ICM vs. EMD
A 9 pin Wire Bond BGA Example

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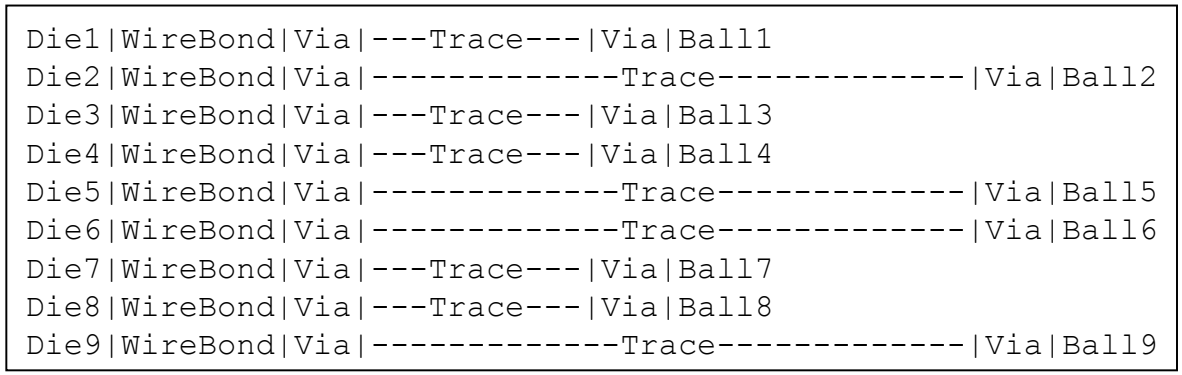
ICM Method

```
Example package has 9 pins (0,1,2,3,4,5,6,7,8,9)
-----------------
Die1|WireBond|Via|---Trace---|Via|Ball1
Die2|WireBond|Via|-------------Trace-------------|Via|Ball2
Die3|WireBond|Via|---Trace---|Via|Ball3
Die4|WireBond|Via|---Trace---|Via|Ball4
Die5|WireBond|Via|-------------Trace-------------|Via|Ball5
Die6|WireBond|Via|-------------Trace-------------|Via|Ball6
Die7|WireBond|Via|---Trace---|Via|Ball7
Die8|WireBond|Via|---Trace---|Via|Ball8
Die9|WireBond|Via|-------------Trace-------------|Via|Ball9
```

ICM is really three independent modeling languages.

An ICM file has one [Family]. The [Family] can contain multiple [Model]s. Each [Model]'s Model_Type can be Single-Line, Multi-Line or S-Parameter. A [Model] has a [Node_Map] for both sides of the connector. A [Node_Map] a list of the pin numbers on the side and the corresponding Node name used in the Section netlist. A [Model] consists of a netlist of Sections. A Section is really a simulator netlist instance of an RLGC lumped model, an RLGC Distributed model or an S-Parameter Touchstone File. RLGC models consist of Resistance, Inductance, Capacitance, and Conductance matrices. These matrices are specified in Diagonal, Banded, or Sparse Format. A section can have instances of both RLGC Lumped and RLGC Distributed models.

RLGC ICM Solution




```
[Begin ICM Family] package
[Begin ICM Model] 9_pin_package
ICM_model_type MLM
[Nodal Path Description]
Model_nodemap Die
N_section (D1 D2 D3 D4 D5 D6 D7 D8 D9
           11 12 13 14 15 16 17 18 19) Mult=1 WireBondVia
```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RLGC ICM Solution (Cont.)

```
| Units in meters
N_section (11 21) Len=.01 Trace
N_section (12 22) Len=.02 Trace
N_section (13 23) Len=.01 Trace
N_section (14 24) Len=.01 Trace
N_section (15 25) Len=.02 Trace
N_section (16 26) Len=.02 Trace
N_section (17 27) Len=.01 Trace
N_section (18 28) Len=.01 Trace
N_section (19 29) Len=.02 Trace
N_section (21 22 23 24 25 26 27 28 29
           B1 B2 B3 B4 B5 B6 B7 B8 B9)
    Mult=1 ViaBall
Model_nodemap Ball
[End ICM Model]
```

```
|************ Nodemaps *************
[ICM Node Map] Die
| pin   node name
1 D1 Die_1
2 D2 Die_2
3 D3 Die_3
4 D4 Die_4
5 D5 Die_5
6 D6 Die_6
7 D7 Die_7
8 D8 Die_8
9 D9 Die_9
|
[ICM Node Map] Ball
| pin   node name
1 B1 Ball_1
2 B2 Ball_2
3 B3 Ball_3
4 B4 Ball_4
5 B5 Ball_5
6 B6 Ball_6
7 B7 Ball_7
8 B8 Ball_8
9 B9 Ball_9
|
[End ICM Family]
```

RLGC ICM Solution (Cont.)

```
[Begin ICM Section] Trace
[Derivation Method] Distributed
|
[Resistance Matrix] Full_matrix
[Row] 1
0.00121302
[Inductance Matrix] Full_matrix
[Row] 1
4.0174e-011
[Capacitance Matrix] Full_matrix
[Row] 1
3.84177e-014
[Conductance Matrix] Diagonal_matrix
0
[End ICM Section]
```

```
[Begin ICM Section] WireBondVia
[Derivation Method] Lumped

[Resistance Matrix] Diagonal_matrix
 2.645669e+00
 2.644488e+00
 2.645276e+00
 2.643701e+00
 2.644882e+00
 2.645669e+00
 2.644488e+00
 2.645276e+00
 2.643701e+00
```

RLGC ICM Solution (Cont.)

```
[Inductance Matrix] Banded_matrix
[Bandwidth] 2
[Row] 1
2.643701e+00  3.475197e-07   6.842520e-08     9.133858e-09
[Row] 2
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 3
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 4
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 5
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 6
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 7
3.475197e-07   6.842520e-08     9.133858e-09
[Row] 8
3.475197e-07   6.842520e-08     0
[Row] 9
3.475197e-07   0     0
```

RLGC ICM Solution (Cont.)

```
[Capacitance Matrix] Sparse_matrix
[Row] 1
1 3.475197e-07   2 6.842520e-08     3 9.133858e-09
[Row] 2
2 3.475197e-07   3 6.842520e-08     4 9.133858e-09
[Row] 3
3 3.475197e-07   4 6.842520e-08     5 9.133858e-09
[Row] 4
4 3.475197e-07   5 6.842520e-08     6 9.133858e-09
[Row] 5
5 3.475197e-07   6 6.842520e-08     7 9.133858e-09
[Row] 6
6 3.475197e-07   7 6.842520e-08     8 9.133858e-09
[Row] 7
7 3.475197e-07   8 6.842520e-08     9 9.133858e-09
[Row] 8
8 3.475197e-07   9 6.842520e-08
[Row] 9
9 3.475197e-07
```


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RLGC ICM Solution (Cont.)

```
[Conductance Matrix] Diagonal_matrix
0
0
0
0
0
0
0
0
0
[End ICM Section]
```

RLGC ICM Solution (Cont.)

```
[Begin ICM Section] ViaBall
[Derivation Method] Lumped
[Resistance Matrix] Diagonal_matrix
 2.645669e+00
 2.644488e+00
 2.645276e+00
 2.643701e+00
 2.644882e+00
 2.645669e+00
 2.644488e+00
 2.645276e+00
 2.643701e+00
```

RLGC ICM Solution (Cont.)

```
[Inductance Matrix] Sparse_matrix
[Row] 1
1 3.475197e-07
[Row] 2
2 3.475197e-07   3 6.842520e-08
[Row] 3
3 3.475197e-07
[Row] 4
4 3.475197e-07   5 6.842520e-08
[Row] 5
5 3.475197e-07
[Row] 6
6 3.475197e-07   7 6.842520e-08
[Row] 7
7 3.475197e-07
[Row] 8
8 3.475197e-07
[Row] 9
9 3.475197e-07
[Capacitance Matrix] Sparse_matrix
...
[Conductance Matrix] Diagonal_matrix
...
```

EMD Model

Example package has 9 Package nPins (P.1,P.2,P.3,P.4,P.5,P.6,P.7,P.8,P.9)
Example package has 9 Component Pins (D.1,D.2,D.3,D.4,D.5,D.6,D.7,D.8,D.9)

```
D.1|WireBond|Via|---Trace---|Via| P.1
D.2|WireBond|Via|-------------Trace-------------|Via| P.2
D.3|WireBond|Via|---Trace---|Via| P.3
D.4|WireBond|Via|---Trace---|Via| P.4
D.5|WireBond|Via|-------------Trace-------------|Via| P.5
D.6|WireBond|Via|-------------Trace-------------|Via| P.6
D.7|WireBond|Via|---Trace---|Via| P.7
D.8|WireBond|Via|---Trace---|Via| P.8
D.9|WireBond|Via|-------------Trace-------------|Via| P.9
```

EMD Model (Cont.)

```
.subckt package  P.1 P.2 P.3 P.4 P.5 P.6 P.7 P.8 P.9
+                D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
wWireBondVia D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9 0
+             11  12  13  14  15  16  17  18  19 0
+             N=9 Mult=1 LumpedRLGC=WireBondVia
wTrace1 11 0 21 0 Len=.01 N=2 DistributedRLGC=Trace
wTrace1 12 0 22 0 Len=.02 N=2 DistributedRLGC=Trace
wTrace1 13 0 23 0 Len=.01 N=2 DistributedRLGC=Trace
wTrace1 14 0 24 0 Len=.01 N=2 DistributedRLGC=Trace
wTrace1 15 0 25 0 Len=.02 N=2 DistributedRLGC=Trace
wTrace1 16 0 26 0 Len=.02 N=2 DistributedRLGC=Trace
wTrace1 17 0 27 0 Len=.01 N=2 DistributedRLGC=Trace
wTrace1 18 0 28 0 Len=.01 N=2 DistributedRLGC=Trace
wTrace1 19 0 29 0 Len=.02 N=2 DistributedRLGC=Trace
wViaBall  21   22   23   24   25   26   27   28   29 0
+        P.1  P.2  P.3  P.4  P.5  P.6  P.7  P.8  P.9 0
+        N=9 Mult=1 LumpedRLGC=ViaBall
.ends package
```


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EMD Model w. Trace Coupling

```
D.1|WireBond|Via|---Trace---|Via|P.1
D.2|WireBond|Via|-------------Trace-------------|Via|P.2
D.3|WireBond|Via|---Trace---|Via|P.3
D.4|WireBond|Via|---Trace---|Via|P.4
D.5|WireBond|Via|-------------Trace-------------|Via|P.5
D.6|WireBond|Via|-------------Trace-------------|Via|P.6
D.7|WireBond|Via|---Trace---|Via|P.7
D.8|WireBond|Via|---Trace---|Via|P.8
D.9|WireBond|Via|-------------Trace-------------|Via|P.9
```

```
.subckt package  P.1 P.2 P.3 P.4 P.5 P.6 P.7 P.8 P.9
+                D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
wWireBondVia D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9 0
+             11  12  13  14  15  16  17  18  19 0
+             N=9 Mult=1 LumpedRLGC=WireBondVia
wRedTrace  11  12  13  14  15  16  17  18  19 0
+          21  22  23  24  25  26  27  28  29 0
+             N=9 Len=.01 Mult=1 DistributedRLGC=RedTrace
wBlueTrace  22  25  26 29 0
+            32  35  36 39 0
+             N=4 Len=.01 Mult=1 DistributedRLGC=BlueTrace
wViaBall  21   32   23   24   35   36   27   28   39 0
+        P.1  P.2  P.3  P.4  P.5  P.6  P.7  P.8  P.9 0
+             N=9 Mult=1 LumpedRLGC=ViaBall
.ends package
```

Note that this gets complicated if there Red traces are not the same length and if the Blue traces are not the same length.

EMD Model w. Multiple S-Params

```
D.1|WireBond|Via|---Trace---|Via|P.1
D.2|WireBond|Via|-------------Trace-------------|Via|P.2
D.3|WireBond|Via|---Trace---|Via|P.3
D.4|WireBond|Via|---Trace---|Via|P.4
D.5|WireBond|Via|-------------Trace-------------|Via|P.5
D.6|WireBond|Via|-------------Trace-------------|Via|P.6
D.7|WireBond|Via|---Trace---|Via|P.7
D.8|WireBond|Via|---Trace---|Via|P.8
D.9|WireBond|Via|-------------Trace-------------|Via|P.9
```

```
.subckt package  P.1,P.2,P.3,P.4,P.5,P.6,P.7,P.8,P.9
+                D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
sWireBondVia D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
+             11  12  13  14  15  16  17  18  19 0
+             Touchstone_X_File=WireBondVia.s18p
sTrace1 11 21 0 TouchstoneFile=Trace01.s2p
sTrace2 12 22 0 TouchstoneFile=Trace02.s2p
sTrace3 13 23 0 TouchstoneFile=Trace01.s2p
sTrace4 14 24 0 TouchstoneFile=Trace01.s2p
sTrace5 15 25 0 TouchstoneFile=Trace02.s2p
sTrace6 16 26 0 TouchstoneFile=Trace02.s2p
sTrace7 17 27 0 TouchstoneFile=Trace01.s2p
sTrace8 18 28 0 TouchstoneFile=Trace01.s2p
sTrace9 19 29 0 TouchstoneFile=Trace02.s2p
sViaBall  21 22 23 24 25 26 27 28 29
+          1  2  3  4  5  6  7  8  9 0
+          Touchstone_X_File=ViaBall.s18p
.ends package
```

Like RLGC, but S parameter

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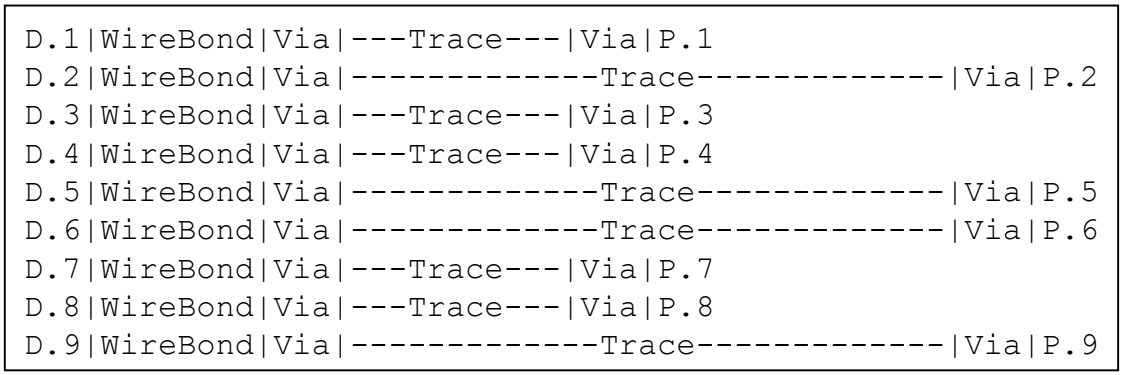
EMD Model w. Single S-Param




```
.subckt package  P.1 P.2 P.3 P.4 P.5 P.6 P.7 P.8 P.9
+                D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
spackage D.1 D.2 D.3 D.4 D.5 D.6 D.7 D.8 D.9
+        P.1 P.2 P.3 P.4 P.5 P.6 P.7 P.8 P.9 0
+        Touchstone_X_File=package.s18p
.ends package
```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Why Spare S-Param Files are Needed

- 18 port network
  - Touchstone 1 has 18x18 = 324 entries
  - Half matrix (Touchstone 2) has 18*(18+1)/2 = 171 entries
- What if sparse matrix specification (Touchstone X) were allowed?
  - Network with no coupling would have 27 entries
  - Network with coupling would have 72 entries

Proposed Touchstone X File Header

```
[Port Names]
D.1 D.2 D.3 D.4 D.5 D.6 D.6 D.8 D.9
B.1 B.2 B.3 B.4 B.5 B.6 B.7 B.8 B.9
[Near-Far Ports]
(D.1 B.1) (D.2 B.2) (D.3 B.3) (D.4 B.4) (D.5 B.5)
(D.6 B.6) (D.7 B.7) (D.8 B.8) (D.9 B.9)
```

Uncoupled.27e and coupled.72e files are Touchstone format files that have for each frequency a vector of 27 (or 72) number pairs (e.g. amplitude and angle). In the Sparse S parameter syntax below, S10 is the 10th entry in each of these frequency vectors.

Touchstone_X_File no coupling package.s18p

```
[Sparam Data File] uncoupled.27e
[Row] D.1
D.1 S1 B.1 S10
[Row] D.2
D.2 S2 B.2 S11
[Row] D.3
D.3 S3 B.3 S12
[Row] D.4
D.4 S4 B.4 S13
[Row] D.5
D.5 S5 B.5 S14
[Row] D.6
D.6 S6 B.6 S15
[Row] D.7
D.7 S7 B.7 S16
[Row] D.8
D.8 S8 B.8 S17
[Row] D.9
D.9 S9 B.9 S18
[Row] B.1
B.1 S19
[Row] B.2
B.2 S20
[Row] B.3
B.3 S21
[Row] B.4
B.4 S22
[Row] B.5
B.5 S23
[Row] B.6
B.6 S24
[Row] B.7
B.7 S25
[Row] B.8
B.8 S26
[Row] B.9
B.9 S27
```

Touchstone_X_File with nearest & next-nearest coupling package.s18p

```
[Sparam Data File] coupled.72e
[Row] D.1
D.1 S1 B.1 S10 D.2 S28 B.2 S29 D.3 S30
    B.3 S31
[Row] D.2
D.2 S2 B.2 S11 D.3 S32 B.3 S33 D.4 S34
    B.4 S35
[Row] D.3
D.3 S3 B.3 S12 ...
[Row] D.4
D.4 S4 B.4 S13 ...
[Row] D.5
D.5 S5 B.5 S14 ...
[Row] D.6
D.6 S6 B.6 S15 ...
[Row] D.7
D.7 S7 B.7 S16 D.8 S52 B.8 S53 D.9 S54
    B.9 S55
[Row] D.8
D.8 S8 B.8 S17 D.9 S56 B.9 S57
[Row] D.9
D.9 S9 B.9 S18
```

```
[Row] B.1
B.1 S19 B.2 S58 B.3 S59
[Row] B.2
B.2 S20 B.3 S60 B.4 S61
[Row] B.3
B.3 S21 ...
[Row] B.4
B.4 S22 ...
[Row] B.5
B.5 S23 ...
[Row] B.6
B.6 S24 ...
[Row] B.7
B.7 S25 B.8 S70 B.9 S71
[Row] B.8
B.8 S26 B.9 S72
[Row] B.9
B.9 S27
```

S-Parameter File Size Comparison

- S Parameter Model with nearest and next nearest coupling
- 1000 frequency points
- 20 characters per entry

Pins	Full Matrix (entries)	Full Matrix (file size)	Half Matrix (entries)	Half Matrix (file size)	TStone X	TStone X (file size)
100	40K	7.6GB	20K	3.8GB	800	15.3MB
1000	4M	76GB	2M	38GB	8K	153MB

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