Computing Impedance in Multilayer PC Boards

Daniel G. Swanson, Jr.
R&D Manager

Bartley RF Systems
37 South Hunt Road
Amesbury, MA 01913

d.swanson@ieee.org

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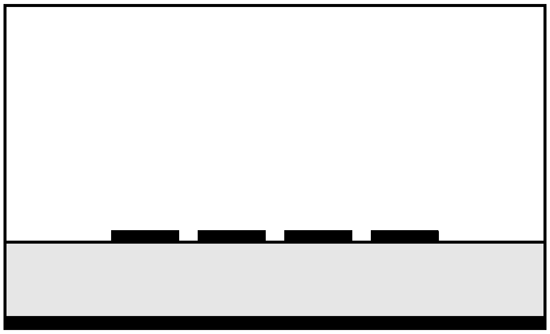
Introduction

Microwave circuit simulators have models for all the traditional transmission line cross-sections such as microstrip, stripline and coplanar-waveguide. But in multilayer PC boards we have the freedom to design transmission lines that may not fit any of the conventional definitions. We may need microstrip or CPW with a dielectric overlay. Or, we may have a buried stripline conductor with grounded isolation strips in close proximity and upper / lower ground planes that are not symmetrically located. This configuration is some kind of stripline / CPW hybrid depending on the strip widths and the various ground plane spacings. For any strip configuration, the effects of strip thickness and trapezoidal cross-sections due to etching are also of interest. Fortunately, there are some inexpensive shareware tools that will allow us to compute the impedance and effective dielectric constant of arbitrary transmission line cross-sections. For good engineering results, our goal is 1% to 5% accuracy. These tools also give us the freedom to ask many interesting “what if” questions regarding the configuration we have chosen.

Notes:

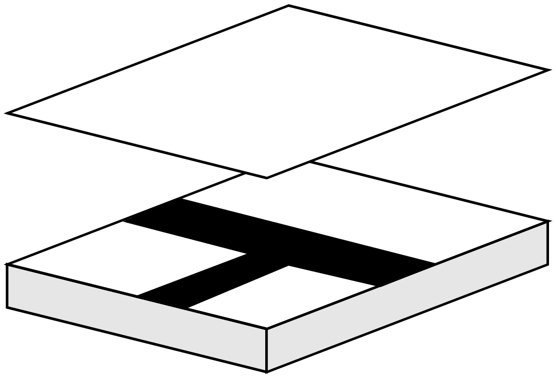
Types of Field-Solvers

There are three broad classes of electromagnetic field-solvers. We characterize each class by the order of the geometry they can analyze. Within each class any number of different numerical methods may be used. The numerical effort required increases dramatically as the geometry gets more complex. In general you want to use the lowest order geometry possible to analyze your structure.



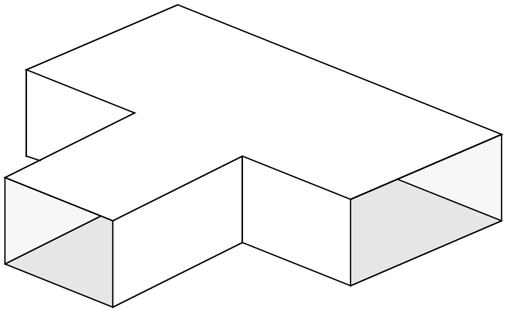
2D Cross-Section-Solvers

- Strips or slots with uniform cross-section
- Easy to compute impedance and phase velocity for single strip problems
- Two subclasses - closed and laterally open
- Discretize only the 2D cross-section



2.5D Planar-Solvers
(3D Mostly Planar)

- Arbitrary metal pattern in one or more planes
- Arbitrary number of homogeneous dielectric layers
- Vias between metal layers allowed
- Two subclasses - closed box and laterally open
- Discretize only the metal in each plane



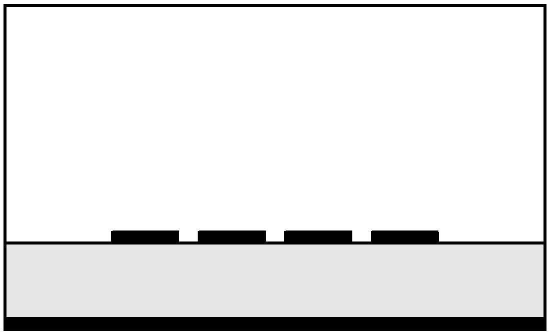
3D Solvers

- Arbitrary geometry
- Closed box with absorbing boundaries allowed
- Must discretize the entire volume

Notes:

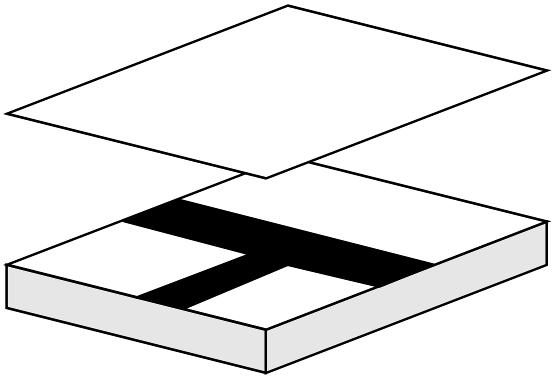
Types of Field-Solvers (cont.)

If we put some names of software packages in each category you may spot a tool you have used. Most of these tools are quite expensive commercial packages. Some of the 2D cross-section-solvers have shareware or student versions that limit the size of problem you can solve but are still quite useful.



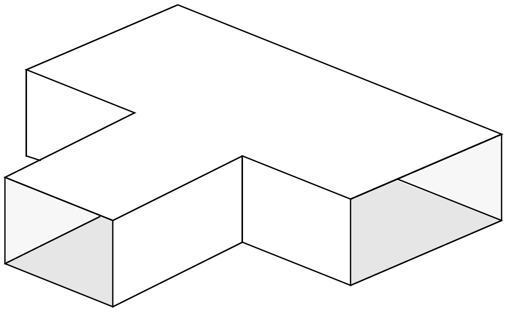
2D Cross-Section-Solvers

- *FlexPDE* - PDE Solutions
- *PDEase2D* - Macsyma
- *QuickField* - Tera Analysis
- *Maxwell Spicelink* - Ansoft
- *LINPAR / MULTLIN* - Artech House



2.5D Planar-Solvers
(3D Mostly Planar)

- *em* - Sonnet Software
- *Momentum* - HP EEsof
- *IE3D* - Zeland Software
- *Ensemble* - Ansoft
- *Strata* - Ansoft



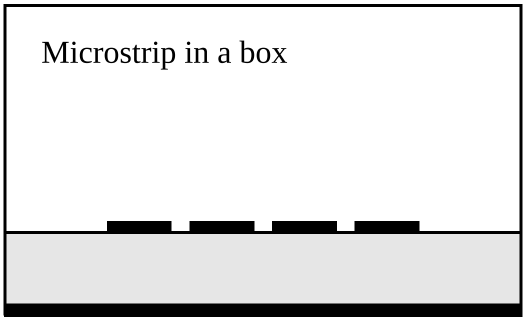
3D Solvers

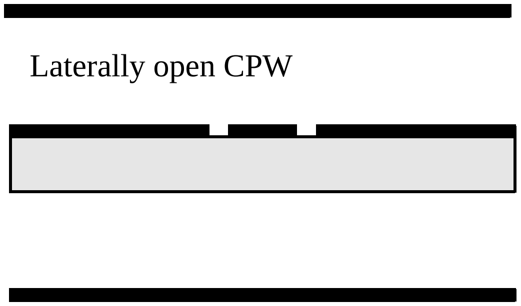
- *HFSS* - Ansoft
- *HFSS* - HP EEsof
- *Micro-Stripes* - KCC Ltd.
- *XFDTD* - REMCOM, Inc.
- *QuickWave-3D* - QWED

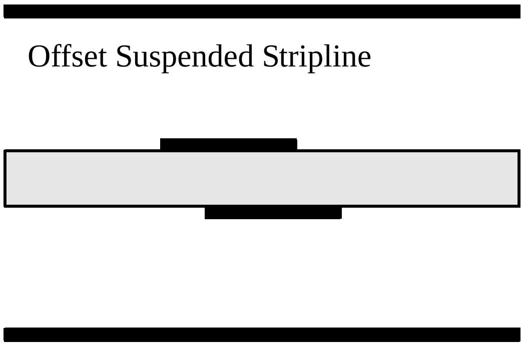
Notes:

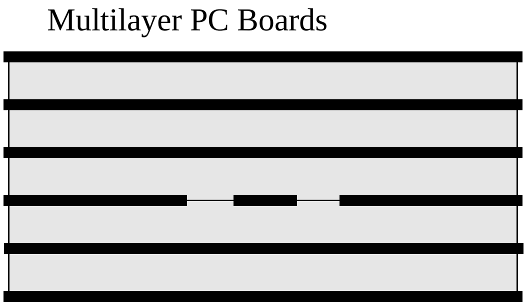
2D Cross-Section-Solvers

This class of field-solver computes the parameters of strips or slots with uniform cross-section. Sets of uniform cross-section lines can be found in Lange couplers, spiral inductors, interdigital capacitors, and many distributed filters. We can also use this tool to compute the impedance and phase velocity of transmission lines with unusual cross-sections. Some example cross-sections are shown below.









- Strips or slots with uniform cross-section
- Discretize only the 2D cross-section - minimum numerical effort
- Solve for current on strips or voltage across slots
- Two subclasses - fully enclosed or laterally open
- Many numerical methods: MoM, FEM, FD, MoL, etc.
- Single strip problems - easy to compute impedance and phase velocity
- Multistrip cases - must deal with N modes
- Key for Lange couplers and many distributed filters
- Buried transmission lines in multilayer PC boards

Notes:

2D Cross-Section-Solvers (cont.)

Let’s begin our review of 2D cross-section software. We can get access to this software in three ways. Some tools are stand alone, some are integrated into a linear or non-linear simulator, and some 2.5D and 3D tools will give you the impedance and phase velocity of a single strip at a port.

1. Stand alone tools
    - *FlexPDE* - PDE Solutions
    - *PDEase2D* - Macsyma
    - *QuickField* - Tera Analysis
    - *Maxwell Spicelink* - Ansoft
    - *LINPAR and MULTLIN* - Artech House Publishers
    - Numerous electrostatic and magnetostatic codes
2. Integrated with linear / non-linear simulator
    - MCPL Model - *Super-Compact*
    - VUSTLS and VSYTSL Model - *LINMIC+*
    - PCLIN Model - *Touchstone Series IV*
    - MSnCTL, SLnCTL, SSnCTL Models - *HP MDS*
3. Subset of 2.5D / 3D tool
    - Some will give you impedance and phase velocity of a single strip at a port.
    - May not get all the information you need for multiple strips.

Notes:

Stand Alone 2D Solvers

For the case of single or coupled strips/slots, a simple stand alone tool can often compute the impedance and phase velocity information that you need. Multistrip problems are more difficult and we will discuss a better approach for those later.

QuickField - Tera Analysis

Numerical Method: FEM
Platforms: MS-DOS, Windows NT 4.0
Features: Handles arbitrary cross-sections and rotationaly symmetric problems.
Also handles magnetostatics, currents, thermal, and stress.
Various solution types can be linked, i.e. thermal with stress.
Comments: Inexpensive shareware program or professional version.
“Windows” like interface in older DOS versions
Manual meshing, no automatic refinement.

FlexPDE - PDE Solutions

Numerical Method: FEM
Platforms: Windows 95 or NT 4.0
Features: Handles arbitrary cross-sections.
Automatic mesh refinement.
2D and 3D geometries.
Comments: Shareware and professional versions available.
Text file input.
Flexible options for graphics.

Notes:

Stand Alone 2D Solvers (cont.)

PDEase2D - Macysma

Numerical Method: FEM

Platforms: Windows 95 or NT 4.0

Features: Handles arbitrary cross-sections.

Automatic mesh refinement.

Comments: A very sophisticated program for the price.

Must write a text file for input.

Many options for graphing and plotting.

Author of the *PDEase2D* module now marketing *FlexPDE*.

LINPAR and MULTLIN - Artech House Publishers

Numerical Method: MoM

Platforms: Windows

Features: Handles a large number of multiconductor transmission line cross-sections.

Microstrip, stripline, coplanar waveguide, coupled rectangular bars, multilayer planar structures and user-defined structures can be analyzed.

LINPAR computes [**L**], [**C**], [**R**] and [**G**] matrices for multiconductor systems. It will also present impedance and scattering parameters for single and coupled lines.

MATPAR accepts [**L**], [**C**], [**R**] and [**G**] matrices and computes multiport S-parameter files or SPICE models.

C_NL2 from Artech has a multiple coupled line model that reads the output file from *LINPAR*.

Comments: Fairly intuitive Windows interface.

Relatively inexpensive.

Summary: If you search the literature you will find any number of electrostatic codes that you could use to compute transmission line parameters at low frequencies. Rather than produce an exhaustive (and exhausting!) list of codes, I have focused on the inexpensive, the accessible, and those few that easily generate parameters that an RF/microwave engineer will quickly recognize.

Notes:

Integrated 2D Field-Solvers

Probably the most useful tools for multistrip problems are 2D solvers that are integrated as models in linear and non-linear circuit simulators. We can solve multistrip cases using stand alone solvers, however the burden of transferring data makes this approach less attractive. The latest integrated 2D engines are also fast enough to be used inside an optimization loop.

MCPL Model - *Super-Compact* (Ansoft)

Numerical Method: Spectral Domain

Platforms: Windows, UNIX

Features: Handles up to 20 strips in microstrip or stripline.

Cover and sidewalls are included in the solution.

Up to four dielectric layers.

Option to speed-up solution by computing only one specified frequency out of the entire sweep.

Comments: Very useful for Lange couplers, edge-coupled filters, interdigital filters, spiral inductors, etc.

VUSTLS, VSTLS Models - *LINMIC+*

Numerical Method: Spectral Domain

Platforms: UNIX workstations and LINUX on PC

Features: Handles up to 20 strips (symmetrical case) in 6 dielectric layers.

Second metal layer can be included in some cases.

Cover and sidewalls are included in the solution.

Look up table approach requires brief pre-computation, but result is very fast analysis.

Comments: Very useful for Lange couplers, edge-coupled filters, interdigital filters, spiral inductors, etc.

LINMIC+ includes several other custom models built around this engine, including spiral inductors and spiral transformers.

Notes:

Integrated 2D Field-Solvers (cont.)

PCLIN Model - *Touchstone Series IV*

Numerical Method: Finite Difference
Platforms: UNIX
Features: Quasi-static solver for up to 10 strips in 7 layers.
Strips not restricted to a single layer.
Comments: Useful for RF and high-speed digital applications.
Use with caution at microwave frequencies.
Discontinuity models are for layout only, short circuit electrically.

MSnCTL, SLnCTL, SSnCTL Models - *HP MDS*

Numerical Method: Finite Difference?
Platforms: UNIX
Features: Quasi-static solver for up for 3 to 5 strips in a single plane.
Covers microstrip, stripline and suspended substrate
Comments: Useful for RF and high-speed digital applications.
Use with caution at microwave frequencies.
Discontinuity models are for layout only, short circuit electrically.

Summary: The *Super-Compact* and *LIMIC+* multistrip models have been used extensively to design distributed filters from a few GHz up to 40 GHz. The key feature is that they include the effects of the sidewalls and cover from first principles, not some tacked on correction factor. There are some second-order effects they cannot predict that have to do with the waveguide channel. The 2.5D and 3D solvers do predict these second order effects but they are too slow to use for optimization. I have had less experience with the *Touchstone* and *MDS* models.

Notes:

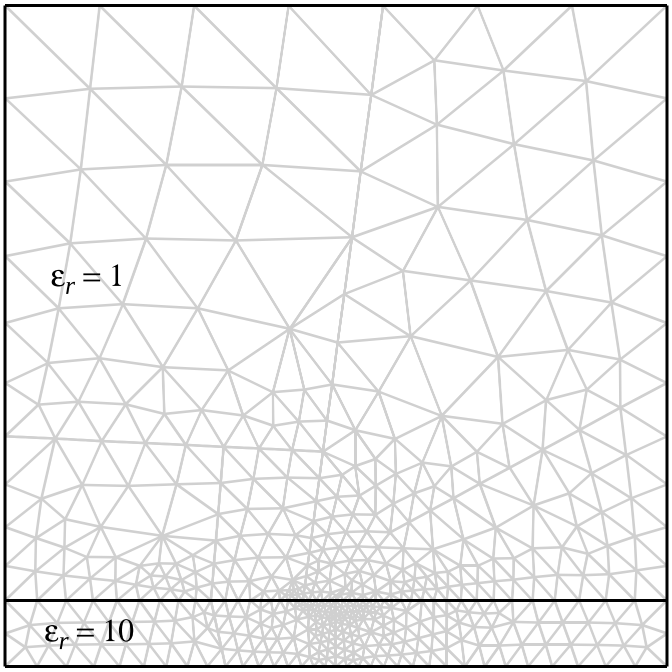
Computing Z_0 and ε_{eff}

For single strip problems it is easy to compute Z_o and ε_{eff} using a stand-alone 2D solver. Actually we need to do two calculations for cases with a dielectric substrates. The first computation is for C, the capacitance per unit length with all dielectrics present. The second computation is for C_0, the capacitance per unit length with all dielectric layers removed (set to $\varepsilon_r = 1$). For non-magnetic materials ($\mu_r = 1$) C_0 is equivalent to the inductance per unit length, $L = 1/(c^2 C_0)$.With the two values for capacitance per unit length in hand, Z_o and ε_{eff} are simply:

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

$$c = 2.98 \times 10^8 \text{ m / s}$$

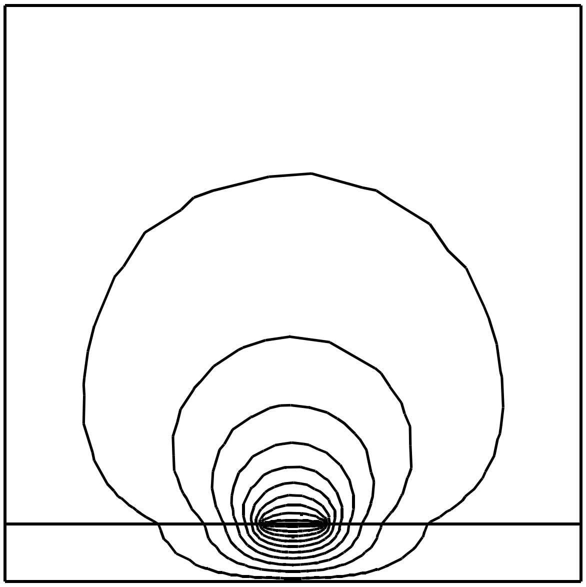
Using *QuickField* we can compute a simple microstrip example. The strip is one unit wide and is centered on a substrate that is one unit thick. We will assume that $\varepsilon_r = 10$. Below is the finite element mesh generated by *QuickField*. We gave “hints” to *QuickField* that gave us a finer mesh around the strip and a coarser mesh in the corners where we know the magnitude of the field is much lower.



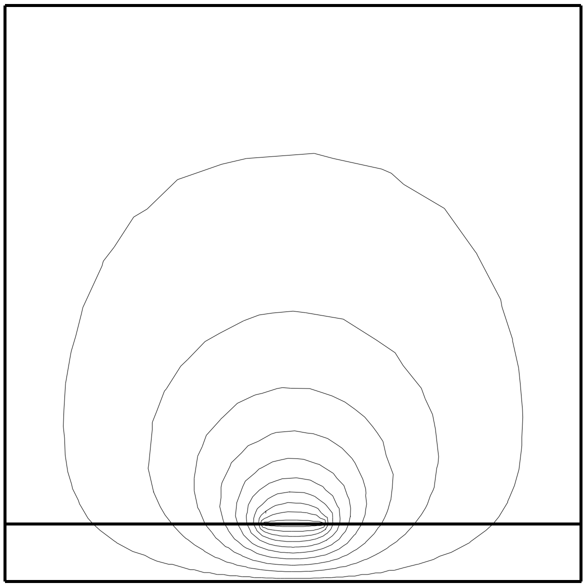
Notes:

Computing Z_0 and ε_{eff} (cont.)

Below are the results of the two analysis runs. The strip potential was set to 1 volt and the shield set to 0 volts. We have plotted lines of constant potential with an increment of 0.1 volt. To compute the capacitance we must integrate the charge along a closed path around the strip. *QuickField* will report the charge per unit length in Coulombs per meter. Because we have set the center strip to 1 V and $q = cv$, the charge per unit length converts directly to capacitance per unit length in Farads per meter.



$$C = 1.838 \times 10^{-10} \ \mathrm{F/m}$$



$$C_0 = 2.783 \times 10^{-11} \ \mathrm{F/m}$$

With the capacitance values in hand only need to do a quick calculation with a pocket calculator:

$$Z_0 = 46.9\ \Omega \qquad \varepsilon_{eff} = 6.6$$

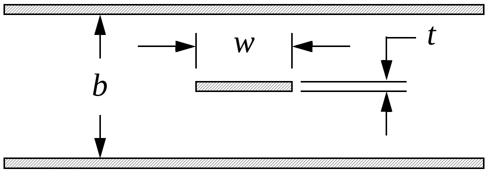
Summary: There are any number of tools that will compute this simple microstrip case. There are also analytical equations for microstrip that we can use to check our results. Later we will look at some unusual transmission line geometries that have no simple analytical solution.

Notes:

Computing Z_0 and ε_{eff} Using Symmetry

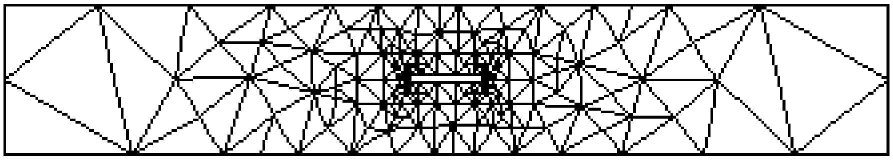
The shareware or student versions of the stand-alone 2D FEM cross-section solvers put a limit on the maximum number of available nodes. We can stretch the usefulness of these programs by applying symmetry to our problems. Symmetry may also save us time when we have a more complicated cross-section to draw. When we apply symmetry, we also have to apply a correction factor to our impedance calculations. Some vendors call this correction factor an "impedance multiplier." Below is a simple stripline example with an impedance of 50 ohms according to the analytical equations in *LineCalc*.

$Z_0 = 50.00$
(*LineCalc*)



$w = 12.5$
$b = 25.4$
$t = 1.4$
$\varepsilon_r = 3.25$

Using the demo version of *FlexPDE*, we can model the complete structure. The outer conductor is set to 0 volts while the inner conductor is set to 1 volt. To minimize the influence of the sidewalls, we typically place them several strip widths away from the center conductor. We could also make the sidewalls perfect magnetic conductors (PMC's) to simulate a laterally open structure.



$$C = 1.2117 \times 10^{-10} \text{ F/m}$$

$$C_0 = 3.7283 \times 10^{-11} \text{ F/m}$$

$$Z_0 = \frac{1}{c\sqrt{CC_0}} = 49.93$$

$$\varepsilon_{eff} = \frac{C}{C_0} = 3.25$$

The impedance we computed is very close to the value from the analytical equation in *LineCalc*. And ε_{eff} is exactly equal to ε_r which is what we expect for a homogenous dielectric TEM line.

Notes:

Computing Z_0 and ε_{eff} Using Symmetry (cont.)

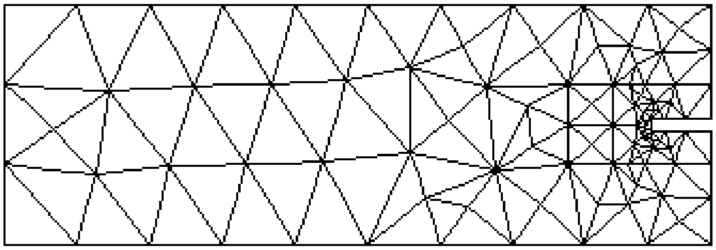
Both *FlexPDE* and *PDease2D* use a text file input rather than a graphical user interface (GUI). At first this seems rather cumbersome, but the advantage is you can "program" your geometry using variables and then make changes very rapidly. The input file for the stripline geometry is shown below. A "feature" called *test* is used to set up the path for the contour integral that is needed to compute total charge. The meshing algorithm also detects this feature and uses it to refine the mesh around the center strip.

```
TITLE   ‘Stripline‘

VARIABLES
   V

DEFINITIONS            {units are mils}
   w = 12.5            {width of center conductor}
   a = 150             {width of box}
   b = 25.4            {ground plane spacing}
   th = 1.4            {thickness of metal}
   eps0 = 8.854e-12    {epsilon sub zero, F/m}
   epsr                {epsilon sub r, must be defined below}
   k = epsr*eps0
   scale_x = 10        {scaling for test box, x dimen}
   scale_y = 6         {scaling for test box, y dimen}
   E = -k*grad(V)      {definition of E field}

EQUATIONS
   div(-k*grad(V)) = 0    {Laplace’s equation}

BOUNDARIES

  region 1
     epsr = 3.25
     value(V) = 0      {set outer boundary to zero volts}
     start ‘box’ (-a/2, -b/2)   line to (-a/2, b/2)   to (a/2, b/2)   to (a/2, -b/2)   to finish

     value(V) = 1      {set center conductor to one volt}
     start ‘center’ (-w/2, -th/2)   line to (-w/2, th/2)   to (w/2, th/2)   to (w/2, -th/2)   to finish

     feature           {set path for contour integral}
     start  “test” (-a/scale_x, -b/scale_y)   line to (-a/scale_x, b/scale_y)   to (a/scale_x, b/scale_y)
       to (a/scale_x, -b/scale_y)   to (-a/scale_x, -b/scale_y)

MONITORS

PLOTS
   grid(x, y)          {the finite element mesh}
   contour(V)          {potential plot}
   vector(E)           {E-field vector plot}

   elevation (normal(E)) on ‘test’    {contour integral to find total charge}

END
```

Notes:

Computing Z_0 and ε_{eff} Using Symmetry (cont.)

If we divide the problem using a vertical magnetic wall, we can apply our limited number of nodes to half the geometry. But we now have half the capacitance per unit length, so the computed impedance will be too high. An “impedance multiplier” of 0.5 in our impedance equation will correct this.



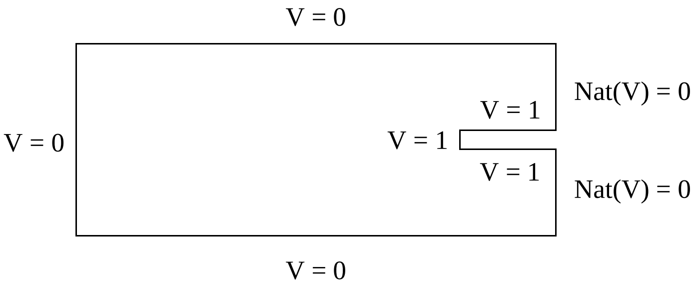
$$C = 5.9639 \times 10^{-11}\ \mathrm{F/m}$$

$$C_0 = 1.835 \times 10^{-11}\ \mathrm{F/m}$$

$$Z_0 = \frac{0.5}{c\sqrt{CC_0}} = 50.71$$

$$\varepsilon_{eff} = \frac{C}{C_0} = 3.25$$

There are a number of different ways this geometry can be described to *FlexPDE* or *PDease2D*. If you modify the original file and use a box for the outer conductor and a box for the center conductor, the software can get confused when it comes to the vertical symmetry plane. The most unambiguous way to describe this geometry is shown below. The entire geometry is one closed polygon with the appropriate boundary condition on each segment. The magnetic wall is specified as a “natural” boundary.



Notes:

Computing Z_0 and ε_{eff} Using Symmetry (cont.)

The input file for the symmetrical stripline problem is shown below. In this case the “feature” called *test* that sets the path for the line integral only has three segments. Again, the meshing algorithm will detect this feature and use it for mesh refinement.

```
TITLE   ‘Stripline - using vertical magnetic wall symmetry‘

VARIABLES
   V

DEFINITIONS             {units are mils}
   w = 12.5             {width of center conductor}
   a = 150              {width of box}
   b = 25.4             {ground plane spacing}
   th = 1.4             {thickness of metal}
   eps0 = 8.854e-12     {epsilon sub zero, F/m}
   epsr                 {epsilon sub r, must be defined below}
   k = epsr*eps0
   scale_x = 10         {scaling for test box, x dimen}
   scale_y = 6          {scaling for test box, y dimen}
   E = -k*grad(V)       {definition of E field}

EQUATIONS
   div(-k*grad(V)) = 0     {Laplace’s equation}

BOUNDARIES

  region 1
    epsr = 3.25
    value(V) = 0                                              {set outer boundary to zero volts}
    start 'box' (0, -b/2)   line to (-a/2, -b/2)   to (-a/2, b/2)   to (0, b/2)

    natural(V)=0 line to (0, th/2)                            {upper magnetic wall}
    value(V)=1 line to (-w/2, th/2) to (-w/2, -th/2) to (0, -th/2)     {set strip to 1 volt}
    natural(V)=0 line to (0, -b/2)                            {lower magnetic wall}
    finish

  feature
    start  "test" (0, -b/scale_y)   line to (-a/scale_x, -b/scale_y)
      to (-a/scale_x, b/scale_y)   to (0, b/scale_y)

MONITORS

PLOTS
   grid(x, y)           {the finite element mesh}
   contour(V)           {potential plot}
   vector(E)            {E-field vector plot}

   elevation (normal(E)) on ‘test’    {contour integral to find total charge}

END
```

Notes:

Summary for Computing Z_0 and ε_{eff} Using Symmetry

When resources are limited, applying symmetry to our problem can often stretch those resources. For shareware programs, the limited resource may be the number of nodes available. For large complicated structures, computer memory or processing time may be the limitation. Symmetry can also save time when drawing a large, complicated structure. The symmetry plane is often specified as a magnetic wall or “natural” boundary. When we invoke symmetry, we must apply a correction factor or “impedance multiplier” to the impedance calculation. Some 2D cross-section solvers use a text file input and some use a graphical user interface (GUI). The text file input is actually quite useful for parametric studies. Once the geometry has been “programmed,” changes can be made very quickly.

Summary:

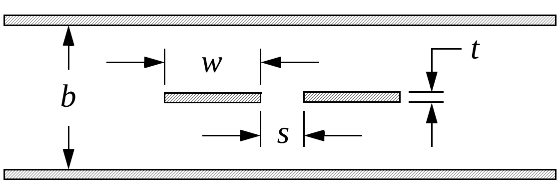
- Shareware or student versions of 2D solvers limit number of nodes.
- Symmetry uses limited resources more efficiently.
- Symmetry may save time when drawing a complicated cross-section.
- Symmetry plane is a magnetic wall or “natural” boundary.
- A correction factor or “impedance multiplier” must be applied to the impedance calculation.
- Text mode input has advantages for parametric studies.

Notes:

Coupled Line Parameters Using Symmetry

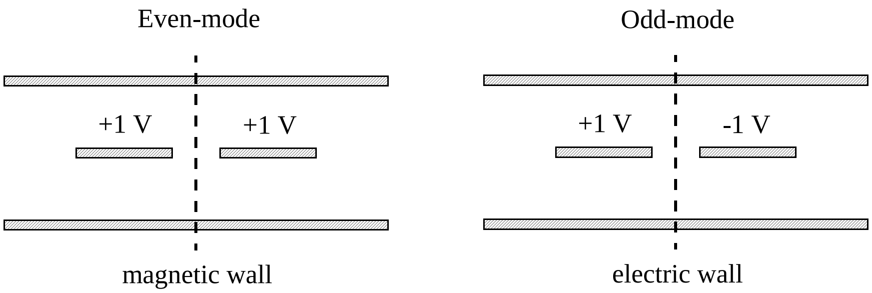
Symmetry is also a useful concept when we compute coupled line parameters. We could compute the complete two strip cross-section, or we can make use of the vertical line of symmetry in most coupled strip problems. Like the single strip case, symmetry will stretch our limited resources if we are using the shareware or student version of a 2D FEM cross-section solver. Below is a coupled stripline example with electrical parameters computed by *LineCalc*.

$Z_{even} = 59.99$
$Z_{odd} = 42.09$
(*LineCalc*)



$w = 11.7$
$s = 6.4$
$b = 25.4$
$t = 1.4$
$\varepsilon_r = 3.25$

The even-mode has equal potentials on both strips with the same sign. We can place a vertical magnetic wall between the two strips without modifying the pattern of electric field lines. The odd-mode has equal potentials with opposite signs on the two strips. A vertical electric wall between the two strip will not modify the pattern of electric field lines.

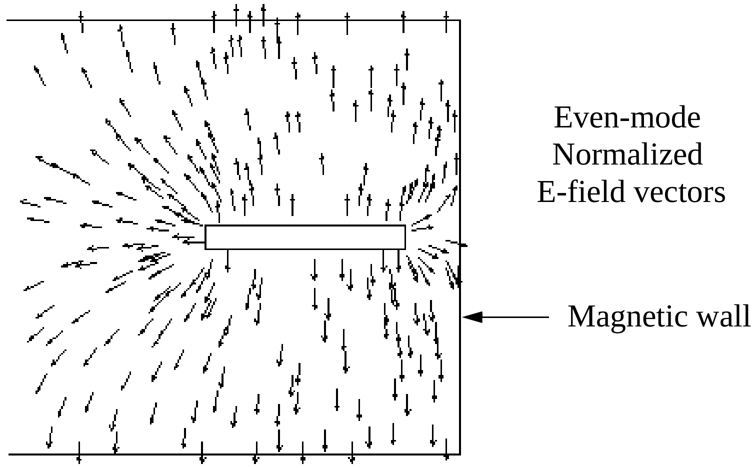


Like the single strip case, we need to compute C and C_0 for the even-mode and for the odd-mode, a total of four capacitance calculations. For more than two strips, this procedure can get very tedious.

Notes:

Coupled Line Parameters Using Symmetry (cont.)

The even-mode analysis proceeds as expected, computing C then C_0. We put 1 volt on the strip, 0 volts on the outer conductor and a magnetic wall down the symmetry plane. The "feature" used to define the integral should completely enclose the strip and not touch the center symmetry plane. Below is a plot of the E-field vectors for the even-mode, with all the lengths normalized to one value.



The computed electrical parameters for the even-mode are shown below. No correction to the impedance equation is needed in this case.

$$C = 9.8772 \times 10^{-11} \text{ F/m}$$

$$C_0 = 3.0391 \times 10^{-11} \text{ F/m}$$

$$Z_{even} = \frac{1}{c\sqrt{CC_0}} = 61.25$$

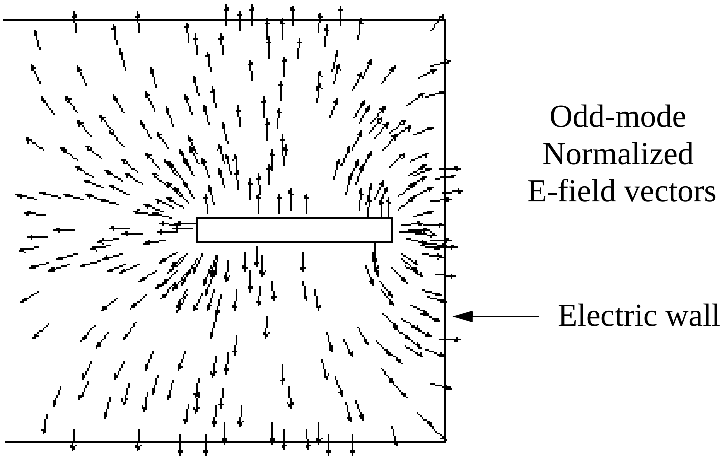
$$\varepsilon_{eff} = \frac{C}{C_0} = 3.25$$

For microstrip we would expect the even-mode ε_{eff} to be lower than ε_r.

Notes:

Coupled Line Parameters Using Symmetry (cont.)

The odd-mode analysis puts 1 volt on the strip, 0 volts on the outer conductor and an electric wall at the symmetry plane. The “feature” used to define the integral should completely enclose the strip and not touch the center symmetry plane. Below is a plot of E-field vectors for the odd-mode, with all the vector lengths normalized to one value.



The computed electrical parameters for the odd-mode are shown below. No correction to the impedance equation is needed in this case.

$$C = 1.4650 \times 10^{-10}\ \text{F/m}$$

$$C_0 = 4.5078 \times 10^{-11}\ \text{F/m}$$

$$Z_{odd} = \frac{1}{c\sqrt{CC_0}} = 41.29$$

$$\varepsilon_{eff} = \frac{C}{C_0} = 3.25$$

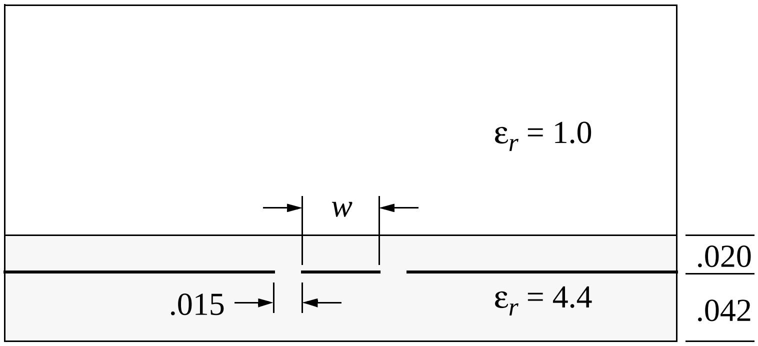
Summary:

- Vertical line of symmetry present in most coupled strip problems.
- Even-mode uses magnetic wall at symmetry plane.
- Odd-mode uses electric wall at symmetry plane.
- Need to compute C and C_0 for both modes.
- With 1 V on the strip and 0 V on the box, no impedance multiplier is needed.

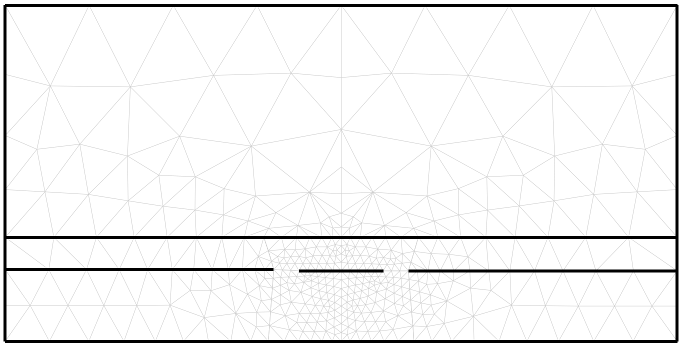
Notes:

CPW with Dielectric Overlay

In multilayer PC boards we can dream up many transmission line configurations that are not addressed by standard analytical models. If we can compute an impedance and phase velocity for the structure, we can include these non-standard cross-sections in our circuit designs. One afternoon an engineer brought me this CPW like structure that includes a dielectric overlay.



We can use a 2D cross-section-solver, *QuickField* in this case, to compute impedance as a function of the center line width, *w*. Below is the mesh we developed for this problem. We fine tuned the mesh at the edges of the strips to maximize accuracy.

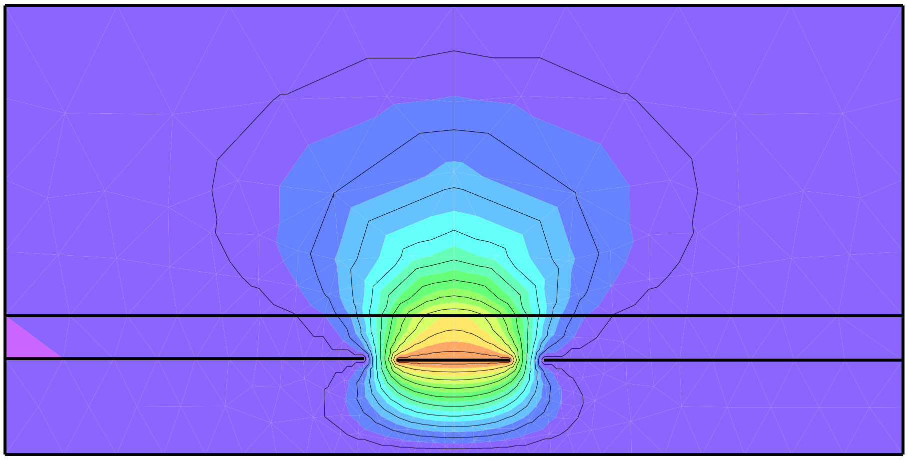


If we are using a shareware or student tool, we should probably apply a symmetry plane down the middle of the problem to maximize the number of available nodes.

Notes:

CPW with Dielectric Overlay (cont.)

After setting up our problem and doing the first solution, we can look at the lines of constant potential to make sure they make sense. The center strip is set to 1.0 volt and the contour lines have an increment of 0.1 volt.



We computed results for several line widths while we held the gap constant at 0.015 inch. The results are tabulated below.

w (in.)	C (F / m)	C_0 (F / m)	Z_0 (ohms)	ε_{eff}
.030	1.376e-10	3.373e-11	49.26	4.08
.040	1.490e-10	3.720e-11	45.07	4.01
.050	1.583e-10	3.991e-11	42.22	3.97
.060	1.711e-10	4.333e-11	38.97	3.95

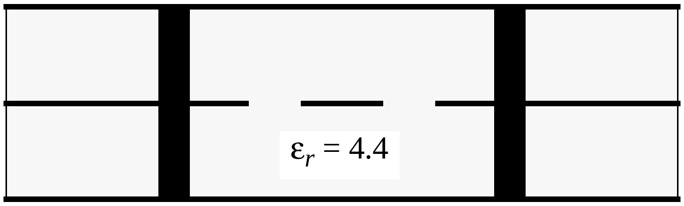
Once we have the impedance and effective phase velocity information we can plug those into an ideal transmission line element in our favorite linear simulator. With a little more work we could fit a curve to our data and program that equation into the linear simulator for automatic updates.

Summary: This geometry is another example of a cross-section not found in the standard library of any linear simulator. If we compute the impedance for several line widths, we can fit this data to an equation and program it into our simulator using the equation block.

Notes:

Buried Transmission Lines

In multilayer PC boards we are using buried transmission lines more and more. Depending on the relative dimensions we might call this CPW or we might call it stripline. The label we put on it is less important than our ability to analyze any structure that can be manufactured at a reasonable cost. A typical buried conductor cross-section might look like the figure below.

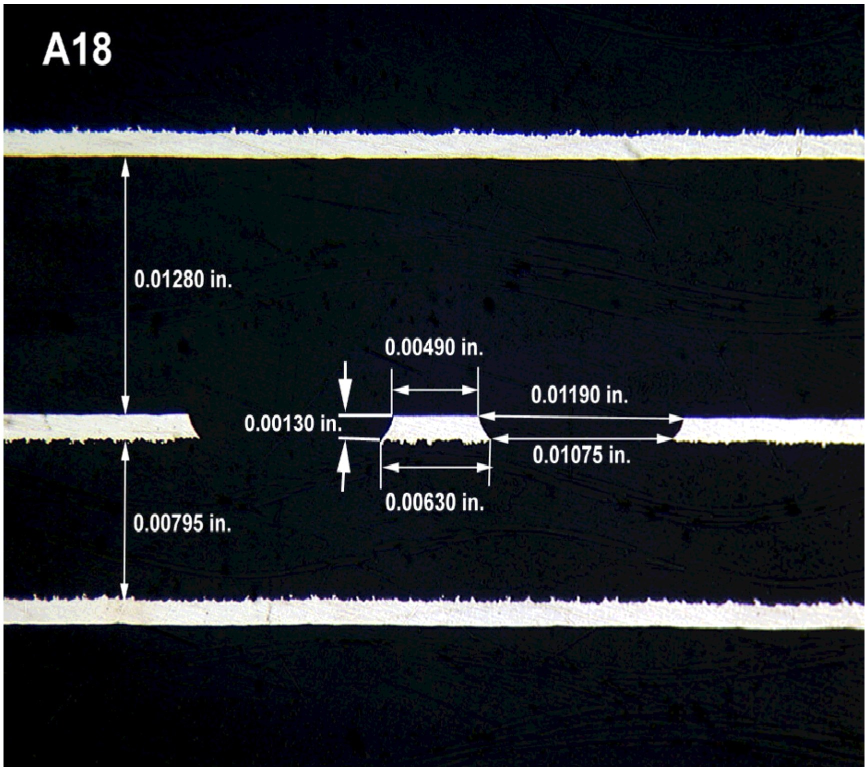


This may be three metal layers out of a board with up to 12 layers. There may or may not be vias close to edge of what we intend to be buried ground planes. The thickness of any one dielectric layer might be anywhere from 0.005 inch to 0.032 inch and several different layer thicknesses are typically used in a multilayer PC board.

Notes:

Buried Transmission Lines (cont.)

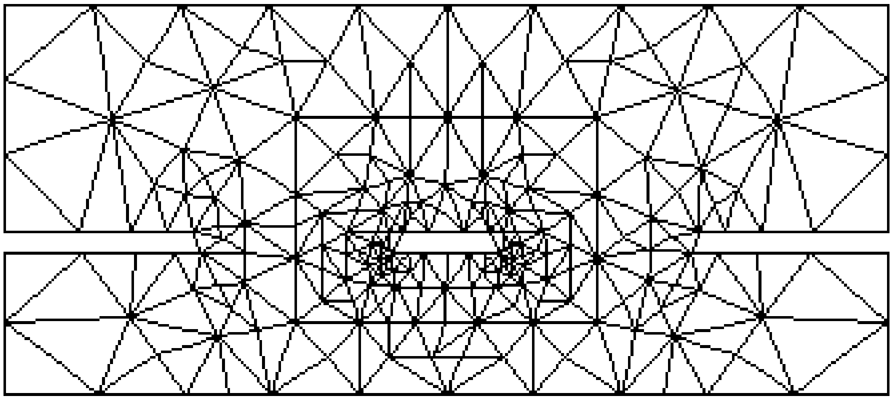
Below is a cross-section from an 8 layer PC board, only 3 of the metal layers are shown. We can clearly see the trapezoidal cross-section of the etched conductors. Also note that the distance to the upper and lower ground planes is not equal.



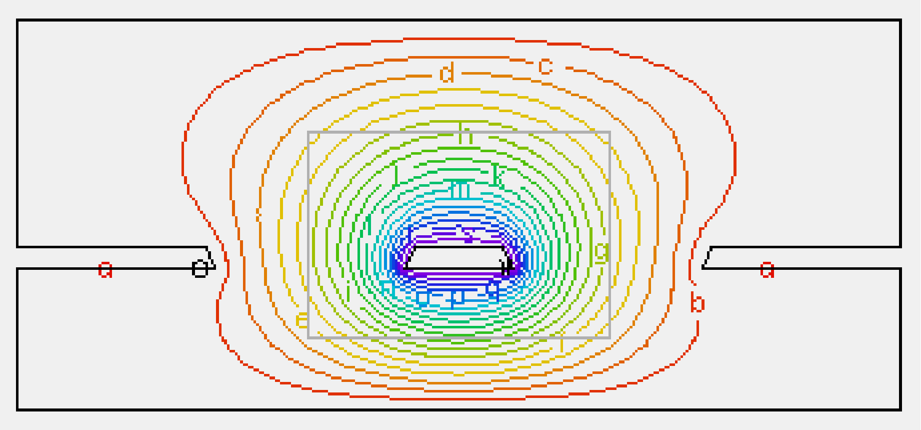
Notes:

Buried Transmission Lines (cont.)

Using *FlexPDE* we can certainly compute the impedance of this structure for the given dimensions. We can also explore the effects of the trapezoidal cross-section on impedance. Or, we might investigate the effects of the various ground planes on the computed impedance.



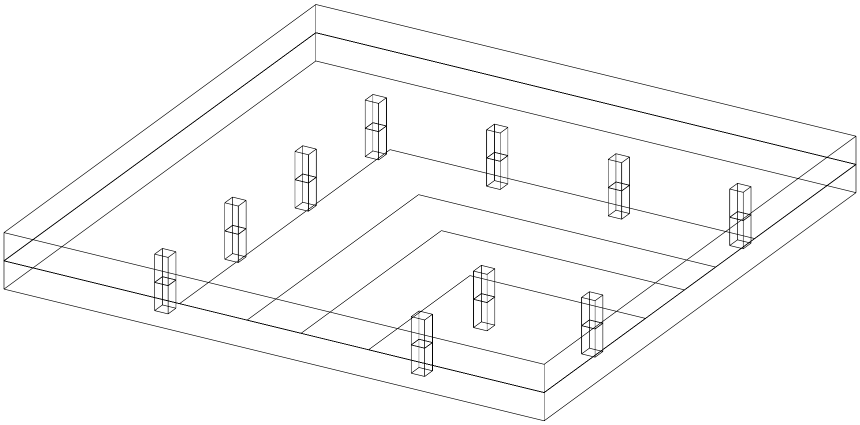
The lines of constant potential and the “feature” that defines the path for the contour integral are shown in the plot below.



Notes:

Buried Transmission Lines (cont.)

Once we have determined the impedance and phase velocity of our buried transmission line our next concern might discontinuities buried in the same layer. We can use a 2.5D or 3D tool to generate S-parameters for any number of structures like this right angle bend.



The beauty and power of these tools is that we can analyze structures that may never be seen in the model library of a commercial linear simulator. We can also analyze proprietary structures that our competition may not have thought of.

Summary: Buried transmission lines of various cross-sections are found when we route RF traces in multilayer PC boards. The cross-section we choose may not fit any standard definition of transmission line. When ground planes are brought in close to the signal line, the cross-section has some stripline properties and some CPW characteristics. We can also include the trapezoidal cross-section of various traces due to etching. Once we have fully explored our basic transmission line structure, we can also analyze various discontinuities buried in the same layer. We are no longer dependent on the linear simulator vendor to provide all the models we need.

Notes:

Conclusion

Some of the transmission line cross-sections we would like to use in multilayer PC boards do not fit any of the standard transmission line definitions. For these cases we need to use a 2D cross-section solver to compute the impedance and phase velocity. We can also include finite strip thickness and trapezoidal cross-sections in our analysis. Our goal for engineering work is 1% to 5% accuracy which is comparable to the manufacturing tolerances. Some of the tools we would like to use might be student or shareware versions with limited node counts. We can stretch the usefulness of these tools by taking full advantage of symmetry in our problems. While we are getting comfortable with a new tool it is helpful to analyze several known cases, just to be sure we are using the tool correctly. A known case is also useful if we are not sure how to apply an “impedance multiplier” to a problem with symmetry. If our substrate is thin in terms of wavelengths, and if the dielectric constant is low, we can use the quasi-static impedance that these tools compute to quite high frequencies.

Summary:

- Use 2D cross-section solver for non-standard configurations
- Shareware or student versions of 2D solvers limit number of nodes
- Symmetry uses limited resources more efficiently
- Can include thickness and trapezoidal cross-sections
- May need a correction factor for impedance
- When in doubt, analyze a known case

Notes:

List of Software Vendors

Student’s QuickField Tera Analysis Co. P.O. Box 571086 Tarzana, CA 91357 TEL: 818-831-9662 FAX: 805-493-2172 EMAIL: terainfo@tera-analysis.com WEB: www.tera-analysis.com	*Momentum, HFSS, MDS and Touchstone* HP EEsof 1400 Fountaingrove Parkway Santa Rosa, CA 95401 TEL: 1-800-343-3763 FAX: EMAIL: WEB: www.tmo.hp.com/tmo/hpeesof
PDEase2D Macsyma, Inc. 20 Academy Street Arlington, MA 02174 TEL: 617-646-7962 FAX: 617-646-3161 EMAIL: info@macsyma.com WEB: www.macsyma.com	*LINPAR, MULTLIN and C_NL2* Artech House 685 Canton Street Norwood, MA 02062 TEL: 617-769-9750 FAX: 617-769-6334 EMAIL: artech@world.std.com WEB: www.artech-house.com
FlexPDE PDE Solutions Inc. 38841 Garibaldi Cm. Fremont, CA 94536 TEL: 510-739-6058 FAX: 510-739-6059 EMAIL: sales@pdesolutions.com WEB: www.pdesolutions.com	*LINMIC+* Jansen Microwave GmbH Kackertstr. 16-18 D-52072 Aachen Germany TEL: 49-241-879-3022 FAX: 49-241-879-3023 EMAIL: jmgemail@aol.com WEB:
Compact-Explorer and Super-Compact Ansoft Corporation 201 McLean Blvd. Paterson, NJ 07504 TEL: 201-881-1200 FAX: 201-881-8361 EMAIL: info@ansoft.com WEB: www.ansoft.com	