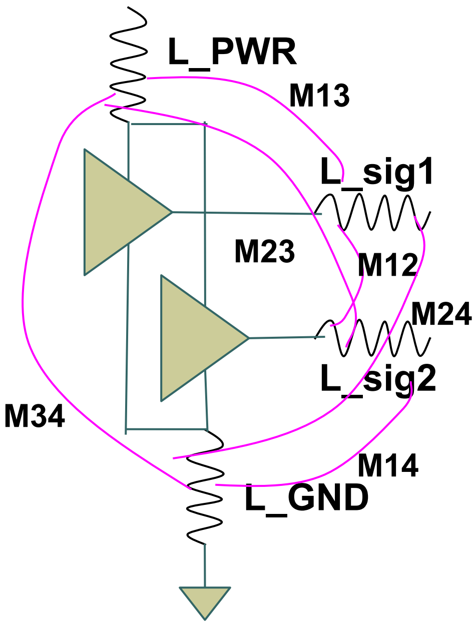
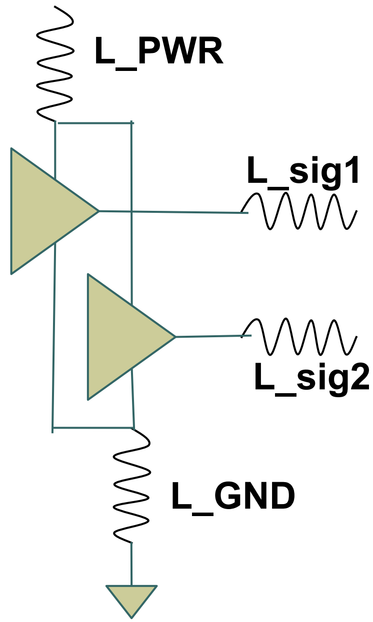
The myth about ideal ground

Zhiping Yang, Ph.D.
Google

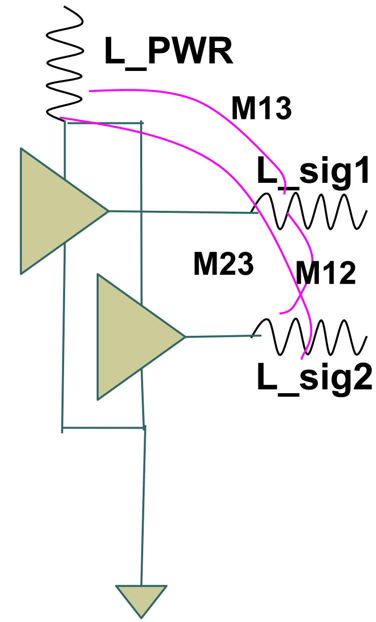
Quiz



A



B



C

Which package model is the best at **high frequency**?

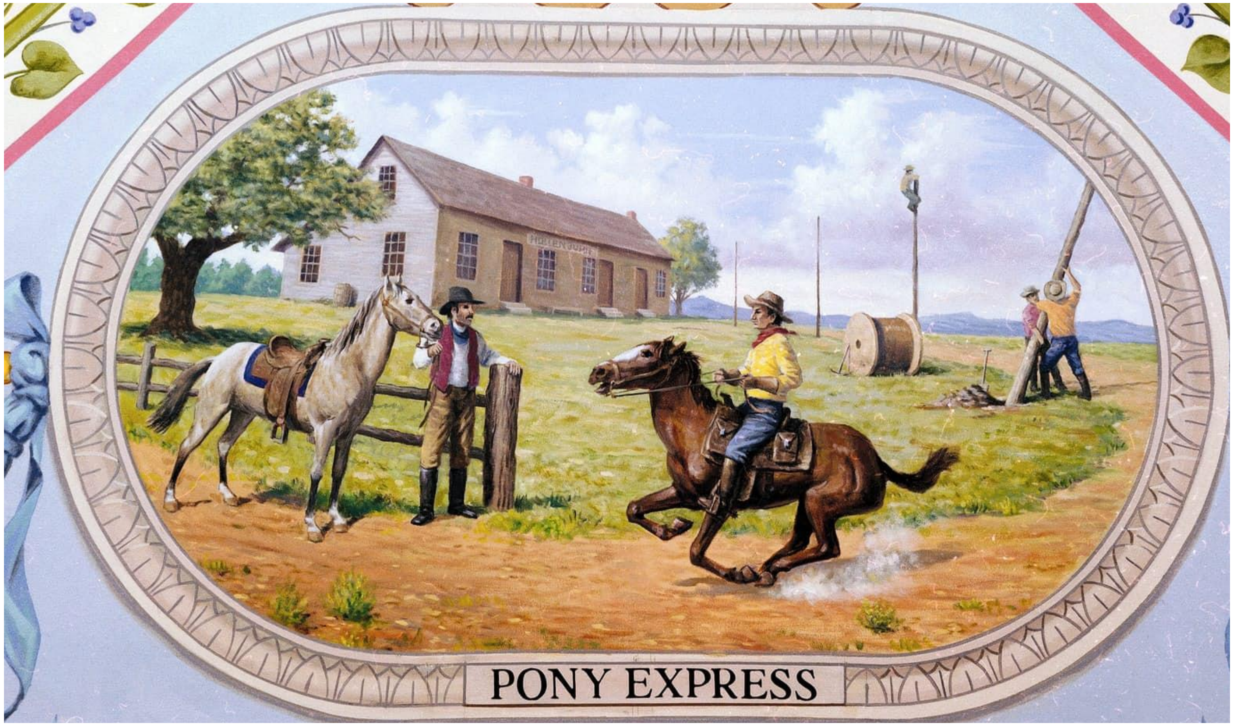
Content

- What are the myths about *ground*
- History of *ground* in electrical design
- Terms related to *ground*
- A package example with signal and *ground* nets only
- A package example with *ground*, signal and power nets
- S-parameter and W-element models in high-speed modeling and simulation
- Conclusions

What are myths about ground

- Myth #1: Does ideal ground really exist? If not, why do we use it in modeling and simulation?
- Myth #2: Should we put partial inductance and resistance on the ground net? (i.e. is ground bounce real?)
- Myth #3: Should I have a different reference node for each port of W-element or S-parameter model?

History of ground in electrical design

- *Ground* was first used by telegraph system to reduce wiring cost. (Discovered by German scientist Carl August Steinheil in 1836-1837)
- 

History of ground in electrical design

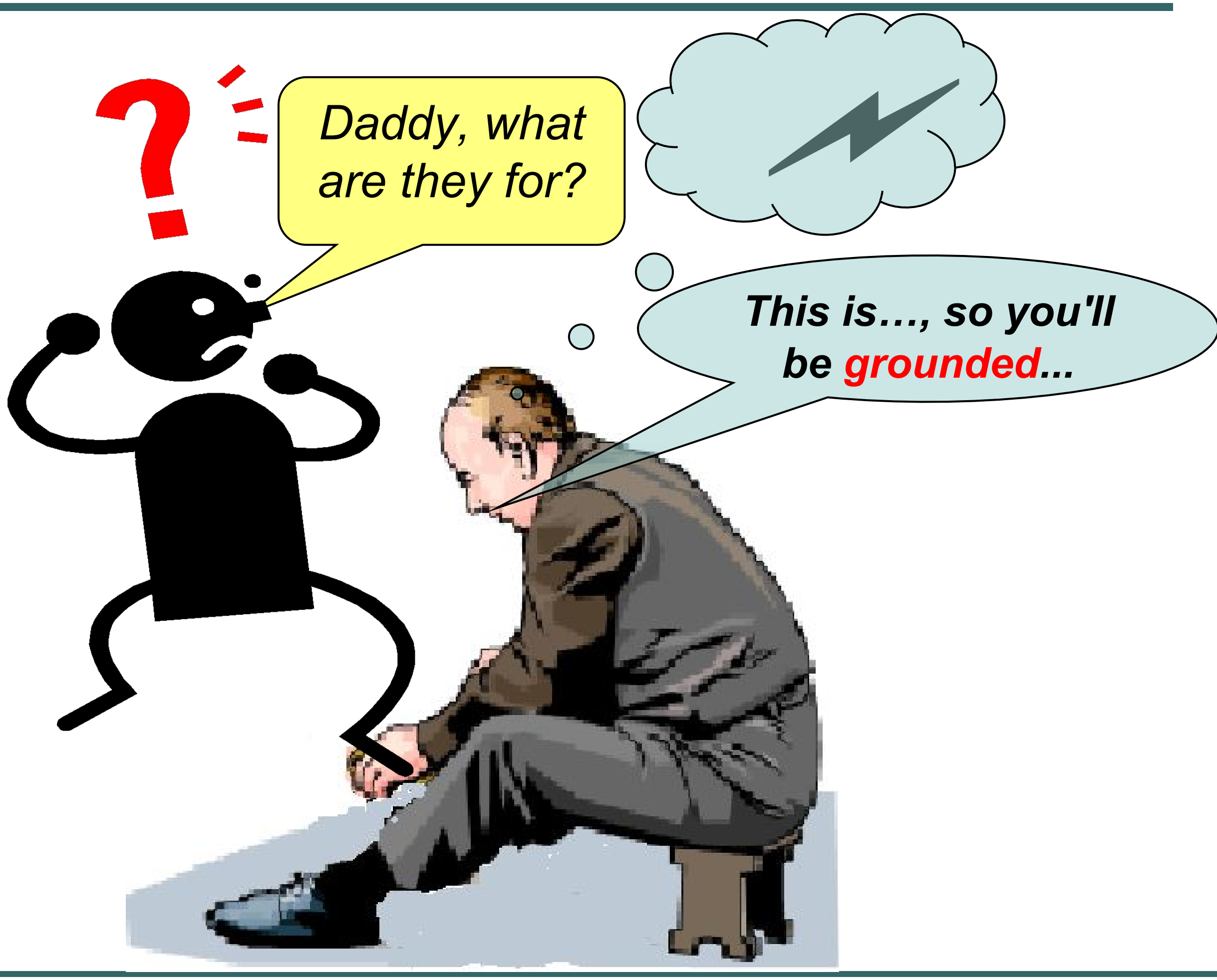
- Later, power engineers used the *ground* as return path in Single Wire Earth Return (SWER) electrical distribution system
- The *ground* is connected to protective earth (PE) or Neutral (N) conductor of modern power systems for prevention of electrical shock (Safety) and fault detection and protection
- The *ground* of circuit boards and IC chips are typically connected to the metal box and ground of AC power systems

History of ground in electrical design (continued)

- The *ideal ground* concept (zero voltage and infinite current sink capability) was introduced to analog and digital circuits to simplify circuit schematics and analysis.
- The *ideal ground* node was used in SPICE-type simulators to solve KCL and KVL more effectively.
- At high frequency, the concept of *local ground/reference* was used to get more precisely and meaningful results

One of the unwanted misimpressions from ideal ground node: The voltage signal can travel from driver to receiver on a single wire.

A true story about ground



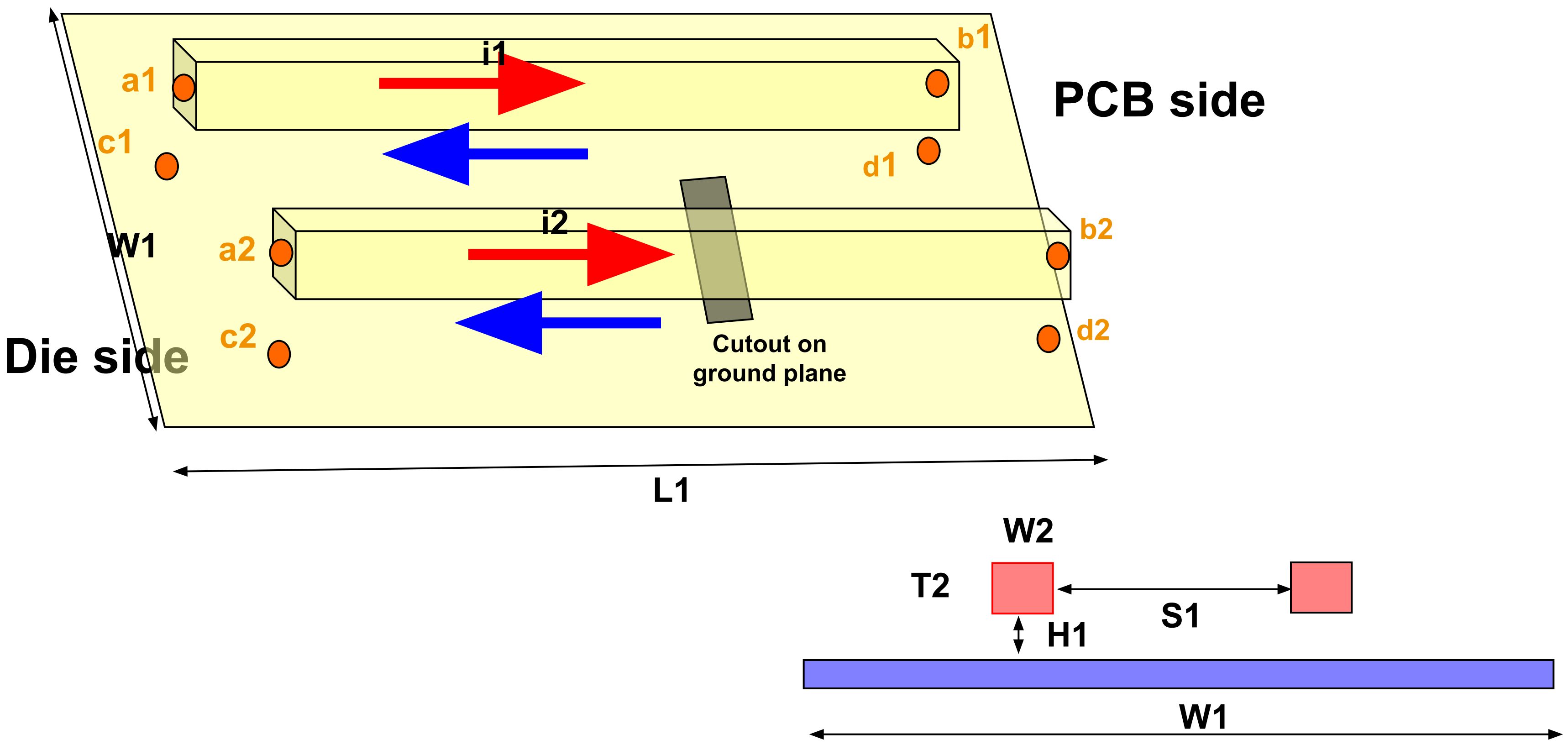

Grounded!
GROUNDED? What did I do wrong?!!

Terms related to ground

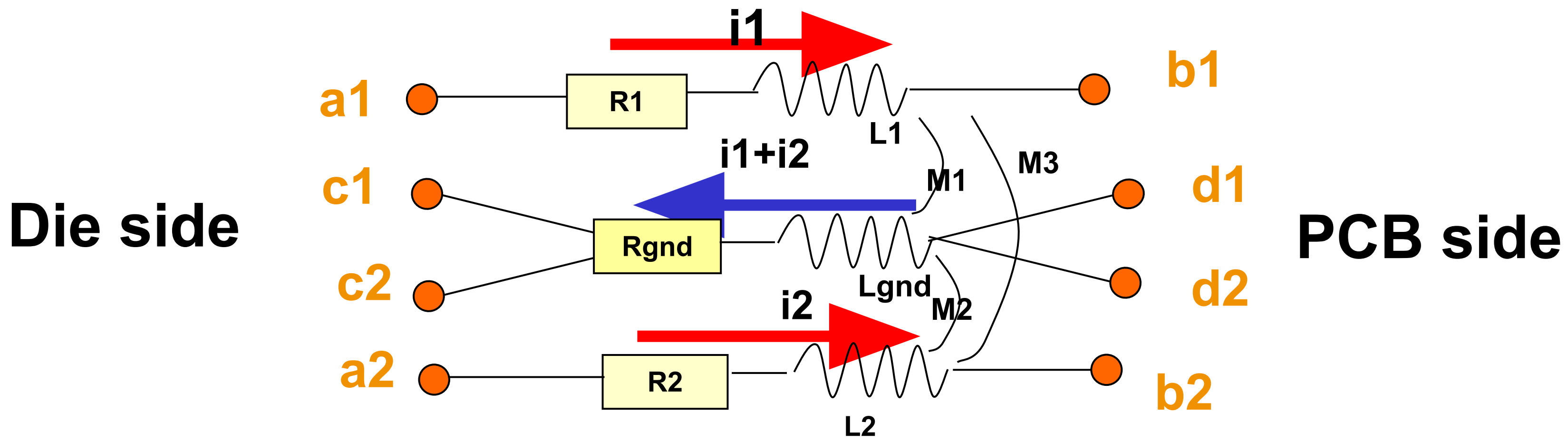
- ***Global Ground***, ***Ideal Ground*** and ***Virtual Ground***
- ***Local Ground*** or ***Local reference***
- ***Self Loop Inductance***, ***Mutual Loop Inductance, Partial Self Inductance, Partial Mutual Inductance, Partial Loop Self Inductance***, and ***Partial Loop Mutual inductance.***
- ***Ground Bounce, Power Bounce*** and ***Voltage Bounce***.

"***Ground*** is a place where potatoes and carrots thrive"—by Bruce R. Archambeault, PCB Design for Real-World EMC Control

A package example with signal and ground nets only



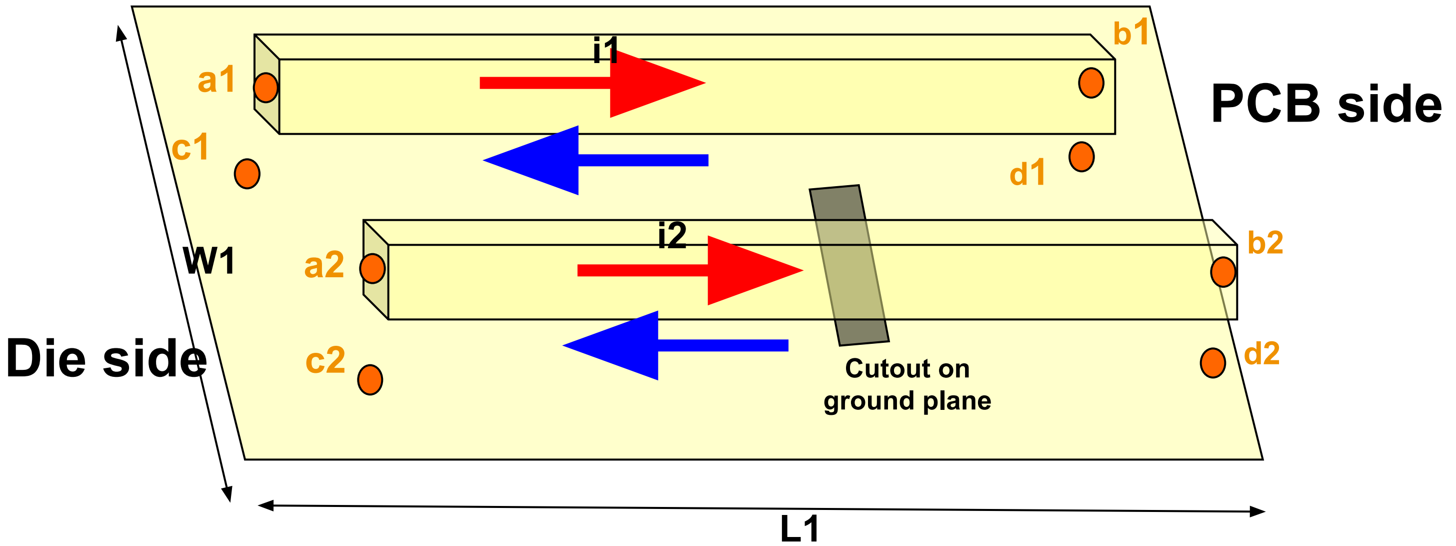
A valid circuit model at low frequency

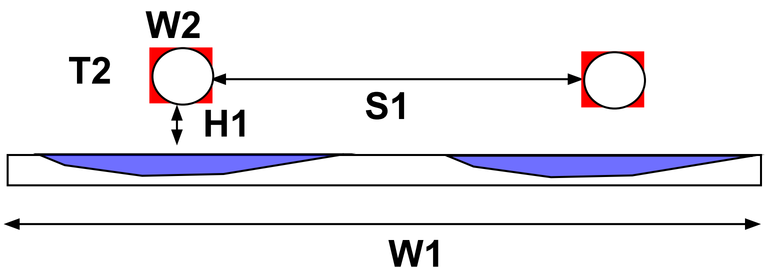


Good things about this model:

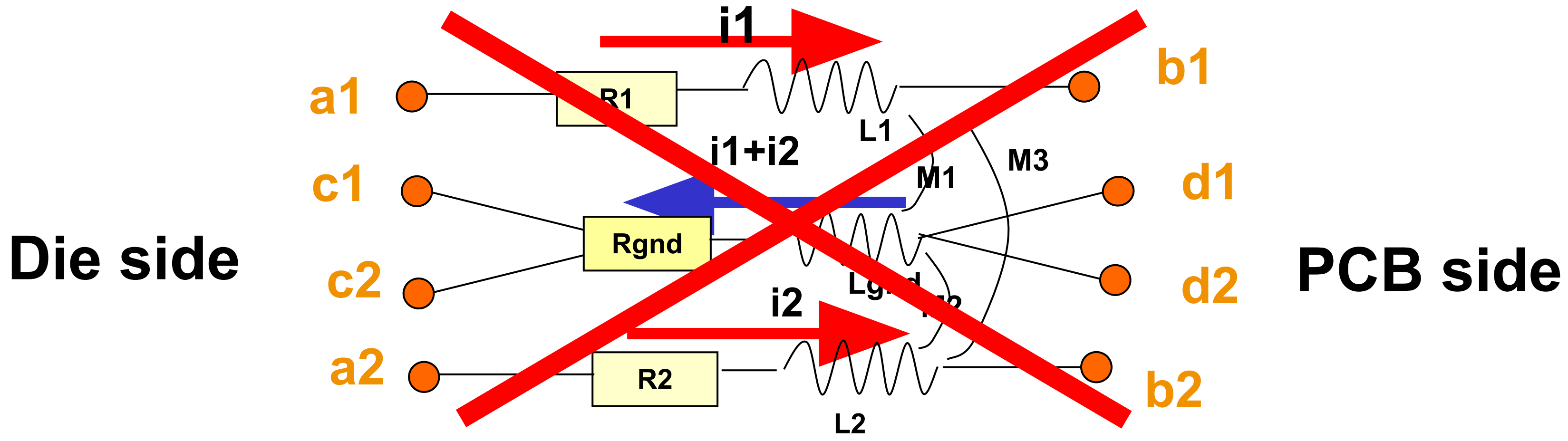
1. It is valid at very low frequency at which current is evenly distributed across the ground plane and c1 & c2 (d1&d2) have the same voltage potential.
2. You can actually probe the voltage across any two points in this circuit and it is meaningful and could match the measured data very well, so ground bounce (voltage difference between c1/c2 and d1/d2) is well defined.

What could change at high frequency?





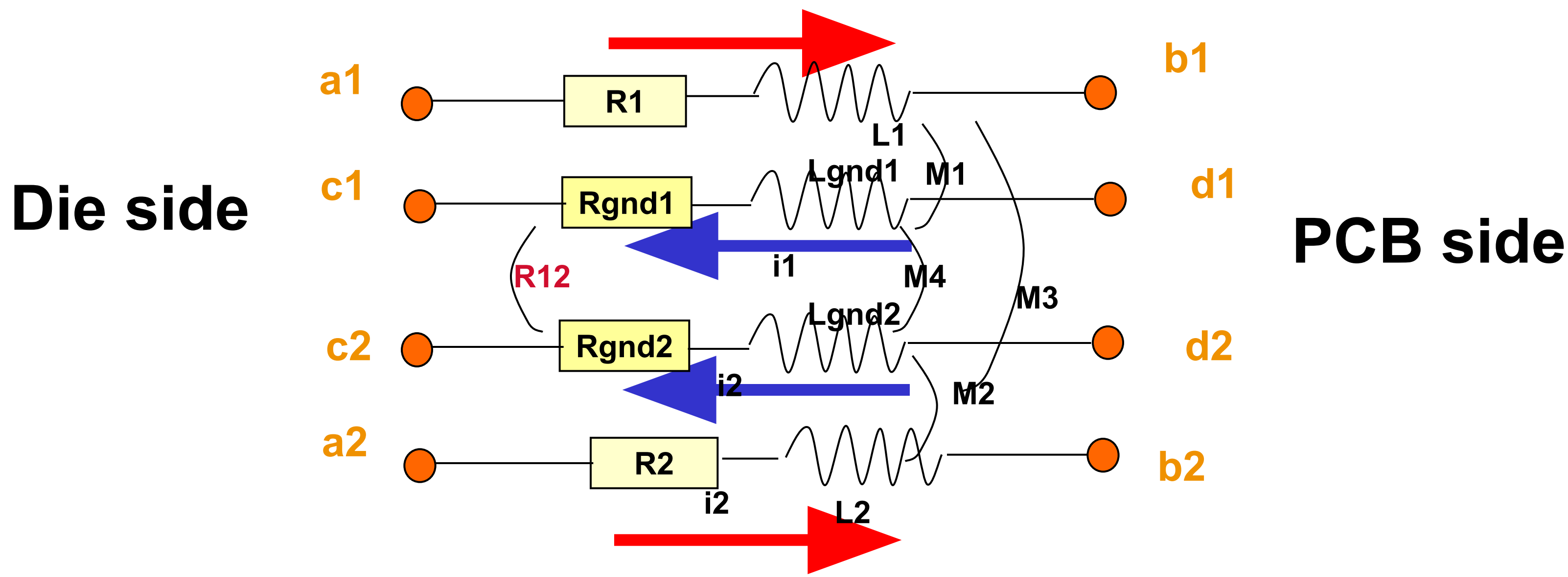
Is previous low-frequency model still valid at high frequency?



What could be wrong with this model?

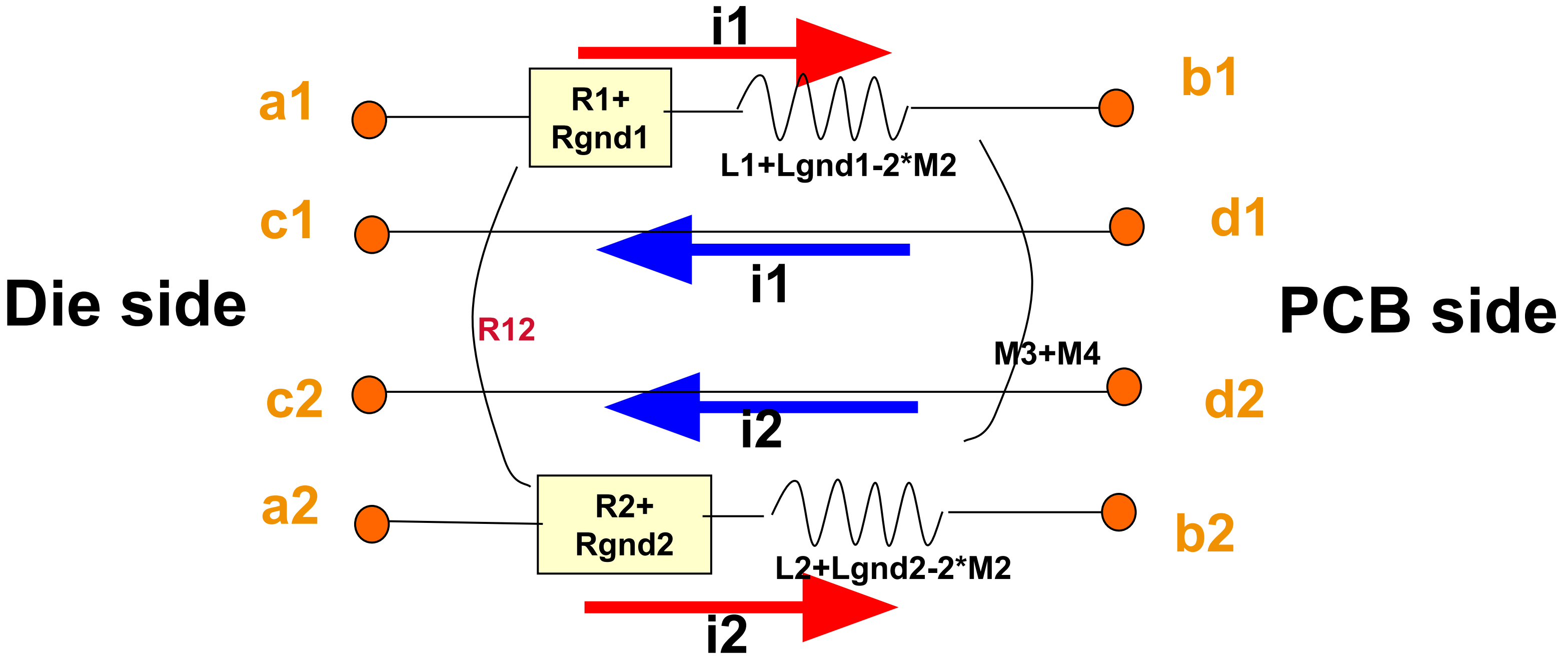
1. **It is clearly shown that the return current for conductor 1 and 2 are not the same. How can Rgnd and Lgnd be well defined?**
2. **How to separate the L1, Lgnd and M1 from the physical loop inductance? No unique definition for L1, Lgnd and M1.**
3. **At high-frequency, when wavelength is close to the structure size, (such as L in the previous figure), the voltage is not well defined between die ground and PCB ground. Local reference voltage definition is the only meaningful voltage at high frequency.**

A working circuit model at high frequency



Compared with the previous model, the above is a much better and accurate model. The only drawback is too many components (especially partial and mutual inductances) and these inductances are not well defined. Since we only care about the voltage with local reference, this model can be further simplified by model reduction.

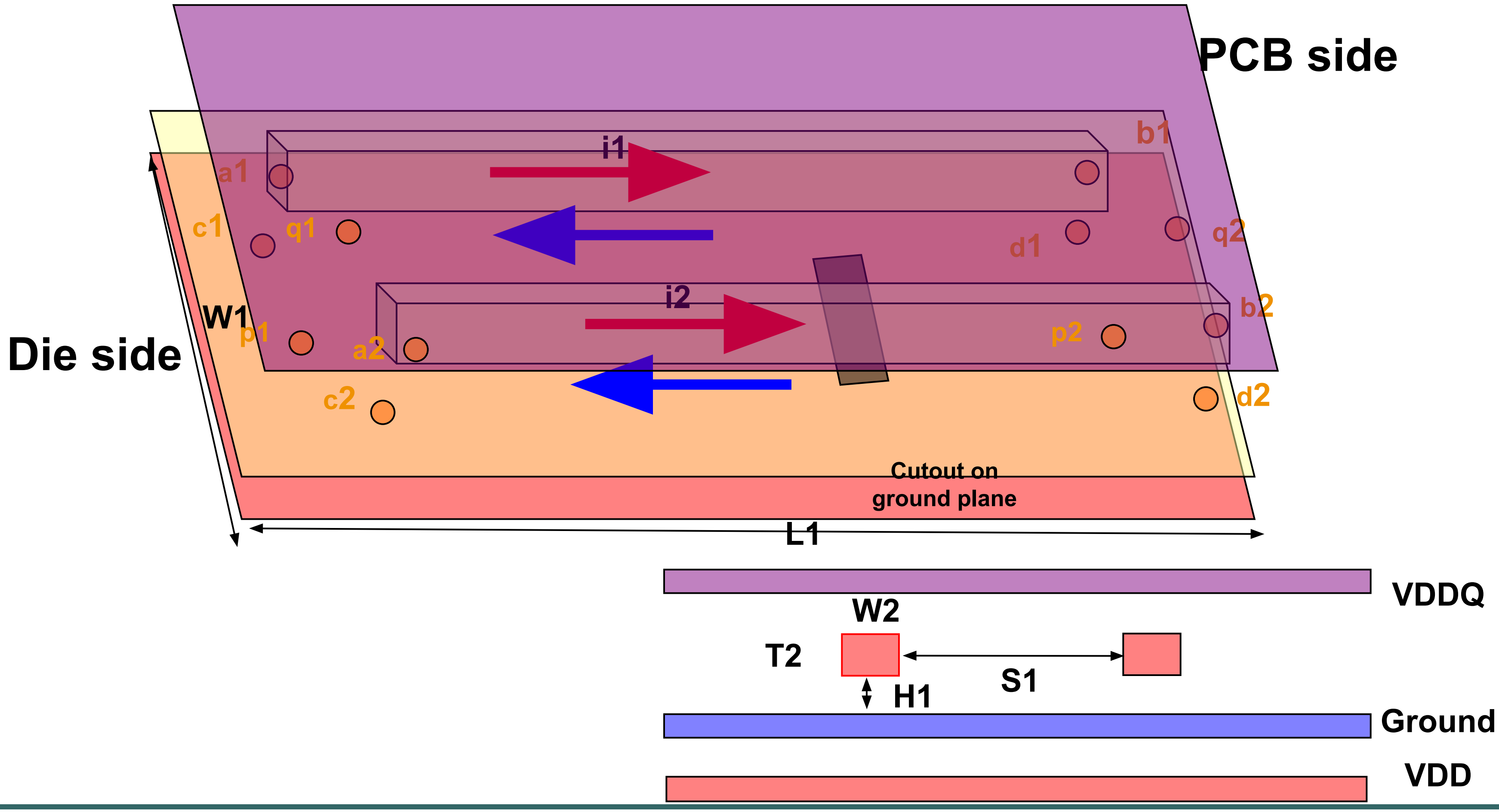
A Simplified and better model



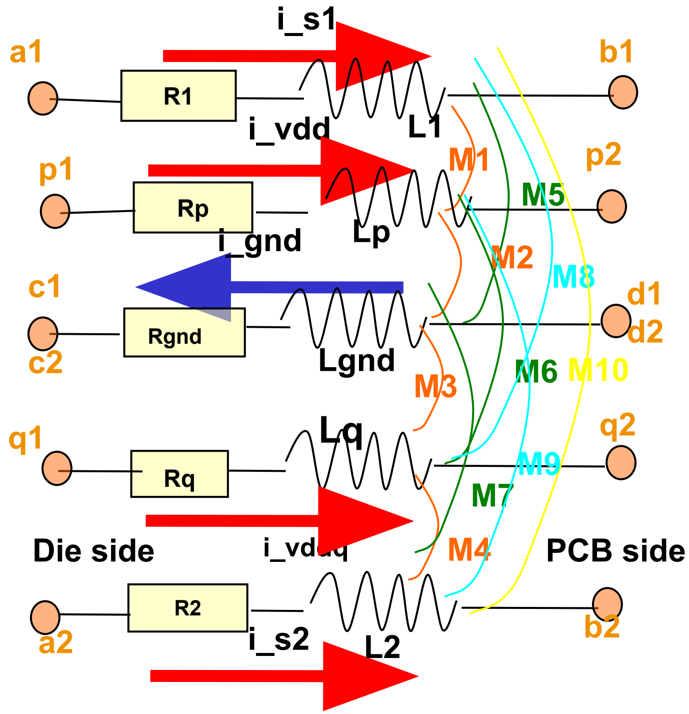
This model is much simpler and it is accurate from DC to very high-frequency. All components in this circuit are well defined and have unique physical meanings.

The ground nodes c1/c2/d1/d2 could be shorted together (by doing so, it loses the mapping between physical locations and circuit nodes.

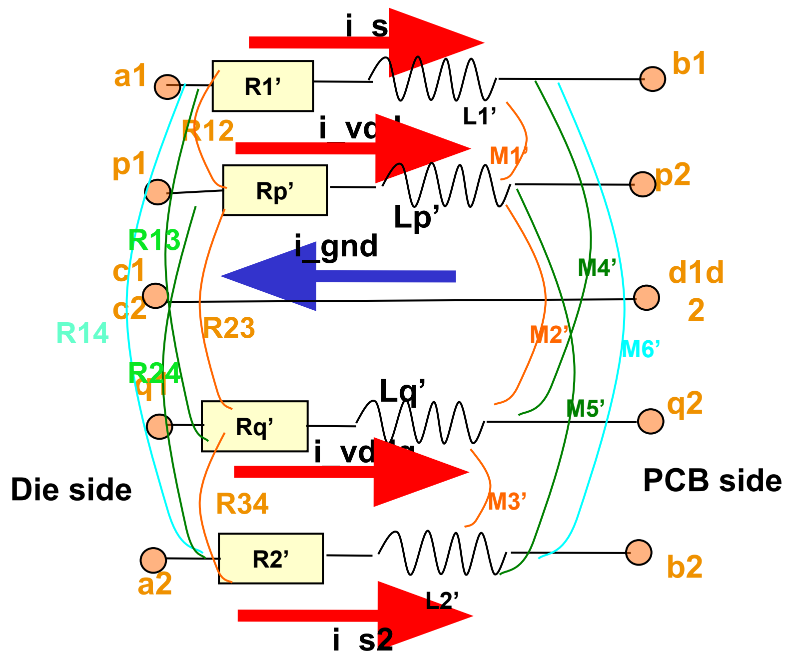
A package example with power, signal and ground nets



Which package model is better?

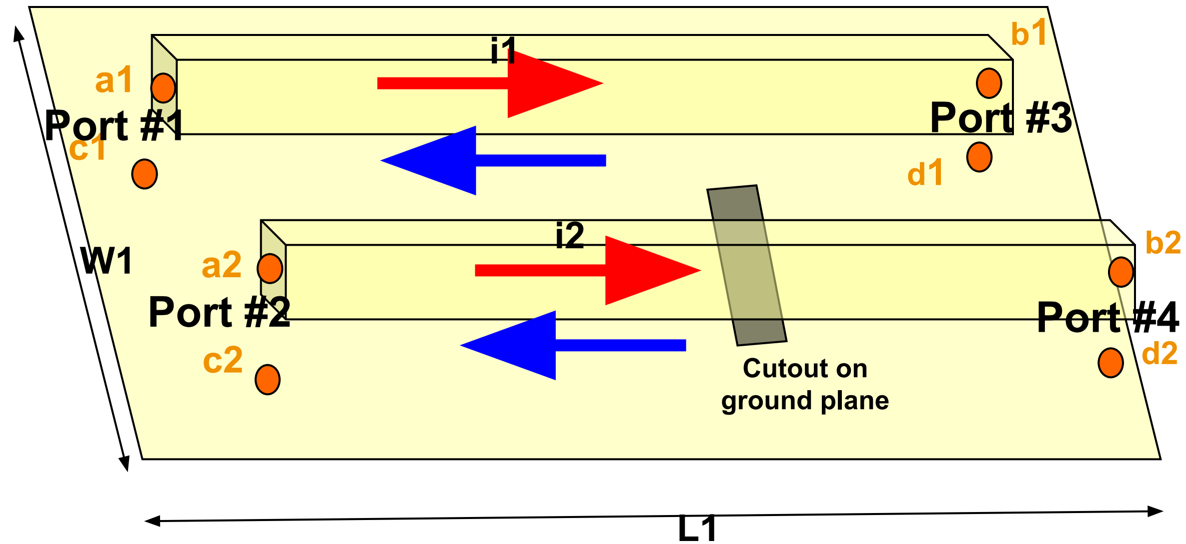


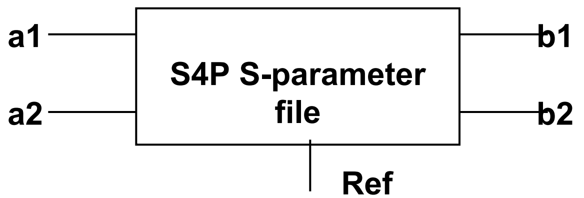
a. Package model with ground parasitic



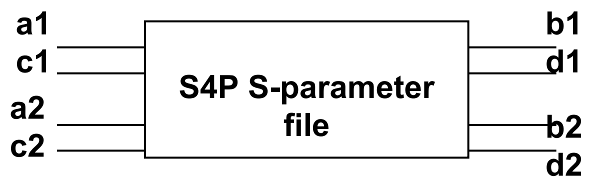
b. Package model without ground parasitic

S-parameter and W-element model in high-speed modeling and simulation



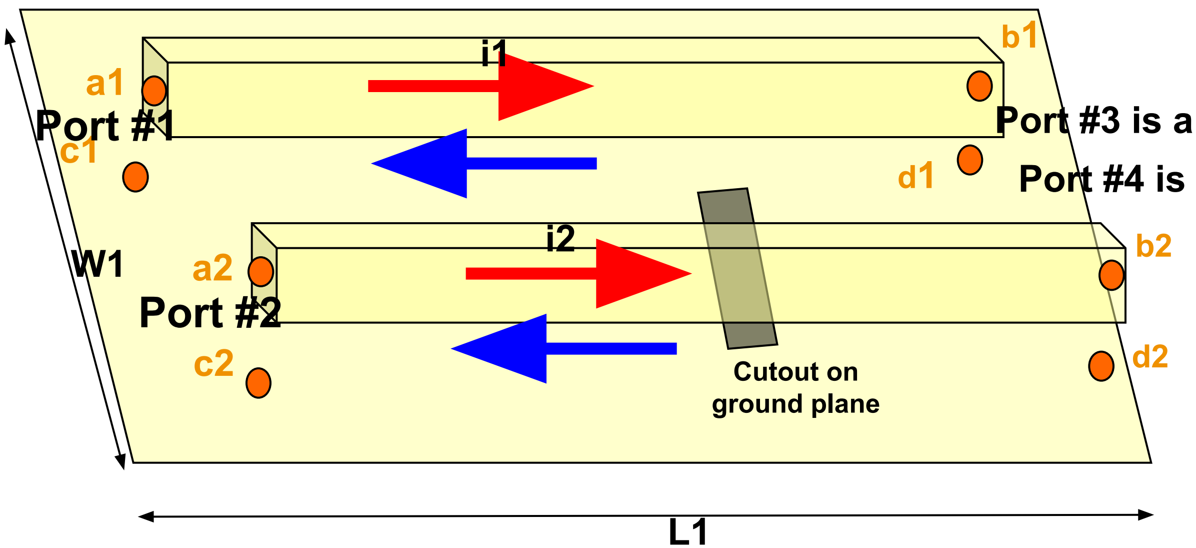


a. S-parameter file connection case #1



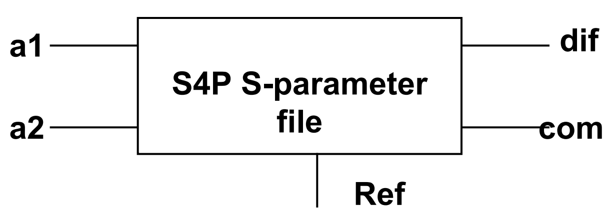
b. S-parameter file connection case #2

More complicated port settings

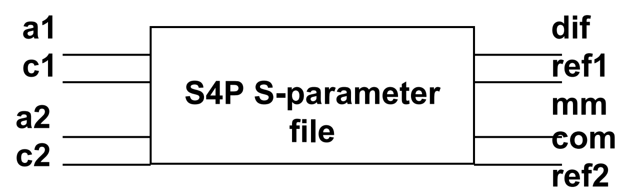


Port #3 is a differential-mode port

Port #4 is a common-mod port



a. S-parameter file connection case #1

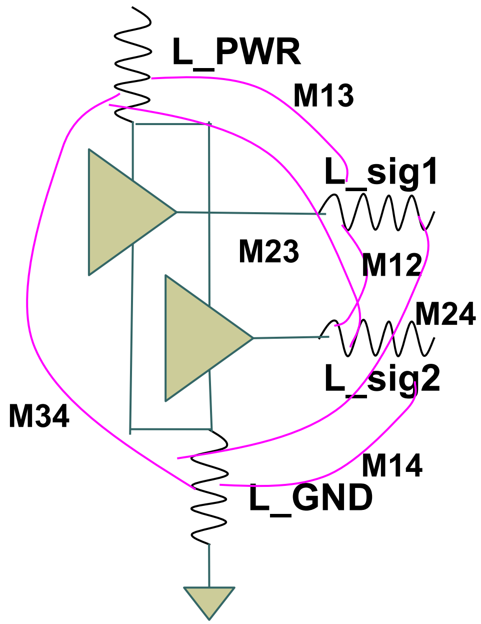


b. S-parameter file connection case #2

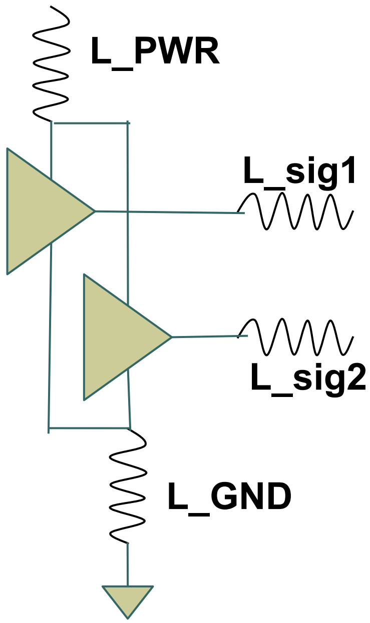
Suggestions for the application of S-parameter model

- Do not add circuit components between positive port terminals if their negative terminals are not defined on the same surface and conductor(s).
- It is better to have common reference conductor(s) for all ports located on the same surface.

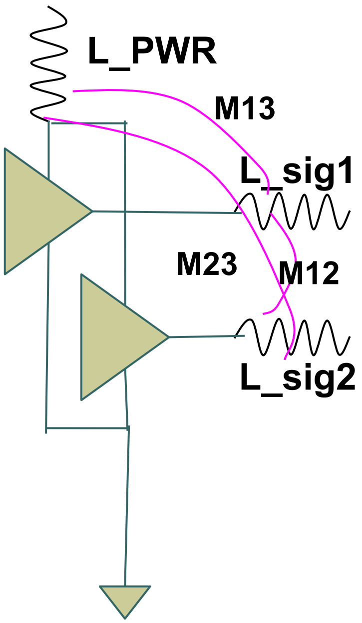
Quiz



A



B



C

Which package model is the best at **high frequency**?

Conclusions

- Ground bounce and power bounce are only valid terms at low frequency.
- Voltage bounce is more precise and should be used at high frequency.
- Partial loop inductance and partial mutual inductance are well defined and have unique values.
- Package model without parasitic in ground net is not only valid, but also more computationally effective and accurate.
- S-parameter based model should be connected with other circuit elements in ways which are consistent with the port definition when it was extracted.

Q&A

?