IC CONTACT RESISTANCE ANALYSIS

http://www.leapcad.com/Other_Tech/IC_Probe_Contact_Resistance_Method.mcd

READ DATA FROM FILE (Array Origin = 1):

$Z := \text{READPRN}(\text{"http://www.leapcad.com/Other\_Tech/probe\_nh.prn"})$ $Die := \text{rows}(Z)$ Die $die := 1 .. Die$

First 18 columns are descriptors, D. has 200 tests, tn: $D := 18$ $tn := 1 .. \text{cols}(Z) - D$
The first two are die X,Y. First 72 tests are Logic Pins.
Last 8 x 16 are output tests. $tests := \text{cols}(Z) - D$ $tests = 200$
The max X and Y width is 37 and 34, respectively.
Create vectors X, Y, of die coordinates.

$X := Z^{\langle 14 \rangle}$ $Y := Z^{\langle 15 \rangle}$ $maxX := \max(X)$ $maxY := \max(Y)$ $minX := \min(X)$ $minY := \min(Y)$

$X_{width} := maxX - minX + 1$ $Y_{width} := maxY - minY + 1$

$X_{width} = 24$ $rr := 1 .. Y_{width}$ $Y_{width} = 30$ $cc := 1 .. X_{width}$

Find Start of New Wafer Row, Y

$NewY :=$
- $OldY \leftarrow 0$
- for $die \in 1 .. \text{rows}(Z)$
  - $NY_{die} \leftarrow -10$
  - if $Y_{die} \neq OldY$
    - $NY_{die} \leftarrow 20$
    - $OldY \leftarrow Y_{die}$
- NY

Create Normatlized Function that varies with X Location

$$NX_{die} := \frac{X_{die} + 6}{X_{width}} \cdot 0.7 + 0.9$$

The 79th test is the contact resistance from the power source's force/sense point for 1st output(#8)tested.
The 80st test is the contact resistance from the wafer's sense_probe for the first output.
A 3 Ohm resistor is used in series with the power source. Current remains the same.
The 87th test is the series resistance from the power source's force/sense point for 1st output(#8)tested.
The 88st test is the contact resistance from the wafer's sense_probe for the 1st output. Repeats 80th test.
The next output is offset by 16 tests from these.
The order of test for the outputs is 8, 2, 1, 6, 5, 3, 4, 7

$O := 1 .. 8$ $T := 16$

$\text{mean}\left(Z^{\langle D+79 \rangle}\right) = 0.807$ $\text{mean}\left(Z^{\langle D+80 \rangle}\right) = 0.431$ $\text{mean}\left(Z^{\langle D+87 \rangle}\right) = 4.034$ $\text{mean}\left(Z^{\langle D+88 \rangle}\right) = 0.431$

Absolute accuracy is tenth of an ohm Outputs 8, 2, 1, 6, 5, 3, 4, 7

$Rres_O := \text{mean}\left[Z^{\langle D+87+T\cdot(O-1) \rangle} - Z^{\langle D+79+T\cdot(O-1) \rangle} \right]$

$Rres^T = (3.227 \quad 3.044 \quad 2.938 \quad 3.092 \quad 3.009 \quad 2.812 \quad 3.029 \quad 2.926)$

$R1\_8 := (3.2 \quad 3.26 \quad 3.1 \quad 3.2 \quad 3.23 \quad 3.36 \quad 3.22 \quad 3.56)$ $R3 := (3.56 \quad 3.26 \quad 3.2 \quad 3.36 \quad 3.23 \quad 3.1 \quad 3.2 \quad 3.22)$

$Rerr := 100 \cdot \left(\overrightarrow{\left[\left(R3^T - Rres \right) \cdot \left(R3^T \right)^{-1} \right]} \right)$ $Rerr^T = (9.342 \quad 6.617 \quad 8.191 \quad 7.98 \quad 6.856 \quad 9.275 \quad 5.331 \quad 9.128)$

$\text{mean}(Rerr) = 7.84$

Repeatability is a milliohm.

$$Rrep_O := mean\left[Z^{\langle D+88+T\cdot(O-1)\rangle} - Z^{\langle D+80+T\cdot(O-1)\rangle} \right] \cdot 1000$$

$$Rrep^T = (-0.086 \quad -2.954 \quad -1.261 \quad -0.398 \quad -1.112 \quad -2.716 \quad 0.091 \quad -1.641)$$

$$max\left[Z^{\langle D+78+T\cdot(O-1)\rangle} \right]$$

For Each Output, O, find the Resistance, R, Change, Dev and Change Normalized to Spread, NDev

$$Rs^{\langle O\rangle} := \left[Z^{\langle D+80+T\cdot(O-1)\rangle} \right] \qquad Devs^{\langle O\rangle} := Rs^{\langle O\rangle} - median\left(Rs^{\langle O\rangle}\right) \qquad Ss_O := stdev\left(Rs^{\langle O\rangle}\right)$$

$$NDevs^{\langle O\rangle} := Devs^{\langle O\rangle} \cdot \left(Ss_O\right)^{-1}$$

$$Rf^{\langle O\rangle} := \left[Z^{\langle D+79+T\cdot(O-1)\rangle} \right] \qquad Devf^{\langle O\rangle} := Rf^{\langle O\rangle} - median\left(Rf^{\langle O\rangle}\right) \qquad Sf_O := stdev\left(Rf^{\langle O\rangle}\right)$$

$$NDevf^{\langle O\rangle} := Devf^{\langle O\rangle} \cdot \left(Sf_O\right)^{-1}$$

Smooth the Data with Gaussian Kernal

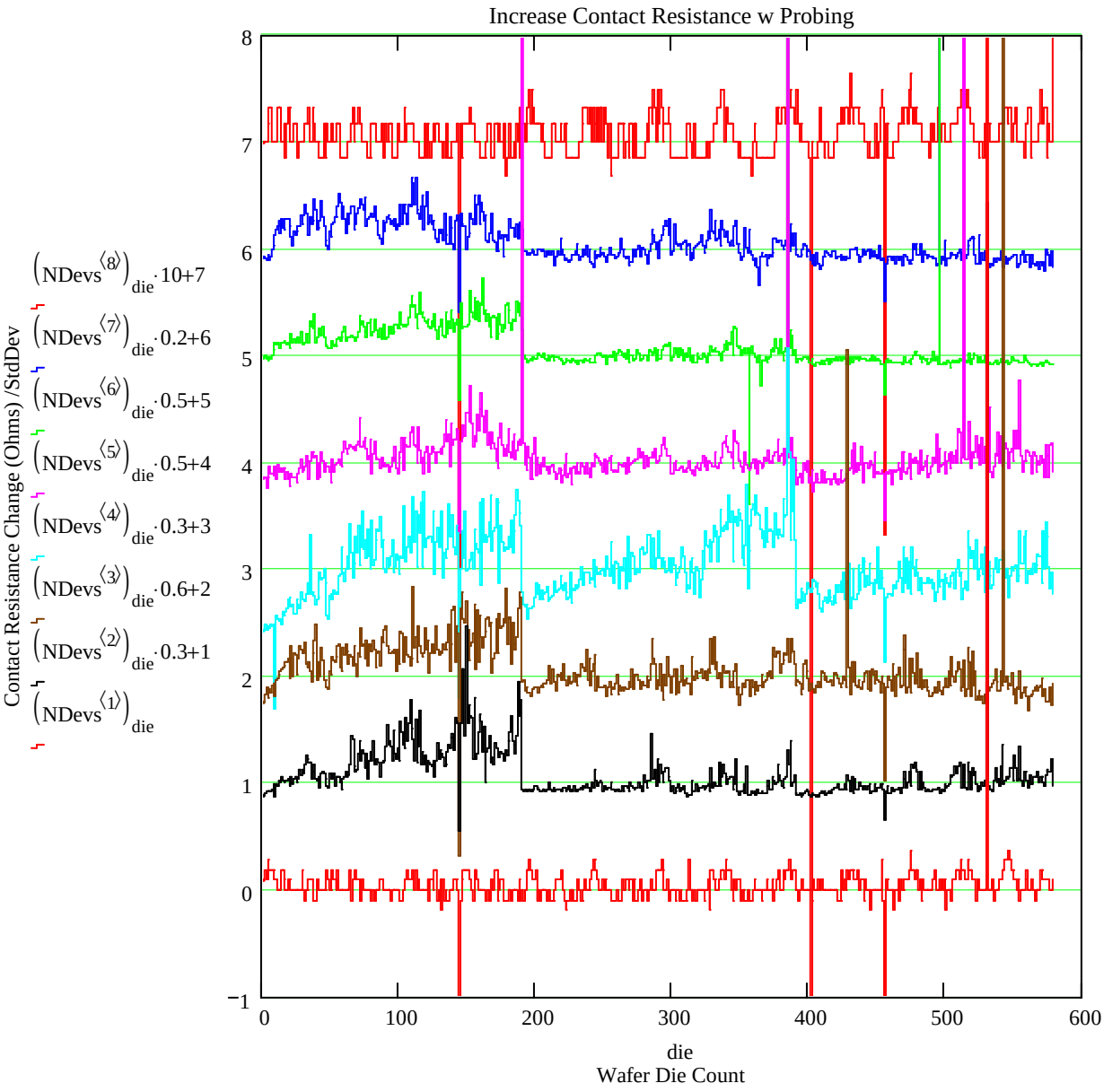
$$DIE_{die} := die \qquad Rss^{\langle O\rangle} := ksmooth\left(DIE, Rs^{\langle O\rangle}, 8\right) \qquad Rfs^{\langle O\rangle} := ksmooth\left(DIE, Rf^{\langle O\rangle}, 8\right)$$

Rs CONTACT SERIES RESISTANCE (OHM) STATISTICS FOR EACH OUTPUT (8, 2, 1, 6, 5, 3, 4, 7)

$min\left(Rs^{\langle O\rangle}\right)$ =	$mean\left(Rs^{\langle O\rangle}\right)$ =	$median\left(Rs^{\langle O\rangle}\right)$ =	$max\left(Rs^{\langle O\rangle}\right)$ =	$max\left(Rss^{\langle O\rangle}\right)$ =	$stdev\left(Rs^{\langle O\rangle}\right)$ =
0.361	0.431	0.429	1.213	0.535	0.033
0.683	1.009	0.957	4.351	1.425	0.187
0.577	0.969	0.951	3.864	1.332	0.133
0.942	1.274	1.266	1.776	1.452	0.074
0.812	1.031	1.013	3.527	1.382	0.152
0.278	0.845	0.809	4.113	1.234	0.19
0.617	0.813	0.797	1.547	0.94	0.06
-1.535	0.43	0.423	4.089	1.293	0.193

Rf CONTACT SERIES RESISTANCE (OHM) STATISTICS FOR EACH OUTPUT (8, 2, 1, 6, 5, 3, 4, 7)

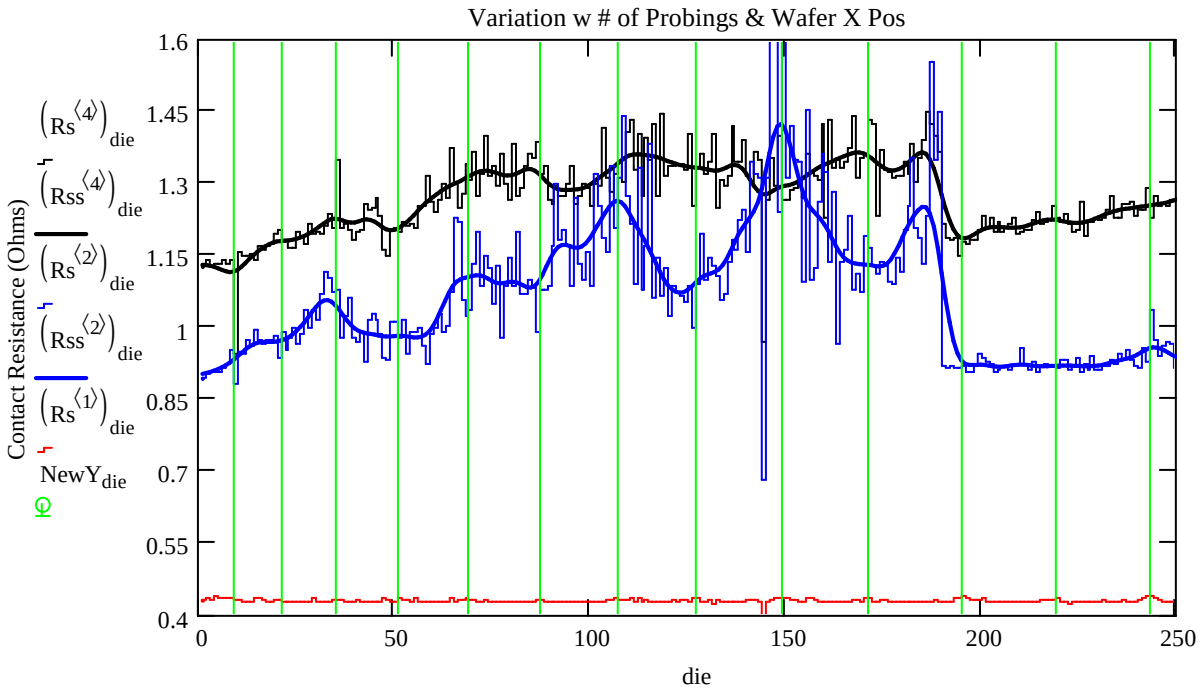
$min\left(Rf^{\langle O\rangle}\right)$ =	$mean\left(Rf^{\langle O\rangle}\right)$ =	$median\left(Rf^{\langle O\rangle}\right)$ =	$max\left(Rf^{\langle O\rangle}\right)$ =	$max\left(Rfs^{\langle O\rangle}\right)$ =	$stdev\left(Rf^{\langle O\rangle}\right)$ =
-18.01	0.807	0.842	1.356	1.034	0.793
-14.87	1.71	1.648	2.799	2.428	0.729
-17.42	1.752	1.735	4.609	2.09	0.816
1.731	2.455	2.408	4.325	3.068	0.352
-18.16	1.641	1.673	4.137	2.025	1.133
-15.78	1.304	1.331	1.747	1.62	1.004
-17.97	1.282	1.284	1.657	1.55	0.806
-17	0.725	0.746	1.633	1.06	1.014

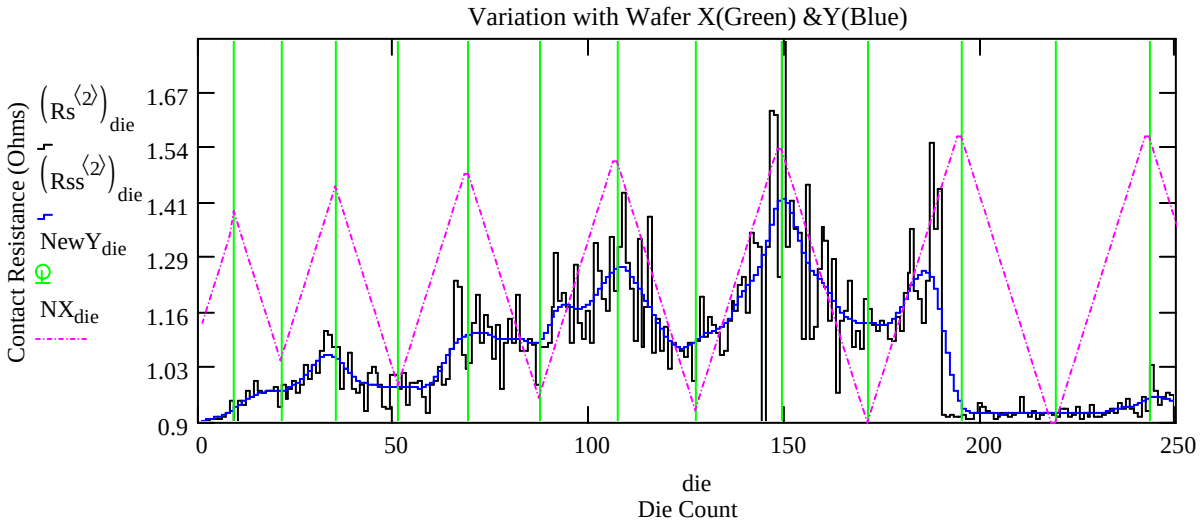

Increase Contact Resistance w Probing
Contact Resistance Change (Ohms) /StdDev
(NDevs⟨8⟩)die·10+7
(NDevs⟨7⟩)die·0.2+6
(NDevs⟨6⟩)die·0.5+5
(NDevs⟨5⟩)die·0.5+4
(NDevs⟨4⟩)die·0.3+3
(NDevs⟨3⟩)die·0.6+2
(NDevs⟨2⟩)die·0.3+1
(NDevs⟨1⟩)die
8
7
6
5
4
3
2
1
0
−1
0
100
200
300
400
500
600
die
Wafer Die Count

Contact Rs, Variation to 3 IC Pad Output Locations vs. touch downs & X

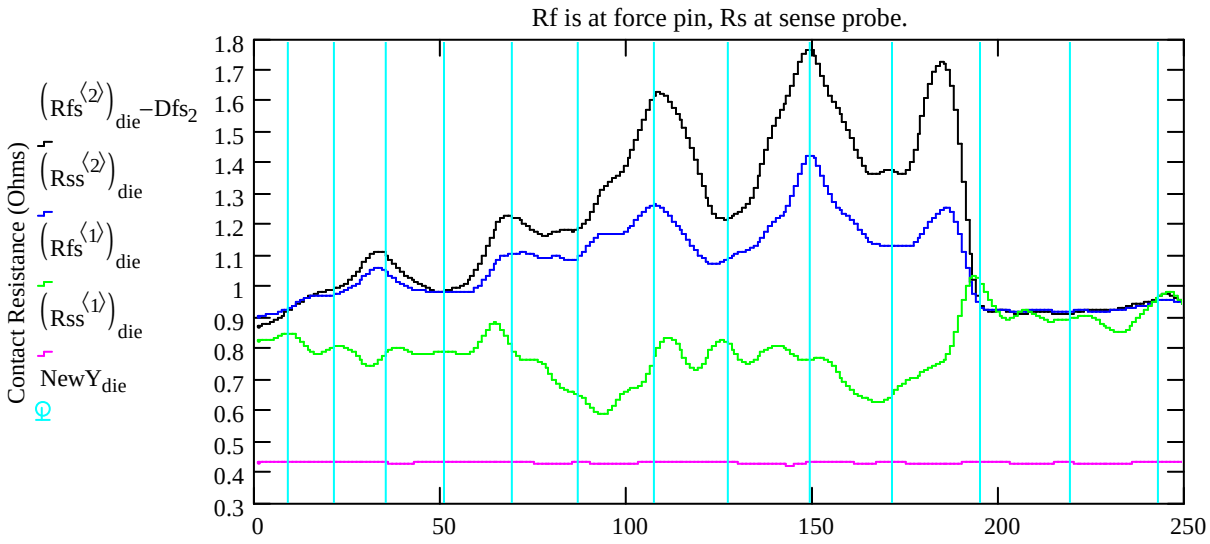
Contact resistance is at three different outputs 6, 2, 8 for 250 mA max current.
Top, middle and lower plots located at the right, middle and left side outputs.
The scrub points probably corresponds to 0.3 ohm minimum contact resistance.
Smooth (Average) Contact Resistance, Rss, to show variation with wafer row X.
Vertical lines (Green) are at the beginning of a new row for the wafer prober.
Local peaks and mins correspond to right and left side of wafer, respectively.
Double touch down scrub. Maximum pressure. Four mil over-travel.
Probes scrub cleaned on ceramic after 189 touch downs. Prober cycle is 200.
Possible causes of increase of contact resistance with number of touch downs:

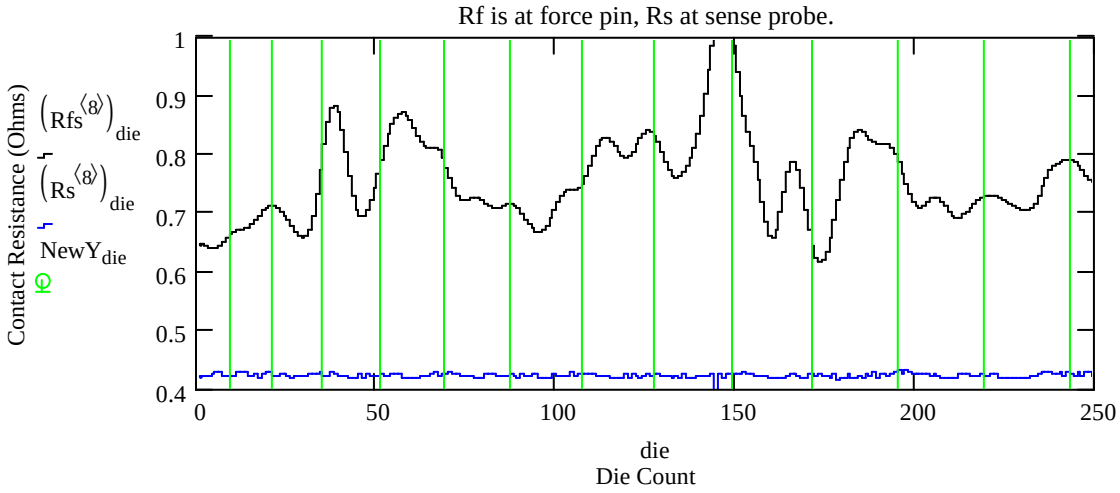
- Probe card flexure fatigue causes reduction of probing force.
- Contamination (oxide, debris) impacted into tungsten.
- Probing at 250 mA causes local heating of probe tip and oxidation.

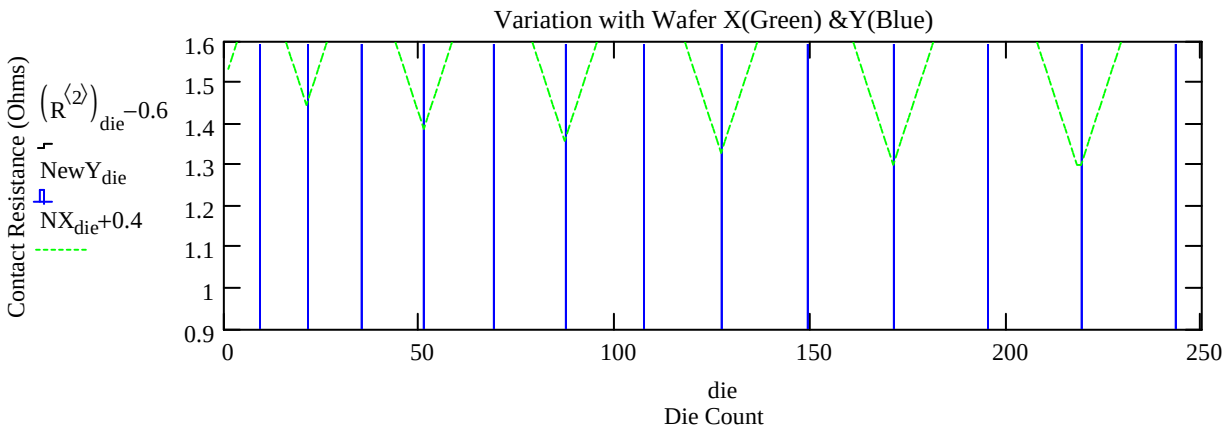


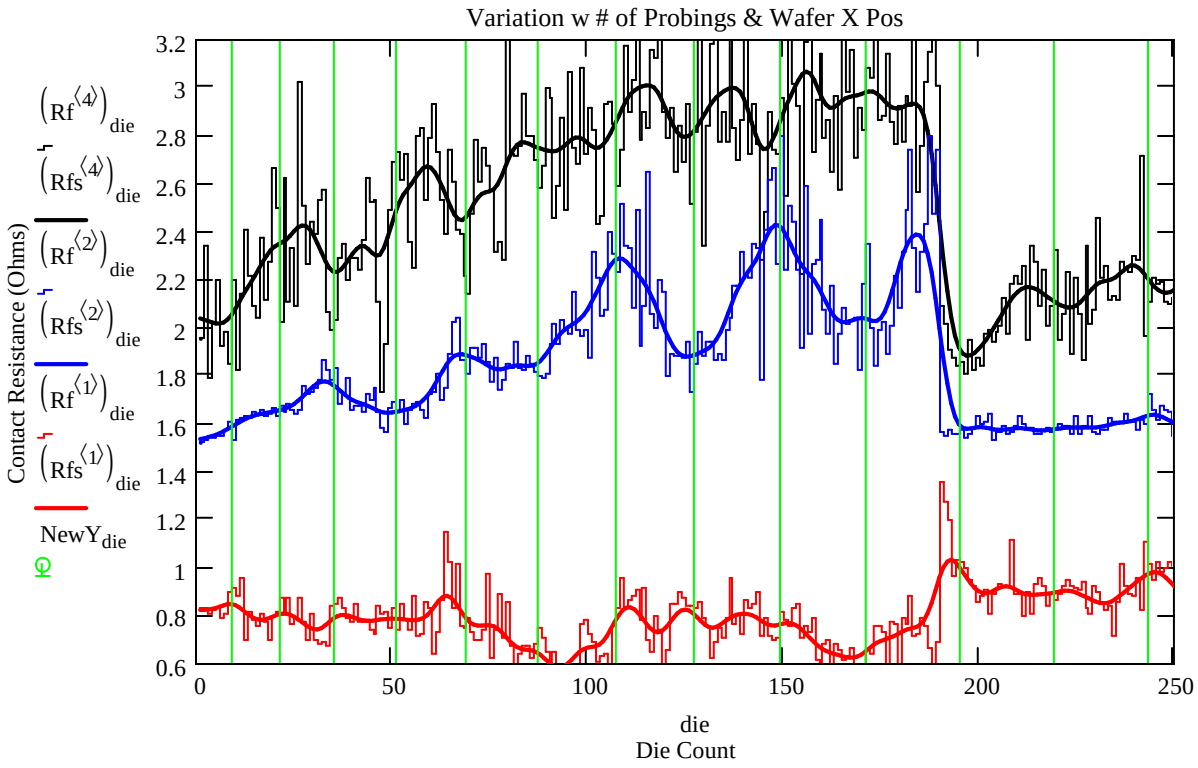


$$NX6_{die} := \frac{X_{die} + 6}{X_{width}} \cdot 0.2 + 0.8 \qquad Dfs_O := \overrightarrow{\left[\left(Rfs^{\langle O \rangle} \right)_{200} - \left(Rss^{\langle O \rangle} \right)_{200} \right]}$$









FIND LOCATIONS OF MAXIMUMS

LOC := for $o \in 1..6$
  $mx \leftarrow \max(Rs^{\langle o \rangle})$
  for $die \in 1..rows(Rs)$
    if $Rs_{die,o} = mx$
      $L_{o,1} \leftarrow X_{die}$
      $L_{o,2} \leftarrow Y_{die}$
L

$$LOC^T = \begin{pmatrix} -3 & -3 & 9 & 17 & 14 & -3 \\ 25 & 25 & 26 & 18 & 25 & 24 \end{pmatrix}$$

samples := 1 .. Die

$W1_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 1 \rangle})_{samples}$

$W2_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 2 \rangle})_{samples}$

$W3_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 3 \rangle})_{samples}$

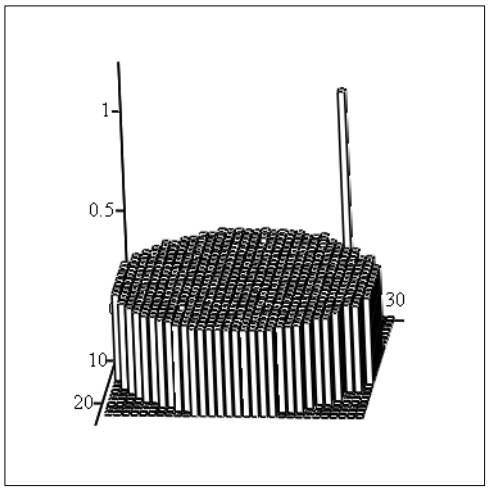
$W4_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 4 \rangle})_{samples}$

$W5_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 5 \rangle})_{samples}$

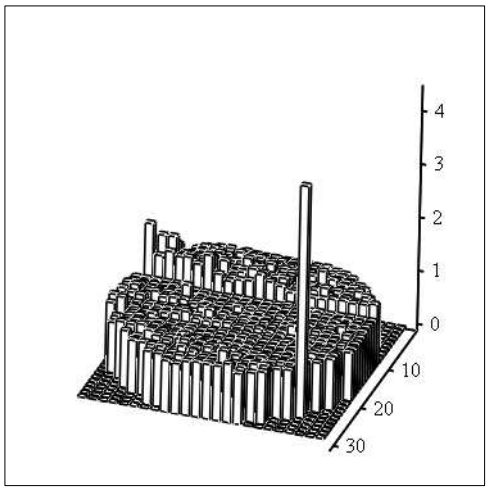
$W6_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 6 \rangle})_{samples}$

$W7_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 7 \rangle})_{samples}$

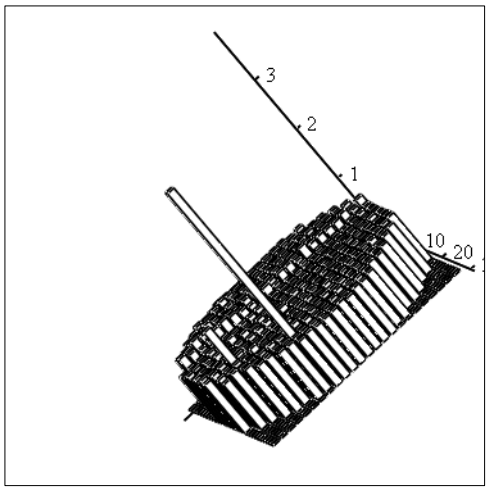
$W8_{X_{samples}-minX+1,\,Y_{samples}-minY+1} := (Rs^{\langle 8 \rangle})_{samples}$



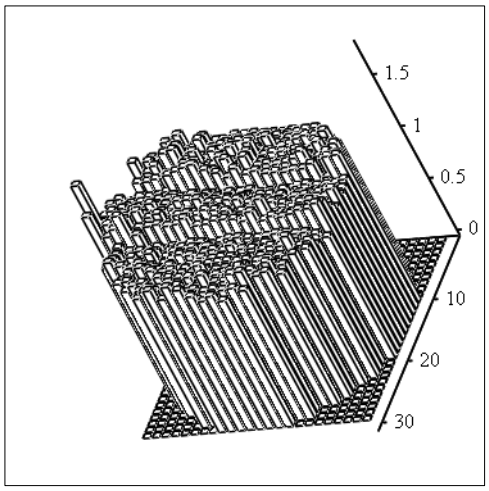
W1



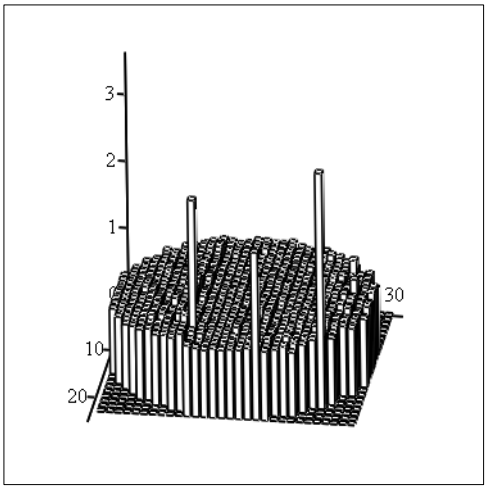
W2



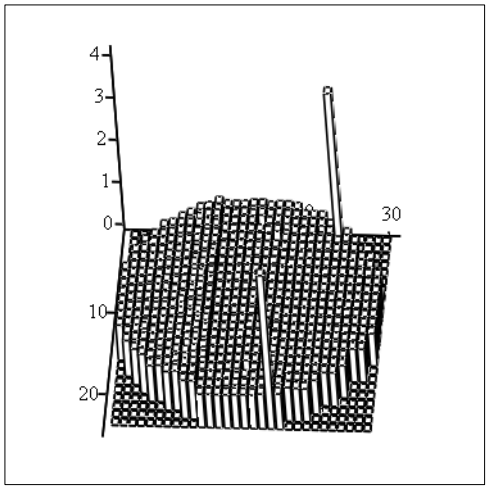
W3



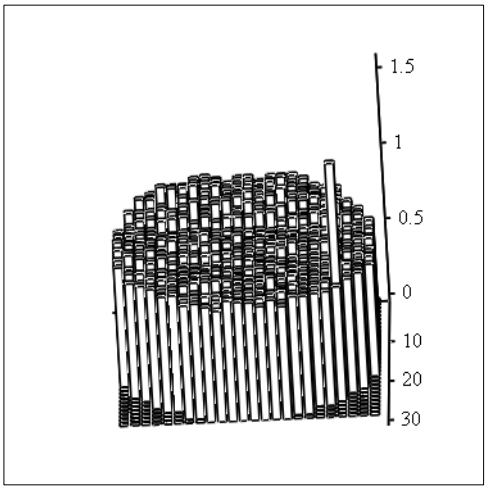
W4



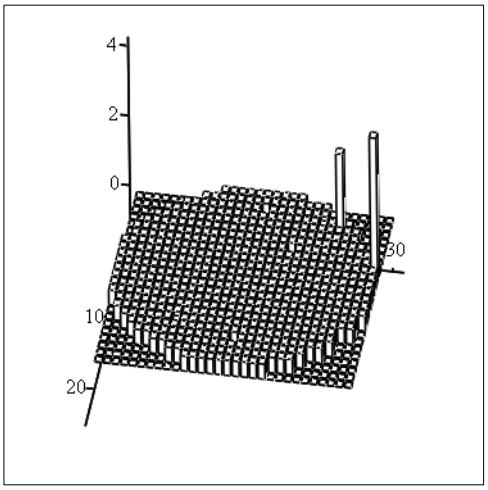
W5



W6



W7



W8

LOGIC PIN CONTACT RESISTANCE

The 4th test is the contact resistance from the force/sense point for 1st pad (VDD) tested.
The 8st test is a repeat of the contact resistance from the force/sense point for the first pad.
The next pad is offset by 8 tests from these.
The order of test for the pads is Vdd, IN6, EN, SCLK, DI CS IN5, VBAT, DO
To obtain correct value of contact resistance, test program data needs to be increased by 40.5/37.5

$L := 1..9 \qquad T := 8$

Absolute accuracy is tenth of an ohm

$RL^{\langle L \rangle} := Z^{\langle D+4+T\cdot(L-1) \rangle} \qquad RLr^{\langle L \rangle} := Z^{\langle D+8+T\cdot(L-1) \rangle}$

$DRL^{\langle L \rangle} := \left(RL^{\langle L \rangle} - \text{mean}\left(RL^{\langle L \rangle}\right)\right)\cdot \text{stdev}\left(RL^{\langle L \rangle}\right)^{-1}\cdot 0.5$

Smooth the Data with Gaussian Kernal

$RLs^{\langle L \rangle} := \text{ksmooth}\left(DIE, RL^{\langle L \rangle}, 8\right)$

$VL1^{\langle L \rangle} := Z^{\langle D+1+T\cdot(L-1) \rangle} \qquad VL2^{\langle L \rangle} := Z^{\langle D+2+T\cdot(L-1) \rangle} \qquad VL3^{\langle L \rangle} := Z^{\langle D+3+T\cdot(L-1) \rangle}$

PAD ORDER FROM TOP: VDD, IN6, EN, SCLK, DI, CS, IN5, VBAT, DO
The mean RL of IN5 and IN6 was 2.7X > the other pads.
The max values and stddev are small.

$\text{min}\left(RL^{\langle L \rangle}\right) =$	$\text{mean}\left(RL^{\langle L \rangle}\right) =$	$\text{edian}\left(RL^{\langle L \rangle}\right) =$	$\text{max}\left(RL^{\langle L \rangle}\right) =$	$\text{max}\left(RLs^{\langle L \rangle}\right) =$	$\text{stdev}\left(RL^{\langle L \rangle}\right) =$
0.363	0.455	0.451	0.636	0.524	0.032
0.173	1.236	1.229	1.421	1.32	0.077
-0.198	0.472	0.475	0.543	0.519	0.038
-0.173	0.44	0.444	0.506	0.477	0.036
-0.173	0.446	0.451	0.5	0.48	0.036
-0.215	0.475	0.475	0.518	0.496	0.038
0.285	1.351	1.341	1.465	1.443	0.074
-4.176	$-3.327\cdot10^{-3}$	0	2.934	0.397	0.238
0.228	0.315	0.309	0.759	0.45	0.045

Repeatability is within one milliohm

$Lrep_L := \text{mean}\left(RL^{\langle L \rangle} - RLr^{\langle L \rangle}\right)\cdot 10^3$

$Lrep^T = (-1.979 \quad 0.508 \quad -0.076 \quad 1.356 \quad 0.472 \quad 0.694 \quad 1.248 \quad 10.056 \quad -1.333)$

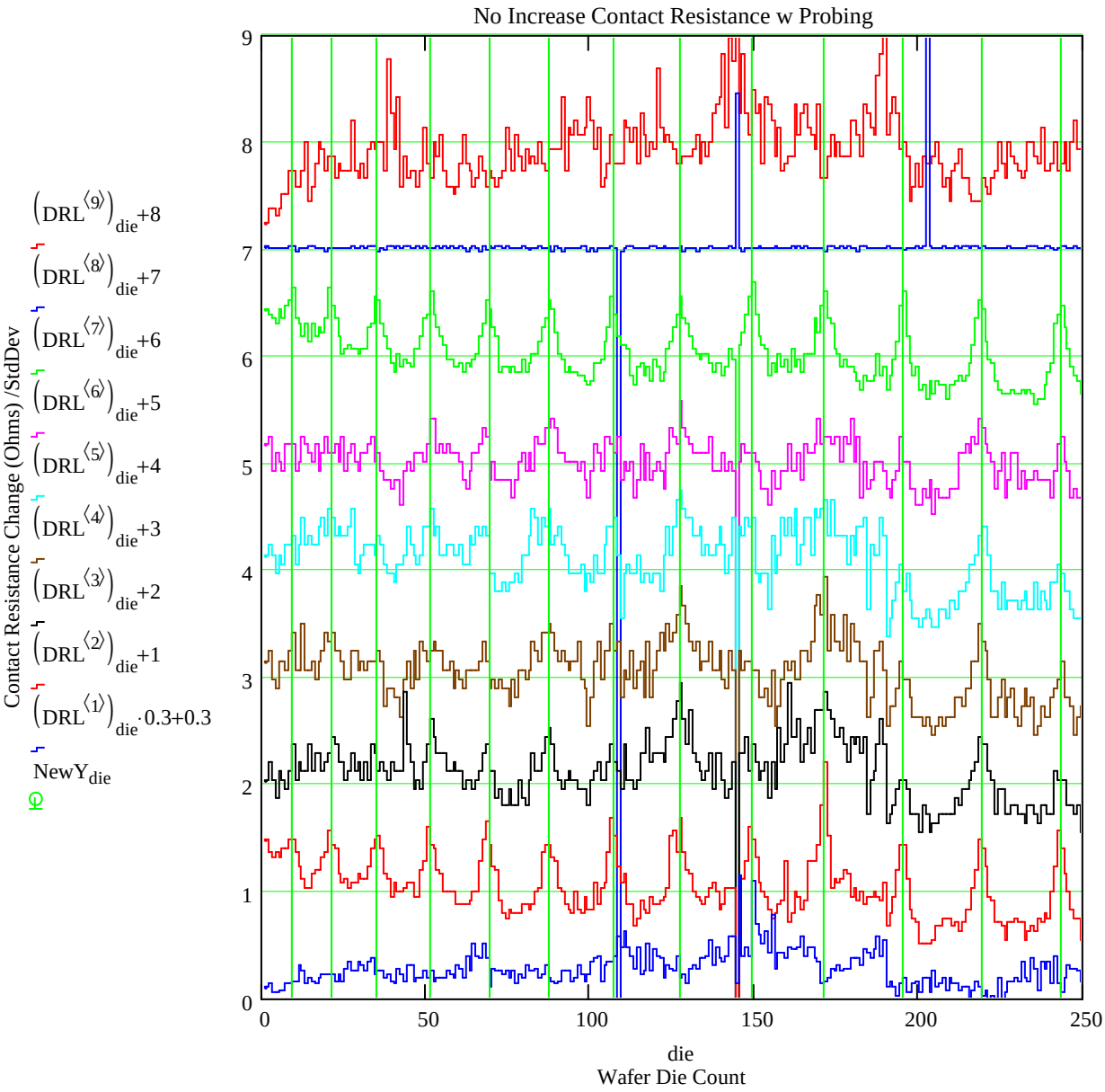
Crom bottom up: Vdd, IN6, EN, SCLK, DI CS IN5, VBAT, DO

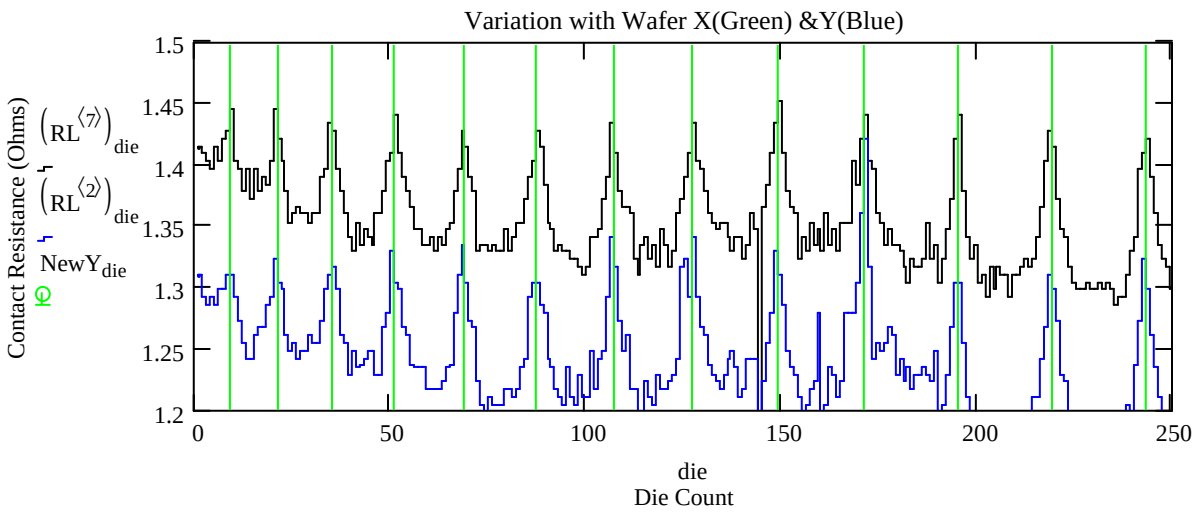
Normalize plots: DRL = 0.5 x (Rs -(mean of Rs))/(Sigma of Rs)

Contact Resistance is a maximum at both edges of wafer.

Minimum Contact Resistance at X and Y center of wafer.

Degradation with probe touch downs is not as severe as outputs.




Variation with Wafer X(Green) &Y(Blue)
Contact Resistance (Ohms)
$\left(RL^{\langle 7 \rangle}\right)_{die}$
$\left(RL^{\langle 2 \rangle}\right)_{die}$
$NewY_{die}$
1.5
1.45
1.4
1.35
1.3
1.25
1.2
0
50
100
150
200
250
die
Die Count