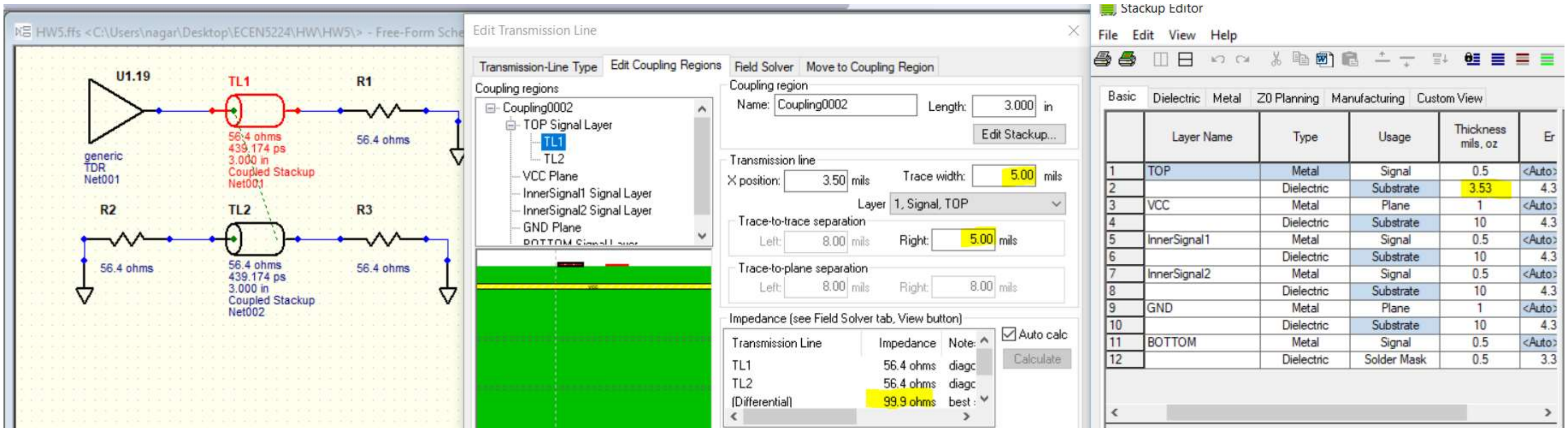
ECEN 5224 | **HIGH SPEED DIGITAL DESIGN** | **NAGARAJ SIDDESHWAR**
SOUMOJIT BOSE

HW5 | **DATE – 26th FEB 2018**

Goal: The goal of this lab is to get a hands-on experience to analyse how parameters affect the various impedance features of a Differential pair of a Microstrip and Stripline. Tool used is Hyperlynx.

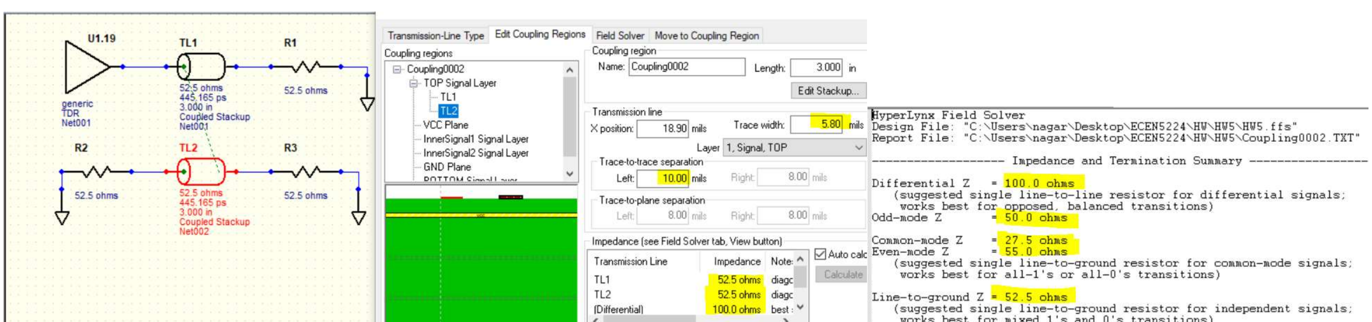
Plan: The plan is to theoretically anticipate the various impedance features theoretically and apply the same to 2D Field Solver.

Design a tightly coupled 100 Ohm microstrip differential pair, with 5 mil wide trace. Adjust the dielectric thickness



Coupling	Trace width (mil)	Zsingle(ohm)	Comment
Tight	5	56.4	As per the above figure, Single ended impedance Zsingle=56.4 ohm nearly equal to half of Differential Impedance (Zdiff) of 100 ohms. Also, Odd mode impedance (Zodd) is theoretically half of Zdiff, its observed that Zodd = 50 ohm. By theory, Common mode impedance (Zcomm) is defined as impedance between the two lines when the line pair is driven with common mode signal. Even mode Impedance (Zeven) is defined by the impedance of a single transmission line when the pair is driven by a common mode signal. So, Zdiff=2Zodd and Zcomm=0.5*Zeven. Since, the **fringe lines** across the Differential pair is greater than Common signal pair, displacement current across the Differential pair is greater than Common signal pair. Hence, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the below figure. However, loss is greater in tight coupling compared to other coupling as width is narrower; advantages being low cost and high interconnect density.
------------------ Impedance and Termination Summary -------------------- Differential Z = 99.9 ohms (suggested single line-to-line resistor for differential signals; works best for opposed, balanced transitions) Odd-mode Z = 50.0 ohms Common-mode Z = 31.5 ohms Even-mode Z = 62.9 ohms (suggested single line-to-ground resistor for common-mode signals; works best for all-1's or all-0's transitions) Line-to-ground Z = 56.4 ohms			

Now make the pair loosely coupled. What line width is needed to make it 100 Ohms.



Coupling	Trace width (mil)	Zsingle (ohm)	Comment
Loose	5.8	52.5	If the separation is blindly increased from the above condition (tight coupling), Zdiff would be more than 100 ohms. So, to compensate, trace is made wider. As per the above figure, Single ended impedance Zsingle=52.5 ohm nearly equal to half of Differential Impedance (Zdiff) of 100 ohms. Due to increase in trace width, Zsingle is lesser than the corresponding value in tight coupling. Since spacing is increased, Zeven decreases as the common mode fringe field interference decresases (hence, displacement current increases); so does Zcomm. Zodd is theoretically half of Zdiff, its observed that Zodd = 50 ohm. Also, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the figure. All the above discussed ideas are valid from above figures.

Now make it uncoupled. What line width is needed to make it 100 Ohms

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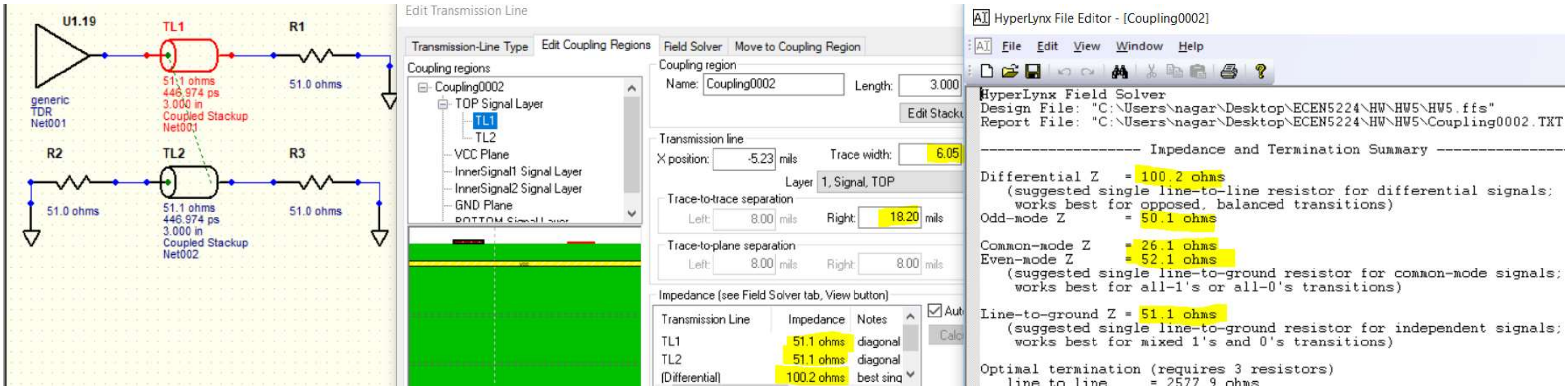
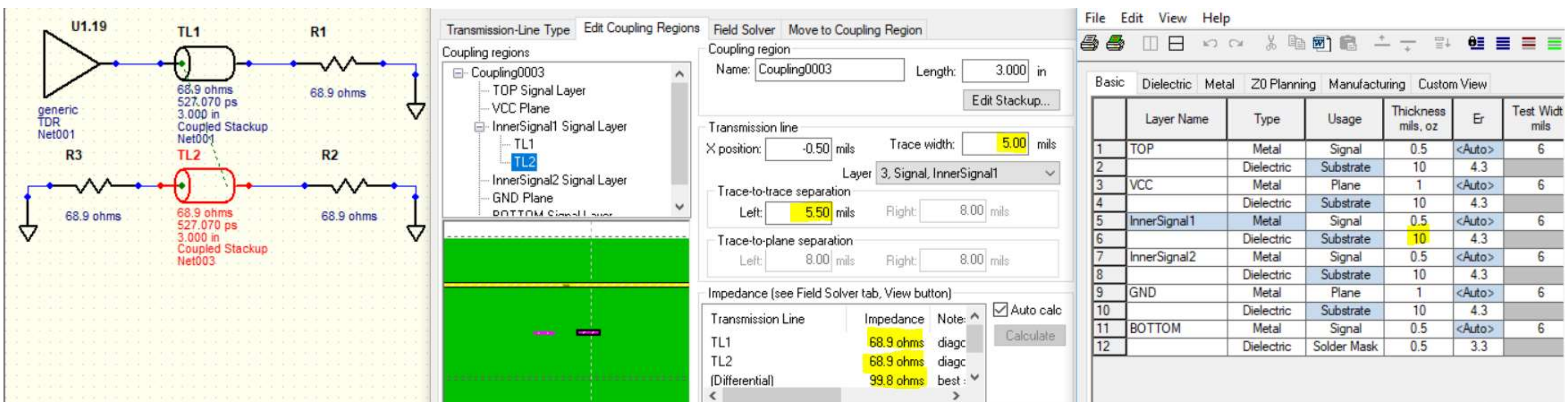


Coupling	Trace width (mil)	Zsingle (ohm)	Comment
Uncoupled	6.05	51	If the separation is blindly increased from the above condition (tight coupling), Zdiff would be more than 100 ohms. So, to compensate, trace is made wider. As per the above figure, Single ended impedance Zsingle=51 ohm nearly equal to half of Differential Impedance (Zdiff) of 100 ohms. Due to increase in trace width, Zsingle is lesser than the corresponding value in loose coupling. Since spacing is increased, Zeven decreases as the common mode fringe field interference decresases (hence, displacement current increases); so does Zcomm. Zodd is theoretically half of Zdiff, its observed that Zodd = 50 ohm. Also, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the figure. All the above discussed ideas are valid from above figures.

Repeat for stripline diff pairs.



Coupling	Trace width (mil)	Zsingle(ohm)	Comment
Tight	5	68.9	As per the above figure, Single ended impedance Zsingle=68.9. Also, Odd mode impedance (Zodd) is theoretically half of Zdiff, its observed that Zodd = 50 ohm. By theory, Common mode impedance (Zcomm) is defined as impedance between the two lines when the line pair is driven with common mode signal. Even mode Impedance (Zeven) is defined by the impedance of a single transmission line when the pair is driven by a common mode signal. So, Zdiff=2Zodd and Zcomm=0.5*Zeven. Since, the **fringe lines** across the Differential pair is greater than Common signal pair, displacement current across the Differential pair is greater than Common signal pair. Hence, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the below figure. However, loss is greater in tight coupling compared to other coupling as width is narrower; advantages being low cost and high interconnect density. It can be observed that Dielectric thickness for target Differential Impedance in Stripline is more than that of a Microstrip.

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------------------- Impedance and Termination Summary -------------------

Differential Z    = 99.8 ohms
    (suggested single line-to-line resistor for differential signals;
     works best for opposed, balanced transitions)
Odd-mode Z        = 49.9 ohms

Common-mode Z     = 43.9 ohms
Even-mode Z       = 87.9 ohms
    (suggested single line-to-ground resistor for common-mode signals;
     works best for all-1's or all-0's transitions)

Line-to-ground Z = 68.9 ohms
    (suggested single line-to-ground resistor for independent signals;
     works best for mixed 1's and 0's transitions)
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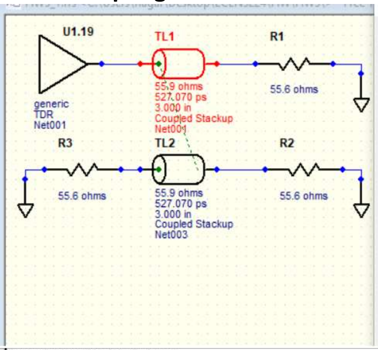
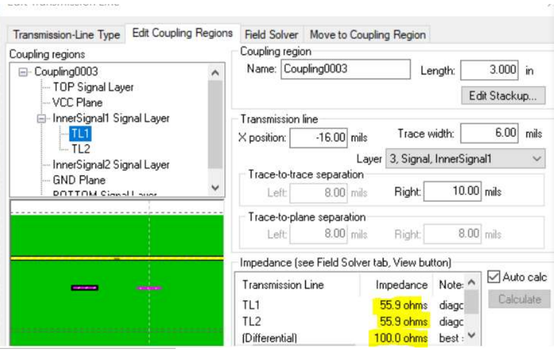
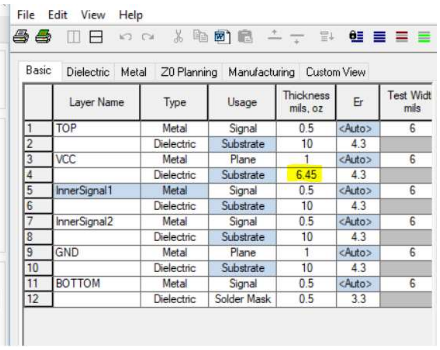
Loose Coupling:







	Layer Name	Type	Usage	Thickness mils, oz	Er	Test Width mils
1	TOP	Metal	Signal	0.5	<Auto>	6
2		Dielectric	Substrate	10	4.3	
3	VCC	Metal	Plane	1	<Auto>	6
4		Dielectric	Substrate	6.45	4.3	
5	InnerSignal1	Metal	Signal	0.5	<Auto>	6
6		Dielectric	Substrate	10	4.3	
7	InnerSignal2	Metal	Signal	0.5	<Auto>	6
8		Dielectric	Substrate	10	4.3	
9	GND	Metal	Plane	1	<Auto>	6
10		Dielectric	Substrate	10	4.3	
11	BOTTOM	Metal	Signal	0.5	<Auto>	6
12		Dielectric	Solder Mask	0.5	3.3	

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HyperLynx Field Solver
Design File:  "C:\Users\nagar\Desktop\ECEN5224\HW\HW5\HW5_1.ffs"
Report File:  "C:\Users\nagar\Desktop\ECEN5224\HW\HW5\Coupling0003.TXT"

------------------- Impedance and Termination Summary ----------------

Differential Z    = 100.0 ohms
   (suggested single line-to-line resistor for differential signals;
    works best for opposed, balanced transitions)
Odd-mode Z        = 50.0 ohms

Common-mode Z     = 30.9 ohms
Even-mode Z       = 61.8 ohms
   (suggested single line-to-ground resistor for common-mode signals;
    works best for all-1's or all-0's transitions)

Line-to-ground Z = 55.9 ohms
   (suggested single line-to-ground resistor for independent signals;
    works best for mixed 1's and 0's transitions)
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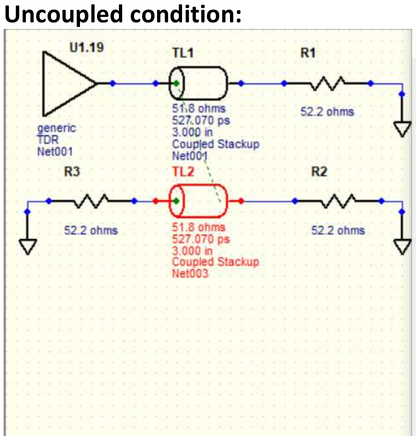
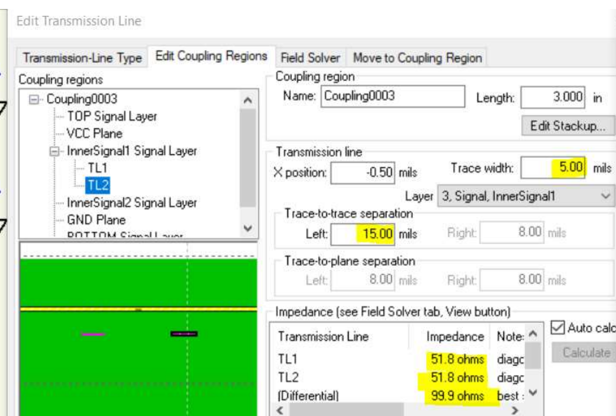
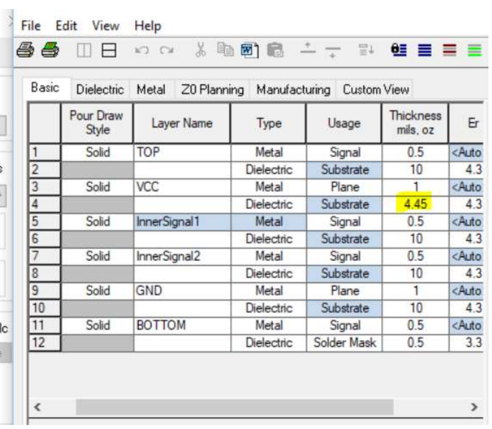
Coupling	Trace width (mil)	Zsingle (ohm)	Comment
Loose	6	55.6	If the separation is blindly increased from the above condition (tight coupling), Zdiff would be more than 100 ohms. So, to compensate, trace is made wider. In case of As per the above figure, Single ended impedance Zsingle=55.6 ohm nearly equal to half of Differential Impedance (Zdiff) of 100 ohms. Due to increase in trace width, Zsingle is lesser than the corresponding value in tight coupling. Since spacing is increased, Dielectric thickness needs to be reduced to retain the Differential Impedance of 100 ohm. Zeven decreases as the common mode fringe field interference decresases (hence, displacement current increases); so does Zcomm. Zodd is theoretically half of Zdiff, its observed that Zodd = 50 ohm. Also, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the figure. All the above discussed ideas are valid from above figures.

Uncoupled condition:







	Pour Draw Style	Layer Name	Type	Usage	Thickness mils, oz	Er
1	Solid	TOP	Metal	Signal	0.5	<Auto
2			Dielectric	Substrate	10	4.3
3	Solid	VCC	Metal	Plane	1	<Auto
4			Dielectric	Substrate	4.45	4.3
5	Solid	InnerSignal1	Metal	Signal	0.5	<Auto
6			Dielectric	Substrate	10	4.3
7	Solid	InnerSignal2	Metal	Signal	0.5	<Auto
8			Dielectric	Substrate	10	4.3
9	Solid	GND	Metal	Plane	1	<Auto
10			Dielectric	Substrate	10	4.3
11	Solid	BOTTOM	Metal	Signal	0.5	<Auto
12			Dielectric	Solder Mask	0.5	3.3

```
------------------- Impedance and Termination Summary ----------------

Differential Z    = 99.9 ohms
   (suggested single line-to-line resistor for differential signals;
    works best for opposed, balanced transitions)
Odd-mode Z        = 49.9 ohms

Common-mode Z     = 26.8 ohms
Even-mode Z       = 53.6 ohms
   (suggested single line-to-ground resistor for common-mode signals;
    works best for all-1's or all-0's transitions)

Line-to-ground Z = 51.8 ohms
   (suggested single line-to-ground resistor for independent signals;
    works best for mixed 1's and 0's transitions)
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Coupling	Trace width (mil)	Zsingle (ohm)	Comment
Uncoupled	6	51.8	If the separation is blindly increased from the above condition (tight coupling), Zdiff would be more than 100 ohms. So, to compensate, trace is made wider. As per the above figure, Single ended impedance Zsingle=52.2 ohm nearly equal to half of Differential Impedance (Zdiff) of 100 ohms. Due to increase in trace width, Zsingle is lesser than the corresponding value in loose coupling. Since spacing is increased, Dielectric thickness needs to be reduced to retain the Differential Impedance of 100 ohm . Since spacing is increased, Zeven decreases as the common mode fringe field interference decresases (hence, displacement current increases); so does Zcomm. Zodd is theoretically half of Zdiff, its observed that Zodd = 50 ohm. Also, **Zeven>Zodd,** but definitely lesser than Zdiff which can be verified by the figure. All the above discussed ideas are valid from above figures.

Conclusions/ Lessons Learnt:

1. **In any case, Zdiff > Zeven>Zodd**
2. **Tight coupling should be the first approach as it gives more dielectric thickness, low cost and more interconnect density; the downside being more conductor loss due to narrow width**
3. **As separation increases compared to trace width, Differential Impedance increases and Even mode impedance decreases. So configure the parameters accurately**
4. **Its not a good idea to decrease the dielectric thickness to get lower impedance as this leads to higher fabrication cost**