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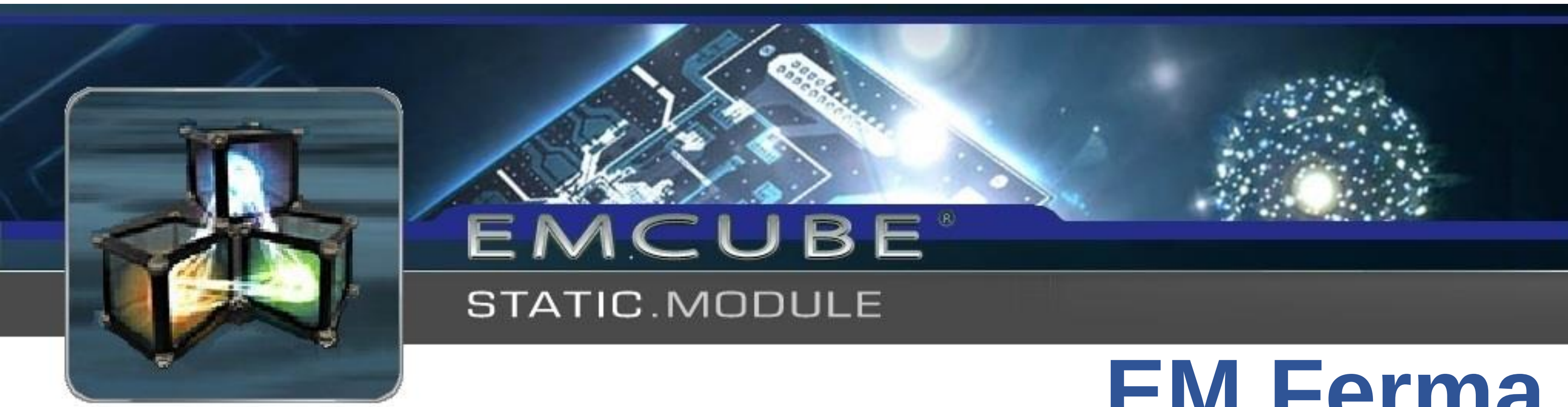

# EM.Ferma

## Tutorial Lessons

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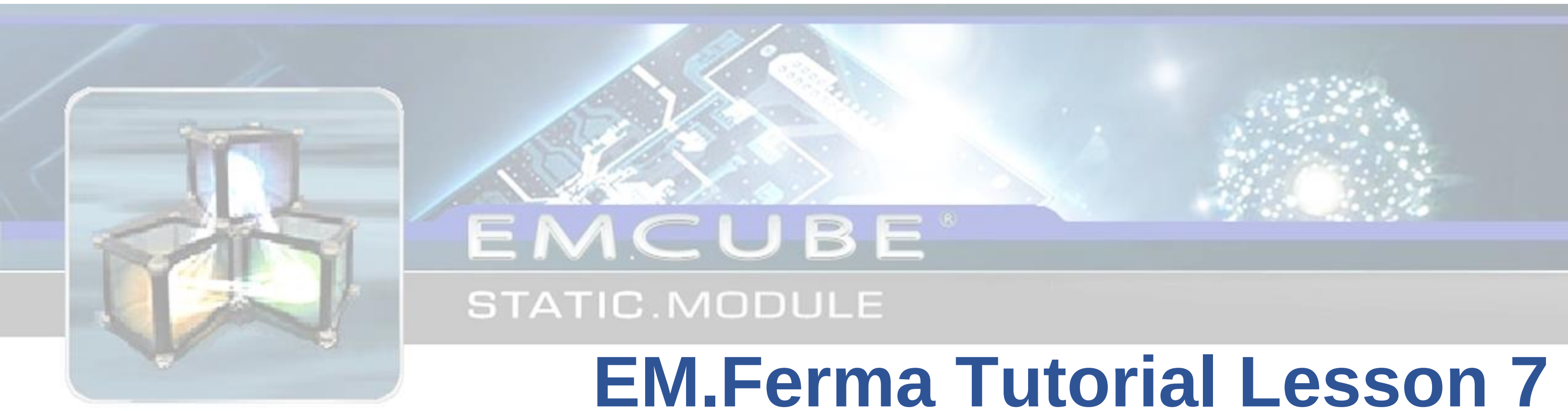
# 7



# EM.Ferma Tutorial Lesson 7

## Analyzing A Microstrip Transmission Line

# Table of Contents

## 7.1 What You Will Learn

In this tutorial you will learn how to define and characterize a 2D transmission line structure like a microstrip line using quasi-static analysis. You will use EM.Ferma's transmission line wizards.

**EM.Ferma Manual:**

http://www.emagtech.com/wiki/index.php/EM.Ferma

**EM.Ferma Tutorial Gateway:**

http://www.emagtech.com/wiki/index.php/EM.Cube#EM.Ferma_Documentation

**Download projects related to this tutorial lesson:**

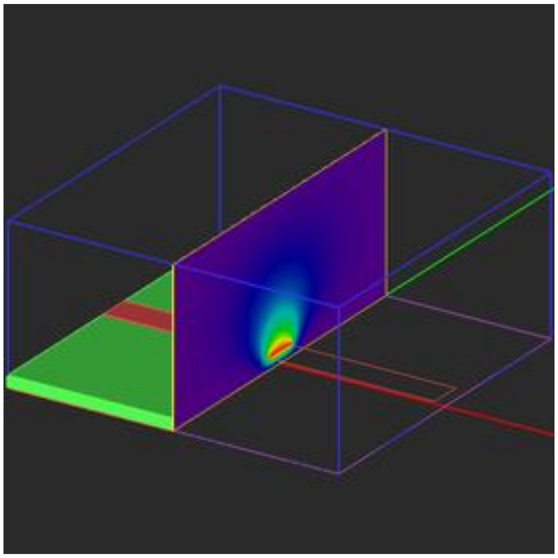
http://www.emagtech.com/downloads/ProjectRepo/EMPicasso_Lesson7.zip

## 7.2 Getting Started

Start a new project with the following parameters:

| Starting Parameters | |
|---|---|
| **Name** | EMFerma_Lesson7 |
| **Length Units** | Millimeters |
| **Frequency Units** | N/A (keep default) |
| **Center Frequency** | N/A (keep default) |
| **Bandwidth** | N/A (keep default) |

**Tutorial Project: Analyzing A Microstrip Transmission Line**



**Objective:** In this project, you will analyze a microstrip transmission line using EM.Ferma's quasi-static simulation engine.

**Concepts/Features:**

- Fixed-Potential PEC Object
- Dielectric Object
- 2D Solution Plane
- Quasi-Static Analysis
- Characteristic Impedance
- Effective Permittivity
- Variables
- Parametric Sweep

**Minimum Version Required:** All versions

## 7.3 A Note on Quasi-Static Solution of Transmission Line Problems

Most popular two-conductor transmission line types like microstrip, stripline, coplanar waveguide (CPW), etc., feature a single dominant TEM or TEM-like propagating mode. Therefore, they can be reasonably modeled using quasi-static methods. EM.Ferma takes the cross section of an infinitely long 2D transmission line structure and encloses it by a PEC domain box. Shielded transmission lines are naturally well-represented using this approach. To model open-boundary transmission lines like a microstrip line, you must place the domain boundary walls far enough from the signal line.

EM.Ferma can perform 2D electrostatic and quasi-static simulations. For this purpose, you need to define a "2D Solution Plane". The cross section of your physical structure on this 2D solution plane is taken as the geometry to be solved. In other words, EM.Ferma assumes that this cross sectional geometry is invariably extended to the infinity from both sides of the solution plane.

To compute the characteristic impedance $(Z_0)$ and effective permittivity $(\varepsilon_{eff})$ of the transmission line, EM.Ferma first analyzes the structure "As Is" and finds the electric field everywhere in the computational domain. Gauss' law is used to compute the total charge on the signal line, from which the capacitance $C$ is calculated. Then, all the dielectric parts are replaced with air ($\varepsilon_r$ = 1). The electrostatic problem is solved one more time and the "air-filled" capacitance $C_a$ is calculated. The characteristic impedance and effective permittivity of the transmission line are then calculated from the following relations:

$$Z_0 = \frac{1}{c_0\sqrt{CC_a}}$$

$$\varepsilon_{eff} = \frac{C}{C_a}$$

where $c_0 = 3\times10^8$ m/s is the speed of light in the free space.

## 7.4 Creating the Microstrip Line Geometry

Click on the **One-Port Microstrip Wizard** button of the **Wizard Toolbar** (Figure 1) or select the menu item **Tools** → **Transmission Line Wizards** → **Microstrip Line**. The geometry of a microstrip line appears at the center of the project workspace (Figure 2).

***Figure 1.*** *EM.Ferma's Wizard Toolbar.*

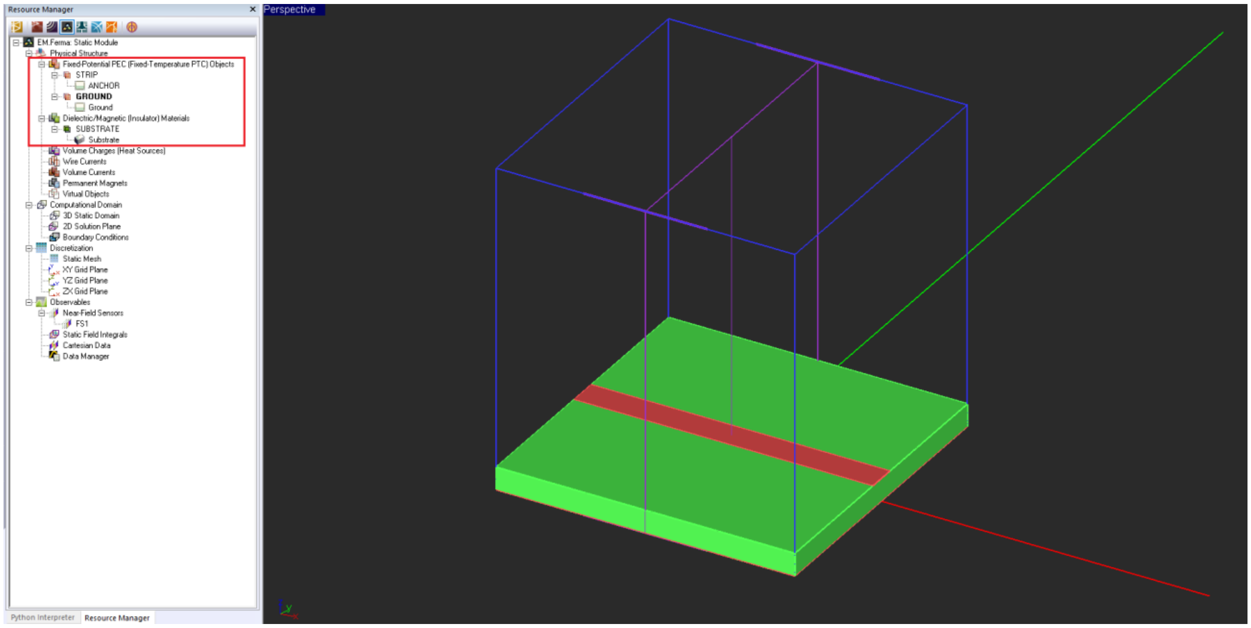
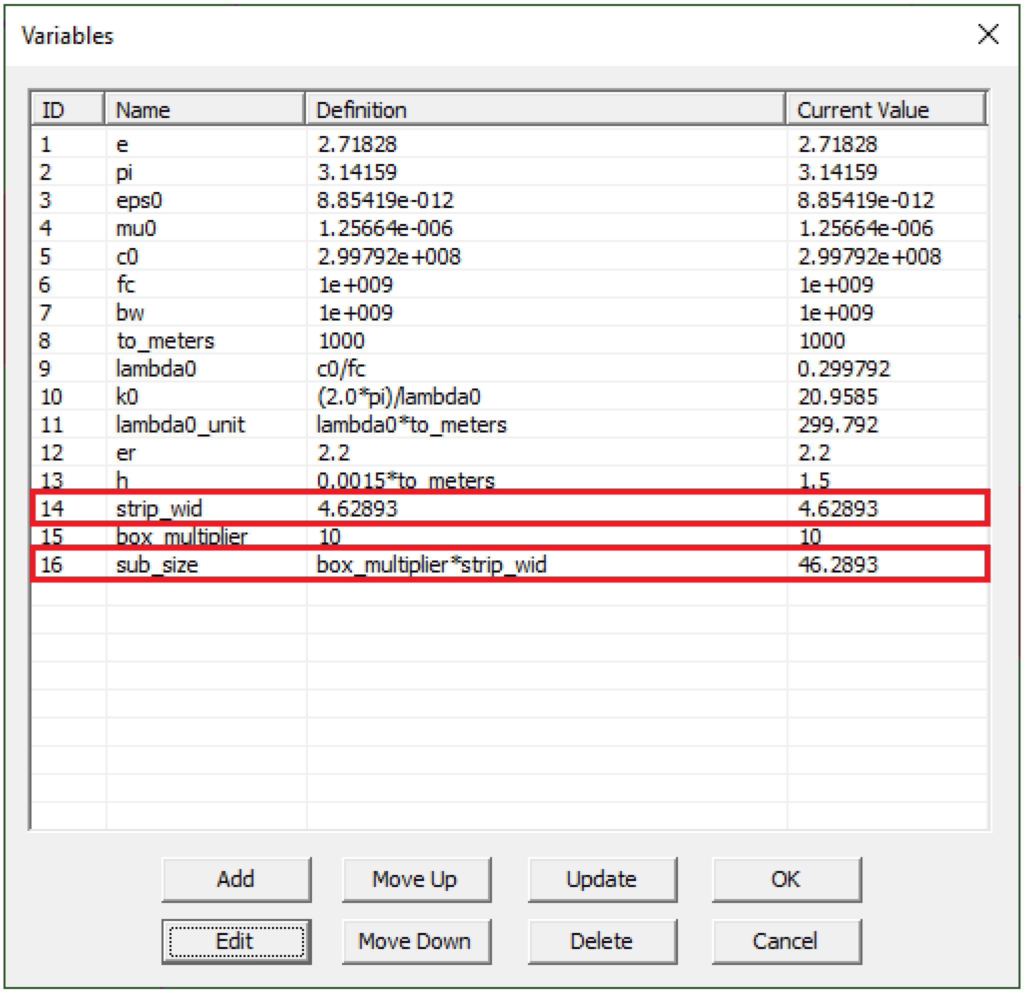


***Figure 2.*** *The microstrip geometry created by the wizard in the project workspace.*

A microstrip line consists of a metallic strip printed on top of a dielectric substrate with a conductor backing on its other side. The geometry created by the wizard consists of three objects belonging to three different material groups

| Object Name | Object Type | Material Group Name | Material Group Type |
|---|---|---|---|
| ANCHOR | Rect Strip | STRIP | Fixed-potential PEC |
| Ground | Rect Strip | GROUND | Fixed-potential PEC |
| Substrate | Box | SUBSTRATE | Dielectric material |

Open the property dialogs of the three material groups and examine their parameters. The fixed voltage of the "STRIP" PEC group is 1V, while the fixed voltage of the "GROUND" PEC group is 0V. The geometry created by the wizard is fully parameterized. Open the Variables dialog and review the list of the variables used for the definition of the microstrip line (Figure 3). Change the value of "strip_wid" to 4.62893mm. You will notice that the "sub_size" will change to 46.2893mm (Figure 3).



| ID | Name | Definition | Current Value |
|---|---|---|---|
| 1 | e | 2.71828 | 2.71828 |
| 2 | pi | 3.14159 | 3.14159 |
| 3 | eps0 | 8.85419e-012 | 8.85419e-012 |
| 4 | mu0 | 1.25664e-006 | 1.25664e-006 |
| 5 | c0 | 2.99792e+008 | 2.99792e+008 |
| 6 | fc | 1e+009 | 1e+009 |
| 7 | bw | 1e+009 | 1e+009 |
| 8 | to_meters | 1000 | 1000 |
| 9 | lambda0 | c0/fc | 0.299792 |
| 10 | k0 | (2.0*pi)/lambda0 | 20.9585 |
| 11 | lambda0_unit | lambda0*to_meters | 299.792 |
| 12 | er | 2.2 | 2.2 |
| 13 | h | 0.0015*to_meters | 1.5 |
| 14 | strip_wid | 4.62893 | 4.62893 |
| 15 | box_multiplier | 10 | 10 |
| 16 | sub_size | box_multiplier*strip_wid | 46.2893 |

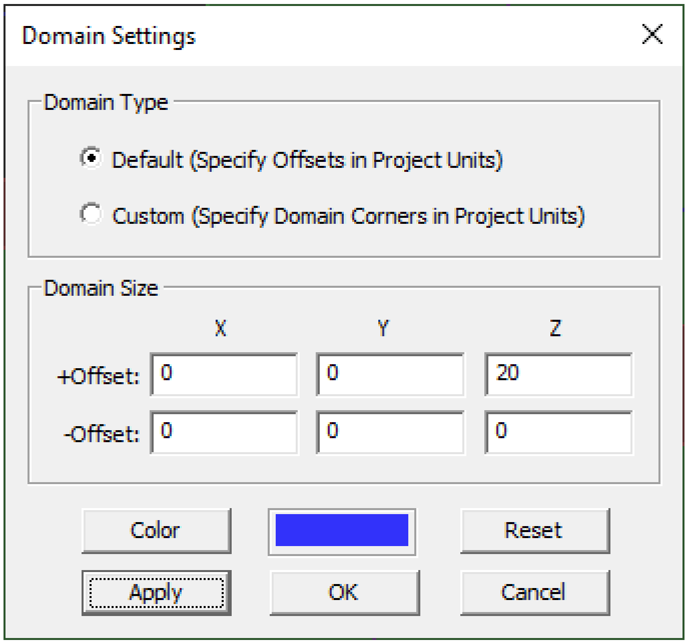
***Figure 3.*** *The Variables dialog showing the parameters of the microstrip line.*

Note that since EM.Ferma uses the finite difference method for quasi-static analysis of 2D transmission lines, it requires a substrate of finite size. For this reason, the wizard has set the widths of the substrate and ground equal to 10 times the width of the microstrip.

## 7.5 Examining the Computational Domain & the 2D Solution Plane

So far in all the previous tutorial lessons, you dealt with 3D domain boxes and performed 3D electrostatic or 3D magnetostatic simulations of 3D physical structures. EM.Ferma also lets you perform 2D electrostatic analysis of 2D structures. By a 2D structure we mean a geometry that is invariant along one of the three principal axes and has an infinite extent along that direction. The cross section of a 2D structure is identical at any point along the so-called invariance axis. Therefore, you can build a 3D transmission line geometry just like other structures you built earlier and then specify a "2D Solution Plane" that would capture the cross section of your transmission line geometry and would pass its mesh to the simulation engine. In EM.Ferma, 2D solution planes are defined based on existing field sensor observables. Since in EM.Ferma, a field sensor plane extends across the entire computational domain, it can also serve to capture the cross section of your transmission line geometry.

Open the Domain Settings dialog. You will see that the wizard has set the domain offset values in the ±X and ±Y directions equal to zero. The -Z-offset is zero, too (see Figure 4).



Domain Type

● Default (Specify Offsets in Project Units)

○ Custom (Specify Domain Corners in Project Units)

Domain Size

| | X | Y | Z |
|---|---|---|---|
| +Offset: | 0 | 0 | 20 |
| -Offset: | 0 | 0 | 0 |

| Offset | Value |
|---|---|
| -X | 0 |
| +X | 0 |
| -Y | 0 |
| +Y | 0 |
| -Z | 0 |
| +Z | 20mm |

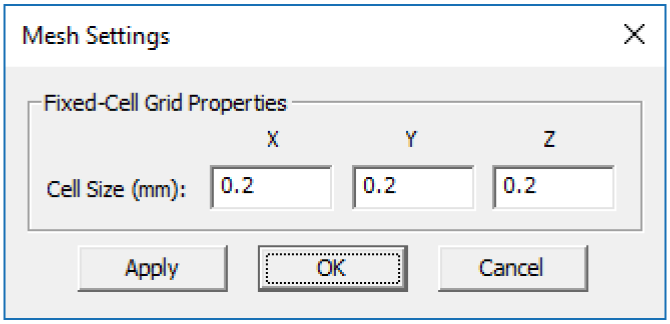
***Figure 4.*** *EM.Ferma's Domain Settings dialog.*

Remember that all the six walls of the domain box are held at zero potential by default (due to the Dirichlet boundary condition). This means that all six walls are assumed to be fix-potential PEC surface with a fixed zero voltage. You may pick a nonzero value for the -Z-offset parameter, but this will create a redundant air region between the object "Ground" and the bottom domain wall, both of which have zero voltages.

## 7.6 Running a Quasi-Static Simulation of the Microstrip Line

The wizard defines a vertical X-directed field sensor observable called "FS1", which is centered at (0, 0, 0).

Open the mesh settings dialog. You will find that the wizard has set the mesh cell size to a very fine value of $\Delta x = \Delta y = \Delta z = 0.2$mm (Figure 5). Since the width of your microstrip is about 4.6mm, this will place 23 cells across the width of the transmission line. To get accurate results, you typically need to set a very high resolution mesh for 2D transmission line structures.

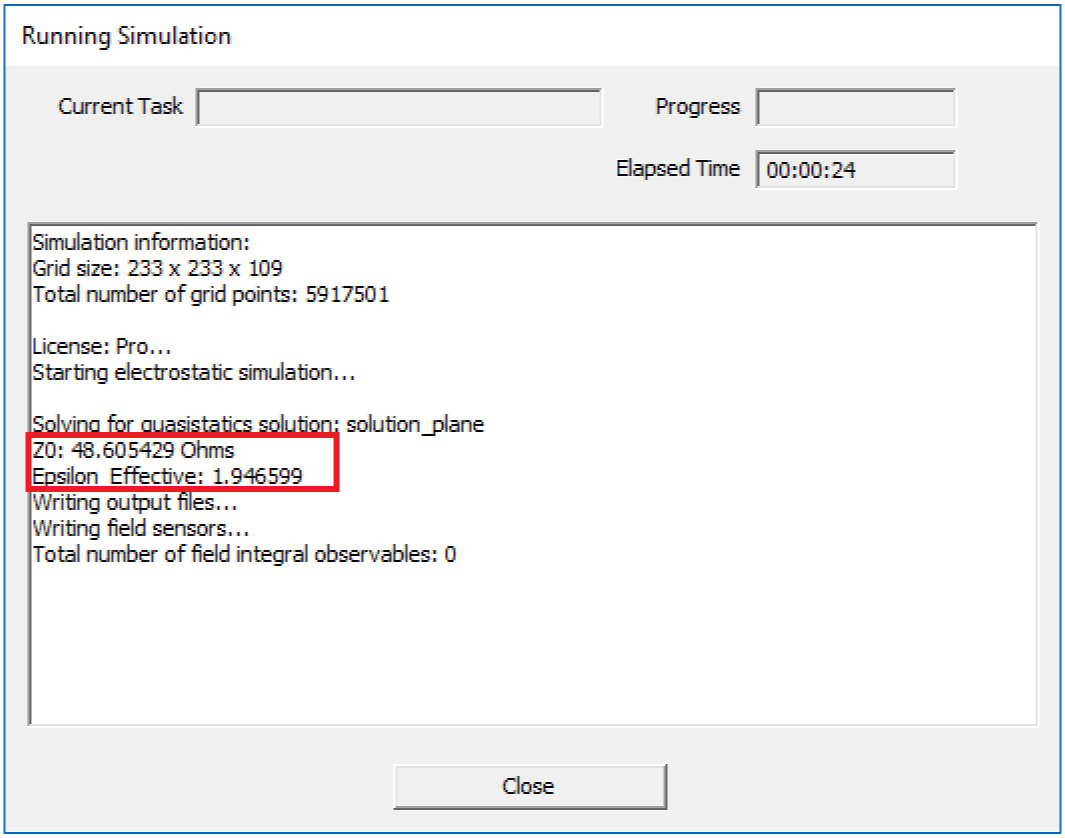


Cell Size (mm): X 0.2, Y 0.2, Z 0.2

***Figure 5.*** *High resolution fixed-cell mesh settings.*

Run a quasi-static "Analysis" of your 2D structure. At the end of the simulation, the output message window reports the computed values of the characteristic impedance and effective permittivity of the transmission line as shown in Figure 6:

**Z0: 48.605429 Ohms**
**Epsilon_Effective: 1.946599**



Elapsed Time: 00:00:24

```
Simulation information:
Grid size: 233 x 233 x 109
Total number of grid points: 5917501

License: Pro...
Starting electrostatic simulation...

Solving for quasistatics solution: solution_plane
Z0: 48.605429 Ohms
Epsilon_Effective: 1.946599
Writing output files...
Writing field sensors...
Total number of field integral observables: 0
```

***Figure 6.*** *The computed values of the characteristic impedance and effective permittivity of the transmission line in the output message window.*

Visualize the electric field and potential distribution on the “FS1” plane (see Figure 7 and 8). From the vector plot, you can clearly see the field confinement inside the dielectric substrate underneath the micrsotrip as well as the fringing fields at the edges of the metal strip.

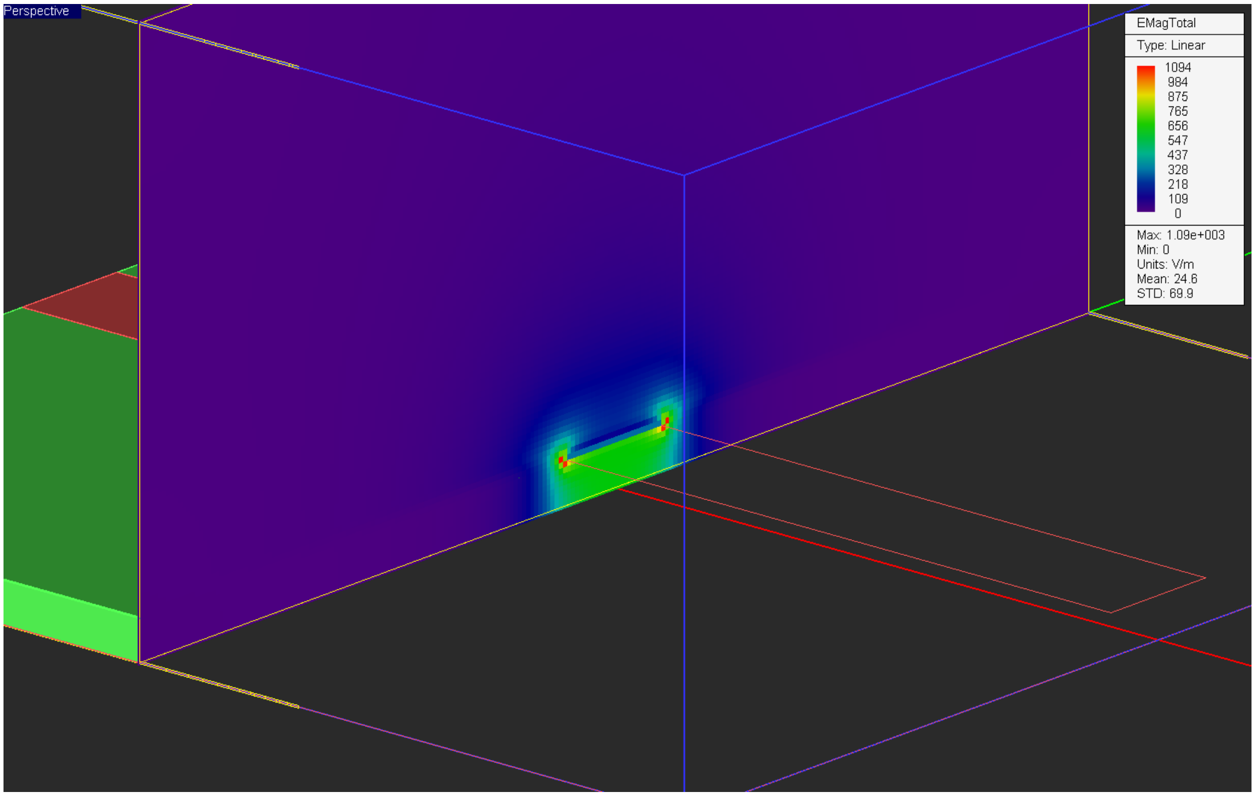


***Figure 7.*** *The intensity plot of the total electric field distribution in the YZ plane.*

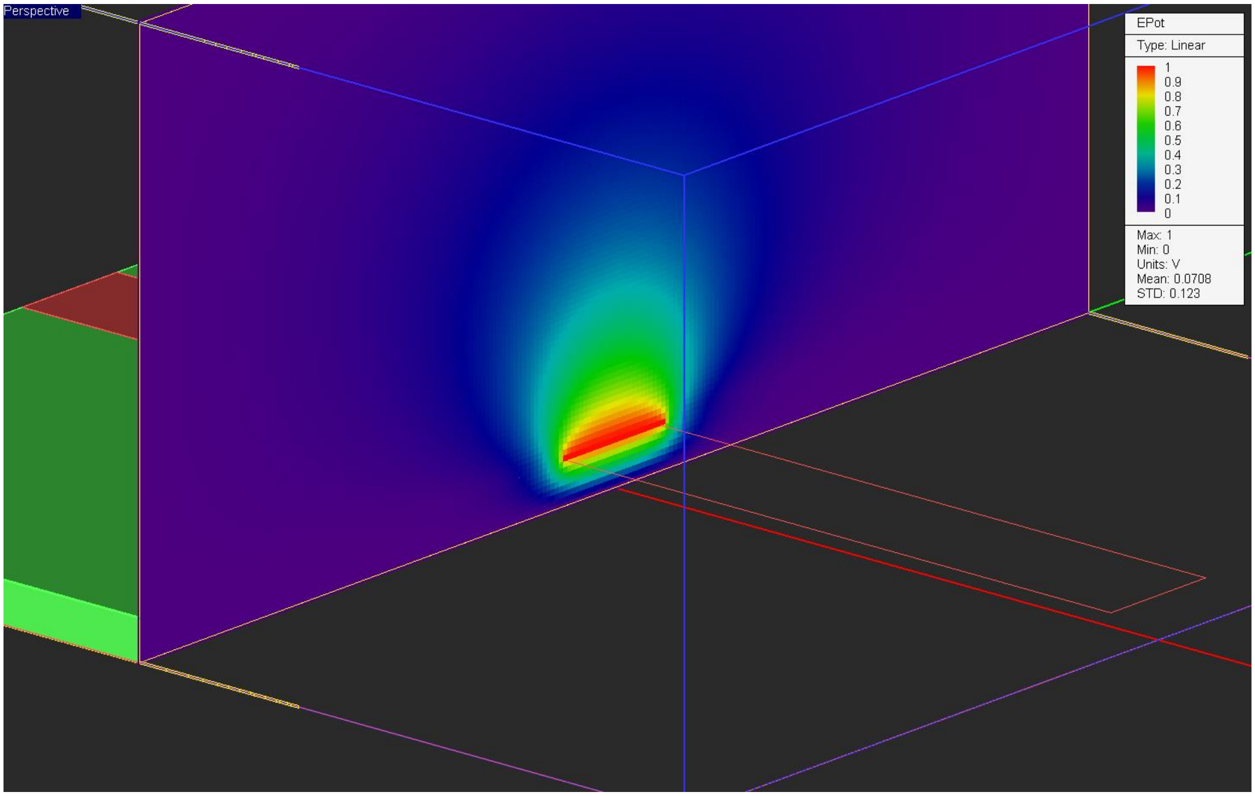


***Figure 8.*** *The intensity plot of the electric potential distribution in the YZ plane.*

It is worth visualizing the vector plot of the total electric field distribution in the YZ plane. To get a better view of the position of the field distribution, click the **Right View** button of the **View Toolbar**.

Then, open the property dialog of the field sensor "FS1". In the Field Sensor dialog, change the **Plot Type** to **Vector** and set the values of **Max Size**, **Cone Length Ratio,** and **Cone Radius Ratio** all to 2, 0.5, and 0.25, respectively, according to the table below:

| Field Sensor | Direction | Coordinates | Plot Type | Max. Size | Cone Length Ratio | Cone Radius Ratio |
|---|---|---|---|---|---|---|
| FS1 | X | (0, 0, 0) | Vector | 2 | 0.5 | 0.25 |

Figure 9 shows the vector plot of the total electric field distribution in the YZ plane.

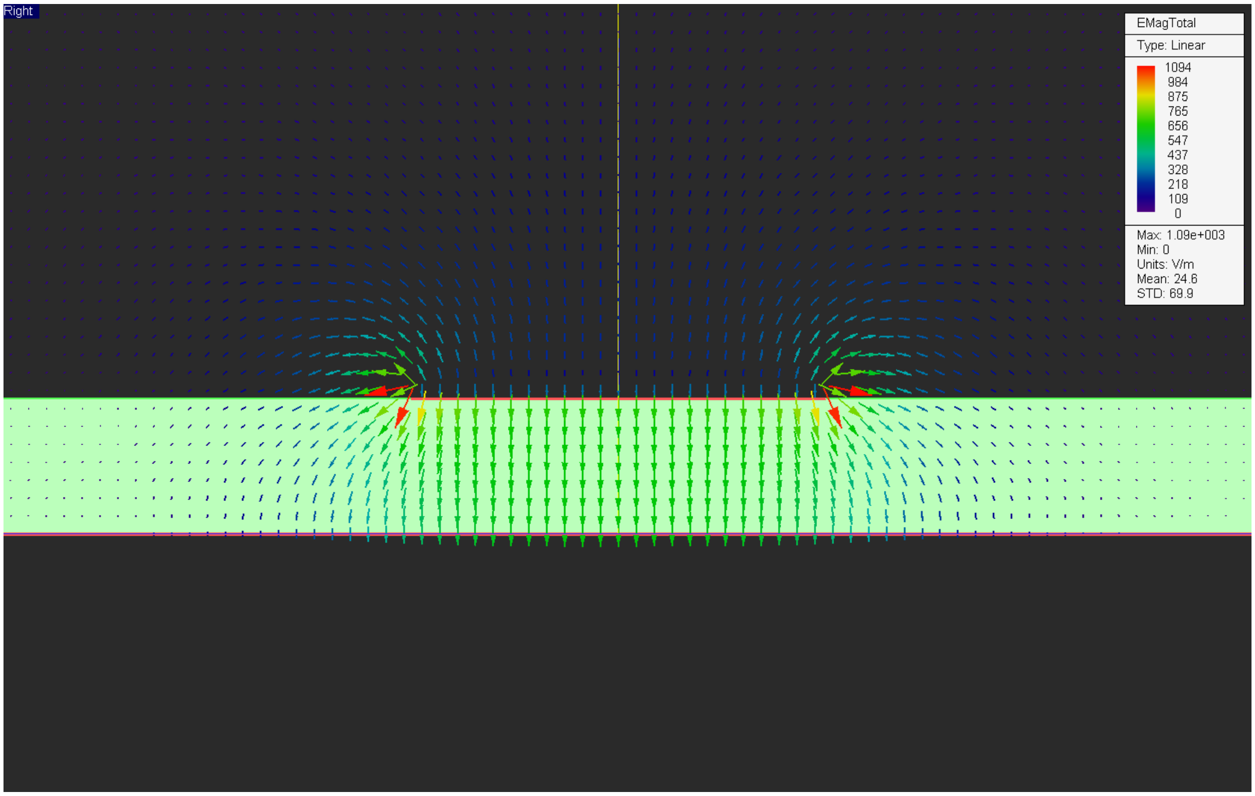


***Figure 9.*** *The vector plot of the total electric field distribution in the YZ plane.*

## 7.7 Verifying Your Simulation Results

To verify the computed results for the characteristic impedance $Z_0$ and $\varepsilon_{eff}$, let's take a look at the analytical formulas available for the characteristic impedance and effective permittivity of a microstrip line:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r + 1}{2}\left(1 + 12\frac{h}{w}\right)^{-\frac{1}{2}}$$

$$Z_0 = \frac{120}{\pi\sqrt{\varepsilon_{eff}}}\left[\frac{w}{h} + 1.393 + 0.677\ln\left(\frac{w}{h} + 1.444\right)\right]^{-1}$$

where $w$ and $h$ are the microstrip width and substrate thickness, respectively, and $\varepsilon_r$ is the relative permittivity of the dielectric. The above formulas are valid for the case of $w/h \geq 1$. For your microstrip line defined in this project, you have $w = 4.7$mm, $h = 1.5$mm and $\varepsilon_r = 2.2$. For these values, the above formulas give: $Z_0 = 49.54\Omega$ and $\varepsilon_{eff} = 1.87$, which are not far from the simulated results.

You can verify these results using the CPW Transmission Line Calculator tool in the Device Manager of RF.Spice A/D. RF.Spice A/D is a powerful visual simulation environment for analysis and design of analog, digital, RF and mixed-signal circuits and systems. The line calculators take the substrate properties and the physical dimensions of a line types and calculate its characteristic impedance $(Z_0)$ and effective permittivity $(\varepsilon_{\text{eff}})$. The Line Calculator dialog also has an operational frequency input with a default frequency of 1GHz, which is used to calculate the guide wavelength of the transmission line at that frequency. In that case, you must first calculate the guide wavelength of the transmission line as defined by $\lambda_g = \lambda_0/\sqrt{\varepsilon_{\text{eff}}}$, where $\lambda_0 = c/f_c$ is the free space wavelength at the operational frequency.

To access the Transmission Line Calculator, select the menu item **Tools** → **RF.Spice A/D Device Manager** (Figure 10) or use the keyboard shortcut **Ctrl+Shift +V**.

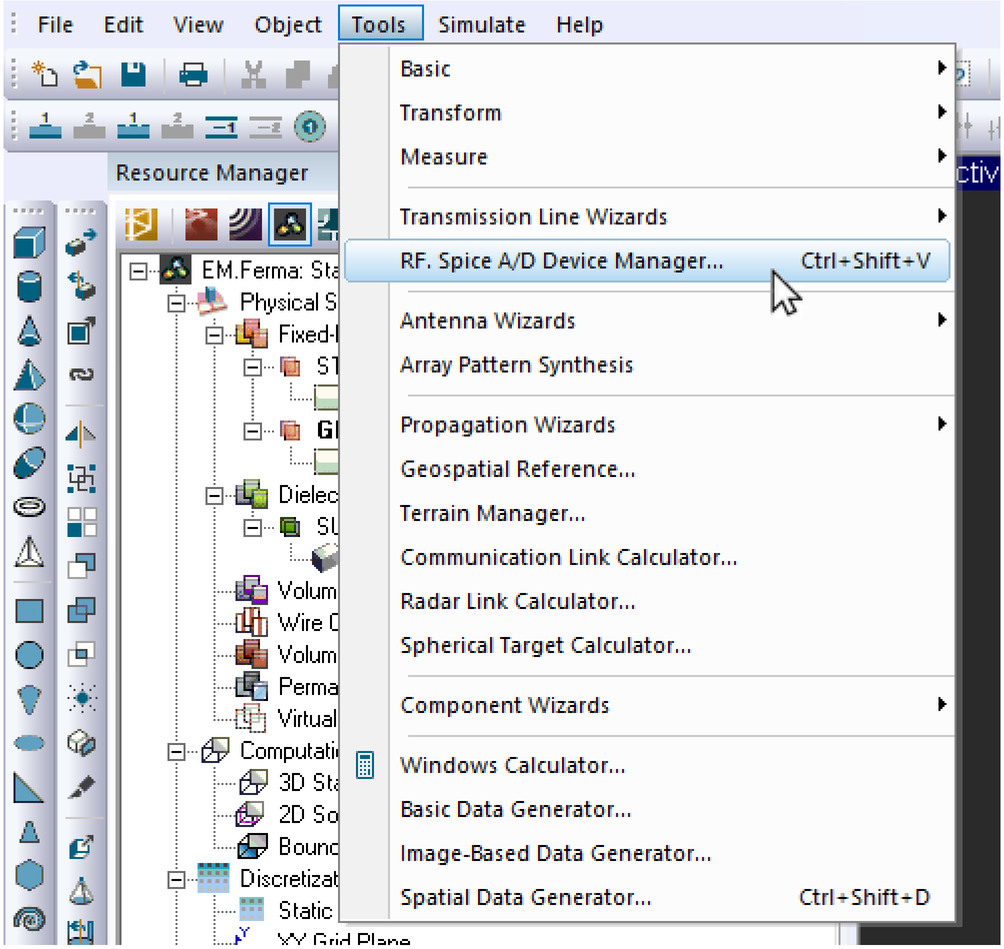


***Figure 10.*** *Accessing the RF.Spice A/D Device Manager in EM.Cube.*

The RF.Spice A/D Device Manager dialog opens up as indicated in Figure 2. Select the menu item **Tools** → **Transmission Line Calculators** → **Microstrip Line** in the RF.Spice A/D Device Manager dialog (see Figure 11).

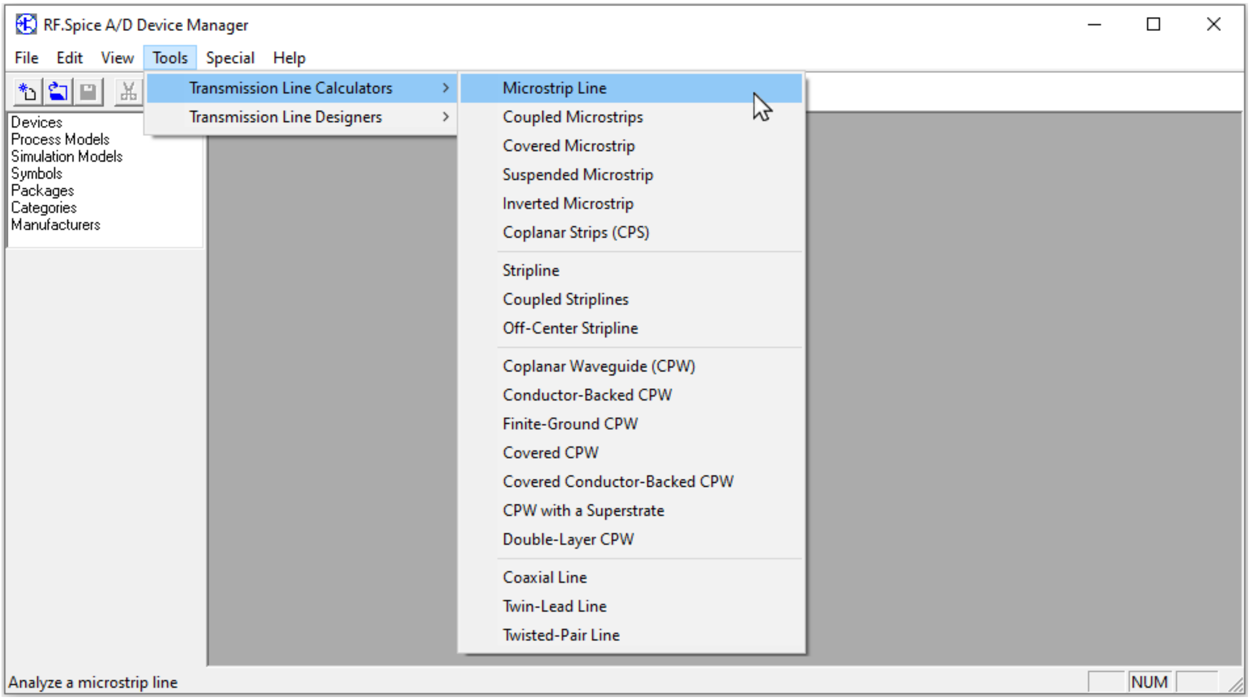
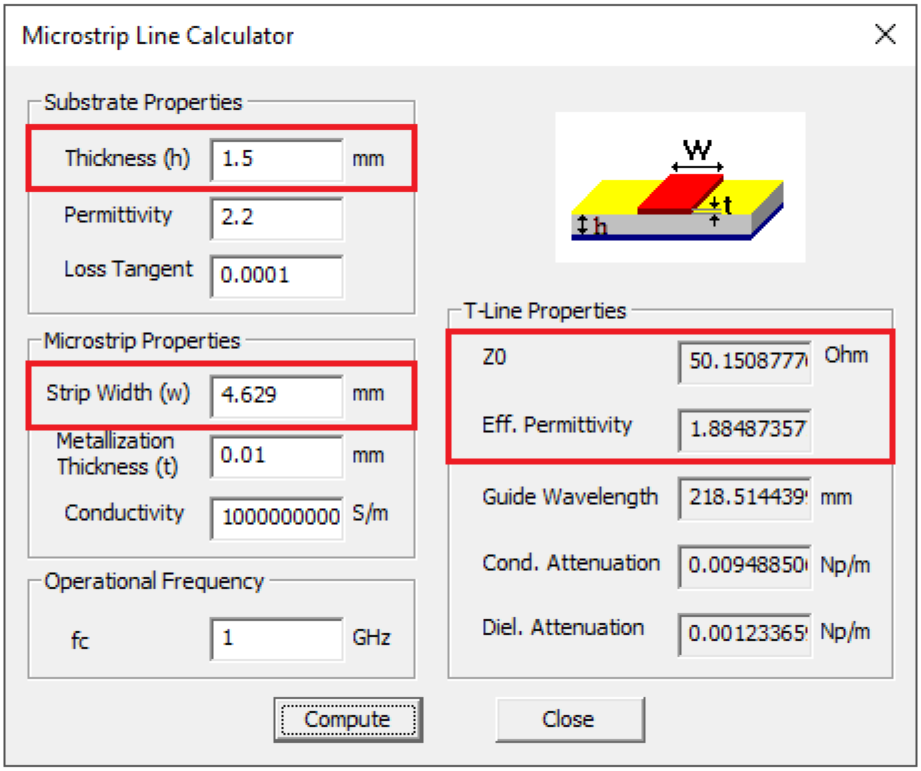


***Figure 11.*** *The RF.Spice A/D Data Manager.*

In the Microstrip Line Calculator dialog, keep the default **Operational Frequency** (fc) at 1GHz and change the value of **Thickness (h)** to 1.5mm. Also, set the value of **Strip Width (w)** to 4.629mm in the **Microstrip Properties** section of the dialog and click the **Compute** button. You will see that **Z0** and **Eff. Permittivity** ($\varepsilon_{\text{eff}}$) are calculated to be 50.17 and 1.885, respectively (see Figure 12).



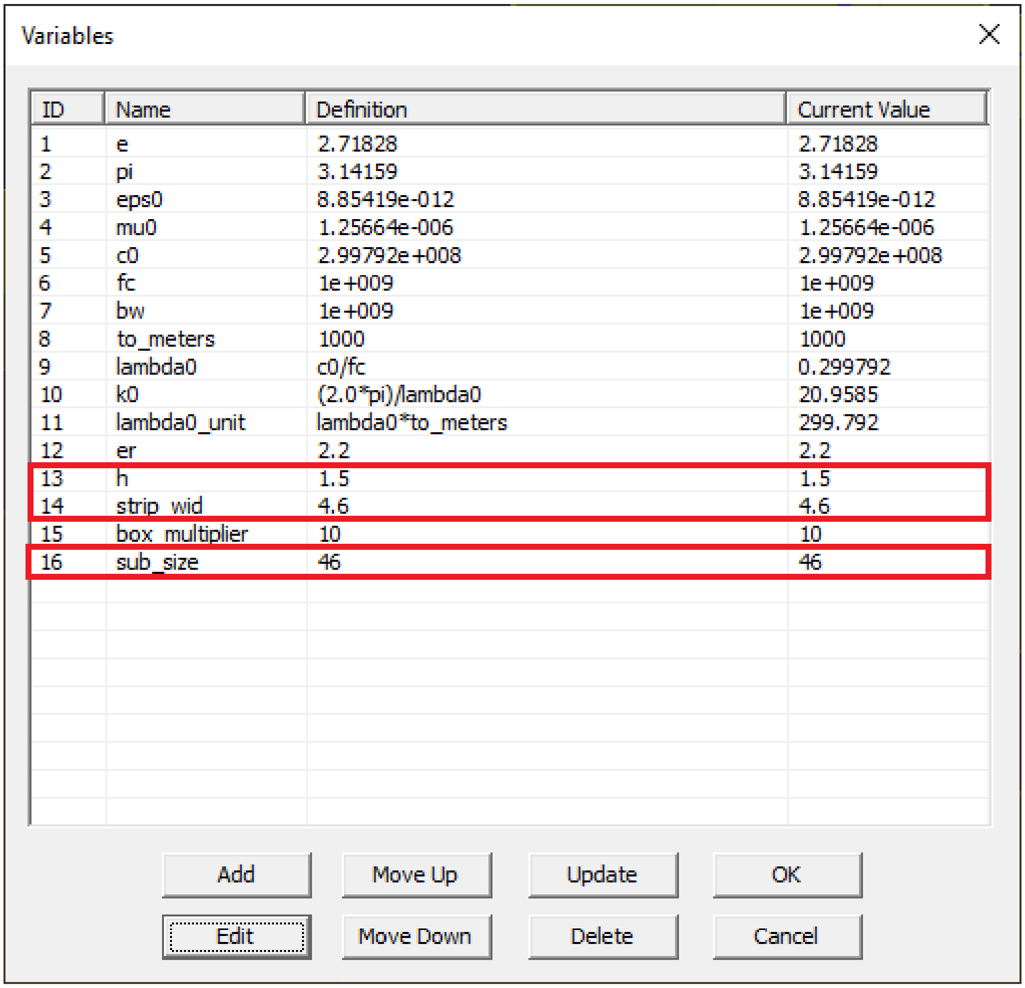
Thickness (h) 1.5 mm
Permittivity 2.2
Loss Tangent 0.0001
Strip Width (w) 4.629 mm
Metallization Thickness (t) 0.01 mm
Conductivity 1000000000 S/m
fc 1 GHz
Z0 50.1508777 Ohm
Eff. Permittivity 1.88487357
Guide Wavelength 218.514439 mm
Cond. Attenuation 0.00948850 Np/m
Diel. Attenuation 0.00123365 Np/m

***Figure 12.*** *The microstrip line calculator of RF.Spice A/D.*

## 7.8 Running a Parametric Sweep of the Microstrip Width

You saw earlier that the variable "sub_size" was defined as a function of the variable "strip_wid". This means that "sub_size" is a dependent variable, while "strip_wid" is an independent variable. You can easily change the definition of any variable and turn it into an independent or dependent variable. Open the Variables dialog and change the values of two variables "h" and "strip_wid" according to the table below (see Figure 13):

| Variable Name | Original Definition | New Definition |
|---|---|---|
| h | 0.0015*to_meters | 1.5 |
| strip_wid | 4.62893 | 4.6 |

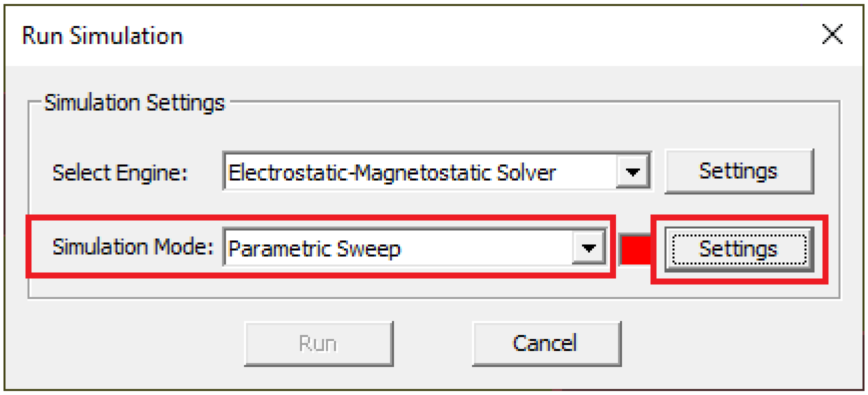


| ID | Name | Definition | Current Value |
|---|---|---|---|
| 1 | e | 2.71828 | 2.71828 |
| 2 | pi | 3.14159 | 3.14159 |
| 3 | eps0 | 8.85419e-012 | 8.85419e-012 |
| 4 | mu0 | 1.25664e-006 | 1.25664e-006 |
| 5 | c0 | 2.99792e+008 | 2.99792e+008 |
| 6 | fc | 1e+009 | 1e+009 |
| 7 | bw | 1e+009 | 1e+009 |
| 8 | to_meters | 1000 | 1000 |
| 9 | lambda0 | c0/fc | 0.299792 |
| 10 | k0 | (2.0*pi)/lambda0 | 20.9585 |
| 11 | lambda0_unit | lambda0*to_meters | 299.792 |
| 12 | er | 2.2 | 2.2 |
| 13 | h | 1.5 | 1.5 |
| 14 | strip wid | 4.6 | 4.6 |
| 15 | box multiplier | 10 | 10 |
| 16 | sub_size | 46 | 46 |

**Figure 13.** *The Variables dialog showing the modified definition of some variables.*

In this part of this tutorial lesson, you will vary the microstrip width and see how it affects the characteristic impedance and effective permittivity of your transmission line. In a sweep simulation, one or more parameters are varied, and the simulation engine is run for each parameter set. Open the Run Simulation dialog and choose the **Parametric Sweep** option from the **Simulation Mode** drop-down list (see Figure 14). Click on the **Settings** button next to this drop-down list to open the Parametric Sweep Settings dialog.

You will notice a red box next to the drop-down list. This means that you are not ready to run a simulation because some parameters haven't been set yet.



Run Simulation

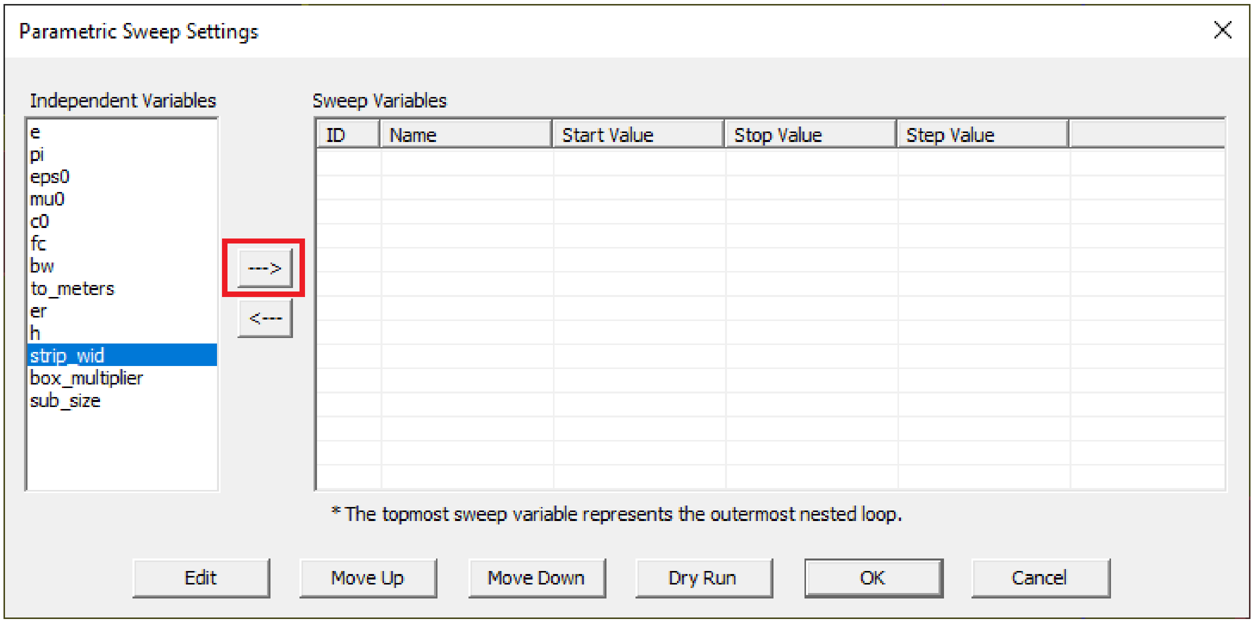
Simulation Settings

Select Engine: Electrostatic-Magnetostatic Solver

Simulation Mode: Parametric Sweep

***Figure 14***. *Selecting parametric sweep as the simulation mode in EM.Ferma's run dialog.*

The sweep variables list is initially empty (Figure 15).



Parametric Sweep Settings

Independent Variables

- e
- pi
- eps0
- mu0
- c0
- fc
- bw
- to_meters
- er
- h
- strip_wid
- box_multiplier
- sub_size

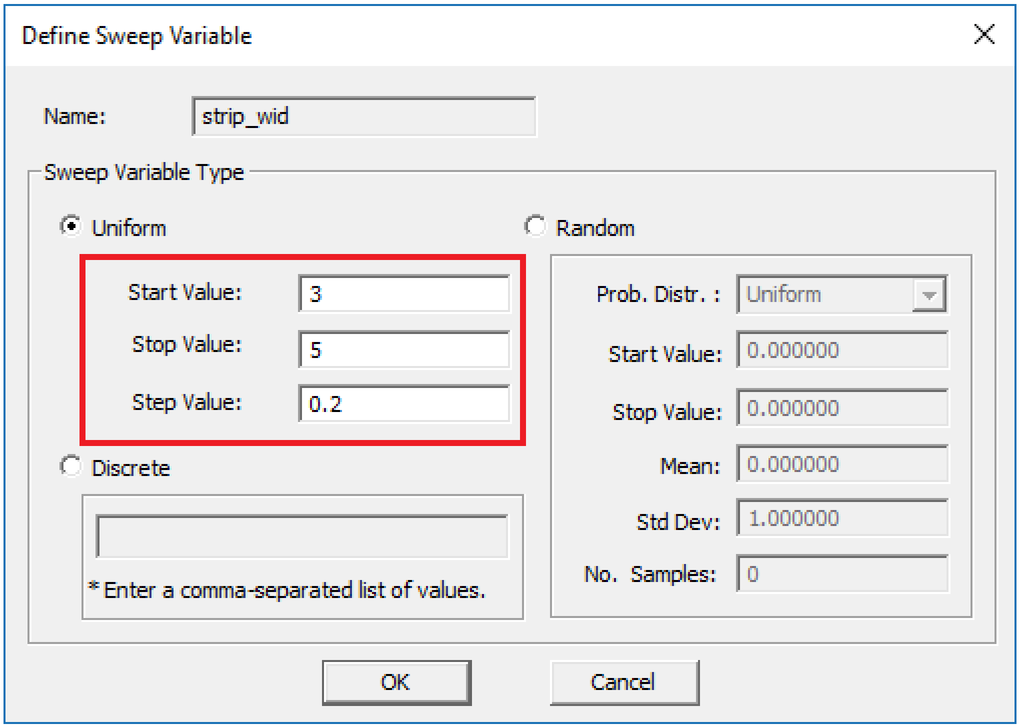
Sweep Variables

| ID | Name | Start Value | Stop Value | Step Value |
|---|---|---|---|---|

* The topmost sweep variable represents the outermost nested loop.

***Figure 15.*** *The parametric sweep settings dialog.*

On the left side of this dialog, you see a list of all the available independent variables. Select "strip_wid" from the left table and use the right arrow ---> button to move it to the right table. Another dialog titled Define Sweep Variable opens up (Figure 16). You have to set the start, stop and step values of your sweep variable. By default, the sweep variable is of uniform type. Enter 3, 5, and 0.2 for the start, stop and step values, respectively. This will create a value list of {3.0, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.4, 4.6, 4.8, 5.0}. Close the sweep variable dialog (Figure 17) and then close the sweep settings dialog to return to the simulation run dialog.



Name: strip_wid

● Uniform

Start Value: 3

Stop Value: 5

Step Value: 0.2

○ Discrete

* Enter a comma-separated list of values.

○ Random

Prob. Distr. : Uniform

Start Value: 0.000000

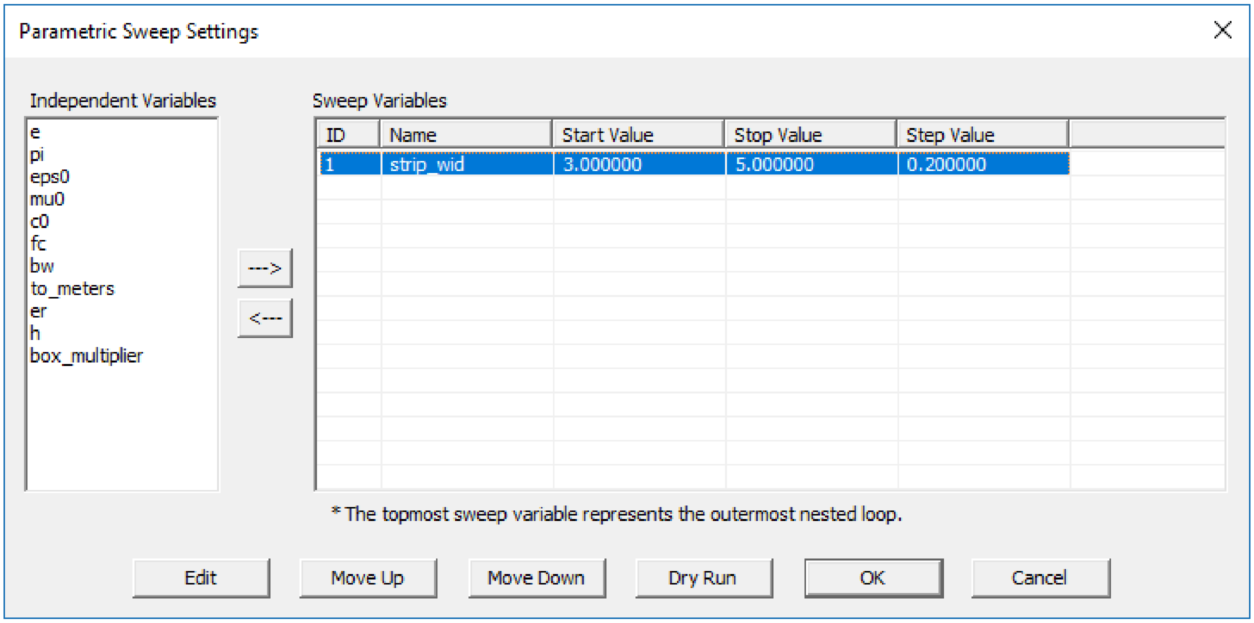
Stop Value: 0.000000

Mean: 0.000000

Std Dev: 1.000000

No. Samples: 0

***Figure 16.*** *The Sweep Variable Settings dialog.*



Independent Variables

e
pi
eps0
mu0
c0
fc
bw
to_meters
er
h
box_multiplier

Sweep Variables

| ID | Name | Start Value | Stop Value | Step Value |
|---|---|---|---|---|
| 1 | strip_wid | 3.000000 | 5.000000 | 0.200000 |

* The topmost sweep variable represents the outermost nested loop.

***Figure 17.*** *The Parametric Sweep Settings dialog showing "strip_wid" as the sweep variable.*

Run the sweep simulation. It may take a while as a total of eleven individual 2D electrostatic simulations must be completed. At the end of the parametric sweep, open the Data Manager and plot the data files "solution_plane_Z0_Sweep.DAT" and " solution_plane_EpsEff_Sweep.DAT". They show the variation of characteristic impedance and effective permittivity as a function of microstrip width. You should see graphs like Figures 18 and 19.

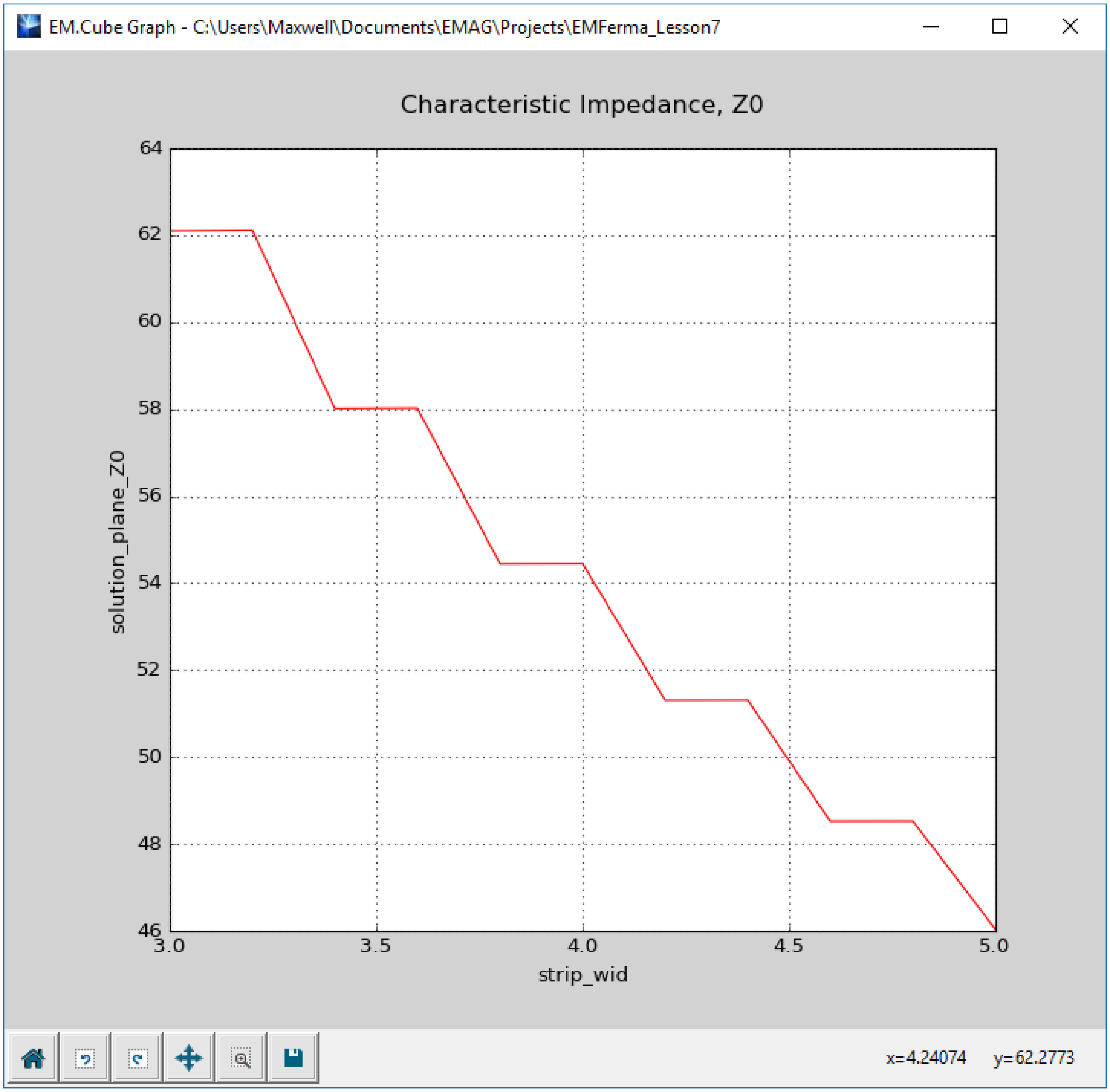


***Figure 18.*** *The graph of variation of characteristic impedance as a function of microstrip width.*

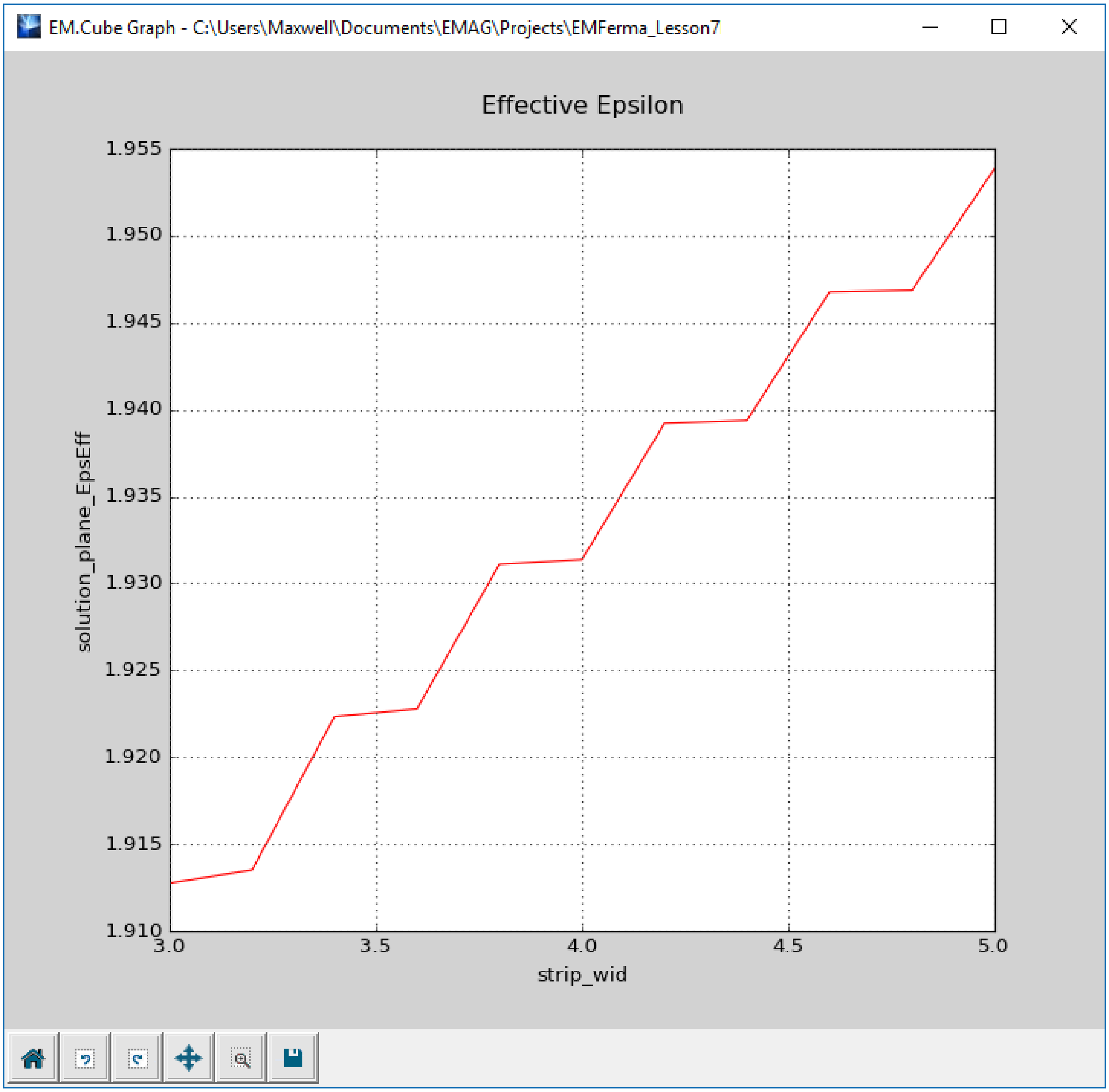


***Figure 19.*** *The graph of variation of effective permittivity as a function of microstrip width.*