7NM SoC ESD & LUP reliability signoff using IC Validator PERC

Sunil Kharate

Dinesh Londhe

Broadcom

Agenda

Agenda

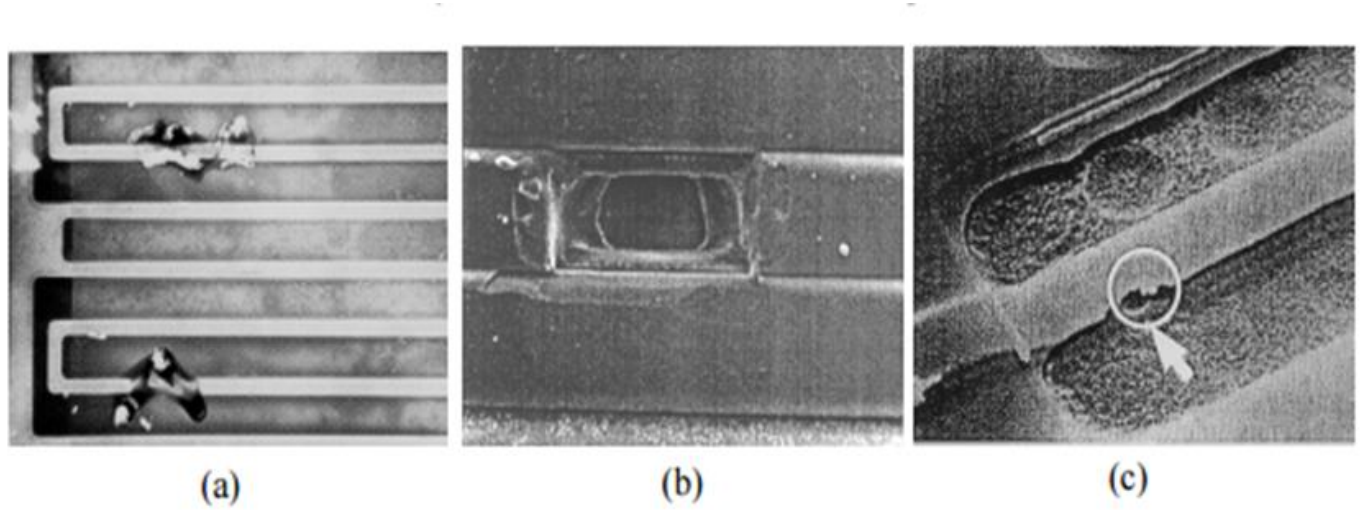
- ESD & LUP Overview
- ICV PERC Flow
- PERC reported Issues and Solutions
- Conclusion
- Acknowledgement

ESD & LUP Overview

ESD & LUP Overview

Why is ESD protection needed?

- Whenever two electrically different bodies make contact there will be a transfer of charge to equalize the electrical potential
- Specifically for ICs examples can be touching by a human being, contacting by a piece of handling equipment, etc.
- Depending on the amount and rate of charge transferred the process can be damaging to the IC



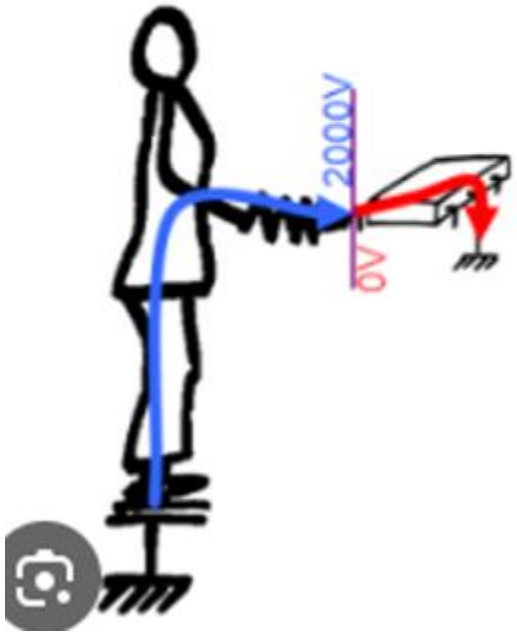
ESD Failures in ICs: (a) junction breakdown, (b) metal/via damage, (c) gate oxide damage

ESD & LUP Overview

Types of ESD models

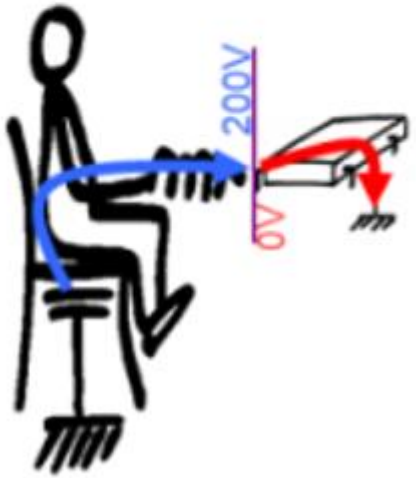
HBM

100pF, 1500 Ohm
(external source)
2kV – 1.33A – 10n/150ns



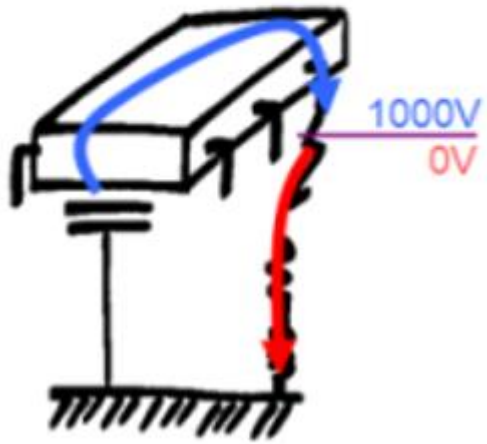
MM

200pF, 0 Ohm
(external source)
200V – 3.5A – 20n/250ns



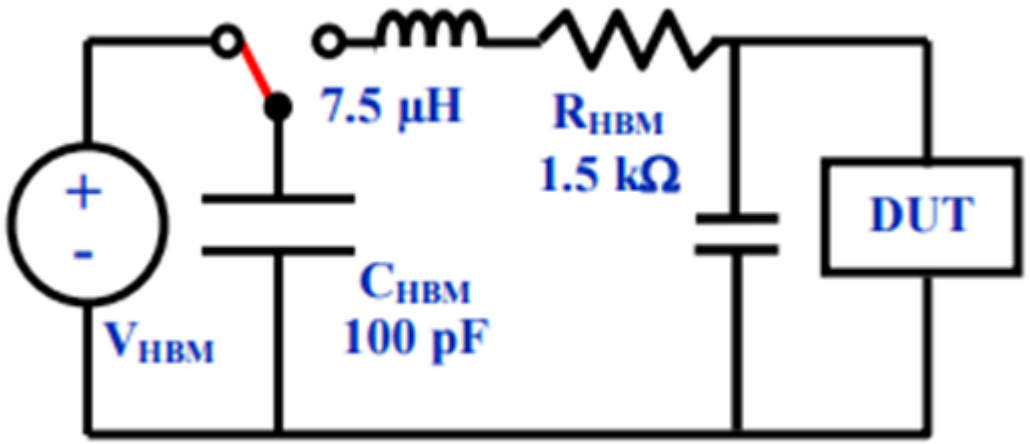
CDM

package cap. vs. gnd
(IC is part of stress model)
1kV – 10A – 1n/5ns



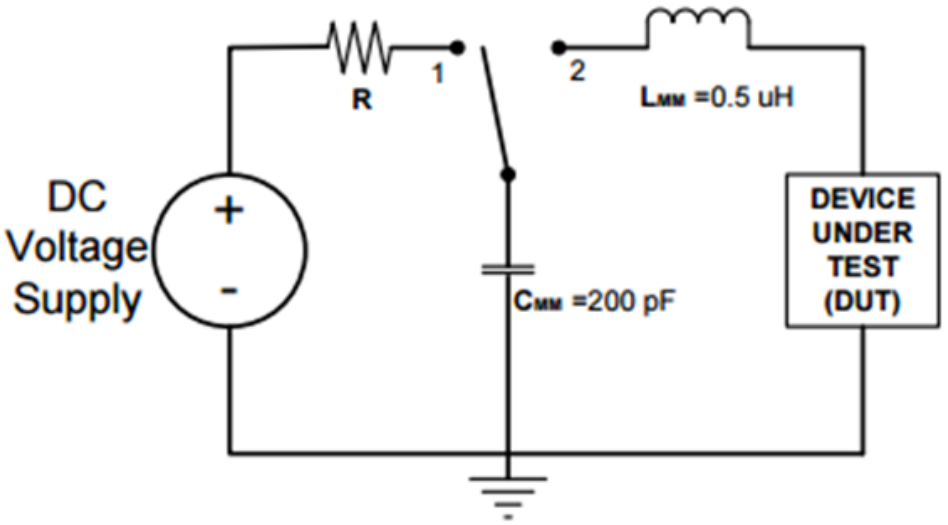
Human Body Model (HBM)

- Simulates a charged person touching an IC
- The capacitance of a typical human body is 100pF
- Discharge resistance is 1.5kOhm
- It is a relatively slow pulse with a 150ns time constant
- The goal is to pass 2kV in both positive and negative polarities of stress and all pin combinations



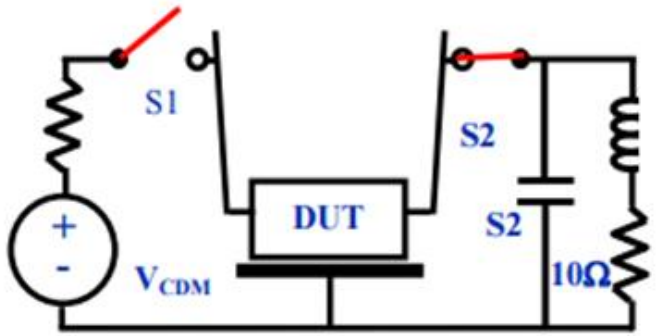
Machine Model (MM)

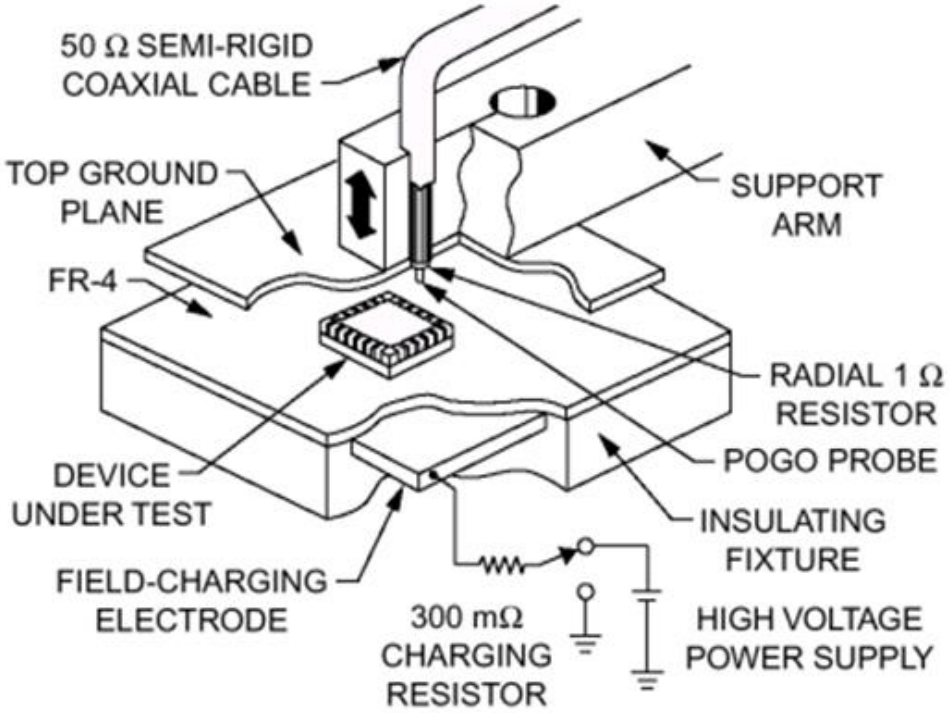
- Simulates a charged metallic handler touching an IC
- The capacitance is 200pF
- Arc resistance is 10-20 ohms
- It is an oscillatory pulse with a few tens of ns period
- Failure modes are similar to HBM – mainly junction breakdown
- 2kV HBM is equivalent to ~200V MM



Charged Device Model (CDM)

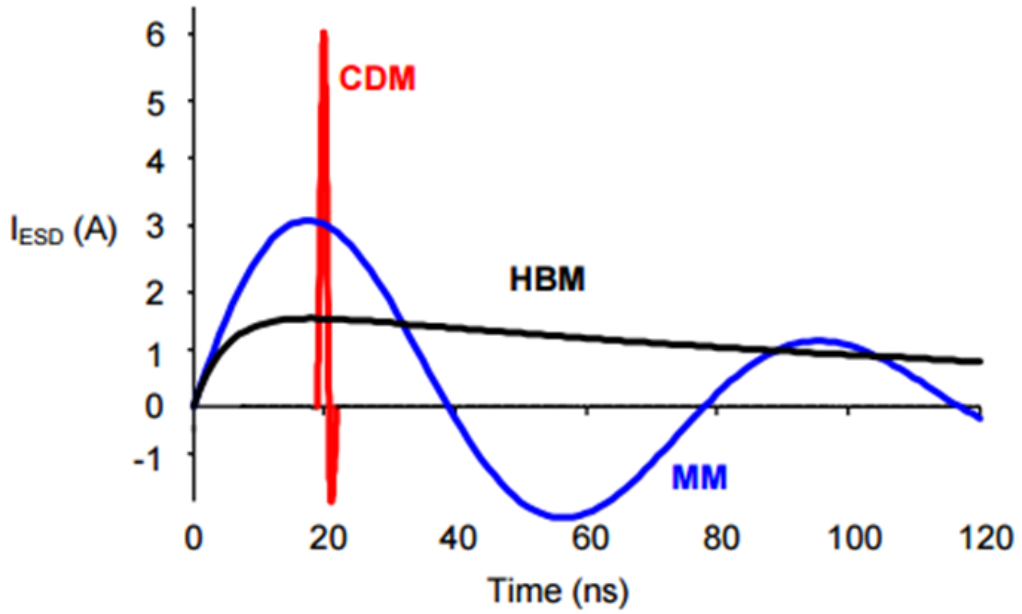
- Simulates a triboelectrically charged device discharging through one pin to ground
- The capacitance is device/package dependent
- Resistance is very low; 1 ohm is used in the tester for consistency
- It is an oscillatory decaying pulse with a fraction of ns period
- Failure modes are usually dielectric breakdown
- Goal is to pass 500V; high speed pins may only pass 200V



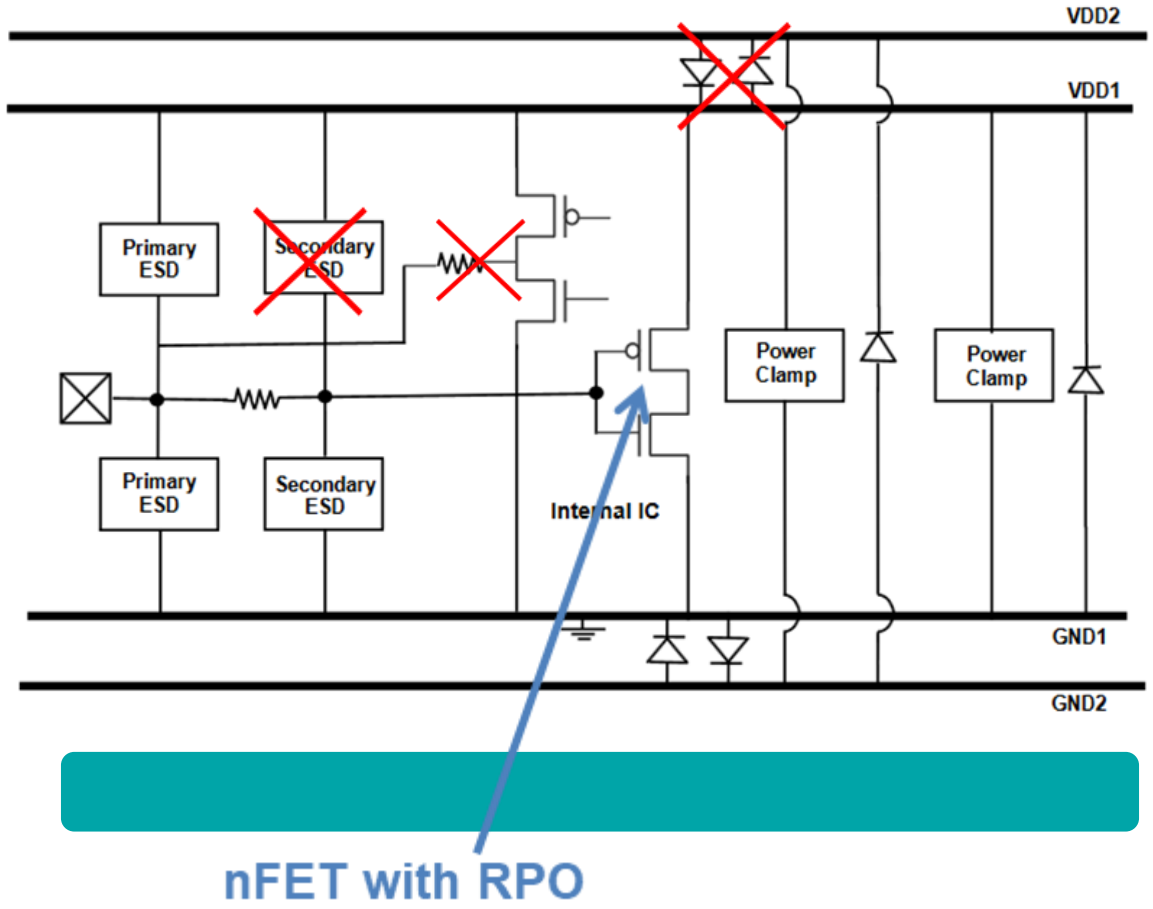


Pulse shapes of the various ESD models

- HBM is the slowest pulse with a time constant of 150ns
- CDM is the fastest, yet the highest peak current pulse
- Because of the similar failure modes between HBM and MM most IC companies adopted a policy of just stressing for HBM and CDM



General configuration of IC Protection

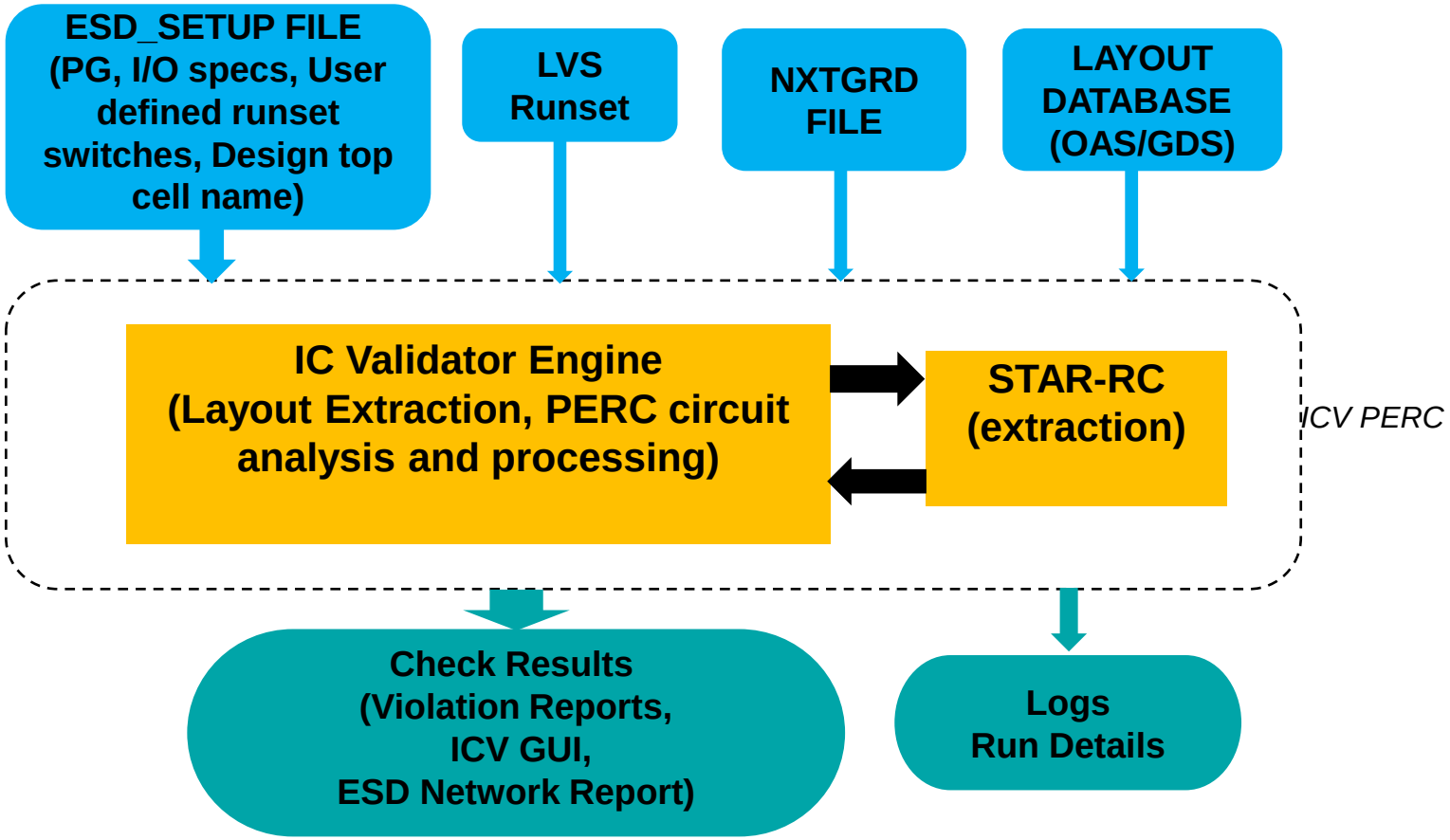


- A network of diodes and ESD clamps provides the ESD discharge paths
- VDD1 to VDD2 back-to back (b2b) diodes - although good for ESD are not desirable since they create dependency between power supplies
- The secondary ESD to VDD1 is not needed
- The resistor to both pFET and nFET of the output driver is replaced with nFET with RPO in the drain

IC Validator PERC Flow

ICV PERC Flow

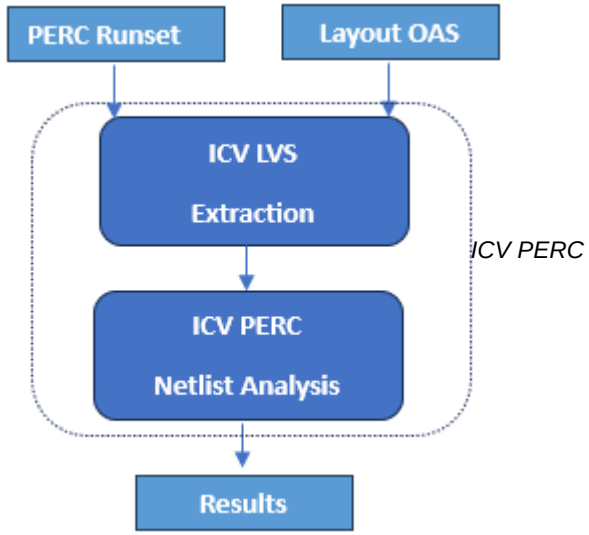
Flow Chart



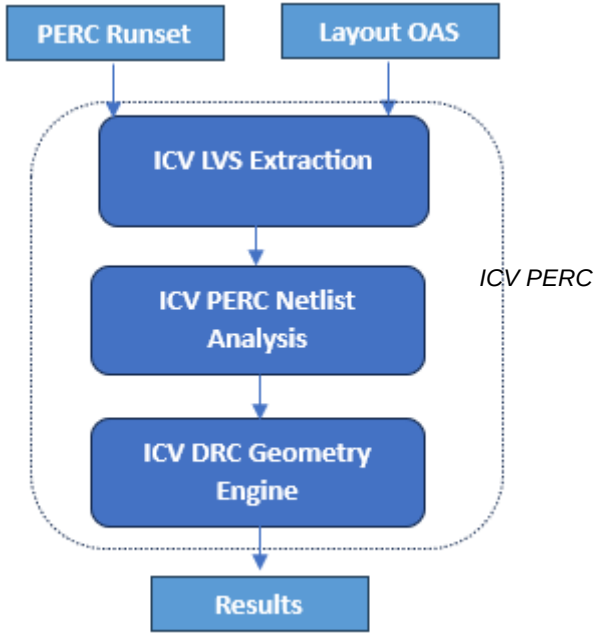
ICV PERC Flow

Different Modes

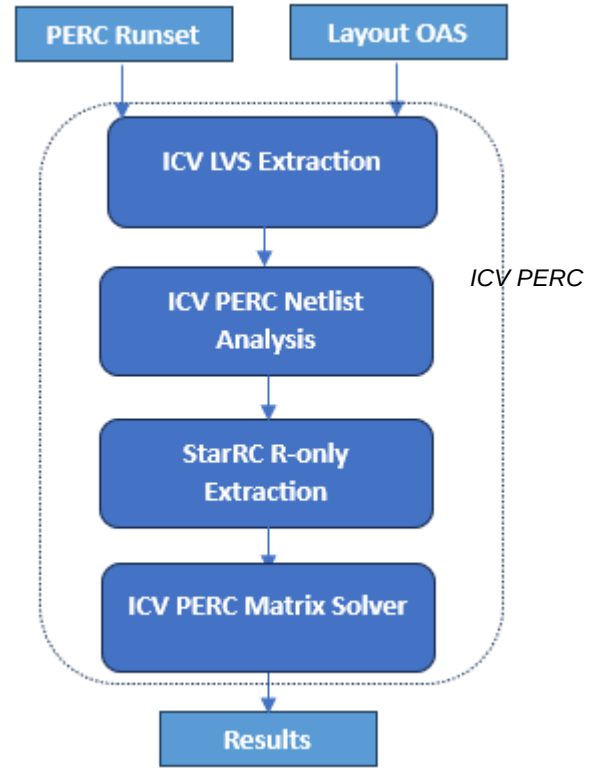
TOPO Check



LDL Check



P2P/CD Check



Rule Coverage

Topology Checks (TOPO)	Layout Driven Check (LDL)	Effective Resistance Check (P2P)	Current Density Check (CD)
Checks primary I/O ESD	Checks primary I/O ESD	Checks primary I/O ESD	Checks primary I/O ESD
Secondary IO ESD	Power Clamp	Secondary IO ESD	Secondary IO ESD
Power Clamp	Cross Domain	IO/PG to Clamp Path	Power Clamp Path
Cross Domain ESD	Gate Victim	Clamp to Clamp Path	Current Density Check (CD)
Ground B2B Diode	Latch-up	Ground B2B Diode Path	Checks primary I/O ESD
		PG Pad to Pickup Path	Secondary IO ESD

ICV PERC Flow

Debug Flow

CHECK ESD_NETWORK_REPORT AND RULES

CHECK TOP LEVEL POWER CLAMP VIOLATIONS

CHECK CROSS DOMAIN VIOLATIONS (IF THERE IS NO COMMON GROUND).

CHECK OTHER INTEGRATION LEVEL PERC VIOLATIONS

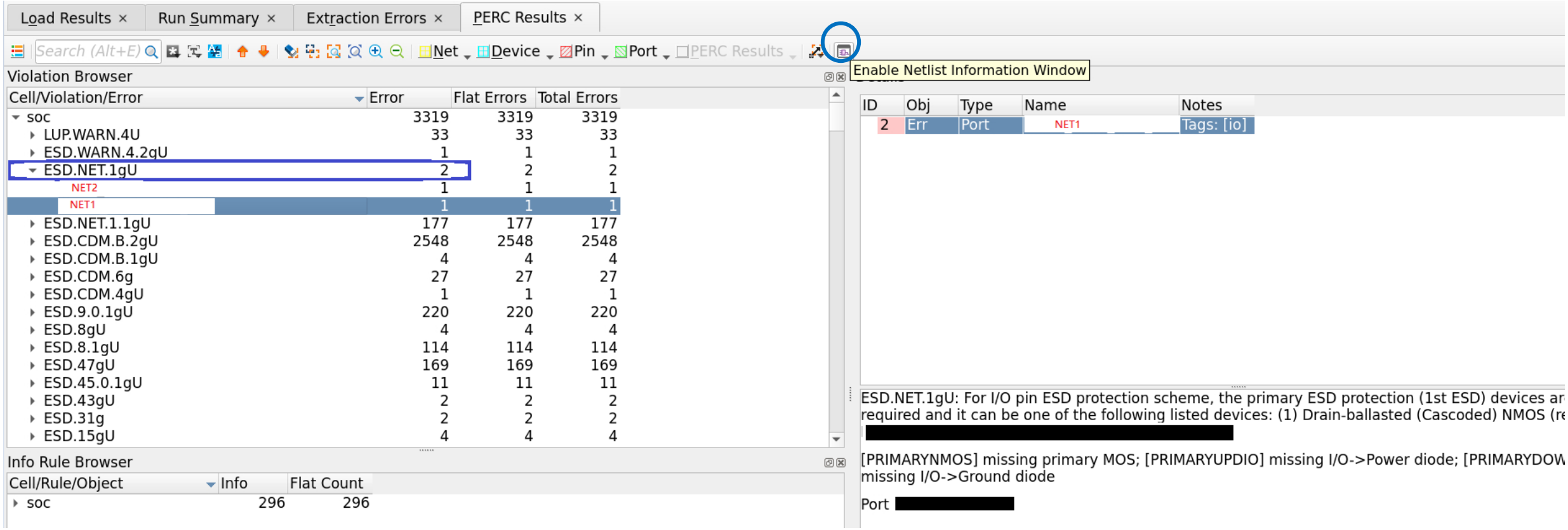
CROSS CHECK IP INTERNAL VIOLATION WAIVERS

ICV PERC Violations & Solutions

TOPO Check

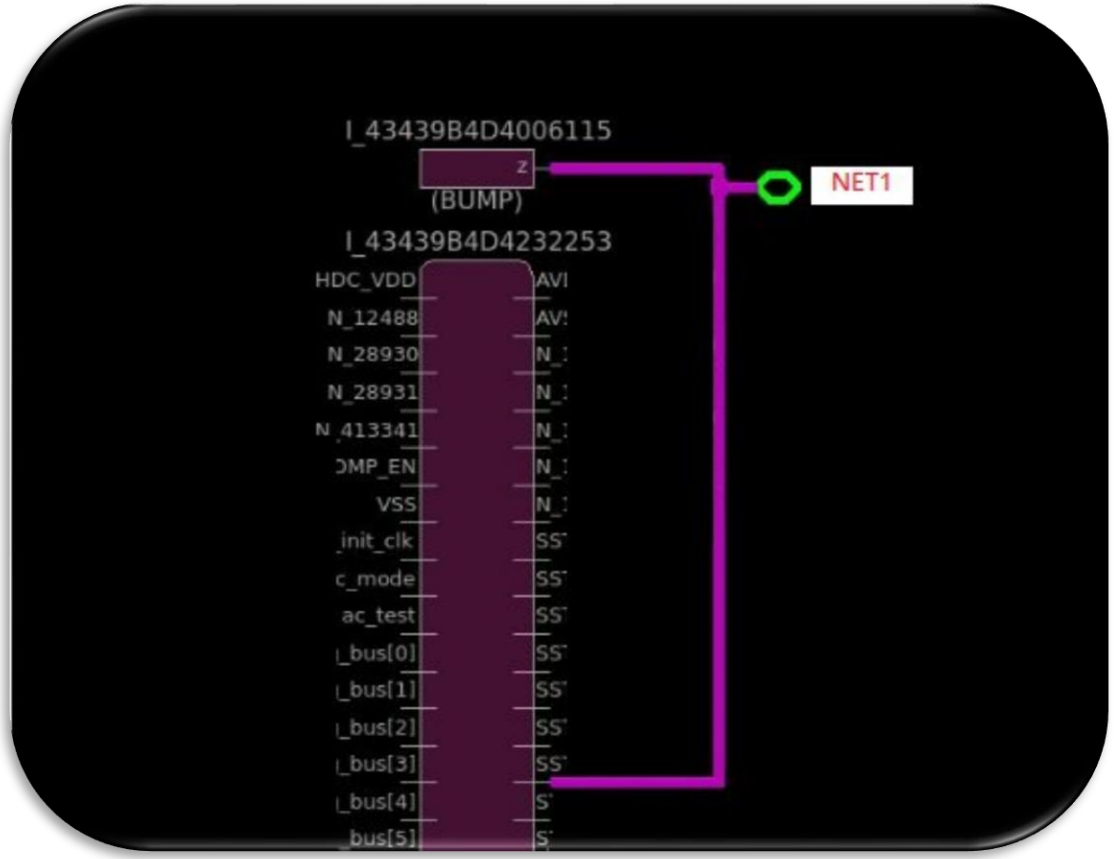
Violation: ESD.NET.1gU

- Issue: Primary ESD protection missing for I/O pin



TOPO Check

Violation: ESD.NET.1gU

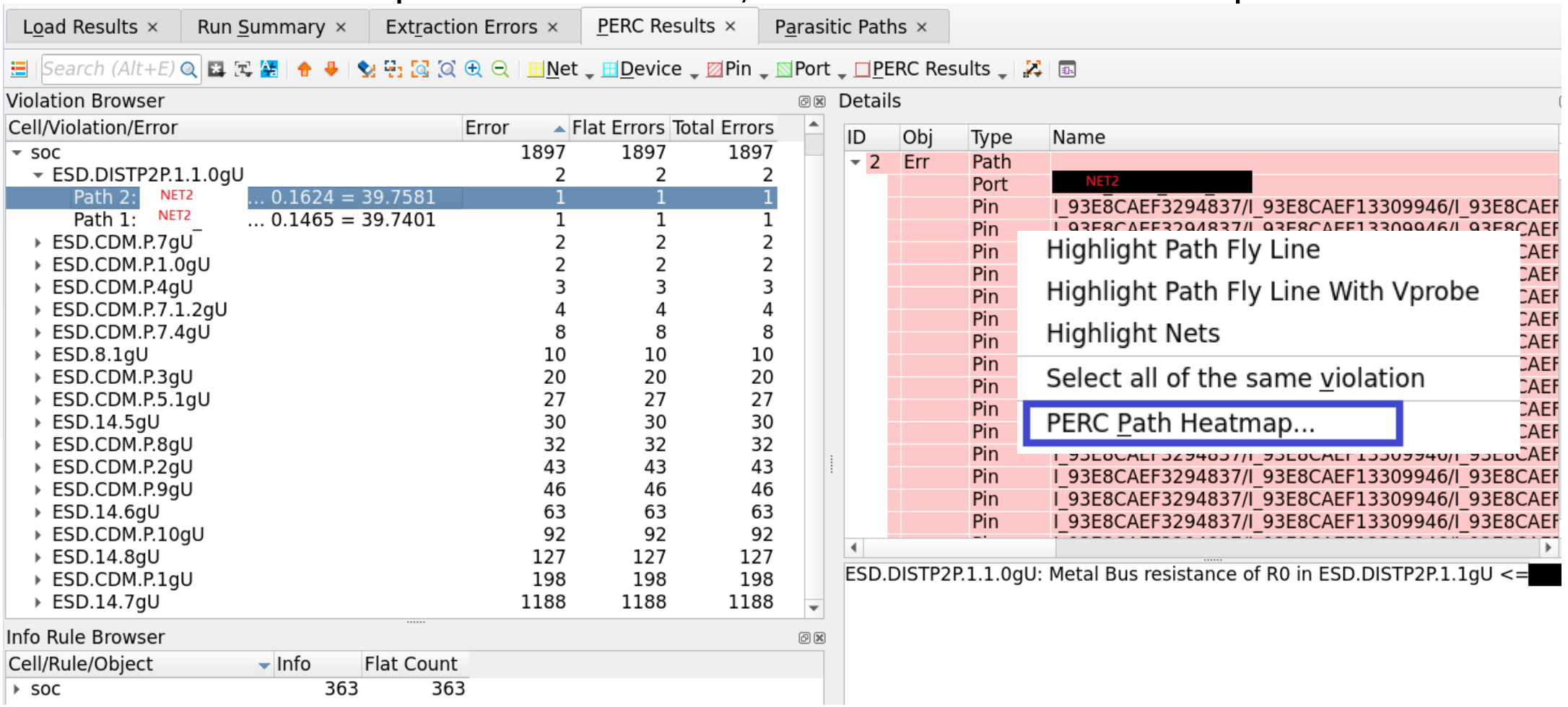


Solutions:
Topo check done in initial phase to check primary ESD protection.

P2P Check

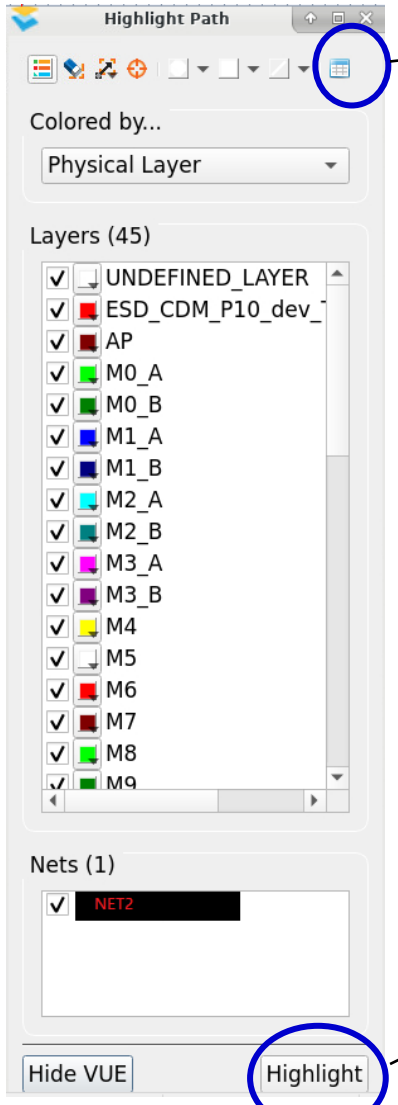
Violation: ESD.DISTP2P

- Issue: BUMP to Clamp distance is more, resistance is more than spec.



P2P Check

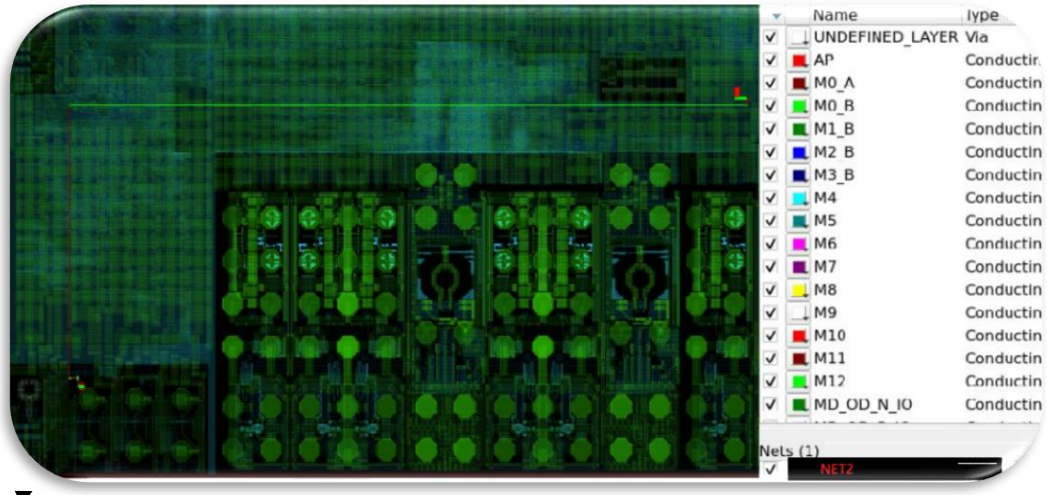
Violation: ESD.DISTP2P : PERC PATH HEATMAP



Contribution to Path Resistance

Layer ID	Name	Type	Contribution (%)	R (Ω)
0	Total		100.000000	39.758100
20	M12	Conducting	67.290372	26.753373
19	M11	Conducting	25.038859	9.954975
18	M10	Conducting	6.753456	2.685046
45	VIA11	Via	0.224224	0.089147
44	VIA10	Via	0.214761	0.085385
31	n_odtap_io	Via	0.162031	0.064421
3	AP	Conducting	0.035155	0.013977
26	VD_MD_OD_N_IO	Via	0.031970	0.012711
34	VIA0	Via	0.029111	0.011574
16	M8	Conducting	0.020571	0.008178
7	M1_B	Conducting	0.018946	0.007533
33	RV	Via	0.017332	0.006891
15	M7	Conducting	0.015375	0.006113
14	M6	Conducting	0.014079	0.005598
42	VIA8	Via	0.013812	0.005492
13	M5	Conducting	0.013202	0.005249
35	VIA1	Via	0.010780	0.004286
12	M4	Conducting	0.010058	0.003999
37	VIA3	Via	0.010054	0.003997
36	VIA2	Via	0.009793	0.003894
9	M2_B	Conducting	0.009207	0.003661
11	M3_B	Conducting	0.008373	0.003329
41	VIA7	Via	0.008075	0.003211
21	MD_OD_N_IO	Conducting	0.007529	0.002993
40	VIA6	Via	0.005404	0.002149
39	VIA5	Via	0.004371	0.001738

Close

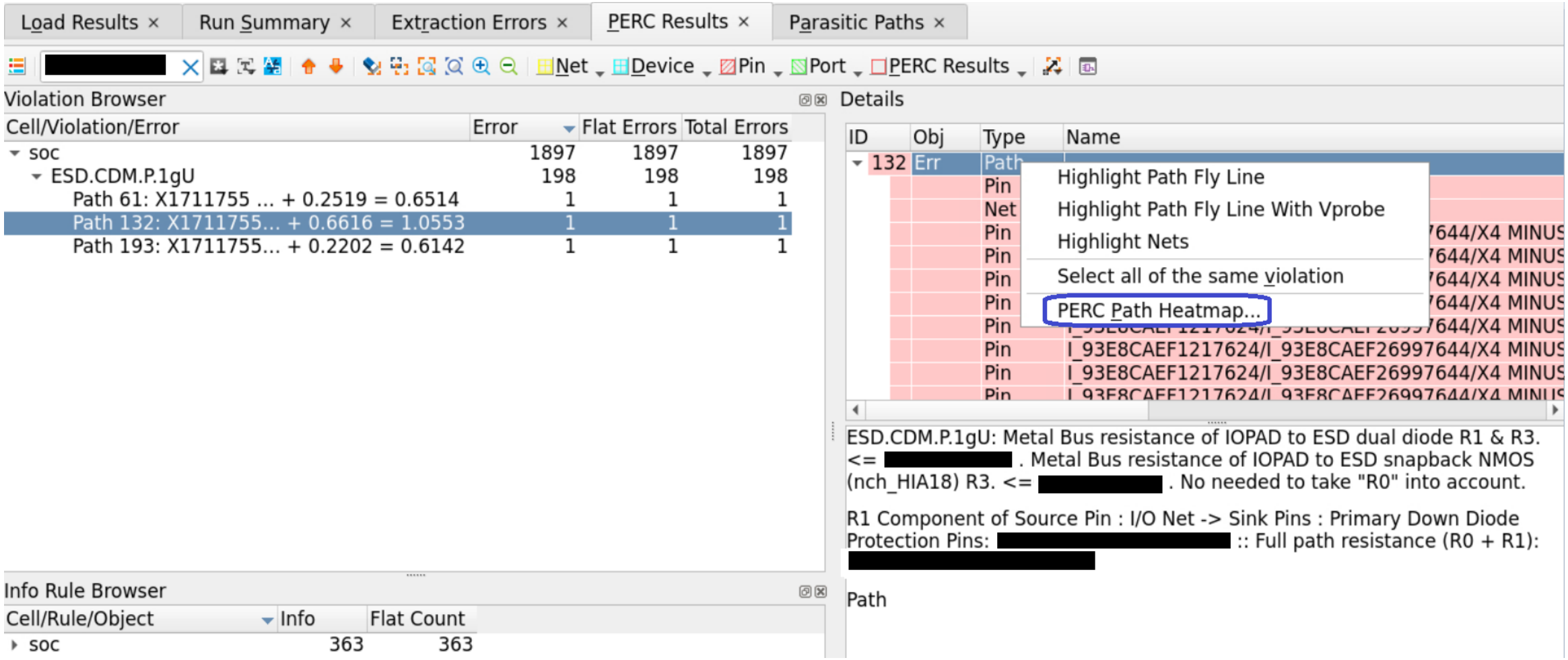


Solutions: we moved bump closure to clamp to reduce the M11 and M12 resistance.

P2P Check

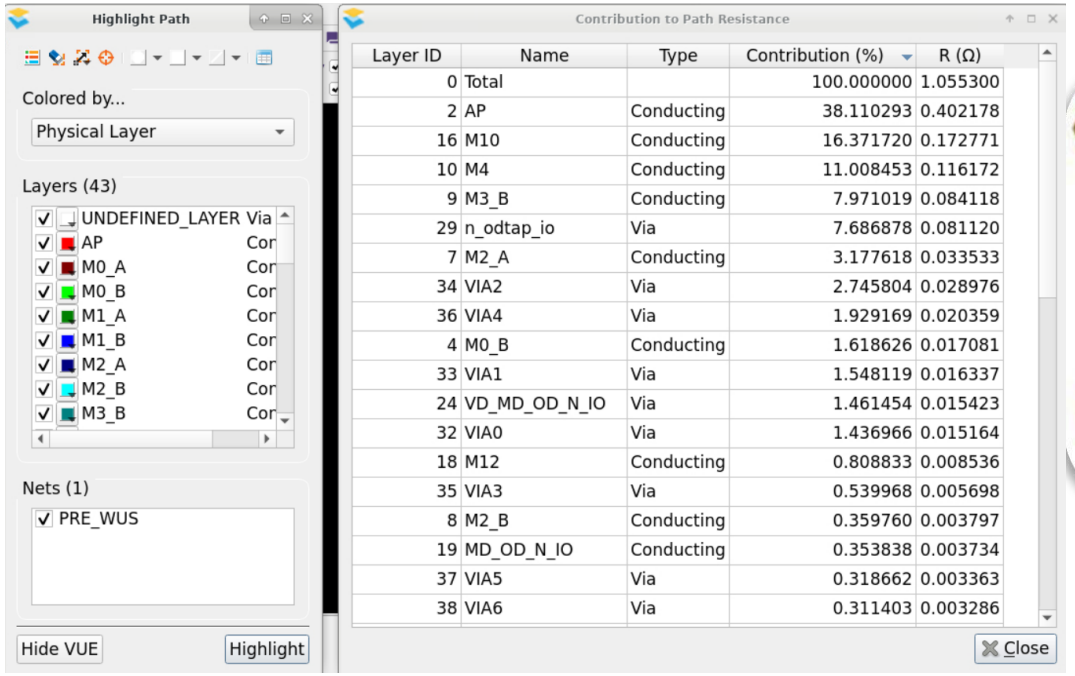
Violation: ESD.CDM*

- Issue: BUMP to Clamp resistance is out of specs.

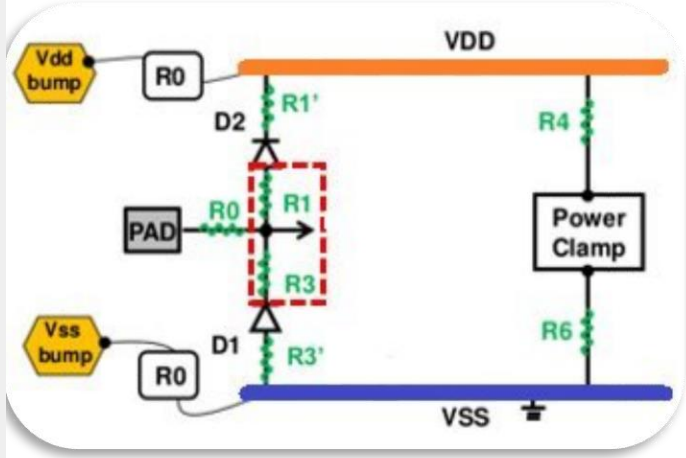


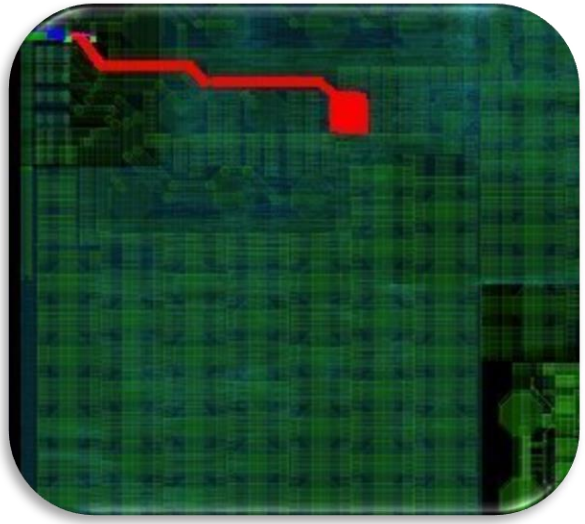
P2P Check

Violation: ESD.CDM*



Layer ID	Name	Type	Contribution (%)	R (Ω)
0	Total		100.000000	1.055300
2	AP	Conducting	38.110293	0.402178
16	M10	Conducting	16.371720	0.172771
10	M4	Conducting	11.008453	0.116172
9	M3_B	Conducting	7.971019	0.084118
29	n_odtap_io	Via	7.686878	0.081120
7	M2_A	Conducting	3.177618	0.033533
34	VIA2	Via	2.745804	0.028976
36	VIA4	Via	1.929169	0.020359
4	M0_B	Conducting	1.618626	0.017081
33	VIA1	Via	1.548119	0.016337
24	VD_MD_OD_N_IO	Via	1.461454	0.015423
32	VIA0	Via	1.436966	0.015164
18	M12	Conducting	0.808833	0.008536
35	VIA3	Via	0.539968	0.005698
8	M2_B	Conducting	0.359760	0.003797
19	MD_OD_N_IO	Conducting	0.353838	0.003734
37	VIA5	Via	0.318662	0.003363
38	VIA6	Via	0.311403	0.003286



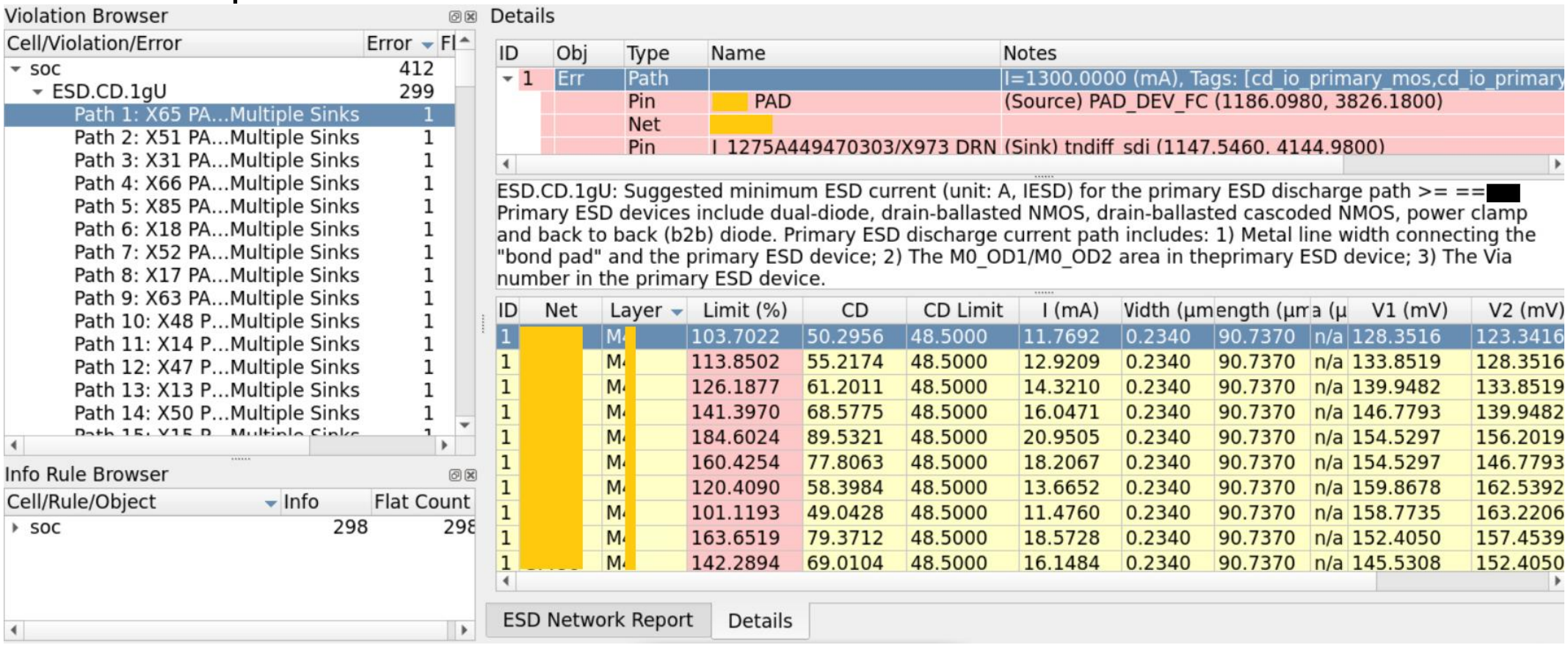


Solution: We reduced R3 resistance value by reducing route length of RDL

CD Check

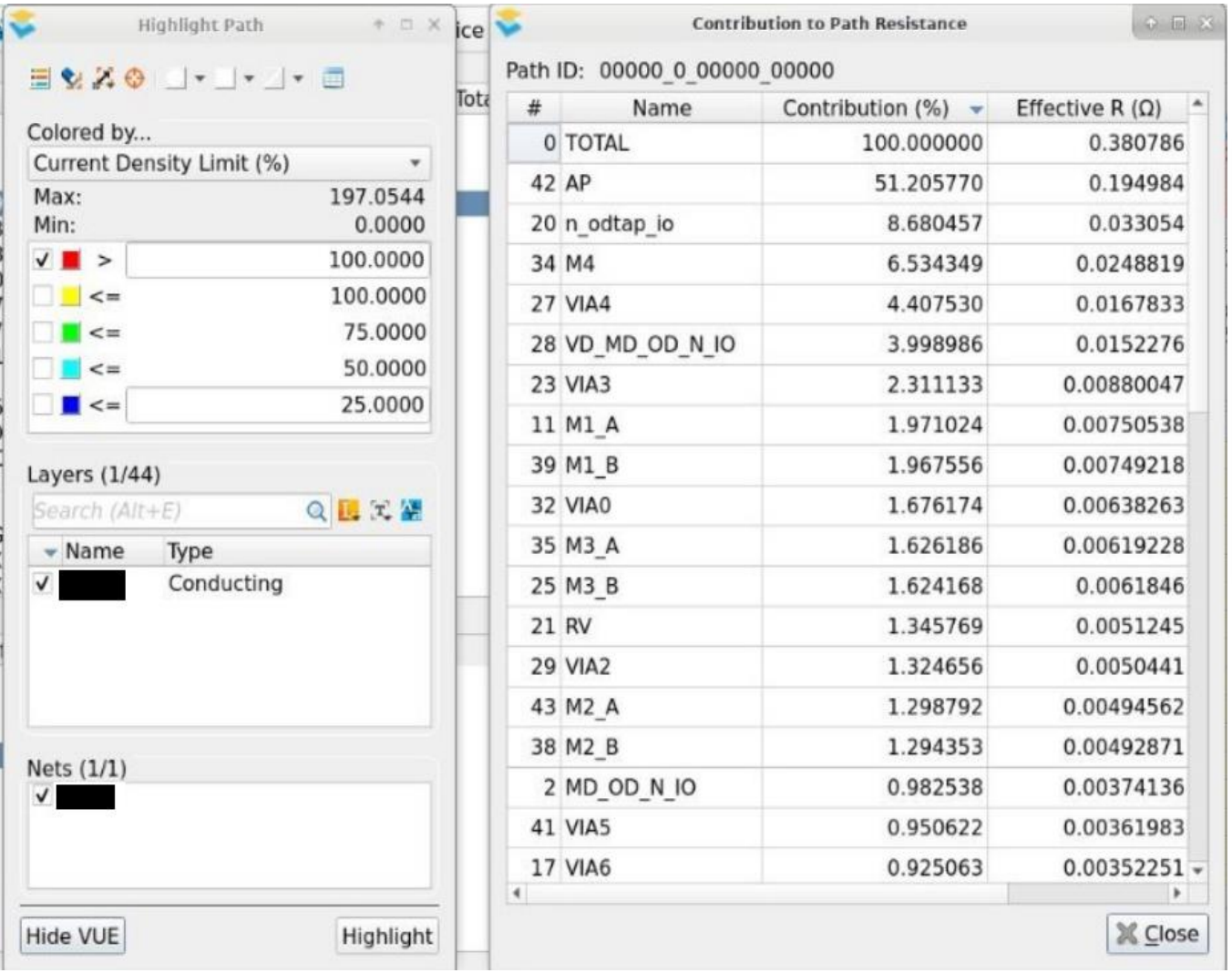
Violation: ESD.CD*

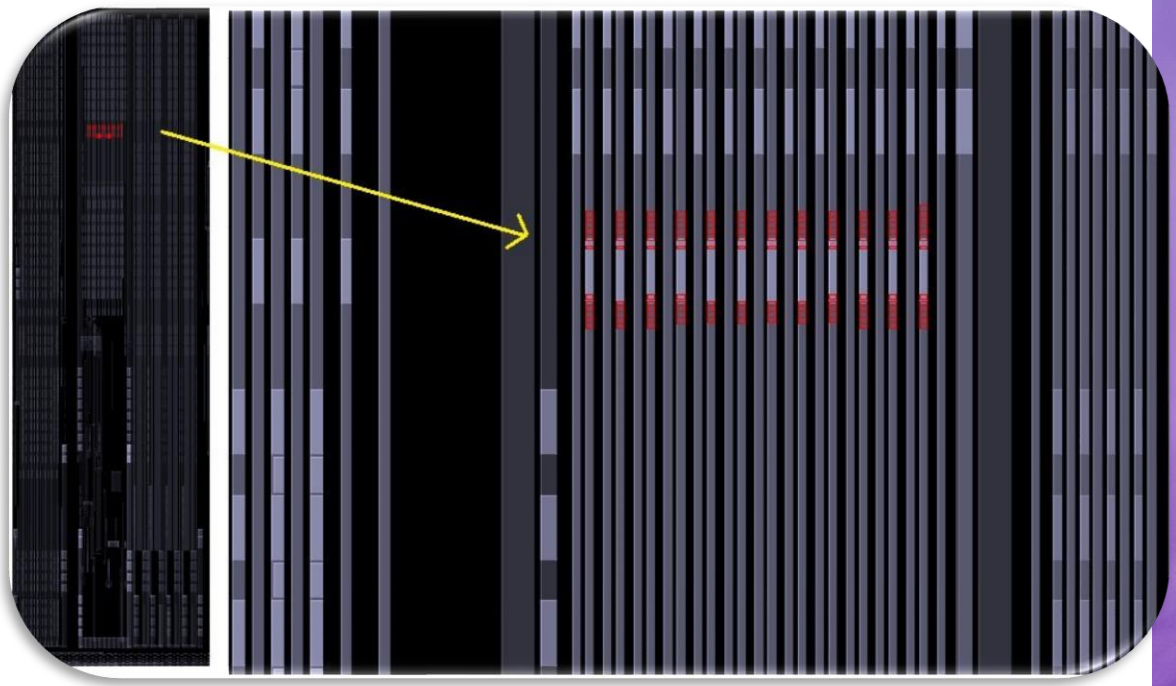
Issue: minimum ESD current for primary ESD discharge path is more than specs



CD Check

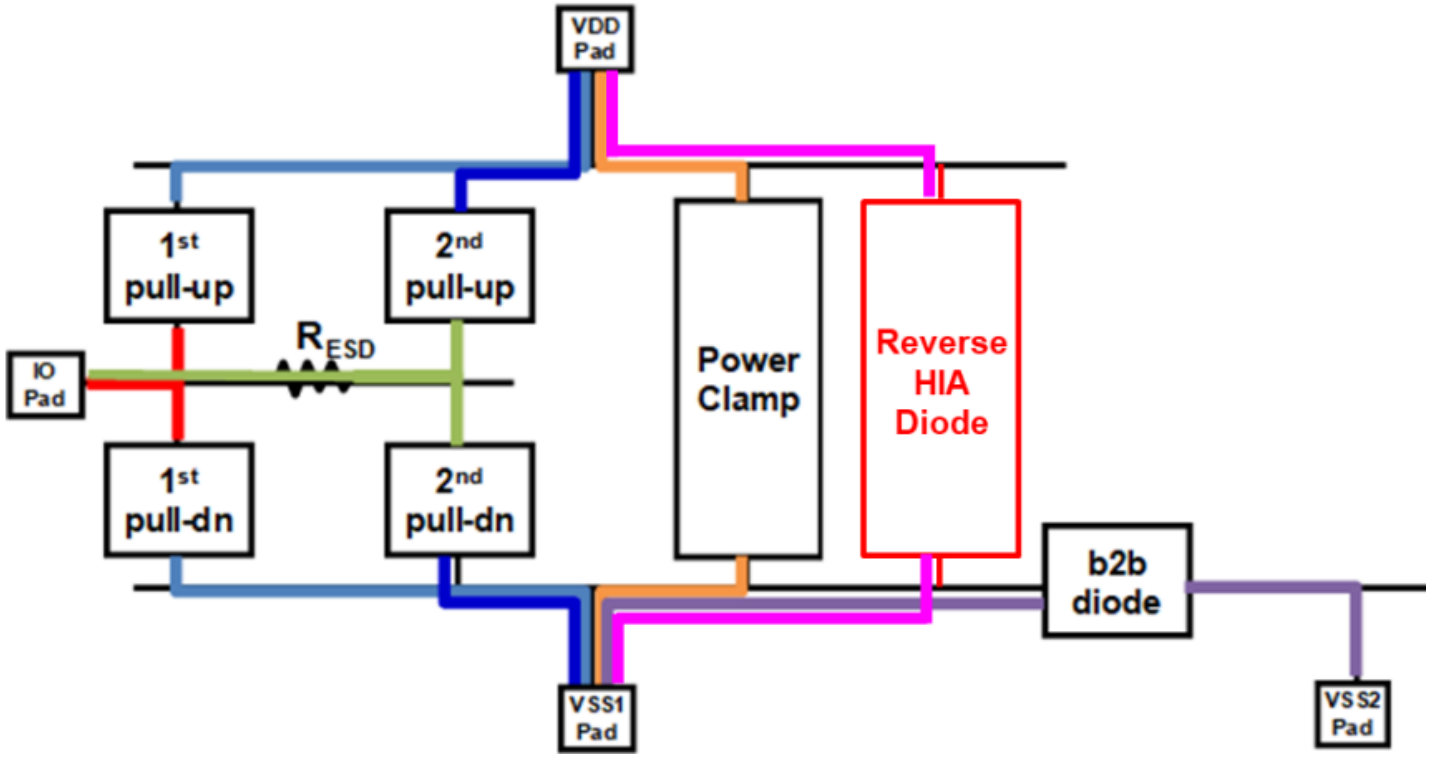
Violation: ESD.CD*





CD Check

Violation: ESD.CD*



Solution: We reviewed the violations, violations on RDL/PG connections are fixed by increasing width of layers.
Violations inside IP/IO PADs reviewed with designers.

LDL Check

Violation: Latch-up

Issue: LUP.2*U, LUP.1*U, LUP.14* violations reported related to N+/P+ guard-ring and their tied connection to power/ground

Load Results × | Run Summary × | Extraction Errors × | PERC Results ×

Show All | Search (Alt+E)

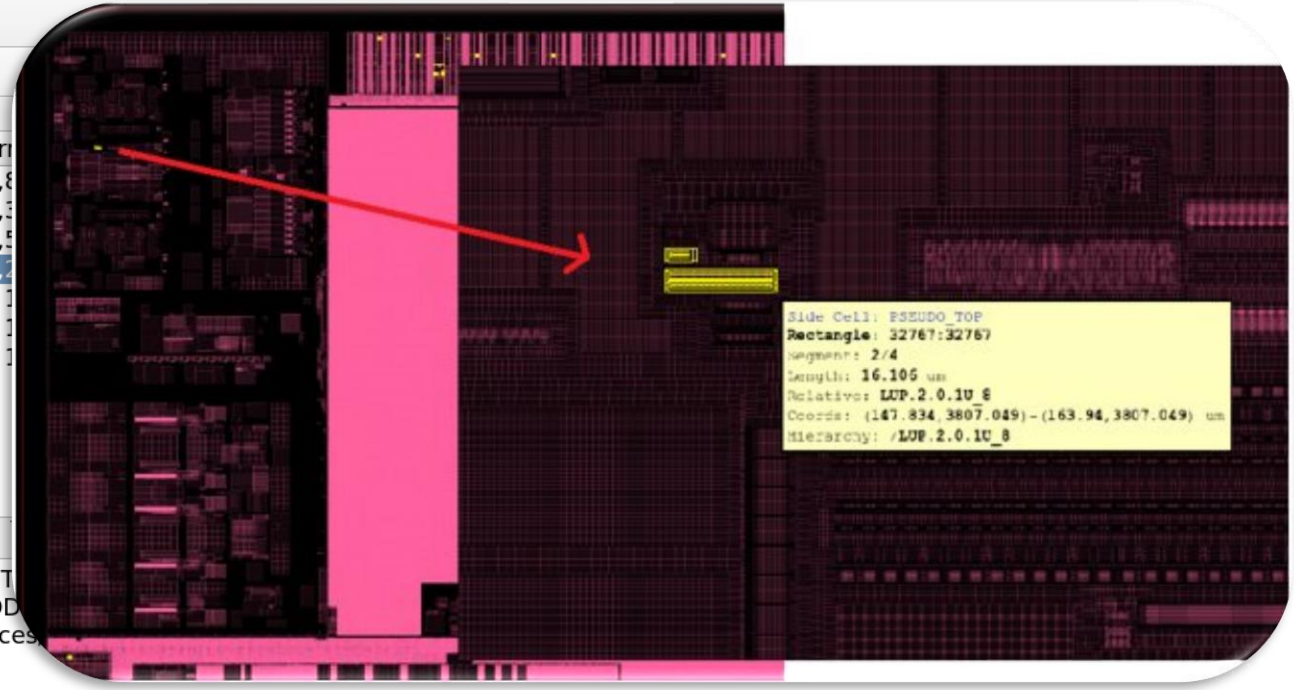
Violation Browser

Top-cell/Violation/Function	Error	Waive	Total Err
soc	257,679	158	257,8
ESD.CDM.C.2gU	244,381	0	244,3
ESD.CDM.2gU	9,505	0	9,5
LUP.2.0.1U	3,287	0	3,2
LUP.1.0.1U	149	0	1
LUP.14.0.1U	139	0	1
layout_grid_errors:non_45_edge	138	0	1
ESD.43.1gU	28	0	
ESD.CDM.1gU	22	0	
LUP.2.1U	21	0	
ESD.CDM.C.3.2gU	6	0	
ESD.9.5gU	2	0	

Violation Detail

LUP.2.0.1U: The N+/P+ guard-ring for LUP.2 should be tied to power/ground accordingly. a. ACT RWSTRAP OD injector] connect to ultra-low noise signal pin. For the detail of ultra-low noise OD by LUPIEDMY [redacted]. It is not recommended to use LUPIEDMY before sillicon proven. d. Devices

---



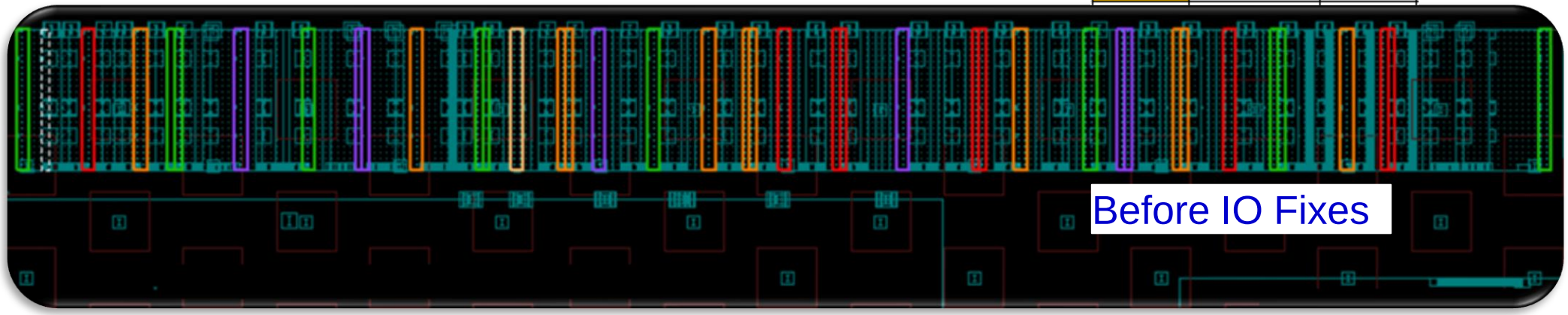
Solution:

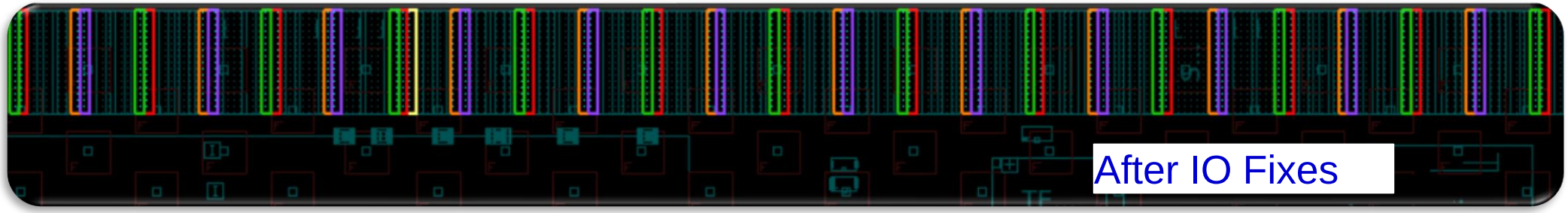
- We reviewed violations with design team and vendors.
- Violations which needs Devices/Guard-rings covered by LUP dummy layer are waived.

IO Ring ESD Fixes

IO Ring SSO Ratio/PG IO distribution

	green	VSSIO
	purple	VSS
	red	VDD
	orange	VDDIO

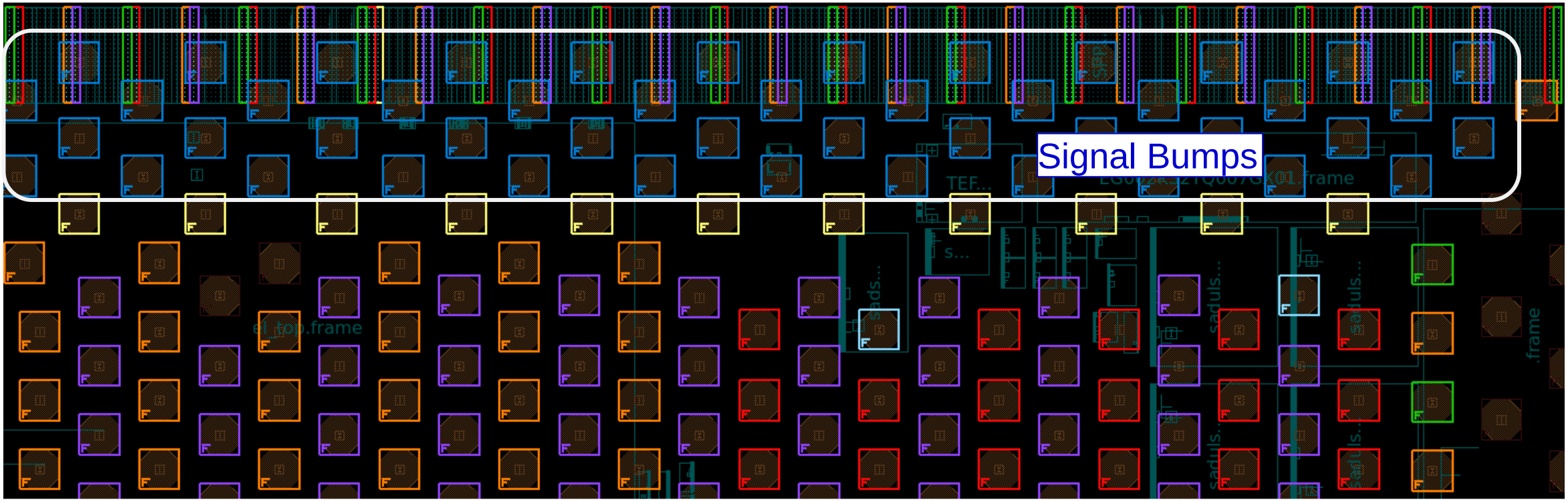




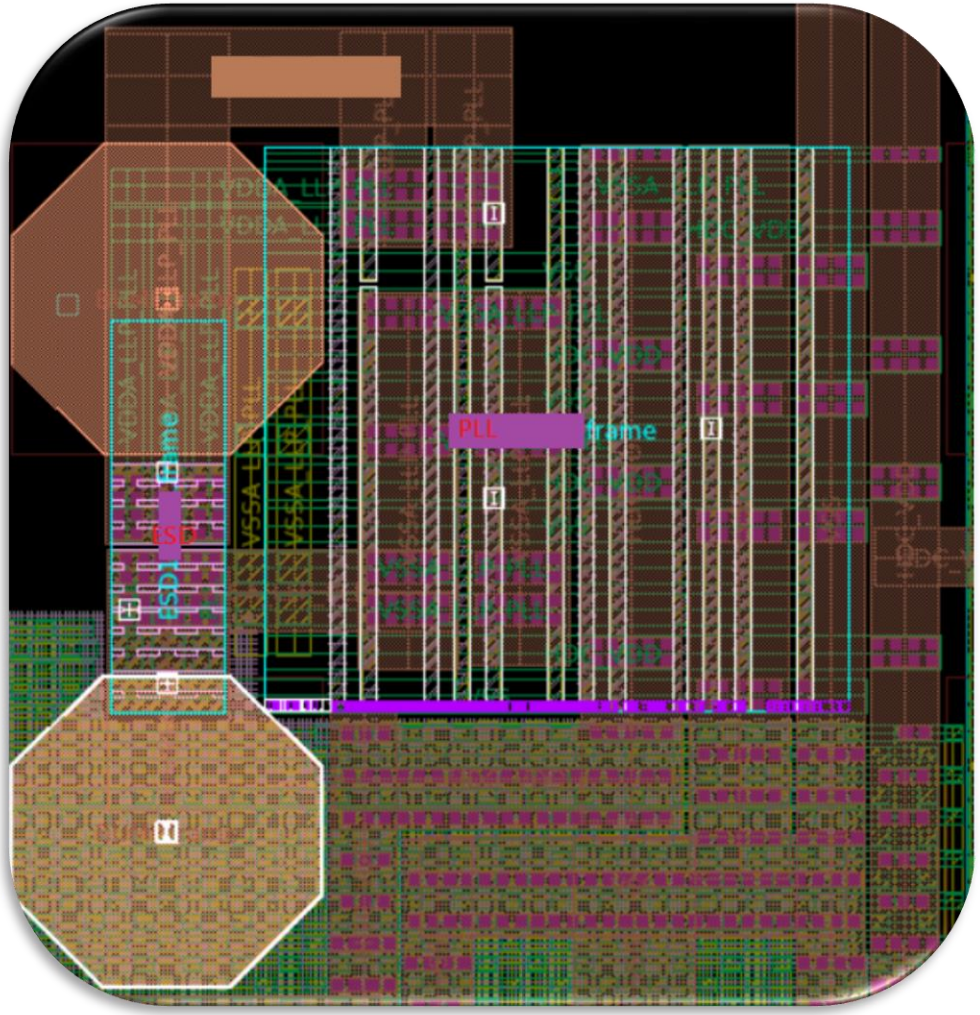
IO Ring ESD Fixes

Bump Dept has reduced for Signals

	green	VSSIO
	purple	VSS
	red	VDD
	orange	VDDIO



IP ESD Fixes



ESD, Bump Position and RDL routes for IP (e.g PLL) is important

Other useful reports

- esd_network_report

ICV PERC - ESD Network Report for soc

Summary of Clamp Network

Power	Ground	Clamp Type	Width (um)
AVDD[redacted]	AVSS15_[redacted]	Single	4027.97
[redacted]R_VDDIO_[redacted]	[redacted]R_VSSIO	Single	81789.31
HDC_VDD	VSS	Single	70723.10
[redacted]_CORE_VDD	[redacted]_VSSD	Single	4475.52

Summary of I/O ESD Network

I/O	Power	Ground	Primary Up (Type)	Primary Down (Type)	Secondary Up (Type)	Secondary Down (Type)	Clamp Type	Width (um)
[redacted]	[redacted]	[redacted]	PRIMARYUPDIO (Single)	PRIMARYDOWNDIO (Single)			Single	12083.90

Summary of Back-To-Back Diode Network

Inter-connected ground net groups	Net pair with back-to-back diode
[redacted]	[redacted]

Summary of Power / Ground / IO Nets

Design Power Net definition(s) -> [[redacted]HDC_VDD,

Design Ground Net definition(s) -> [[redacted]VSSIO,

Design I/O Net definition(s) -> [[redacted]

- perc_report/perc_configs.txt, pcgroups.txt
- run_details/block.rules : list of executed rules

Run time Details

PERC MODEs	CPU	Run time	Comment
TOPO	8	4 hrs	
LDL	8	3 hrs	Input Mode- Layout
P2P (full path & heatmap)	8	17 hrs	Need more computing resource #define CHECK_FULL_PATH_P2P #define P2P_HEATMAP_ENABLE
P2P (without full path, heatmap)	8	7 hrs	
CD (full path)	8	6 hrs	Need more computing resource “#define CHECK_FULL_PATH_CD

P2P runs involving CHECK_PICK_UP_P2P. We use marker layout .gds/oas generated from LDL run.

Conclusion

Conclusion

- ICV PERC reduces the Risk of Costly Failures and Delays
- The ICV PERC Features helped us in SoC ESD reliability signoff are mainly Path HEATMAP visualizer, calculation of resistance contribution by layer, diverse types of detail reports for root cause analysis.
- ICV PERC was significantly important for our soc ESD LUP reliability signoff of our 7nm designs as it checked issues of designs which is not checked with signoff DRC check

Acknowledgement

- We thank "Akhil, Bhavani & Soumyajit " from Synopsys team for valuable support.
- We thank "Sachin Bastimane" from Broadcom.

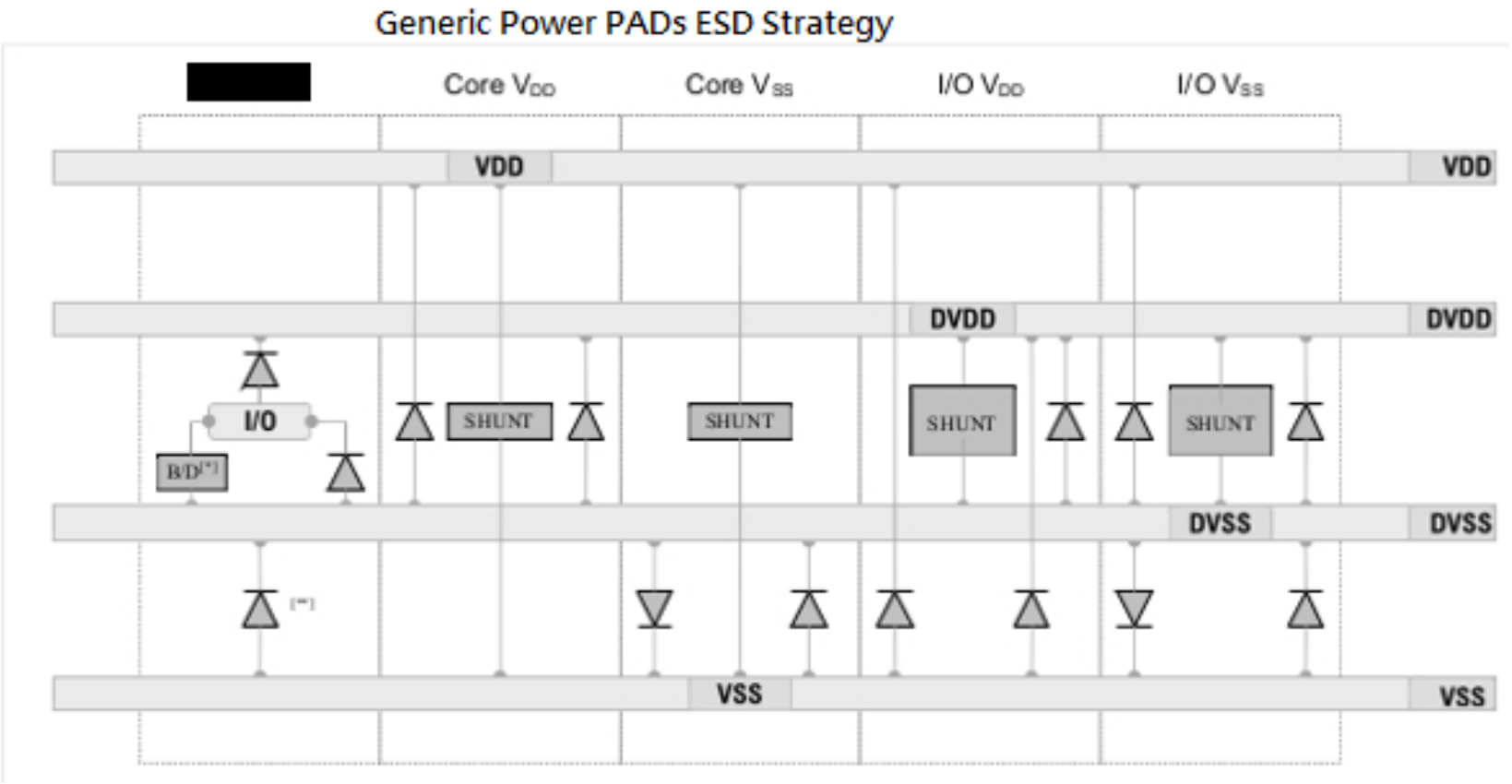
References

- https://solvnet.synopsys.com/
- ICV PERC / IC Validator User Guide
- TSMC 7nm Design Rule Manual
- Synopsys document on ICV PERC

dinesh.londhe@broadcom.com

sunil.kharate@broadcom.com

IO Ring ESD Fixes



Other useful reports

perc_report/perc_configs.txt

*** User defined Config ***

Switch	value
LVS_RUNSET	[redacted]_ESD_LU/NEW_SETUP/1P12M_1X1Xa1Ya4Y2Yy2R/DFM_LVS_RC_ICV_N7_1p12M_1X1Xa1Ya4Y2Yy2R_ALRDL.1.2b.perc
NXTGRD_FILE	[redacted]_ESD_LU/NEW_SETUP/cln7_1p12m_1x1xa1ya4y2yy2r_mim_ut-alrdl_typical.nxtgrd
CD_PRE_CHECK	False
CHECK_FULL_PATH_P2P	True
CHECK_PICK_UP_P2P	True
DISABLE_IODMY	False
DISABLE_PG_SANITY_CHECK	False
DISABLE_XDOMAIN_ALL	True
ENABLE_R0_CHECK	TRUE
EXPORT_ONE_VICTIM	False
GROUP_PWR_CLAMP	0
Hi_CDM	True
INPUT_MODE	LAYOUT_MODE
INT_PWR_LIMIT	10000
LAYOUT_FORMAT	OASIS
LDL	False
METAL_STACK	1P12M_1X1Xa1Ya4Y2Yy2R
NETLIST_FORMAT	SPICE
P2P_HEATMAP_ENABLE	True
P2P_PRE_CHECK	False
PC_GROUP_DISTANCE	5
PC_GROUP_FILTER	100
PC_GROUP_WIDTH	2000
REF_OBJ_COUNT	5
TOPO	False
USER_STARRC_OPTIONS	starrc_options_p2p_a.txt
P2P	True

/perc_reports/*

```
perc_configs.txt
pcgroups.txt
esd_network_report.txt
esd_network_report.html
p2p_topo_violation.txt
p2p_results.xls
p2p_results.txt
p2p_results.html
```

Other useful reports

perc_report/pcgroups.txt

```
------------------------------------
POWER CLAMP GROUP: RC_CORE_VDD (Power) -> RC_VSSD (Ground)

  RC_CORE_VDD

        PCGroup_172 (width=2237.760000; x=610.000000; y=2490.000000; device count=4320, [nch_svt_mac]) [nmos]
        PCGroup_173 (width=2237.760000; x=690.000000; y=2830.000000; device count=4320, [nch_svt_mac]) [nmos]

  RC_VSSD
------------------------------------
POWER CLAMP GROUP: VDDIO_A (Power) -> VSS (Ground)

  VDDIO_A

        PCGroup_90 (width=2033.982000; x=920.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_91 (width=2033.982000; x=1080.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_92 (width=2033.982000; x=1125.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_93 (width=2033.982000; x=1235.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_94 (width=2033.982000; x=1305.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_95 (width=2033.982000; x=1380.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_96 (width=2033.982000; x=1450.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_97 (width=2033.982000; x=1540.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_98 (width=2033.982000; x=1585.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_99 (width=2033.982000; x=1650.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_100 (width=2033.982000; x=1770.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_101 (width=2033.982000; x=1845.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_102 (width=2033.982000; x=2000.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_103 (width=2033.982000; x=2060.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_104 (width=2033.982000; x=2265.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_105 (width=2033.982000; x=2360.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_106 (width=2033.982000; x=2460.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_107 (width=2033.982000; x=2595.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
        PCGroup_108 (width=2033.982000; x=2705.000000; y=4090.000000; device count=3519, [nch_18_mac]) [nmos]
```

Sample run esd check command

```
bsub -q [redacted]-n 20 -R "select [type == local] rusage[mem=500000]" icv esd_setup.rs -host_init 20 \
    -D LVS_RUNSET=[redacted]1P12M_[redacted]/DFM_LVS_RC_ICV_N7_1p12M_1X1
1Y[redacted]R_ALRDL.1.2b.perc \
    -D NXTGRD_FILE=[redacted]cln7_1p12m_[redacted]_mim_ut-alrdl_typical.r
tgrd \
    -I [redacted]/1P12M_1X1Xa1Ya4Y2Yy2R/runset \
    -vue -ex
## NOTE:
#   This is a simple setting.
```