



BREAKTHROUGH SIMPLICITY

Microwave wirebond model from die to laminate

Jimmy Hoang / Ryan Lee

20 Feb 2004

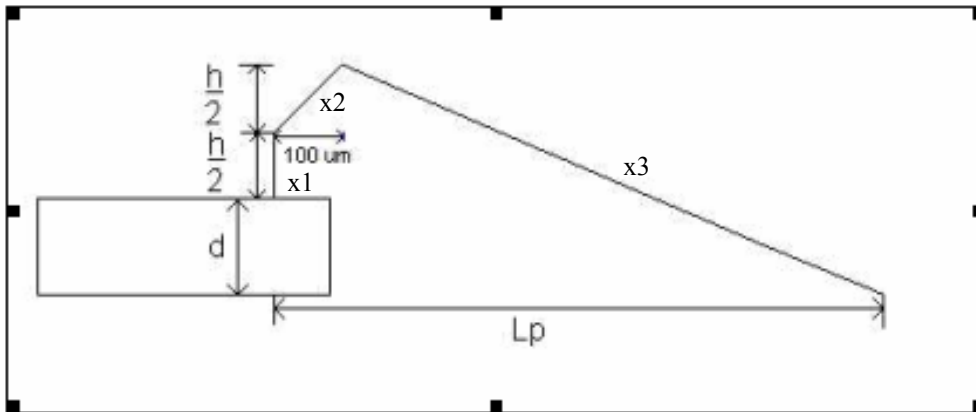


Abstract

- The measurement and HFSS modeling of self and mutual inductance between coupled wires up to 8.0 GHz is considered.
- Differences less than 6% between measured and HFSS modeled inductance are presented.
- Provide a generic, flexible model with different wire length, wire distance, and wire angles.
- Verification the lumped model LRC pi-network of bondwire matching S-parameter model.
- Other parameters such as Resistance, Capacitance and its modeling methodology is also analyzed.

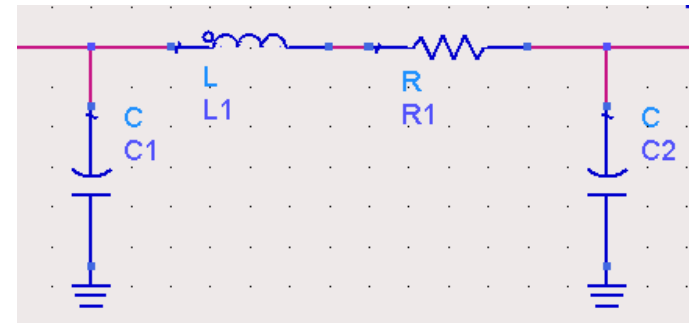
Wirebond profile and its lumped model pi-network

Skywork's wirebond profile



- h = wire loop height (μm)
- d = die thickness (μm)
- L_p = projected wirelength (μm)
- Wirebond has 3 sections (x_1 , x_2 , x_3)

Lumped model Pi-network



Equivalent circuit of wirebond model

- c_1 = wire capacitance on the die side (F)
- c_2 = wire capacitance on the laminate side (F)
- L_1 = wire inductance (H)
- R_1 = wire resistance (Ohm)

Test vehicle and Measurement setup

- A single wire, two wires in parallel, two wires and four wires with different angles were built from die “DE152_out” to MCM laminate package (see fig. 1).
- The structures were measured for S-parameter in the frequency range from 50 MHz to 8.0 GHz with a HP8510C network analyzer using 150 um pitch GS wafer Picoprobe.
- The inductance, resistance and capacitance were extracted from these measured S-parameter files on ADS tool.

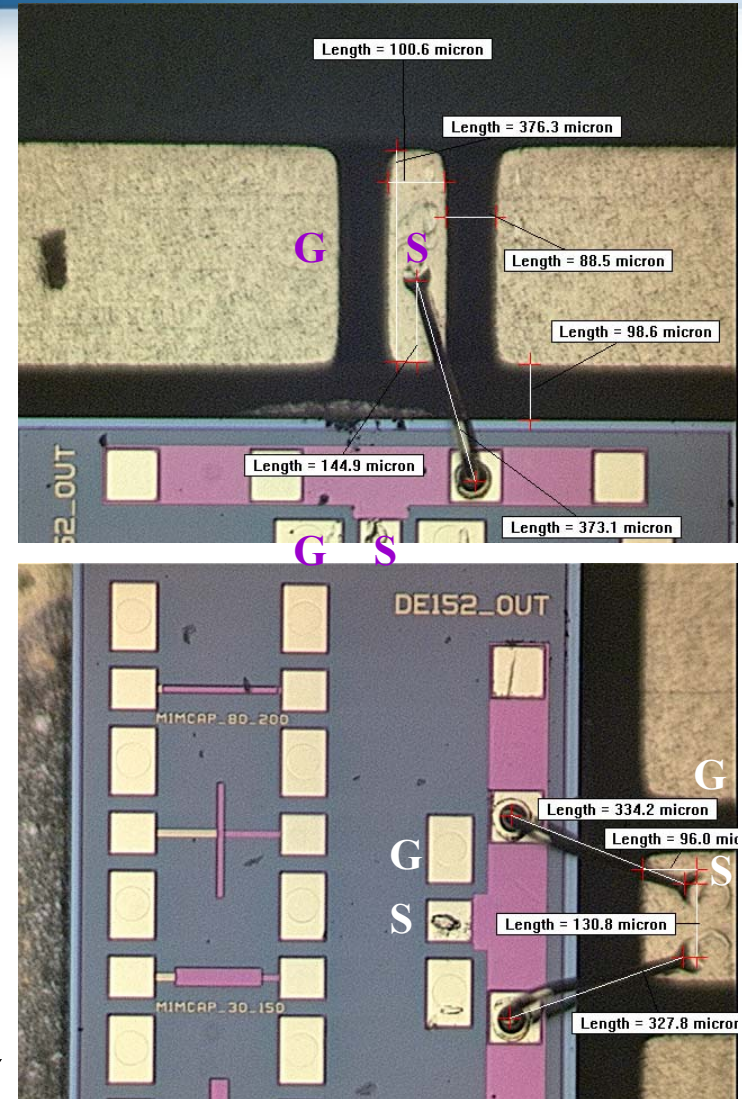


Fig.1 dimensions of wirebonds on test vehicle

Correlation between measured and simulated data

- The structures were modeled on HFSS exactly as built for measurement of a single, double and four wires (Fig.2)
- All dimensions of wire profile were captured before modeling.
- From HFSS s-parameter result, all the lumped parasitic parameters Inductance, resistance and capacitance were extracted and compared to measurement.
- Correlation agreement between measurement and HFSS simulation as showed next slides.

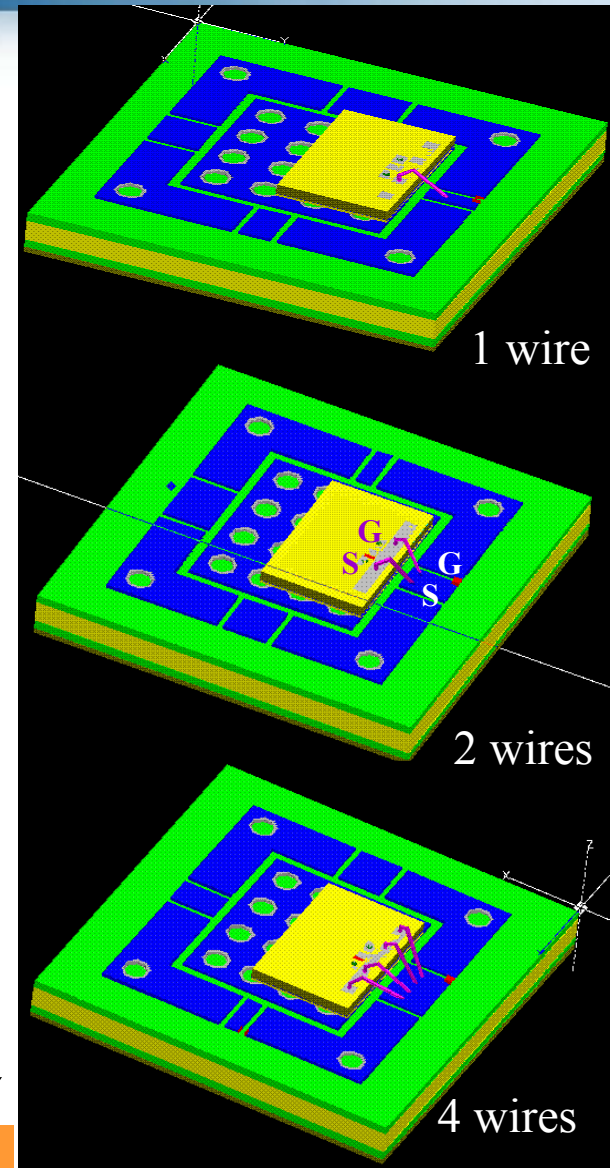
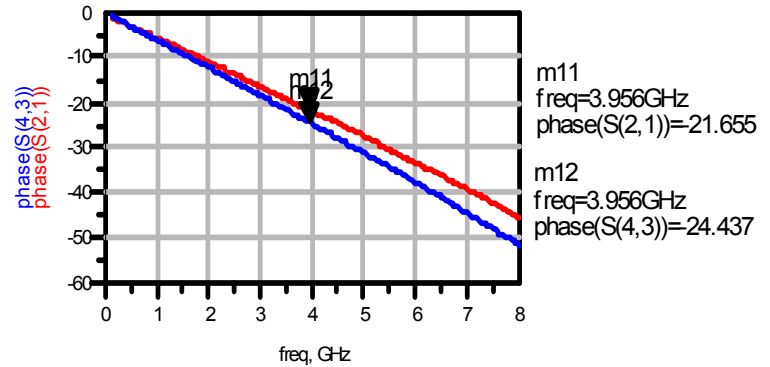
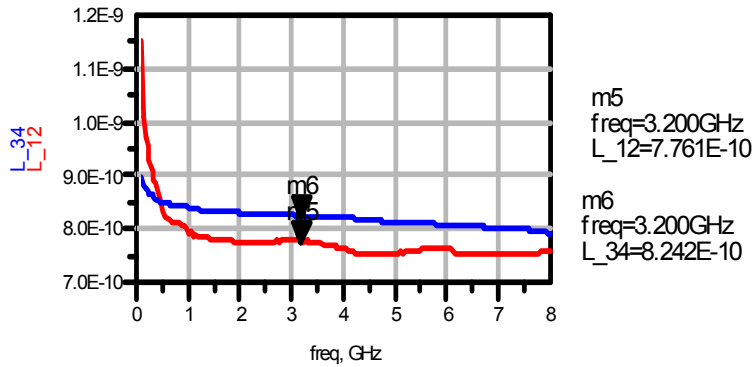


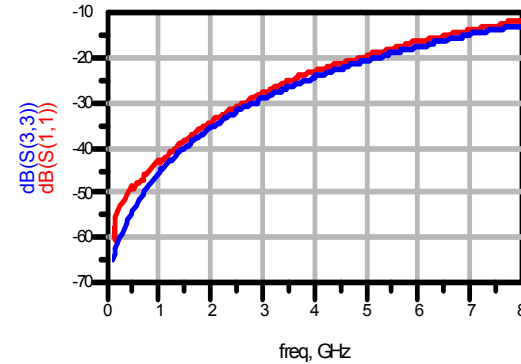
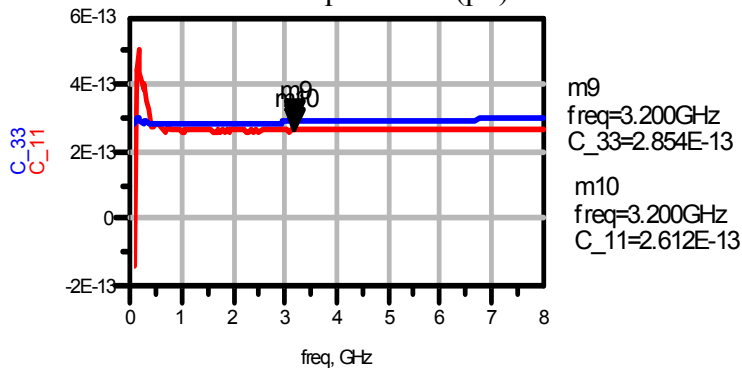
Fig.2 HFSS modeling for 1,2, and 4 wires

Measurement .vs. HFSS of one single wire structure

Inductance (nH)

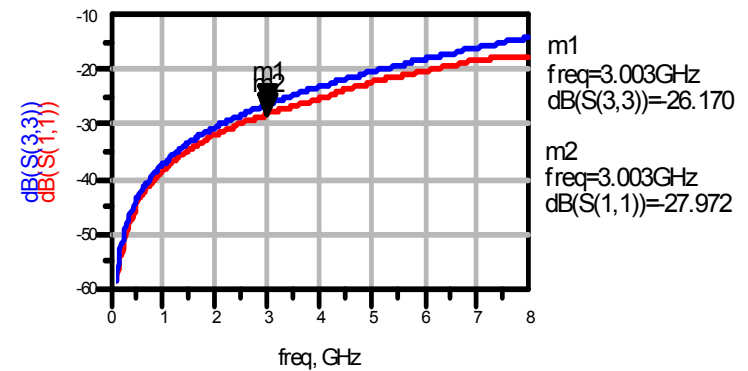
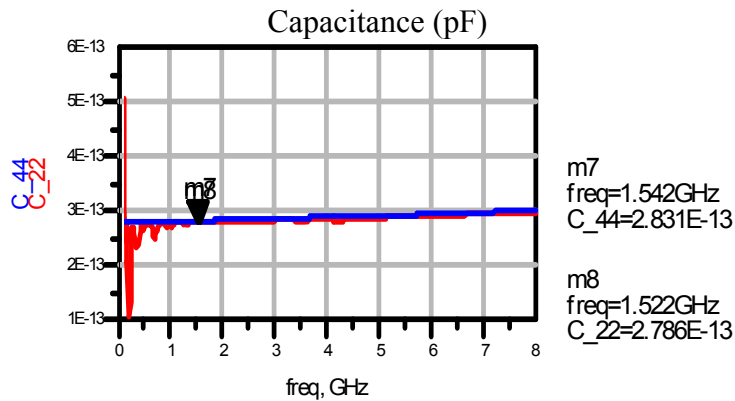
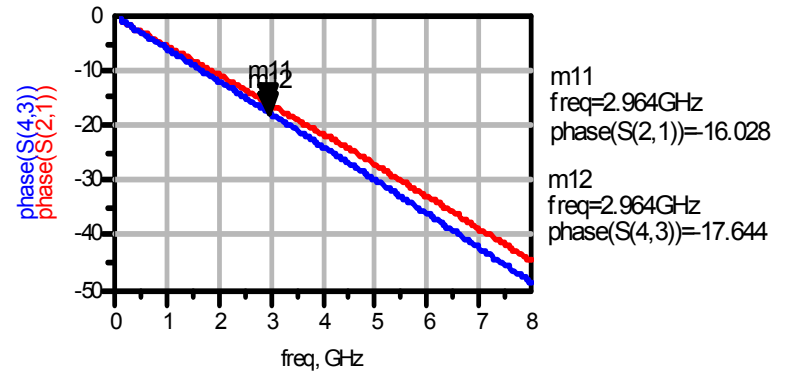
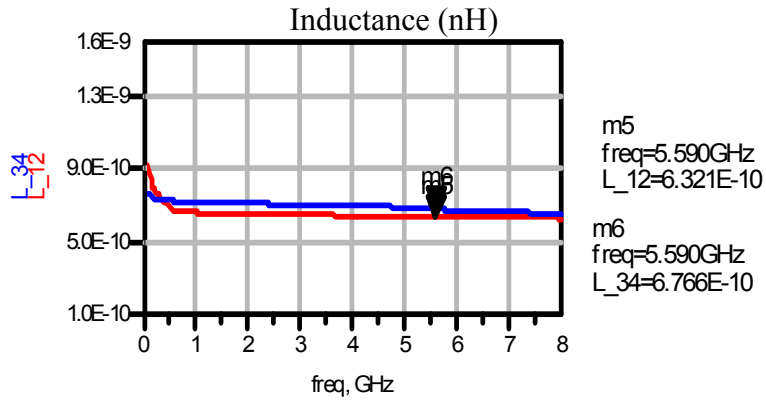


Capacitance (pF)



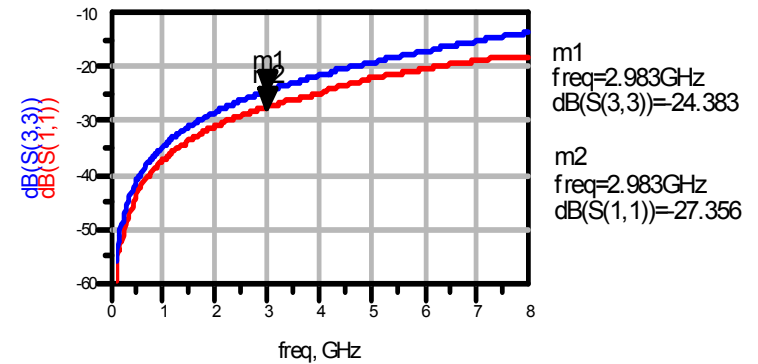
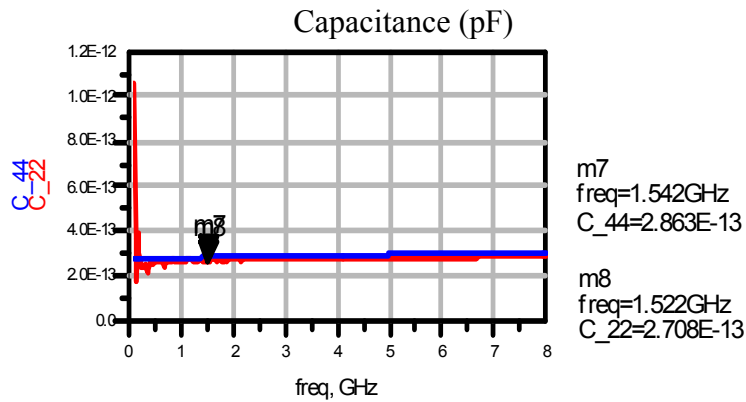
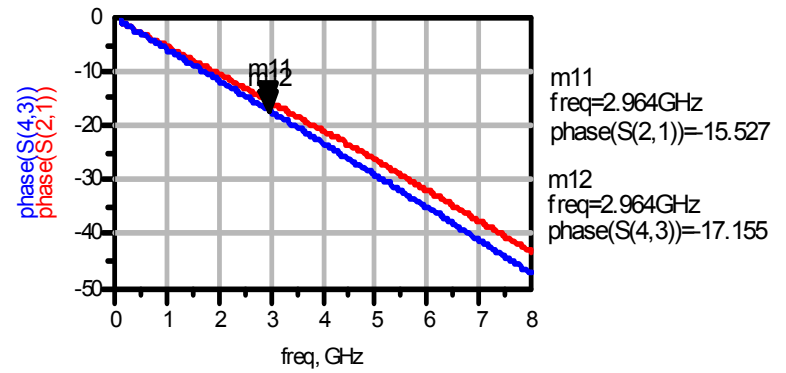
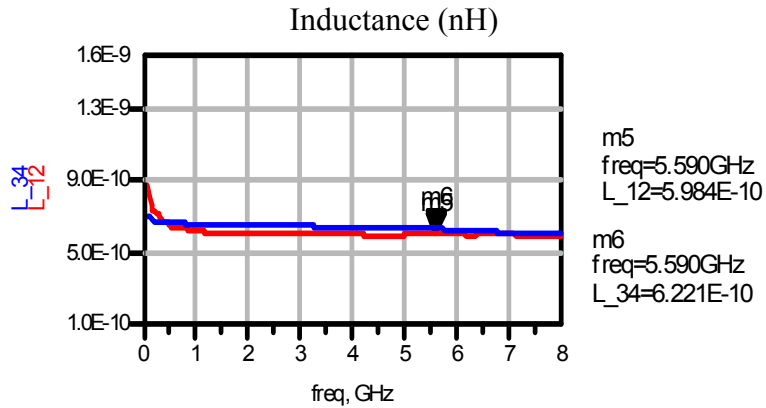
Results of 1 single bondwire

Measurement .vs. HFSS of 2-wire angle structure



Results of 2 bondwires

Measurement .vs. HFSS of 4-wire angle structure

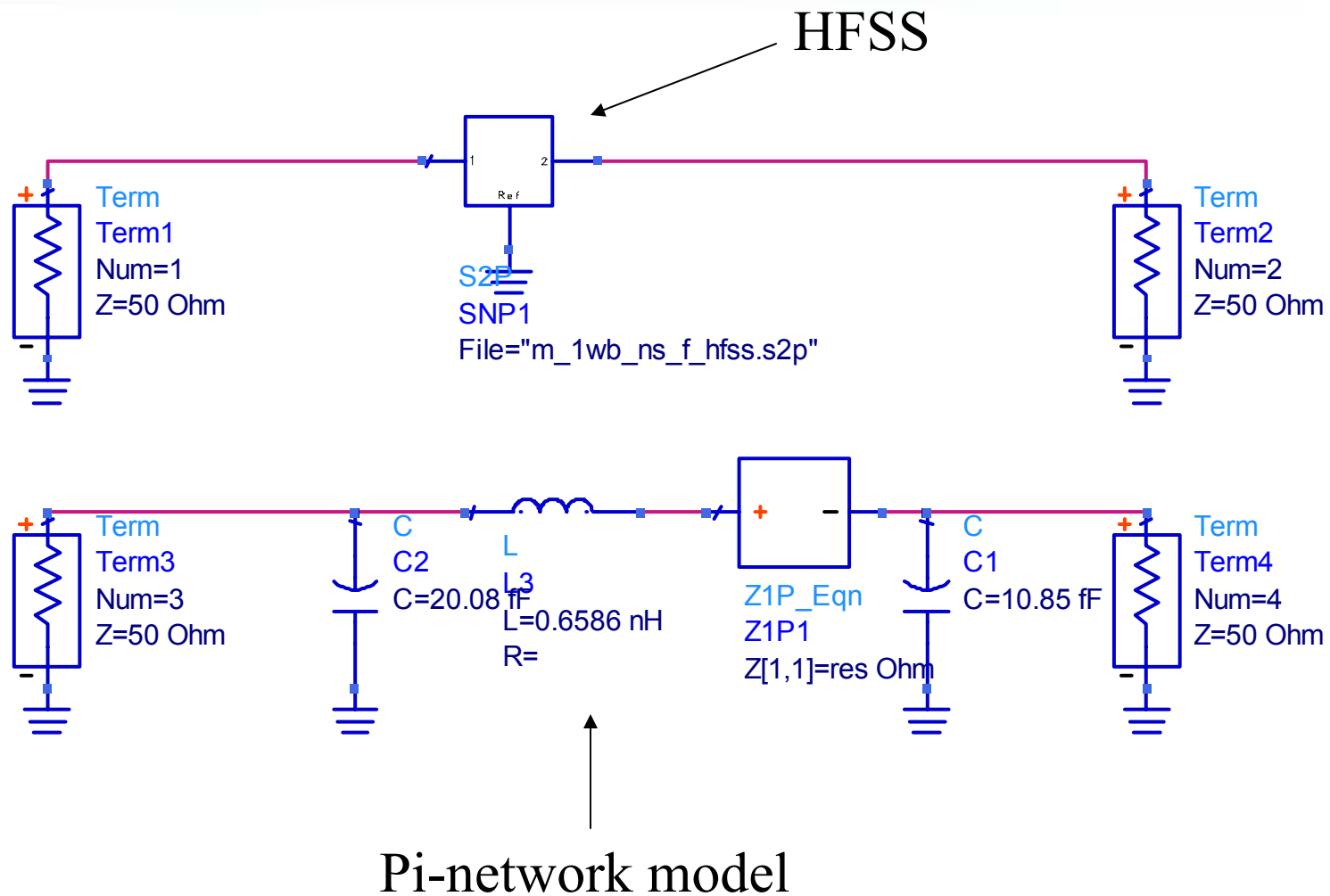


Results of 4 bondwires

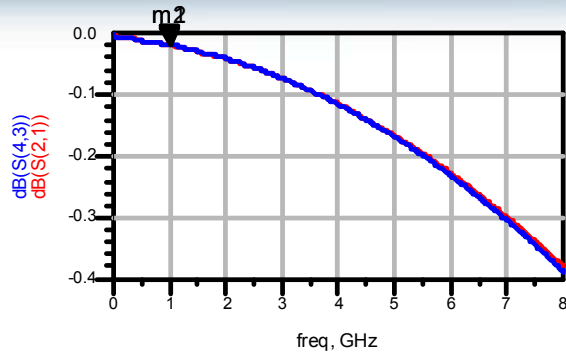
Lumped model LRC pi-network of bondwire matching S-parameter model

- The lumped model is given in terms of an equivalent low-pass pi-network that is composed by a series inductance, resistance and two shunt capacitances.
- These quantities LRC can be calculated as
 - $L = 1/(j\omega Y_{21})$ (H)
 - $C1 = (Y_{11} + Y_{21}) / j\omega$ (F)
 - $C2 = (Y_{22} + Y_{12}) / j\omega$ (F)
 - $R_{21} = \text{real}(1/Y_{21})$ (Ohm)

Lumped model LRC pi-network and S-parameter setup on ADS

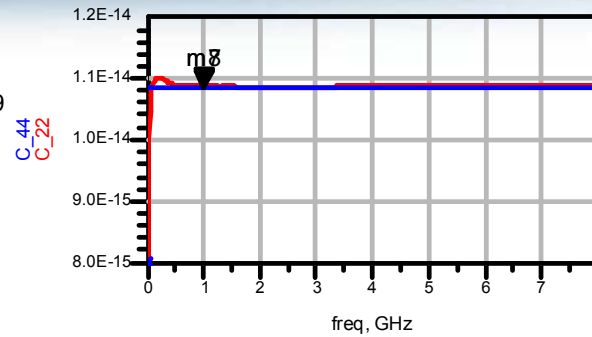


Lumped model LRC pi-network of bondwire matching S-parameter model



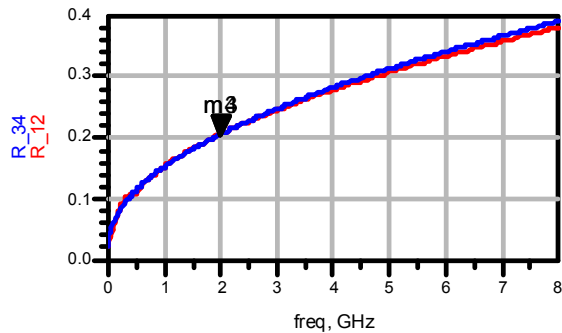
m1
freq=1.000GHz
dB(S(4,3))=-0.019

m2
freq=1.000GHz
dB(S(2,1))=-0.019



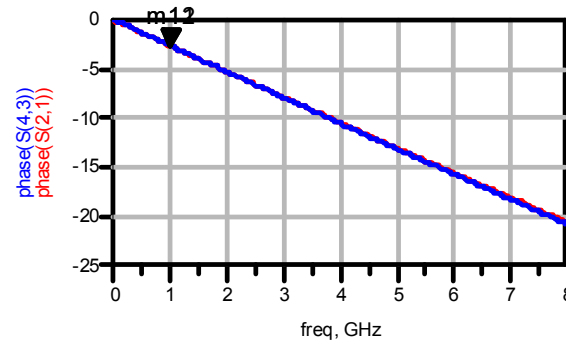
m7
freq=1.000GHz
C₄₄=1.085E-14

m8
freq=1.000GHz
C₂₂=1.086E-14



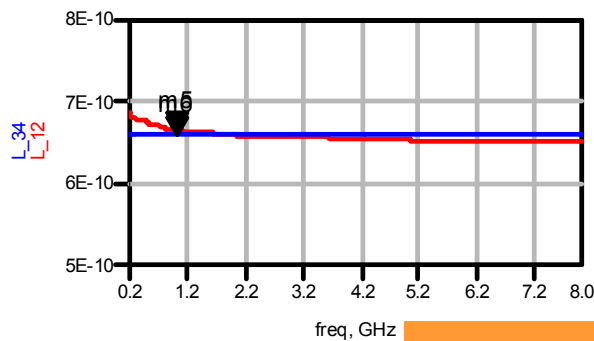
m4
freq=2.000GHz
R₃₄=0.206

m3
freq=2.000GHz
R₁₂=0.206



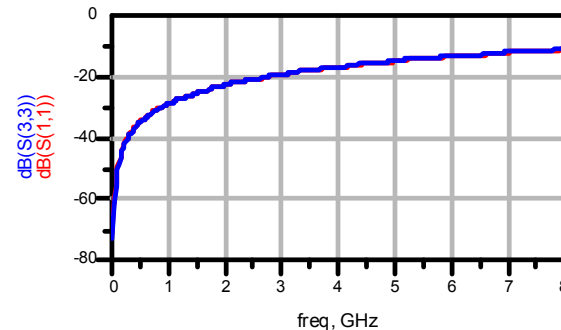
m11
freq=1.000GHz
phase(S(2,1))=-2.669

m12
freq=1.000GHz
phase(S(4,3))=-2.645



m5
freq=1.000GHz
L₁₂=6.651E-10

m6
freq=1.000GHz
L₃₄=6.586E-10



Lumped model exactly match S-parameter model

Modeling method

- The wirebond model is based on the combination of measurement, HFSS simulation and “Inductance calculations working formulas and tables” [1].
- About 300 HFSS simulations for a single, multiple wires with different wire lengths, distances and angles.
- All the S-parameter files collected from HFSS were extracted in ADS for parasitics LRC.
- Each parasitic was separately modeled then combined together as a lumped model pi-network.

Inductance modeling

- Self inductance:

$$L = 0.0002 \times \lambda \cdot \left[\text{Ln} \left(2 \cdot \frac{\lambda}{r} \right) - \frac{3}{4} \right] \quad (\text{nH})$$

$\lambda(\ell) = \text{model wirelength} \quad (\mu\text{m})$

$r = \text{wirebond radius} \quad (\mu\text{m})$

Proj Length (μm)	simulated Ind (nH)	Model Ind (nH)	%
300	0.6378	0.6382	0.1%
500	0.8039	0.7999	0.5%
700	0.9646	0.9771	1.3%
900	1.1460	1.1541	0.7%
1100	1.3000	1.3323	2.5%

Inductance modeling (cont)

- Mutual inductance:

$$M(\ell, S_m) = 0.0002 \times \ell \cdot \left[\text{Ln} \left(\frac{\ell}{S_m} + \sqrt{1 + \frac{\ell^2}{S_m^2}} \right) - \sqrt{1 + \frac{S_m^2}{\ell^2}} + \frac{S_m}{\ell} \right]$$

ℓ = physical wirelength (um)

S_m = space mod el (um)

- Mutual inductance with angle:

$$M(\ell, S_m, \theta_A) = M(\ell, S_m) \cdot \cos(0.0278 \cdot \theta_A^2 - 0.4205 \cdot \theta_A + 37.485) \quad (\text{nH})$$

θ_A = actual angle (degree)

Inductance modeling (cont)

- Comparison between simulated and modeled mutual inductance.

Proj Length (um)	Simulated Mut Ind (nH)	Model Mut Ind (nH)	different Ind (pH)
300	0.2985	0.2847	14
300	0.1930	0.1911	2
300	0.1213	0.1142	7
300	0.1000	0.0659	34
500	0.4059	0.4043	2
500	0.2830	0.2801	3
500	0.1780	0.1751	3
500	0.1080	0.1057	2
700	0.5217	0.5538	32
700	0.3574	0.3936	36
700	0.222	0.2554	33
700	0.1537	0.1604	7
900	0.7016	0.7198	18
900	0.4638	0.5216	58
900	0.3460	0.3484	2
900	0.2380	0.2259	12

Resistance Modeling

- dc Resistance:

$$R_{dc} = \frac{1}{\sigma} \times \frac{\ell}{A} \quad (\Omega)$$

ℓ = physical wirelength (um)

σ = wire conductivity (S/m)

- Total and ac Resistance:

$$R_{Total}(\ell) = R_{dc} \left(1 + \frac{(-10^{-8} \cdot \ell^2 + 9 \cdot 10^{-5} \times \ell + 0.1355)}{R_{dc}} \times \sqrt{freq} \right)$$

$$R_{ac} = R_{Total} - R_{dc}$$

Resistance Modeling (cont)

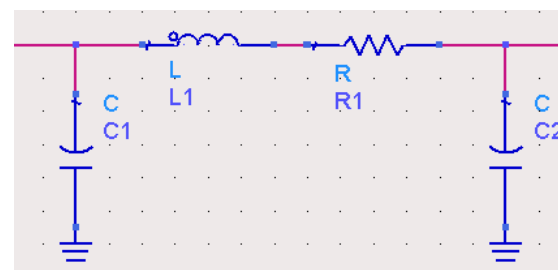
- Comparison between simulated and modeled resistance.

Proj Length (um)	Simulated Res (Ohm)	Model Res (Ohm)	% model vs simulation
300	0.204	0.200	2%
500	0.229	0.224	2%
700	0.254	0.251	1%
900	0.276	0.279	-1%
1100	0.299	0.307	-3%

Capacitance Modeling

- After de-embedding wirebond pad, the shunt capacitances on both sides of wire are very small in the range from 10 to 25 fF depending on the physical wirelength.
- Shunt capacitance C1 on the die side is little higher than C2 on laminate. Perhaps, the dielectric constant on die is higher.

Proj Length (um)	Capacitance die_port1 (fF)	Capacitance sub_port2 (fF)
300	19.6	10.3
500	21.5	12.7
700	23.7	17.3
900	24.5	18.8
1100	25.8	20.0



$$C_1 = -4 \cdot 10^{-6} \ell^2 + 0.0136 \cdot \ell + 15.911$$

$$C_2 = -1 \cdot 10^{-5} \ell^2 + 0.0264 \cdot \ell + 2.9259$$

$$\ell = \text{physical wirelength (um)}$$

Notes and capability of wirebond model

I. Input parameters of the wire model

- The model's parameters are set as default of 4mil die thickness plus 20um epoxy thickness, 5mil wire loop height and 1mil wire diameter. However, these parameters can be changed by user for appropriate needs.
- User basically enters:
 - + The projected wire length in um
 - + Distance in um between bondwires
 - + Angles in degree between bondwires

II. What the model computes

- Self and mutual inductance with or without wire angles .
- Dc and ac resistance
- Shunt capacitances

Notes and capability of wirebond model (cont)

III. Wirebond features and restrictions

- The skin effect is included as well where the ac resistance rapidly changes over freq.
- Frequency valid up to 8 GHz
- It is well applicable for wire length less than 1100 μm
- It doesn't account for capacitive coupling between bondwires
- Model also covers the epoxy thickness underneath the die
- Wires are not allowed to cross each other.

IV. Percent error

- Both self inductance, and resistance are very sensitive to the wire's geometry. For example, 2.5 μm wire diameter difference, self inductance can be changed about 3%.
- Mutual inductance for coupled wires with angle is really critical to get. mutual value varies about 5% if angle between 2 wires changes from zero to seven degrees

Conclusions

- In this presentation the measurement, HFSS simulation and modeling technique of microwave bondwire from die to laminate were considered. HFSS is a powerful full-wave tool to build wirebond model.
- The aim of this task was to provide an accurate, flexible model with various wire length, wire distance and wire angles valid up to 8 GHz .
- The difference between measurement and simulation is less than 6% which is acceptable and meeting Skywork's SPEC.
- Parasitic lumped model pi-network LRC is applicable to wirebond structure. It is exactly matching with S-parameter.

References

- [1] F.W.Grove, Inductance Calculations Working Formulas and Tables. Dover Publication, Inc., New York, 1946.
- [2] David K. Cheng, Field and Wave Electromagnetics. Addison-Wesley Publishing Company, Inc. US, 1983.