Purpose:
Learn how Maxwell’s equations solve the EM fields associated with the operation of an electronic structure.
Learn Computational EM techniques using EM simulation software tools.

Tools:
Ansys/Ansoft HFSS (High Frequency Structure Simulator - version 14).
Ansys/Ansoft Designer (Circuit Simulator)

Operation:
Divides up a three-dimensional electronic structure into thousands of tiny cells.
Then solves the Electric and Magnetic Fields within each cell as they interact with all other cells.

Files Provided:
1. Instructions.
3. HFSS and Designer templates.

Objectives:
1. Draw Structure.
   PCB Board Stack-up (Ground, Dielectric, Trace, Air Box).
   Transmission Line (Differential Pair, Ports for excitation).
2. Set up Analysis.
   Frequency Domain (Terminal Solution Type)
   Time Domain (Transient Solution Type)
3. Results from Simulation.
   Channel Losses (from Frequency Domain Analysis).
   Signal Attenuation and Delay (from Time Domain Analysis).
   Eye Diagram (Defines allowable voltage and time variation of a received signal).
1. Structure Overview: Differential Pair

**3-D View**

- Air Box
- Differential Pair
- T1, T2, T3, T4
- Port 1
- Port 2
- Dielectric

**Front View - Stack up**

- Port
- Copper Traces
- Dielectric Layer
- Ground
1. Draw Structure. Detail of Ground, Dielectric, Ports

Location of coordinates:
Ground
Dielectric
Ports
1. Draw Structure. Detail of Differential Pair

(The “Trapezoidal” shape is typical of manufactured traces.)

Location of coordinates to form “Trapezoidal” shape.

- \(-\left(\frac{gT}{2}+wT-xT\right),0,(hG+hD+hT)\)

- \(-\left(\frac{gT}{2}+xT\right),0,(hG+hD+hT)\)

- \(-\left(\frac{gT}{2}+wT\right),0,(hG+hD)\)

- \(-\left(\frac{gT}{2}\right),0,(hG+hD)\)

Trace 1

Trace 2

Copper

Dielectric

FR4

Ground

Copper

x

z

hT

hD

hG

xT

0.3 (mm)

Origin

Draw Structure. Detail of Differential Pair

(The “Trapezoidal” shape is typical of manufactured traces.)

Location of coordinates to form “Trapezoidal” shape.

- \(-\left(\frac{gT}{2}+wT-xT\right),0,(hG+hD+hT)\)

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- \(-\left(\frac{gT}{2}\right),0,(hG+hD)\)

Trace 1

Trace 2

Copper

Dielectric

FR4

Ground

Copper

x

z

hT

hD

hG

xT

0.3 (mm)

Origin
Design Properties (Variables)

Excitations

Differential Pairs

Frequency Sweep

Solution Setup

2. Analysis Set-ups.
2. Analysis Set-ups.

Report

Parametric Sweep

Variable | Description
--- | ---
dxT | Linear Step from 0 to 0.5, step=0.1
LT | Linear Step from 2cm to 10cm, step=2cm
wT | Linear Step from 10mil to 15mil, step=1mil
hT | Single Value at 1.3mil
GT | Linear Step from 10mil to 20mil, step=5mil
3. Results. Frequency Plots.

**Differential**

<table>
<thead>
<tr>
<th>Name</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>1cm</td>
<td>-0.1738</td>
</tr>
<tr>
<td>m2</td>
<td>5cm</td>
<td>-0.7252</td>
</tr>
<tr>
<td>m3</td>
<td>10cm</td>
<td>-1.4576</td>
</tr>
<tr>
<td>m4</td>
<td>20cm</td>
<td>-2.9208</td>
</tr>
</tbody>
</table>

**Single Ended**

<table>
<thead>
<tr>
<th>Name</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>1cm</td>
<td>-0.2380</td>
</tr>
<tr>
<td>m2</td>
<td>5cm</td>
<td>-1.3329</td>
</tr>
<tr>
<td>m3</td>
<td>10cm</td>
<td>-3.4996</td>
</tr>
<tr>
<td>m4</td>
<td>20cm</td>
<td>-12.1328</td>
</tr>
</tbody>
</table>

**S21 - Insertion Loss**

**Attenuation, Delay**

**Eye Diagram**
S11 (Return Loss)

- Prefer to have least amount of power reflected (e.g., $\frac{P_o}{P_i} = \frac{1}{10}$)

- Example:
  - $10 \log_{10} \left( \frac{P_o}{P_i} \right) \ dB$
  - $10 \log_{10} \left( \frac{1}{10} \right) \ dB$
  - $10 \log_{10} \left( 0.1 \right) \ dB$
  - $10 \log_{10} \left( 1 \right) \ dB$
  - $10 \log_{10} \left( 0 \right) \ dB$
  - $-10 \ dB$

S21 (Insertion Loss)

- Prefer to have most of power pass through to load (e.g., $\frac{P_o}{P_i} = \frac{9}{10}$)

- Example:
  - $10 \log_{10} \left( \frac{P_o}{P_i} \right) \ dB$
  - $10 \log_{10} \left( \frac{9}{10} \right) \ dB$
  - $10 \log_{10} \left( 0.9 \right) \ dB$
  - $10 \log_{10} \left( 0.05 \right) \ dB$
  - $10 \log_{10} \left( 0.5 \right) \ dB$
  - $-0.5 \ dB$
Frequency Plot. 1cm

**XY Plot 2**

**Setup 1: Spectral**

<table>
<thead>
<tr>
<th>Name</th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>m1</td>
<td>7.8500</td>
<td>-0.4088</td>
</tr>
<tr>
<td>m2</td>
<td>7.8500</td>
<td>-38.8654</td>
</tr>
<tr>
<td>m3</td>
<td>16.2000</td>
<td>-0.9989</td>
</tr>
<tr>
<td>m4</td>
<td>16.2000</td>
<td>-45.5763</td>
</tr>
</tbody>
</table>

**Curve Info**

- 
- dB(St(Trace_T1,Trace_T1))
- dB(St(Trace_T1,Trace_T2))

**Legend**

- Red: dB(St(Trace_T1,Trace_T1))
- Blue: dB(St(Trace_T1,Trace_T2))

**Freq [GHz]**

- 0.00 2.50 5.00 7.50 10.00 12.50 15.00 17.50 20.00
- -50.00
- -40.00
- -30.00
- -20.00
- -10.00
- 0.00

**Plot Details**

- S11
- S21

**Graph Details**

- Axis:
  - X: Frequency [GHz]
  - Y: dB

- Units:
  - X: 1cm
  - Y: 1cm
Designer Circuit
Report
**Specification:**

A. Ansoft HFSS (Structure Simulator).
   1. Draw structure in Ansoft HFSS (Transient).
   2. Set up Attributes, Excitation, and Boundary Conditions.
   3. Simulate the design.
   4. Results:
      a. Time Domain (Transient).
      b. Frequency Domain (Spectral).

B. Ansoft Designer (Circuit Simulator).
   1. Set up Signal Generator Circuit in Ansoft Designer.
   2. Import HFSS Model.
   3. Simulate the Circuit (Vary “Data Rate” to get EYE opening).
   4. Results.
      a. EYE Diagram.
1. HFSS Solution Process.

FEM. (eg: HFSS uses FEM (Finite Element Method) to mesh the Computational Domain. FEM divides this space into thousands of smaller elements or cells called tetrahedrals (three-dimensional triangles).)

Matrix Equations.
Basis Functions.
Adaptive Analysis.

HFSS Solution Process.

2. Solution of Maxwell’s equations.

Maxwell’s Equations.

Maxwell’s Equations. \[ \bar{\Delta} \times \bar{E} = -\partial \bar{B}/\partial t \quad \bar{\Delta} \times \bar{H} = \bar{J} + \partial \bar{D}/\partial t \]

DGTD Solver. (eg: each mesh element advances in time using its own time step in a synchronous manner. This results in a significant speed-up.)

Parallelism.
Identify figure (eg: This is a figure of a Microstrip line drawn in “HFSS” for analyzing the transient and spectral characteristics.)
Describe components.
(eg: The Air Box confines the computational domain to within ¼ wavelength from conducting surfaces in order to model the radiation of EM waves in space while also reducing the simulation time.)
Identify plot (eg: This is a plot of a broadband pulse in the time domain over the interval ...ps)
Compare time delay and attenuation due to the trace length (from delta markers on plot).
Compare results for time delay from plot with empirical formulation (from formula below).

$$
\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12Dz}{Tx}}} ,
\quad
v_p = \frac{c \text{ (speed light)}}{\sqrt{\varepsilon_e}},
\quad
\text{time delay} = \frac{\text{length of line}}{v_p}
$$
Identify plot (eg: This is a plot of the insertion losses in the frequency domain for a Differential Pair of Traces over the interval ...GHz)

Compare insertion losses (S21) due to the trace lengths and frequency (from maximum markers on plot).

[The interval between resonant troughs for the S11 graph (not shown. Change step size to 0.1GHz and rerun. Takes 5x longer.) can be approximated by the formulation given below.]

$$
\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + \frac{12Dz}{Tx}}}, \quad v_p = \frac{c \text{ (speed light)}}{\sqrt{\varepsilon_e}}, \quad \text{resonant troughs} = \frac{v_p}{2f_y} \text{Hz}^{-1}
$$
Identify plot (eg: This is a plot of the insertion losses in the frequency domain for a Single-Ended Trace over the interval ...GHz)

Compare insertion losses (S21) due to the trace lengths and frequency (from maximum markers on plot).
Identify plot (eg: This is a plot in the frequency domain comparing the insertion losses for a Differential Pair and a Single-Ended Trace over the interval ...GHz)
Compare insertion losses (S21) due to the type of transmission line (from maximum markers on plot).
Identify figure (eg: This is a Signal Generator circuit drawn in “Designer” for analyzing the EYE Diagram and BER (Bit Error Rate))

Describe components.
(eg: The PSRB assigns ___ random bits at a rate of ___ GHz.)
Identify plots. (eg: This figure is the EYE Diagram in the time domain for the EYE opening of a 5 cm line at the data rate of ___ over the interval 1/rate = ____.)

Analyze plots. (eg: Notice that the Voltage and Time differential fall within the given constraints of the EYE Mask for the 5 cm line.)
Conclusion

**HFSS tool:**
(C:\Program Files\Ansoft\HFSS14.0\Win64\Help\hfss_onlinehelp p1-1)

**HFSS simulation results:**

**Designer tool :**
(C:\Program Files\Ansoft\Designer7.0\Windows\Help\getstart p 4-1, 5-1, nexxim p 1-10, 1-12).

**Designer simulation results:**