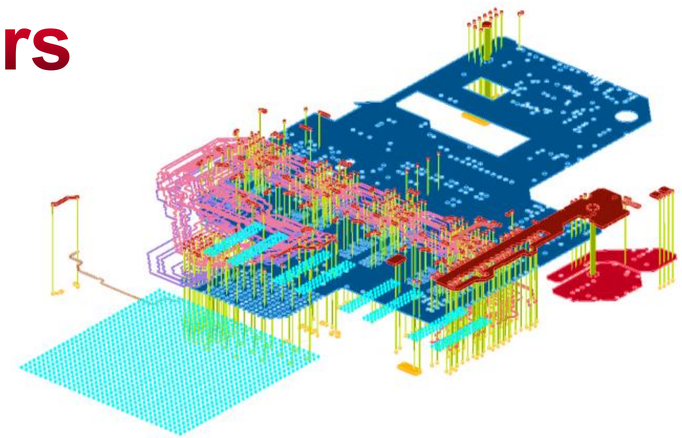
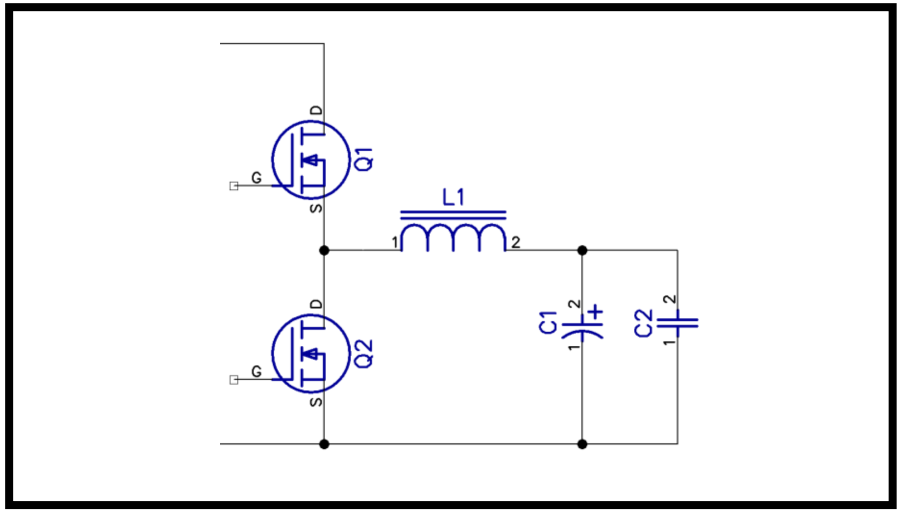
Power Integrity Boot Camp for Designers

Section 2
Measuring, Modeling, Simulating Capacitors and Inductors

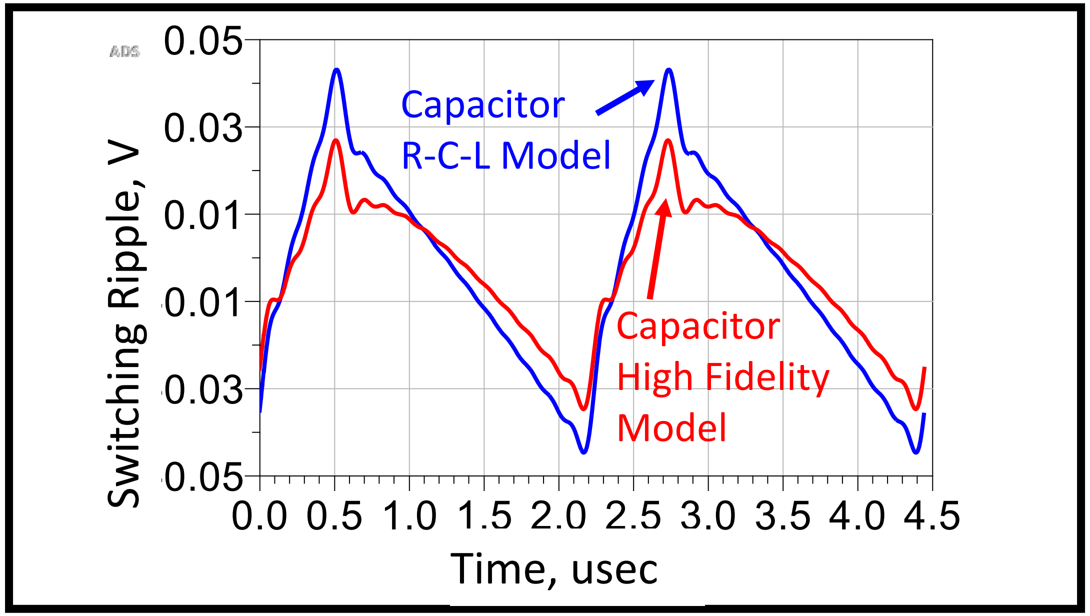


KEYSIGHT TECHNOLOGIES with solutions partner PICOTEST

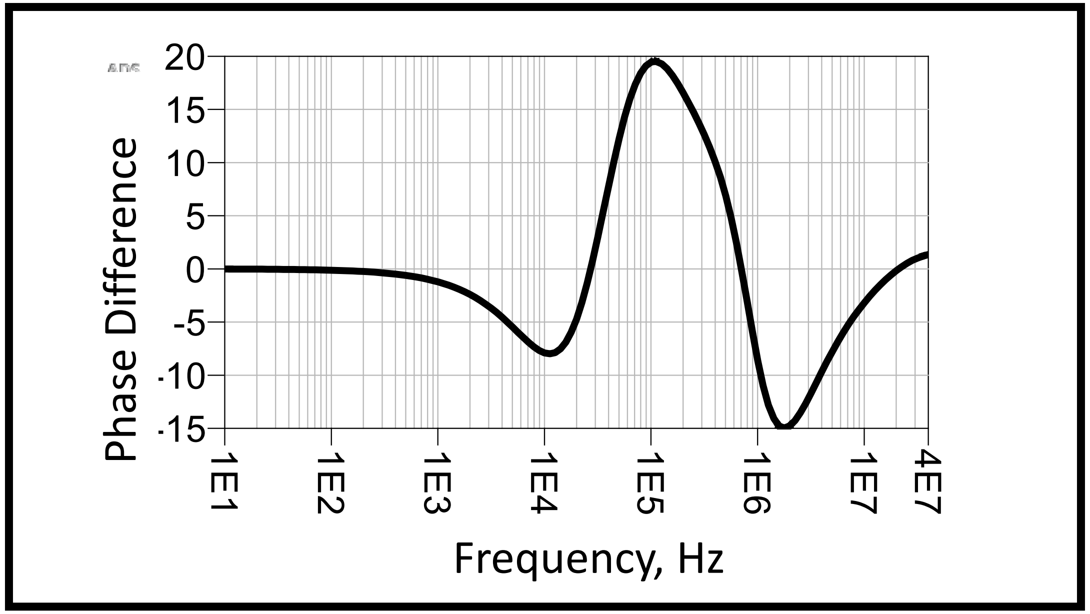
Voltage Regulator Module

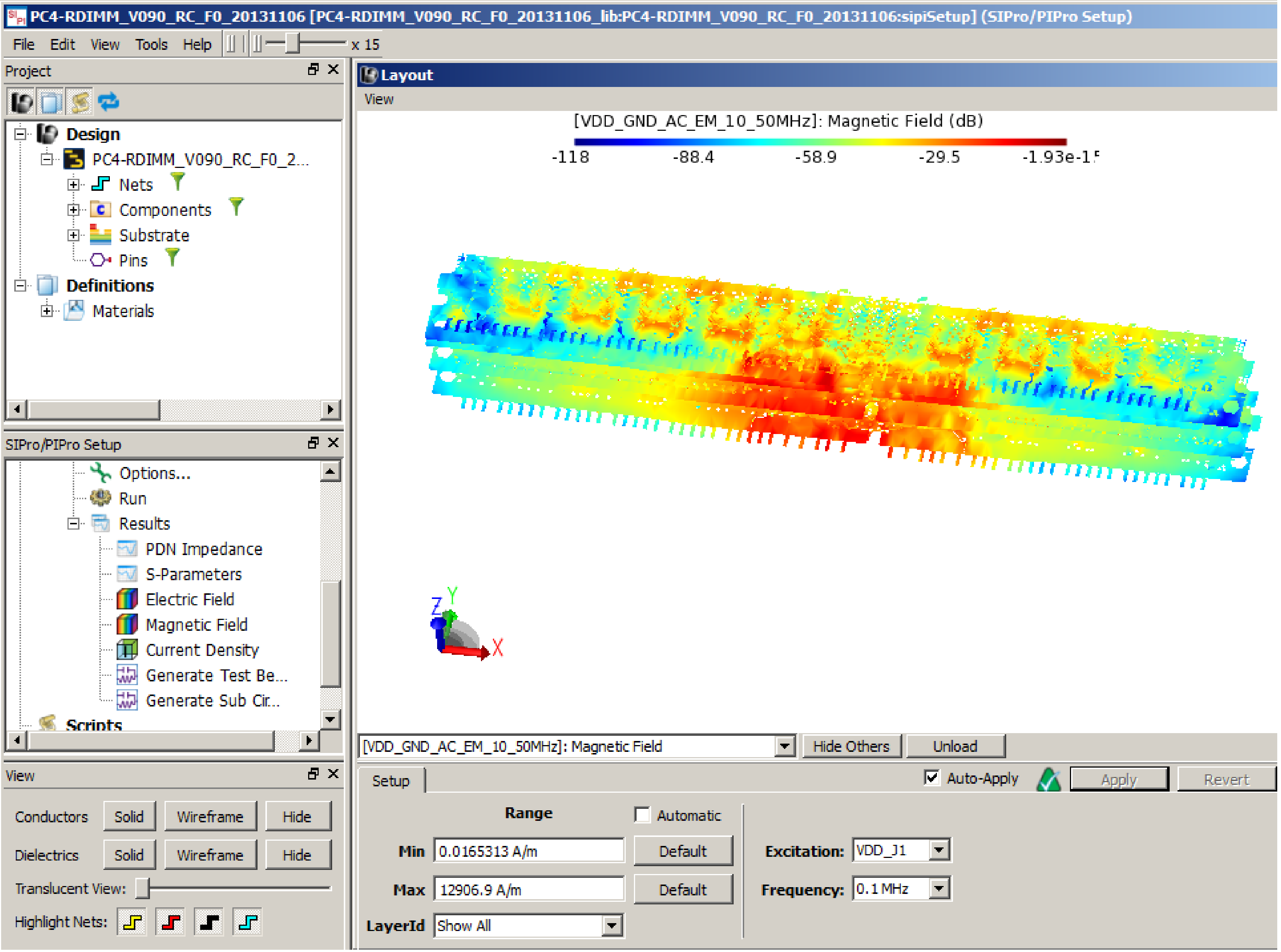


Switching Ripple
Capacitor RLC vs High Fidelity Model

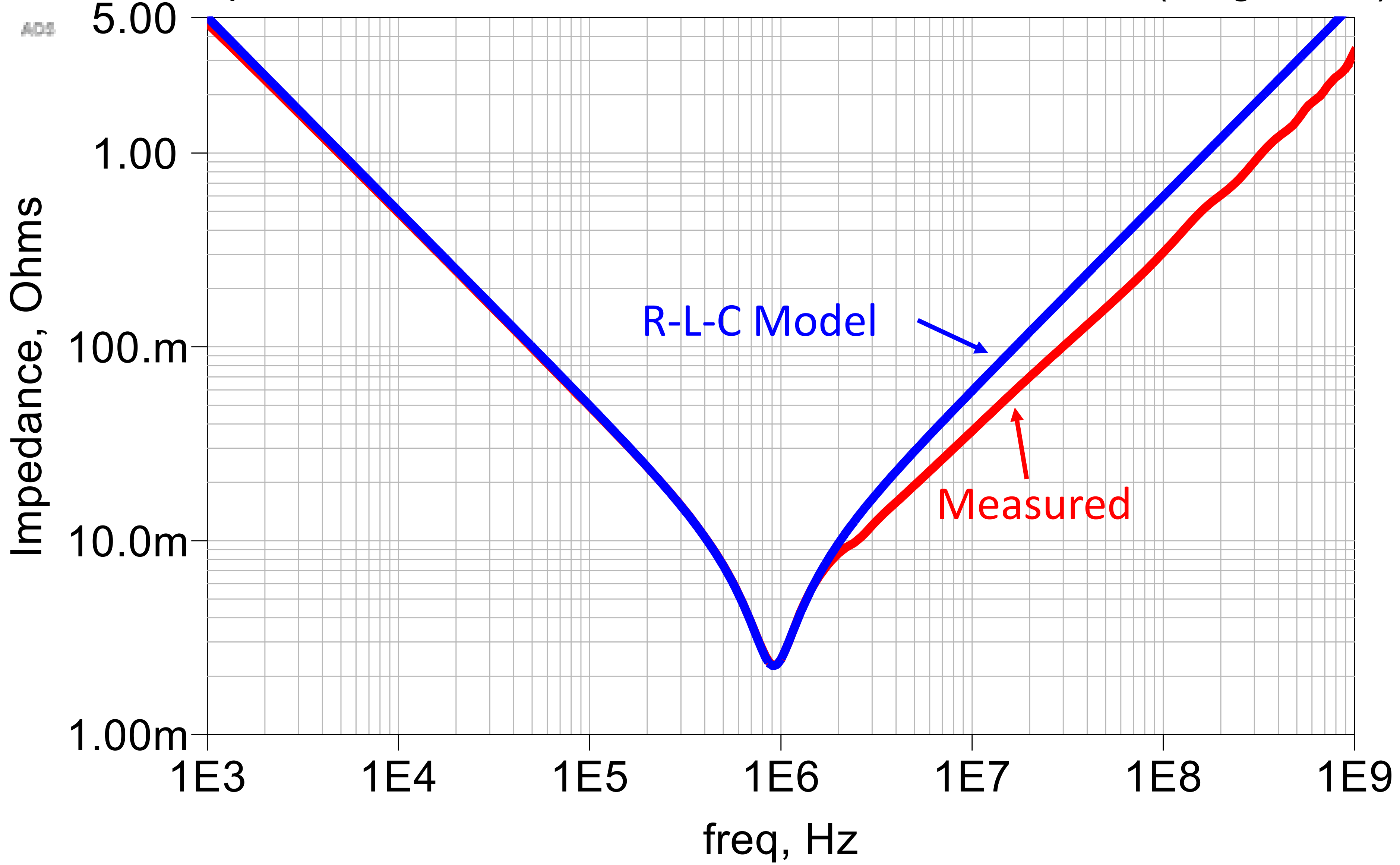


Phase Difference
Phase(RLC Model) – Phase(High Fidelity Model)




PC4-RDIMM_V090_RC_F0_20131106 [PC4-RDIMM_V090_RC_F0_20131106_lib:PC4-RDIMM_V090_RC_F0_20131106:sipiSetup] (SIPro/PIPro Setup)
File Edit View Tools Help
x 15
Project
Design
PC4-RDIMM_V090_RC_F0_2...
Nets
Components
Substrate
Pins
Definitions
Materials
SIPro/PIPro Setup
Options...
Run
Results
PDN Impedance
S-Parameters
Electric Field
Magnetic Field
Current Density
Generate Test Be...
Generate Sub Cir...
Scripts
View
Conductors Solid Wireframe Hide
Dielectrics Solid Wireframe Hide
Translucent View:
Highlight Nets:
Layout
View
[VDD_GND_AC_EM_10_50MHz]: Magnetic Field (dB)
-118 -88.4 -58.9 -29.5 -1.93e-15
Z Y X
[VDD_GND_AC_EM_10_50MHz]: Magnetic Field
Hide Others
Unload
Setup
Auto-Apply
Apply
Revert
Range
Automatic
Min 0.0165313 A/m
Default
Max 12906.9 A/m
Default
LayerId Show All
Excitation: VDD_J1
Frequency: 0.1 MHz

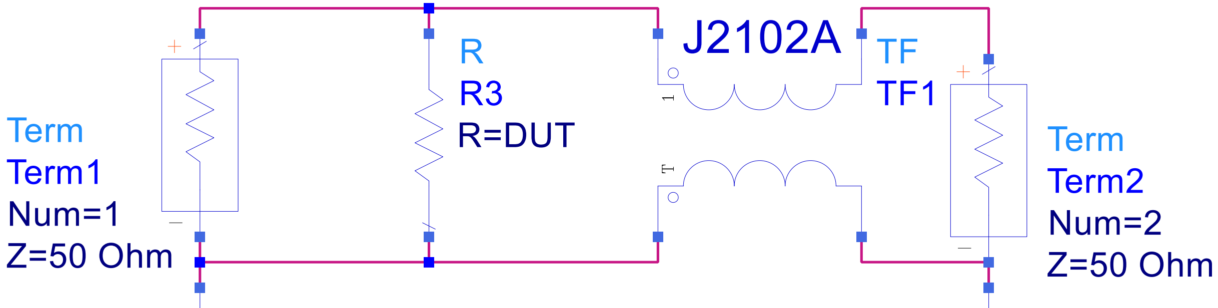
Capacitor RLC Model vs. Measured S-Parameter (Magnitude)



Key Topics

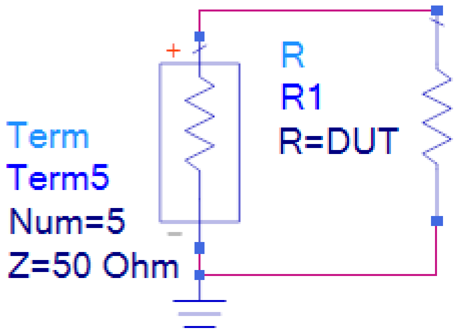
- How to perform a modified 2-port shunt through measurement technique for high fidelity data
- Why different simulation models are needed for SPICE and EM simulators
- How an optimizer can help create the high fidelity models from the measurements

2-Port Shunt



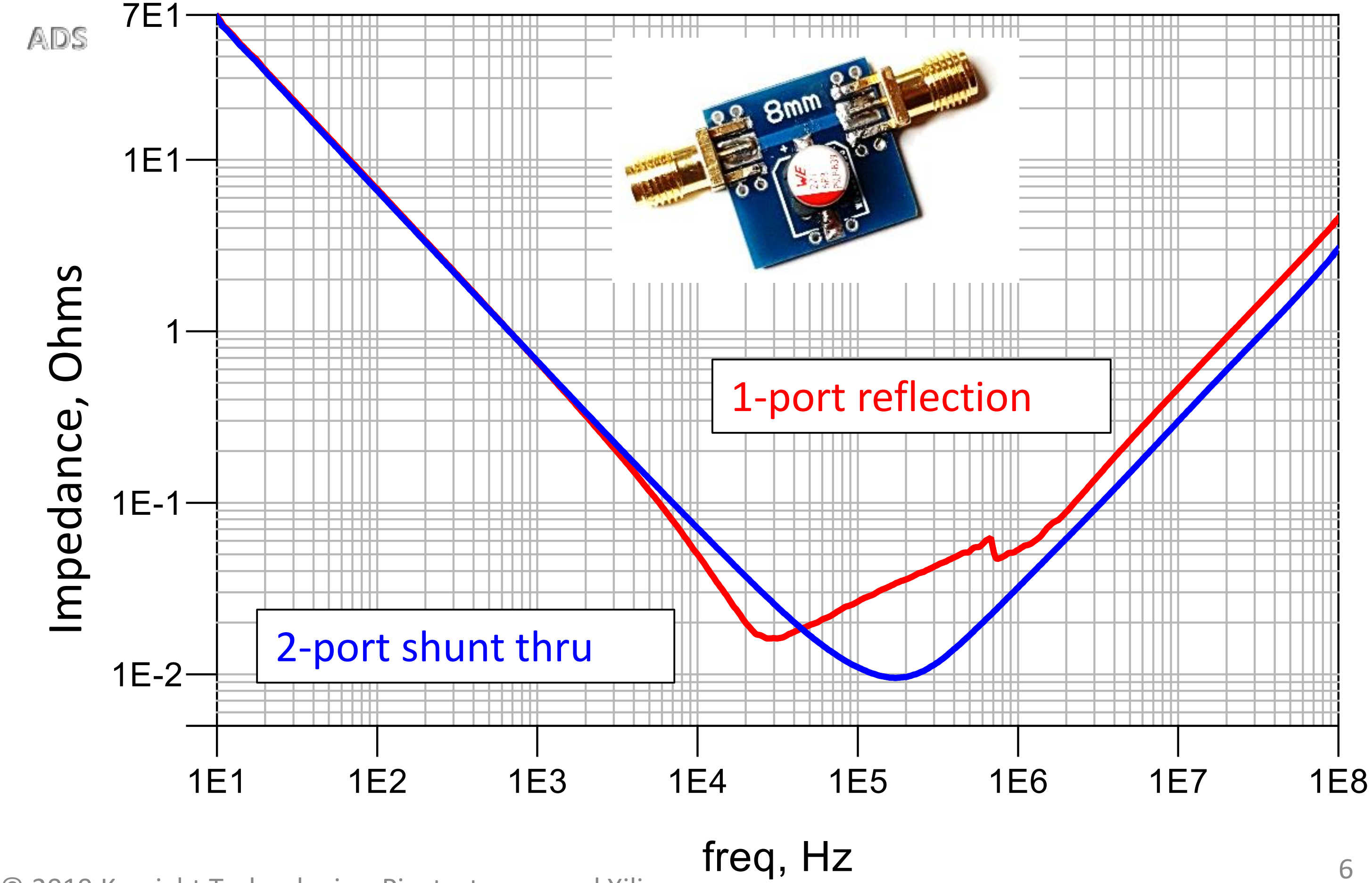
1 mΩ - 225 Ω ≥ 105 dB

1-Port

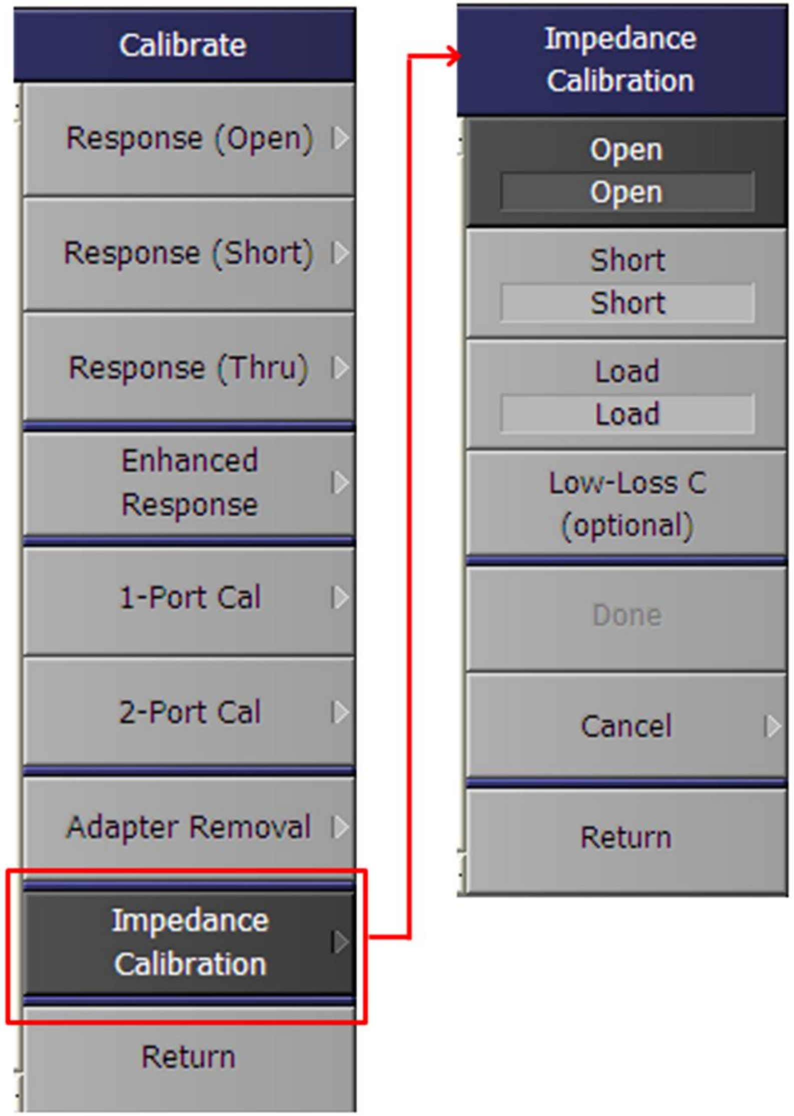


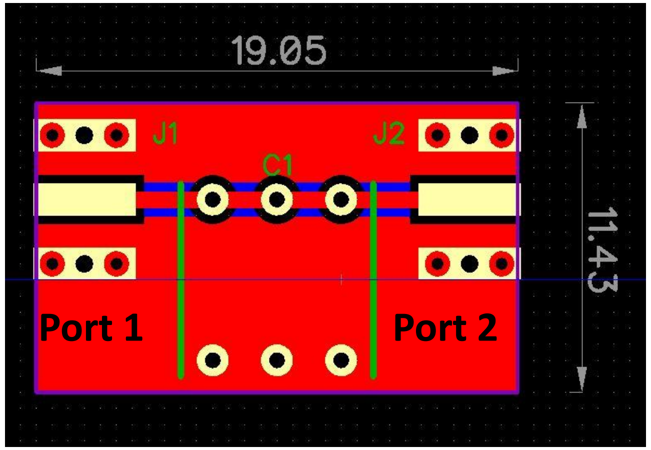
1 Ω - 2 kΩ ≥ 66 dB

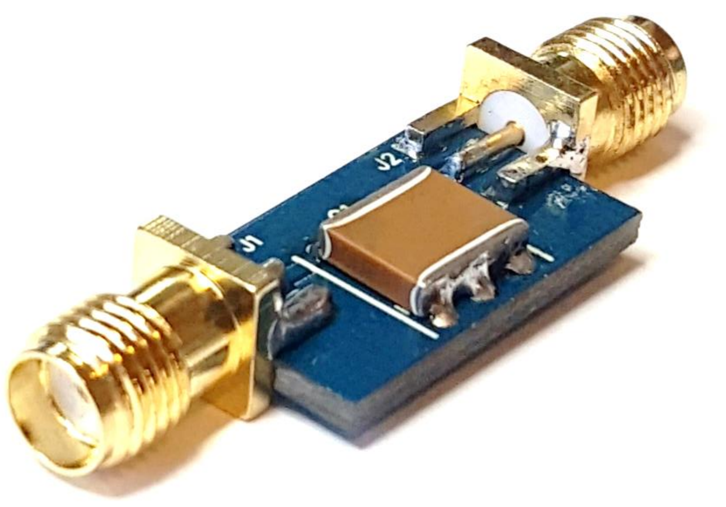
220uF Aluminum Polymer

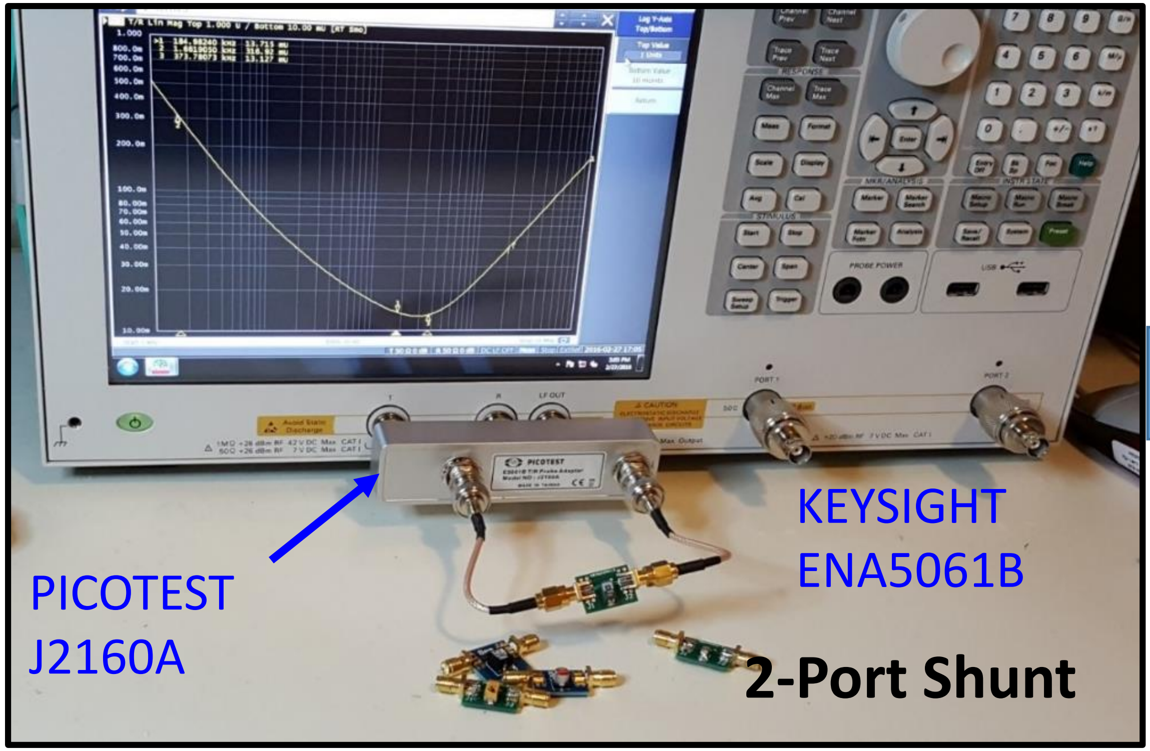


2-Port Shunt Set-up





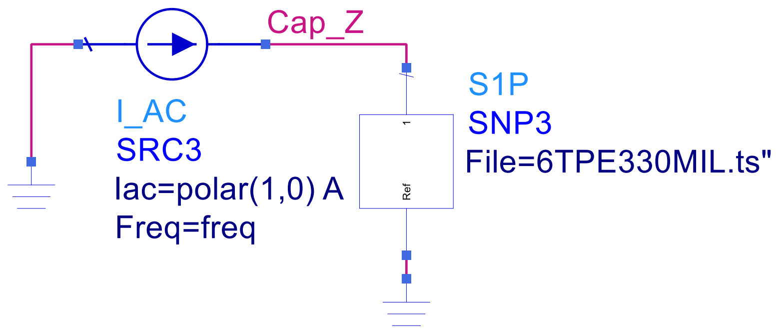




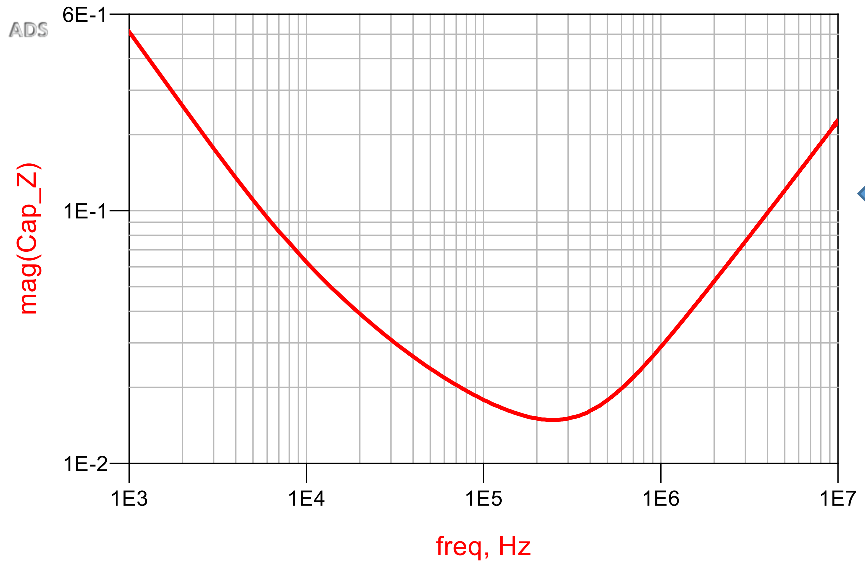
Export

Touchstone S-Parameter file

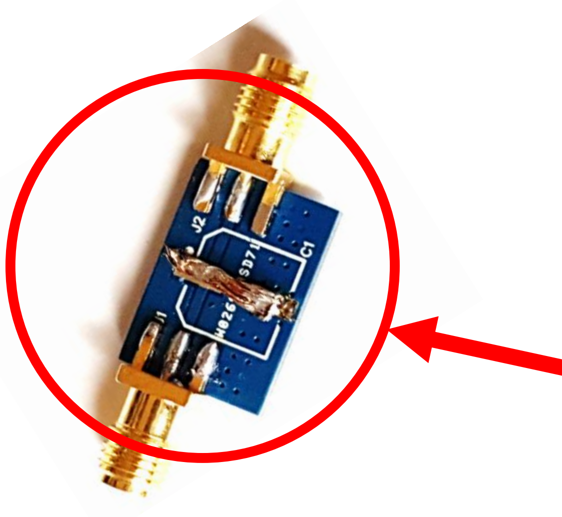
```
# Hz Z RI R 50
[Number of Ports] 1
[Number Of Frequencies] 201
[Network Data]
!freq           ReZ11       ImZ11
1000.00         0.121123    -1.537176
1047.128548     0.111947    -1.468758
1096.478196     0.104285    -1.403602
1148.153621     0.097308    -1.341032
1202.264435     0.090883    -1.280776
1258.925412     0.085359    -1.224046
1318.256739     0.079624    -1.169881
1380.384265     0.075118    -1.117441
1445.439771     0.070178    -1.067565
1513.561248     0.066014    -1.020212
1584.893192     0.061078    -0.974788
1659.586907     0.058686    -0.930364
```

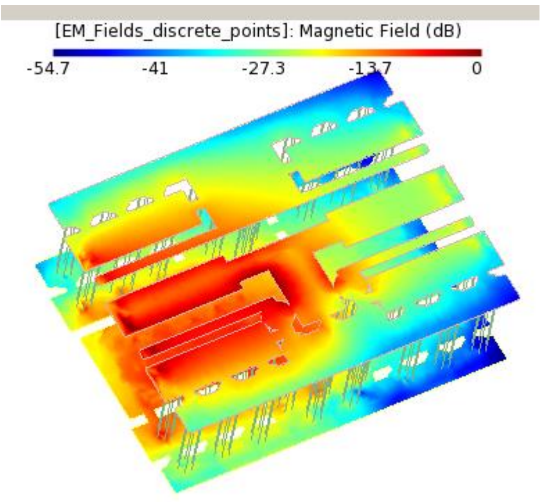


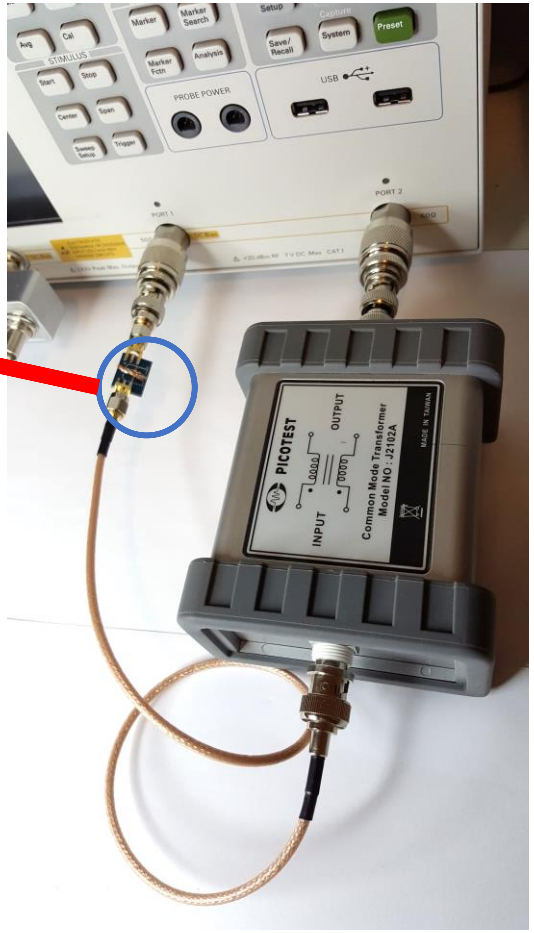
Measured Model



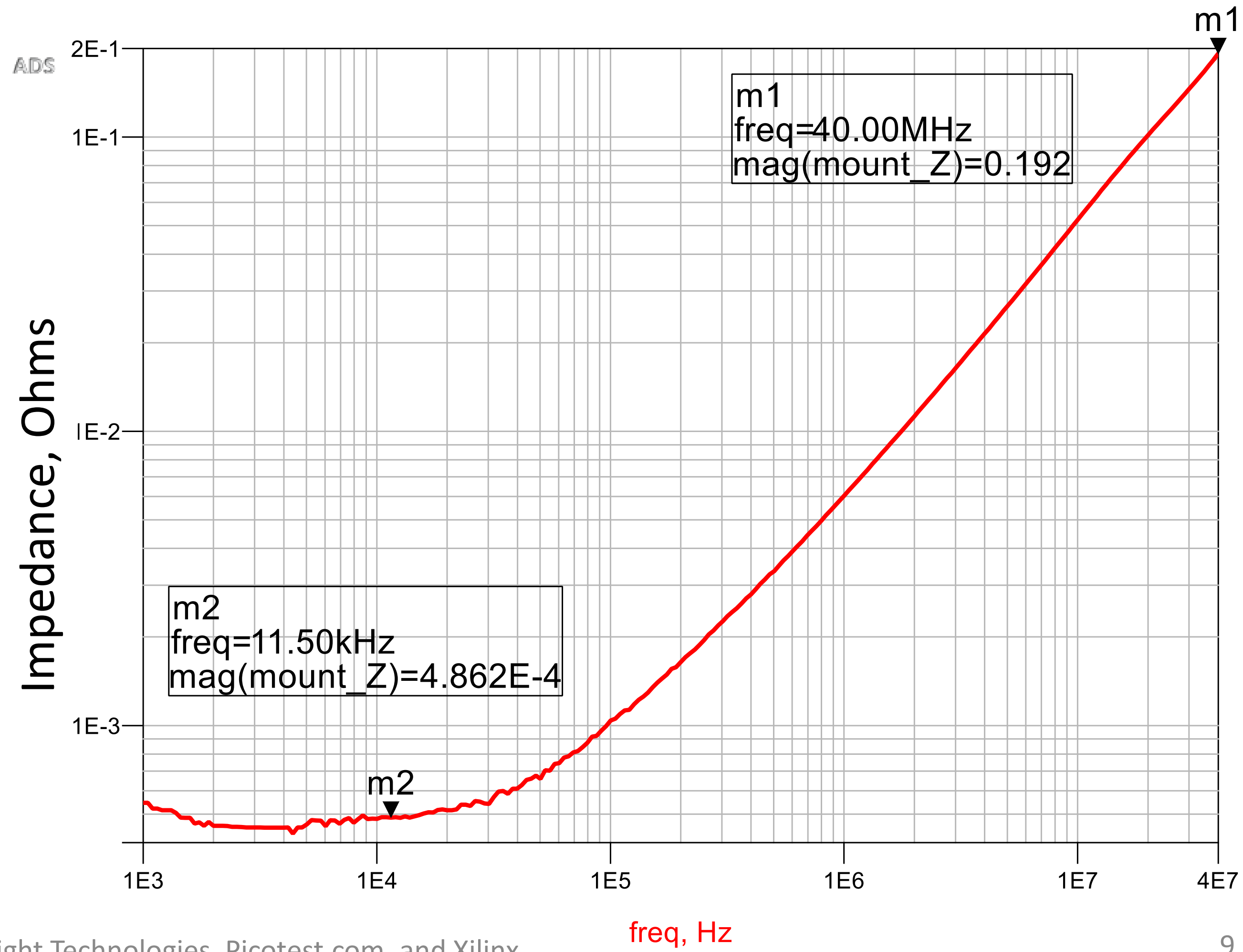
Mounting Inductance Measured with Short to Ground

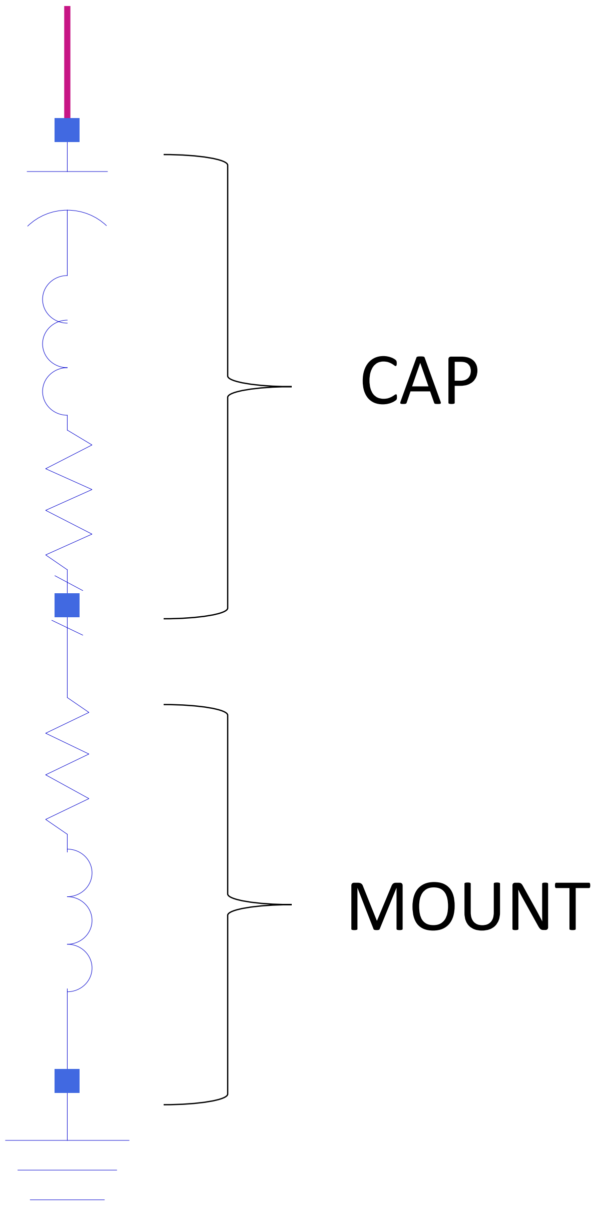


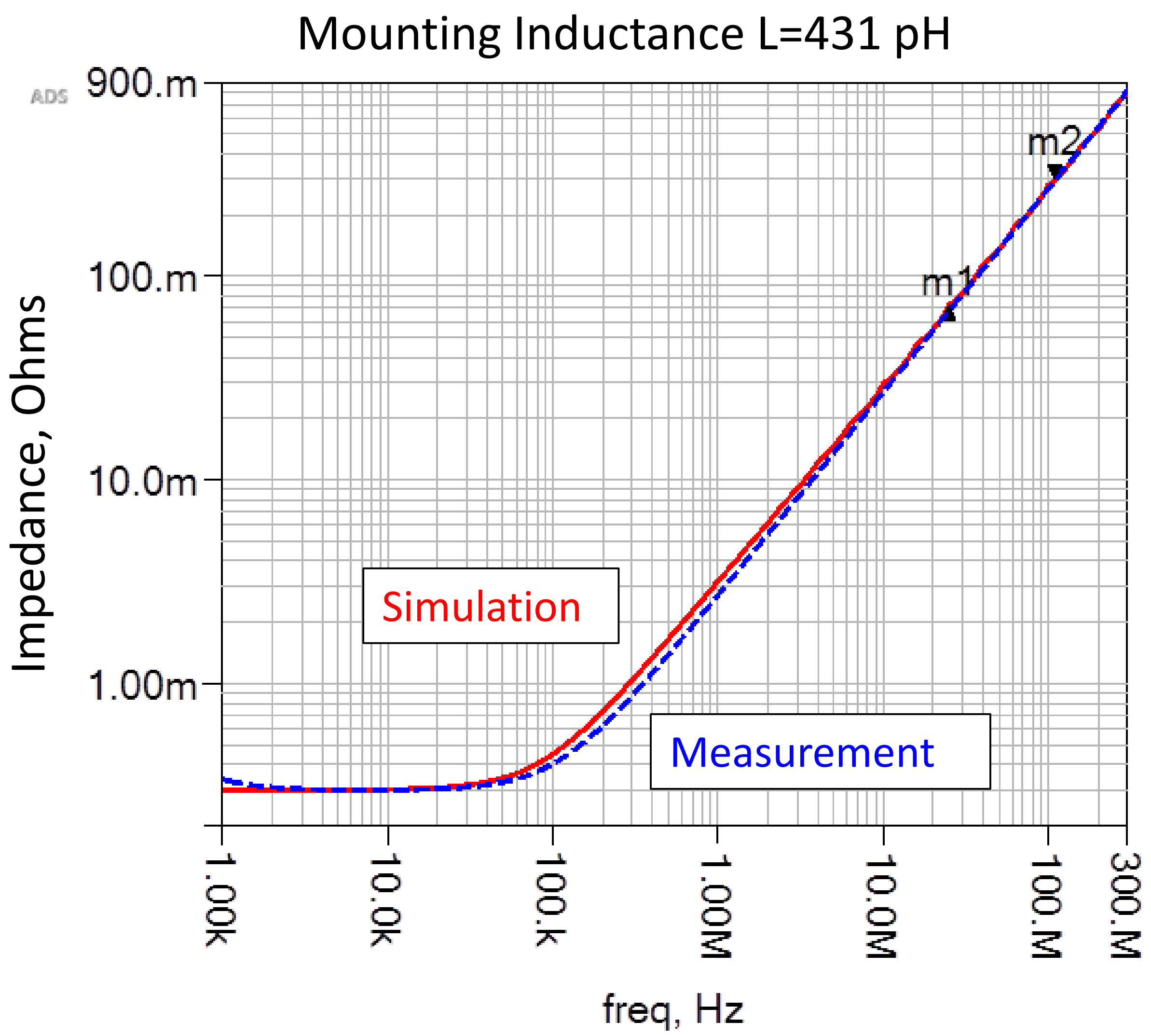




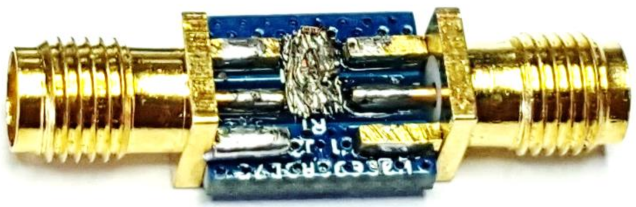
$$L_{mount} = \frac{0.192}{2\pi \cdot 40MHz} = 764pH$$



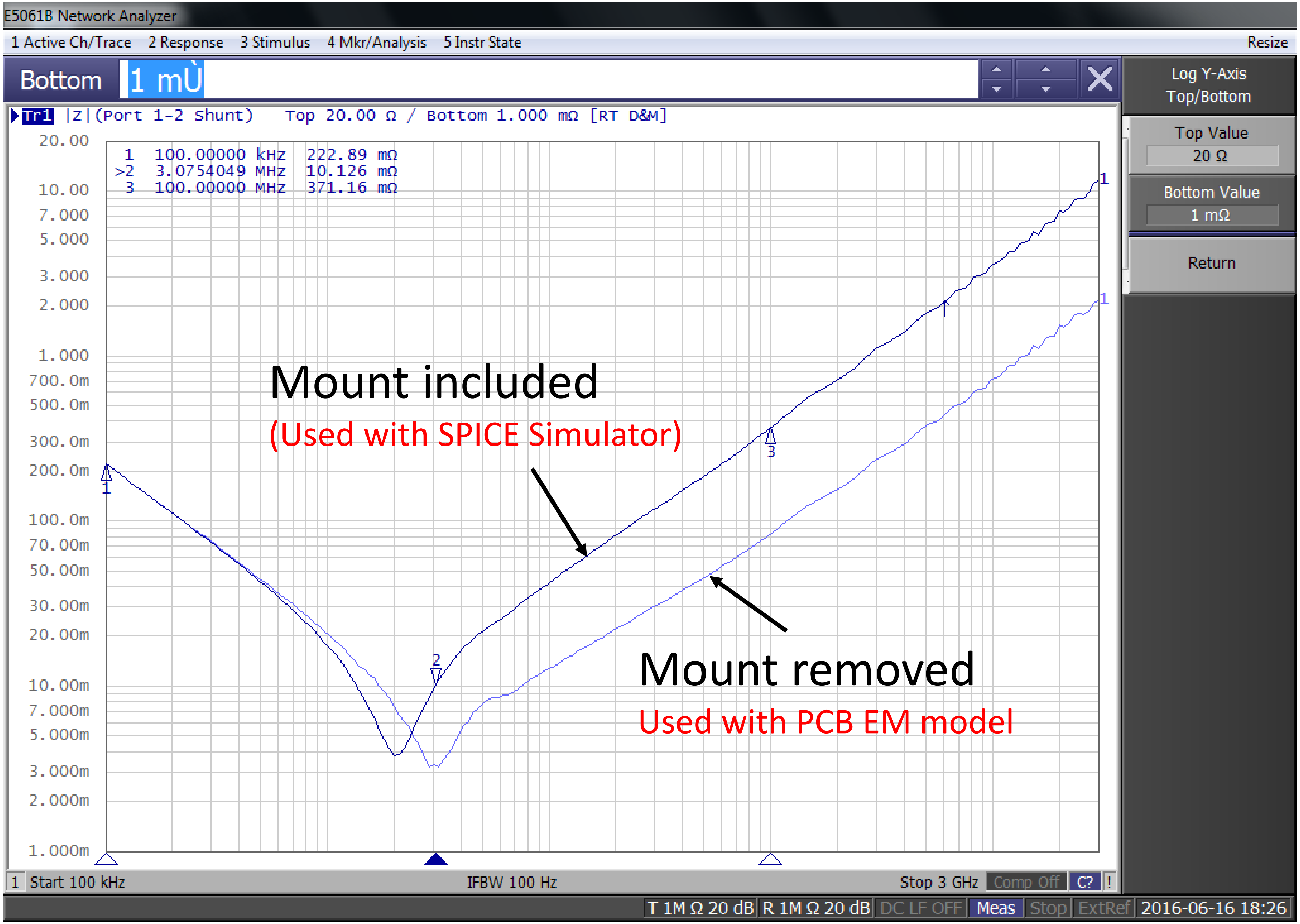


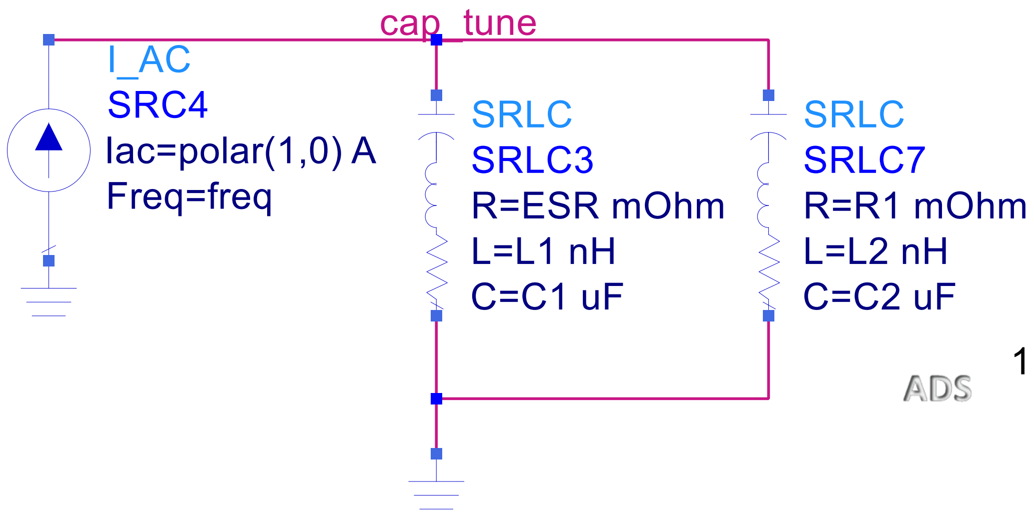


MOUNT



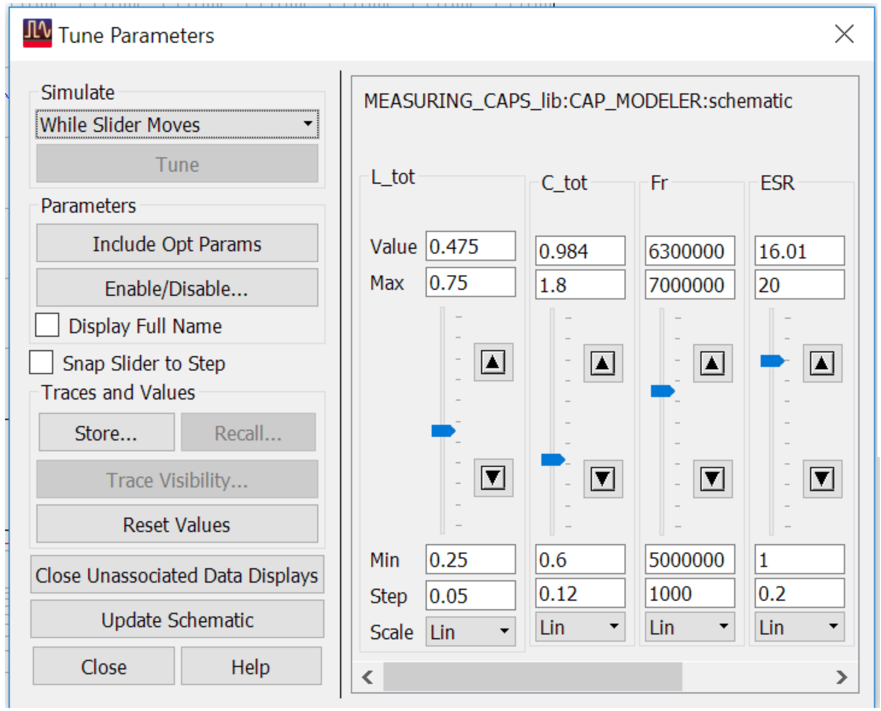
Shorted to Ground

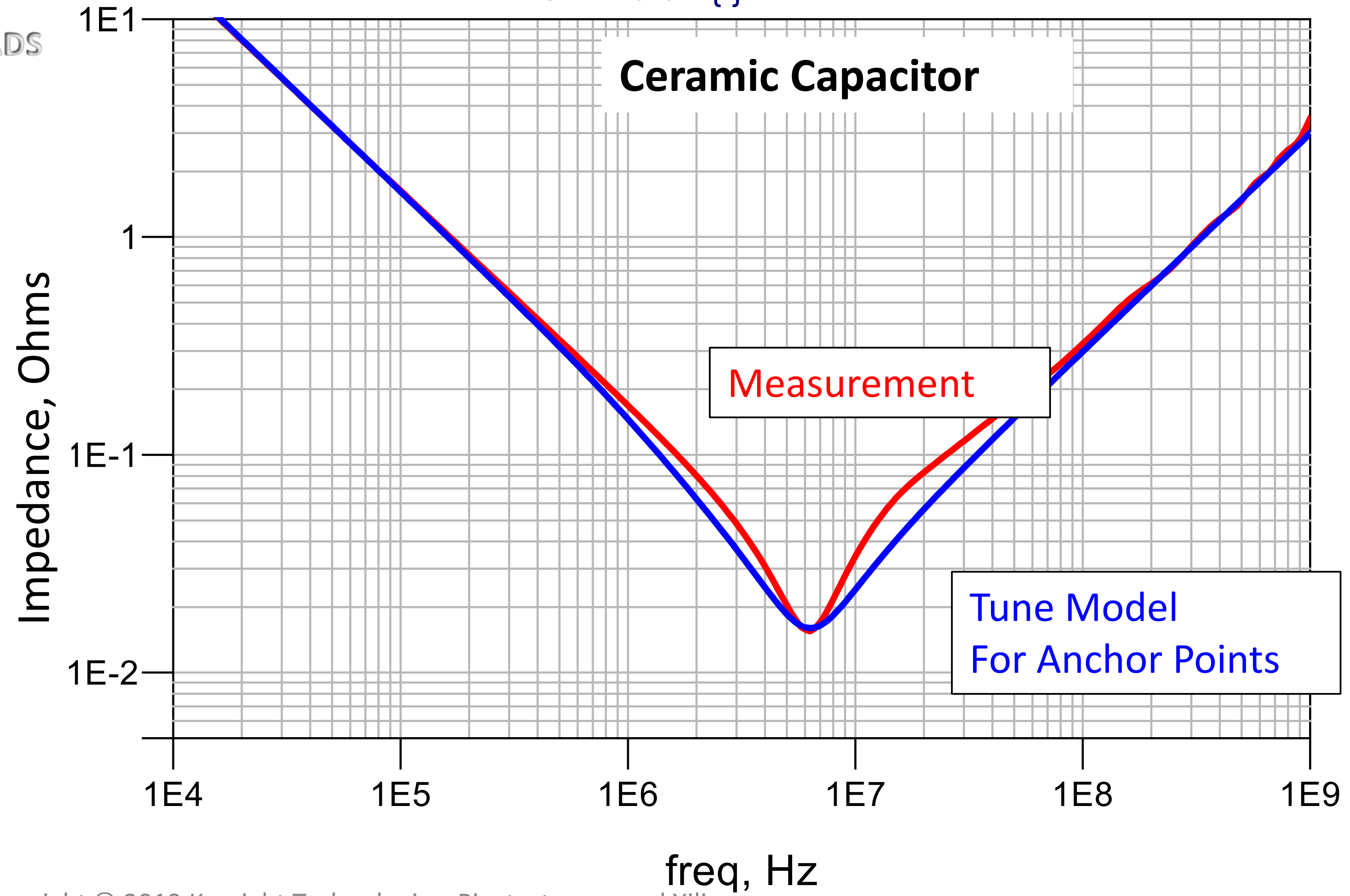

E5061B Network Analyzer
1 Active Ch/Trace
2 Response
3 Stimulus
4 Mkr/Analysis
5 Instr State
Resize
Bottom
1 mÙ
Log Y-Axis Top/Bottom
Top Value
20 Ω
Bottom Value
1 mΩ
Return
Tr1 |Z|(Port 1-2 Shunt) Top 20.00 Ω / Bottom 1.000 mΩ [RT D&M]
1 100.00000 kHz 222.89 mΩ
>2 3.0754049 MHz 10.126 mΩ
3 100.00000 MHz 371.16 mΩ
20.00
10.00
7.000
5.000
3.000
2.000
1.000
700.0m
500.0m
300.0m
200.0m
100.0m
70.00m
50.00m
30.00m
20.00m
10.00m
7.000m
5.000m
3.000m
2.000m
1.000m
Mount included
(Used with SPICE Simulator)
Mount removed
Used with PCB EM model
1 Start 100 kHz
IFBW 100 Hz
Stop 3 GHz
Comp Off
C?
T 1M Ω 20 dB
R 1M Ω 20 dB
DC LF OFF
Meas
Stop
ExtRef
2016-06-16 18:26

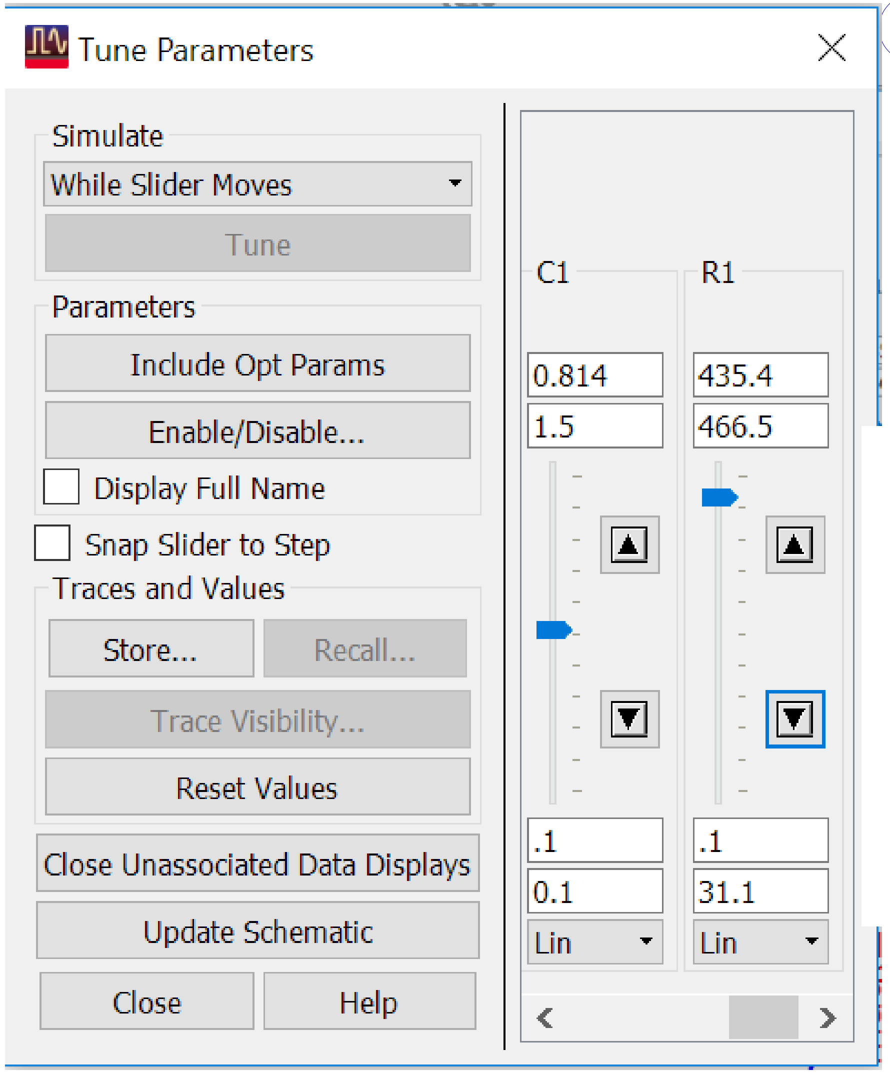


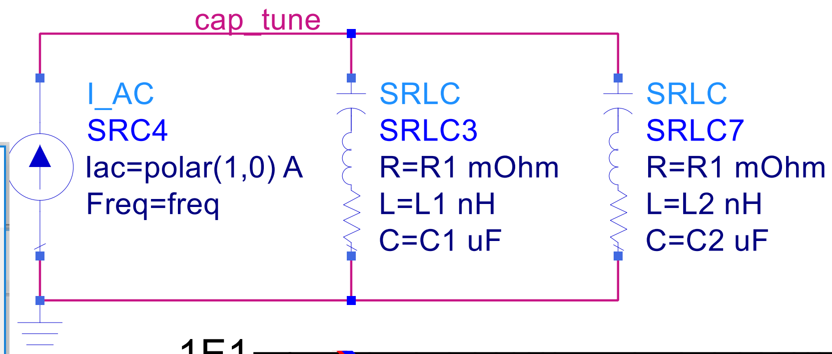
Anchor values

Var Eqn VAR
VAR1
L_tot=0.475 {t}
C_tot=0.984 {t}
Fr=6300000 {t}
ESR=16.01 {t}





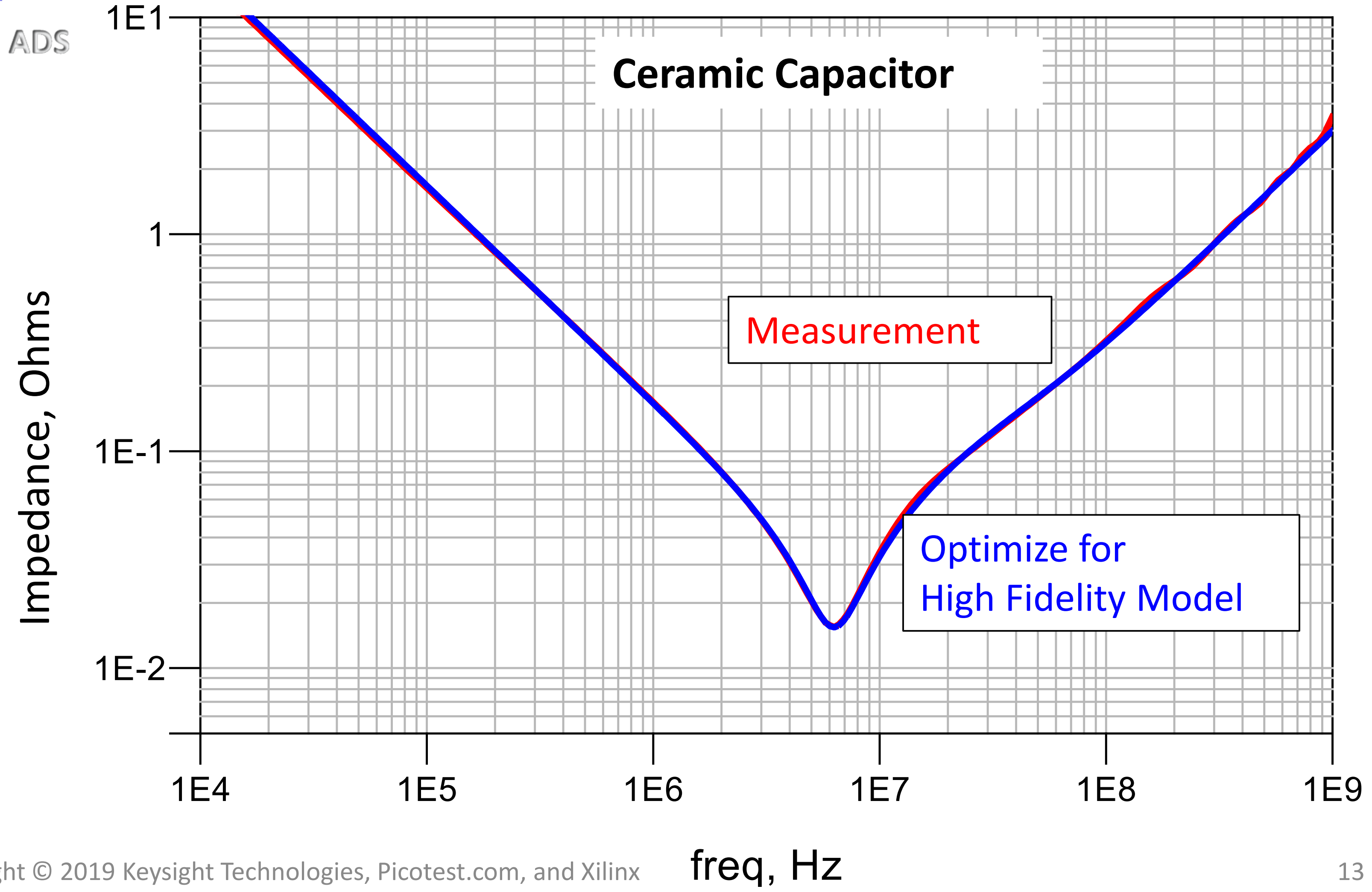




Shaping values

Var Eqn

VAR
VAR3
C1=0.75 {t}
R1=311 {t}

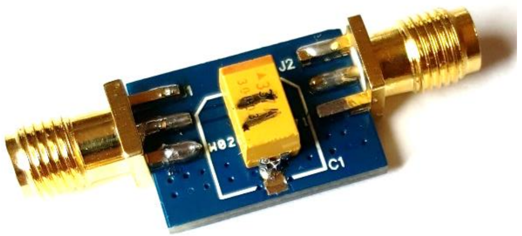


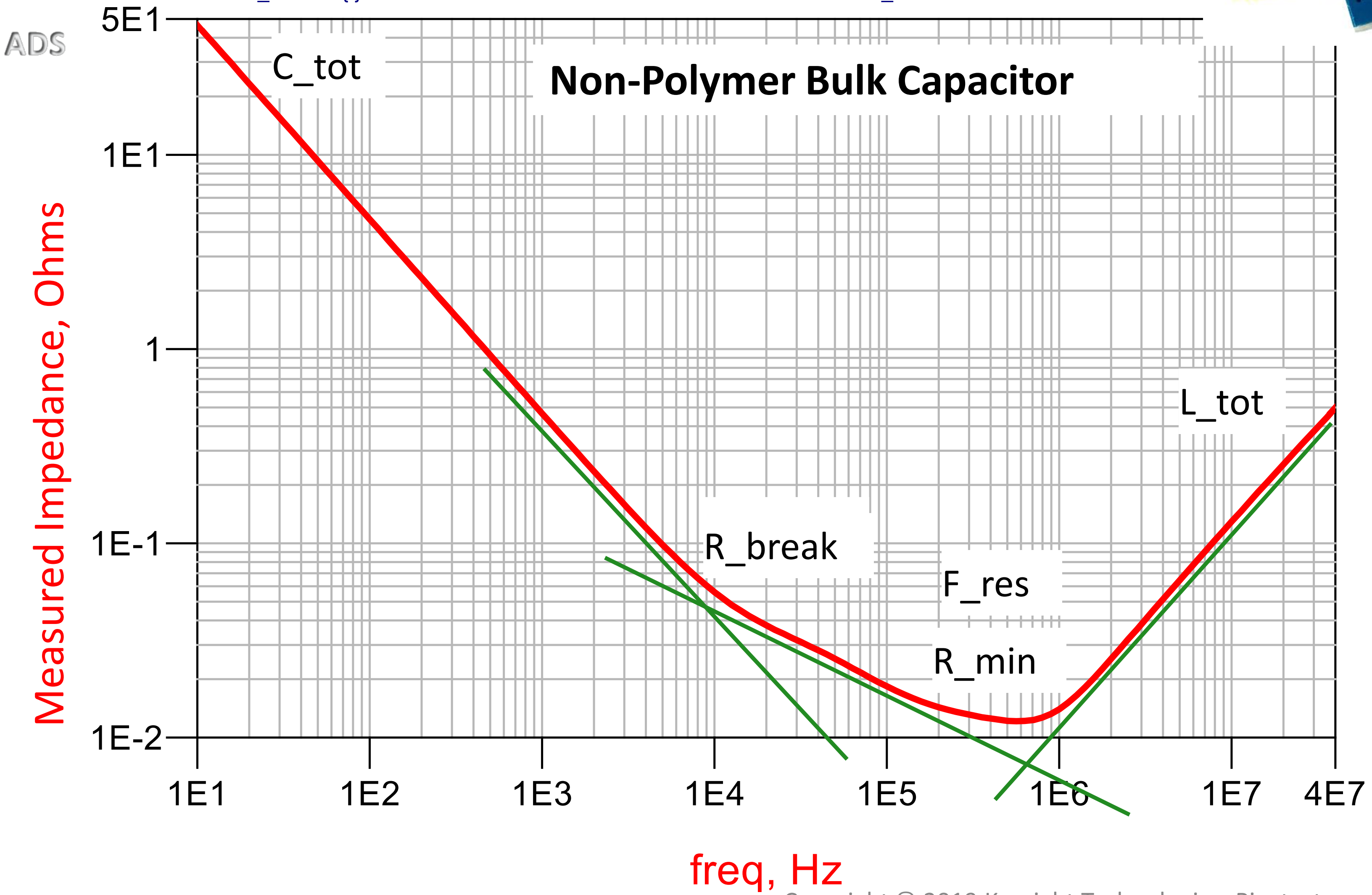
Anchor values

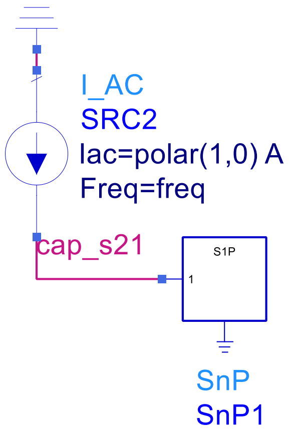
Var Eqn VAR
VAR9
L_tot=1.76 {t}
C_tot=330 {t}
F_break=11520 {t}
R_break=42 {t}
F_res=600000 {t}
R_res=12 {t}

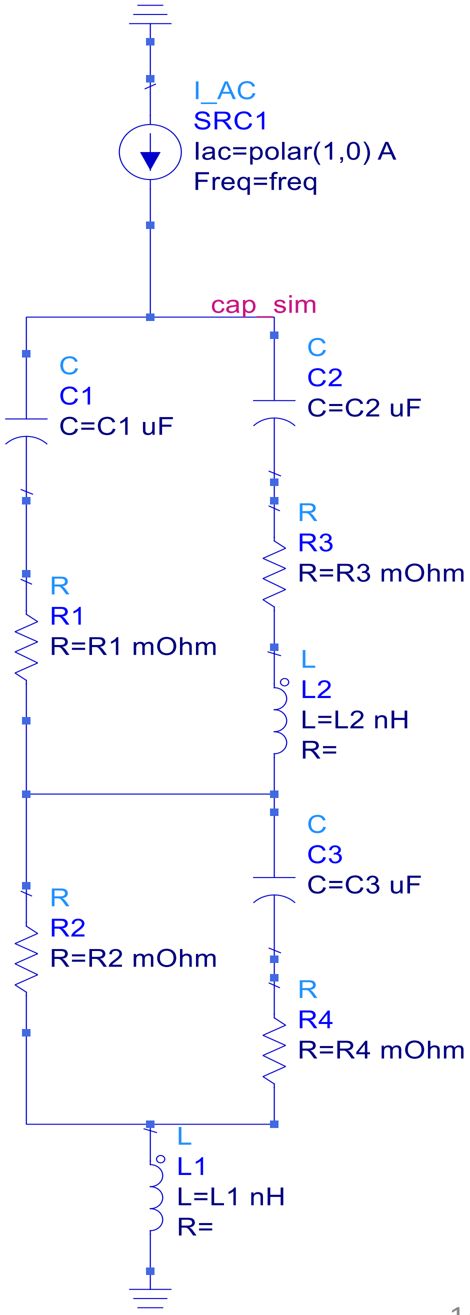
Default values and tuning

Var Eqn VAR
VAR6
C1=K1*1E9/(8.89*F_break*R_break)
R2=K2*R_res
L2=K3*5E15/(39.5*F_res*F_res*C_tot)
C3=K4*1E9/(15*F_res*R2)
R4=K5*R_res
R3=K6*R_res









Meas Eqn
MeasEqn
cap_err
cap_err=mag(cap_meas)-mag(cap_sim)
cap_meas=cap_s21*25/(1-cap_s21)

Before Optimization

Shaping values

Var Eqn
VAR
VAR12
K1=1 {t} {o}
K2=1 {t} {o}
K3=1 {t} {o}
K4=1 {t} {o}
K5=1 {t} {o}
K6=1 {t} {o}

GOAL

Goal
OptimGoal1
Expr="cap_err"
SimInstanceName="AC1"
Weight=1
LimitName[1]="limit1"
LimitType[1]="EqualTo"
LimitMin[1]=0
LimitMax[1]=0

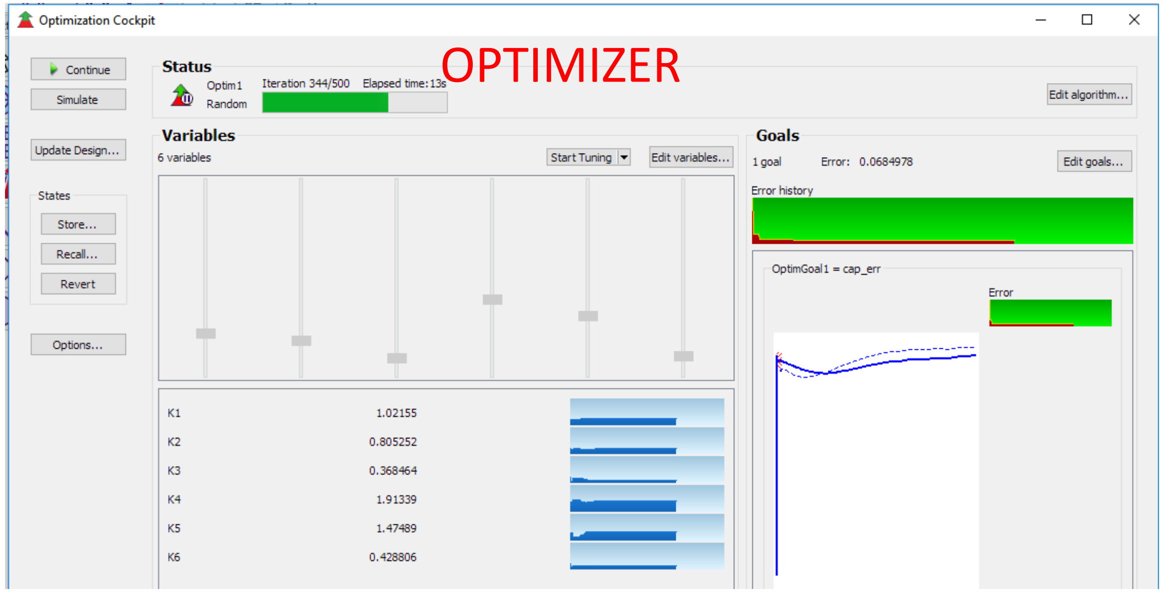
OPTIM

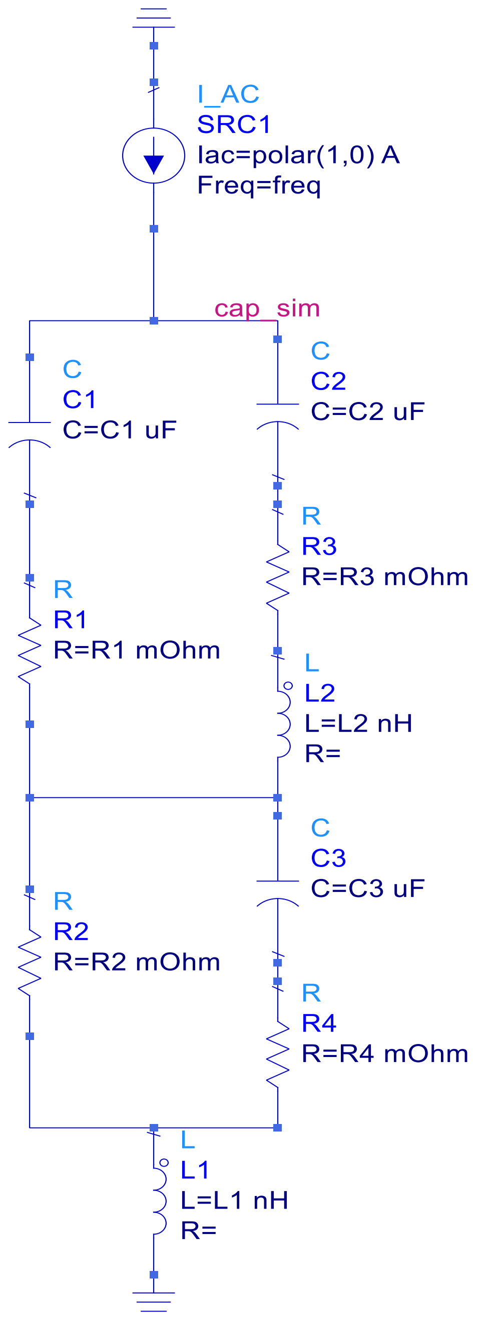
Optim
Optim1
OptimType=Random
MaxIters=1000
UseAllOptVars=yes
UseAllGoals=yes
GoalName[1]=
SaveAllTrials=no

After Optimization

Shaping values

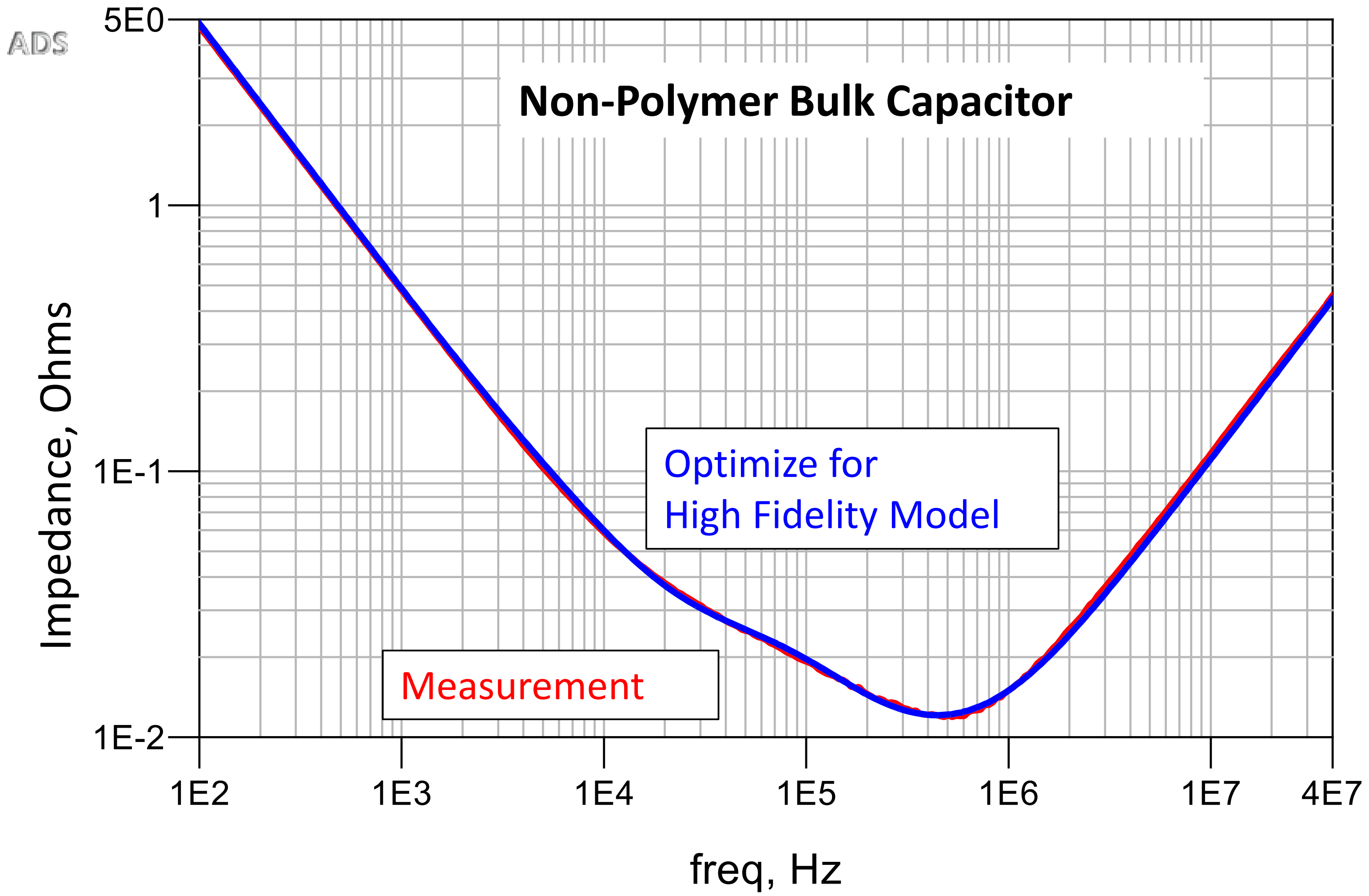
Var Eqn
VAR
VAR11
K1=1.00876 {t} {o}
K2=0.837194 {t} {o}
K3=0.41982 {t} {o}
K4=2.09546 {t} {o}
K5=1.56776 {t} {o}
K6=0.409425 {t} {o}



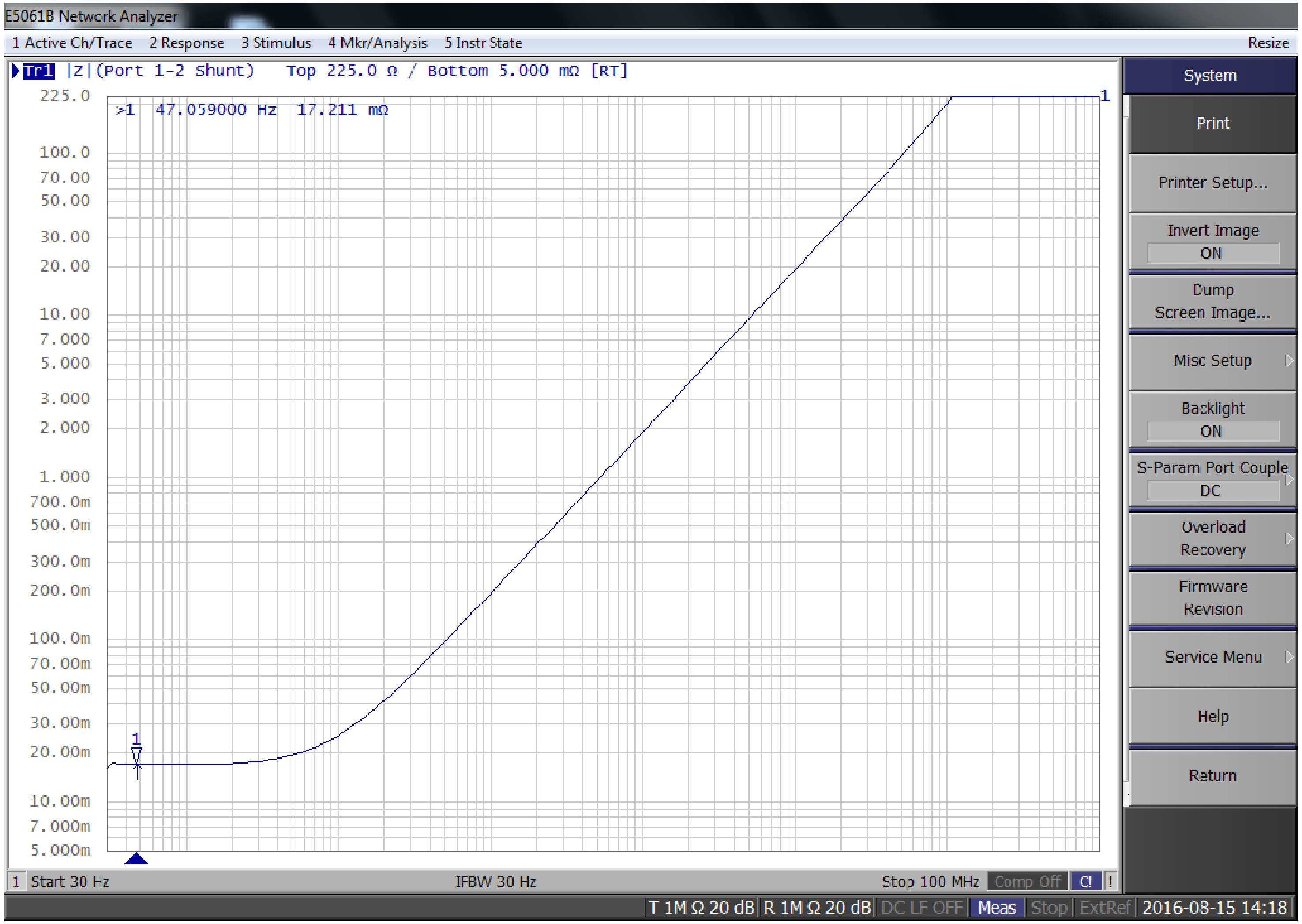


OPTIMIZER DETERMINED COMPONENT VALUES

C1_val	C2_val	C3_val	L1_val	L2_val	R1_val	R2_val	R3_val	R4_val
234.522	95.478	23.176	1.760	0.447	30.000	10.046	4.913	18.813

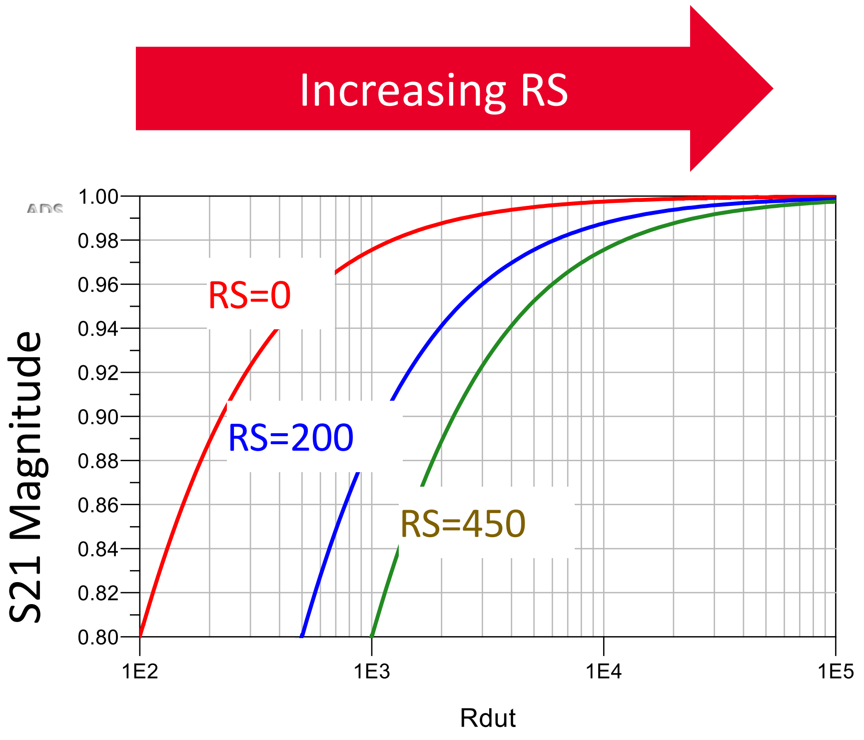


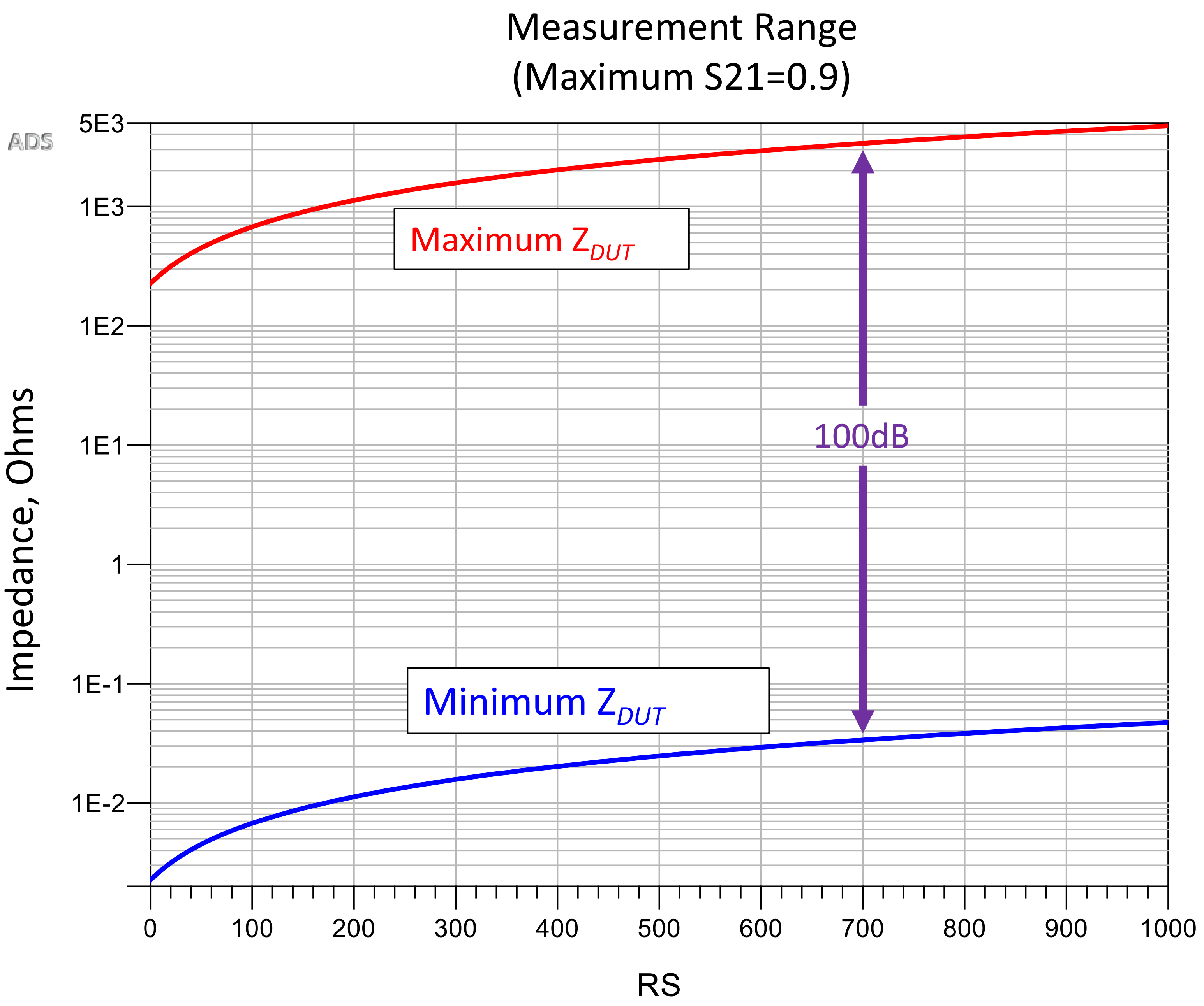
Inductors and Ferrite Beads

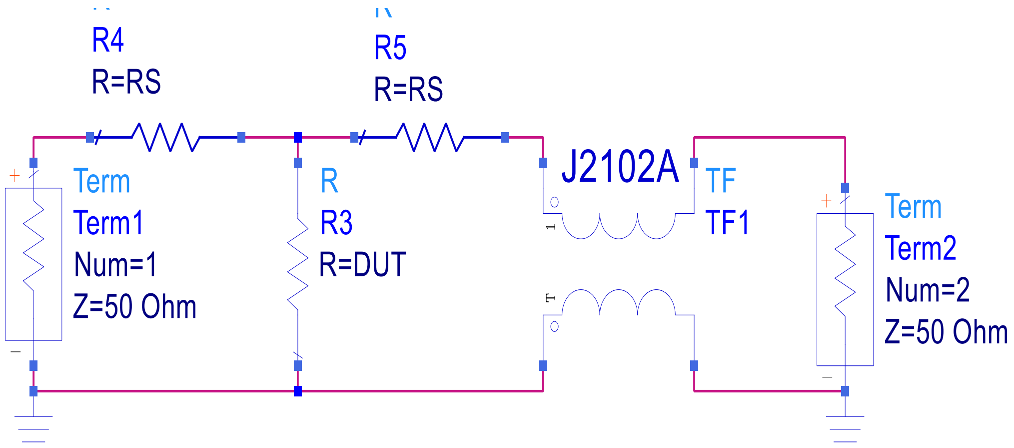


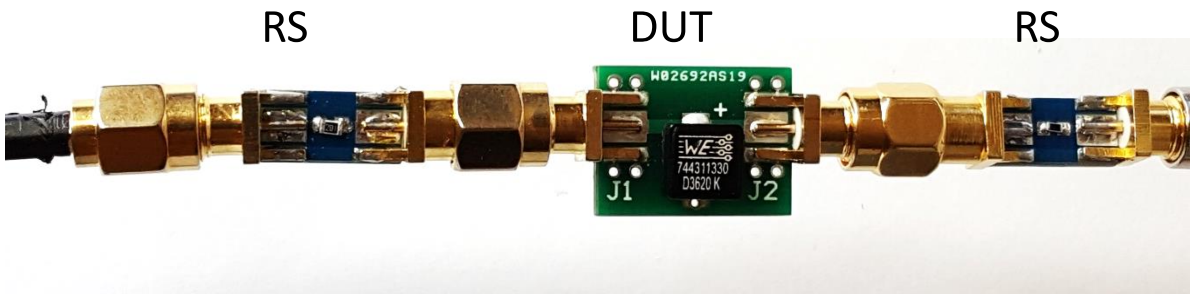
$$S21 = \frac{2 \cdot Z_{DUT}}{2 \cdot Z_{DUT} + Z_{ref} + Rs}$$

$$Z_{DUT} = \frac{Z_{ref} + Rs}{2} \frac{S21}{1 - S21}$$







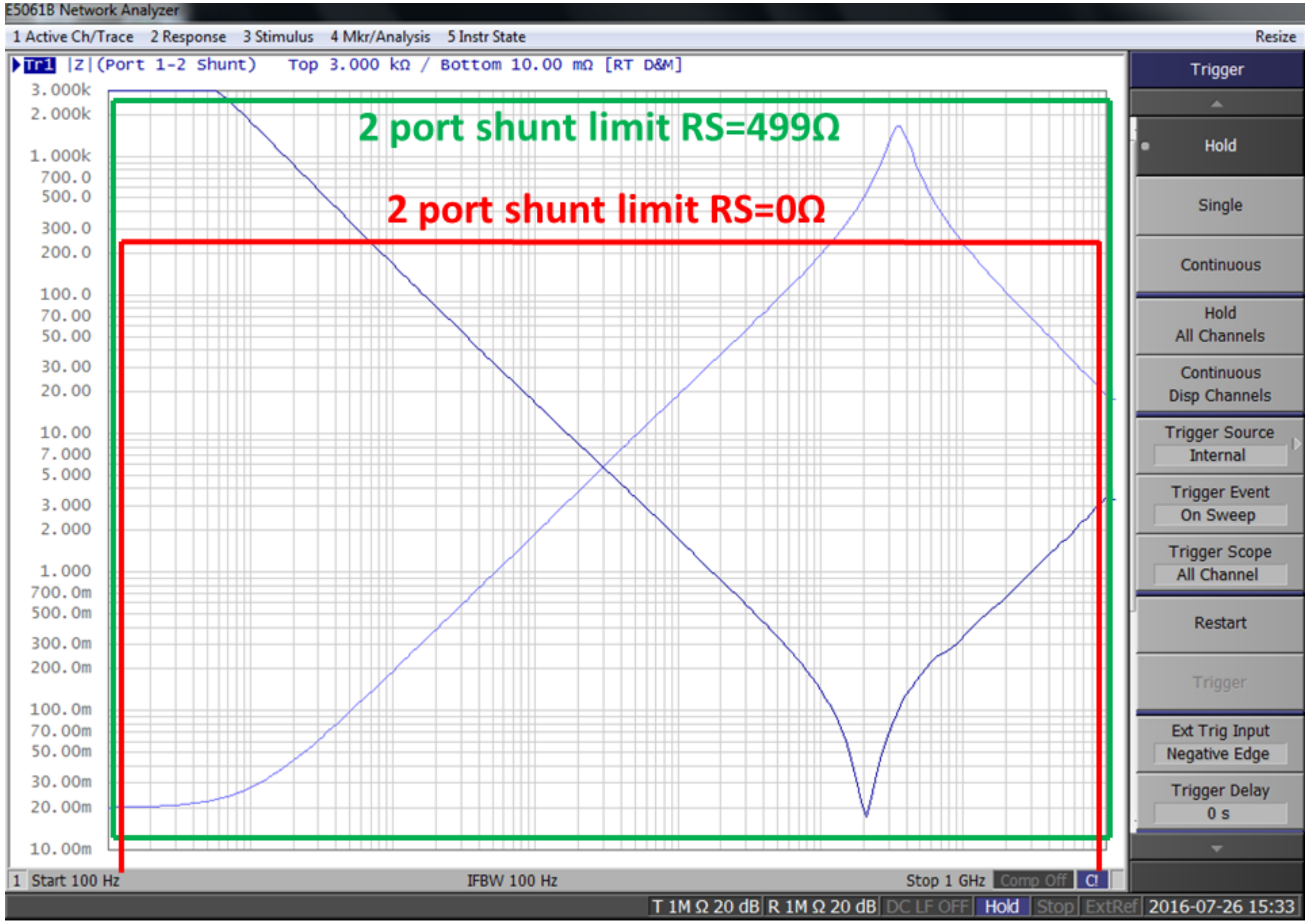


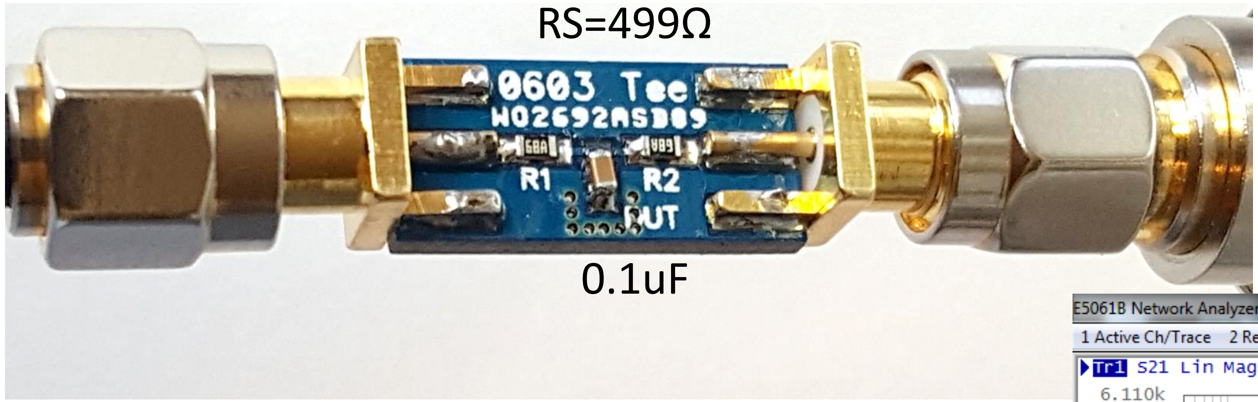
$$Z_{DUT} = \frac{Z_{ref} + R_s}{2} \frac{S21}{1 - S21}$$

$$S21 = \frac{2 \cdot Z_{DUT}}{2 \cdot Z_{DUT} + Z_{ref} + R_s}$$

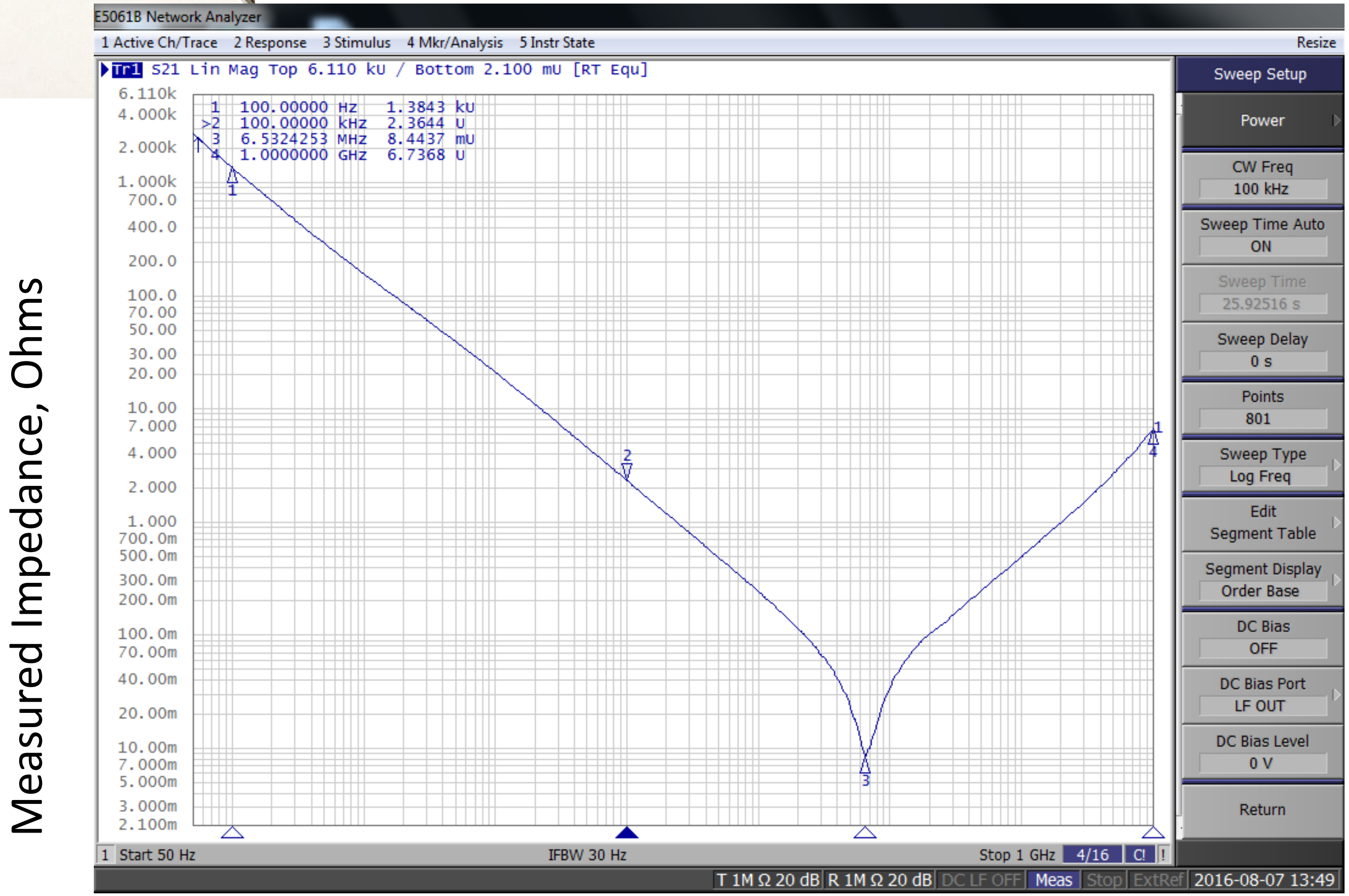
Series Resistor	Min Z	Max Z
200Ω	5 mΩ	1.125kΩ
450Ω	10 mΩ	2.25kΩ
499Ω	11mΩ	2.48kΩ
950Ω	20 mΩ	4.5kΩ

Measurement Range





0.1 uF Ceramic Capacitor



Summary

- How to perform a modified 2-port shunt through measurement technique for high fidelity data
- Why different simulation models are needed for SPICE and EM simulators
- How an optimizer can help create the high fidelity models from the measurements

Big Screen Simulation and Measurement Demo

- Measurement Demo E5061B VNA 2-Port Shunt
- ADS Lab2 Demo

Hands-On Lab 2: 190219_ADS_PI_Lab2_CapModel_2prtShunt_v2_wrk.7zads

Basics –
2- Port Shunt Impedance Measurement

Explore –
Capacitor and Inductor Models

Advanced –
Separating PCB Parasitics from Component Models