EE 201C
Homework 1

Wei Wu

Submit code and report to:
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1. References

**Capacitance Calculation:**

- **Formula based**

- **Table based**

- **Field solver**
1. References

Inductance Calculation:

- Table based
  - Norman Chang, Shen Lin, O. Sam Nakagawa, Weize Xie, Lei He, “Clocktree RLC Extraction with Efficient Inductance Modeling”. DATE 2000

- Circuit model and inductance screening
1. References

Inductance Calculation (cont.):

- PEEC model and Susceptance model
  
  

- Formulas
  

- Field solver
  
2. Further Readings

3. Example for $L_{\text{eff}}$

- Calculation effective loop inductance ($L_{\text{eff}}$) of signal trace T2

Also, two ground traces have the same voltage drop
- Assume all current returns in this block

- KCL: \[ i_1 + i_2 + i_3 = 0 \]

- \( L_{\text{eff}} \) can be solved as a function of partial inductances

\[
L_{\text{eff}} = L_{p_{22}} - 2L_{p_{23}} + \frac{L_{p_{11}}}{2} + \frac{L_{p_{13}}}{2}
\]

3. Homework (due Feb 1, 2016)

[1] Given three wires, each modeled by at least 2 filaments, find the 3x3 matrix for (frequency-independent) inductance between the 3 wires, along with the capacitance and resistance. We assume that the ground plane has infinite size and is 10 um away for the purpose of capacitance calculation.

- wire width: \( W = 9 \text{um} \), wire thickness: \( T = 6 \text{um} \), wire length: \( l = 9000 \text{um} \),
- wire spacing: \( S = 15 \text{um} \), distance to ground: \( H = 10 \text{um} \),
- Copper electrical resistivity \( 0.0175 \, \Omega \text{mm}^2/\text{m} \) (room temperature),
- \( \mu = 1.256 \times 10^{-6} \text{H/m} \),
- free space \( \varepsilon_0 = 8.85 \times 10^{-12} \text{F/m} \)
Discretization and L calculation

- Discretize 3 wires into 6 filaments.
- For each filament, calculate its self-inductance with (e.g.)

\[
L_{self-L} = \frac{\mu l}{2\pi} \left[ \ln \left( \frac{2l}{W' + T} \right) + \frac{1}{2} + \frac{(W' + T)}{4l} \right]
\]

\[
W' = \frac{W}{2}
\]

- For each pair of filament, calculate the mutual inductance with (e.g.)

\[
L_{mutual-L} = \frac{\mu l}{2\pi} \left[ \ln \left( \frac{2l}{D} \right) - 1 + \frac{D}{l} \right]
\]

- Different filaments and formulae may be used for better accuracy.
Step 1.2

Calculate inductance matrix of three wires

- **Mutual Inductance**

  \[ L_{p_{km}} = \frac{1}{P \cdot Q} \sum_{i=1}^{P} \sum_{j=1}^{Q} L_{p_{ij}} \]

  - \( L_{p_{km}} \) is the mutual inductance between conductor \( T_k \) and \( T_m \)
  - \( L_{p_{ij}} \) is the mutual inductance between filament \( i \) of \( T_k \) and filament \( j \) of \( T_m \)
  - \( L_{p_{ij}} \) can be negative to denote the inverse current direction.

- **Self Inductance**

  - If \( k=m \), \( L_{p_{km}} \) is the self \( Lp \) for one conductor
Step 1.3

Capacitance Calculation

\[ C_1 \text{ and } C_5 \text{ equals to average of those for the following two cases:} \]

- single wire over ground
- three parallel wires over ground

Total cap below needs to be split into ground and coupling cap

\[ C = \varepsilon \left\{ \frac{w}{h} + 2.977\left(\frac{t}{h}\right)^{0.232} + \left[ 0.229\left(\frac{w}{s}\right) + 1.227\left(\frac{t}{s}\right)^{1.384} \right]\left(\frac{h}{t}\right)^{0.398} \right\} \]
Step 1.4

- **Resistance Calculation**
- **Copper electrical resistivity** $0.0175 \ \Omega\text{mm}^2/\text{m}$ (room temperature),

\[
R = \rho \frac{l}{A}
\]

- $l$ is length of wire
- $A$ is area of wire’s cross section
[2] Build the RC and RCL circuit models in SPICE netlist for the above wires. (suggest to use matlab script to generate matrix and thus SPICE netlist)

*This is RC circuit*

VDD 1 0 PULSE(0 10 10ps)

C11 3 0 XXXXX
C12 4 0 XXXXX
C21 1 0 XXXXX
C22 2 0 XXXXX
C31 5 0 XXXXX
C32 6 0 XXXXX
C33 4 2 XXXXX
C23 6 2 XXXXX
R1 3 4 XXXXX
R2 1 2 XXXXX
R3 5 6 XXXXX

.op
.TRAN 1ps 50ps
.print all
.plot all
.END
[3] Assume a step function applied at end-end, compare the four waveforms at the far-end for the central wire using SPICE transient analysis for (a) RC and RLC models and (b) rising time is 50ps, or try to use longer rising time.

Suggested Input:
VDD 1 0 PULSE(0 1 0 50ps)
Due on Feb 1, 2016

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