Transmission lines: Part 1 – Electric field

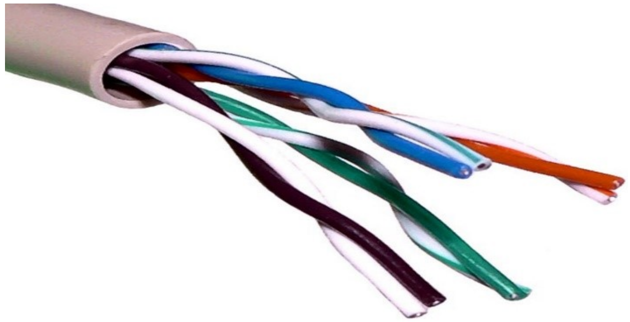
1. What is transmission line?
2. What question can be answered by QuickField, and what cannot?
3. Most popular kinds of planar transmission lines:
   stripline, microstrip, coplanar waveguide, slot line
4. Transmission line parameters: Impedance Z_0, propagation velocity v_p
5. How to find the impedance by electrostatic field calculation

What is transmission line?

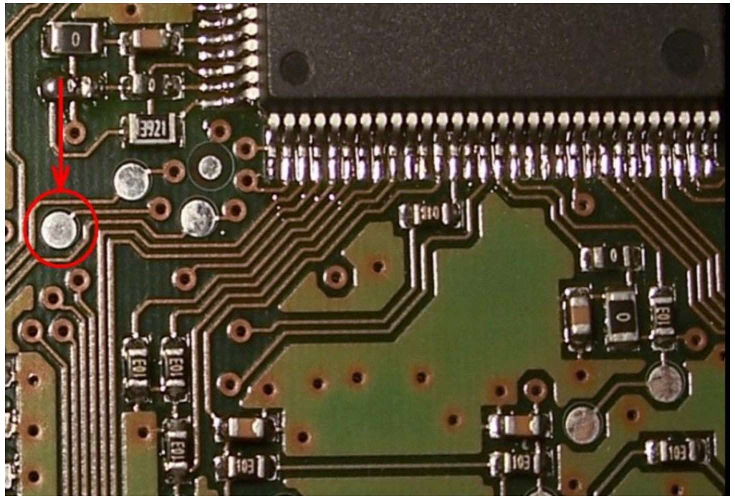
In electronics a transmission line (TL) is a structure composed of conductors and dielectrics, intended for transmission the signal from a source to a target device.

The main feature of TL is the **frequency high enough** that their **wave nature** should be taken into account.

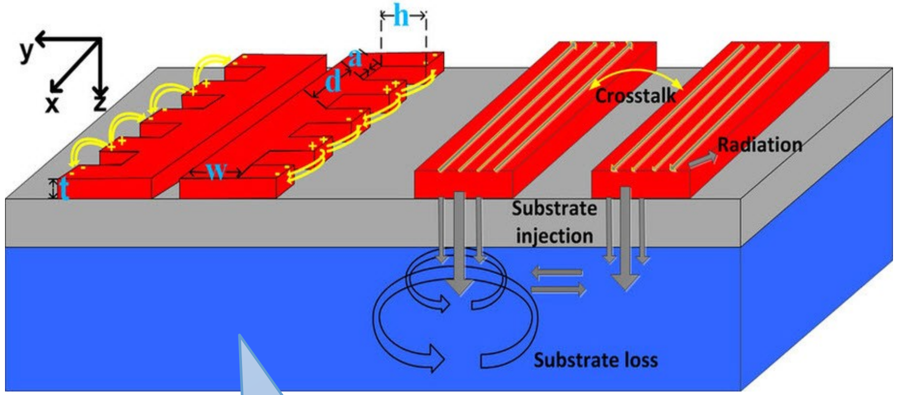
Device level interconnect



Board level interconnect

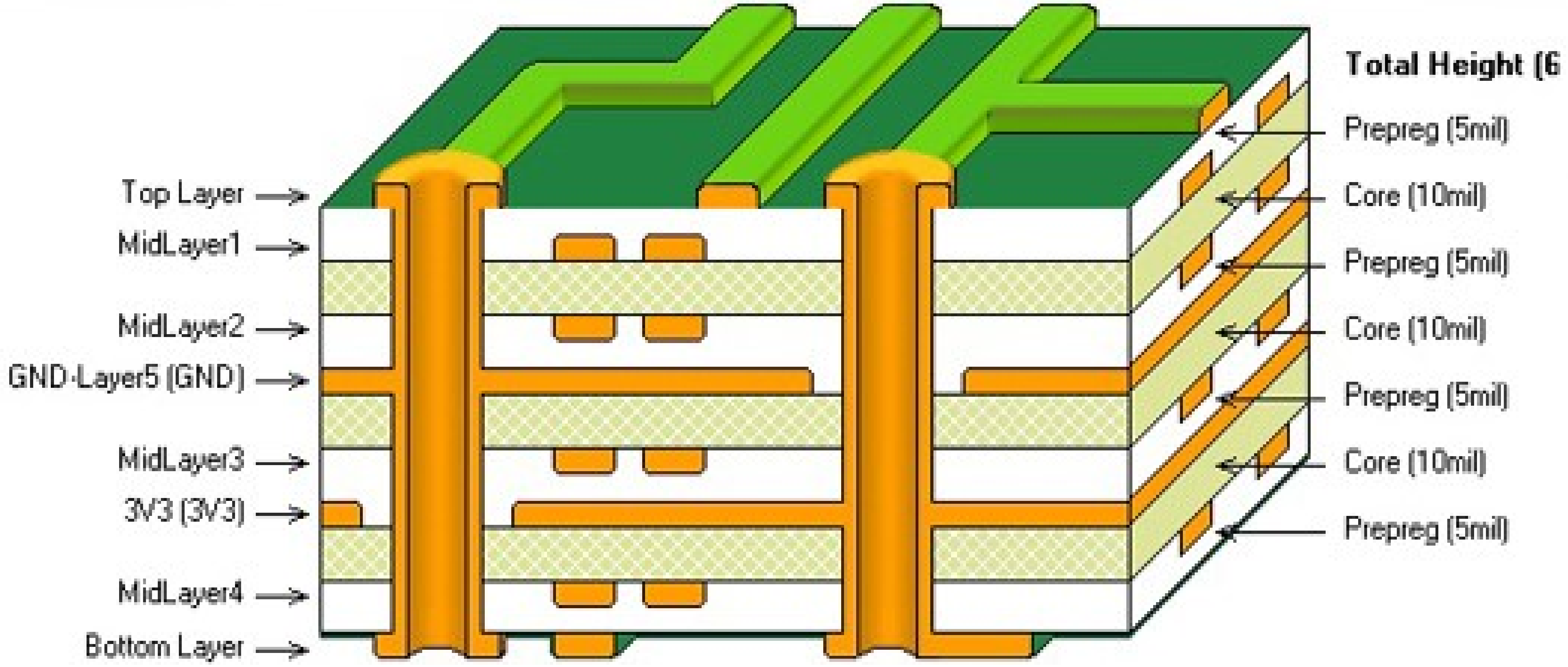


Chip level interconnect

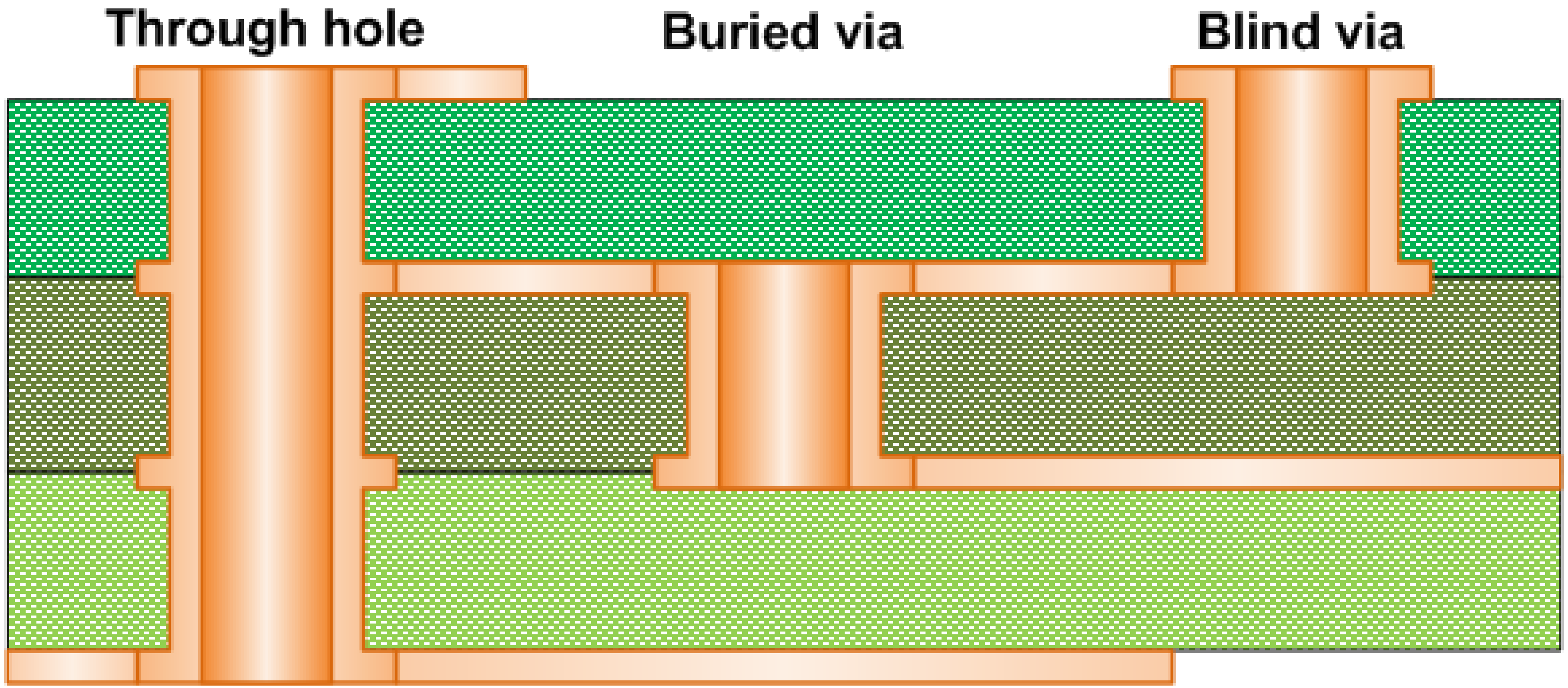


Emerging technology!

Construction of multilayer PCB



Layers are connected with Vias



Frequency Range based on comparison characteristic device size $\mathbf{L}$ vs. wavelength $\boldsymbol{\lambda}$

$L << \lambda$

Lumped

No waves,
no radiation

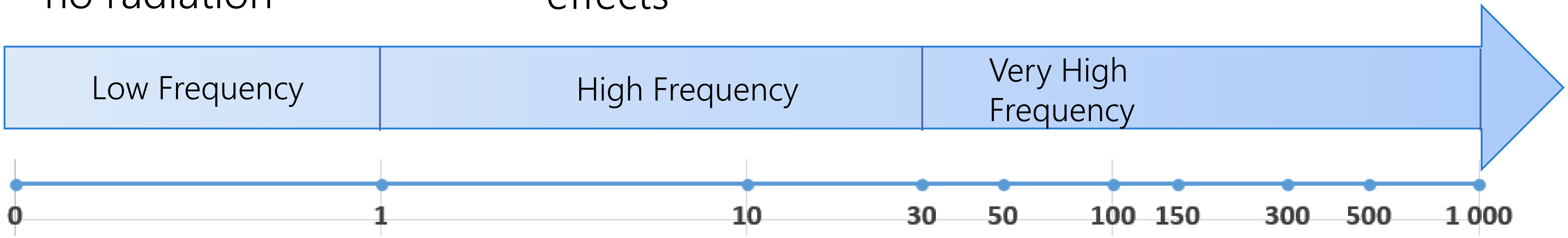
Gray Zone

Some parasitic
effects

$L > \lambda / 8$

Distributed

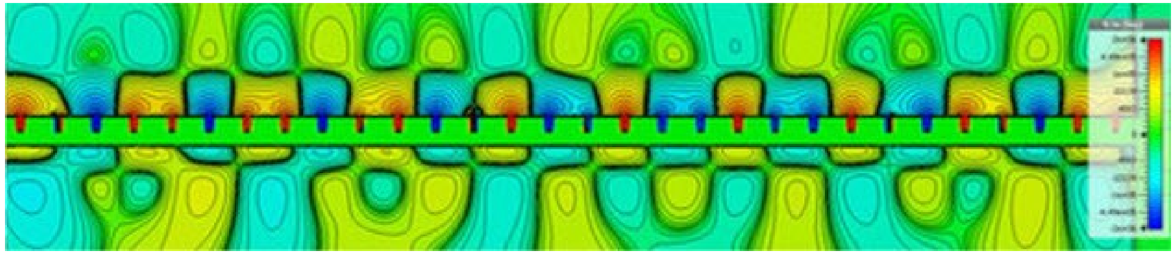
Distributed concept



Frequency, MHz

What questions can be answered by QuickField, and what can not?

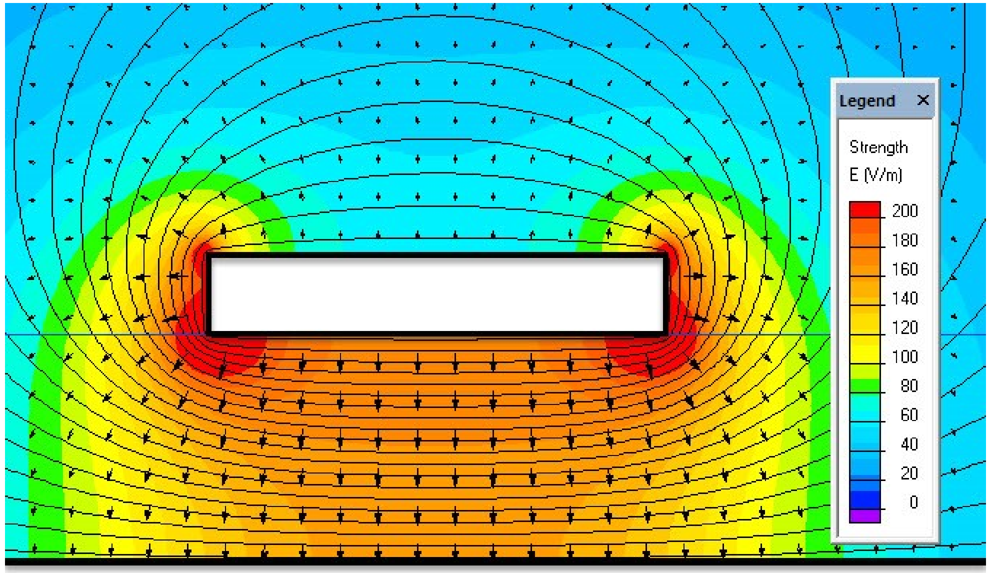
EM Field in the wave propagation plane



- Near-field and far-field zones
- Propagation, Scattering, Reflection
- Absorbing boundary conditions
- Eigen modes, eigen frequency

Other software

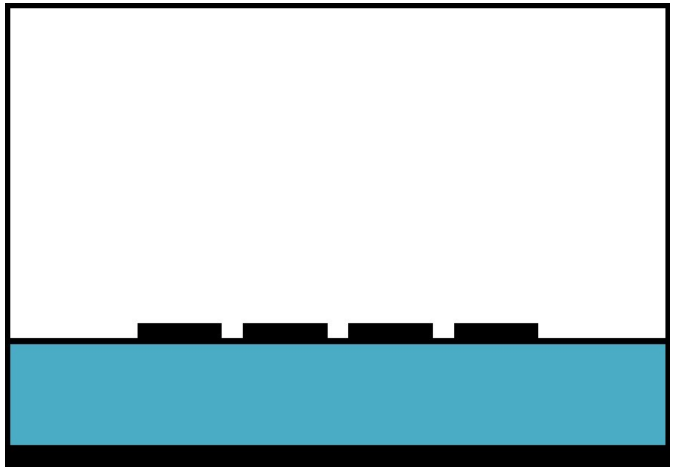
Electric or Magnetic Field in the cross-section plane



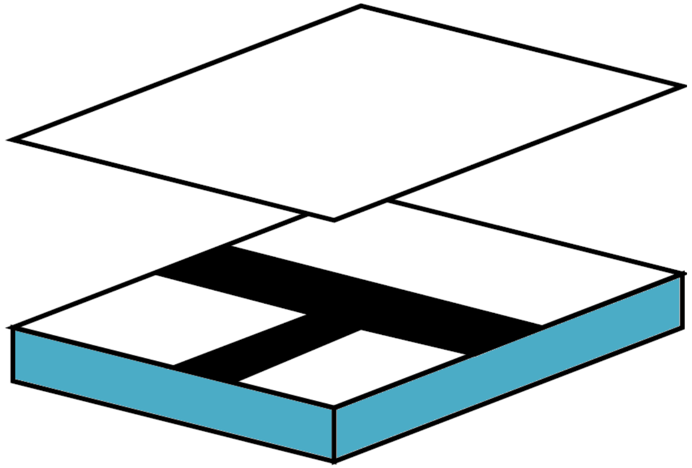
- Self and mutual inductances
- Skin effect, proximity effect
- Self and mutual capacitances
- Conductor and dielectric losses

QuickField

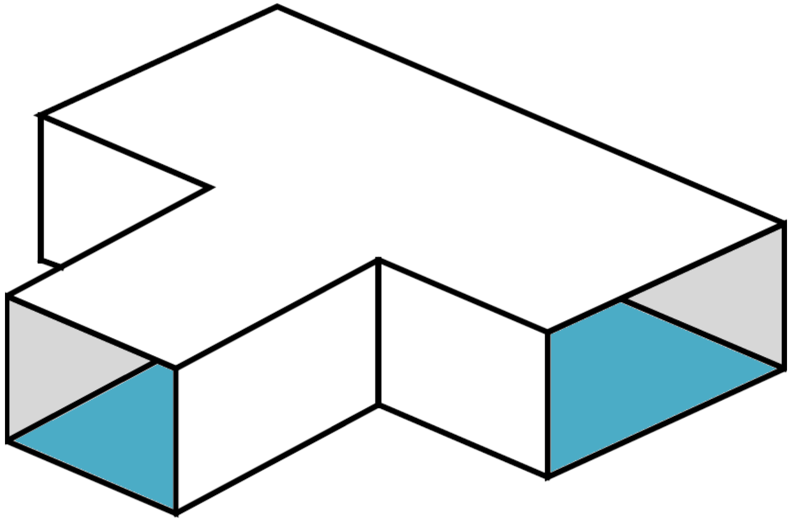
Three kinds of field solver, classified by geometrical dimensionality



2D cross-section



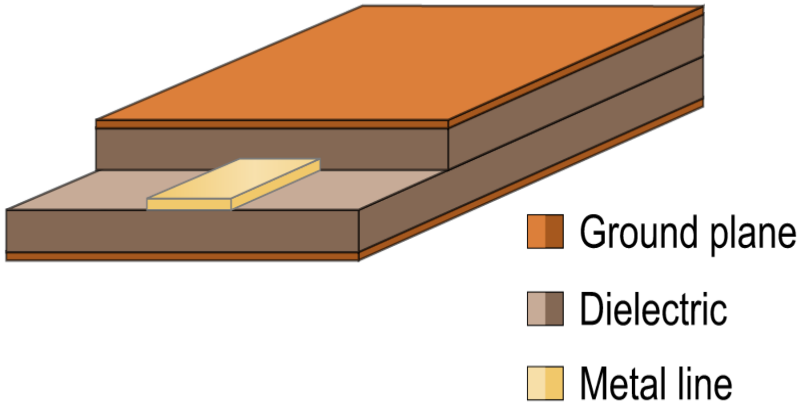
2.5D mostly planar



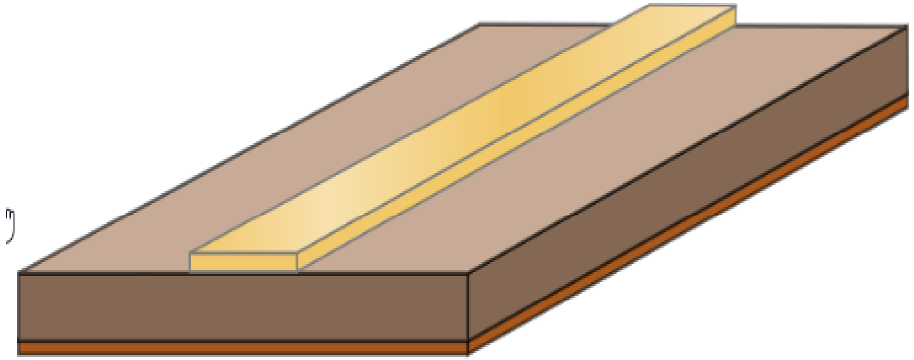
Full 3D

Here lives QuickField

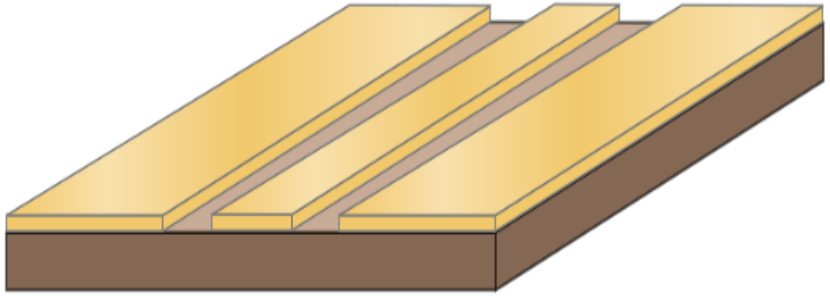
Most popular kinds of planar transmission lines



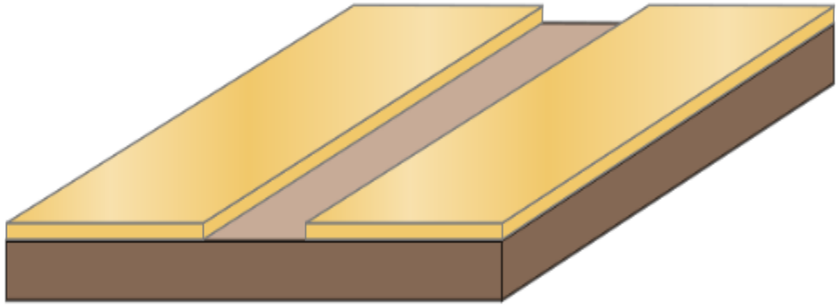
Stripline



Microstrip



Coplanar waveguide (CPW)



Slotline

Electrostatic Analysis

How to calculate transmission line impedance Z_0

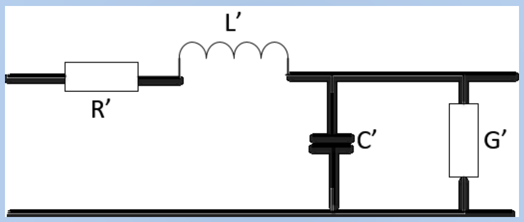
Characteristic Impedance is the ratio of voltage to current magnitude of an infinitely long line (with no reflected wave)

$$Z_0 = \frac{U_{in}}{I_{in}} = \sqrt{\frac{L}{C}}$$

Wave propagation velocity: $v_p = \frac{1}{\sqrt{LC}}$

Take into account that in free space $v_p = c$, so: $c = \frac{1}{\sqrt{LC_0}}$

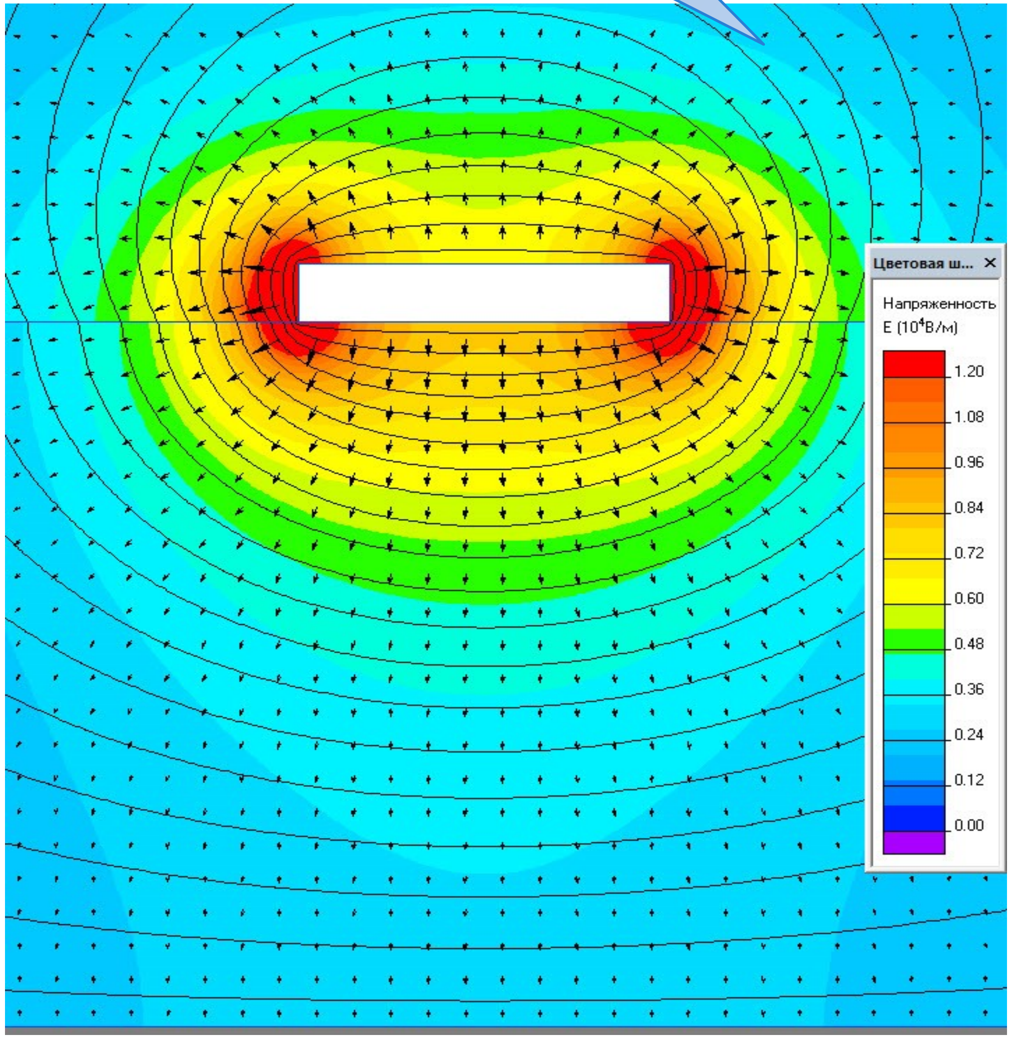
where C_0 is the capacitance with all dielectrics replaced with free space: $\varepsilon = \varepsilon_0$



Finally:

$$Z_0 = \frac{1}{c\sqrt{CC_0}} \qquad v_p = c\sqrt{\frac{C_0}{C}}$$

Electric field **E**



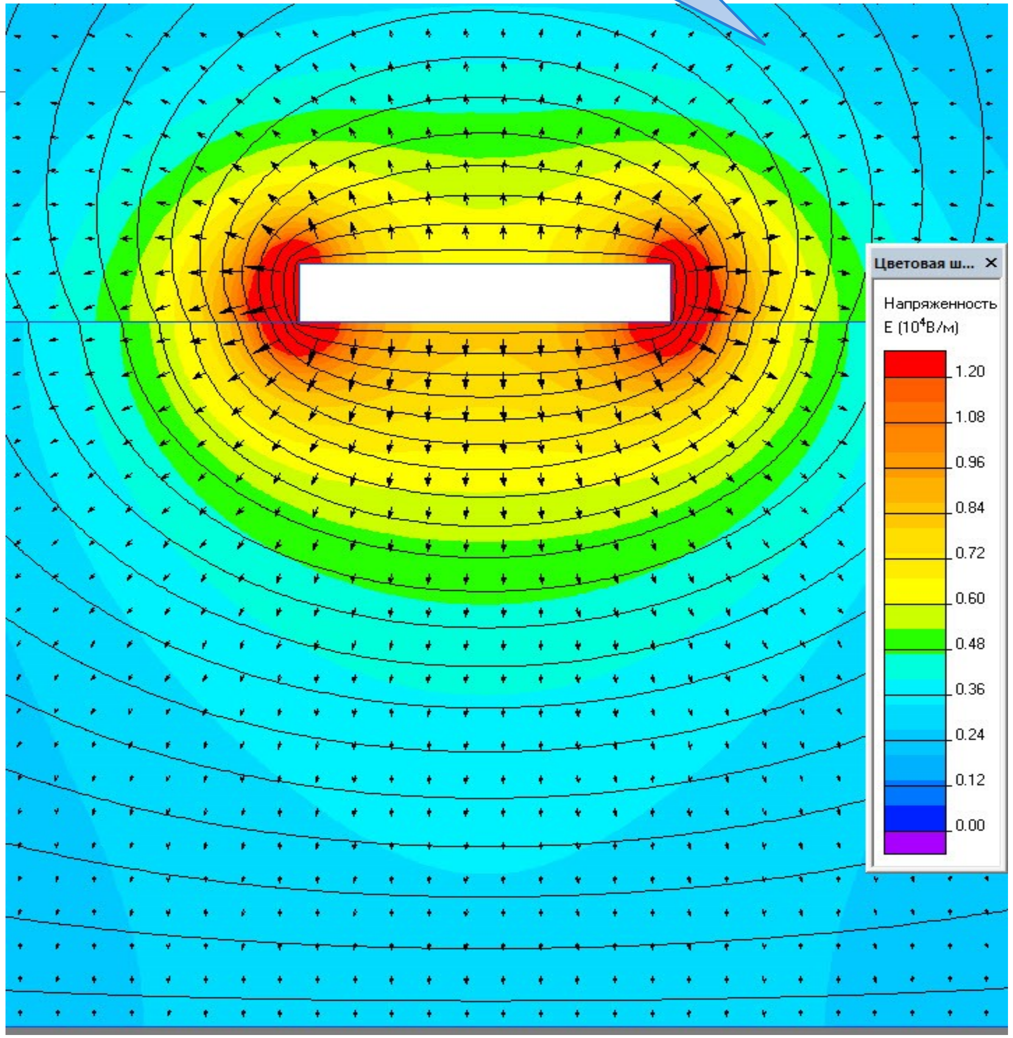
Electrostatic Analysis

How to calculate transmission line impedance Z_0

Electric field **E**

If we know that the EM field is TEM or Quasi-TEM we only need calculate electrostatic field twice for capacitance.

1. **First calculation**: Setting the actual permittivity of dielectrics
2. **Second calculation**: All dielectrics replaced with free space ($\varepsilon = 1$)



We can calculate the capacitance:

- Through the charge of signal conductor $q = \oint_S \mathbf{D} \cdot \mathbf{ds}$
- Or, using the field energy: $W = \frac{1}{2} \oint_V (\mathbf{D} \cdot \mathbf{E}) dv$

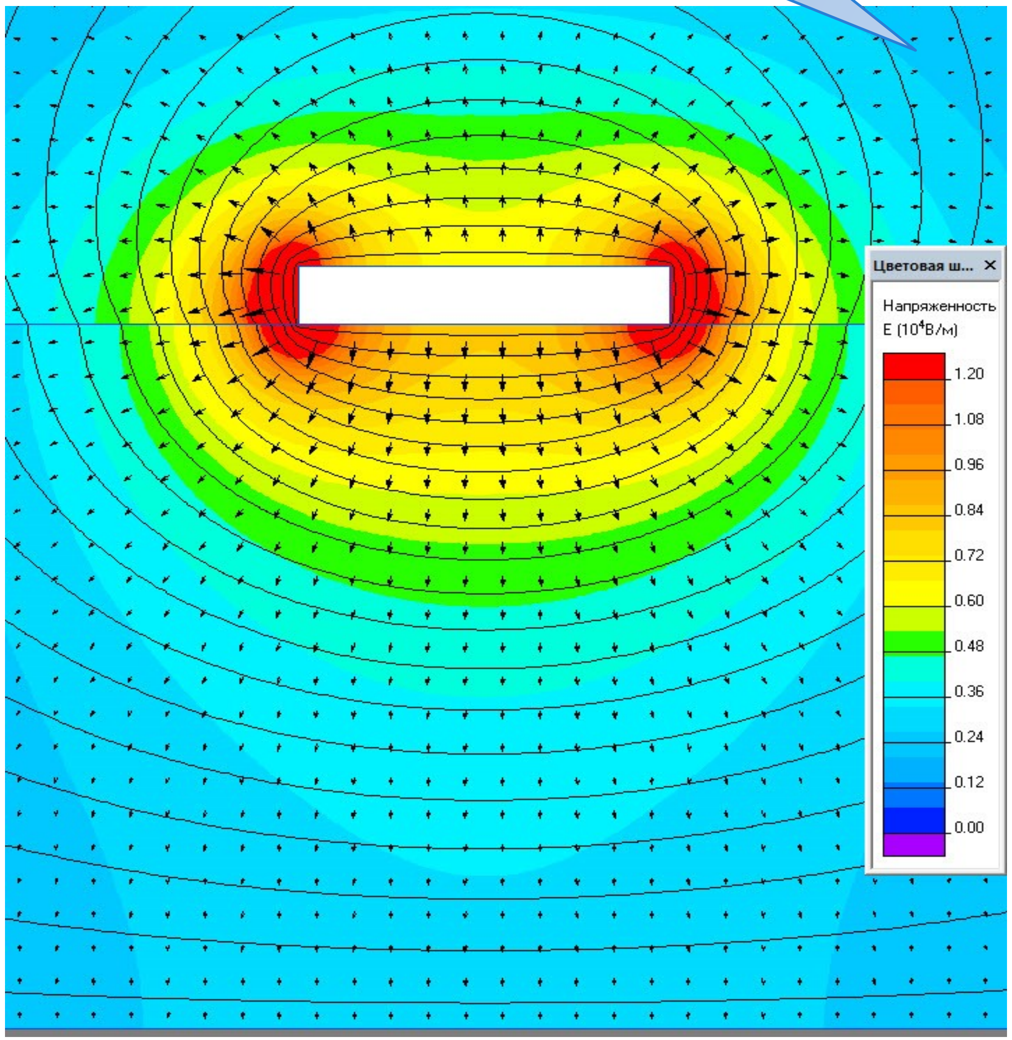
Dielectric Loss

Replacing **Electrostatic analysis**
with **AC Conduction analysis**

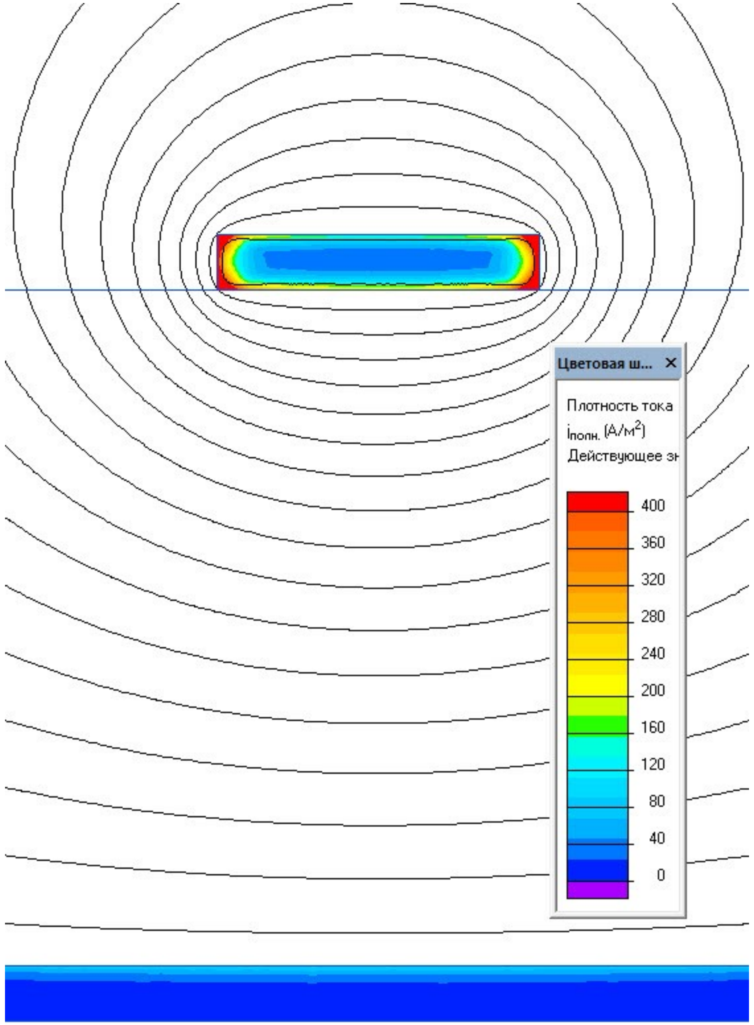
we can calculate dielectric losses at given frequency:

$$P_{diel.} = \int_V (\mathbf{E} \cdot \mathbf{J})\, dv$$

Dielectric
Loss Density



AC Magnetic Analysis:
skin-effect, proximity effect, inductance, conductor loss

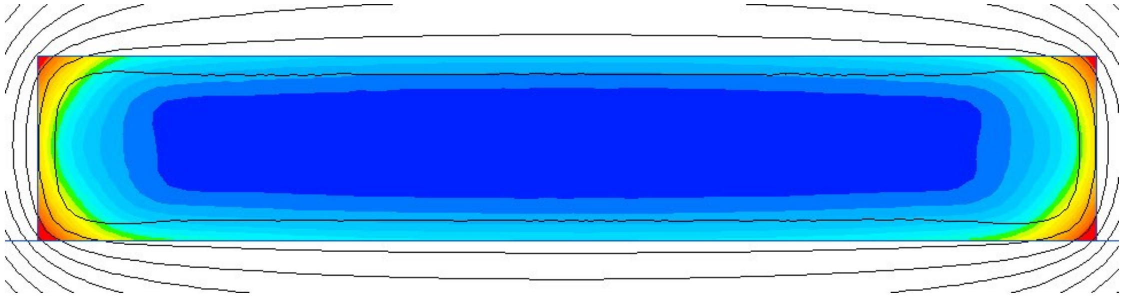


The AC Magnetic field analysis with eddy currents facilitates the calculation of <u>inductance</u> as well as <u>conductor losses</u> in the conductor and in the grounding plane.

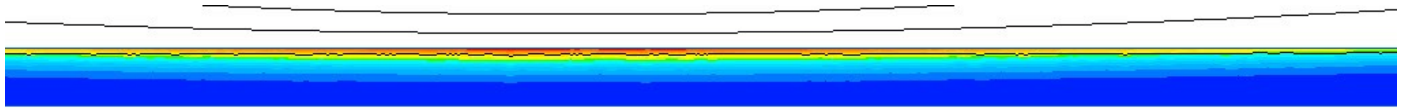
The <u>*skin effect*</u> and <u>*proximity effect*</u> are fully taken into account.

When needed, the analysis is able to take into account the <u>*saturation*</u> of magnetic elements (steel, ferrite)

Conductor



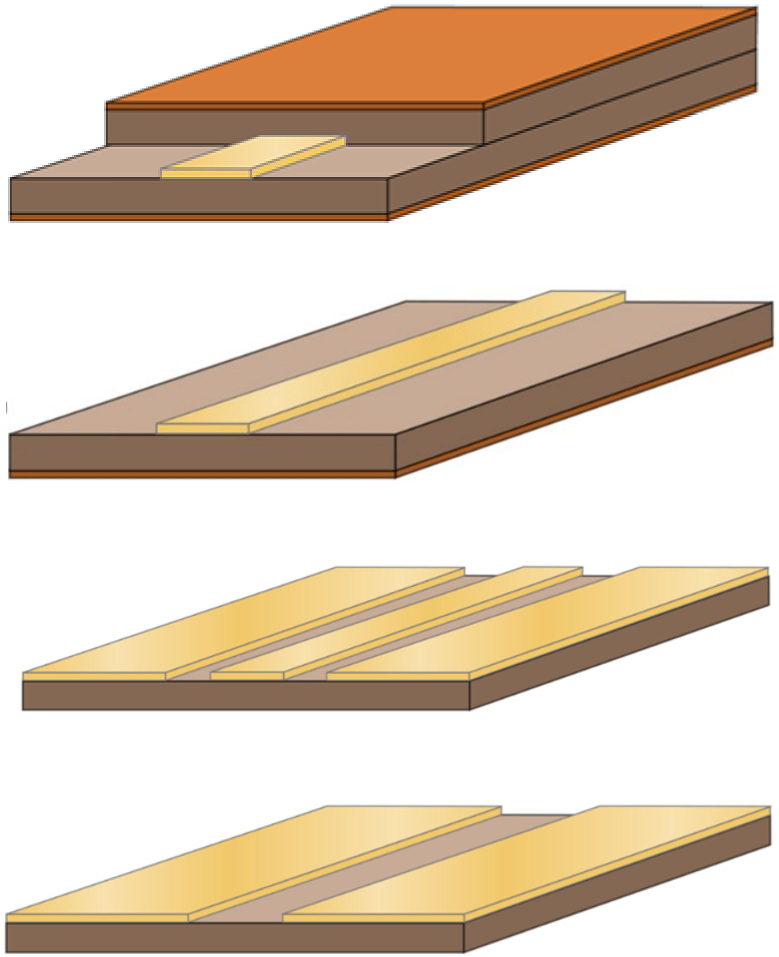
Grounding plane



2D Cross-section EM Field Analysis

Why the field-based calculator is better than the formula-based calculator?

- Any shape of conductor’s cross-section
- Many dielectric layers with different properties
- Loss dielectric
- With multi-conductor configuration – any mode
- Magnetic field tacking into account skin-effect and proximity-effect
- Conductor loss due to skin-effect
- Self- and mutual inductance matrix
- Saturated magnetic media (ferrites, e.t.c)

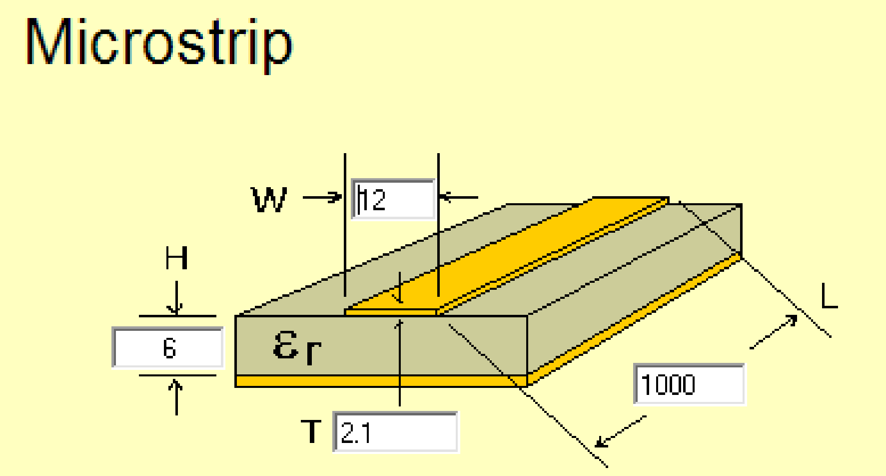


Example

Data		MS-1	
	comment	mil	mm
W	strip width	12	0.305
H	substrate height	6	0.152
ε_r	relative permittivity	4.6	0.117
μ_r	relative permeability	1	
tgδ	dielectric loss factor	0.0002	
σ	conductivity	5.60E+07	
T	strip thickness	2.1	0.053
L	strip length	1000	25.4
f	frequency	100	MHz
Result			
Z_0	Impedance	44.39	Ohm
El_Len	Electric Length / λ	0.307	
v_p	propagation velocity as fraction of c	0.552	

Variation

Parameter	W
min	8
max	16



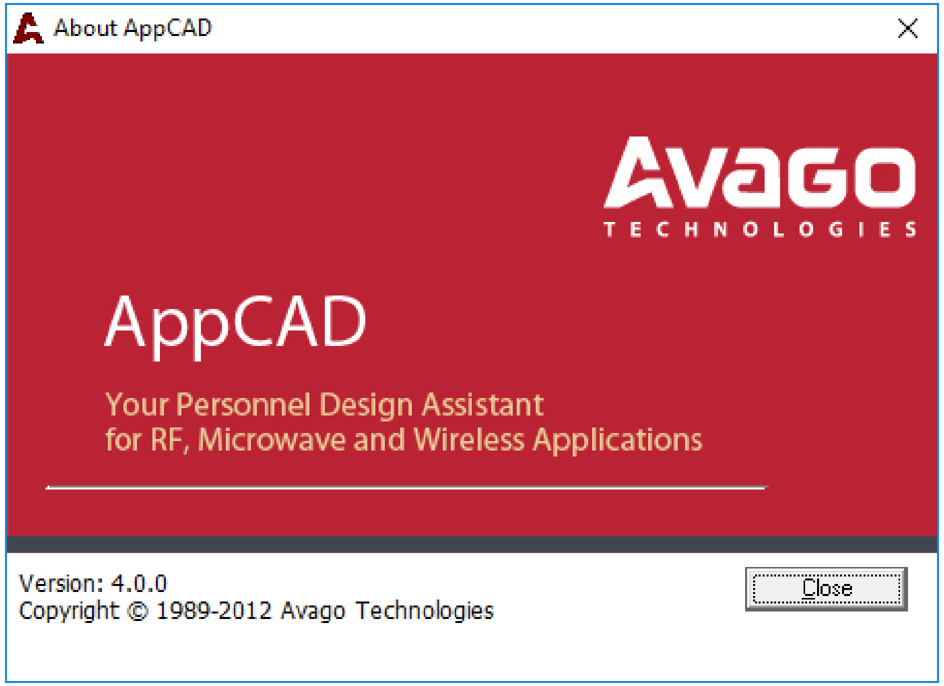
Working Formulae:

Characteristic Impedance: $$Z_0 = \frac{1}{c\sqrt{CC_0}}$$

Propagation Velocity: $$v_p = c\sqrt{\frac{C_0}{C}}$$

where C=capacitance,
C_0=capacitance with $\varepsilon=\varepsilon_0$

Compare with a formula based calculator



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