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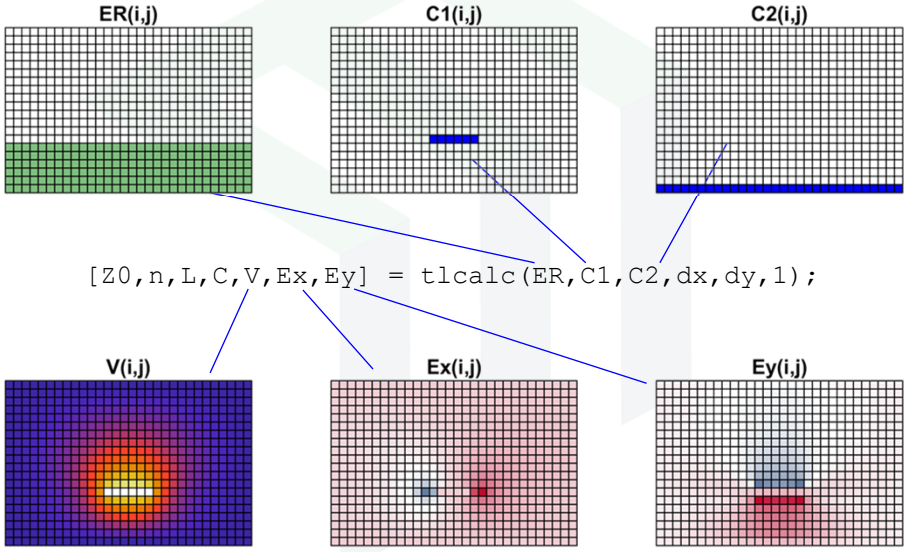
Electromagnetics:
Microwave Engineering

Using `tlcalc()`

Outline

- The Short Story
- Using `tlcalc.p` to Analyze Transmission Lines
- Convergence
- Hints
- Benchmarking Examples

The Short Story



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Using `tlcalc.p` to Analyze Transmission Lines

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`tlcalc()` (1 of 2)

```
tlcalc    Transmission Line Calculator

 [Z0,n,L,C,V,Ex,Ey] = tlcalc(ER,C1,C2,dx,dy,tltype);

 This MATLAB function calculates the properties of an
 arbitrary transmission.

 ER is a 2D array describing the relative permittivity.
 C1 is a 2D array identifying the points of conductor 1.
 C2 is a 2D array identifying the points of conductor 2.
    C2 is ground for single-ended transmission lines.
 dx and dy are the grid resolution parameters.
 tltype is either 1=single-ended or 2=differential

 For single-ended lines, C1 is set to 1 V and C2 is set to 0 V.
 For differential lines, C1 is set to 0.5 V and C2 is set to -0.5 V.
 For both line types, the outer edges of the grid are set to 0 V.

 Electromagnetic Field Theory
 Prof. Raymond C. Rumpf
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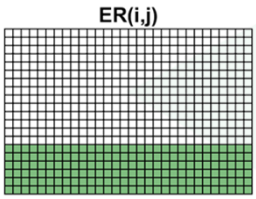
Number Values for Inputs

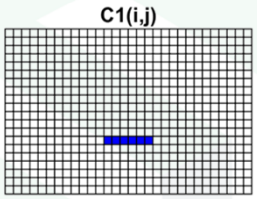


Permittivity Function

$$1 \le \varepsilon_r(x,y) < \infty$$

ε_r should be purely real.

Loss is not handled in this model.

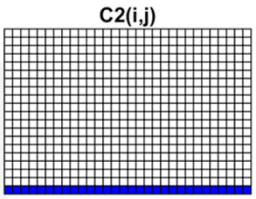


Conductor #1

$0 \equiv$ dielectric

$1 \equiv$ metal

Array should be all 0's except 1's in the positions that describe the first conductor.



Conductor #2

$0 \equiv$ dielectric

$1 \equiv$ metal

Array should be all 0's except 1's in the positions that describe the second conductor.

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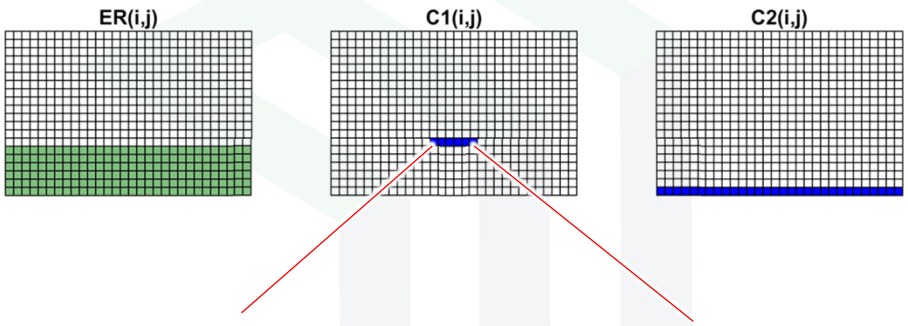
Grid Resolution



Pick the smallest dimension and resolve this with at least 5 to 10 points.

```
dx = w/10;
dy = dx;
```

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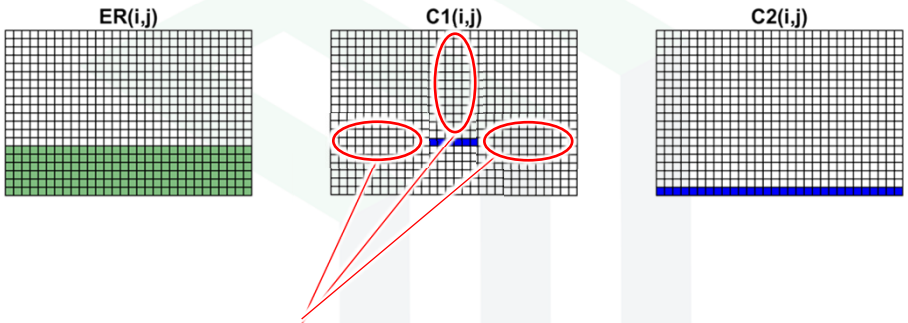
Space Around Transmission Line



Add enough space between transmission line and the boundary to ensure the electric field decays sufficiently. Remember, Dirichlet boundary conditions were used and so the electric potential at the edge of the grid is forced to zero.

$\sim 3w$

Rule of Thumb:
Keep at least three line widths of space around the transmission line.

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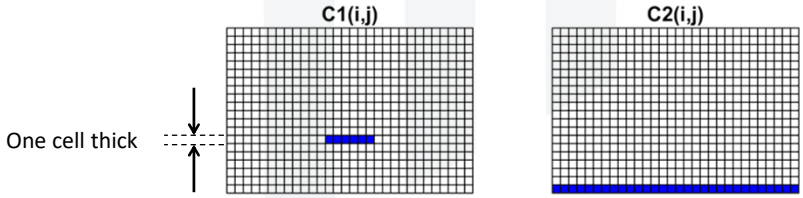
Thickness of Conductors

Conductors are usually very thin (20-50 micrometers).

This is not usually feasible to resolve in this simple analysis tool.

Just make the conductors one cell thick, unless the line has very thick conductors.



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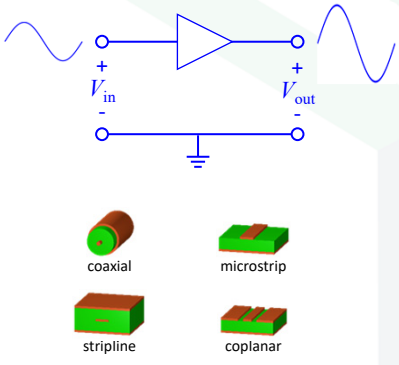
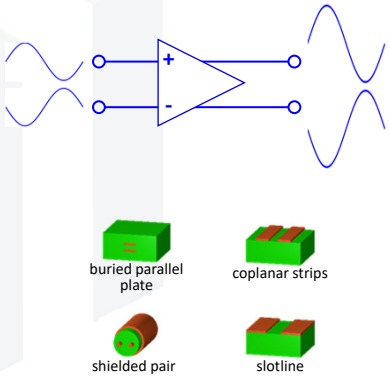
Single-Ended Vs. Differential Transmission Lines

Single-Ended (Unbalanced)




```
tlcalc(ER,C1,C2,dx,dy,1);
```

Differential (Balanced)




```
tlcalc(ER,C1,C2,dx,dy,2);
```

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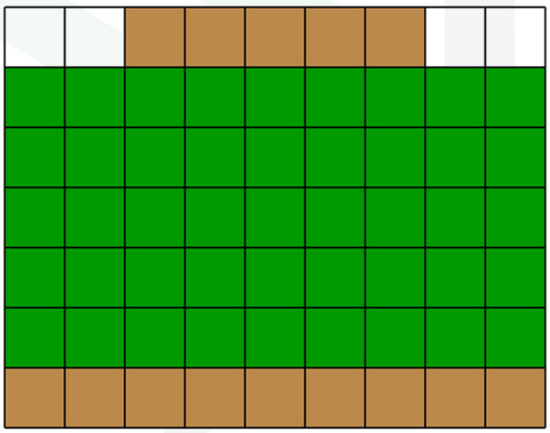
Convergence

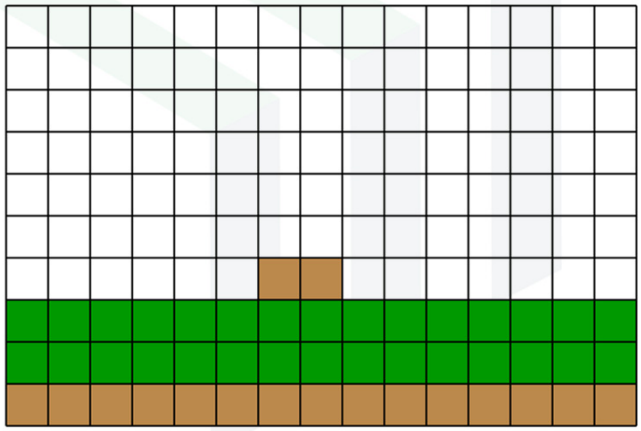
What Needs to Be Evaluated for Convergence?

Spacer Regions – How much space should you put around your transmission line?



What Needs to Be Evaluated for Convergence?

Grid Resolution – How finely should the transmission line be resolved (i.e. Δx and Δy)?



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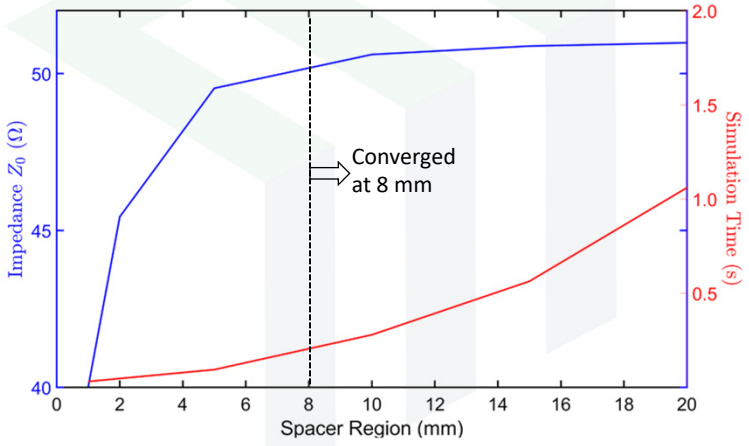
Convergence Behavior of Spacer Regions



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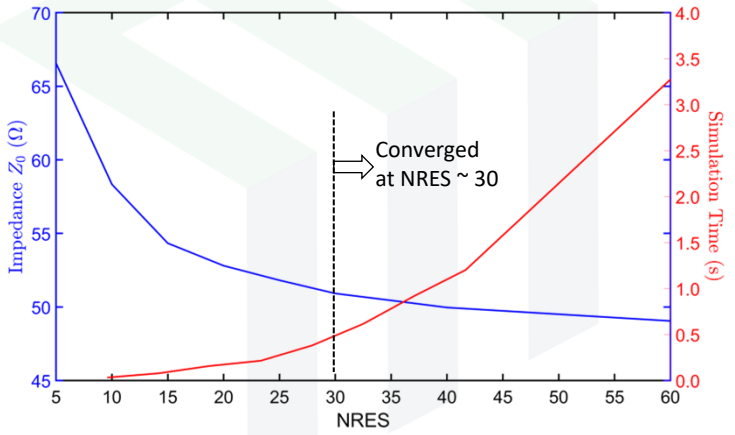
Convergence Behavior of Grid Resolution



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Hints

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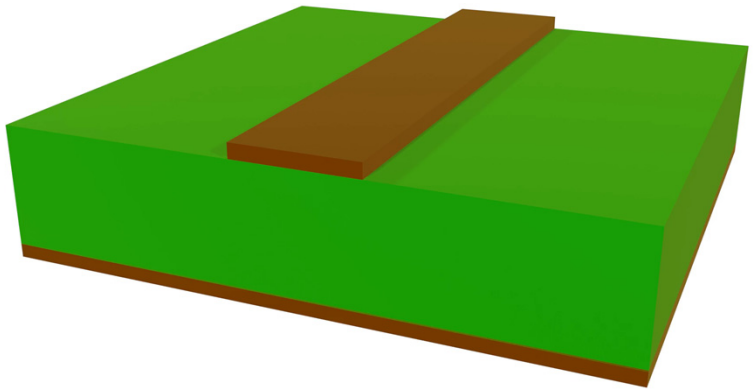
Scalability

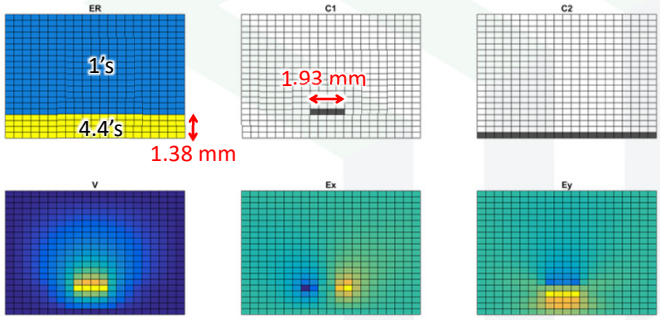


Transmission line parameters $(L, C, Z_c, \beta, n_{\text{eff}})$ are constant regardless of scale.

Electromagnetics has no fundamental size scale!

Benchmarking Examples

Microstrip Transmission Line



$L = 304.7 \text{ nH/m}$
$C = 116.8 \text{ pF/m}$
$Z_0 = 51.1\ \Omega$
$n_{\text{eff}} = 1.7881$

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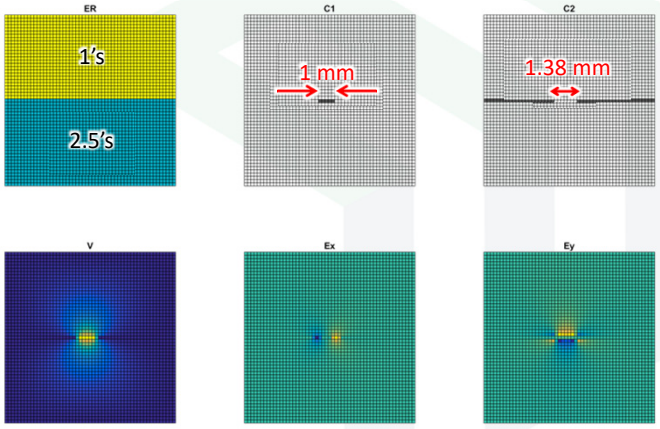
Coplanar Transmission Line



$L = 317.3 \text{ nH/m}$
$C = 59.9 \text{ pF/m}$
$Z_0 = 72.8\ \Omega$
$n_{\text{eff}} = 1.3066$

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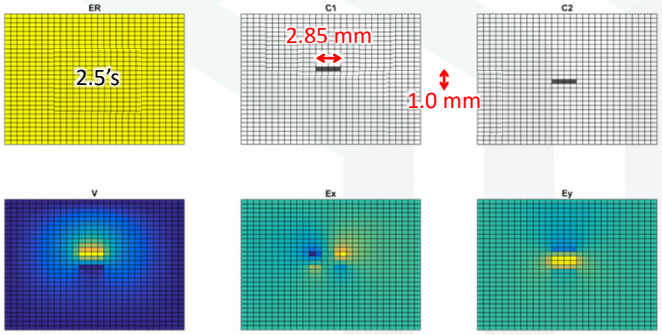
Parallel Plate Transmission Line



$L = 263.3$ nH/m
$C = 105.7$ pF/m
$Z_0 = 49.9\ \Omega$
$n_{\text{eff}} = 1.5811$

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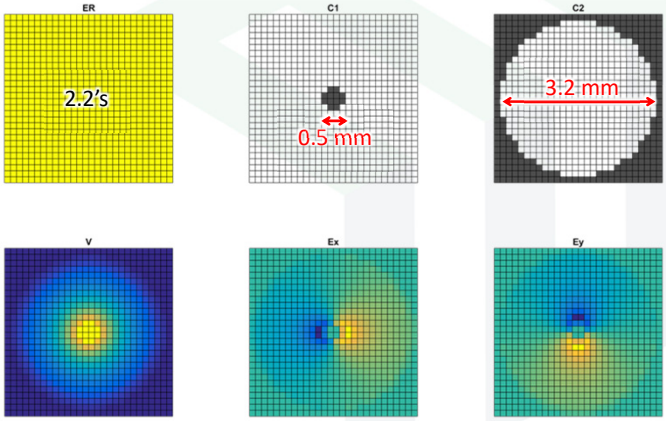
Coaxial Transmission Line



$L = 379.5$ nH/m
$C = 64.5$ pF/m
$Z_0 = 76.7\ \Omega$
$n_{\text{eff}} = 1.4832$

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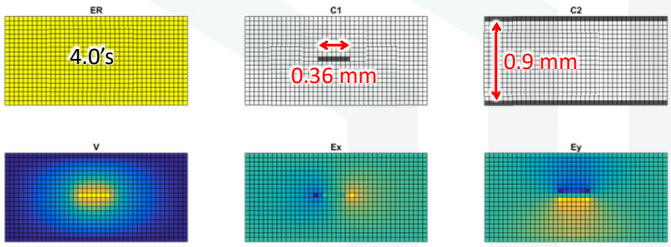
Symmetric Stripline



$L = 381.1 \text{ nH/m}$

$C = 116.8 \text{ pF/m}$

$Z_0 = 57.1\ \Omega$

$n_{\text{eff}} = 2.00$

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