Signal Loop Inductance in [Pin] and [Package Model]

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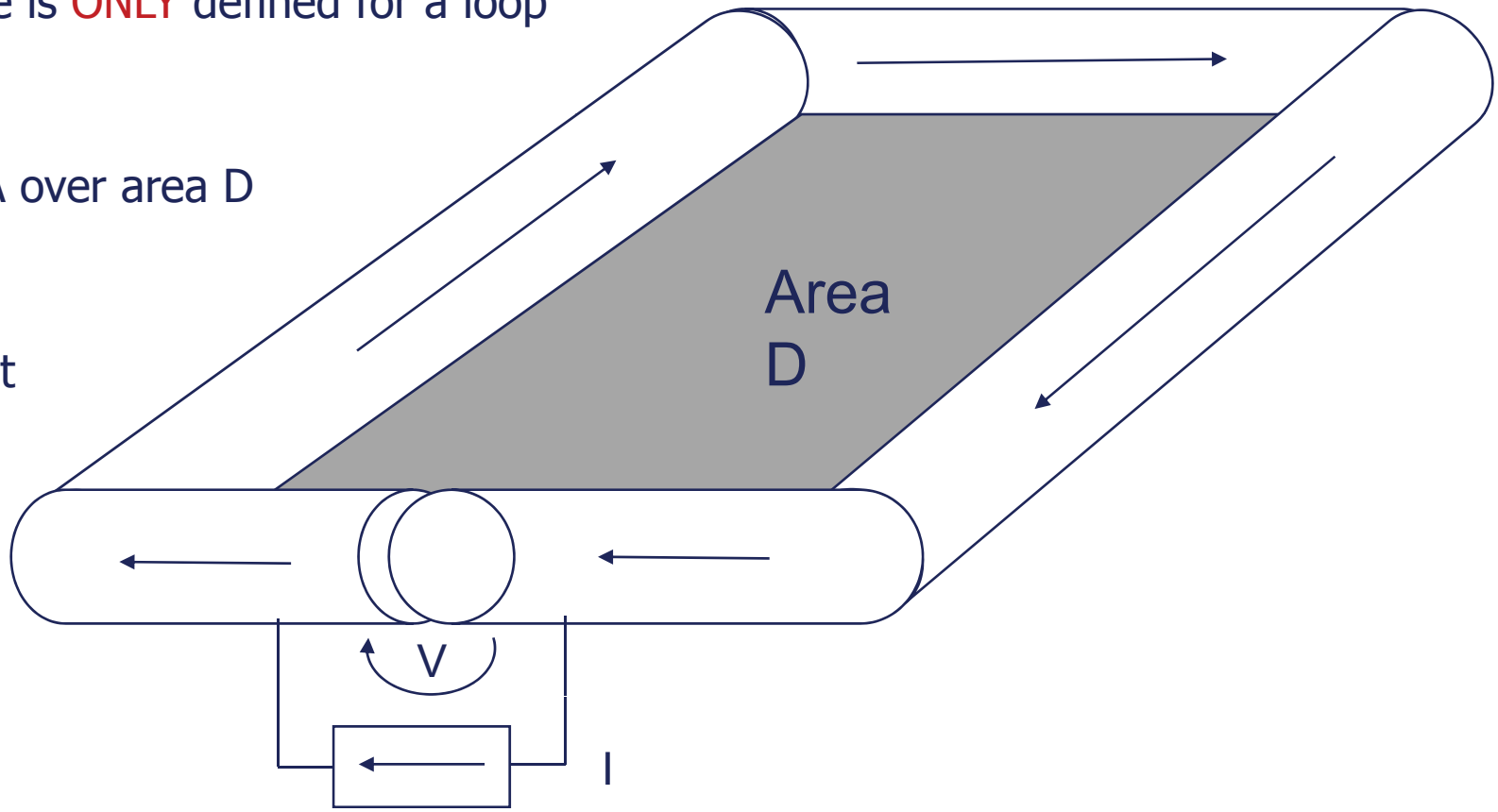
Overview

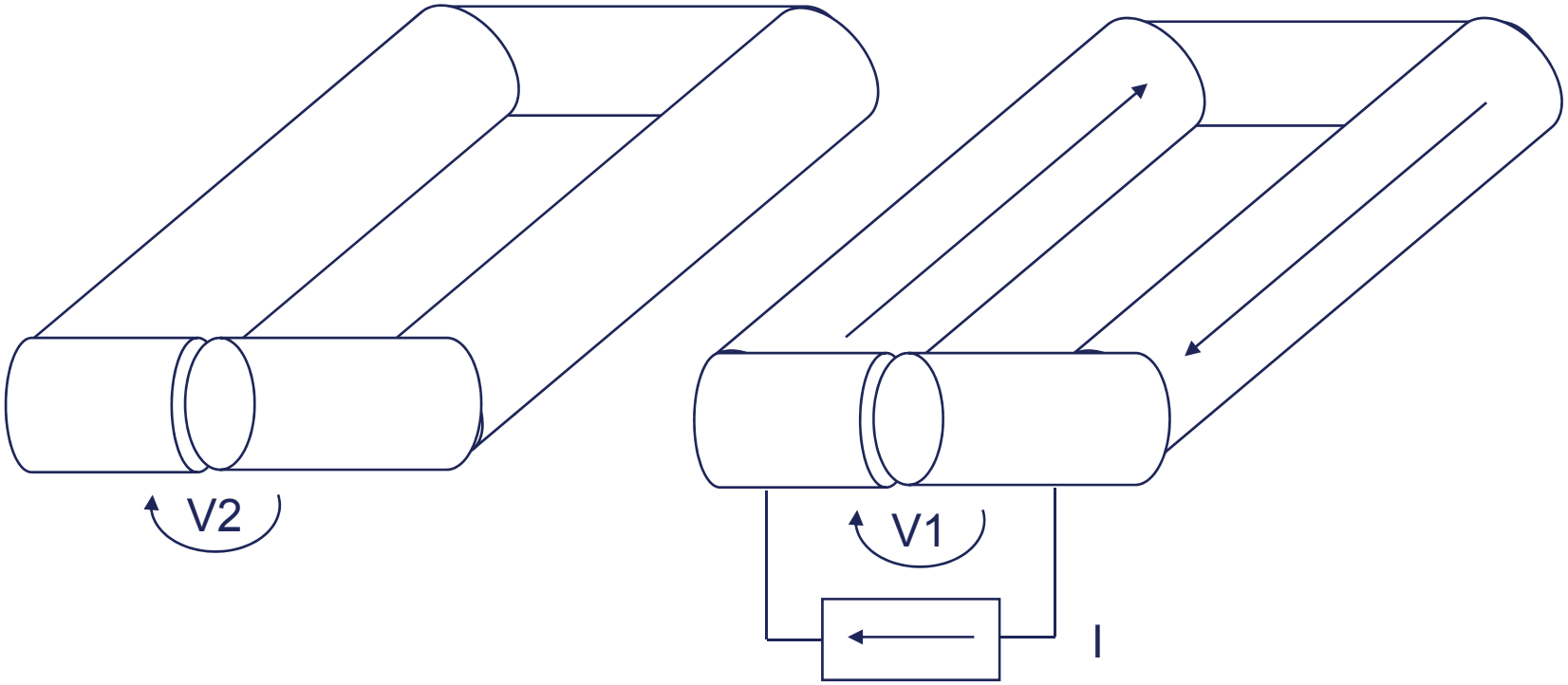
- Inductance terminology
- 3D Field Solver outputs
- Inductance model simulation examples
- Micron's loop inductance analyzer
- Application to IBIS [Pin] and [Package Model]

Definition of Inductance

- Inductance L is magnetic flux through a loop area divided by the current
- Inductance is ONLY defined for a loop
- $\Phi = \int B \cdot dA$ over area D
- $L = \Phi / I$
- $V = L \, dI/dt$



Self and Mutual Inductance



- Self loop inductance generates a voltage V1 in the driven loop
- Mutual loop inductance generates a voltage V2 in the adjacent loop
  - Note – current in adjacent loop is 0

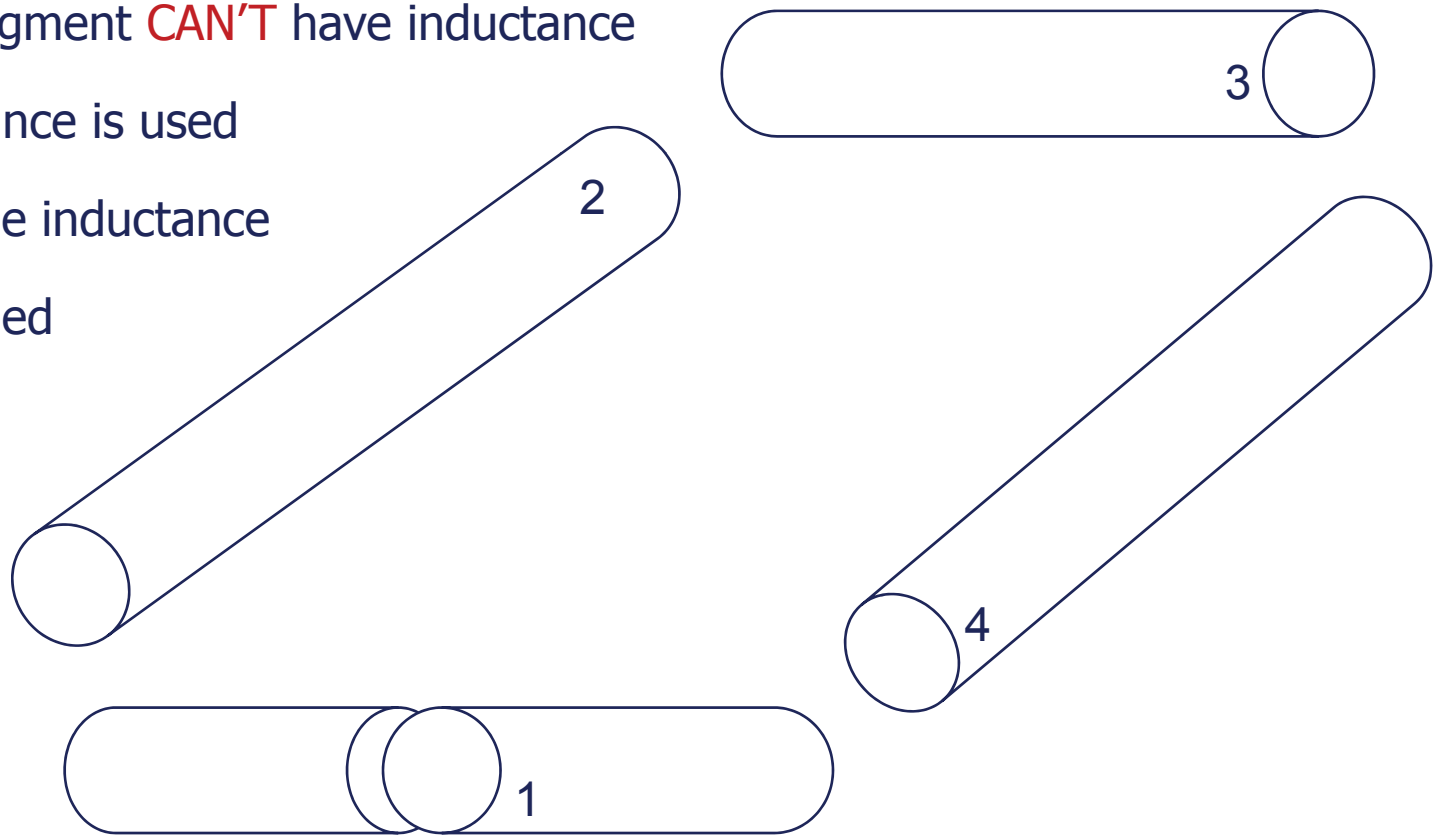
Partial Inductance

- Partial Inductances are the Self and Mutual Inductances of the loop segments
- Mathematical construct - They have NO MEANING independent of other partial inductances that form a loop
- An isolated segment CAN'T have inductance
- Partial inductance is used

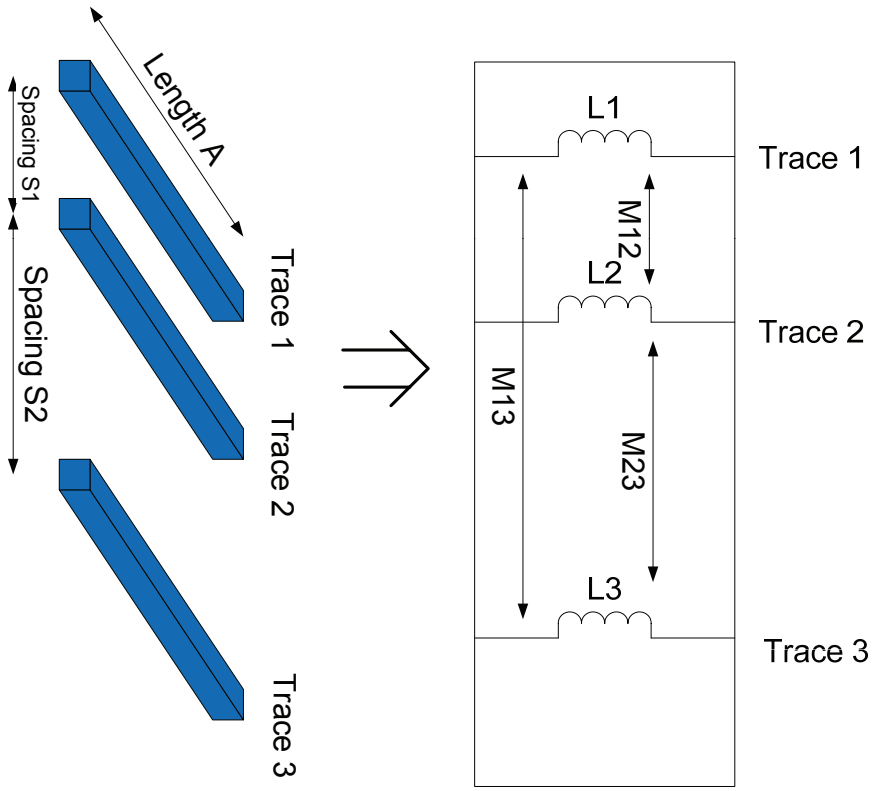
  to calculate the inductance

  of a loop formed

  of segments



3D Field Solver Partial Inductances



- 3 Traces in Free Space (no reference plane in structure)
  - Typical for 2 layer packages
- L1, L2, L3 – **Partial** Self Inductances are determined mostly by length, smaller effects from width and height
- M12, M23, M13 – **Partial** Mutual Inductances mainly a function of spacing and length

3D Field Solver Inductance Matrix

	Trace 1	Trace 2	Trace 3
Trace 1	5.16	3.78	0.458
Trace 2	3.78	5.16	0.464
Trace 3	0.458	0.464	5.16

Partial Mutual Inductance

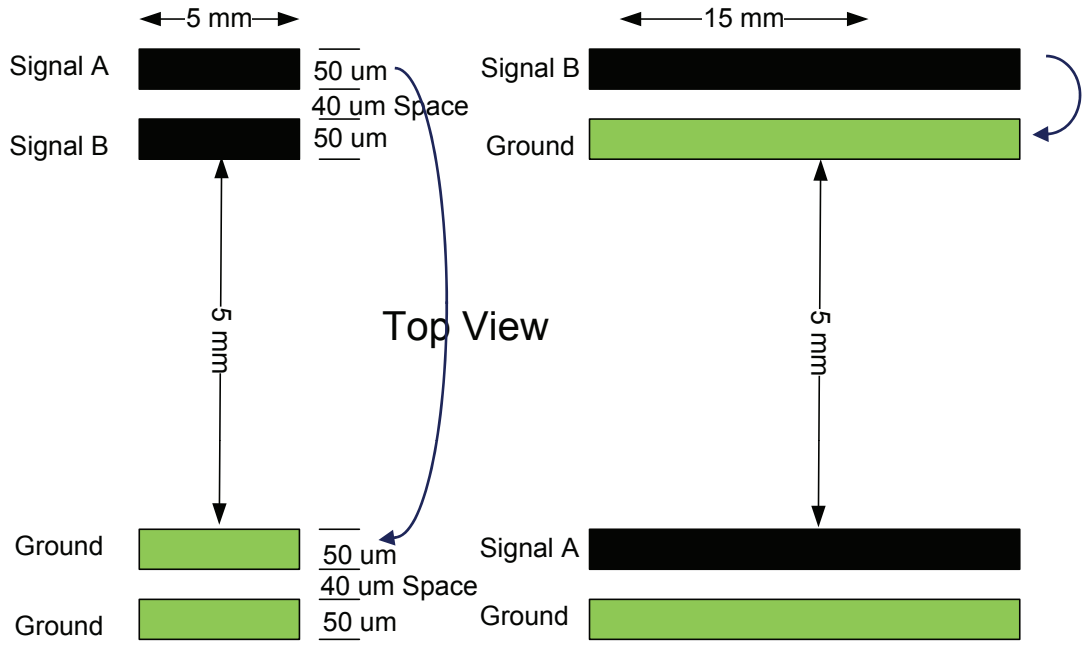
Partial Self Inductance

- ONLY LOOP INDUCTANCE HAS MEANING
- To define loops, the current paths must be defined
- Example: Trace2 is a return path
  - Trace1 to Trace2 loop = 5.16+5.16-2*3.78 = 2.76
  - Trace3 to Trace2 loop = 5.16+5.16-2*0.464 = 9.39

Example – 5 mm vs. 15 mm Long Traces

Partial Self Inductance
-> Case 1 (5mm)
is much better

Loop Inductance
-> Case 2 (15mm)
is somewhat better



	Case 1 - 5 mm long	Case 2 – 15 mm long
Partial Self Inductance	5.16 nH	19.2 nH
Signal A to Gnd Loop Inductance	8.72 nH	7.99 nH

3D Field Solver Inductance Matrix

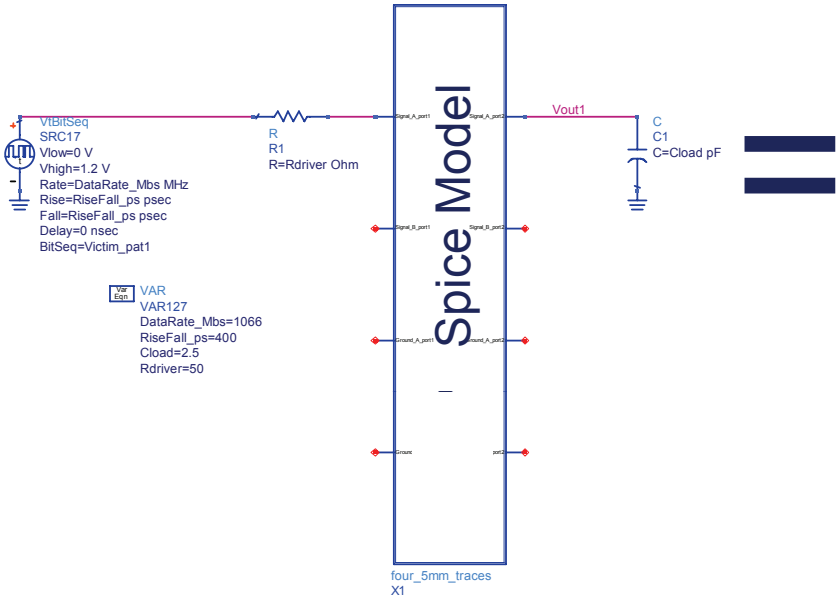
	Signal A	Signal B	Ground	Ground
Signal A	5.16E-09	3.78E-09	4.58E-10	4.52E-10
Signal B	3.78E-09	5.16E-09	4.64E-10	4.58E-10
Ground	4.58E-10	4.64E-10	5.16E-09	3.78E-09
Ground	4.52E-10	4.58E-10	3.78E-09	5.16E-09

Case 1
5 mm Traces

	Signal A	Ground	Signal B	Ground
Signal A	1.92E-08	1.49E-08	3.34E-09	3.30E-09
Ground	1.49E-08	1.92E-08	3.37E-09	3.34E-09
Signal B	3.34E-09	3.37E-09	1.94E-08	1.51E-08
Ground	3.30E-09	3.34E-09	1.51E-08	1.93E-08

Case 2
15 mm Traces

Sims with Global Ground Return Path



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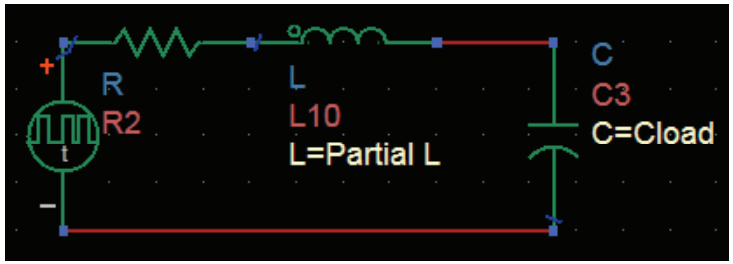
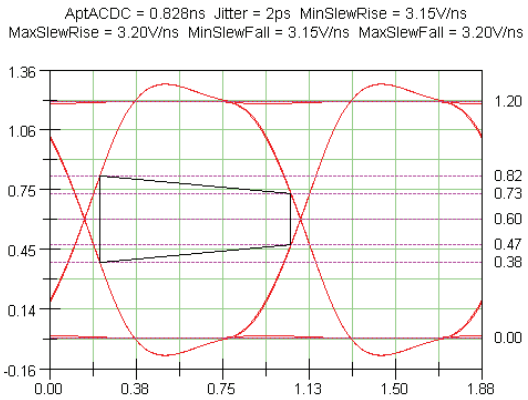
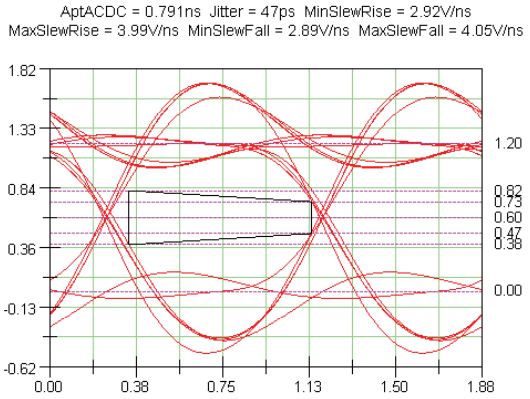


This sim creates a non-real loop with the trace as the only Segment. Inductance of **non-real loop** is trace partial inductance

Case 1 5 mm trace (Partial self L=5.16 nH)

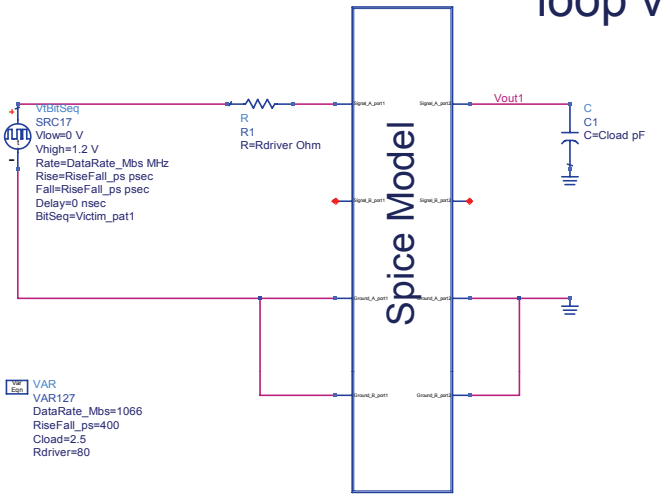


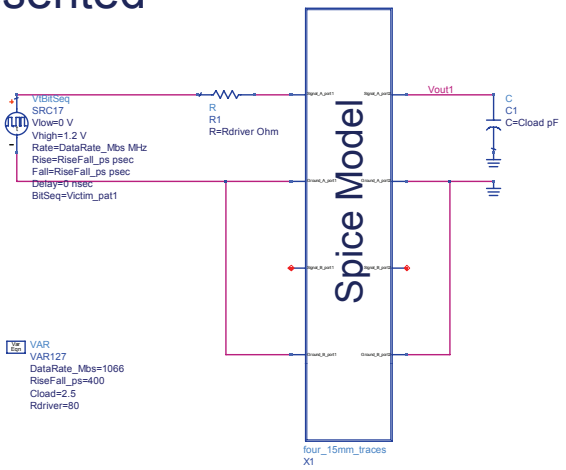
Case 2 15 mm trace (Partial self L=19.2 nH)



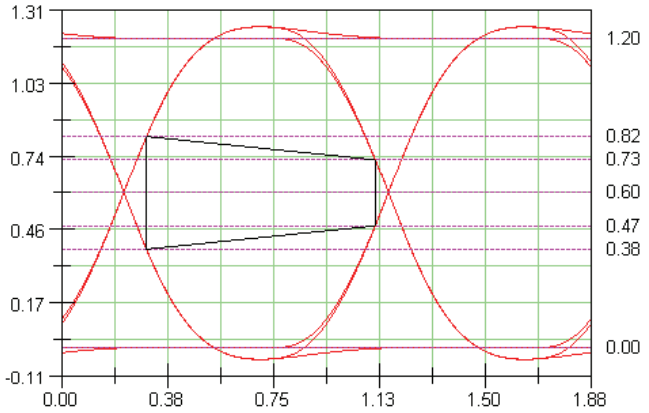
Sims with Return Paths

Spice model includes all partial and mutual inductances so correct loop values are represented



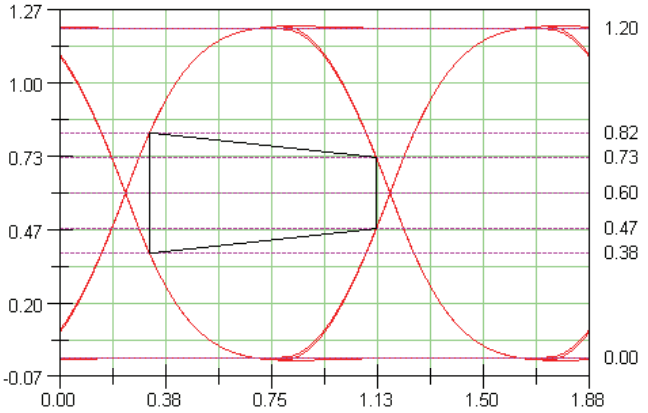


AptACDC = 0.81ns Jitter = 0ps MinSlewRise = 2.70V/ns
MaxSlewRise = 2.74V/ns MinSlewFall = 2.70V/ns MaxSlewFall = 2.74V/ns



Case 1 – 5 mm Trace

AptACDC = 0.803ns Jitter = 1ps MinSlewRise = 2.57V/ns
MaxSlewRise = 2.59V/ns MinSlewFall = 2.57V/ns MaxSlewFall = 2.59V/ns

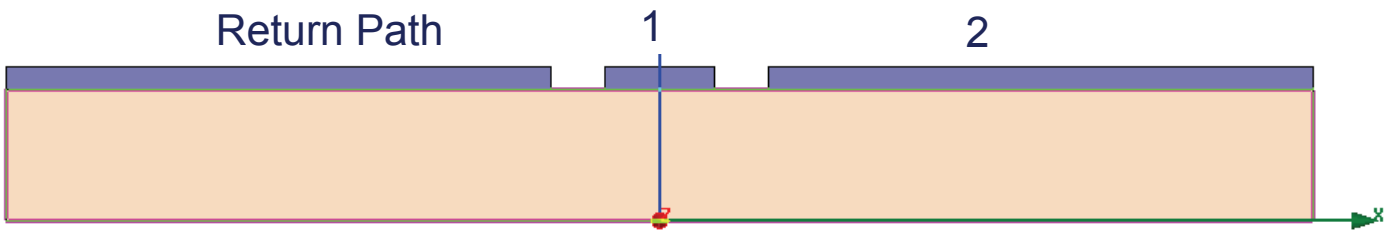


Case 2 – 15 mm Trace

Why Partial Inductances are Misleading

- Actual test case comparing various extraction tools
- Question? Which tool gives the correct partial inductances? Is conductor 1's self partial inductance 4.5 or 10.1?
- Answer? They are all correct! Partial inductance is only meaningful with respect to other partial and mutual inductances within a loop. Partial inductances can't be compared between tools or even different simulations on the same tool. Only loop inductances can be compared. In this case they are all within about 15%.

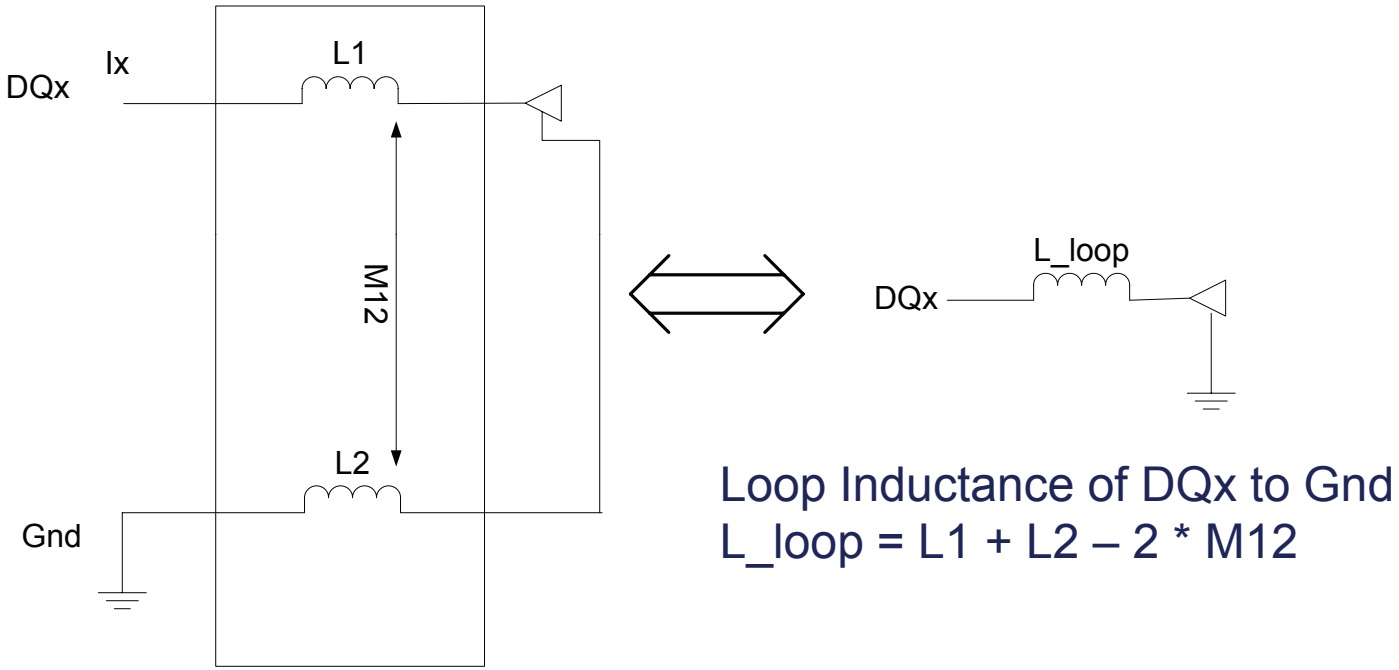
	A	B	C	D
Self Partial 1	5.280	4.533	10.072	10.100
Self Partial 2	5.856	5.375	9.022	9.261
Mutual 1-2	2.929	2.681	7.244	6.900
Loop 1-2	5.278	4.546	4.606	5.561



width of center trace	50	μm
width of reference	250	μm
width of gap	25	μm
thickness of trace/ref.	10	μm
height of substrate	60	μm
dielectric constant	4.5	
length of trace	10	mm

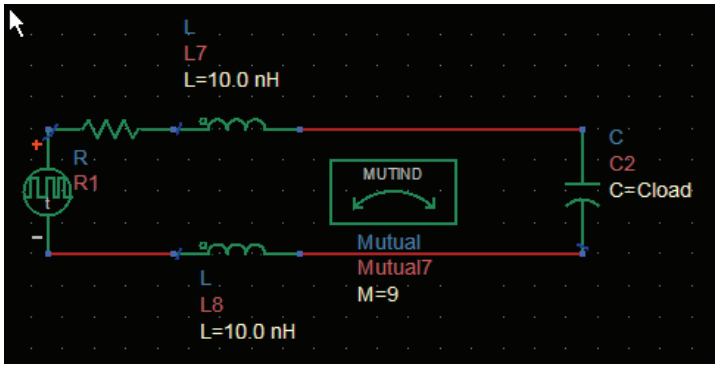
Signal Loop Inductance Model

These 2 circuits are equivalent



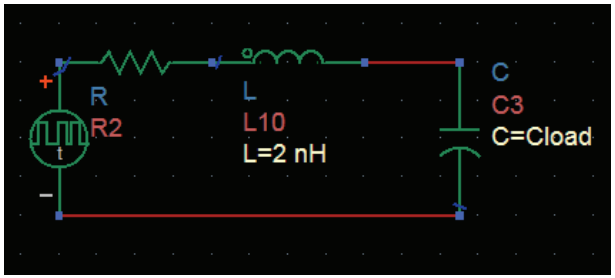
Loop Inductance of DQx to Gnd
L_loop = L1 + L2 – 2 * M12

Simulation with 2 Inductors

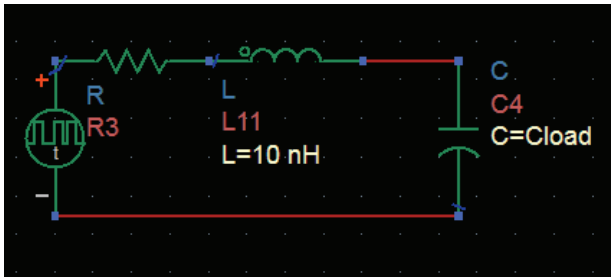


L-loop= 10 + 10 – 2*9 = 2 nH

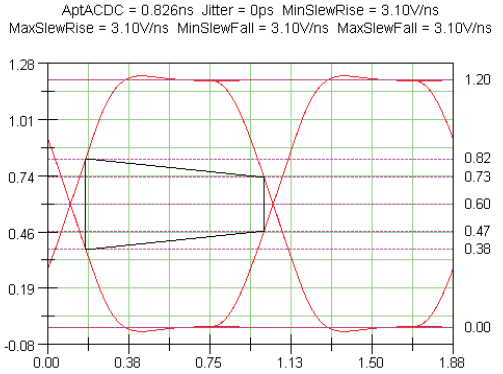
Equivalent Circuits

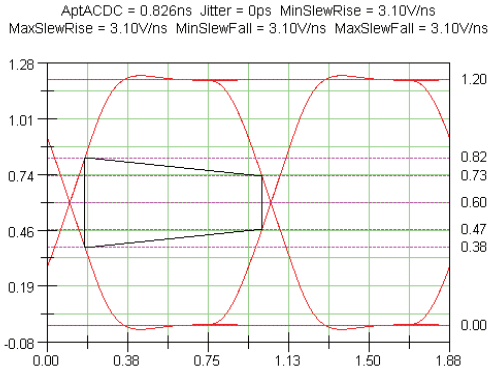


Single L=L_loop = 2nH

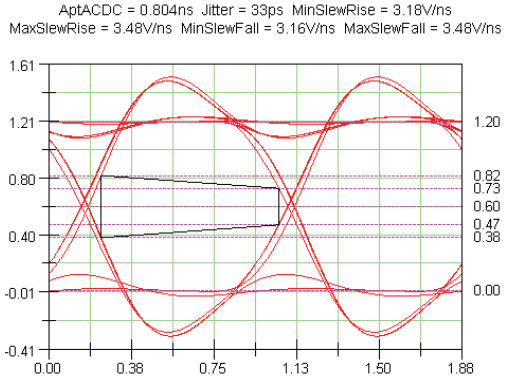


Single L=L_Partial = 10nH

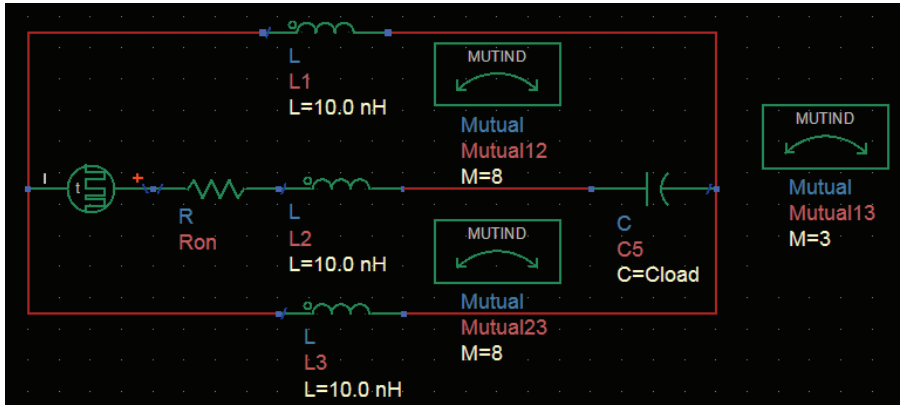




Incorrect result using only partial inductance and ignoring mutual terms

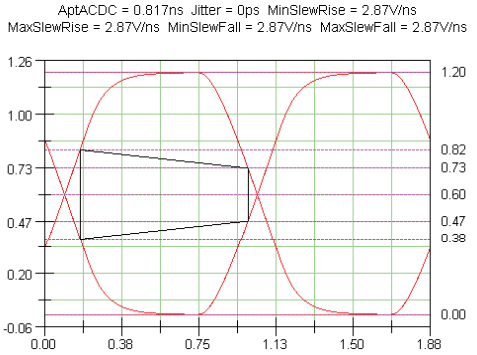


Simulation with 3 Inductors

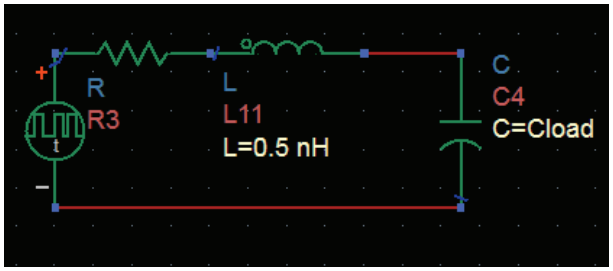


Equivalent loop L = 0.5 nH

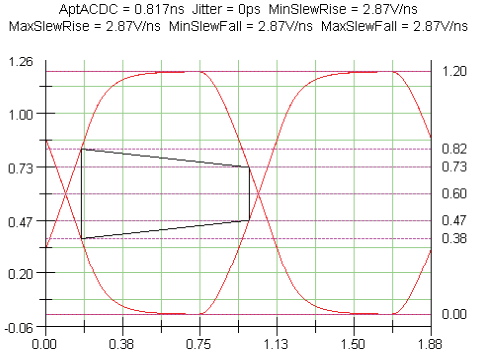
Note: With more than two inductors loop calculation becomes more complex

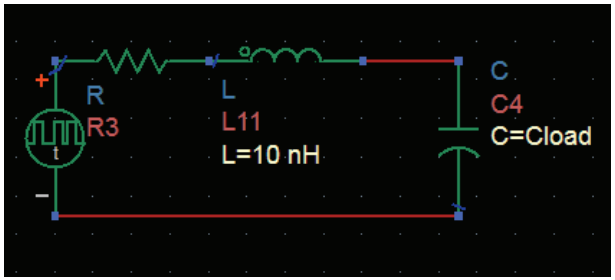


Equivalent Circuits



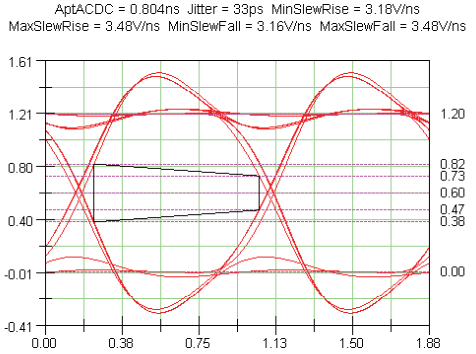
Single L=L_loop = 0.5nH





Single L=L_Partial = 10nH

Incorrect result using only partial inductance and ignoring mutual terms



Application to IBIS [Pin] and [Package Model]

[Pin]	signal_name	model_name	R_pin	L_pin	C_pin
A1	VSS	GND			
A2	DQ15	DQ_18	596.6m	4.09nH	1.61pF
A3	VSSQ	GND			
A7	VDDQ	POWER			
A8	DQ0	DQ_18	751.6m	5.59nH	1.80pF
A9	VDD	POWER			

- Where does the L_pin in the [Pin] list come from?
  - Is it the partial self inductance from a 3D field solver inductance matrix? VERY LIKELY!
  - L_loop is what you really want

    How do you get L_loop from the inductance matrix?

Micron's Loop Inductance Analyzer Tool

- Excel spreadsheet macro
- Reads in matrix data from several Field Solver tools
- Solves for loop inductance to power, ground, or both
- Correlates well to simulation, best with loop inductance to both power and ground

Signal	Simulator Optimized L Value (nH)	Matrix Analyzer Value (nH)	Delta (%)
DQ0	2.783	2.785	0.08%
DQ1	1.624	1.625	0.09%
DQ2	1.294	1.295	0.08%
DQ3	1.425	1.425	0.05%
DQ4	2.020	2.021	0.04%
DQ5	2.900	2.902	0.05%
DQ6	2.439	2.437	-0.09%
DQ7	2.899	2.904	0.17%

Micron's Loop Inductance Analyzer Tool

- Separate analyses are run for Address/Command and DQs due to separate power and ground return paths
  - VDD and VSS versus VDDQ and VSSQ

Line number	Line Name	Definition
1	U1:A0:112|aPadE<0>	Signal
2	U1:A1:111|aPadE<1>	Signal
3	U1:A2:110|aPadE<2>	Signal
4	U1:A3:109|aPadE<3>	Signal
37	U1:DQ15:21|DqPad<23>	Other
38	U1:LDM:64|DmPad<1>	Other
39	U1:LDQS:65|DqsPad<1>	Other
40	U1:RAS#:117|RasPadEF	Signal
41	U1:SV:138|SVPadsW	Other
42	U1:UDM:34|DmPad<2>	Other
43	U1:UDQS:33|DqsPad<2>	Other
44	U1:VDD:62|vccx	Power return
45	U1:VDDQ:72|vccq	Other
46	U1:VSS:2|gnd	Ground return
47	U1:VSSQ:8|vssq	Other
48	U1:WE#:119|WePadEF	Signal

Problems with [Package Model]

- Sparse_Matrix package models in combination with [Pin Mapping] have all the data necessary to correctly model loop inductance
- Many tools use the Partial Self Inductance term from the [Package Model] inductance matrix when modeling a single pin. This is NOT correct.
- So, which is a better single line model?:
  - [Pin] model with the correct loop inductance 
  - [Package Model] with partial self inductance

Conclusions

- Partial Inductance numbers directly from 3D Field Solvers provide minimal information and can be misleading
- For simulations assuming ideal power delivery the appropriate loop self and mutual inductances should be used. The partial self inductances off the diagonal of the inductance matrix should NOT be used.
- A sparse matrix [Package Model] can be less accurate than a [Pin] model if mutual inductances to power and ground are not part of the final EDA tool package model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