Slow-Wave Causal Model for Multi Layer Ceramic Capacitors

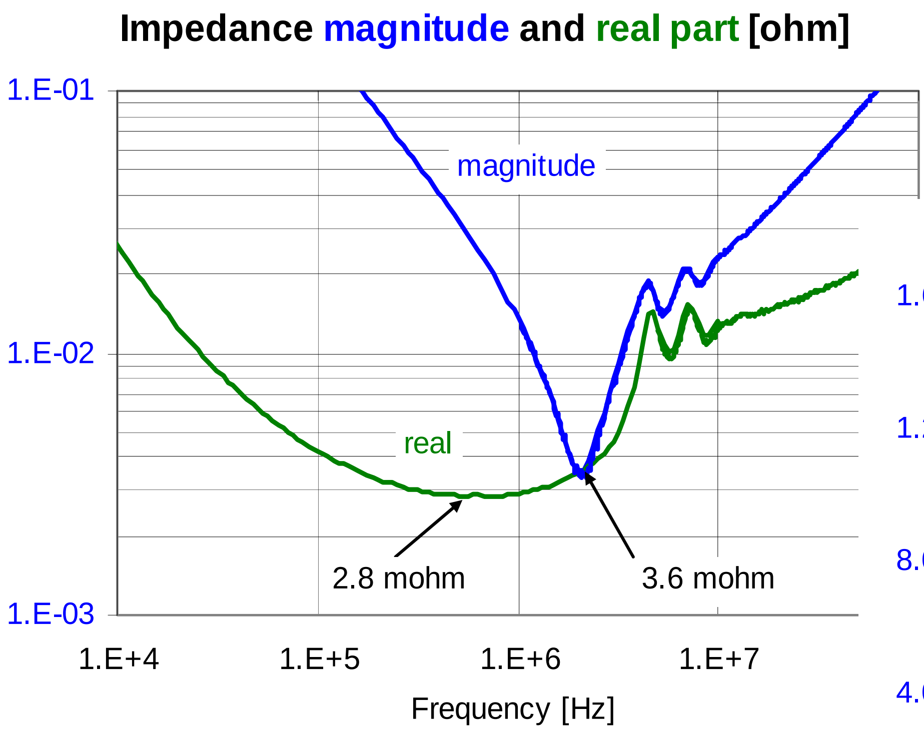
Istvan Novak
Gustavo Blando
Jason R. Miller

DesignCon 2006
11-TA4
February 2006

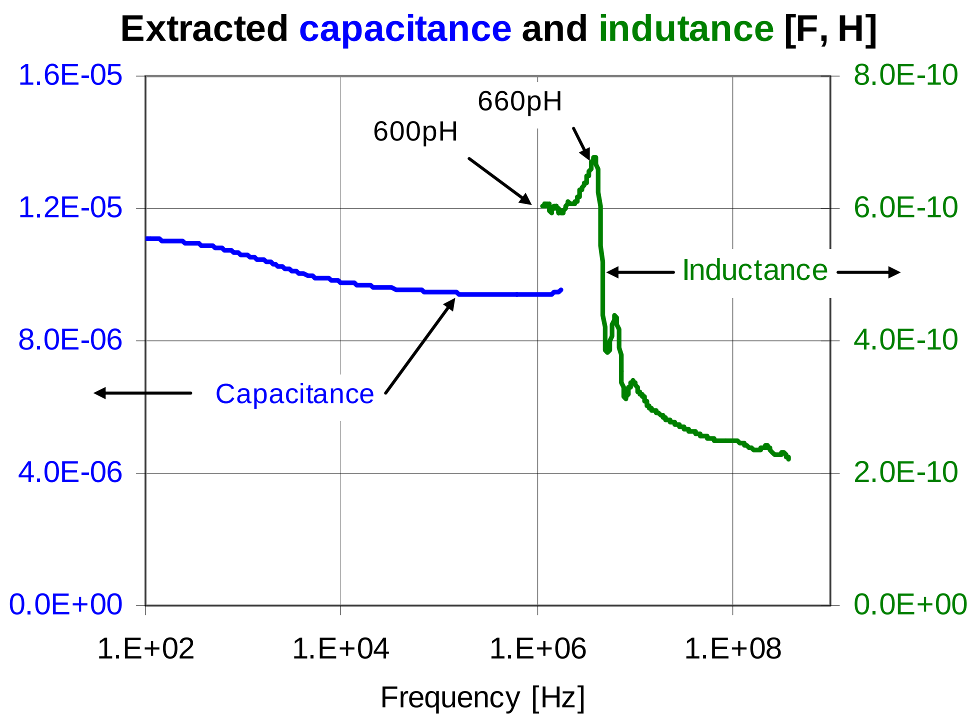
Agenda

- Present modeling options
- Slow-wave causal model
  - Unit-cell model
  - Lossy transmission-line model
- Correlations
  - Test fixture characterization
  - Convergence of unit-cell model
  - Correlation results
- Conclusions and future work

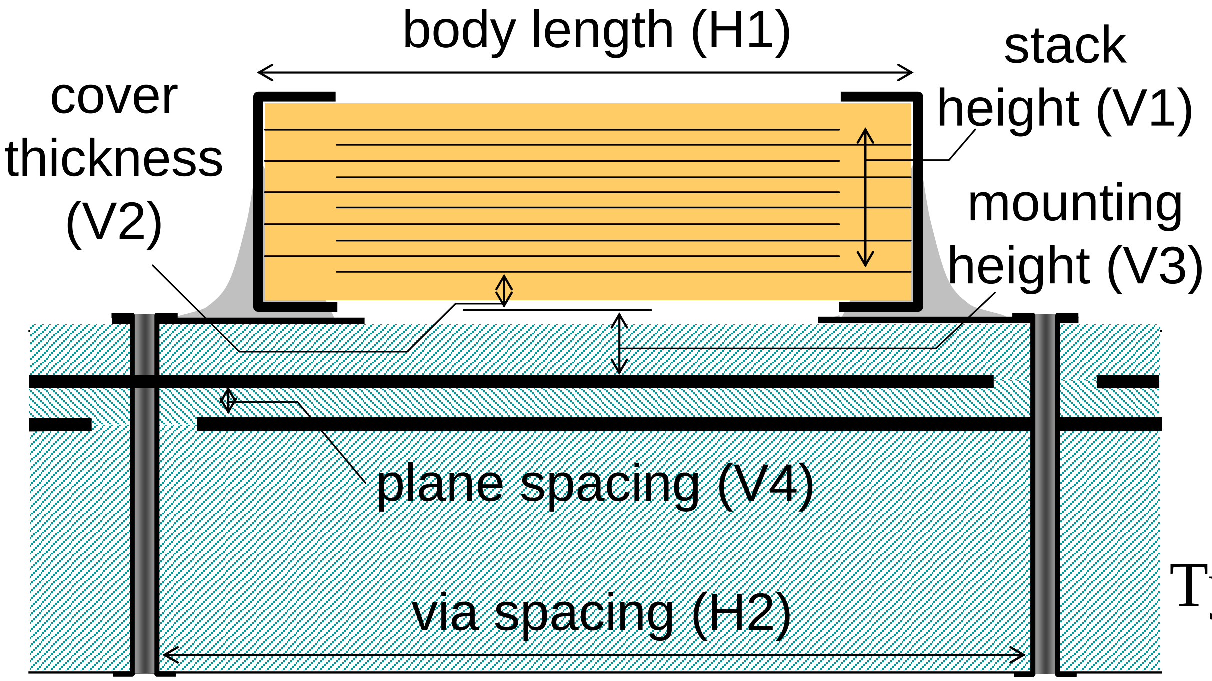
Present Modeling Options (1)



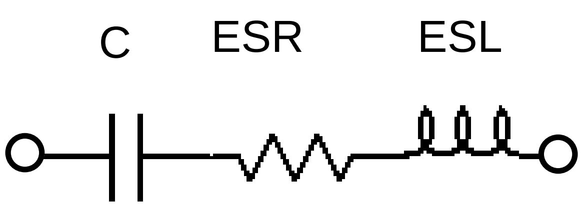
Measured parameters of 10uF 0508 MLCC



Present Modeling Options (2)

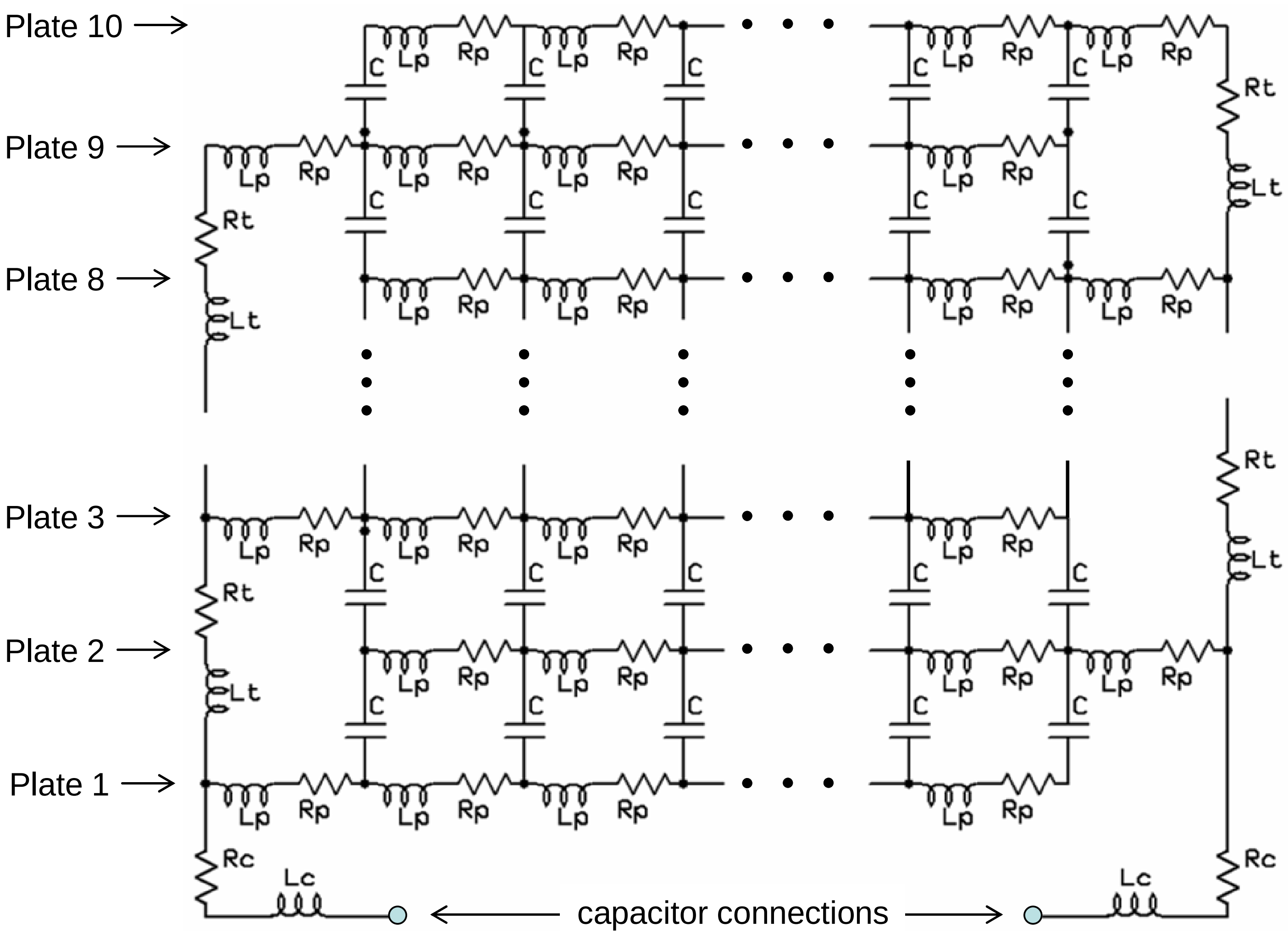


Typical simple model:



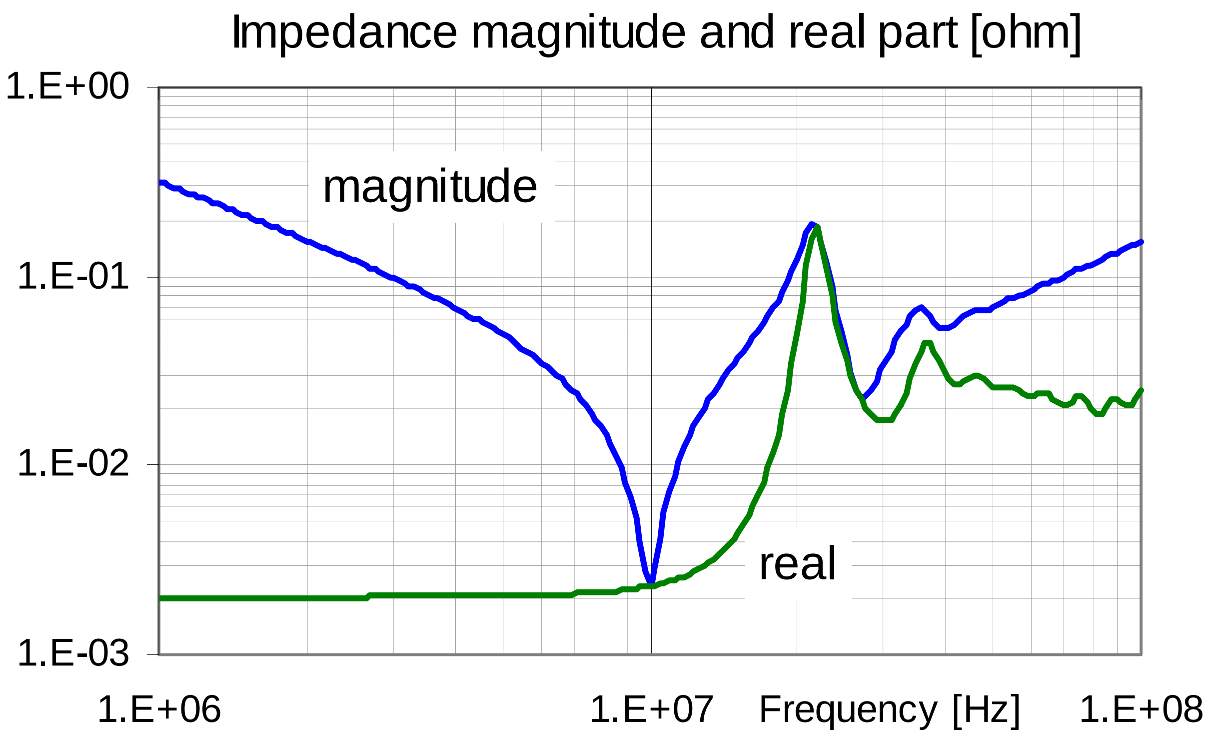
Present Modeling Options

Bedspring model



Present Modeling Options

Simulated impedance with bedspring model

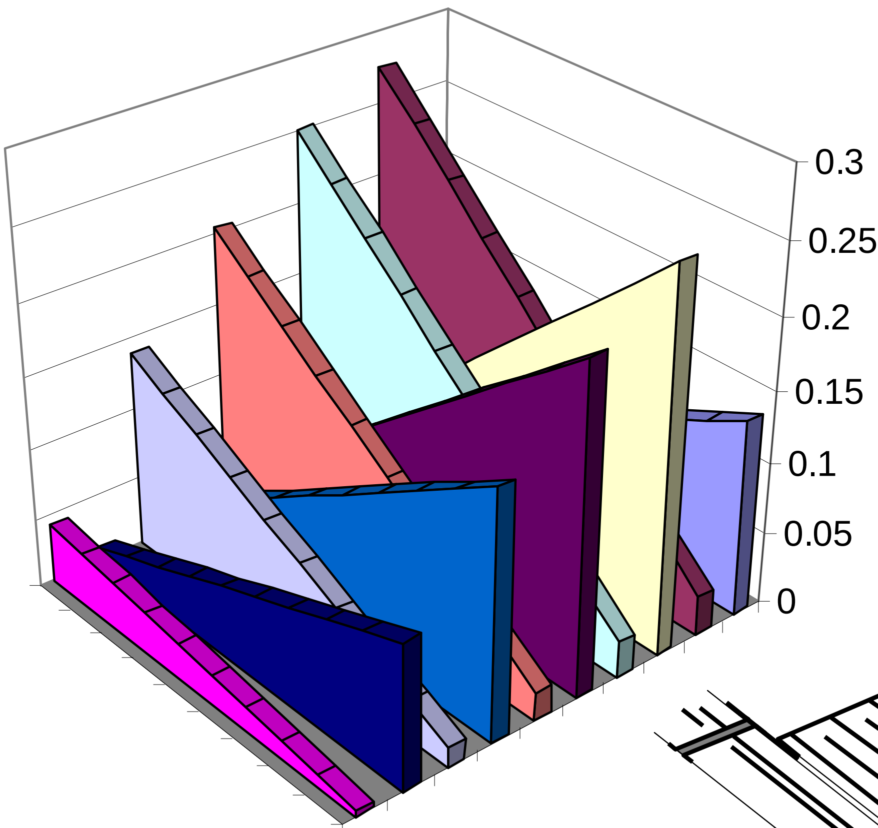


C [F]:	5.00E-09
Lp [H]:	1.00E-11
Rp [ohm]:	1.00E-03
Lt [H]:	1.00E-10
Rt [ohm]:	1.00E-04
Lc [H]:	1.00E-10
Rc [ohm]:	0.00E+00

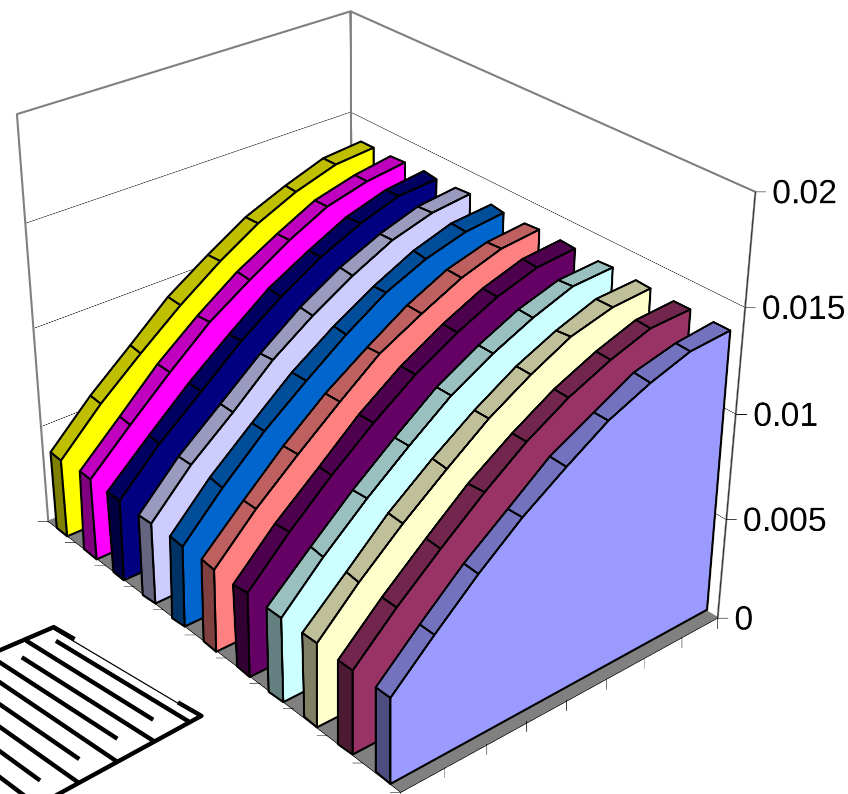
Present Modeling Options

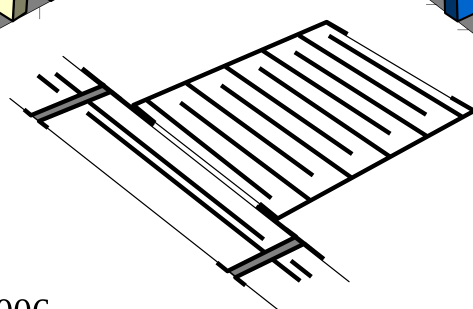
Current distribution at SRF from bedspring model

Plate current:



Dielectric current:

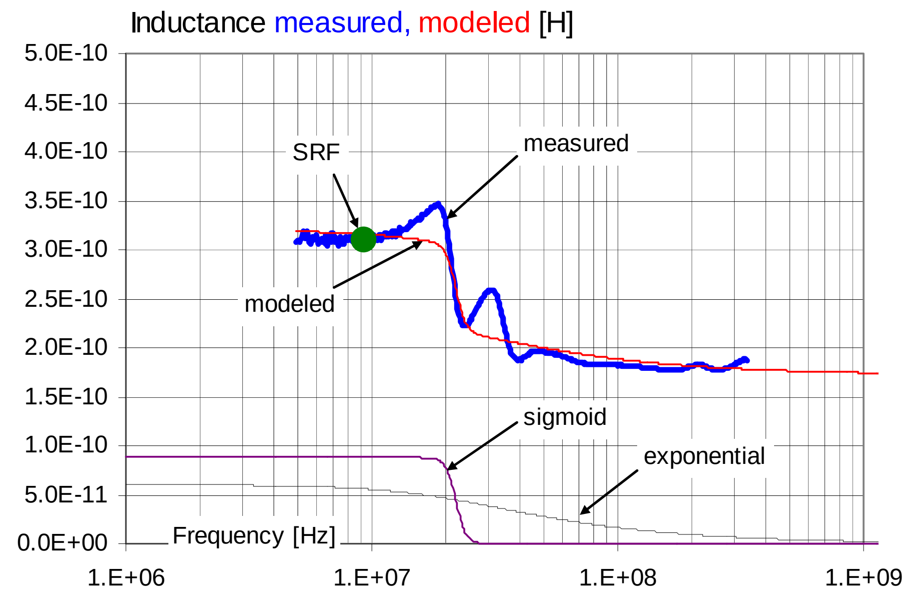


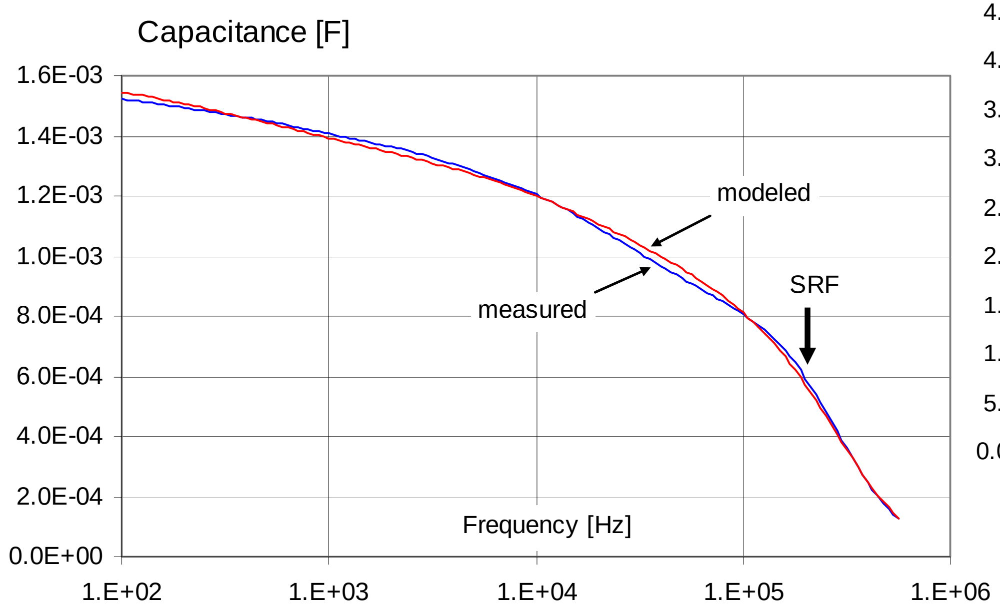


Present Modeling Options

Black-box model, L(f), C(f)

$$L_a = L_{\inf} + \frac{L_1}{(1+(\frac{f}{f_{L1}})^2)^{m_{L1}}} + \frac{L_2}{1+\exp\{\frac{\log(f)-\log(f_{L2})}{m_{L2}}\}}$$





$$C_a = \frac{C_o}{\{1+(\frac{f}{f_{C1}})^2\}^{m_{C1}} \{1+(\frac{f}{f_{C2}})^2\}^{m_{C2}} \{1+(\frac{f}{f_{C3}})^2\}^{m_{C3}}}$$

Present Modeling Options

Limitations

R-L-C models

- Simple model does not capture secondary resonances
- Ladder models are causal, but complex
- Bed-spring model is most accurate, but most complex

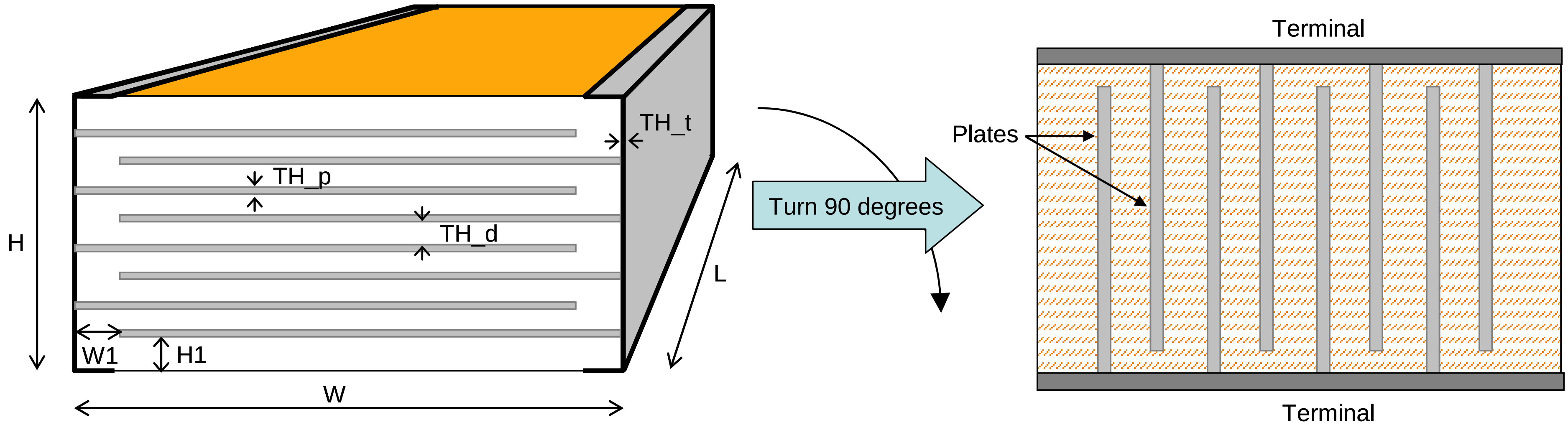
Black-box models

- Hard to guarantee causality

Slow-Wave Causal Model

The unit cell (1)

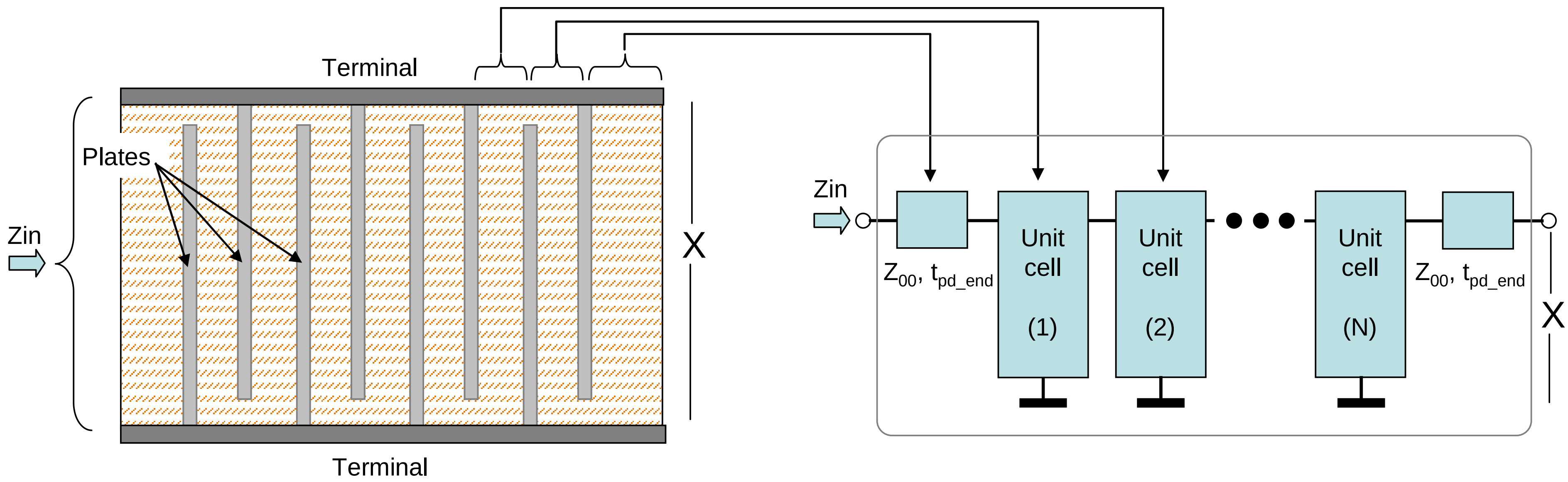
MLCCs are periodically loaded transmission lines



Slow-Wave Causal Model

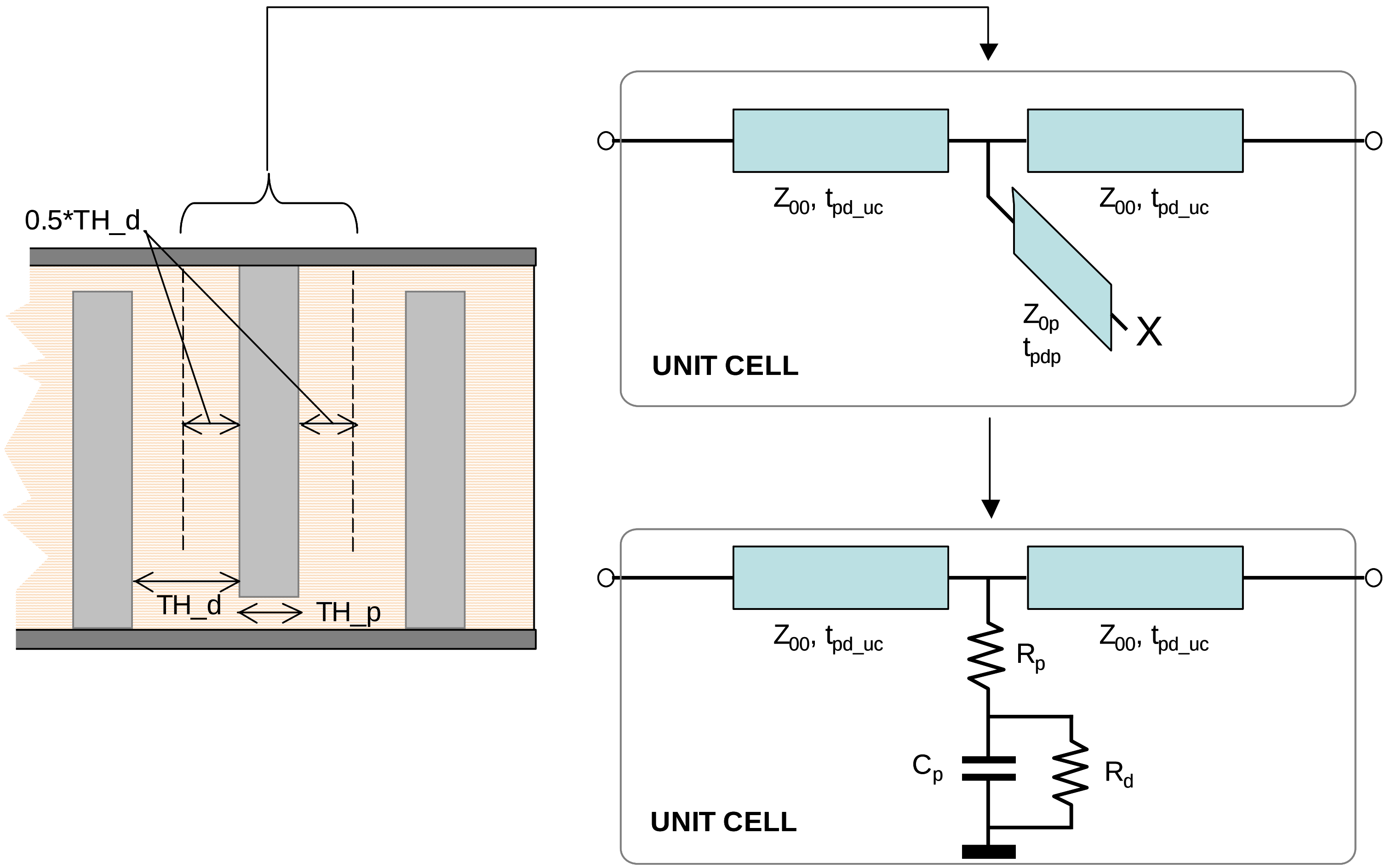
The unit cell (2)

Each capacitor plate pair forms one unit cell of load impedance
Unloaded end pieces are formed by the empty cover layers



Slow-Wave Causal Model

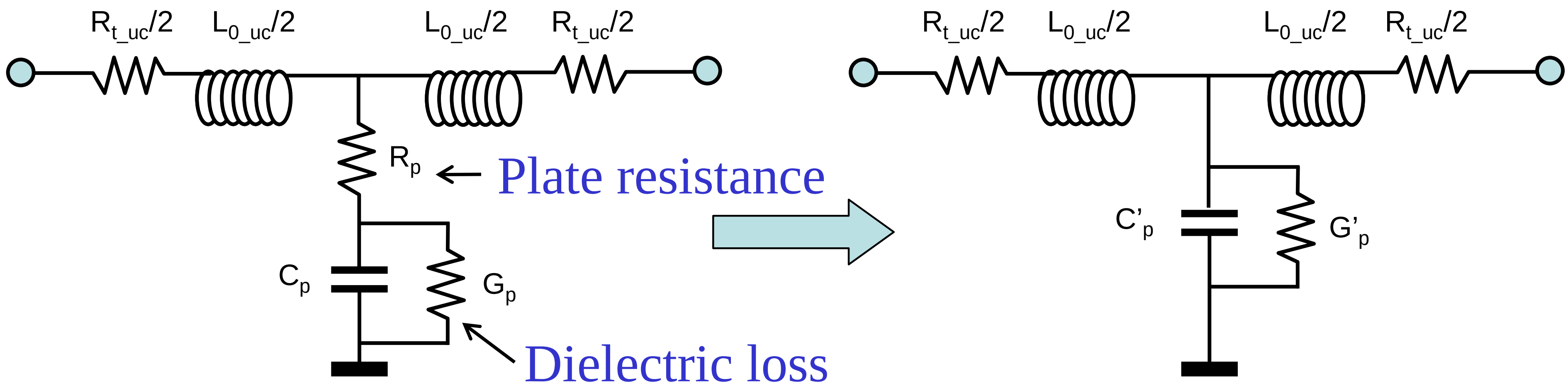
Generating unit cell parameters from geometry



The Lossy Transmission Line Model

Transforming the unit cell

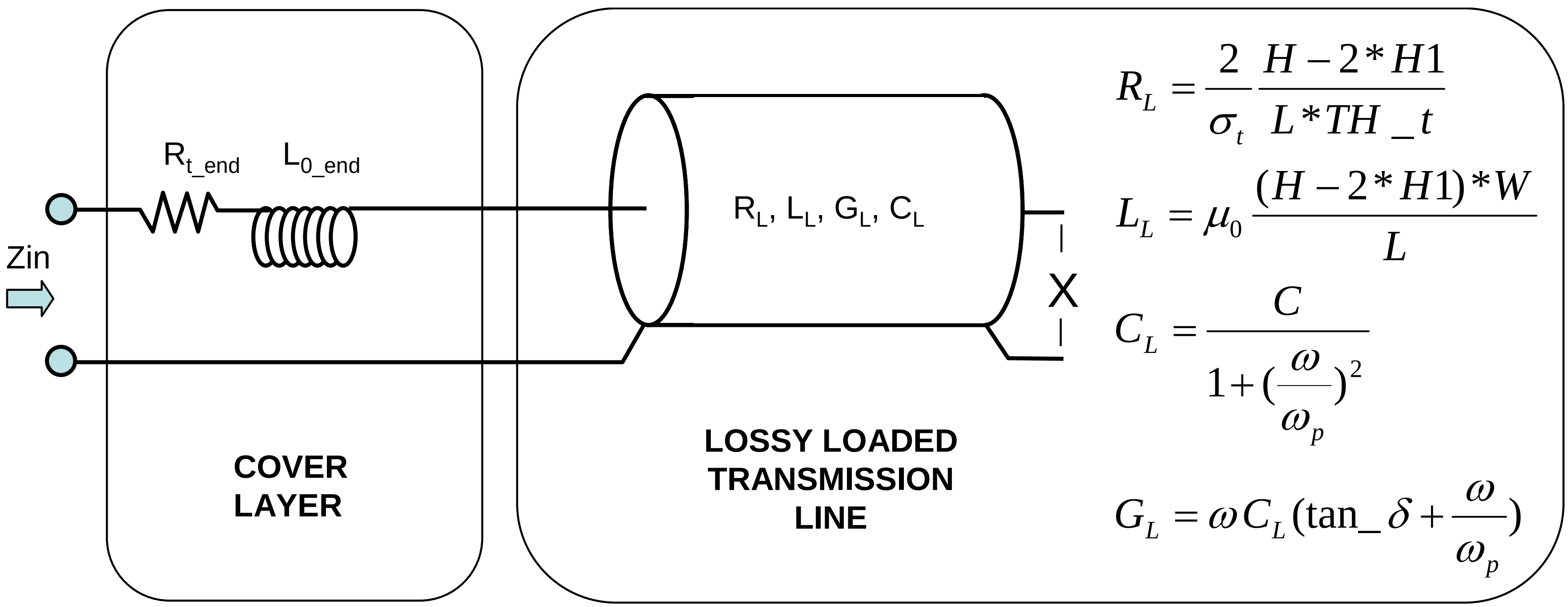
Terminal resistance and inductance



$$\omega_p = \frac{1}{R_p C_p} \qquad C_p^{'} = \frac{C_p}{1+(\frac{\omega}{\omega_p})^2} \quad and \quad G_p^{'} = G_p + \omega\, C_p^{'} \frac{\omega}{\omega_p}$$

The Lossy Transmission Line Model

Simplified model



$$R_L = \frac{2}{\sigma_t} \frac{H - 2*H1}{L*TH\_t}$$

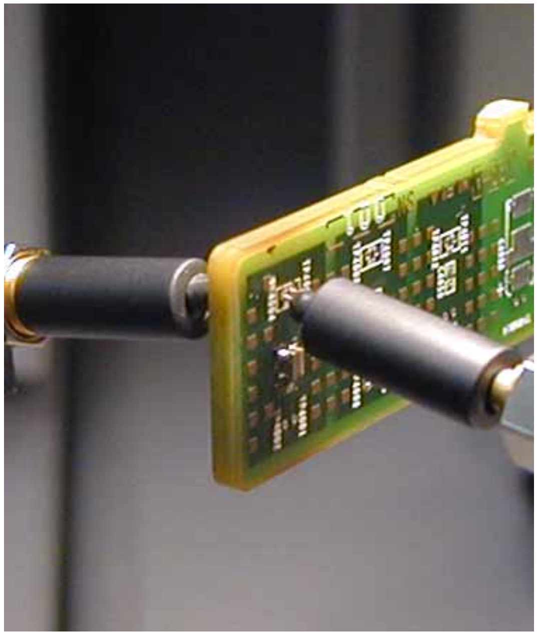
$$L_L = \mu_0 \frac{(H - 2*H1)*W}{L}$$

$$C_L = \frac{C}{1 + (\frac{\omega}{\omega_p})^2}$$

$$G_L = \omega C_L (\tan\_\delta + \frac{\omega}{\omega_p})$$

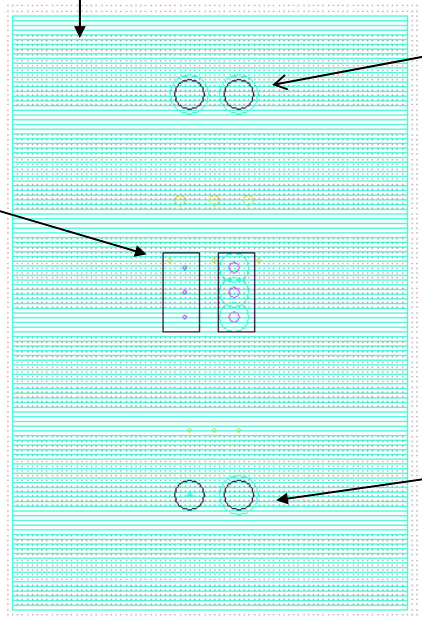
Correlations (1)

Test fixture characterization



Three 7-mil blind vias connect to layer 21 with 25-mil center-to-center spacing. Three 12-mil blind vias connect to layer 20, with 25-mil center-to-center spacing. Horizontal spacing between the two columns of vias is 50 mils. The capacitor pads are 80x35-mil rectangular shapes with 20-mil air gap.

400x600 mil plane shapes with 2.1-mil separation on layers 20 and 21.



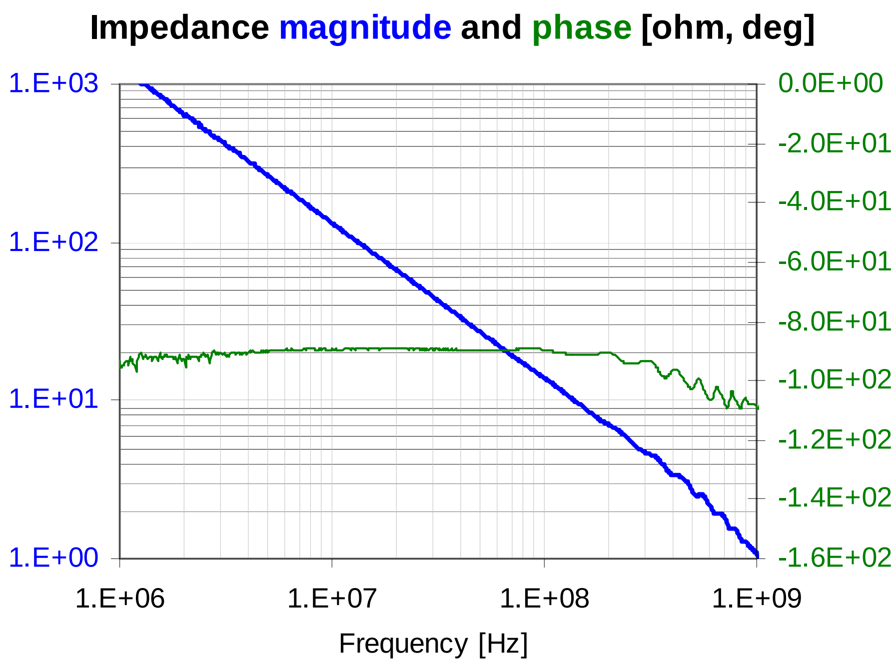
Through holes for test site on layers 2-3.

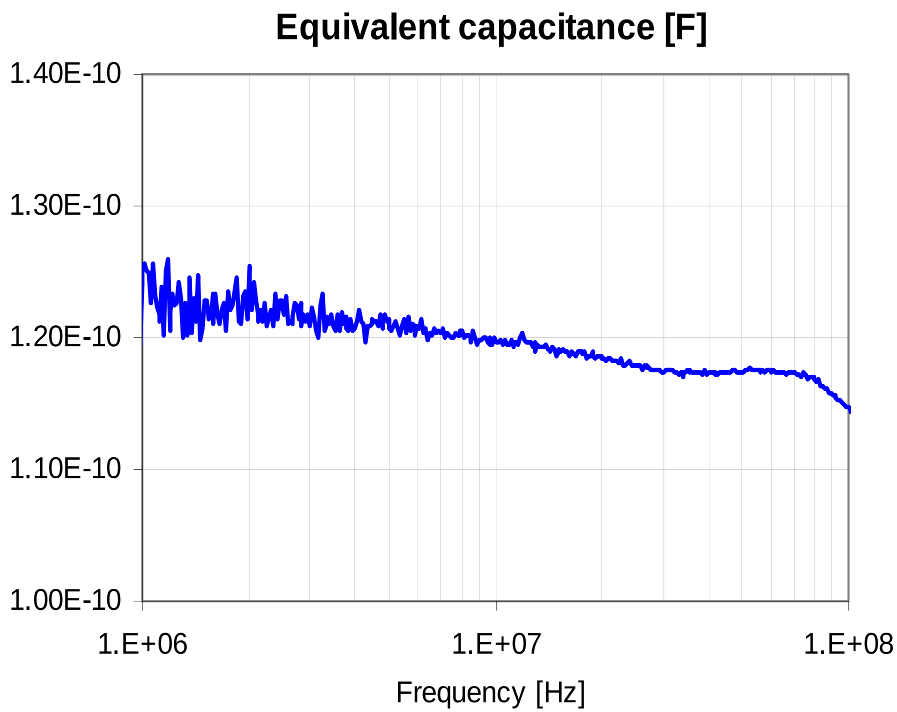
Through holes on 50-mil center-to-center spacing for connecting semirigid probes.

Correlations (2)

Test fixture capacitance

Capacitance extracted from bare fixture's impedance



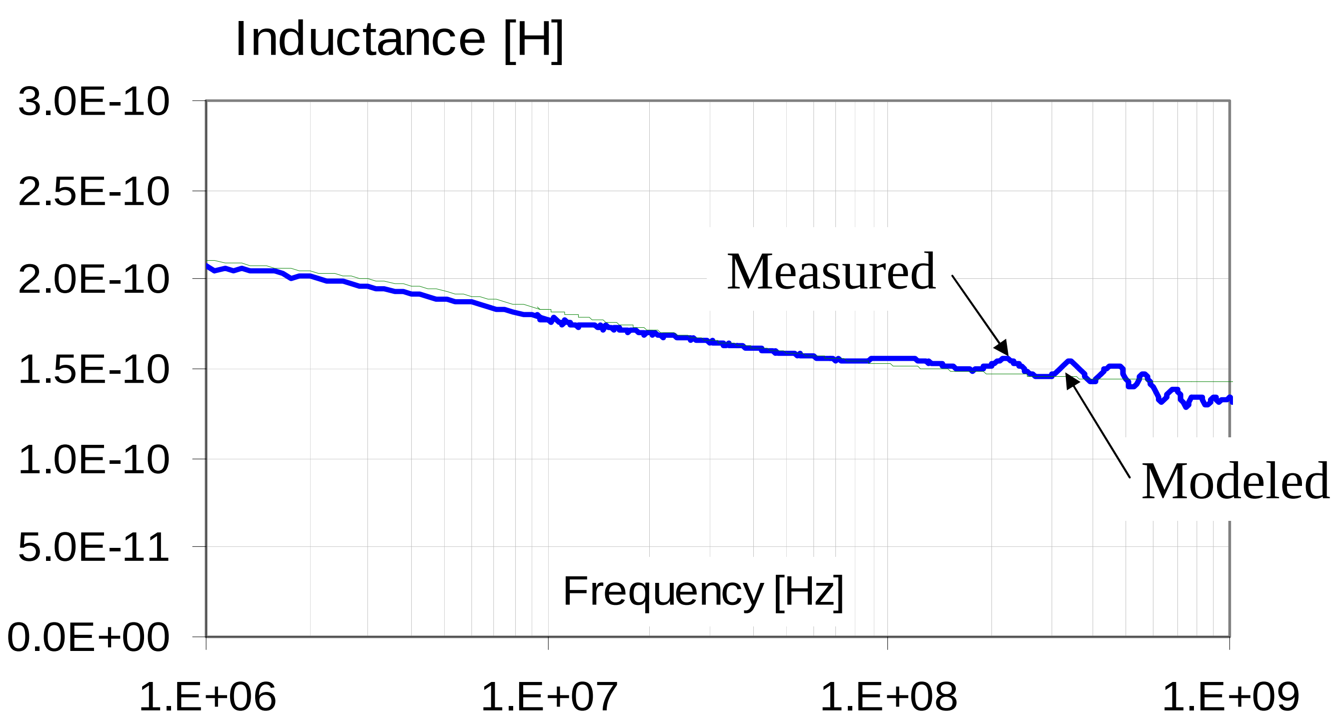


Correlations (3)

Test fixture inductance

Inductance extracted from shorted fixture's impedance

$$L(f) = L_{\inf} + \frac{\Delta L}{1 + (\frac{f}{f_R})^N}$$

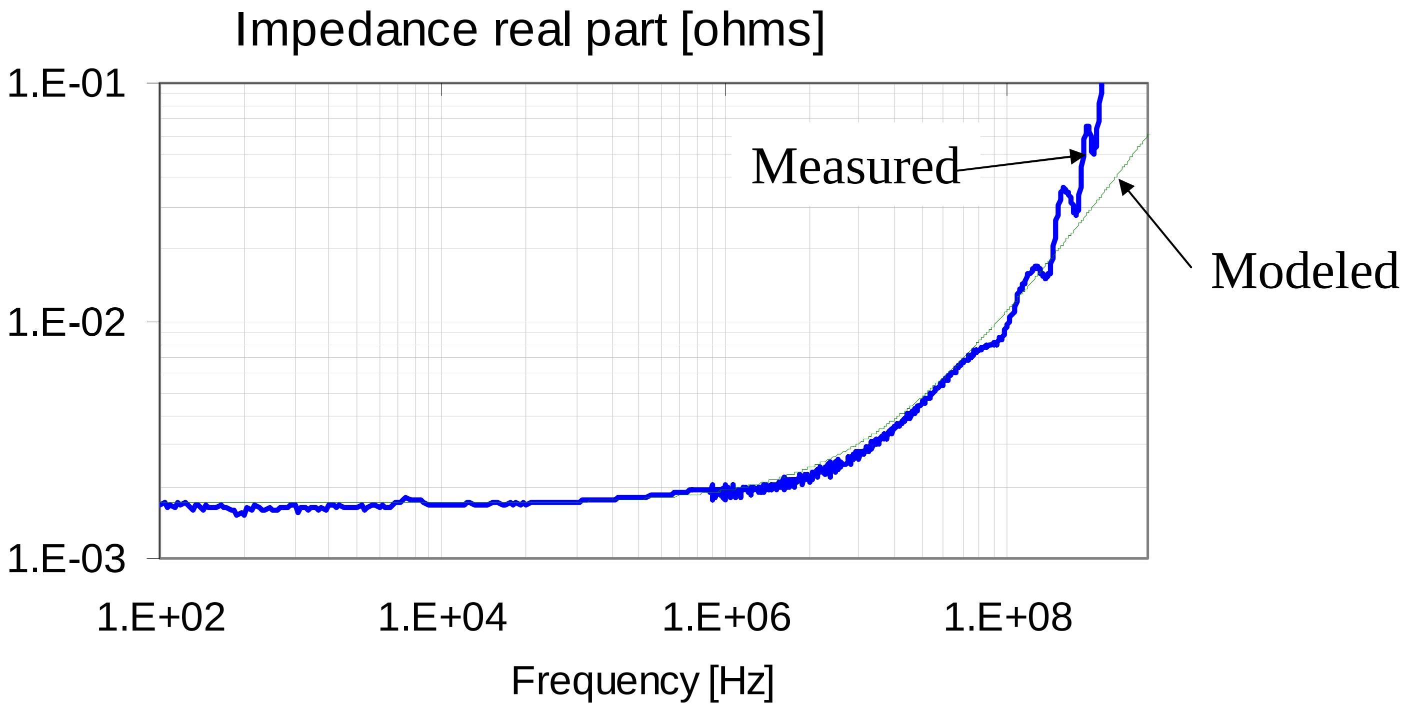


Correlations (4)

Test fixture resistance

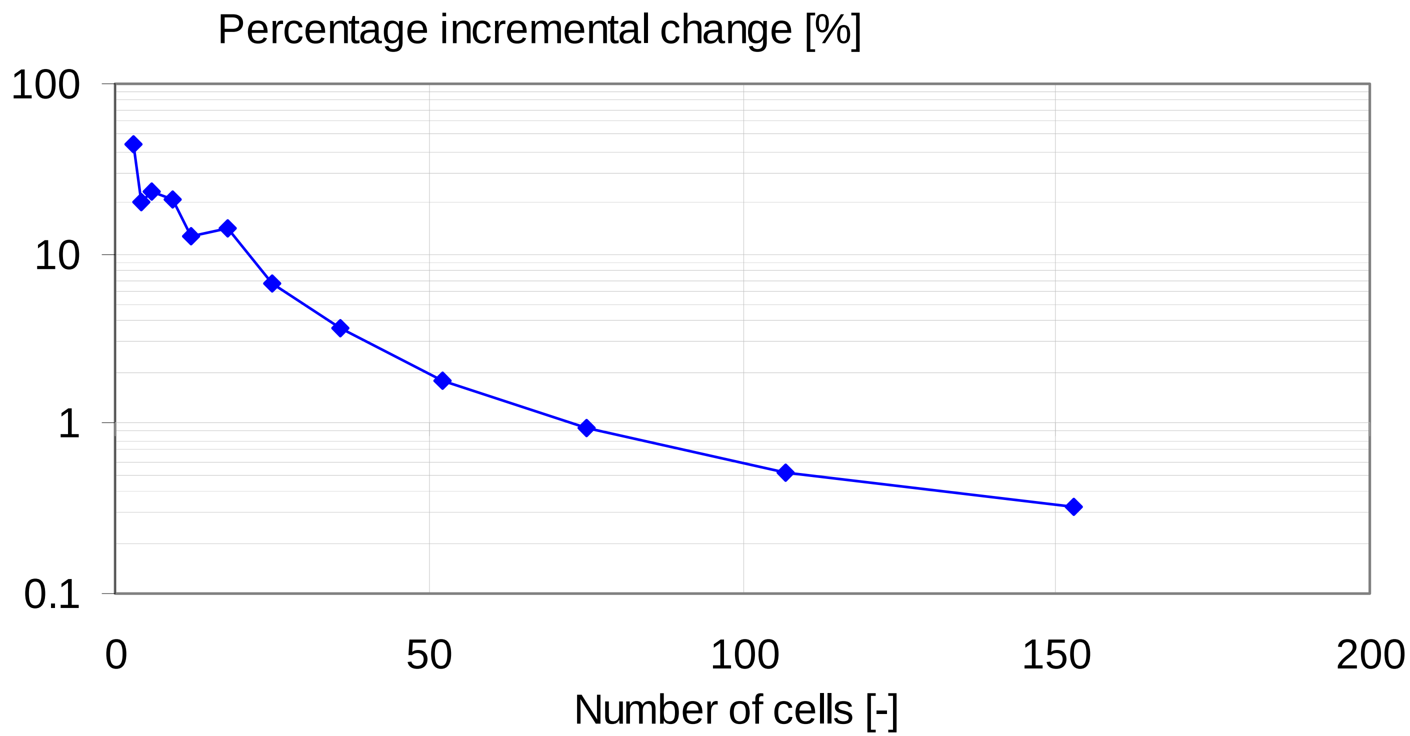
Resistance extracted from shorted fixture's impedance

$$R(f) = R_{DC}\left(1 + \left(\frac{f}{f_R}\right)^N\right)$$



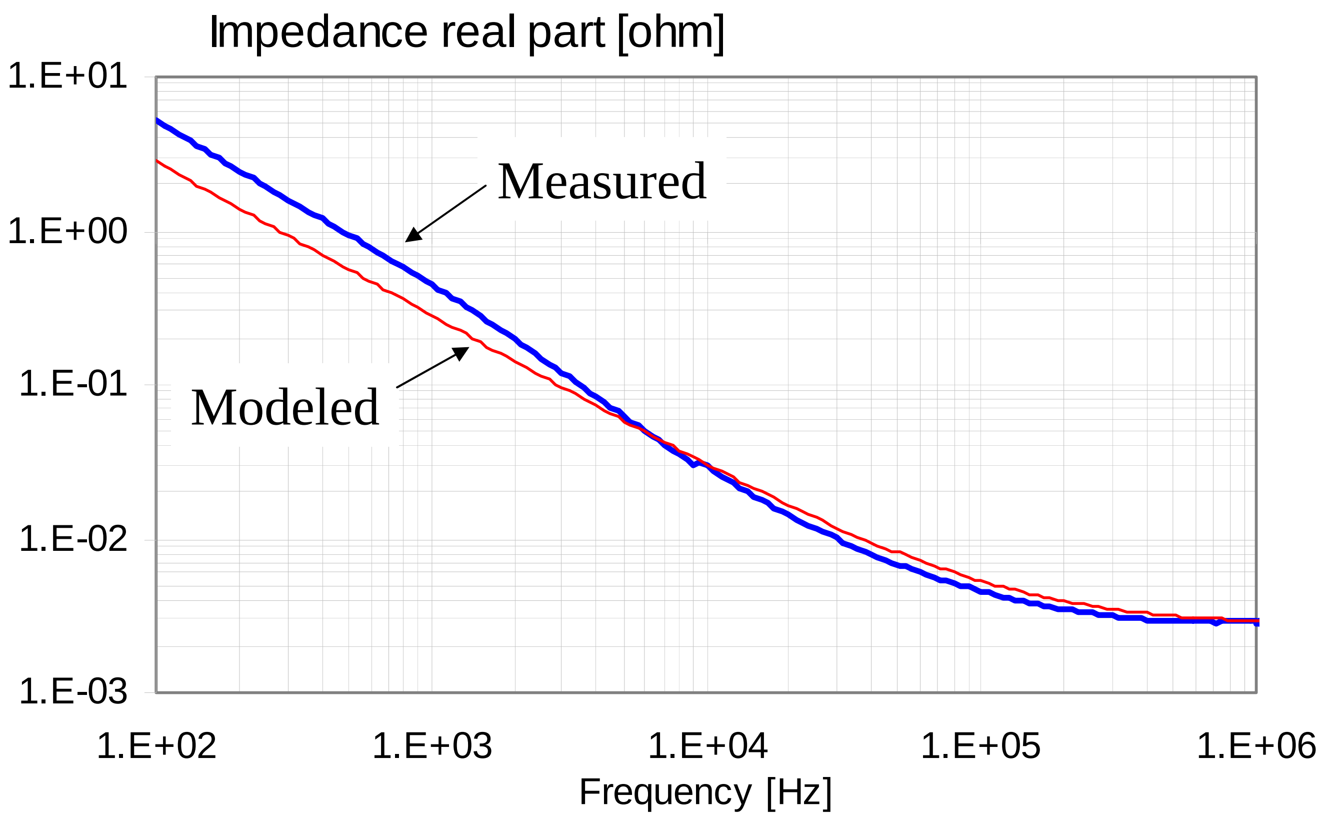
Correlations (5)

Convergence of unit cell model



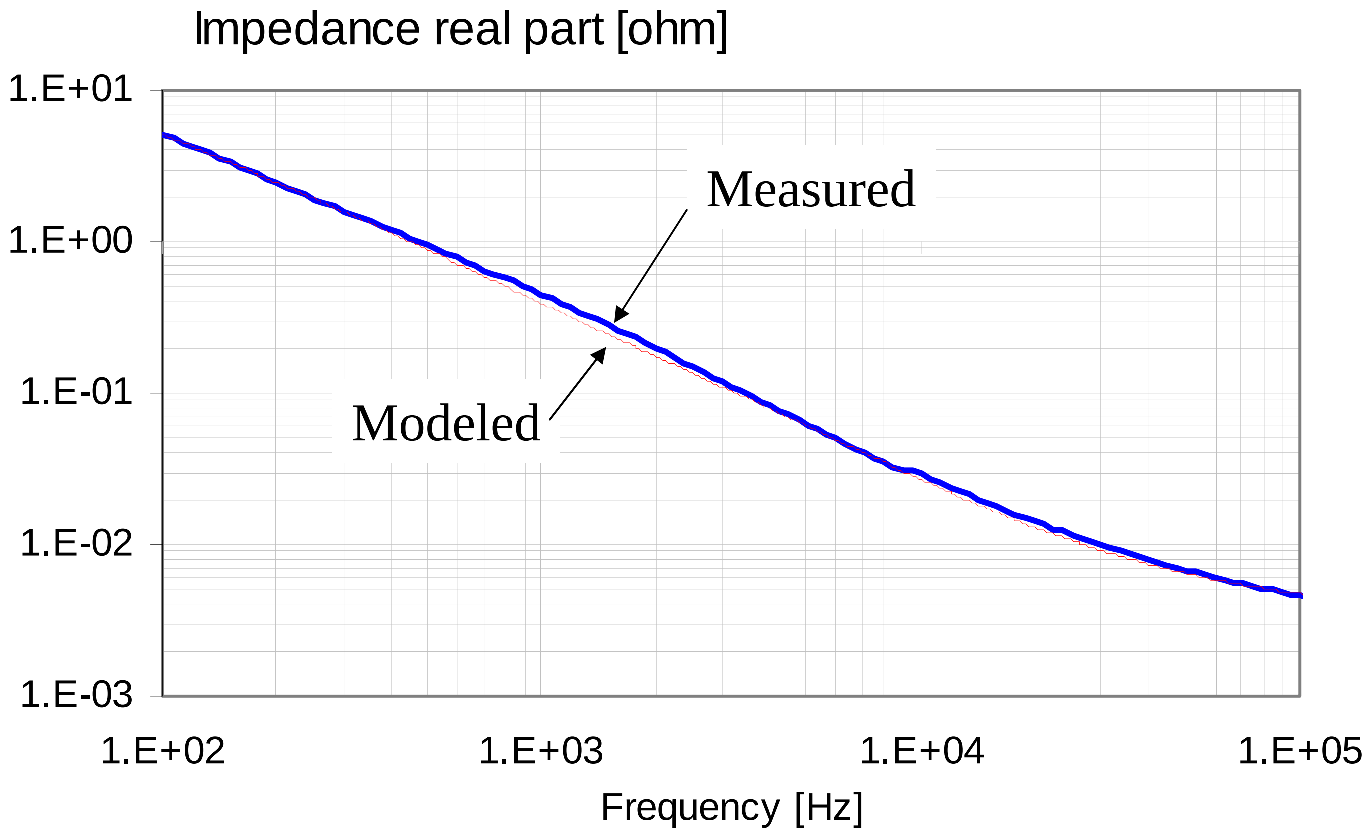
Correlation below SRF

One loss tangent domain



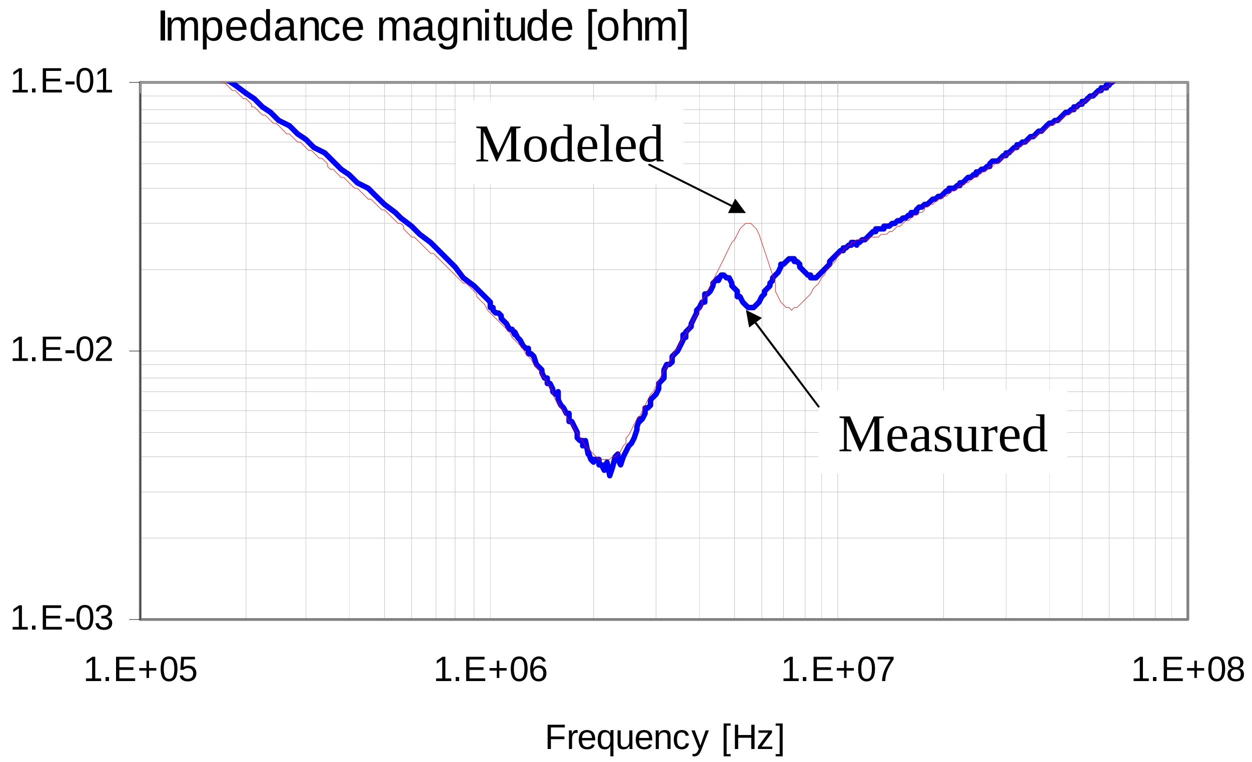
Correlation below SRF

Three loss tangent domains



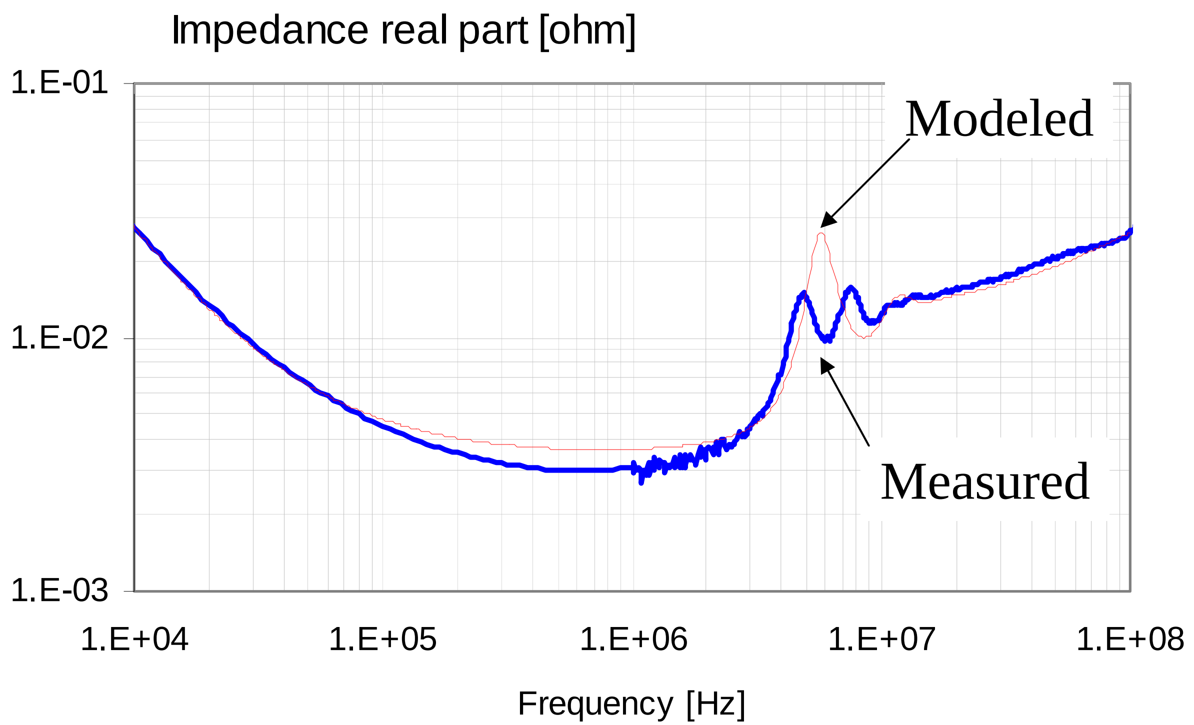
Correlation with unit-cell model

Impedance



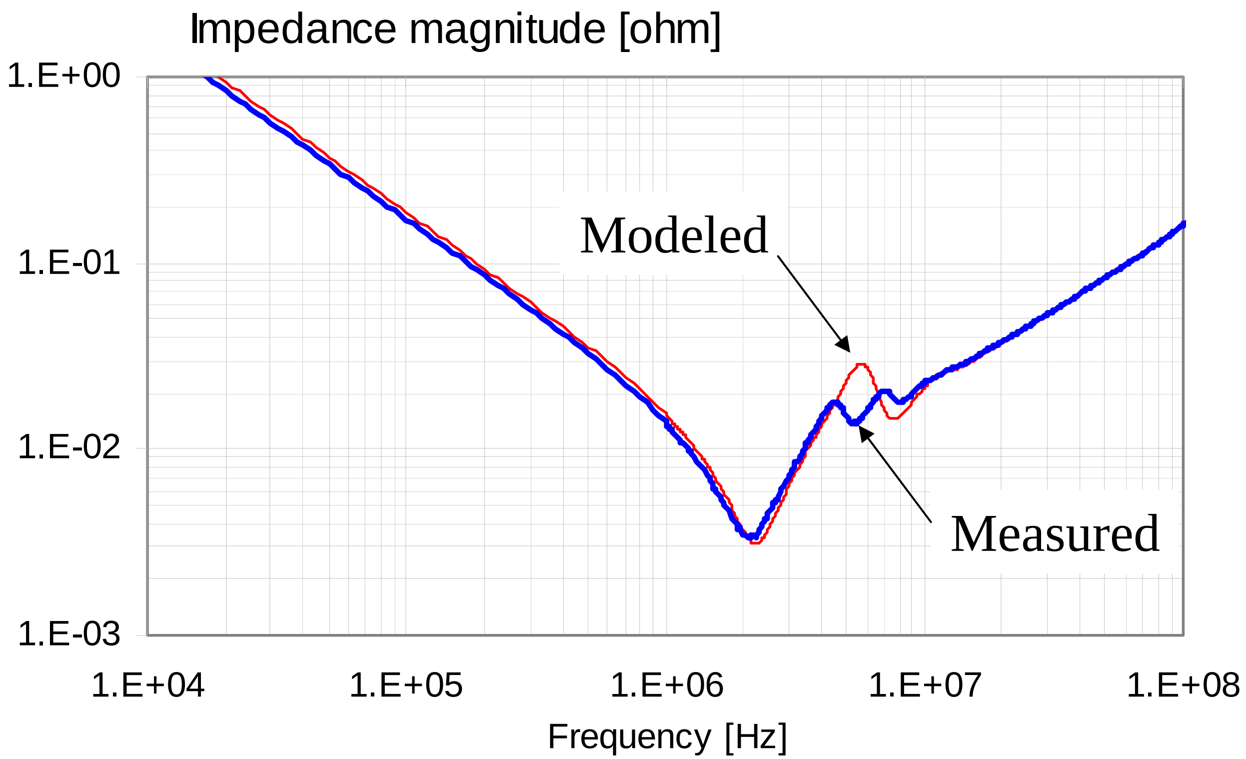
Correlation with unit-cell model

Resistance (ESR)



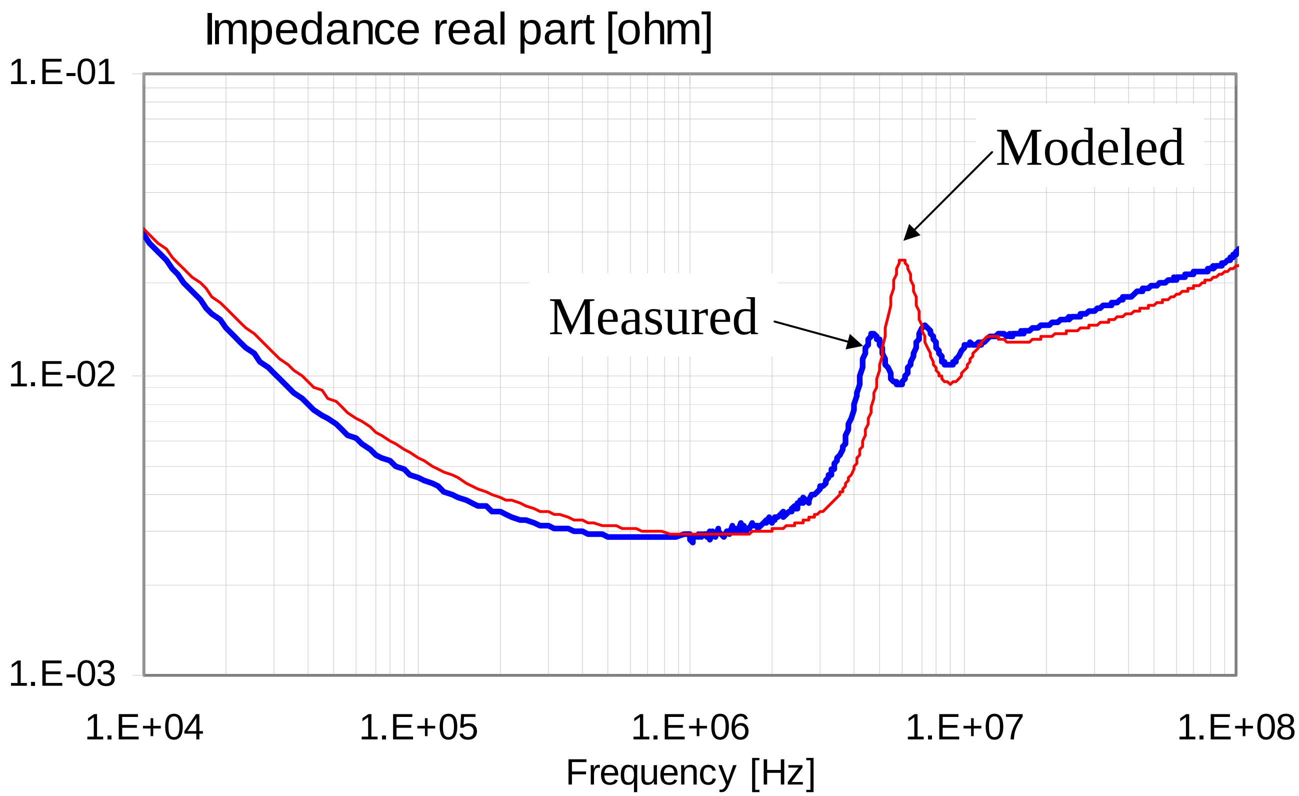
Correlation with lossy-line model

Impedance



Correlation with lossy-line model

Resistance (ESR)



Conclusions and future work

MLCC model based on periodically loaded transmission lines:

- Very simple
- Guaranteed to be causal
- Captures primary and secondary resonances
- Captures C(f) and R(f) below SRF

Coupling among capacitor plates is not captured

THANK YOU