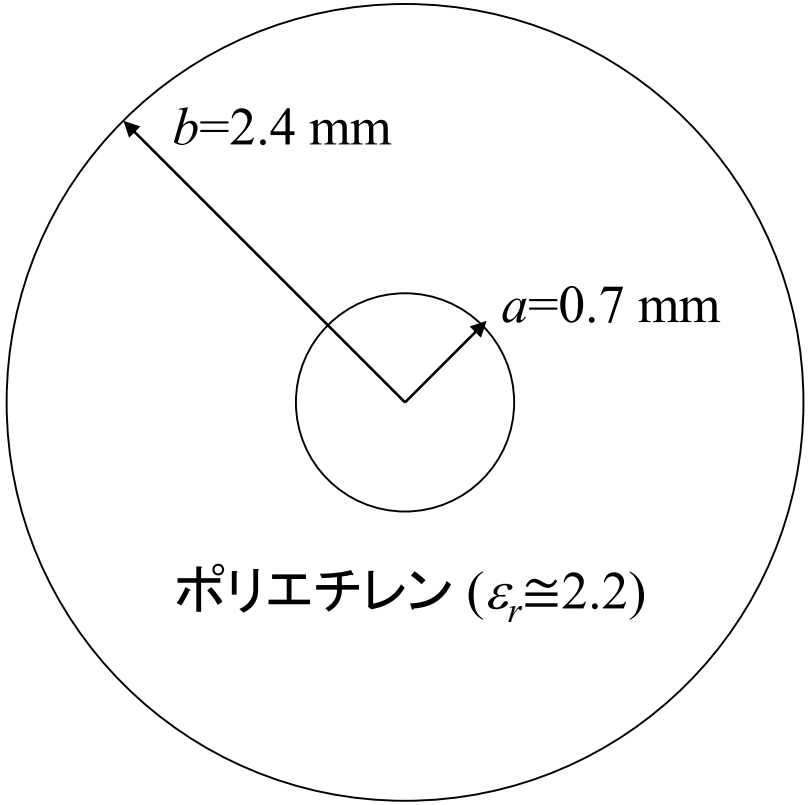
特性インピーダンス

$$Z = \sqrt{\frac{L}{C}} = \sqrt{\frac{\mu}{\varepsilon}}\,\frac{\log\dfrac{b}{a}}{2\pi}$$

同軸線路

JIS規格: 5D-2V同軸ケーブル

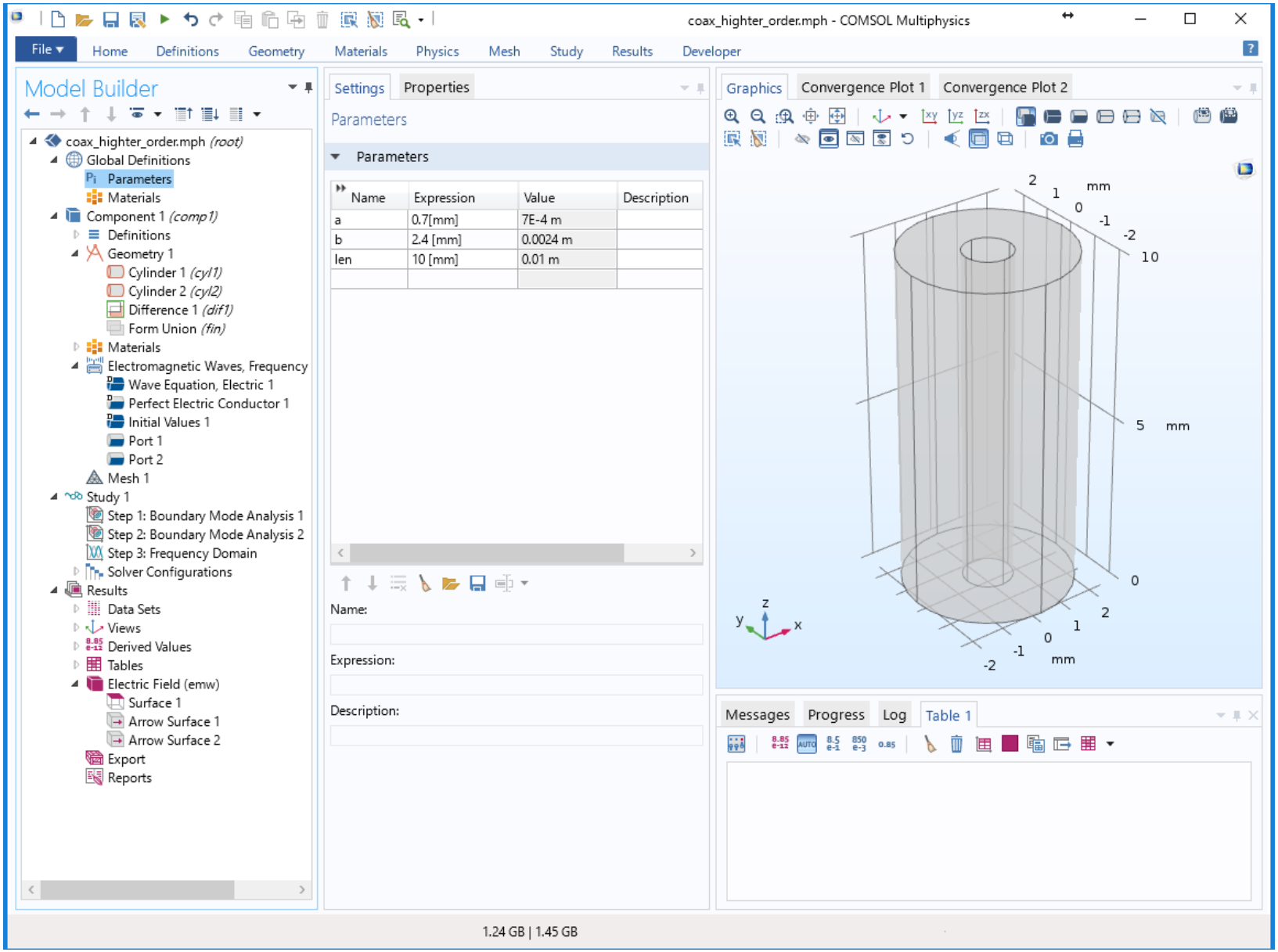




特性インピーダンス 50 Ω

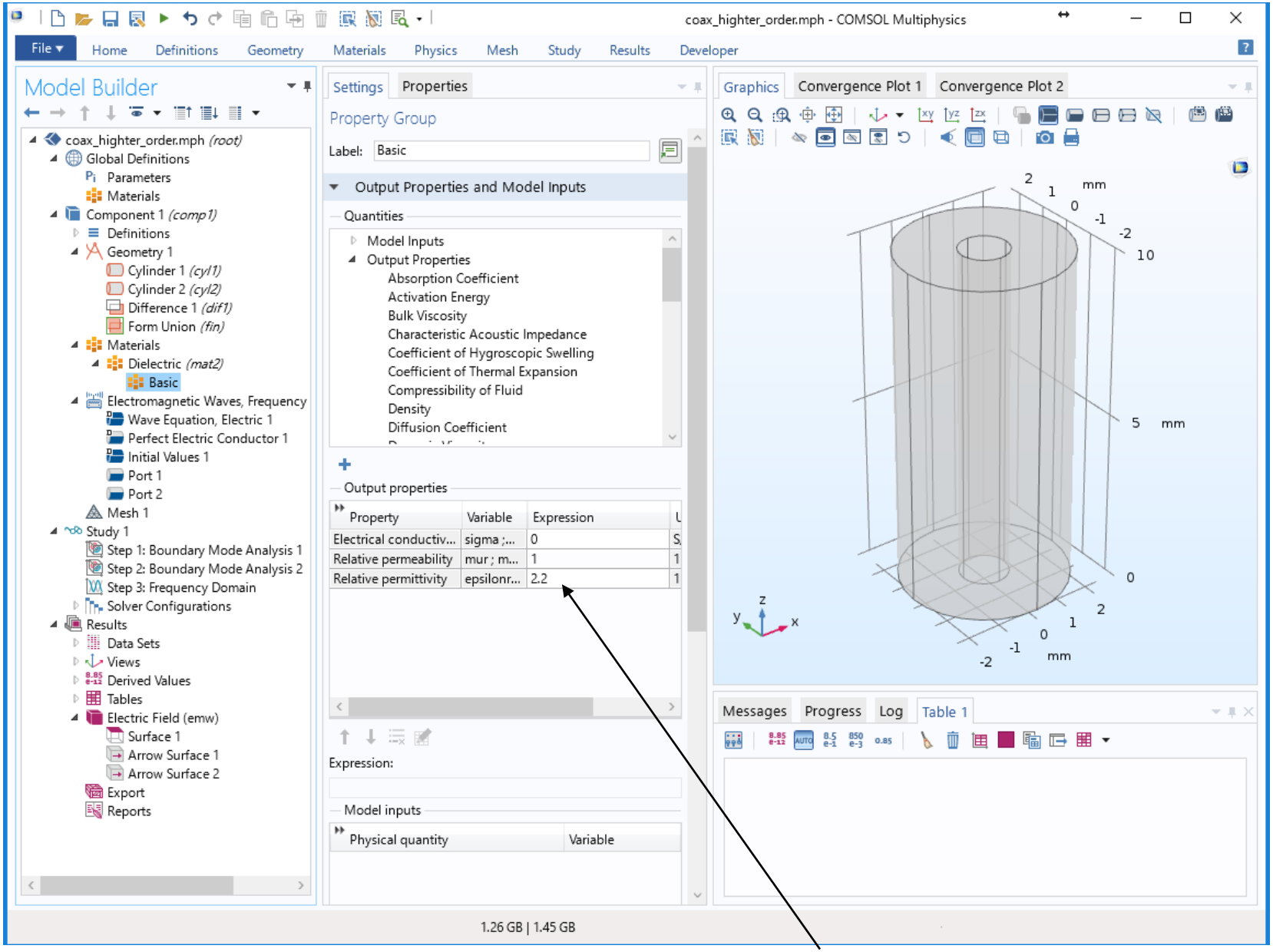
```
In[1]:= a = (1.4 / 2) * 10^-3;
        b = a + 1.7 * 10^-3;
        ϵr = 2.2;
        μr = 1.;

In[5]:= ϵ0 = 8.85418782 * 10^-12;
        μ0 = 1.25663706 * 10^-6;
        ϵ = ϵr * ϵ0;
        μ = μr * μ0;
        cap = 2 * π * ϵ / Log[b / a]
        ind = μ / (2 * π) Log[b / a]   対数

        Z0 = Sqrt[ind / cap]

Out[9]= 9.93322 × 10^-11

Out[10]= 2.46429 × 10^-7

Out[11]= 49.8082
```

モデル化



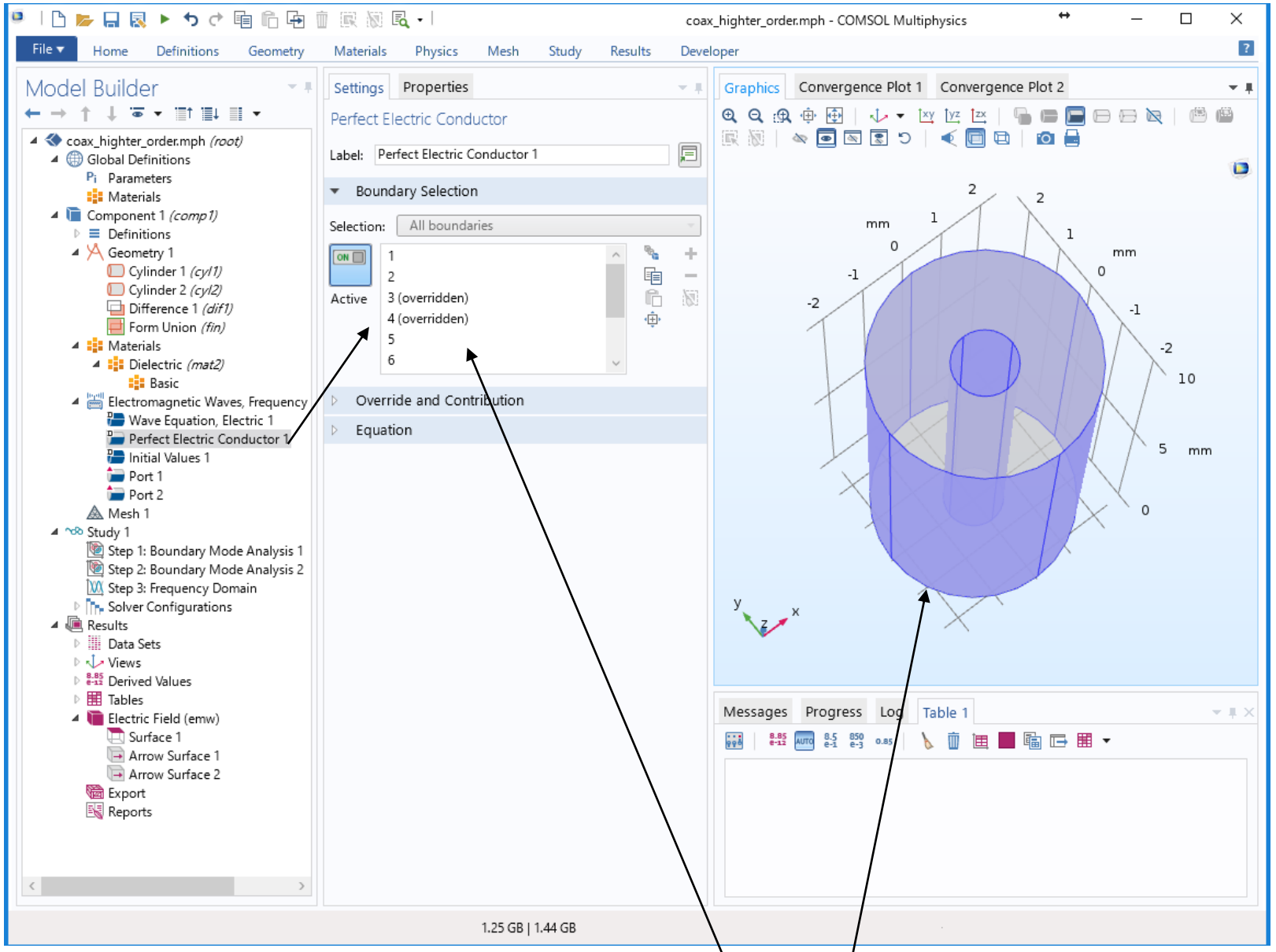
2つの円筒を描き、図形の論理演算で内導体をくり抜く

材料(誘電体)の定義



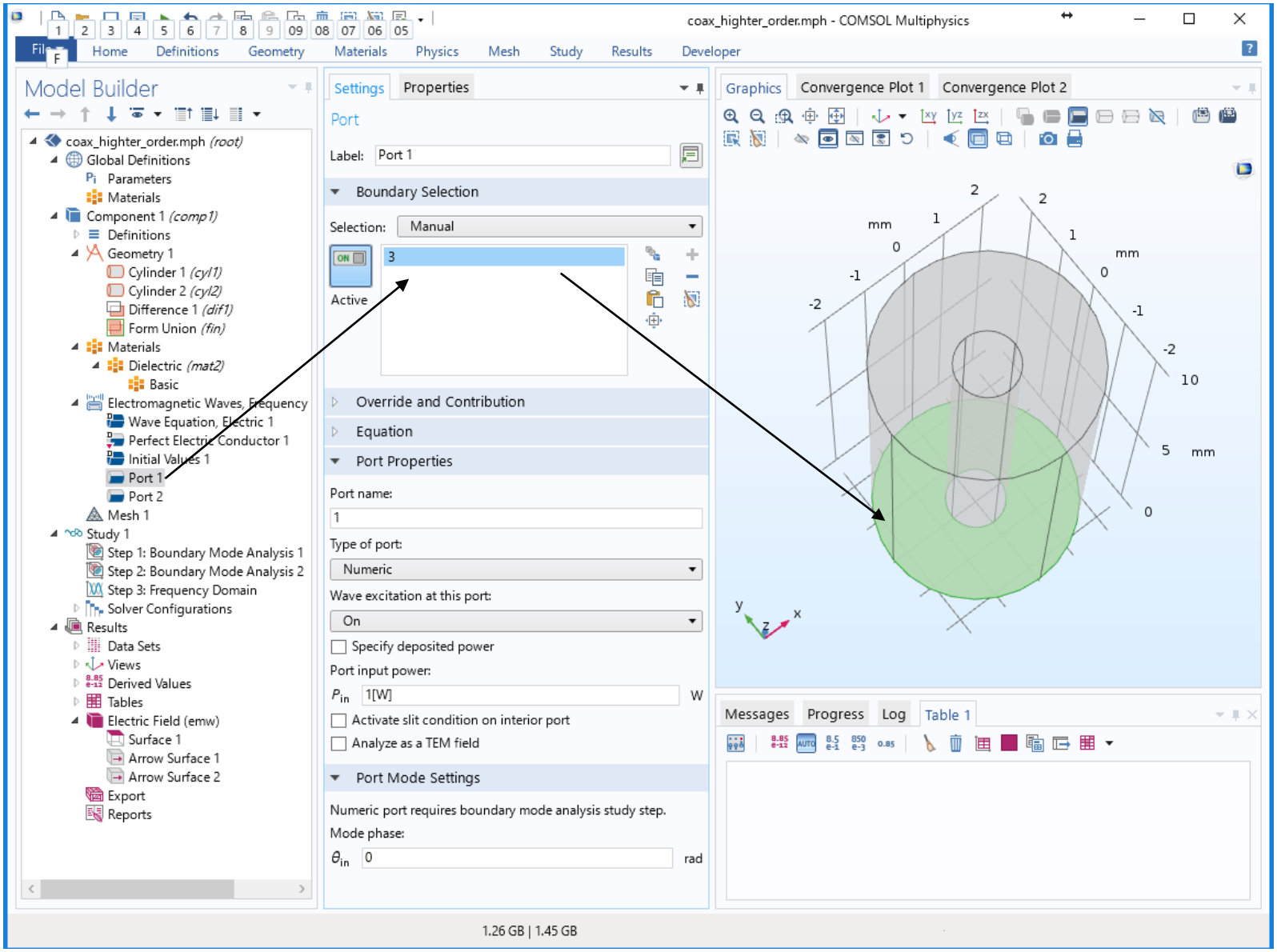
Basic, Output Propertiesのこの3つが指定されていればよい。

境界条件の設定



外導体・内導体をPECに設定

ポートの定義


coax_highter_order.mph - COMSOL Multiphysics
File
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Physics
Mesh
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Results
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Model Builder
coax_highter_order.mph (root)
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Materials
Component 1 (comp1)
Definitions
Geometry 1
Cylinder 1 (cyl1)
Cylinder 2 (cyl2)
Difference 1 (dif1)
Form Union (fin)
Materials
Dielectric (mat2)
Basic
Electromagnetic Waves, Frequency
Wave Equation, Electric 1
Perfect Electric Conductor 1
Initial Values 1
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Port 2
Mesh 1
Study 1
Step 1: Boundary Mode Analysis 1
Step 2: Boundary Mode Analysis 2
Step 3: Frequency Domain
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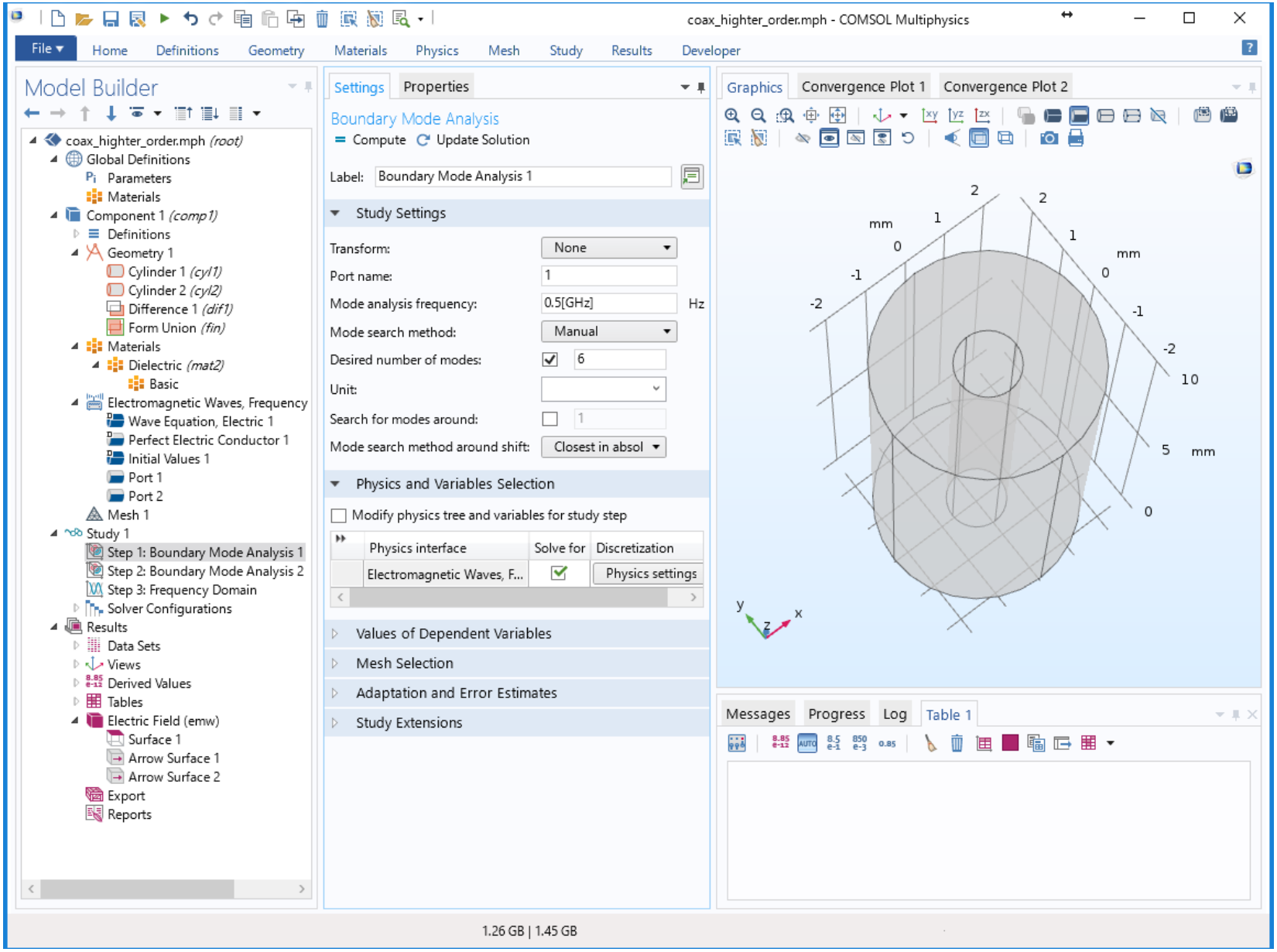
Electric Field (emw)
Surface 1
Arrow Surface 1
Arrow Surface 2
Export
Reports
Settings
Properties
Port
Label: Port 1
Boundary Selection
Selection: Manual
3
Active
Override and Contribution
Equation
Port Properties
Port name:
1
Type of port:
Numeric
Wave excitation at this port:
On
Specify deposited power
Port input power:
P_{in} 1[W] W
Activate slit condition on interior port
Analyze as a TEM field
Port Mode Settings
Numeric port requires boundary mode analysis study step.
Mode phase:
θ_{in} 0 rad
Graphics
Convergence Plot 1
Convergence Plot 2
mm
Messages
Progress
Log
Table 1
1.26 GB | 1.45 GB

境界モード解析の設定


coax_highter_order.mph - COMSOL Multiphysics
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Form Union (fin)
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Mesh 1
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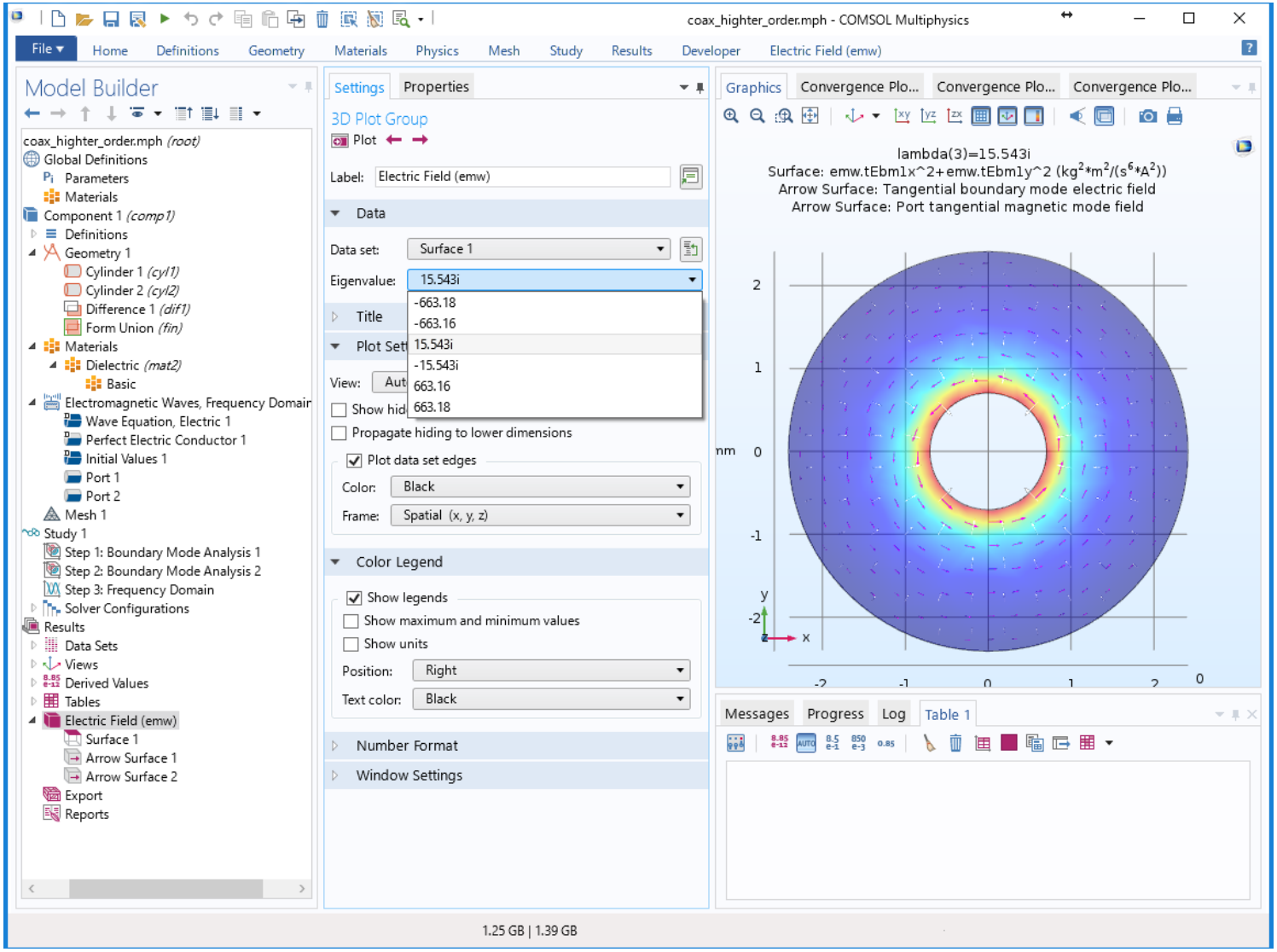
Electric Field (emw)
Surface 1
Arrow Surface 1
Arrow Surface 2
Export
Reports
Settings
Properties
Boundary Mode Analysis
Compute
Update Solution
Label: Boundary Mode Analysis 1
Study Settings
Transform: None
Port name: 1
Mode analysis frequency: 0.5[GHz] Hz
Mode search method: Manual
Desired number of modes: 6
Unit:
Search for modes around: 1
Mode search method around shift: Closest in absol
Physics and Variables Selection
Modify physics tree and variables for study step
Physics interface
Solve for
Discretization
Electromagnetic Waves, F...
Physics settings
Values of Dependent Variables
Mesh Selection
Adaptation and Error Estimates
Study Extensions
Graphics
Convergence Plot 1
Convergence Plot 2
mm
Messages
Progress
Log
Table 1
1.26 GB | 1.45 GB

境界モード解析結果


coax_highter_order.mph - COMSOL Multiphysics
File
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coax_highter_order.mph (root)
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Difference 1 (dif1)
Form Union (fin)
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Wave Equation, Electric 1
Perfect Electric Conductor 1
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Port 2
Mesh 1
Study 1
Step 1: Boundary Mode Analysis 1
Step 2: Boundary Mode Analysis 2
Step 3: Frequency Domain
Solver Configurations
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Derived Values
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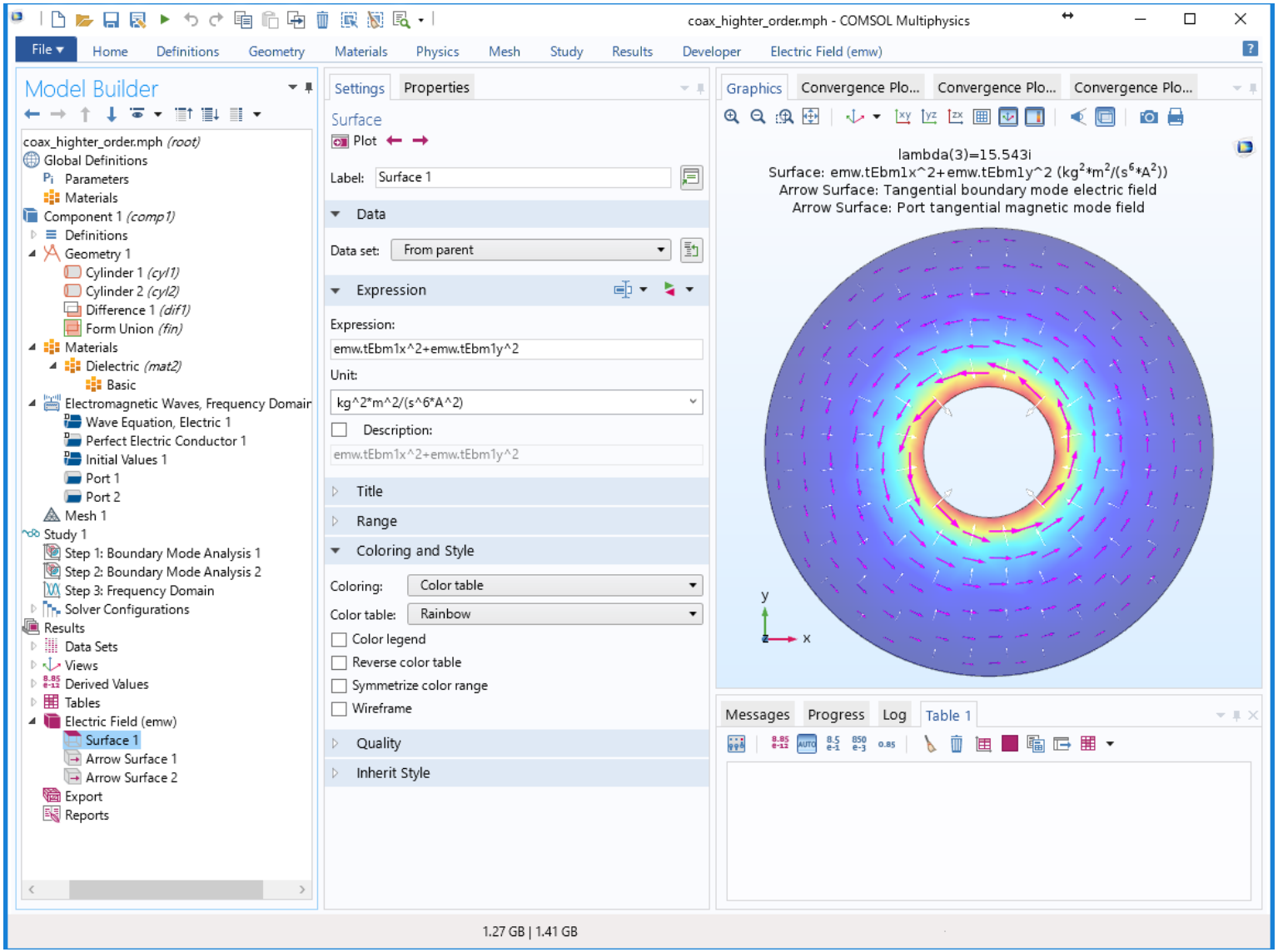
Electric Field (emw)
Surface 1
Arrow Surface 1
Arrow Surface 2
Export
Reports
Settings
Properties
3D Plot Group
Plot
Label: Electric Field (emw)
Data
Data set: Surface 1
Eigenvalue: 15.543i
-663.18
-663.16
15.543i
-15.543i
663.16
663.18
Title
Plot Set
View:
Show hid
Propagate hiding to lower dimensions
Plot data set edges
Color: Black
Frame: Spatial (x, y, z)
Color Legend
Show legends
Show maximum and minimum values
Show units
Position: Right
Text color: Black
Number Format
Window Settings
Graphics
Convergence Plo...
Convergence Plo...
Convergence Plo...
lambda(3)=15.543i
Surface: emw.tEbm1x^2+emw.tEbm1y^2 (kg²*m²/(s⁶*A²))
Arrow Surface: Tangential boundary mode electric field
Arrow Surface: Port tangential magnetic mode field
nm
y
x
Messages
Progress
Log
Table 1
1.25 GB | 1.39 GB

境界モード解析結果


coax_highter_order.mph - COMSOL Multiphysics
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Mesh
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Results
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coax_highter_order.mph (root)
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Form Union (fin)
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Mesh 1
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Step 3: Frequency Domain
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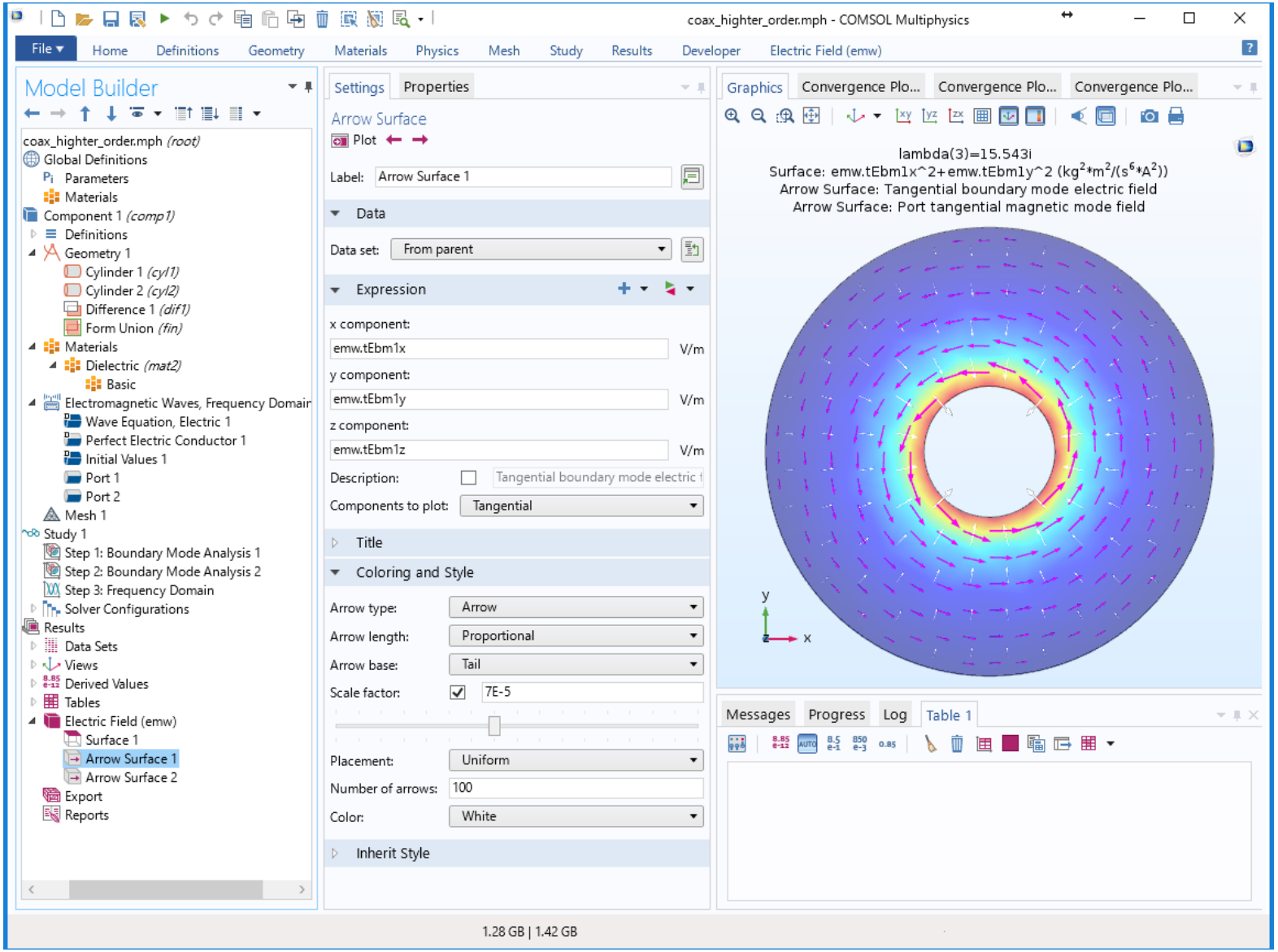
Derived Values
Tables
Electric Field (emw)
Surface 1
Arrow Surface 1
Arrow Surface 2
Export
Reports
Settings
Properties
Surface
Plot
Label: Surface 1
Data
Data set: From parent
Expression
Expression:
emw.tEbm1x^2+emw.tEbm1y^2
Unit:
kg^2*m^2/(s^6*A^2)
Description:
emw.tEbm1x^2+emw.tEbm1y^2
Title
Range
Coloring and Style
Coloring: Color table
Color table: Rainbow
Color legend
Reverse color table
Symmetrize color range
Wireframe
Quality
Inherit Style
Graphics
Convergence Plo...
Convergence Plo...
Convergence Plo...
lambda(3)=15.543i
Surface: emw.tEbm1x^2+emw.tEbm1y^2 (kg²*m²/(s⁶*A²))
Arrow Surface: Tangential boundary mode electric field
Arrow Surface: Port tangential magnetic mode field
y
x
Messages
Progress
Log
Table 1
1.27 GB | 1.41 GB

境界モード解析結果


coax_highter_order.mph - COMSOL Multiphysics
File
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Materials
Physics
Mesh
Study
Results
Developer
Electric Field (emw)
Model Builder
coax_highter_order.mph (root)
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Materials
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Cylinder 2 (cyl2)
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Form Union (fin)
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Dielectric (mat2)
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Port 2
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Step 3: Frequency Domain
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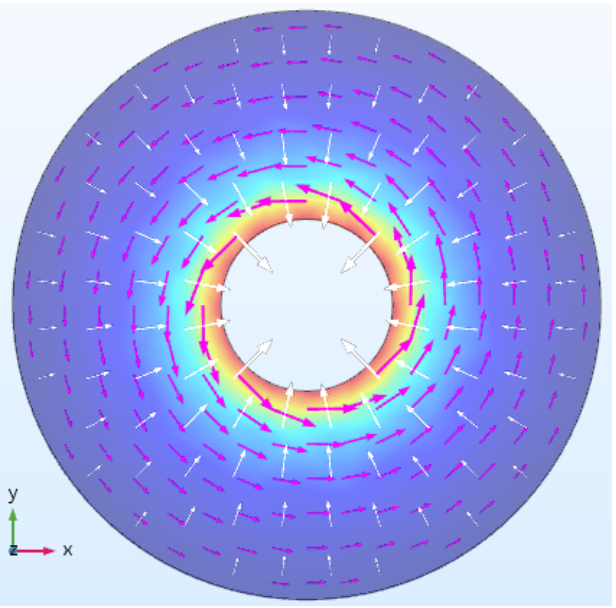
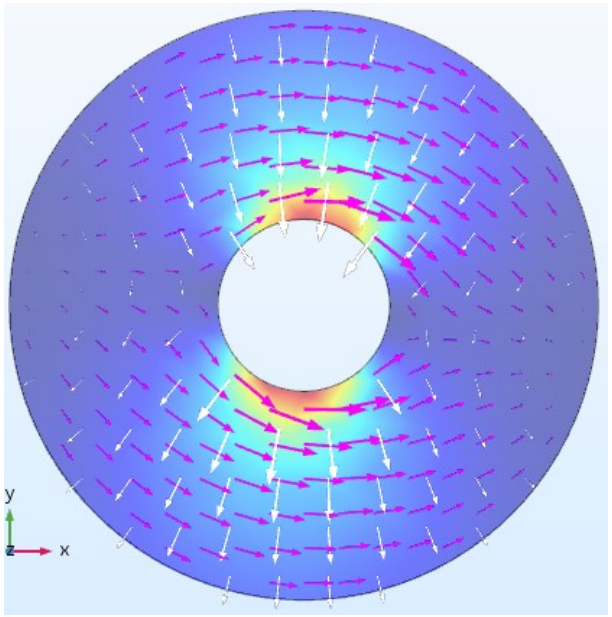
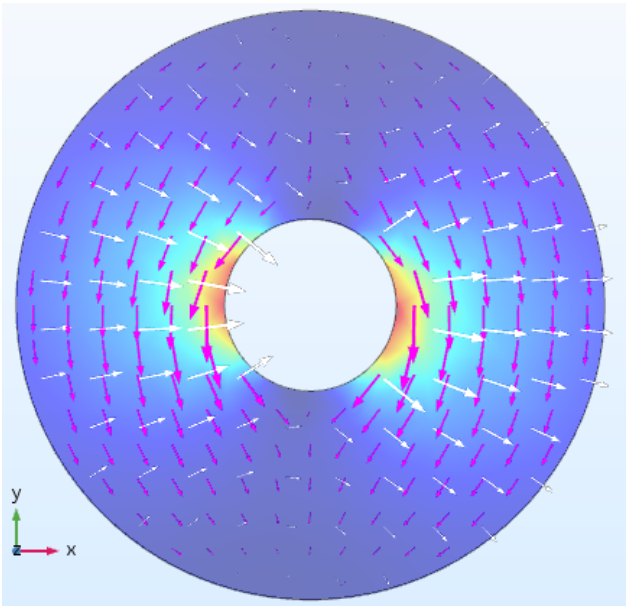
Electric Field (emw)
Surface 1
Arrow Surface 1
Arrow Surface 2
Export
Reports
Settings
Properties
Arrow Surface
Plot
Label: Arrow Surface 1
Data
Data set: From parent
Expression
x component:
emw.tEbm1x
V/m
y component:
emw.tEbm1y
V/m
z component:
emw.tEbm1z
V/m
Description:
Tangential boundary mode electric f
Components to plot: Tangential
Title
Coloring and Style
Arrow type: Arrow
Arrow length: Proportional
Arrow base: Tail
Scale factor: 7E-5
Placement: Uniform
Number of arrows: 100
Color: White
Inherit Style
Graphics
Convergence Plo...
Convergence Plo...
Convergence Plo...
lambda(3)=15.543i
Surface: emw.tEbm1x^2+emw.tEbm1y^2 (kg²*m²/(s⁶*A²))
Arrow Surface: Tangential boundary mode electric field
Arrow Surface: Port tangential magnetic mode field
y
x
Messages
Progress
Log
Table 1
1.28 GB | 1.42 GB

境界モード解析結果

周波数 500 MHz







$j\,15.5413$ 663.16 663.18

$$k_c \cong \frac{2}{a+b}$$

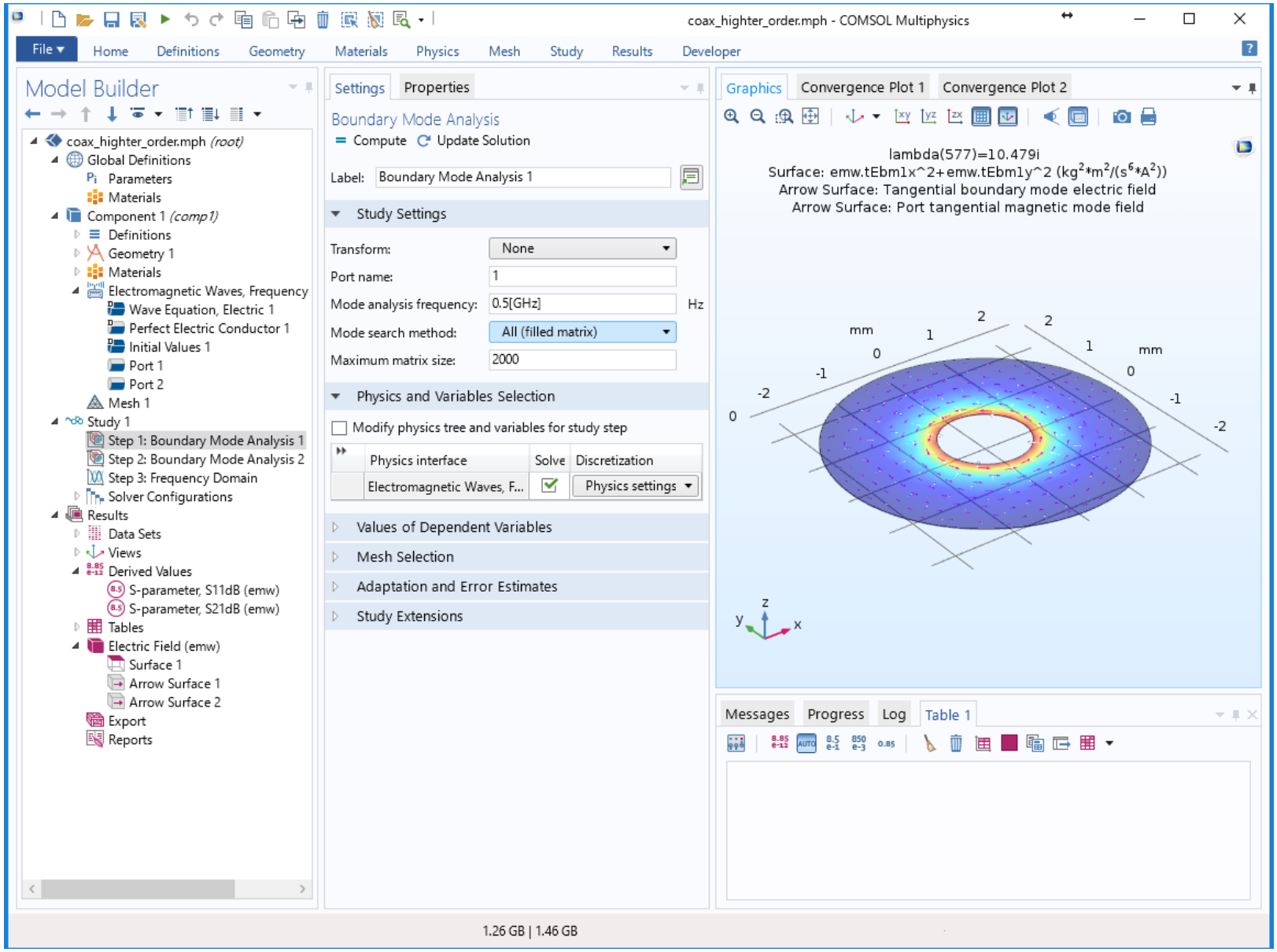
```
In[12]:= kc = 2/(a + b);
         fc = kc/(2 * π * √(μ * ϵ));
         fcGHz = fc * 10^-9
Out[14]= 20.7538
```

```
In[1]:= f = 500. * 10^6;
        ω = 2 * π * f;
        ϵr = 2.2;
        ϵ0 = 8.85418782 * 10^-12;
        μ0 = 1.25663706 * 10^-6;
        β = ω * √(μ0 * (ϵr * ϵ0))
Out[6]= 15.5432
```

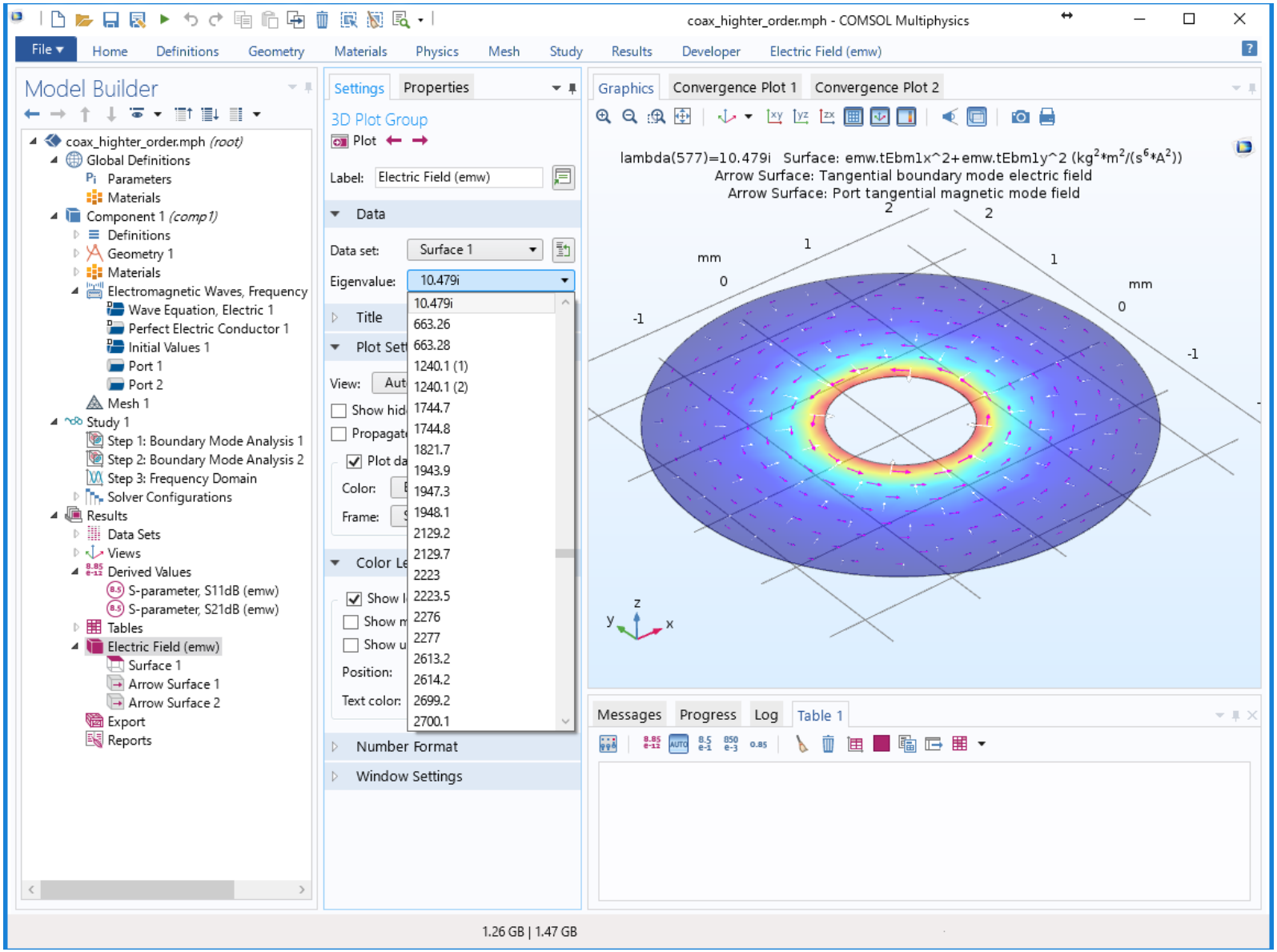
つまり、「境界モード解析」のTransform で”None”とすると、伝搬定数γが出力されている。高次モードのカットオフ周波数を調べるには、解析周波数を変えて、伝搬定数が虚数になる周波数を探せばよい。

21-22 GHzの間に高次モードカットオフ周波数があることがわかる。

参考）全モードの計算と表示(1)

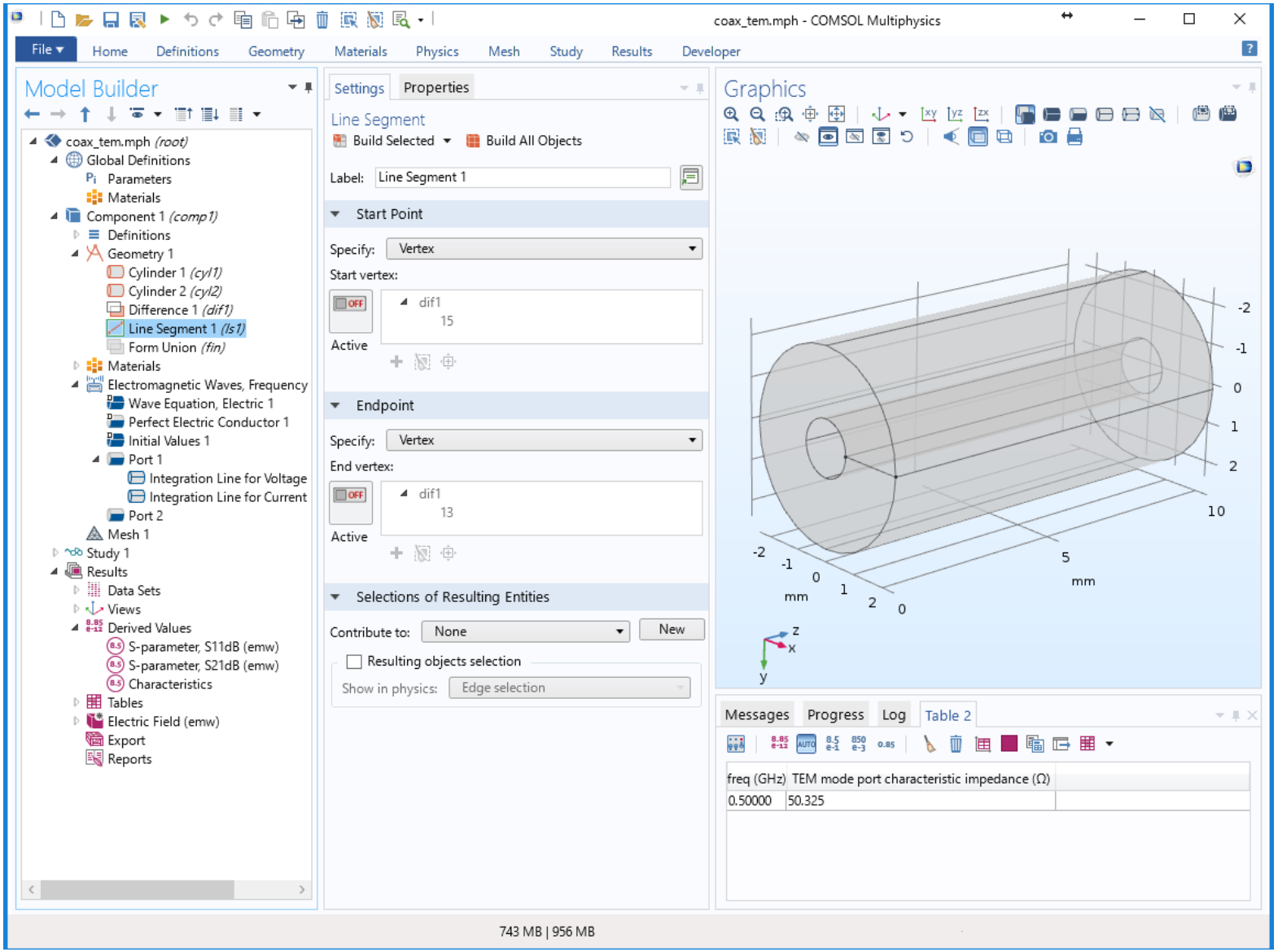


参考）全モードの計算と表示(2)

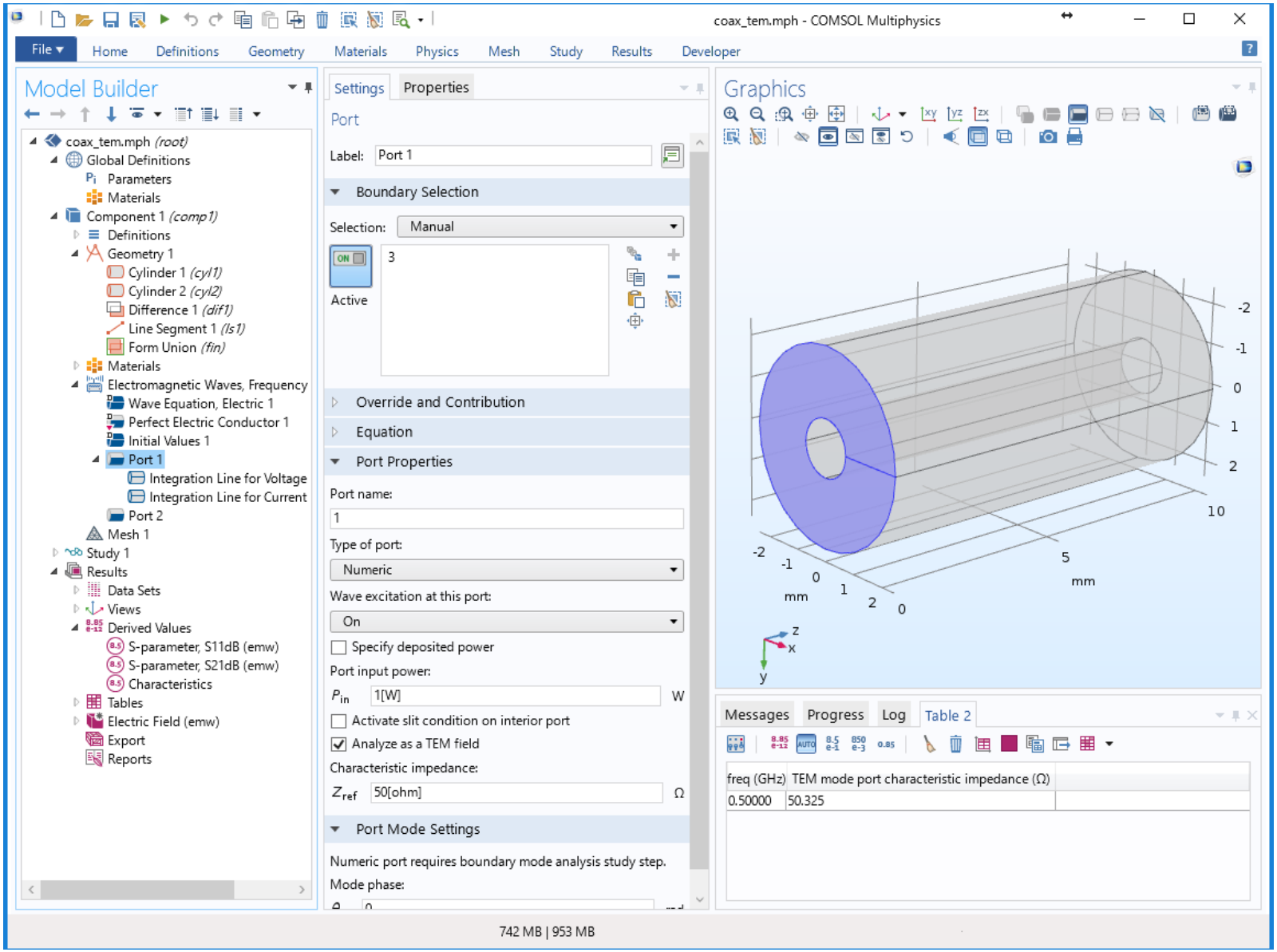


特性インピーダンスの解析

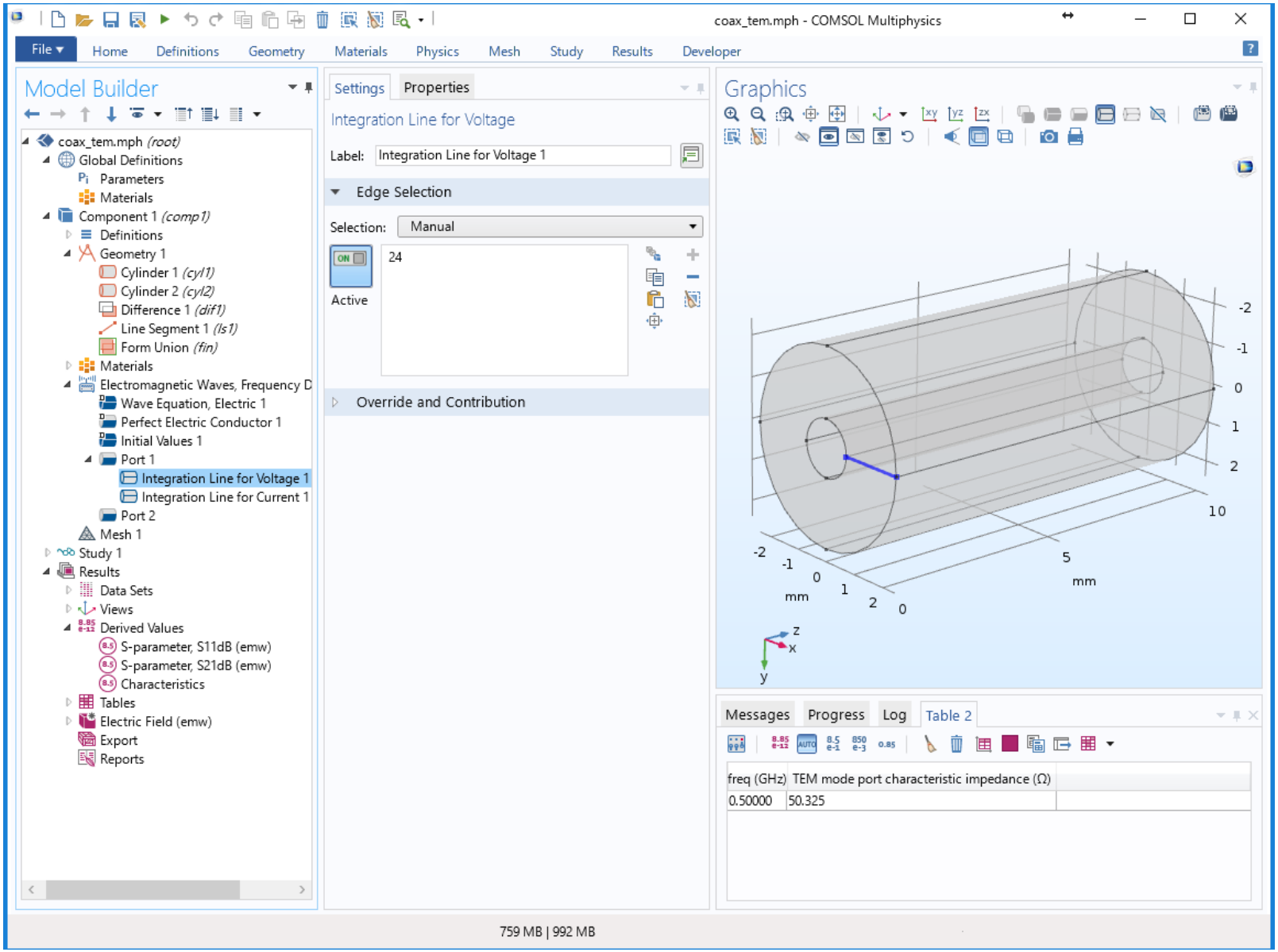
電圧計算用の経路を作成



ポート設定のTEM界解析にチェック



電圧用積分経路設定


coax_tem.mph - COMSOL Multiphysics
File
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coax_tem.mph (root)
Global Definitions
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Geometry 1
Cylinder 1 (cyl1)
Cylinder 2 (cyl2)
Difference 1 (dif1)
Line Segment 1 (ls1)
Form Union (fin)
Materials
Electromagnetic Waves, Frequency D
Wave Equation, Electric 1
Perfect Electric Conductor 1
Initial Values 1
Port 1
Integration Line for Voltage 1
Integration Line for Current 1
Port 2
Mesh 1
Study 1
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Data Sets
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Derived Values
S-parameter, S11dB (emw)
S-parameter, S21dB (emw)
Characteristics
Tables
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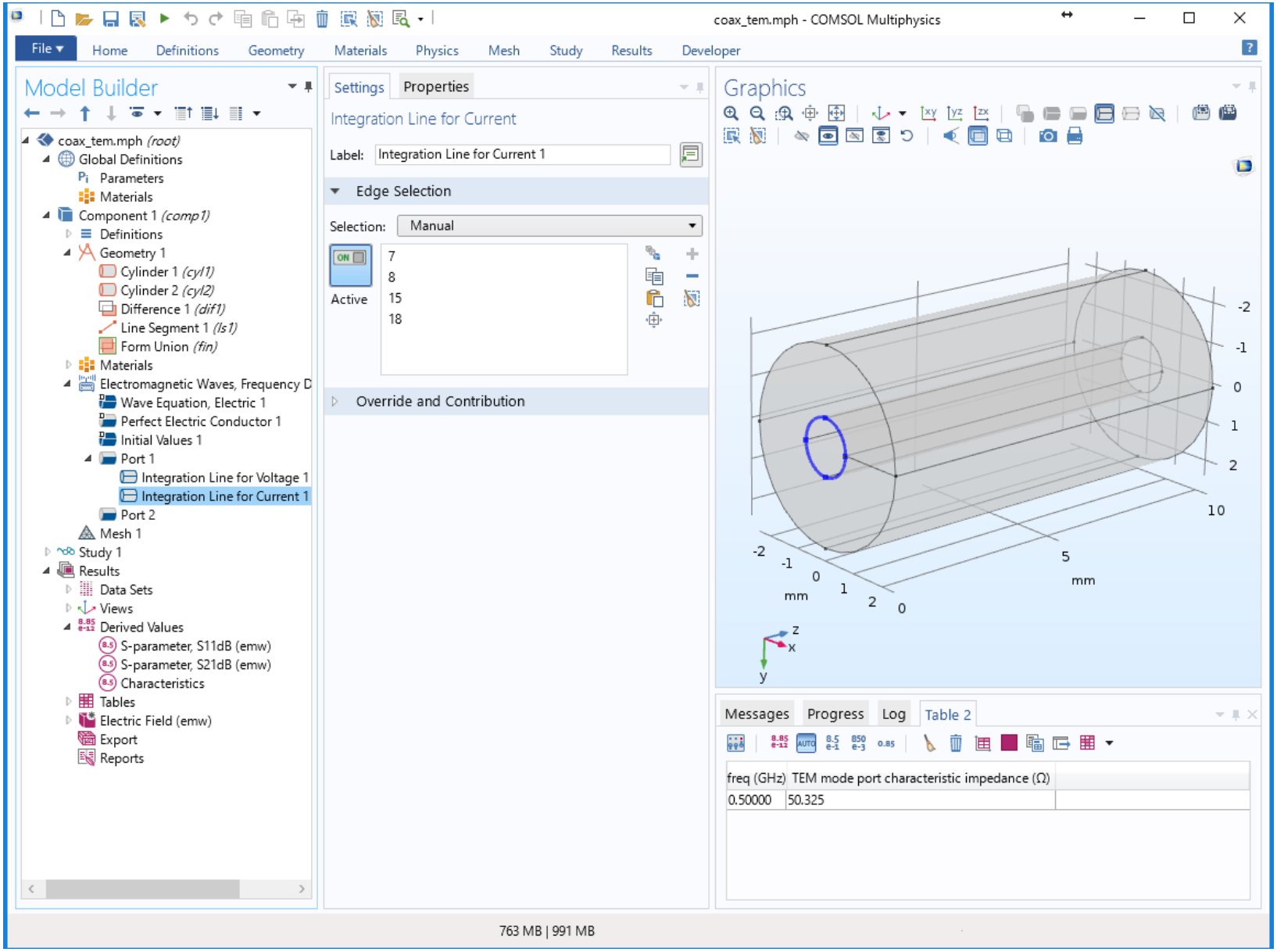
Settings
Properties
Integration Line for Voltage
Label: Integration Line for Voltage 1
Edge Selection
Selection: Manual
ON
Active
24
Override and Contribution
Graphics
mm
Messages
Progress
Log
Table 2
freq (GHz)
TEM mode port characteristic impedance (Ω)
0.50000
50.325
759 MB | 992 MB

電流用積分経路設定


coax_tem.mph - COMSOL Multiphysics
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Wave Equation, Electric 1
Perfect Electric Conductor 1
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Integration Line for Current 1
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Integration Line for Current
Label: Integration Line for Current 1
Edge Selection
Selection: Manual
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7
8
15
18
Override and Contribution
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Table 2
freq (GHz) TEM mode port characteristic impedance (Ω)
0.50000 50.325
763 MB | 991 MB

特性インピーダンスの計算