IEEE SW Test Workshop
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Issues in Power Delivery System Performance Verification

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Objective

- Review power and ground path integrity
- Examine model and measurement approaches
- Show some limitations and workarounds

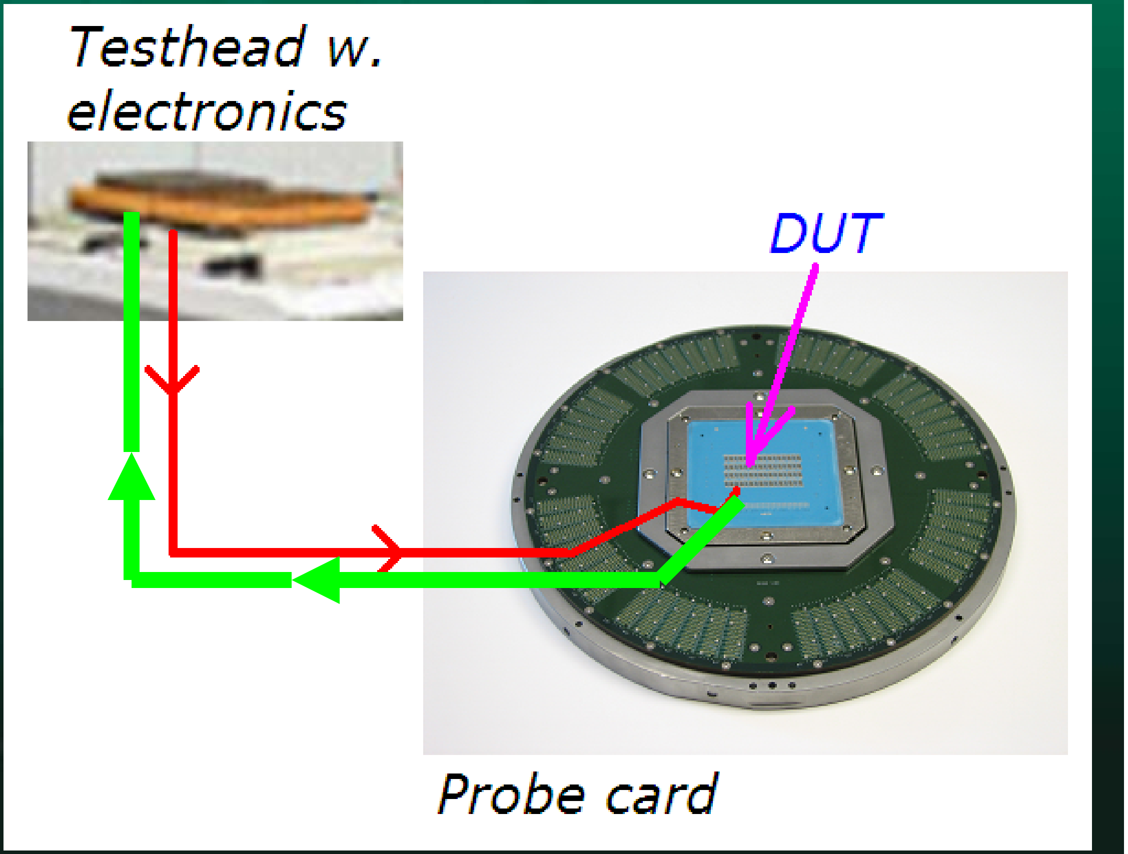
Approach

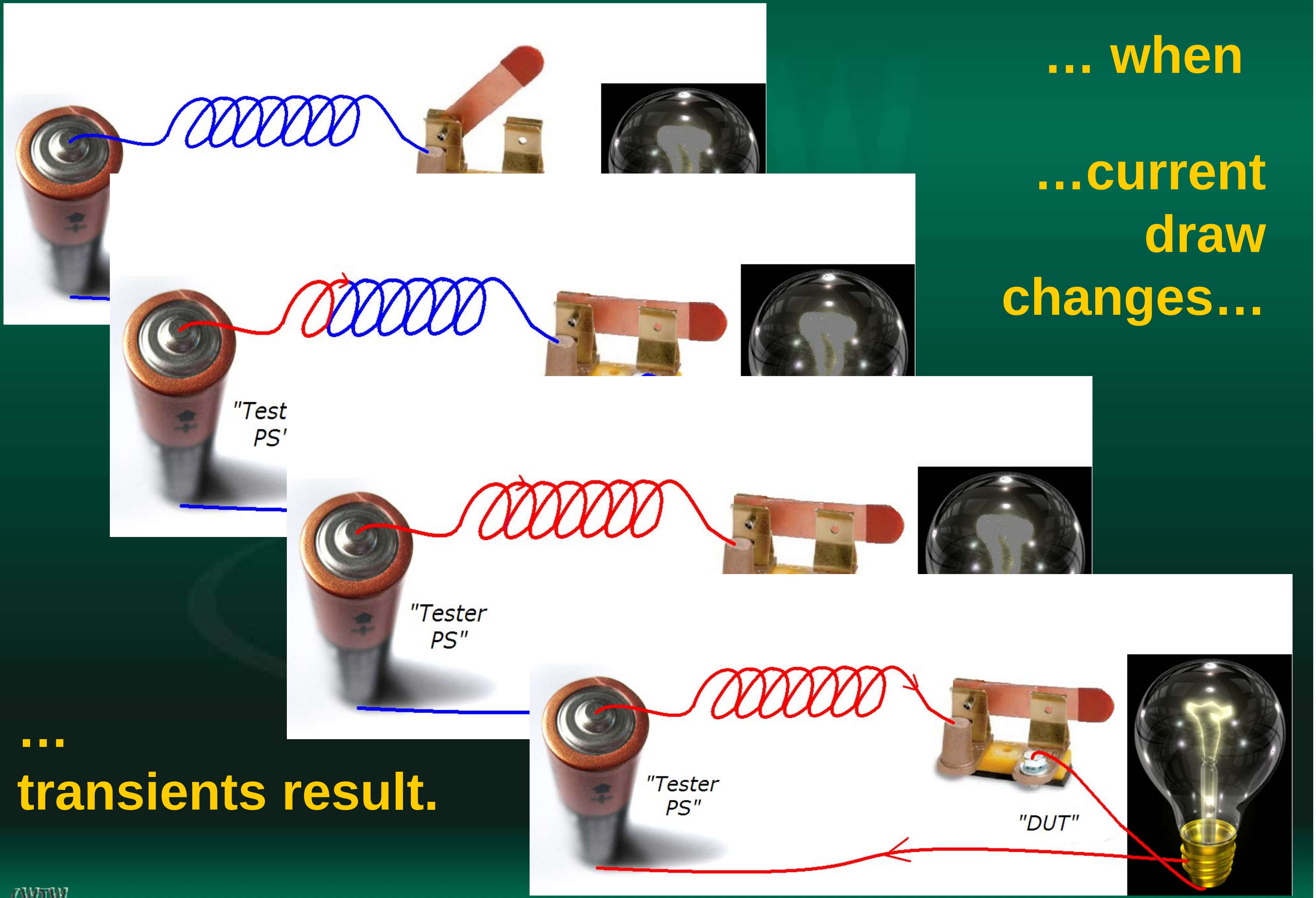
- **Examine power path in a probe card**
- **Illuminate power delivery system integrity requirements (aka power delivery network)**
- **Use models and measurements to evaluate performance**
- **Provide a workable verification approach**

Physical environment

Typical test system

Power travels from tester to DUT over a considerable distances compared to switching times of the devices under test, thus…….





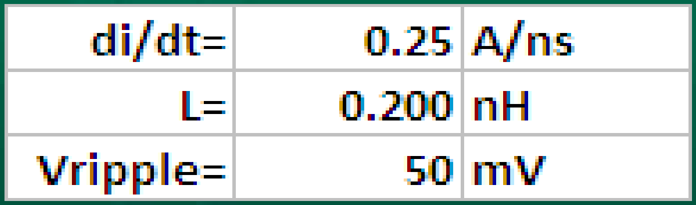
… when

…current draw changes…

… transients result.

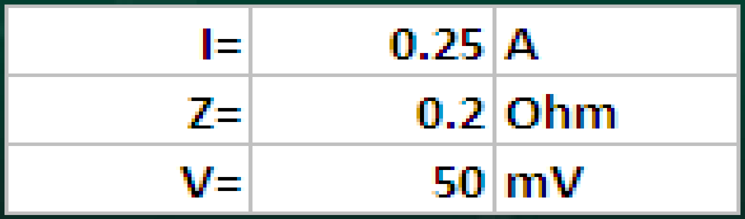
Noise and impedance example

- **Sudden current draw results in a voltage according to V=L*di/dt**



di/dt=	0.25	A/ns
L=	0.200	nH
Vripple=	50	mV

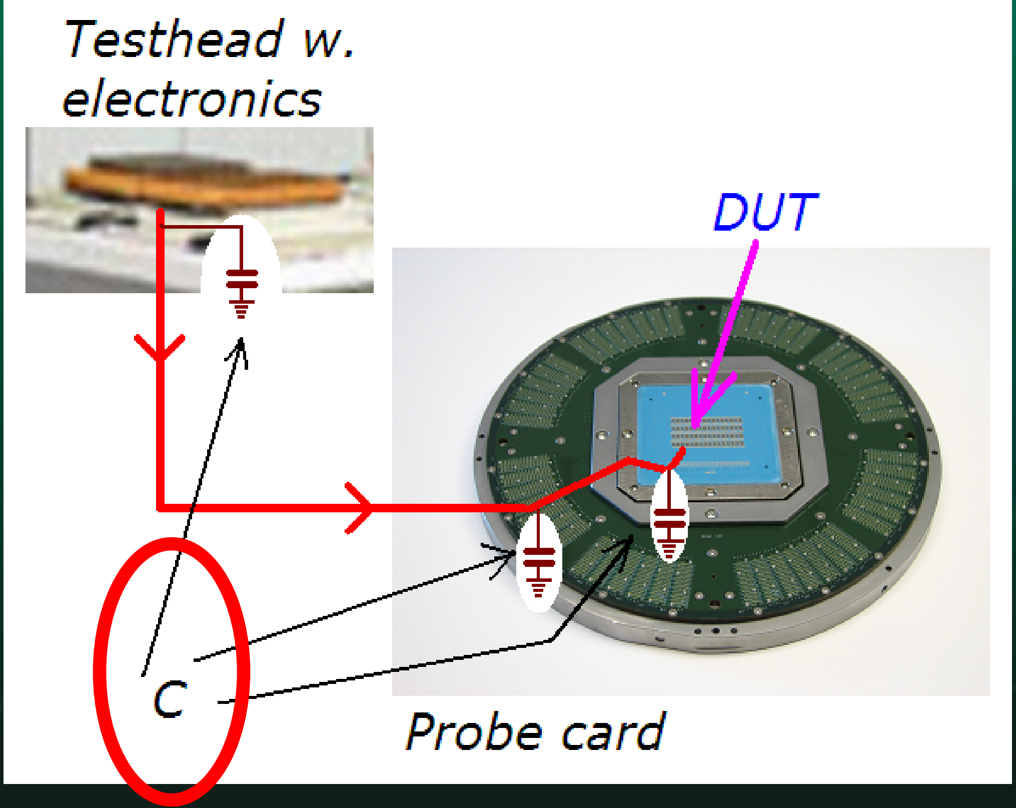
- **Impedance at a particular frequency is an alternate way of expressing noise voltage: V=Z*i**



I=	0.25	A
Z=	0.2	Ohm
V=	50	mV

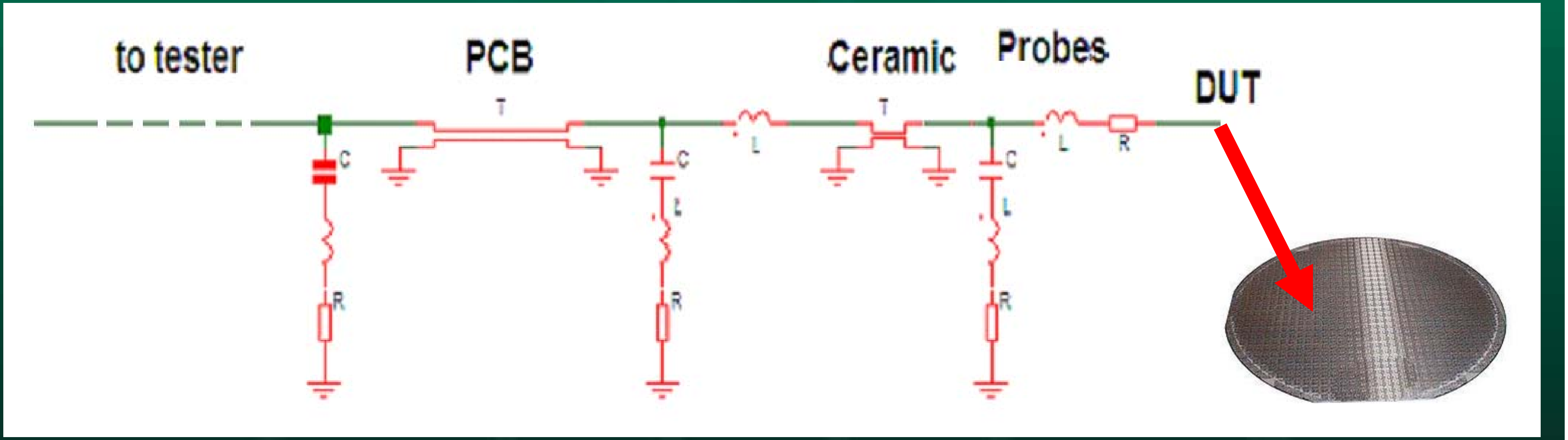
$$Z_{PDS} = R + jX$$

Remedy: Additional energy storage



Bypass capacitors (C) provide additional energy during times of sudden high demand

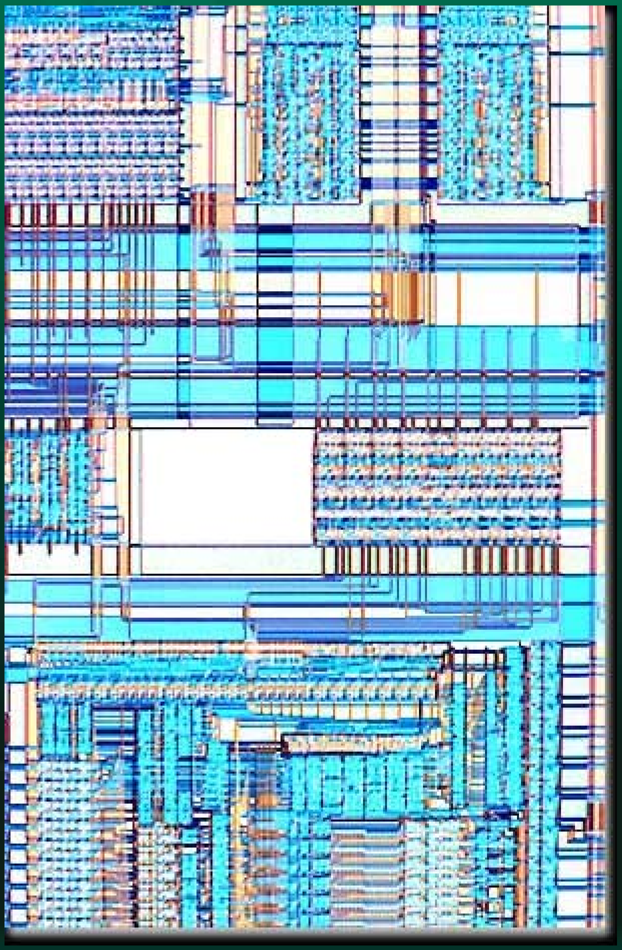
Tester to die path model



Components of the power delivery system (PDS)
{ P/G planes act as low Z transmission lines ‘T’ }

Power distribution inside DUT ?

- **Problem – probe card manufacturer often doesn't know precisely what's in the DUT**



Design

- PDS impedance specification provided by IC manufacturer
    - $Z_{PDS} = R + jX$
- Power delivery system performance depends on path and position

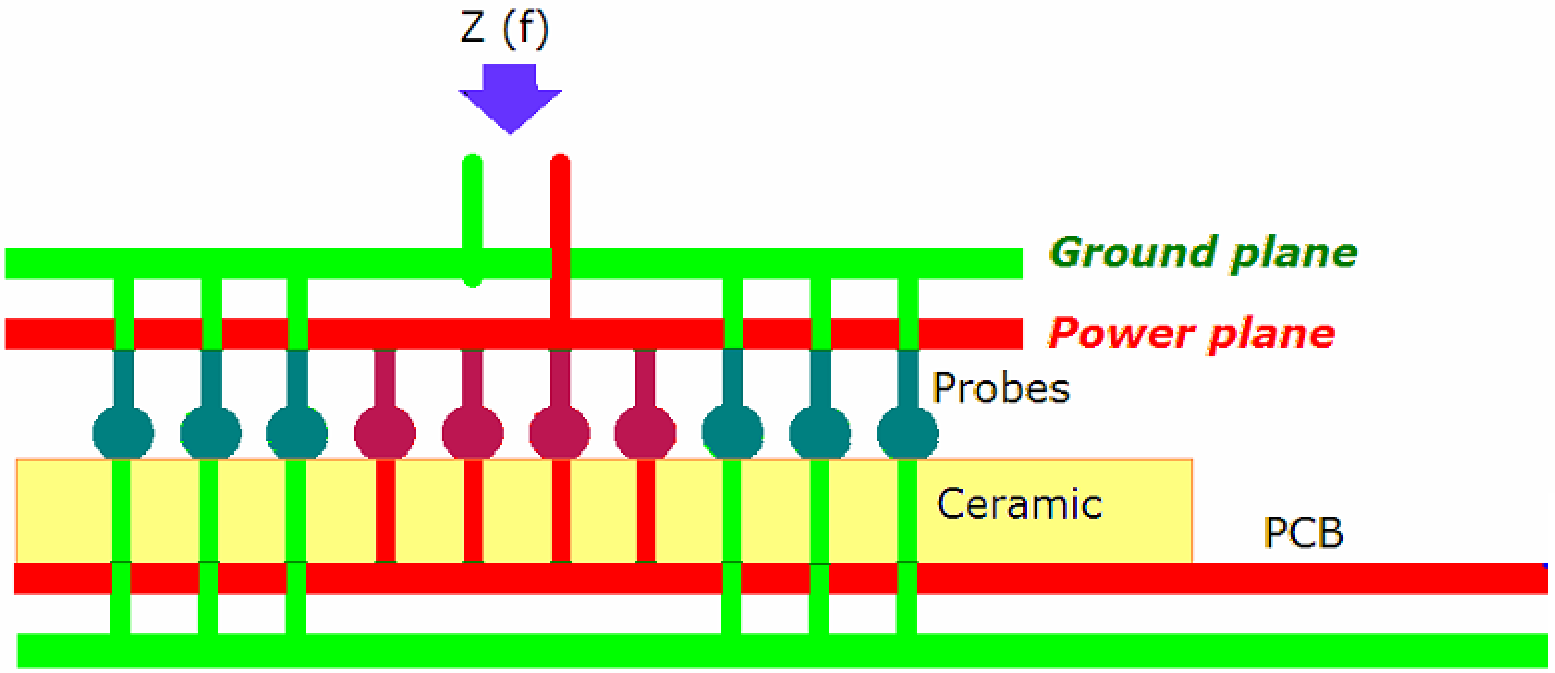
- Both delivery and return paths are important

- Disruptions/detours add inductance

- FEA and CAE tools must be set up to take paths into account

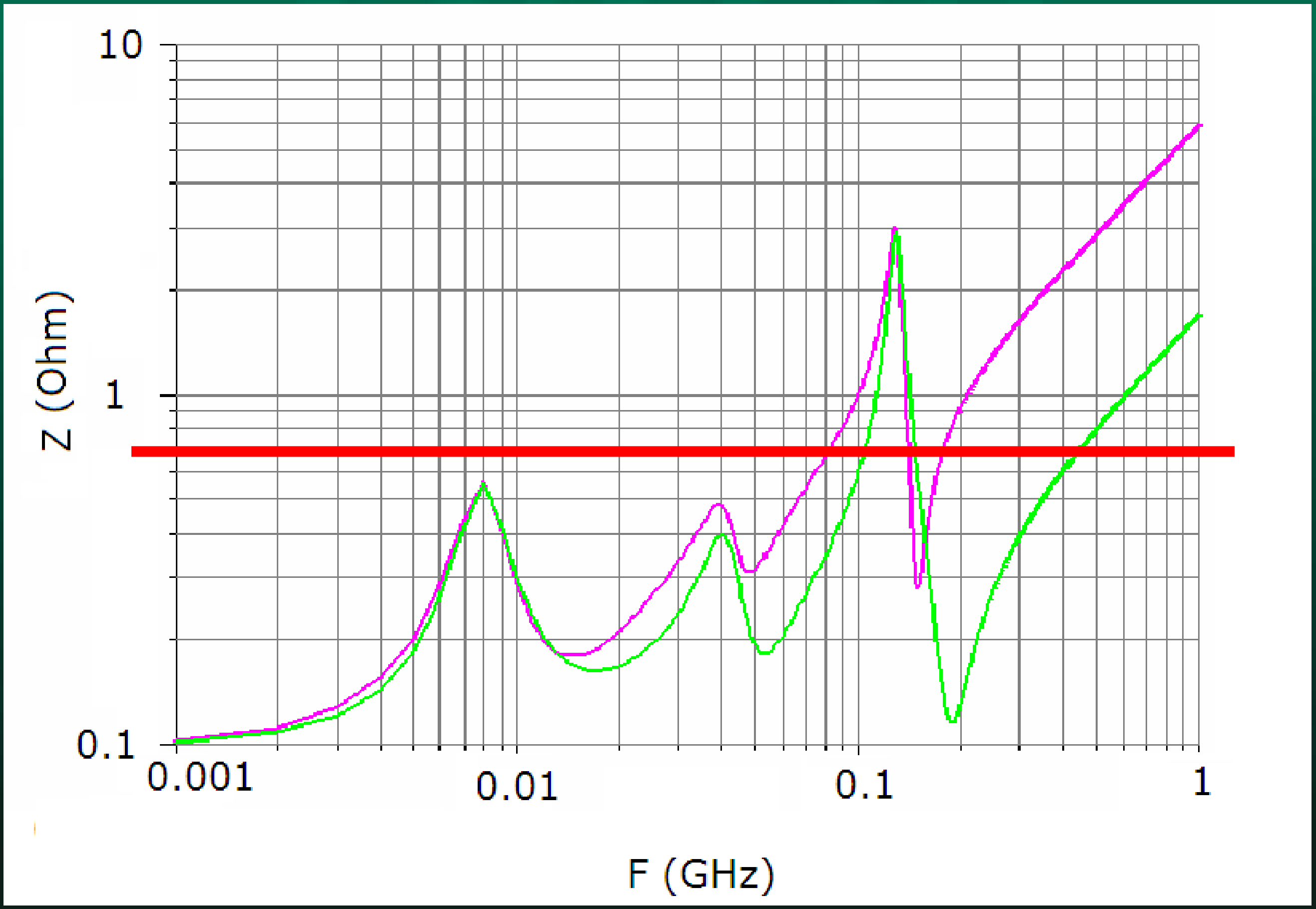
- Verification

Typical model setup



Planes are established at the DUT level - the impedance Z(f) is then determined from the DUT side

Modeled impedance

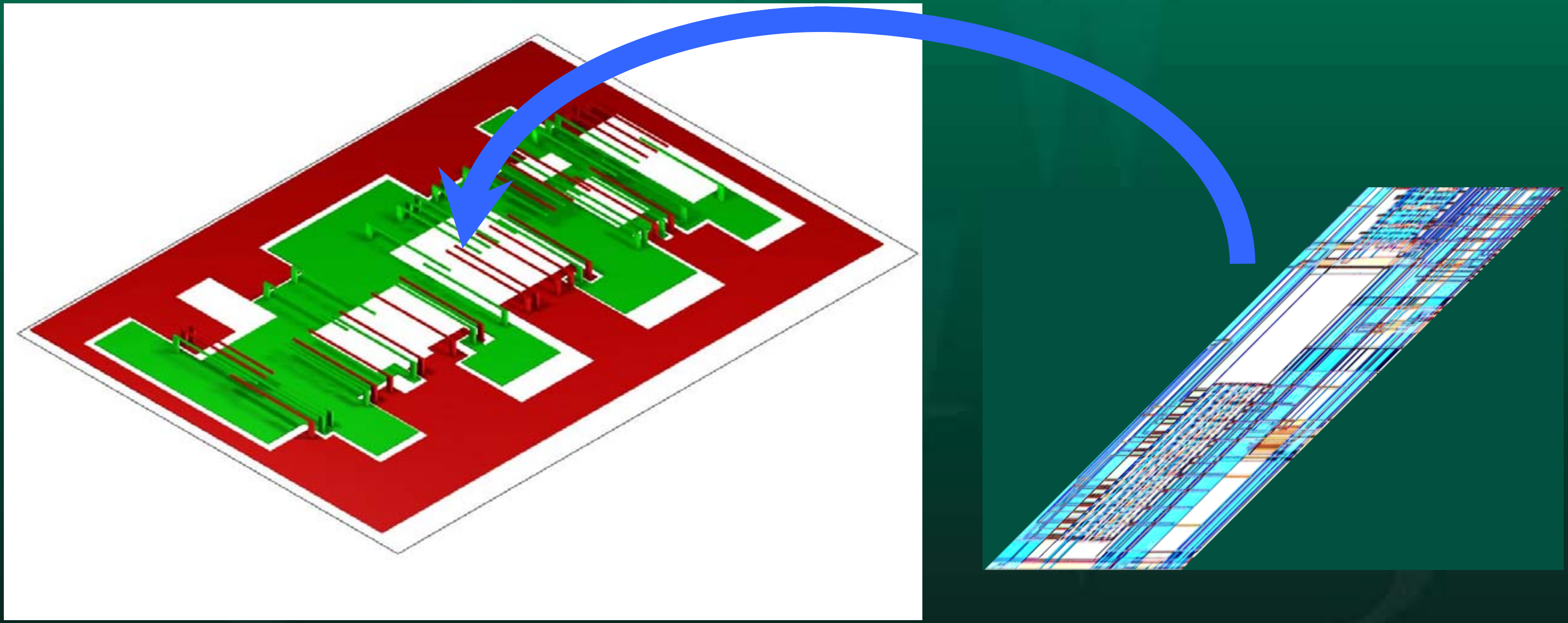


Resonances are due to multiple transmission line sections between bypass capacitors

But does the PDS really work ?

- **Instruments**
  - DMM / Impedance meter
  - Time Domain Reflectometer (TDR)
  - Vector Network Analyzer (VNA)
- **Probes**
  - Individual
  - Whole die (surrogate DUT)

Probing – surrogate DUT

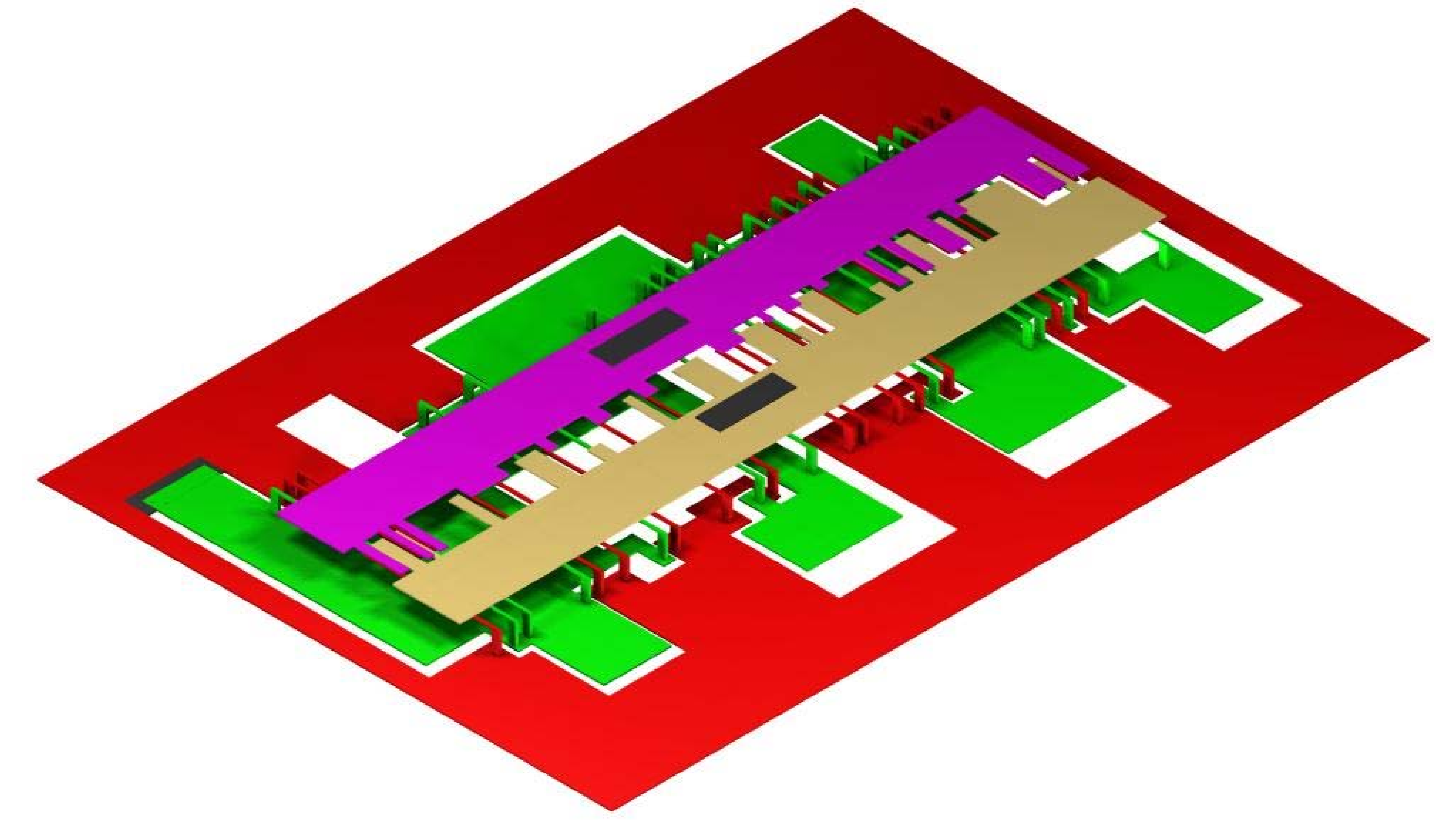


Probe card site

Surrogate DUT

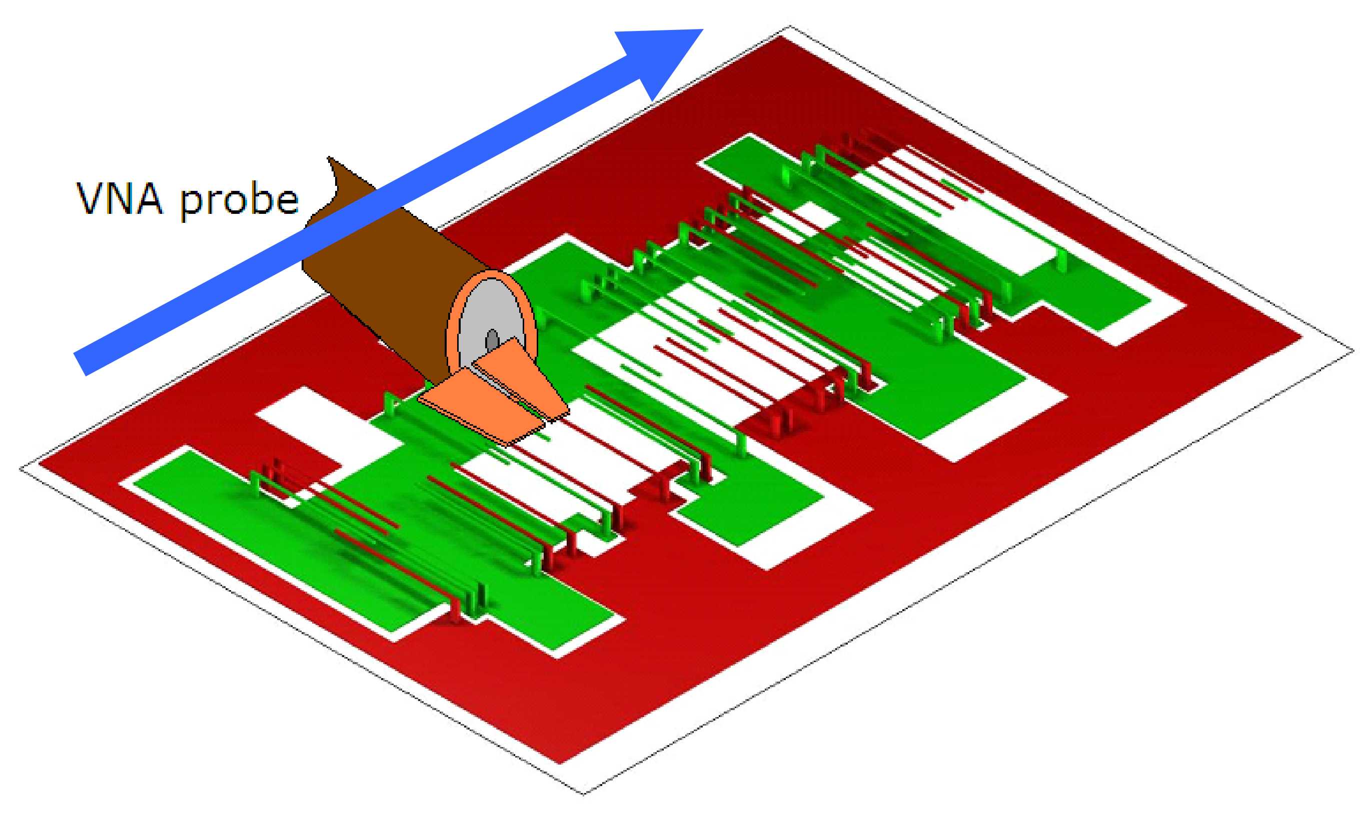
Develop thin film based surrogate DUT circuit, touch down on a probe card die site and measure impedance at relevant locations on surrogate DUT

Surrogate DUT in contact with probes



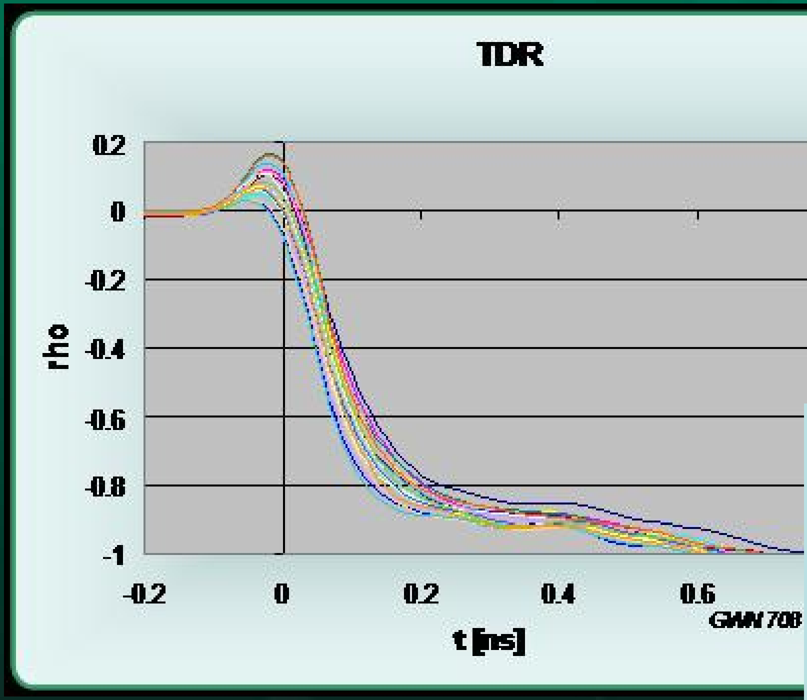
Z can be measured/modeled at various locations of die and represents the Z experienced by a circuit under test

Alternative: Discrete probe test



Measure returned signal for each accessible pad

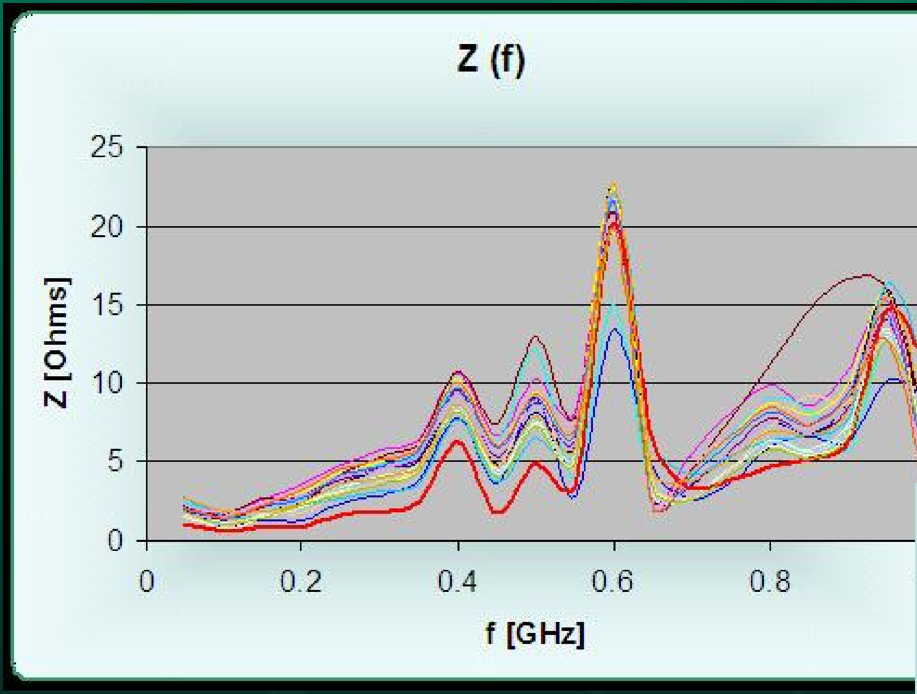
TDR measurement



Model plot for inductance values from 200 pH to 5 nH

TDR does allow for extraction of some info about PDS performance

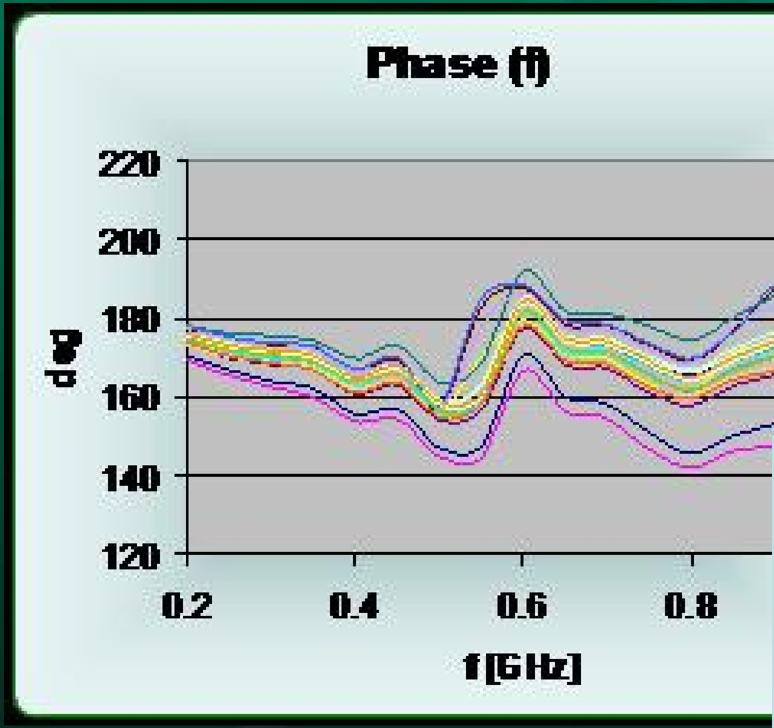
VNA measurement (Z)



Model plot for inductance values from 200 pH to 5 nH

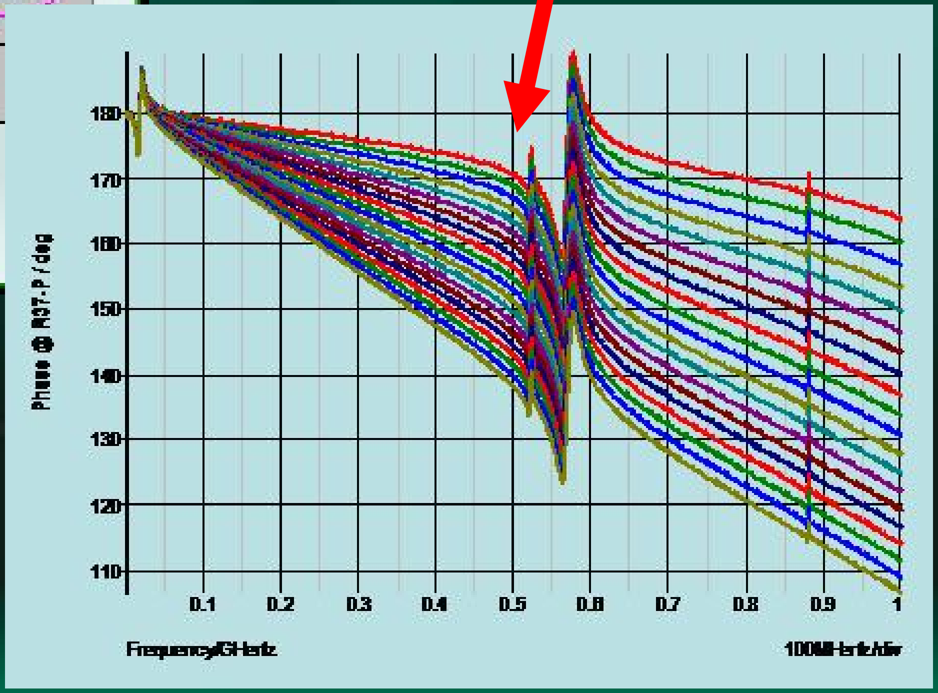
VNA shows whether there are frequencies that are "off limits"

VNA measurement (Phase)

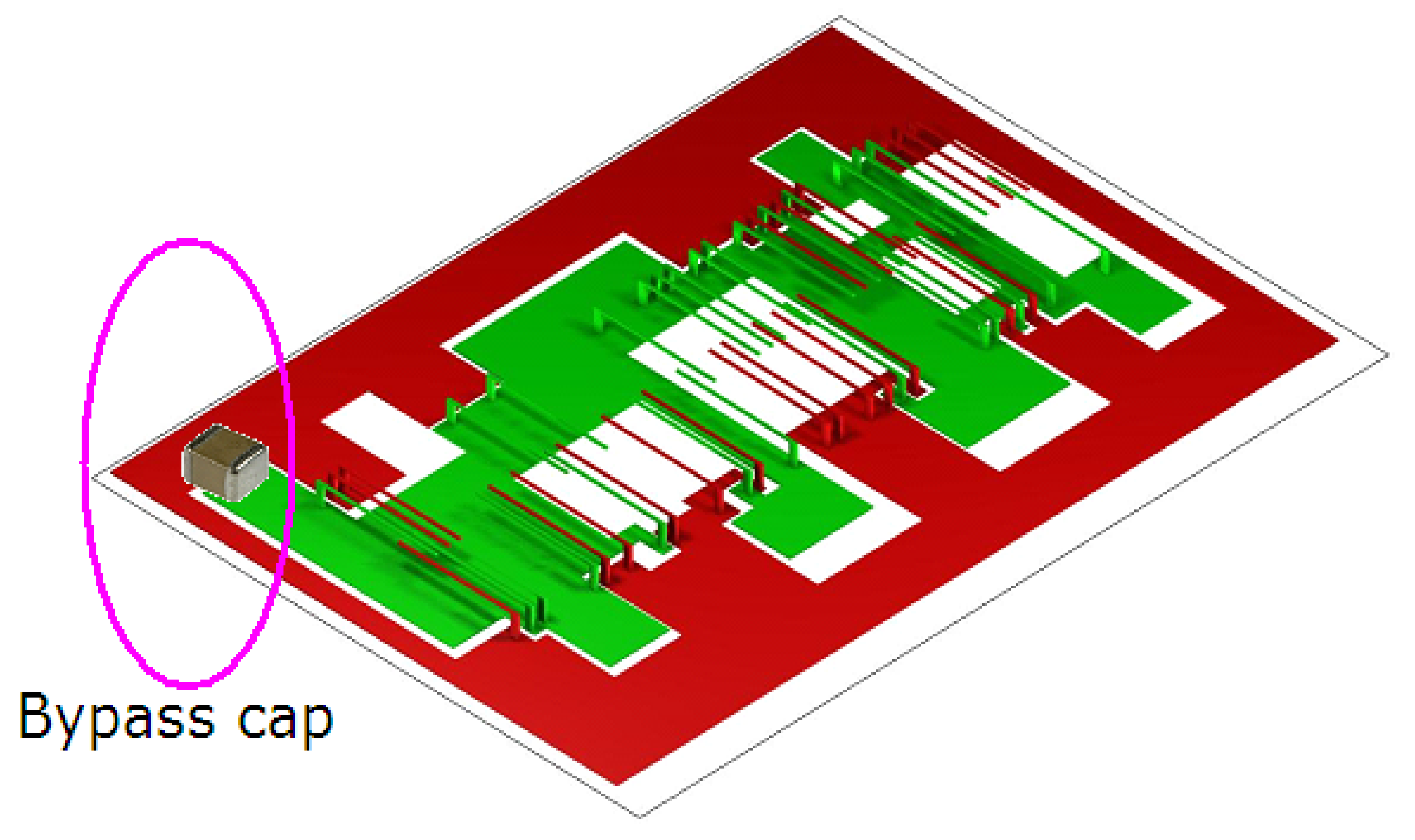


VNA measurement of phase allows determination of complex impedance e.g. inductance

Model plot for inductance values from 200 pH to 5 nH

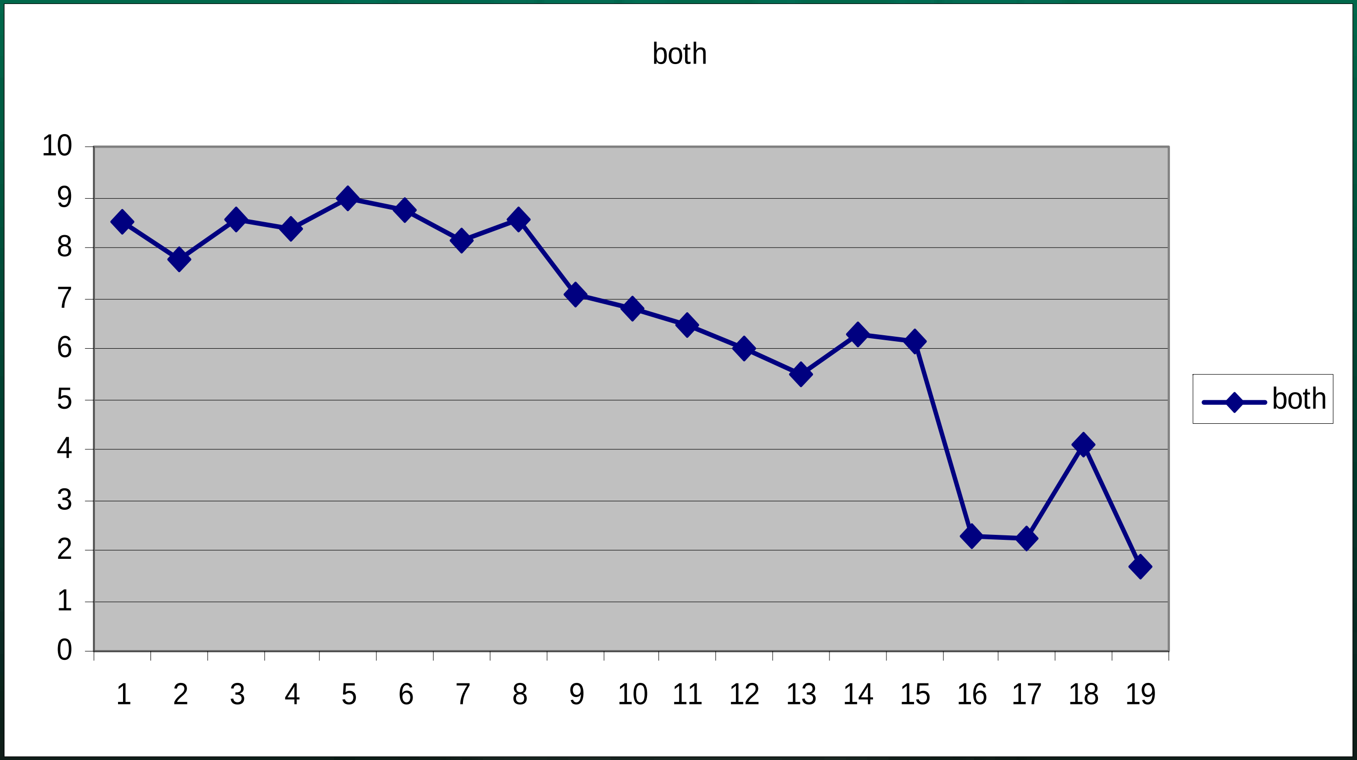


Example configuration



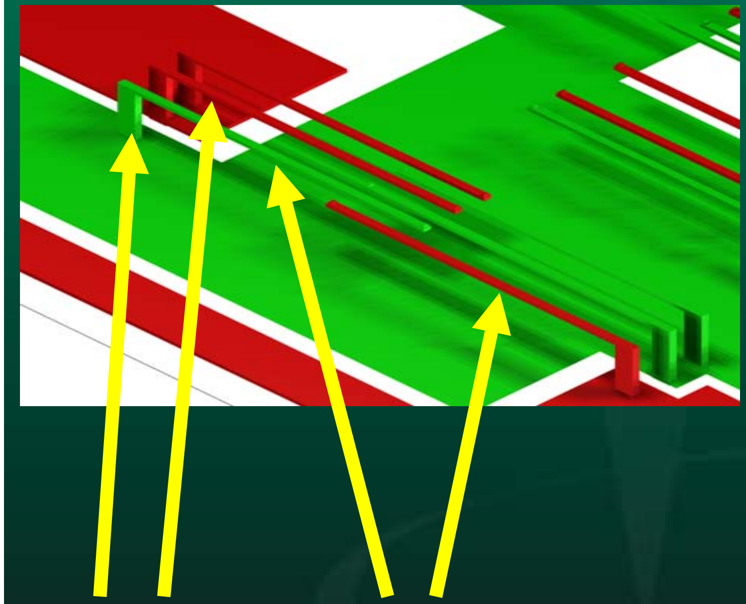
Hypothetical die layout with bypass capacitor placed at one end

Inductance as a function of pad location

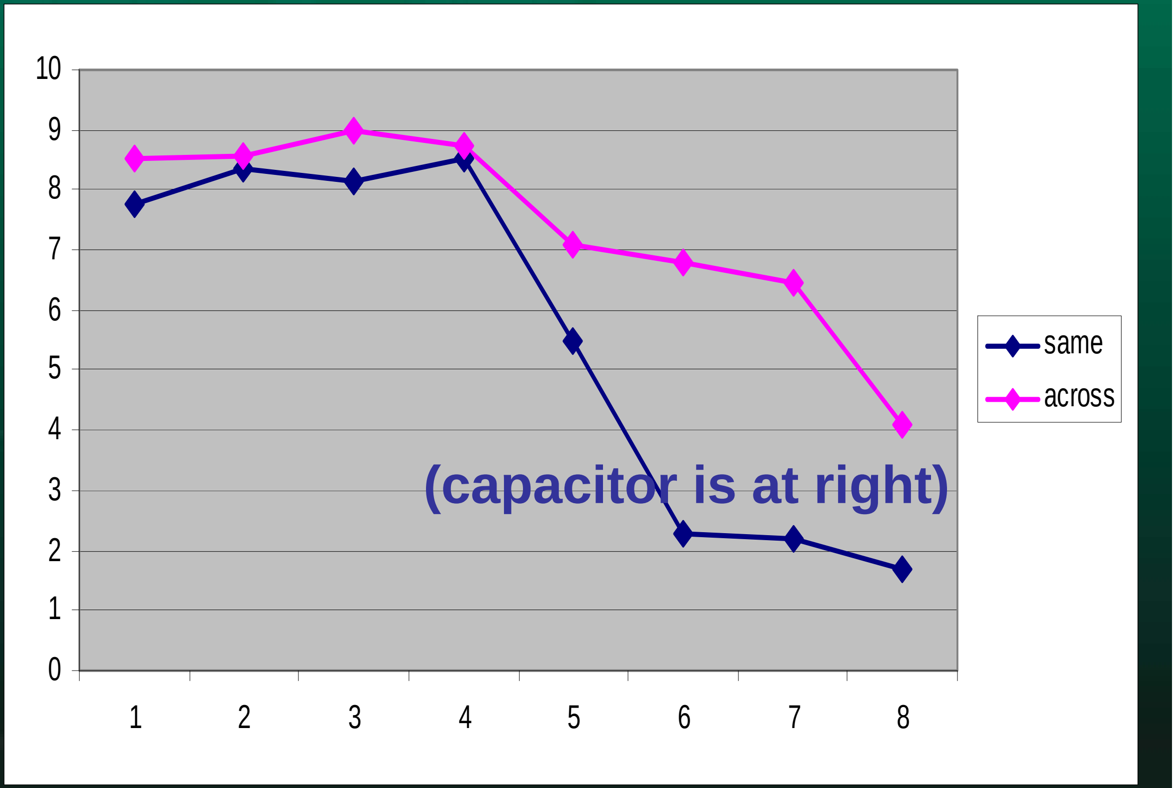


Inductance L (nH) along the die (capacitor location is at right)

Inductance L (nH) along the die



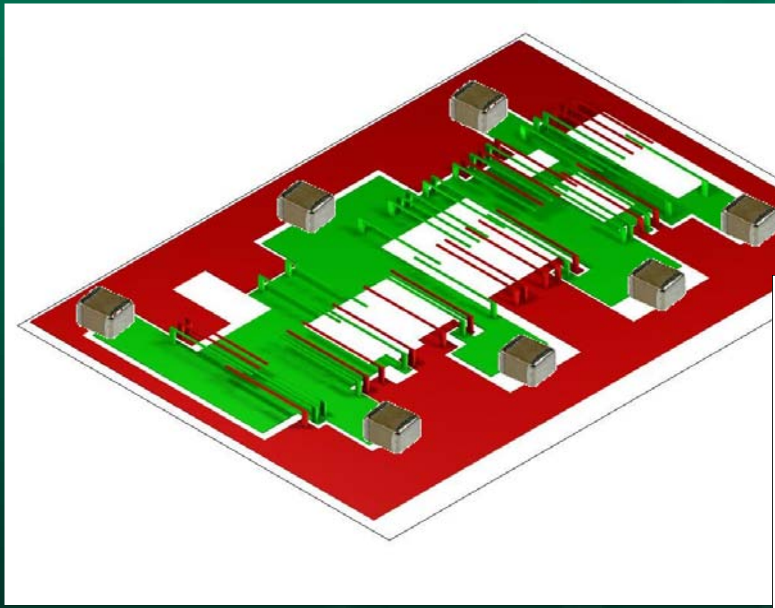
Same side - across

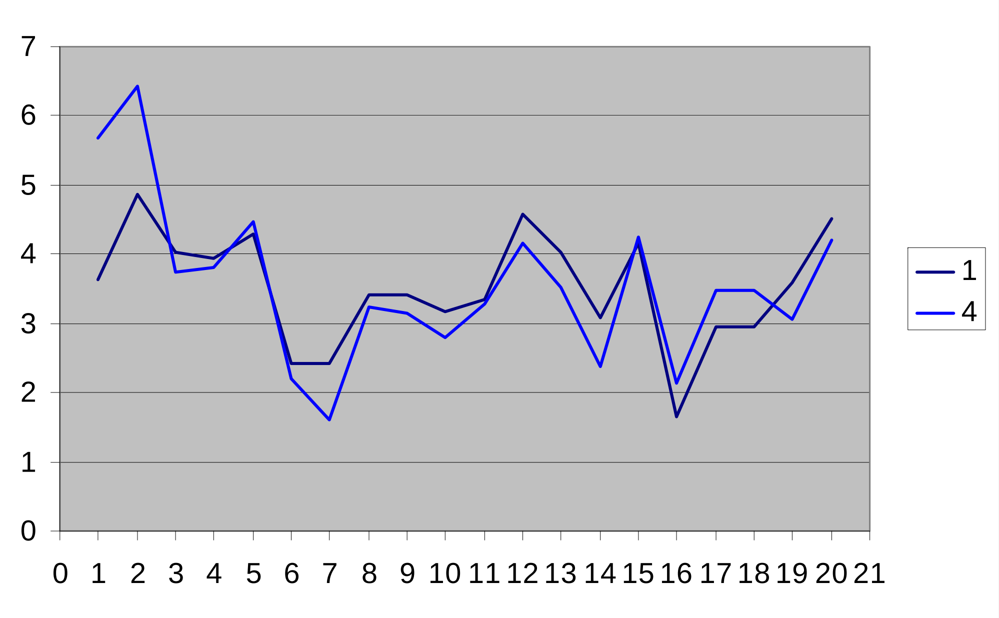


(capacitor is at right)

Measurement taken with probe ground on the same side as signal contact (pink) or across to opposite ground area (blue)

DUT area with multiple bypass caps



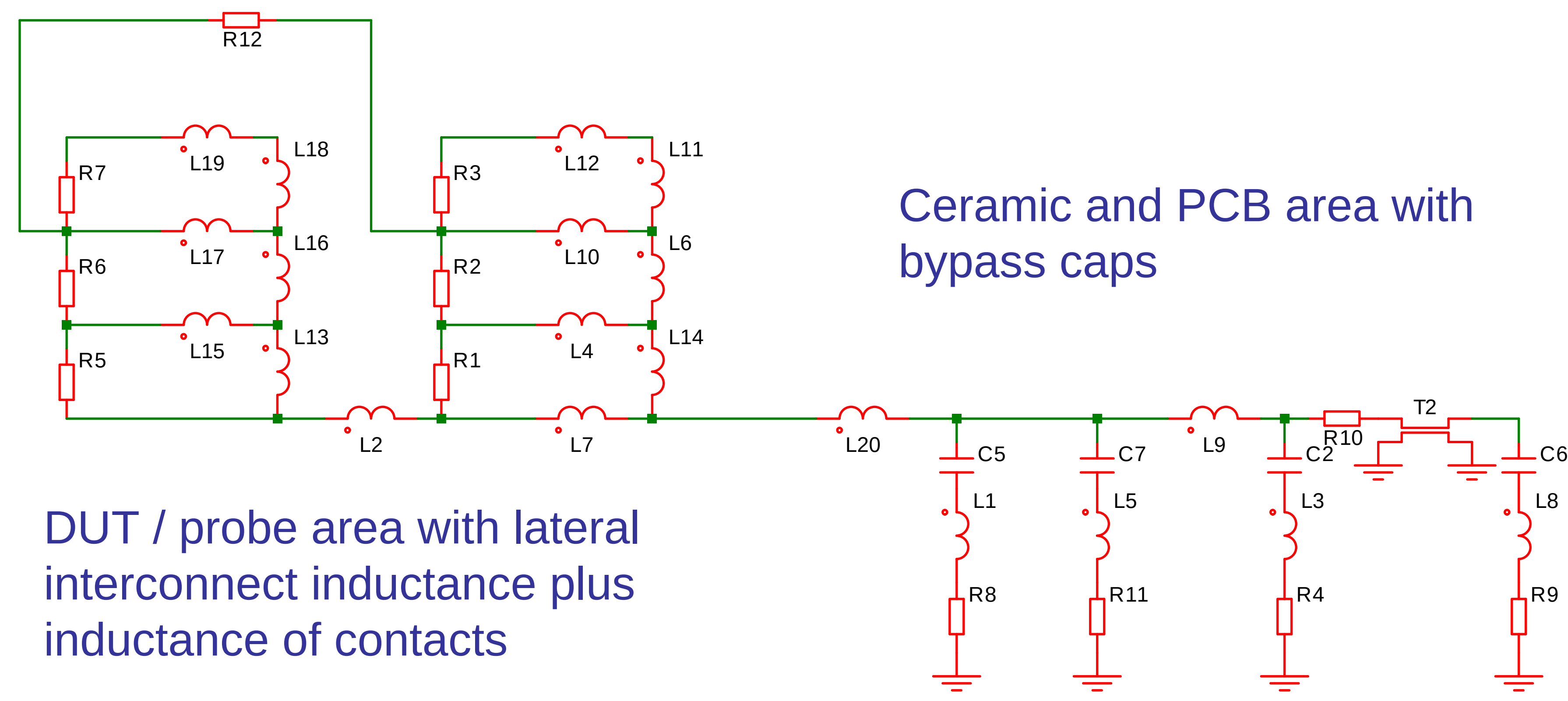


Impedance Z (Ω) at 250 MHz as a function of position across die

(2 nearly identical die)

Still don’t know overall Z…

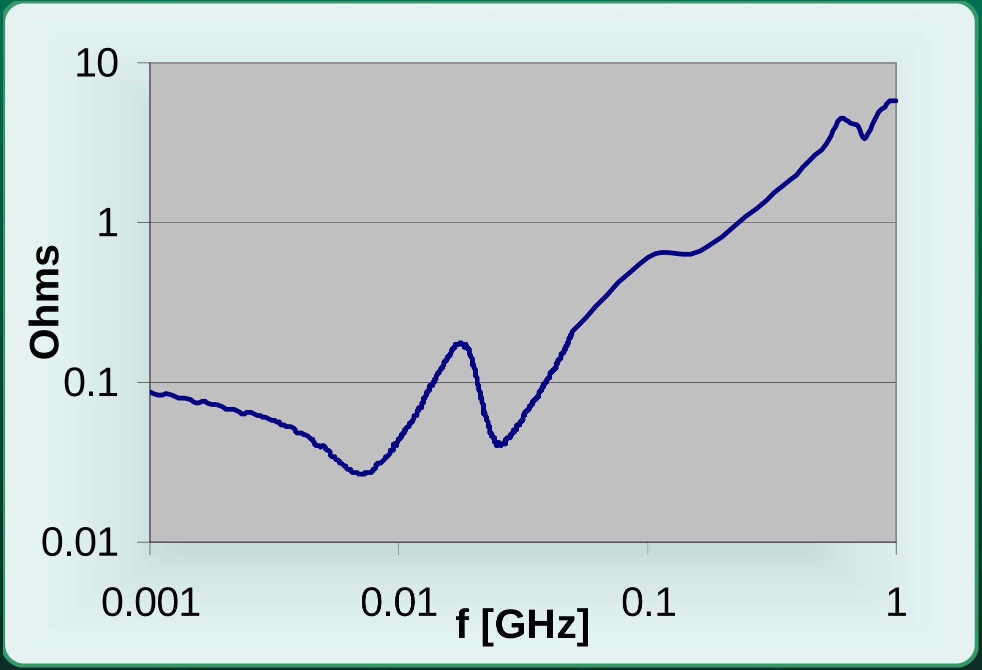
- **Solution: Combine measurements with simulated results for interconnect inductance**



Ceramic and PCB area with bypass caps

DUT / probe area with lateral interconnect inductance plus inductance of contacts

Z combined



Individual Z measurements combined into an overall performance assessment

Summary

- Power delivery system performance depends on path and position
- Grounding during measurement as well as model development must be carefully planned
- The overall performance is NOT the result of assuming that all measurements effectively form a parallel circuit of the individual Z measurements
- A combination of measurements and models allows for assessment of overall performance
- Local performance should be verified against specifications