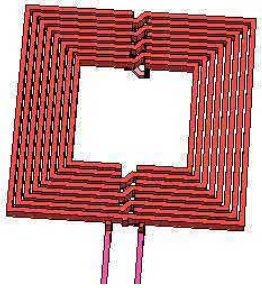
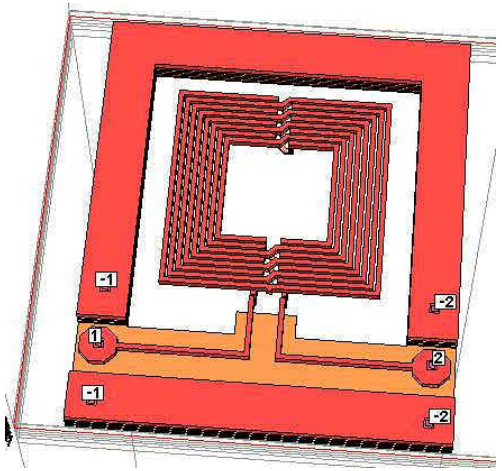
Measure or Simulate?

- **Measurement** with vector network analyzer is typically limited to 2 ports, max. 4 ports
- Difficult to measure center tap inductors and transformers
- Measurement includes pads and feedlines, must be removed by de-embedding
- Measurement is not very accurate at high freqencies and for small devices
- Difficult and expensive to do what-if studies and variation by experiment

- **Simulation** has no limit on port numbers
- Center tap inductors and transformers are no problem
- Simulation can be done on the device alone, or with feed pads and lines to verify measurement
- Simulation can be accurate at high frequencies and for small devices, if done properly
- Easy to do what-if studies and verify the influence of material properties

Influence of Feedlines



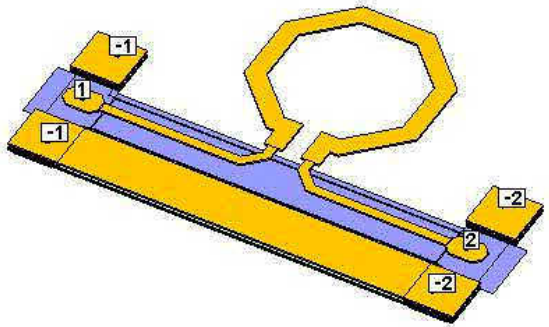


- Simulation can do "inductor only" or complete with feedline
- Measurement requires de-embedding to remove feedlines from measurement result
- De-embedding standards and method are not perfect, result is only approximate

Typical De-embedding

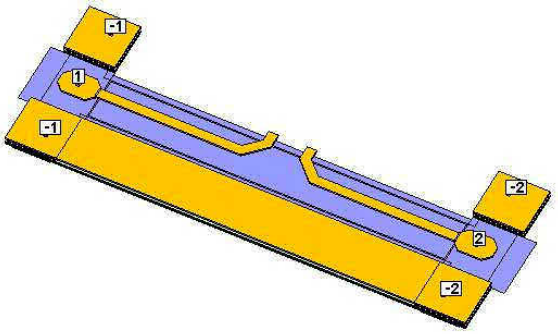
Device Under Test (DUT)

Inductor + Feedlines

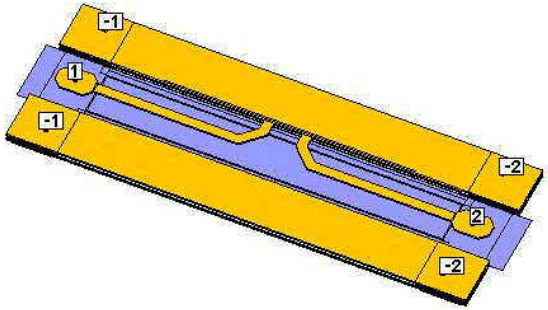


De-embedding Standards

Open



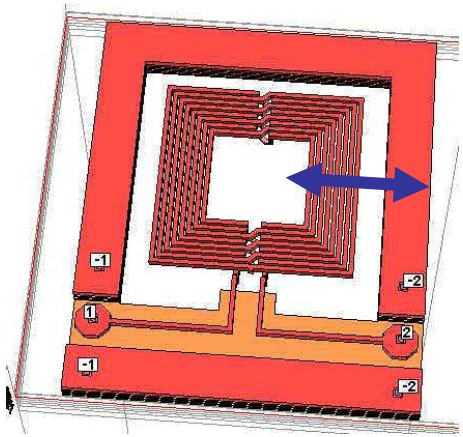
Short



→ Calculate feed lumped elements (series L, series R, shunt C) and remove from measured

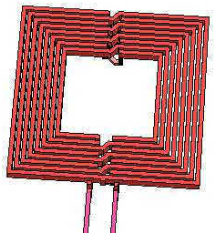
Mistakes in De-embedding

- Possibly different path for return current
- Often, de-embedding assumes lumped elements (low frequency approximation) instead of using transmission line theory
  → error at high frequencies
- Possible coupling between inductor and feed structure is not be removed by de-embedding!

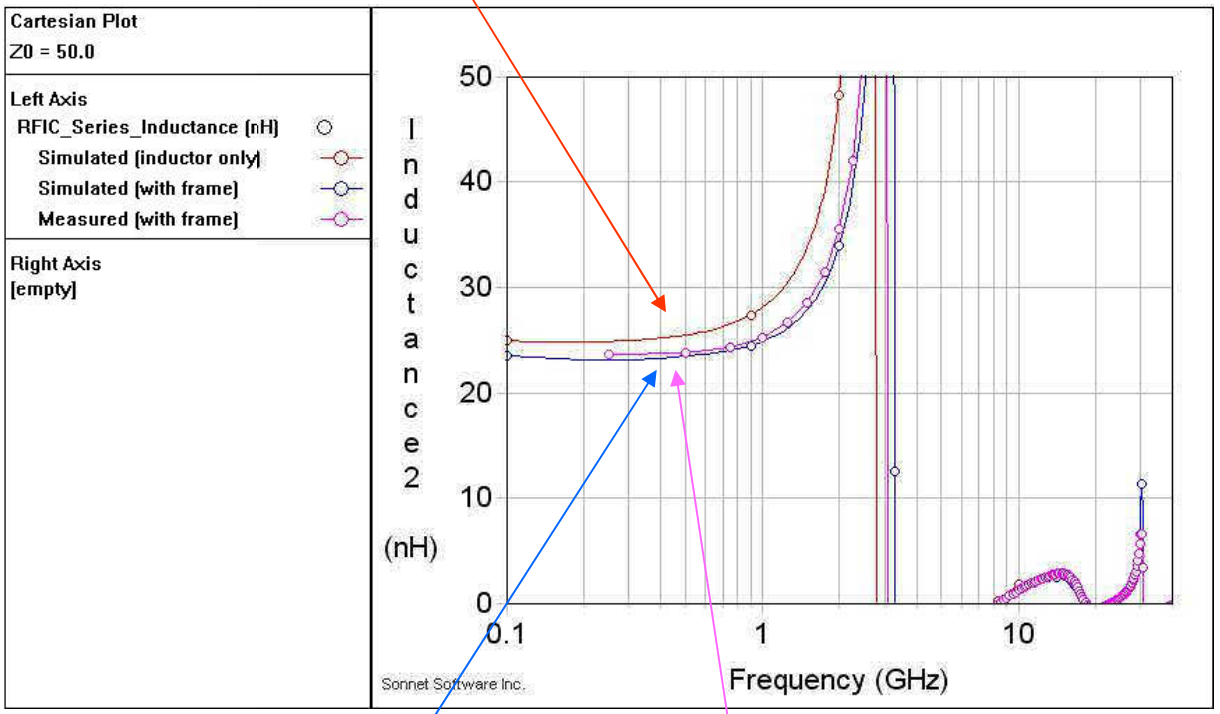


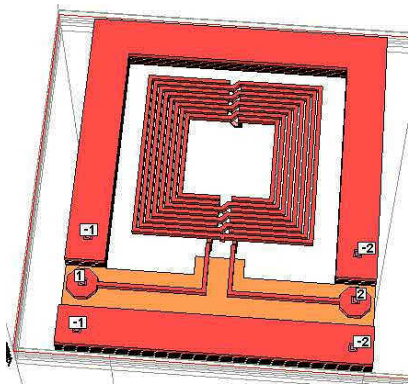
Example :
Coupling between inductor and feed reduces measured L from 25nH to 23.5nH.
This error is not removed by de-embedding!

High Accuracy Simulation



Sonnet simulation inductor only,
as used for circuit design





Sonnet simulation with ground frame coupling,
after feedline de-embedding, as measured

Measured
after de-embedding

Measure or Simulate?

- Measure **and** simulate!
- We want to have some measurement to verify our simulation method and stackup
- Simulation is very flexible
- Simulation allows to test ideas and concepts with very little cost
- Example shown later: test the benefit of substrate back etching by simulation