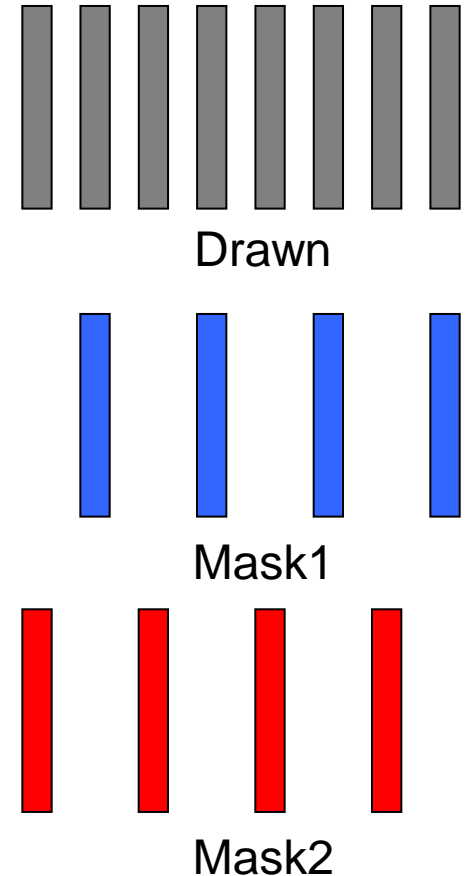
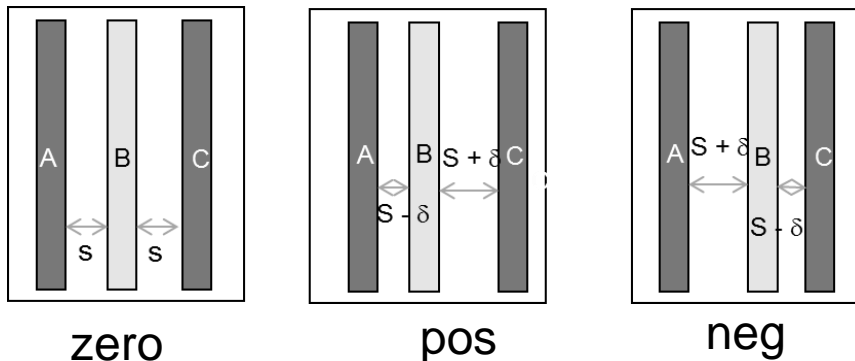


Timing analysis comprehending mask misalignment due to Double Patterning

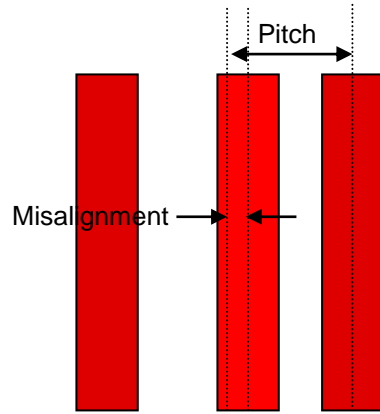
Arvind NV, Ajoy Mandal
Texas Instruments India

Introduction

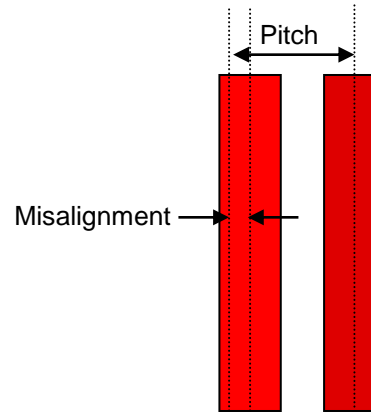
- At 20nm and below technologies, double patterning (DP) technique employed for interconnects.
- Misalignment between the masks leads to variation in wire parasitics and hence to timing
 - We refer to them as positive (“pos”) and negative (“neg”) misalignments
- Depending on the mask misalignment direction, capacitance can either increase or decrease



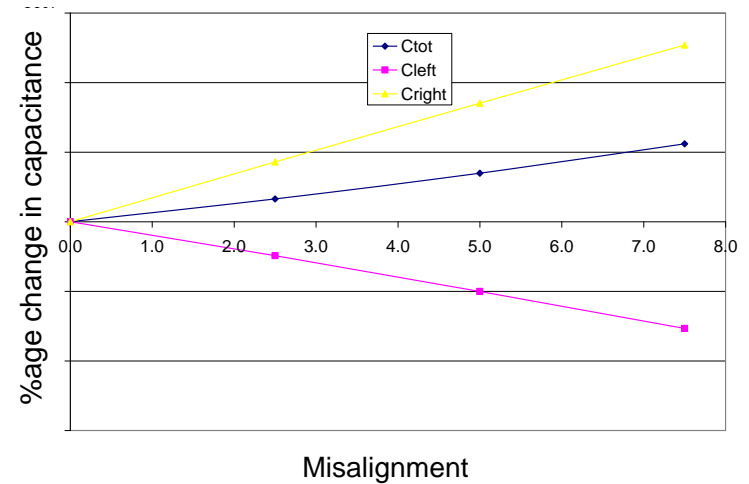
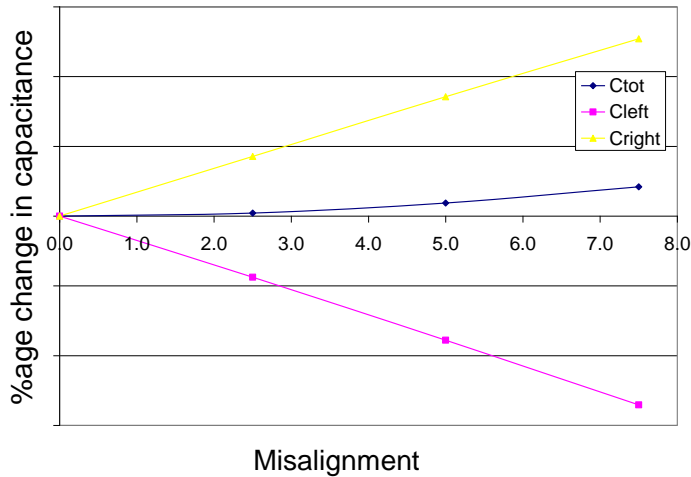
Mask Misalignment Impact On Capacitance



Misalignment Versus Capacitance for 3 Lines



Capacitance Versus Misalignment for 2 Lines



- Total capacitance change not significant
- Coupling capacitance change significant

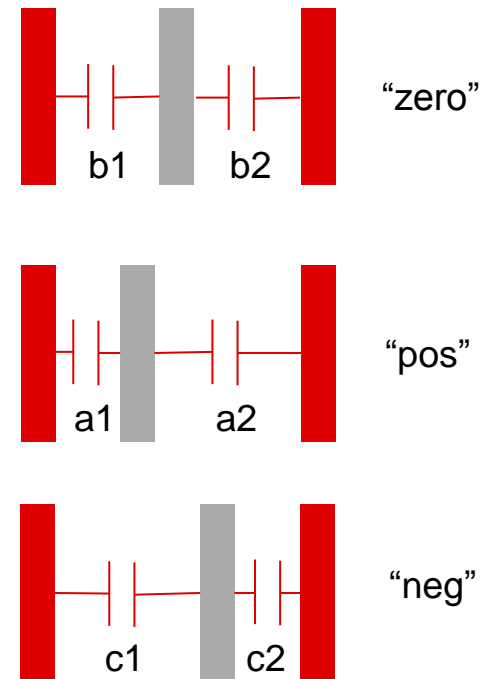
- Both total and coupling capacitance change significant

Existing solutions

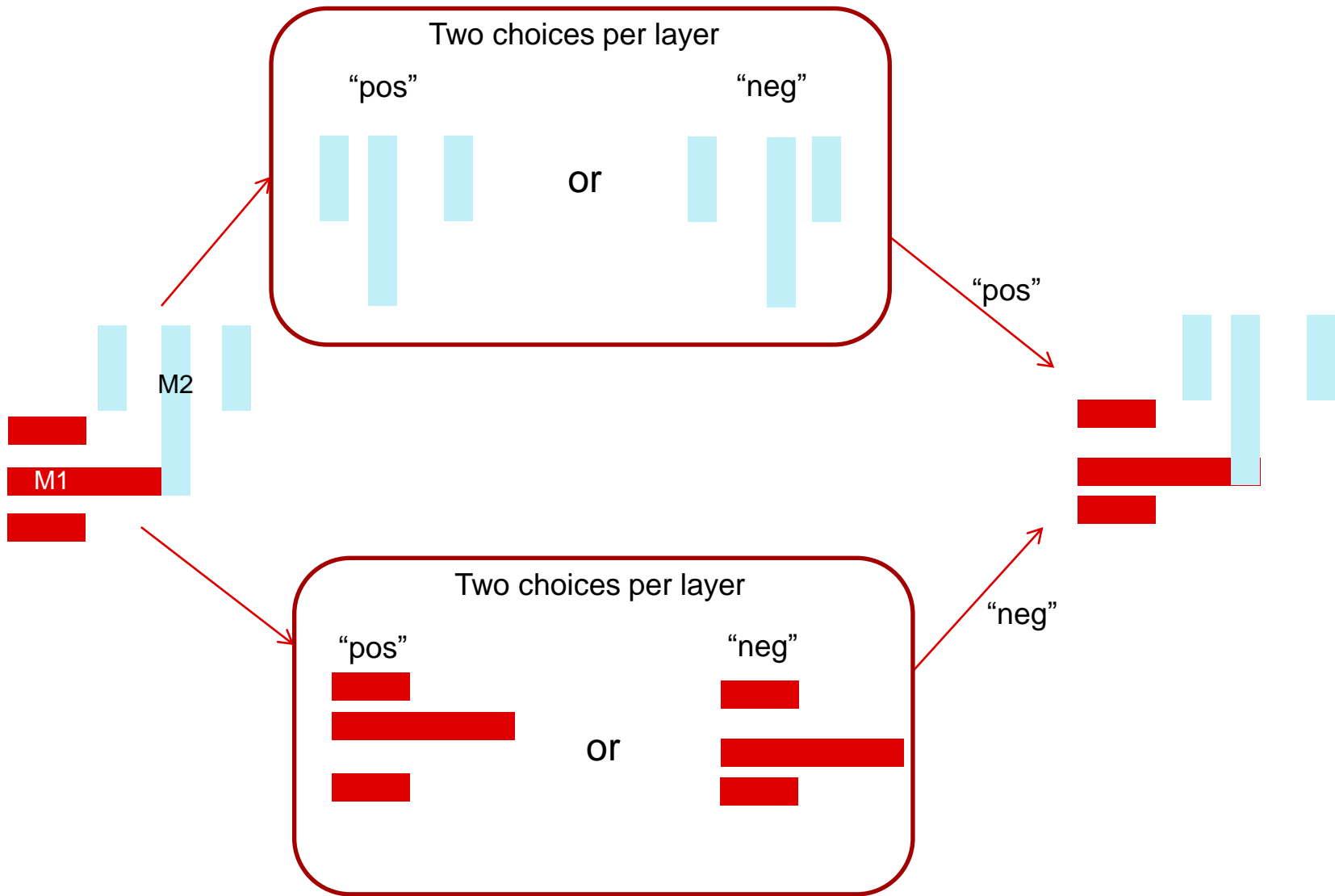
- Deterministic STA based
 - Bounding techniques have been proposed, which appear to be too pessimistic to be usable
- SSTA based
 - Sensitivity based infrastructure required to handle correlations accurately
 - Correlation across wires in a net, across nets in the path
 - Capacitance extracted as a function of misalignment parameters, sensitivity analysis to express delays and slacks in parameterized form
$$\text{Cap} = C_{\text{nom}} + K1 * \delta_{\text{MET1-misalign}} + K2 * \delta_{\text{MET2-misalign}} + \dots$$
$$\text{Slack} = S_{\text{nom}} + M1 * \delta_{\text{MET1-misalign}} + M2 * \delta_{\text{MET2-misalign}} + \dots$$
 - SSTA usage has not picked up in the industry
- Intent of the paper is to outline a proposal to handle this in deterministic STA infrastructure

Basic Idea

- Extraction
 - Extract parasitics in triplet form (a:b:c)
 - “a” → “pos”, “b” → “zero”, “c” → “neg”
miscorrelations
 - Similar to performing 3 separate extractions and combining them as triplets
 - Layer-wise breakup (sub-group) of parasitics
- Timing Calculation
 - Build worstcase parasitics for the net on-the-fly
 - Identify layer-wise worstcase sub-group based on defined metrics
 - Combine all layer-wise worstcase sub-groups
 - Timing computation using the worstcase net parasitics



Basic Idea



Comprehending Misalignment in Extraction

- Capacitance extracted for both positive and negative misalignment
 - Not as min-max capacitance for each net, but, as capacitance that corresponds to positive and negative misalignment
 - In a:b:c format, “a” corresponds to capacitance with pos and “b” with neg, “c” with zero misalignment
- Parasitics representation for the net split into sub-groups – one for each metal layer

Net A

Layer MET1

A → B a1:b1:c1

A → C a2:b2:c2

Layer MET2

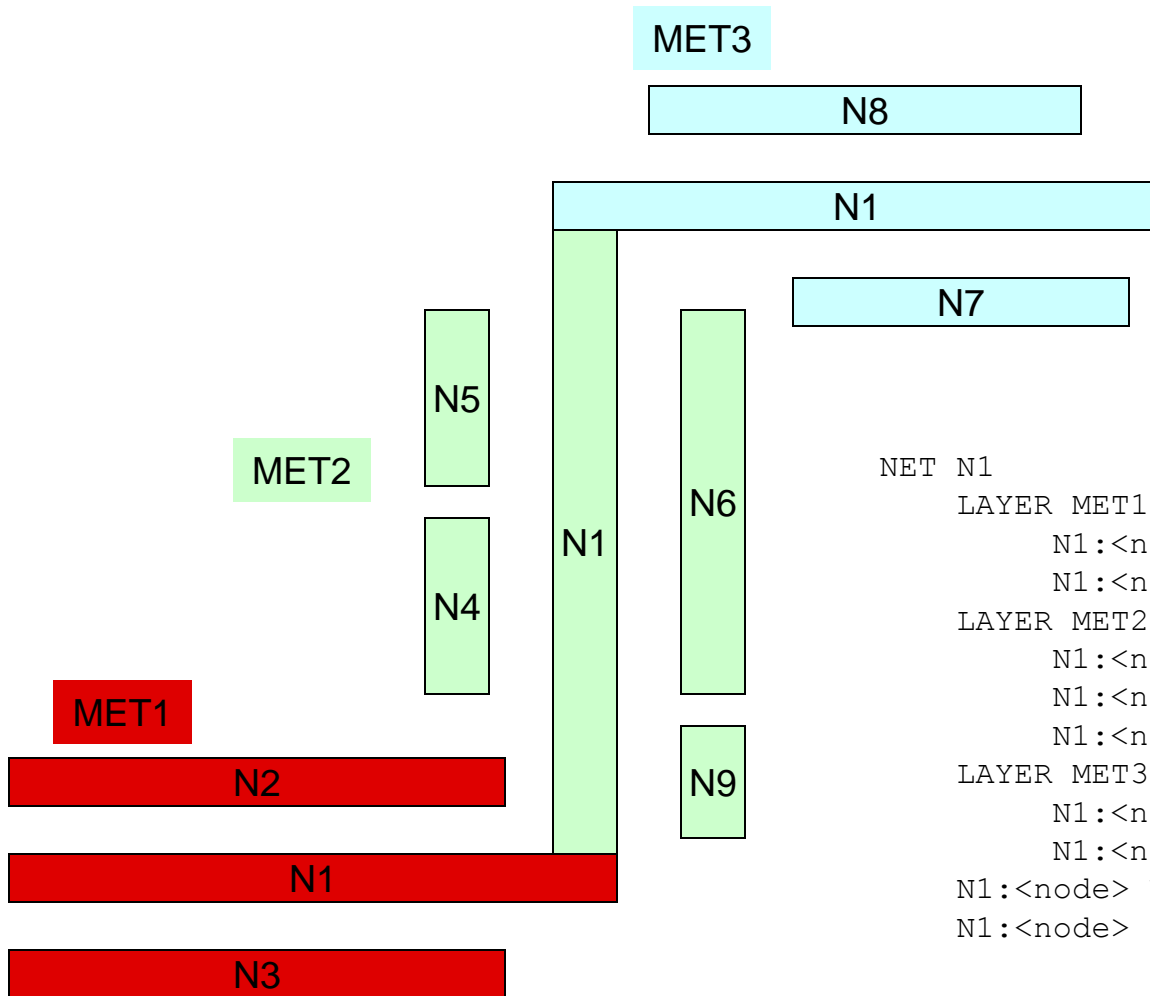
A → D a3:b3:c3

- a1 and a2 will both not be simultaneously min or max. Similarly with c1 and c2.

- Simplifications / Assumptions

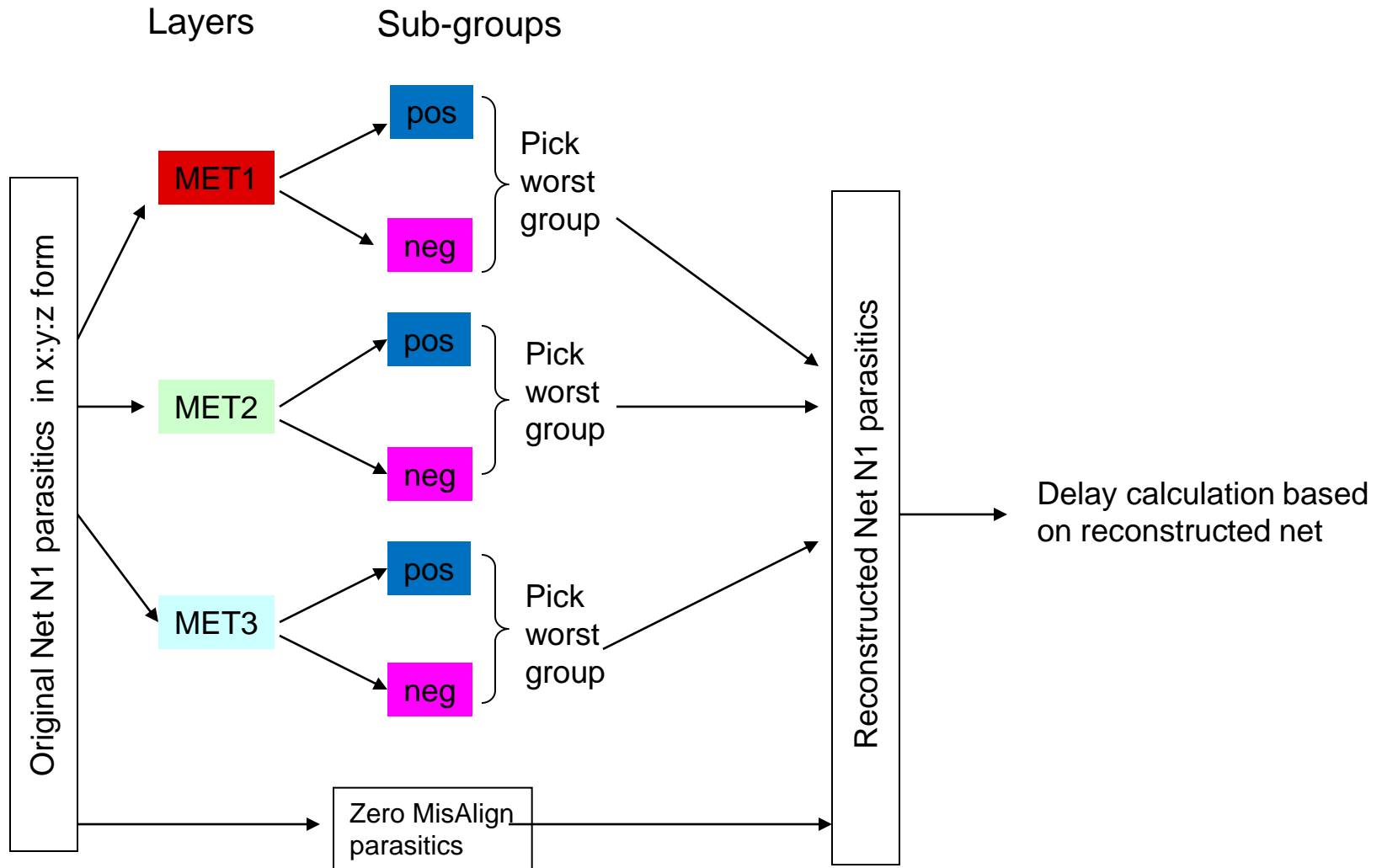
1. Only dominant coupling capacitances (Eg. $C_{c\text{-segment}} > y$ && $C_{c\text{-net}}/C_{\text{tot-net}} > x\%$) extracted for misalignment impact
2. Only lateral coupling capacitance modeled for misalignment. For the rest, only zero misalignment capacitance extracted
3. Ground (non-coupling) capacitance and resistance is based on zero misalignment only.
4. Only one direction misalignment based on metal level (eg. horizontal misalignment for MET1, vertical for MET2)

Eg. Parasitics representation as net-subgroups



| | | pos | | | neg | |
|------------|-----------|-----|---|----|-----|----|
| NET N1 | | | | | | |
| LAYER MET1 | | | | | | |
| N1:<node> | N2:<node> | a1 | : | b1 | : | c1 |
| N1:<node> | N3:<node> | a2 | : | b2 | : | c2 |
| LAYER MET2 | | | | | | |
| N1:<node> | N4:<node> | a3 | : | b3 | : | c3 |
| N1:<node> | N5:<node> | a4 | : | b4 | : | c4 |
| N1:<node> | N6:<node> | a5 | : | b5 | : | c5 |
| LAYER MET3 | | | | | | |
| N1:<node> | N7:<node> | a6 | : | b6 | : | c6 |
| N1:<node> | N8:<node> | a7 | : | b7 | : | c7 |
| N1:<node> | N9:<node> | | | y | | |
| N1:<node> | | | | y | | |

Comprehending Misalignment in STA



Metrics for picking worst sub-group

- Non-SI analysis:
 - Based on max/min coupling capacitance among “pos” and ”neg” subgroup
- SI analysis:
 - Based on worst peak noise contribution among “pos” and ”neg” subgroup
- Choice of worst sub-group becomes difficult in the presence of timing windows
 - Aggressor sub-group dominant based on peak noise contribution may not switch at the same time as victim
 - One simplification is to view the problem as “Worstcase the zero misalignment crosstalk delay” → 2-pass calculation approach
 - Pass1: Calculate crosstalk stage delay with zero misalignment parasitics
 - Pass2: Identify worst sub-groups with the goal to maximize impact of those aggressors affecting victim in zero misalignment analysis
 - Crosstalk delay computed with misalignment considered would be always worse than zero misalignment delay

Open Issues

- Metrics discussed only comprehends correlation (of misalignment between wires in a net) at a stage-level.
 - But, Next stage in the path could use pos/neg alignment which contradicts what was assumed in the previous stage.
- Possible path forward:
 - GBA (Graph Based Analysis) uses the approach as discussed for stage-level delay computation. Also, ensures bounded Graph timing.
 - Apply similar 2-pass approach to PBA → “Worstcase the zero misalignment PBA timing”
 - Pass1: Calculate PBA timing with zero misalignment parasitics
 - Pass2: Identify worst sub-groups with the goal to maximize impact of those aggressors affecting victim in zero misalignment PBA timing
 - Complexity is in ensuring the same misalignment (“pos” or “neg”) for a layer gets used across all nets in the path
 - Need to compare sub-groups (of a layer) across nets in the path to determine the worstcase misalignment

Summary

- Misalignment between the masks used in Double Patterning leads to variation in wire parasitics and hence to timing
- Existing solutions are either pessimistic or not practical for production use
- We proposed an outline of an approach to comprehend impact of mask misalignment in deterministic STA infrastructure
 - Apart from the accuracy of metrics suggested, handling correlation across the path is an open issue
 - Our intent was not provide a complete solution, but to highlight a possible practical path to handle this in timing signoff
- With the extent of “randomness” involved (layer, net, path), it is possible that overall design impact is small enough to margin through OCV