A Simplified QFN Package Characterization Technique

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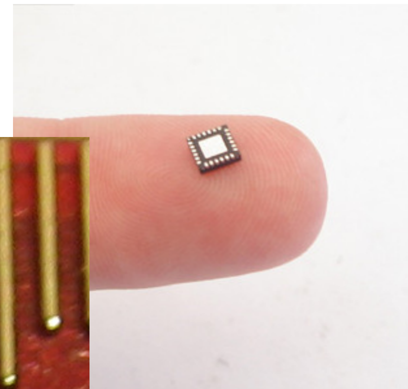
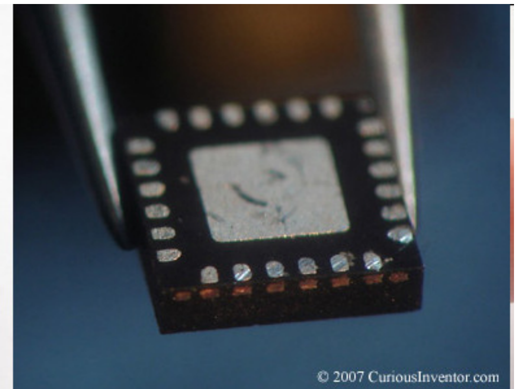
8/1/10

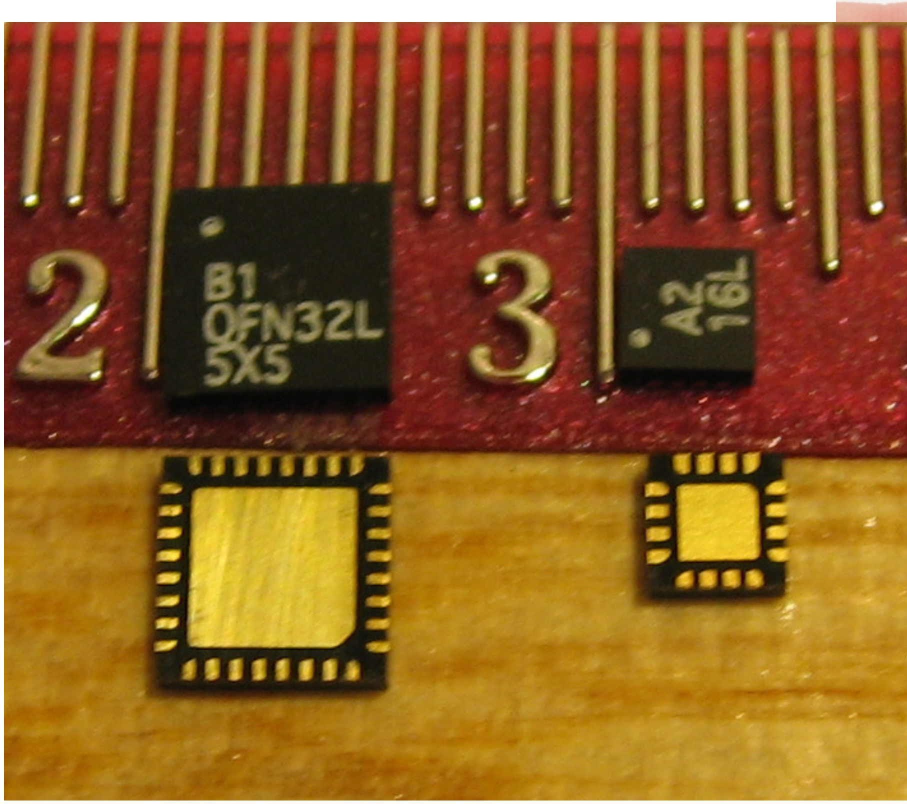
Goal of this Project

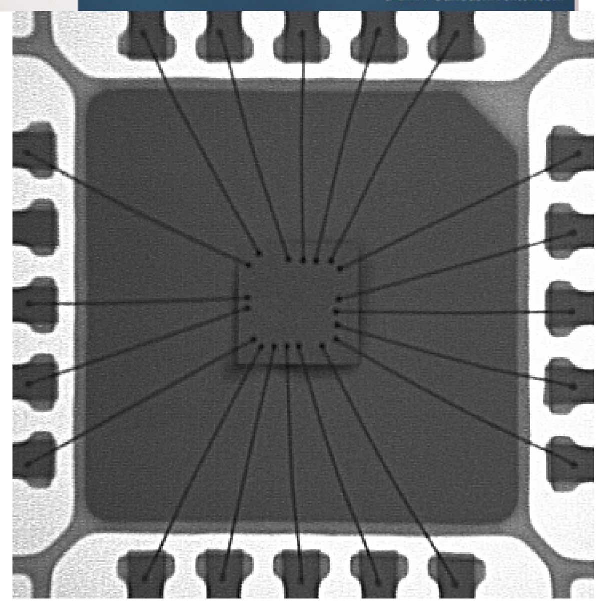
- Develop a simple technique to characterize leads in a QFN suitable to high bandwidth
  - ✓ Include coupling between leads
  - ✓ Using a model that is usable by ALL simulator engines (transportable)
  - ✓ Include an estimate of the bandwidth of the model
- The solution:
  - ✓ Described with LC matrix elements
  - ✓ Describe as single ended characteristic impedance, TD
  - ✓ Describe as a differential impedance and TD
- Constraints
  - ✓ Only have access to the leads outside the package
  - ✓ Surrogate chips with opens or shorts can be added inside die cavity
  - ✓ Generic to multiple package sizes
  - ✓ Dry gold to gold contact to external leads- no soldering
  - ✓ ***Low cost, simple and robust***

Typical QFN Packages

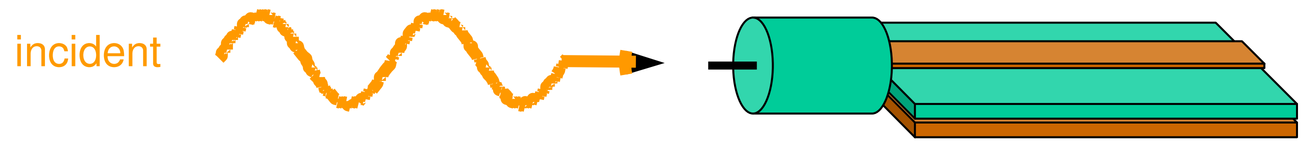


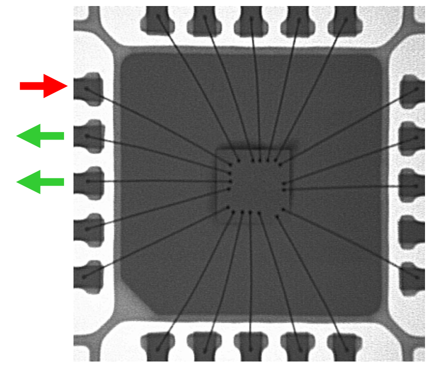






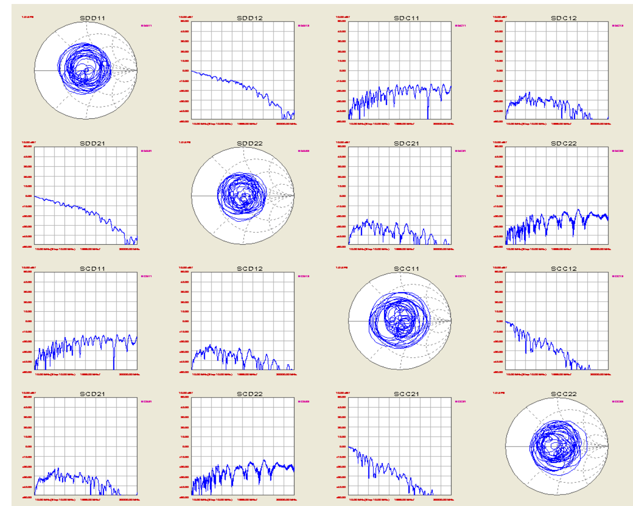
Important Condition when Describing Electrical Properties of Interconnects





- When referring to a signal lead, we ALWAYS include the return path connection
- It is MEANINGLESS to refer to the electrical properties of just one lead
- We can only describe the electrical properties of a signal AND its return path
- When measuring a ”package lead”, we MUST define the specific return path
- The electrical properties will CHANGE if the return path changes

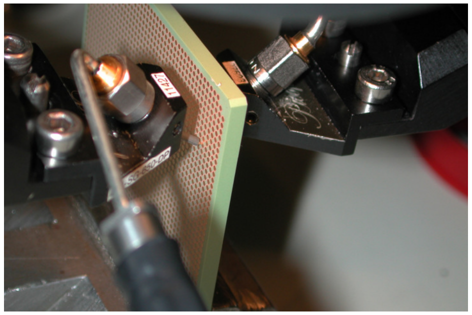
A High Bandwidth Model: S-Parameter Behavioral Model



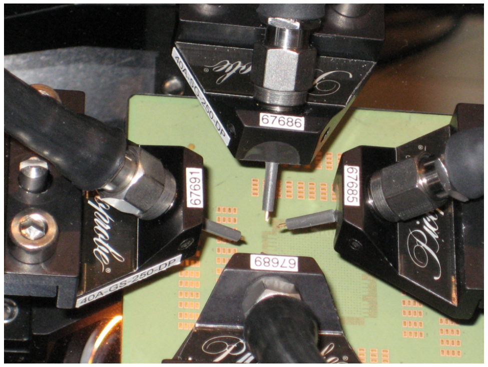
- Features
  - ✓ Values across a wide frequency range
  - ✓ Includes magnitude and phase at each frequency
  - ✓ Every combination of sine waves out and sine waves in
  - ✓ Has a “bandwidth of accuracy”
- Advantages:
  - ✓ Can be incorporated into many simulators
  - ✓ Has potential to be highest bandwidth model
  - ✓ Can come from measurement or 3D simulation
- Disadvantages:
  - ✓ Requires access to ALL ends of the interconnect
  - ✓ Requires a “de-embedding” technique to remove fixturing and probe contributions
  - ✓ 10-100x higher complexity in fixturing and analysis to get quality data
  - ✓ 10-100x higher cost in expertise, time, tools
  - ✓ Difficult to quickly evaluate “goodness” without a system simulation

Direct Measurement of the 4-port S-Parameter Behavior Model

- The Good:
  - ✓ Direct measurement
  - ✓ High bandwidth
  - ✓ No model assumptions



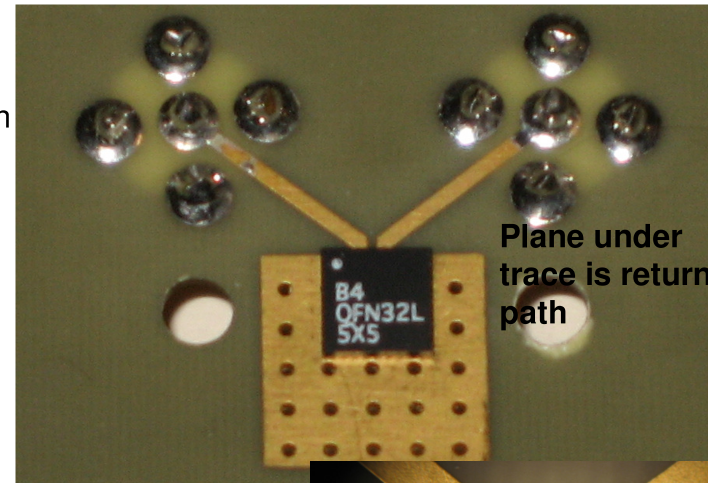
- The Bad:
  - ✓ Requires expensive probe station and probes
  - ✓ Requires either complex calibration process or sophisticated software tools to de-embed fixtures
  - ✓ Must match probe pitch to package pad pitch
  - ✓ Difficult to select return paths
  - ✓ Requires probe access to die attach pads and output leads



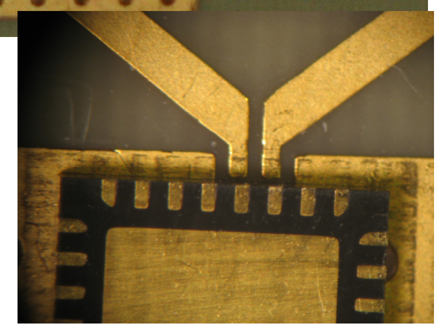
GigaTest Labs

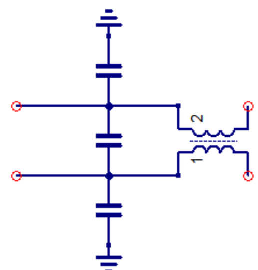
A Dramatically Simplified Process

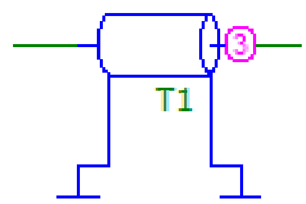
- Simplification #1:
  - ✓ use fixture board to interface between external package leads and SMA to VNA: gold to gold contact, arbitrary return pin configuration
- Simplification #2:
  - ✓ use open source software (free) for all the analysis
- Simplification #3:
  - ✓ use C, L matrix or uniform transmission line for package models
- Simplification #4:
  - ✓ Use frequency range for measurement based on instrumentation available
- Features:
  - ✓ Easy, low cost
  - ✓ Universal for all package types
  - ✓ Can still generate S-parameters
  - ✓ Can extract high bandwidth models (> 5 GHz)
- Disadvantages:
  - ✓ Difficult to verify model bandwidth
  - ✓ Bandwidth of the model limited by fixture
  - ✓ Package model is lossless



Plane under trace is return path

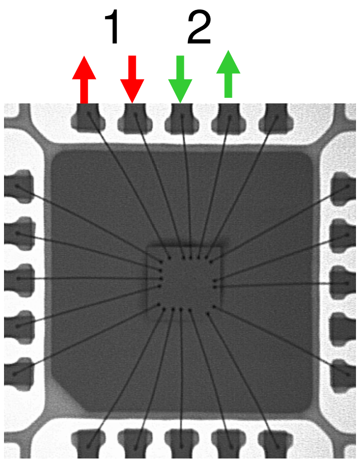


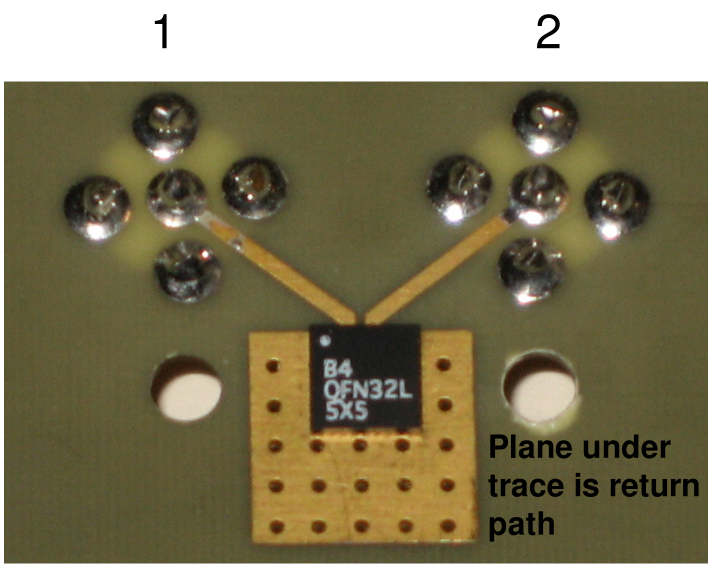




The Process of Extracting Model Parameters from a Measurement

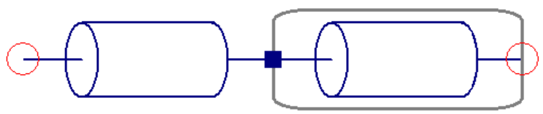
1. Build 2 identical packages with dummy die inside:
   - ✓ At die all leads shorted to return
   - ✓ At die all leads open
2. Build low cost fixture board between SMA connectors and 2 adjacent signal leads- with contact to return paths.
3. Measure fixture board only, open and shorted at far end
   - ✓ Extract C, L matrix of fixture board
4. Measure fixture board + package open and shorted at far end with dummy die
5. Extract package only C, L matrix elements from low frequency measurement
6. Build higher bandwidth transmission line model from LC matrix elements
7. Verify models to as high a bandwidth as the measurements.

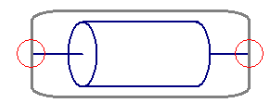


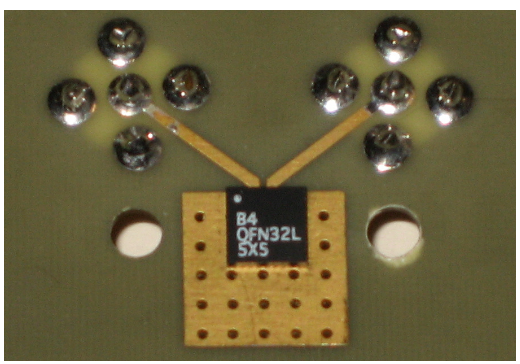


Separating Fixture and Package Models

- Measure fixture only with far end open, short
- Measure fixture + package together, open and short at far end
- Subtract fixture from total measurement to get just package model
- Build model for fixture and package and compare total simulation with total measurement







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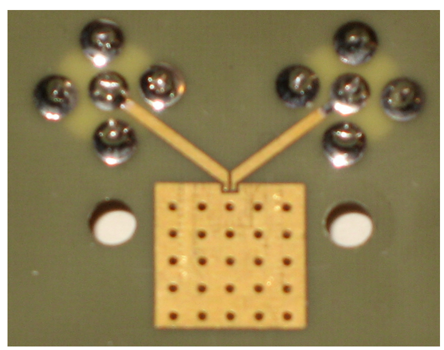

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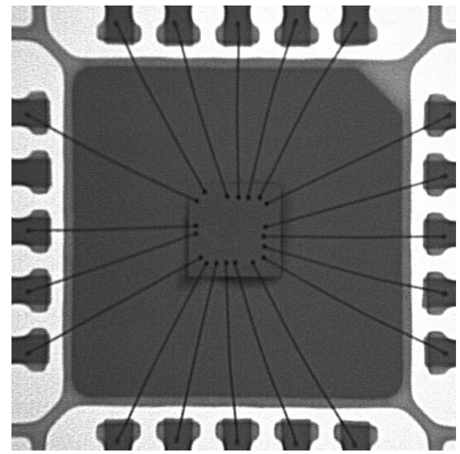
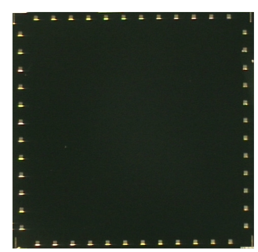
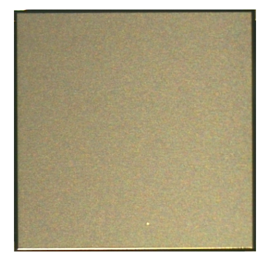
Use two "identical" packages with open and shorts inside cavity

- Inside cavity, wire bonds either open on die or shorted together on die
- Using two different surrogate die with the same wire bond configuration



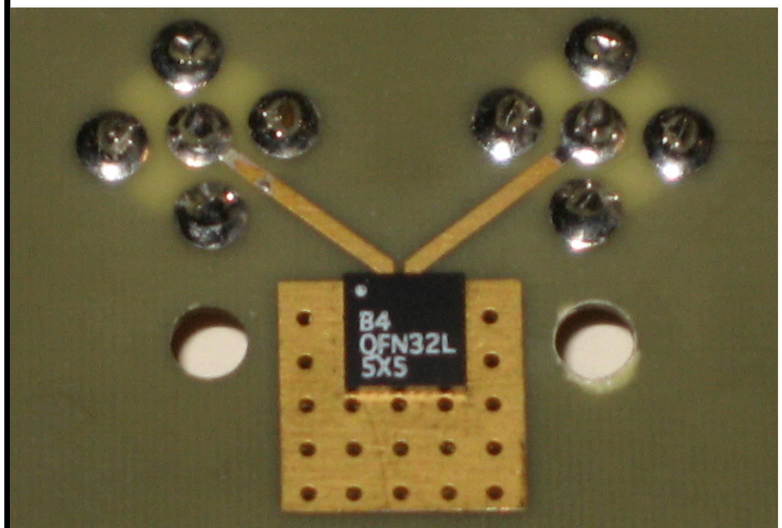


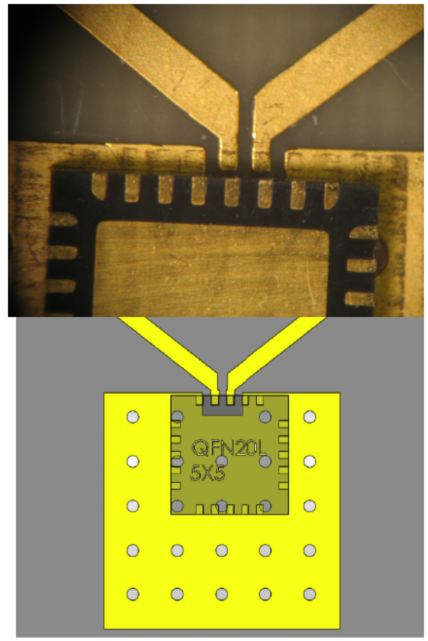
Open pad pattern



Short pad pattern

The Fixture





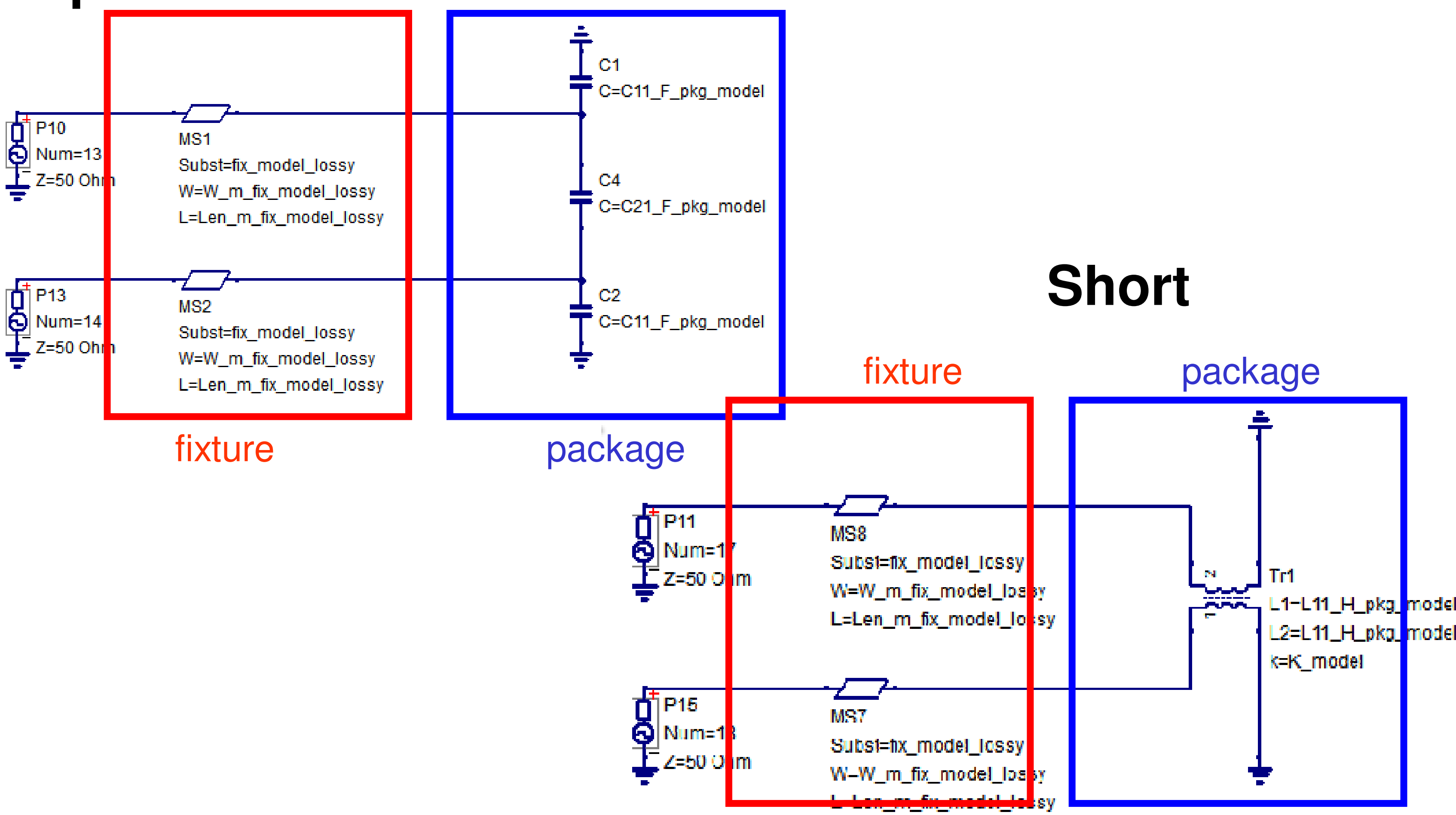
- Fixture is fixed and never changes
- Very stable and reproducible
- Using gold-to-gold contact to connect pads on package to the pads on the circuit board
- Using an alignment clamp for precision lead to board alignment
- Need to subtract off fixture C and L from total measurement to get just the package

Software Analysis Tool: QUCS

- QUCS: Quiet Universal Circuit Simulator
  - ✓ Open sourced
  - ✓ Versatile S-parameter and frequency domain simulation
  - ✓ Parameterized variables
  - ✓ Integrates measured data into simulation environment
  - ✓ Excellent graphical output
  - ✓ But… lossy line models are not transportable, no diff pair model
- Free download from the web (and from www.beTheSignal.com)

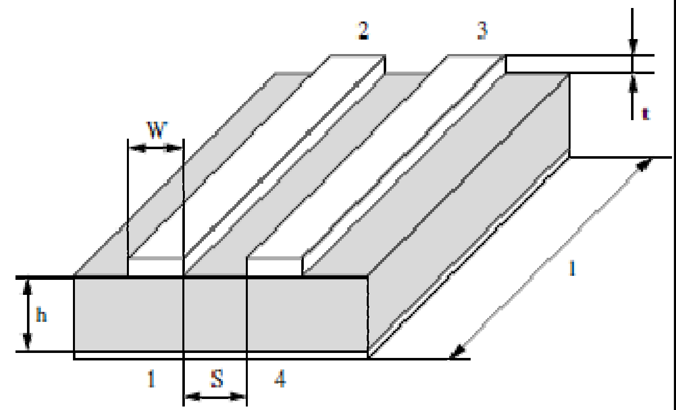
Models for Fixture and Package

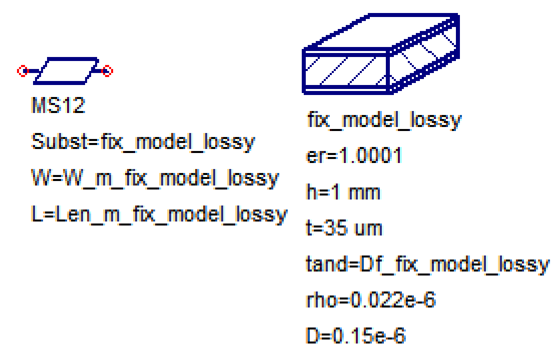
Open



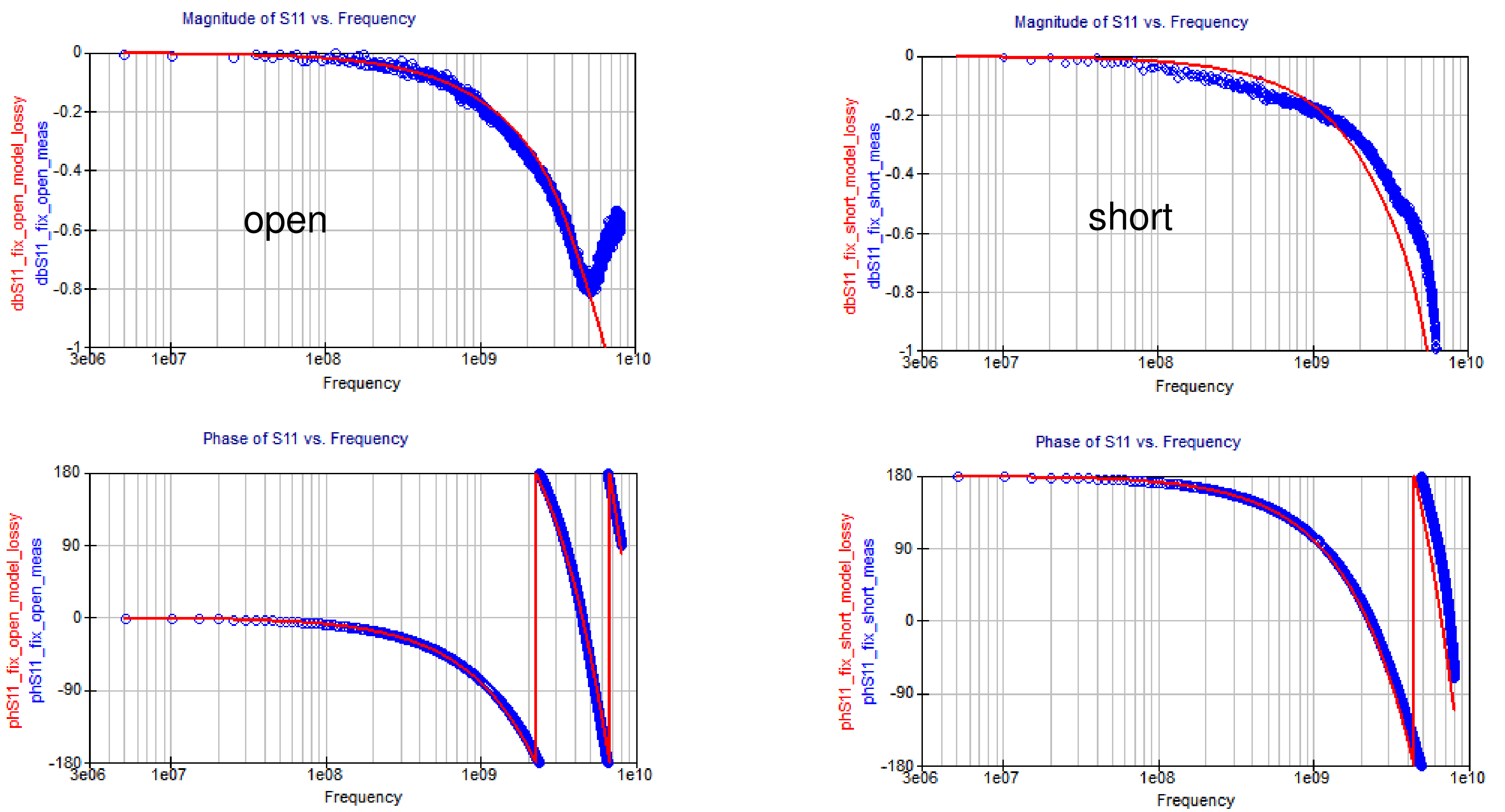
Modeling Fixture with Lossy Transmission Line Model

- The Lossy Model in QUCS (HOL-210C)
- Substrate
  - ✓ Dk is air = 1.0001 (has to be off from 1)
  - ✓ h = 1 mm, fixed
  - ✓ t = 35 microns, fixed
  - ✓ tand = Df
  - ✓ Rho = 2.2e-8, fixed, for copper
  - ✓ D = 1.6e-7- dummy term
- Microstrip line
  - ✓ W= line width
  - ✓ L= length



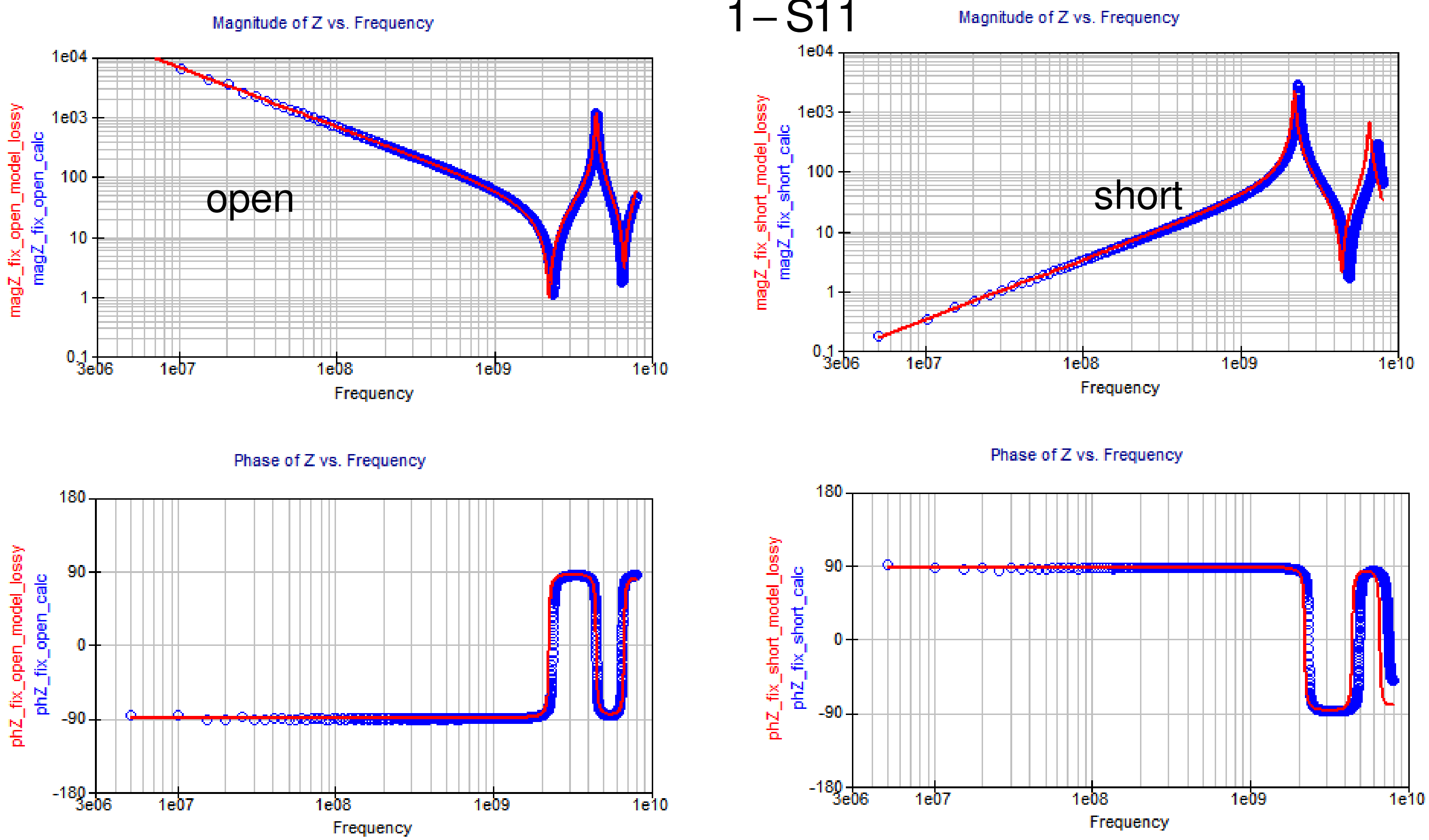


Measuring the Fixture Board Only- and fitting Lossy Transmission Line Model



Convert S11 to Impedance

$$Z = 50\,\frac{1+S11}{1-S11}$$



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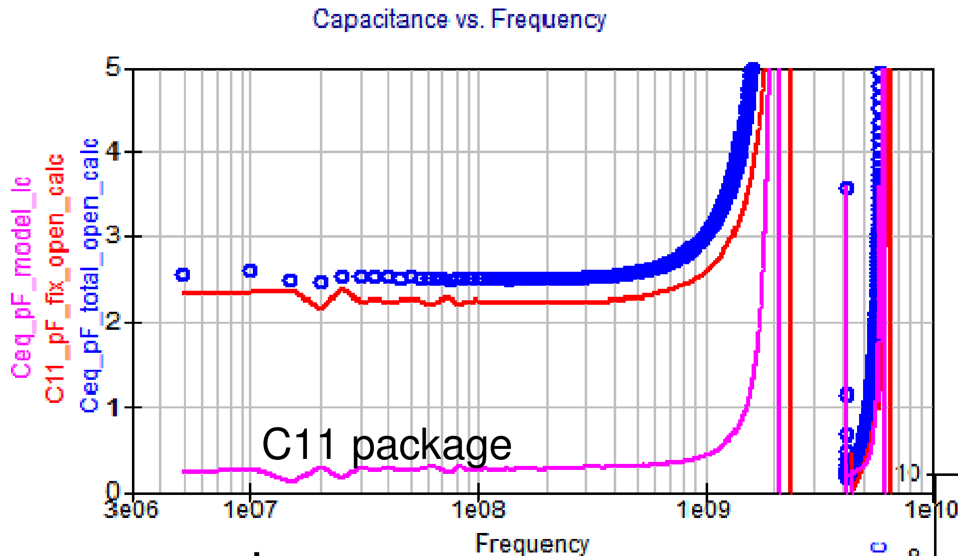
Extracted C11, L11 for: Total, Fixture Only and Package

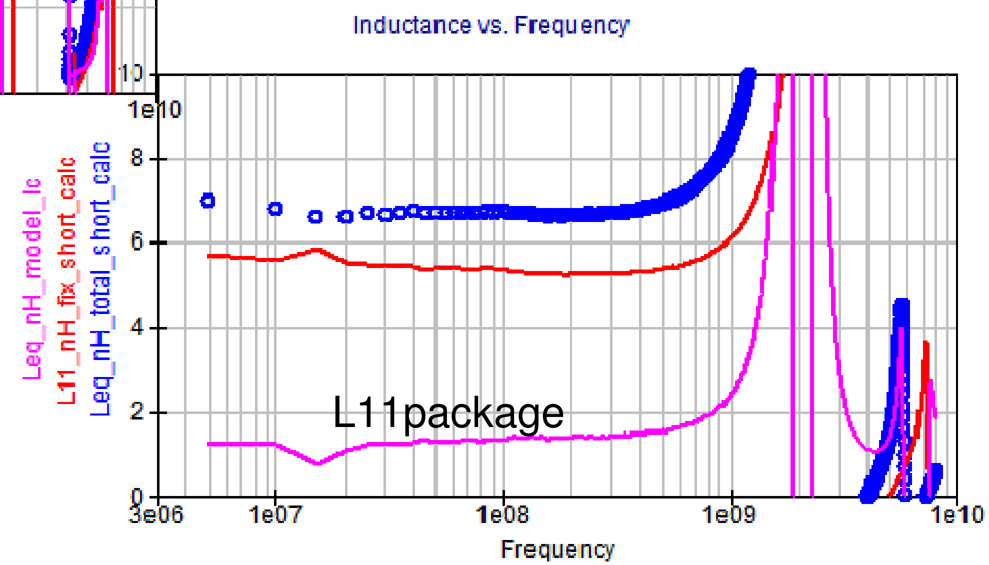


$$Z = i\omega L$$

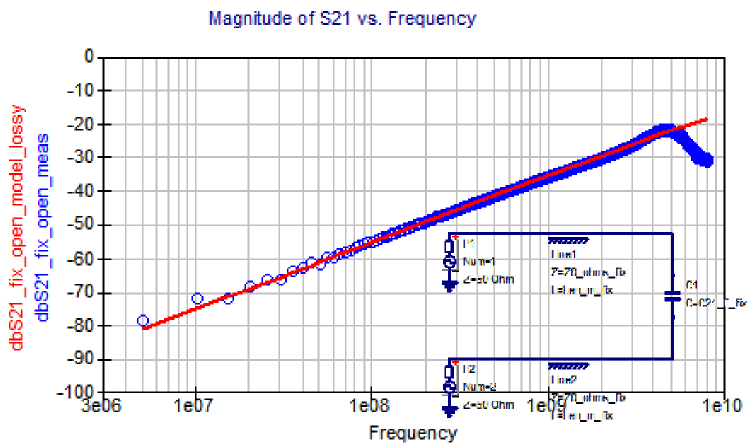
$$L = \frac{\mathrm{imag}(Z)}{2\pi f}$$

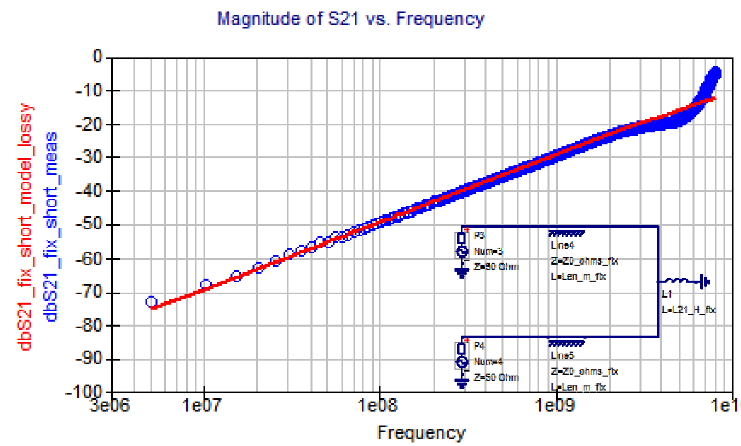
$$Z = \frac{-i}{\omega C}$$

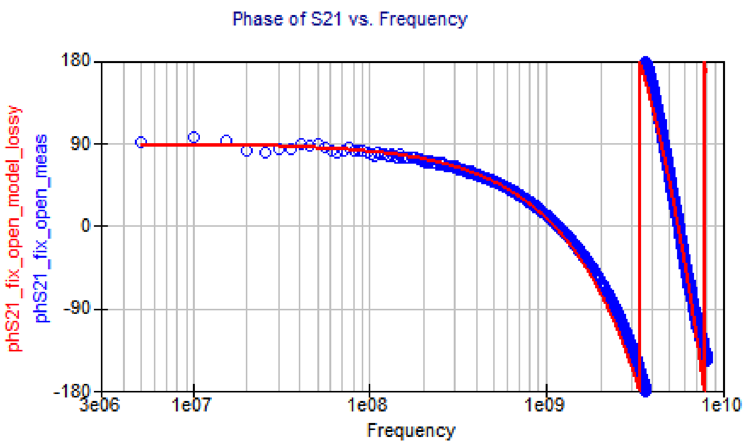
$$C = \frac{-1}{(2\pi f \ \mathrm{x}\ \mathrm{imag}(Z))}$$

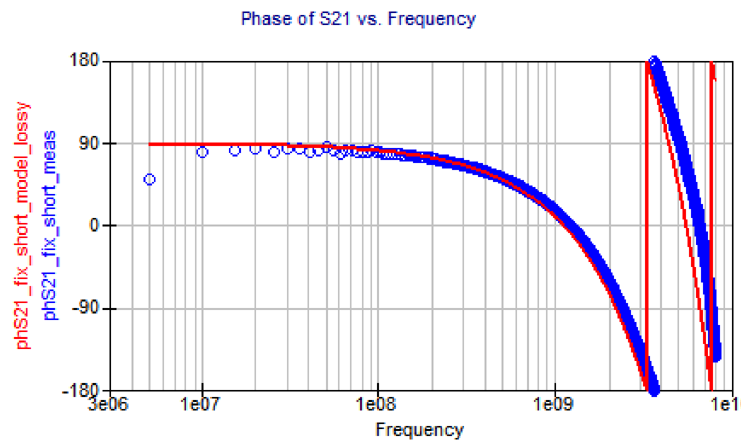


Coupling Between Fixture Signal Paths S21: Measured and Modeled

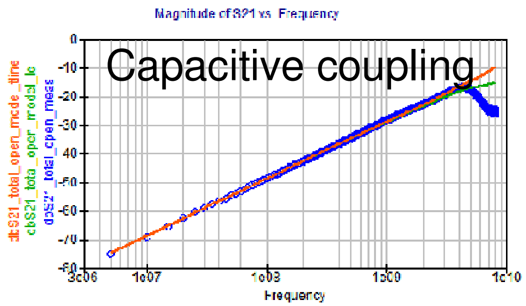


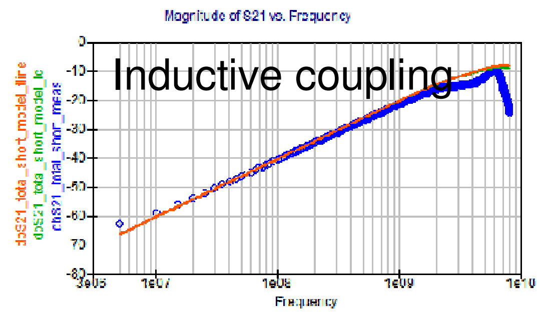


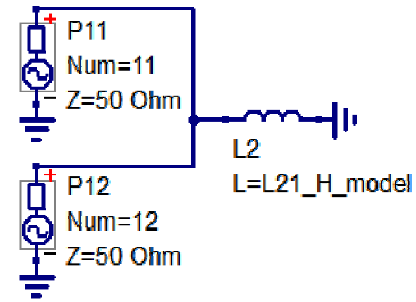




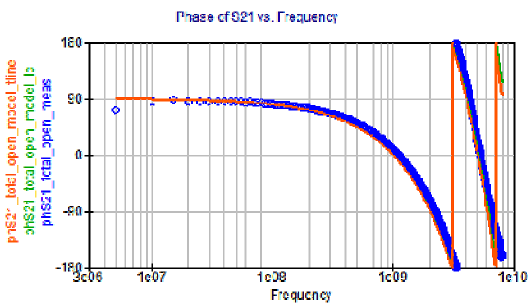
C21 and L21 From the Total Coupling S21, Open and Short

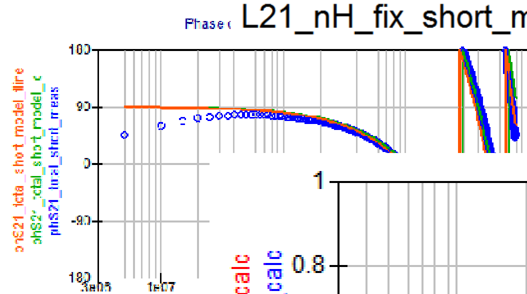


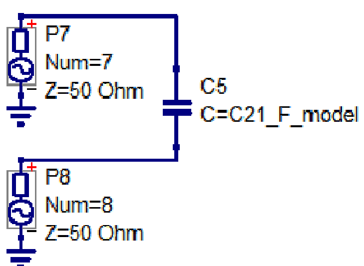


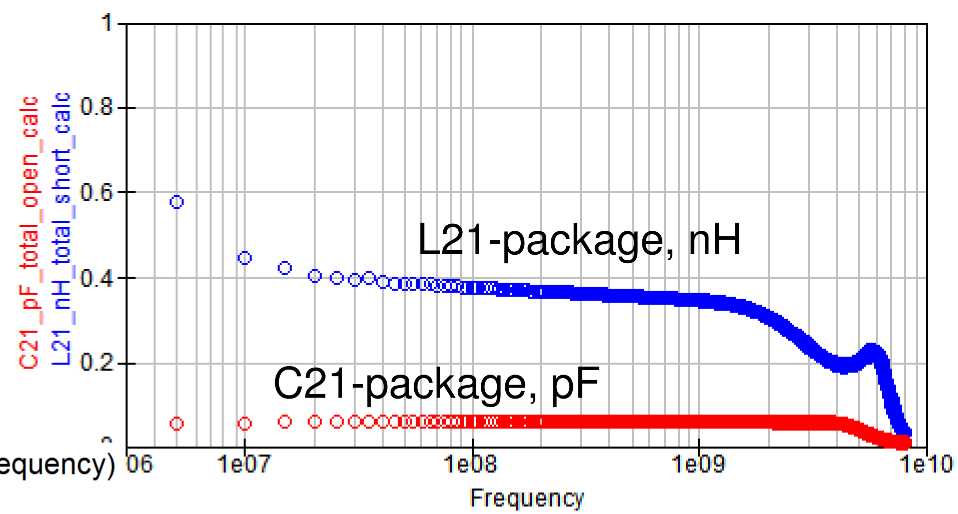


L21_nH_fix_short_model_lc=1e9*mag(S[4,3])*25/(2*pi*frequency)









C21_pF_fix_open_model_lc=1e12*mag(S[2,1])/(100*2*pi*frequency)

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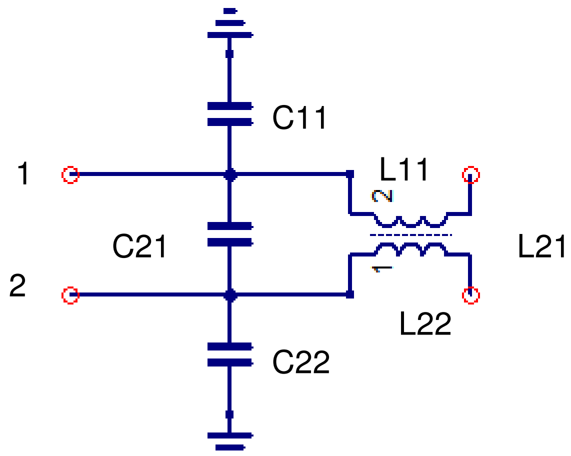
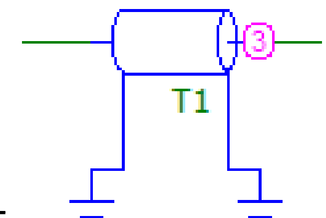
Final Package LC Matrix Elements

C11_pF_model_lc_avg	C21_pF_model_lc_avg	L11_nH_model_lc_avg	L21_nH_model_lc_avg	BW_GHz_model_lc
0.225	0.0597	0.919	0.389	6.95



Converting to single-ended transmission line model:



$$Z_0 = \sqrt{\frac{L11}{C11}} \qquad TD = \sqrt{L11 \times C11}$$

Converting to differential pair transmission line model:

$$Z_{0-odd} = \sqrt{\frac{L11 - L21}{C11 + C21}}$$

Z0_ohms_pkg_model	TD_ns_pkg_model	Zdiff_ohms_pkg_model
63.9	0.0144	86.3

$$Z_{diff} = 2 \times Z_{0-odd}$$

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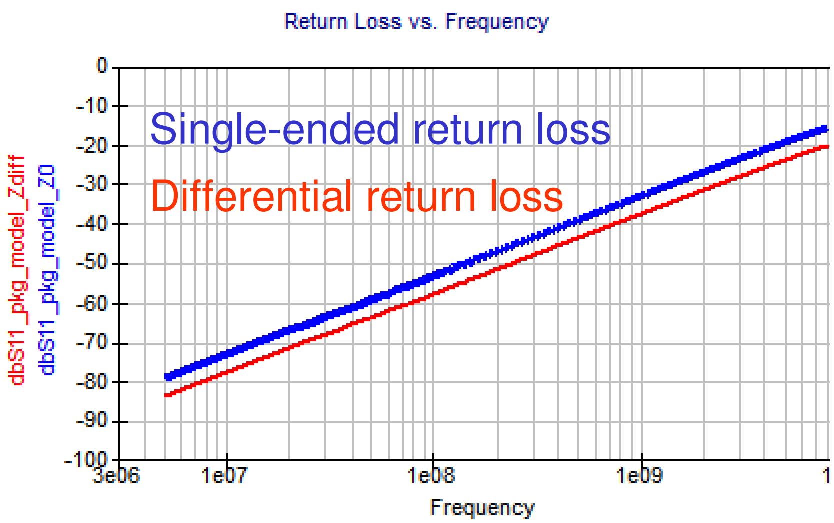
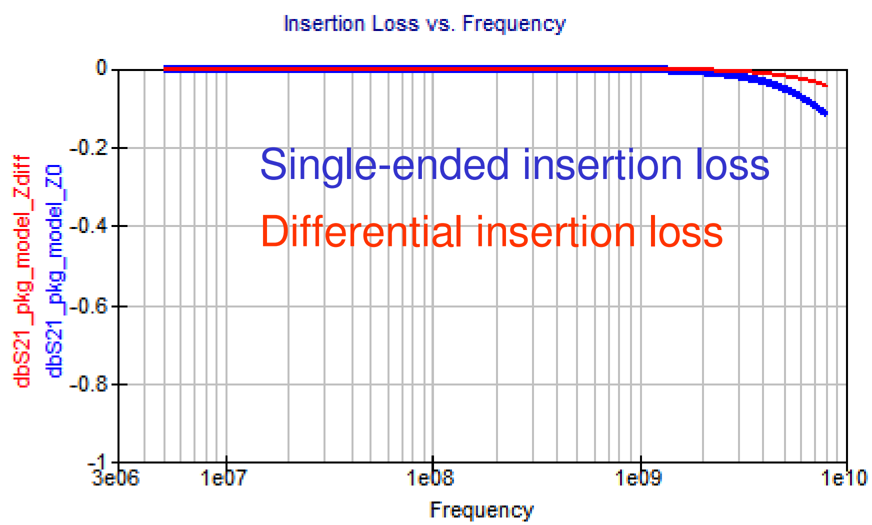
MYTHS

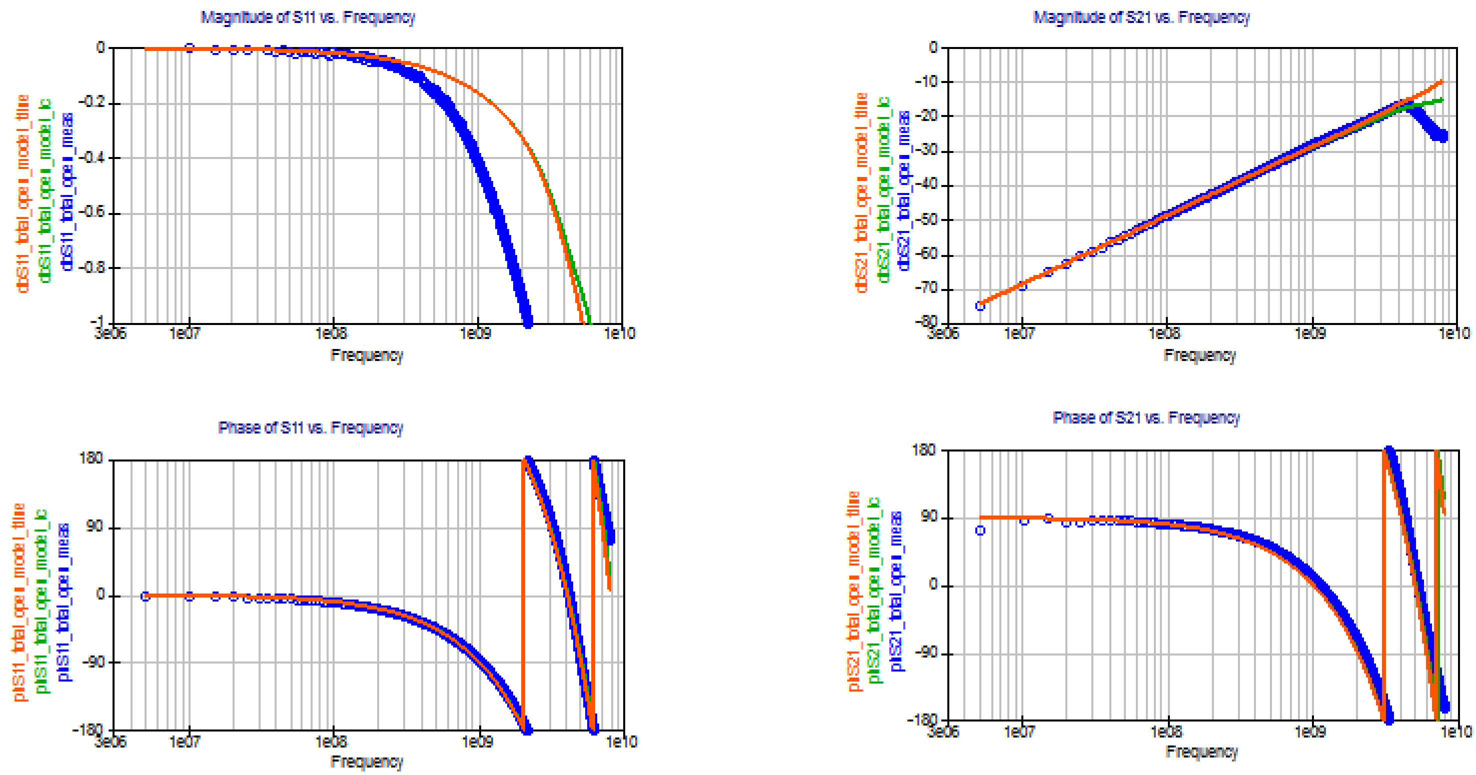
Simulated Insertion and Return Loss of the Transmission Line Models

Z0_ohms_pkg_model	TD_ns_pkg_model	Zdiff_ohms_pkg_model
63.9	0.0144	86.3





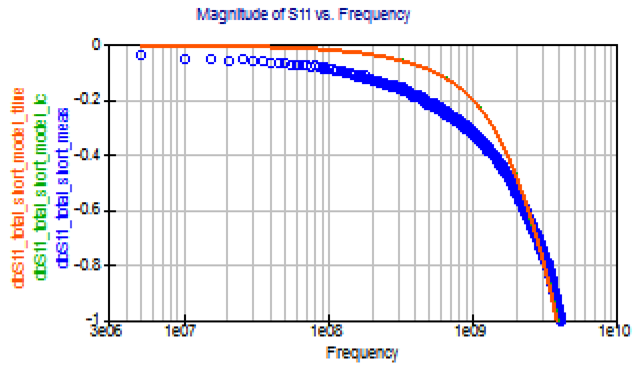
The Bandwidth of the Model: Comparing Total Measurement and Simulation (Open)

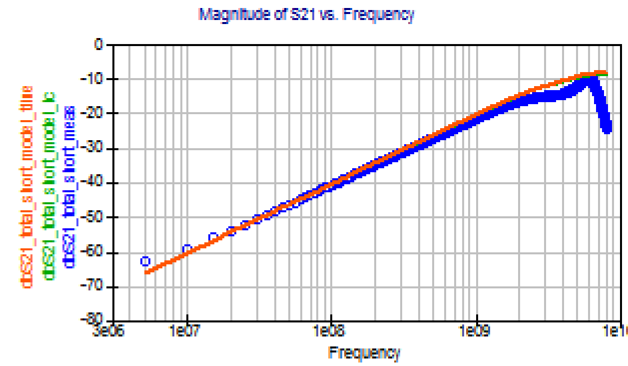


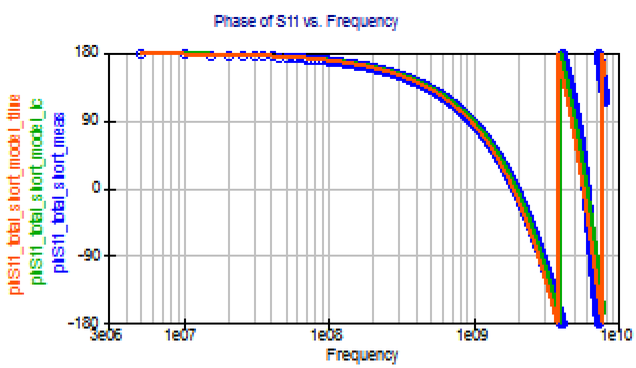
Measured data for opens:
Fixture lossy model
Package LC model
Package transmission line model

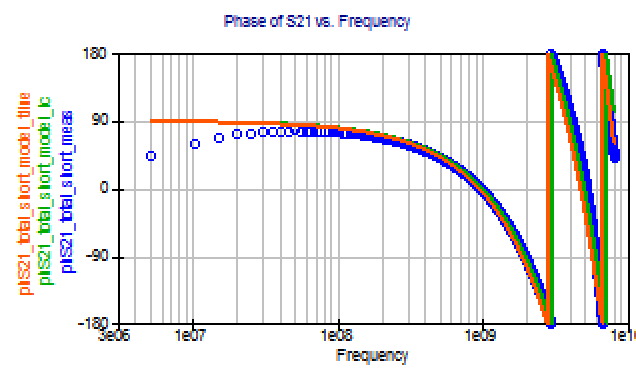
BW of the model is at least 5 GHz

The Bandwidth of the Model: Comparing Total Measurement and Simulation (Shorted)









Measured data for shorts:
Fixture lossy model
Package LC model
Package transmission line model

BW of the model is at least 5 GHz

This General Approach can be Used with other Small Structures

- Other structures:
  - ✓ Vias
  - ✓ Connectors
  - ✓ Circuit board structures
  - ✓ Package leads
- Requires
  - ✓ Specific return paths defined
  - ✓ Custom fixture board with SMA connectors
  - ✓ Access to only one end of the interconnects
  - ✓ Other ends of the interconnects open and shorted
  - ✓ Measurements in the frequency domain with impedance analyzer or network analyzer
  - ✓ Bandwidth of the model can be very high, > 5 GHz