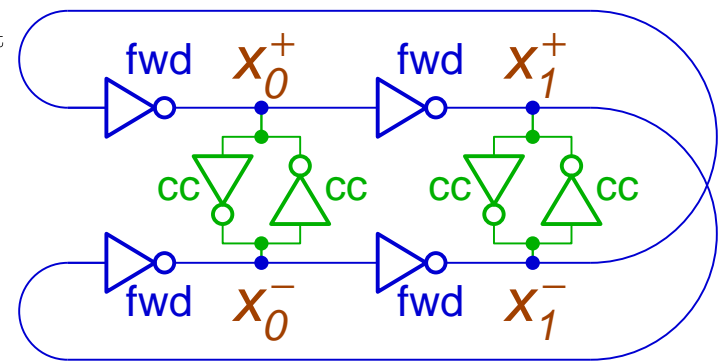
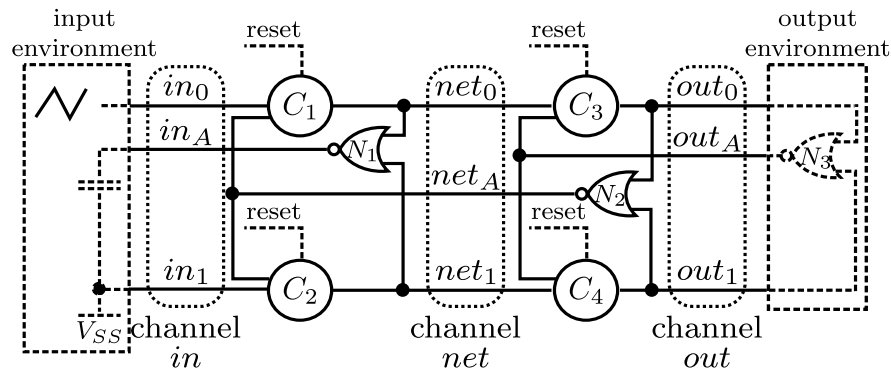


Circuit-Level Verification of Practical Circuits

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Circuit Verification

- Circuit-Level Bugs

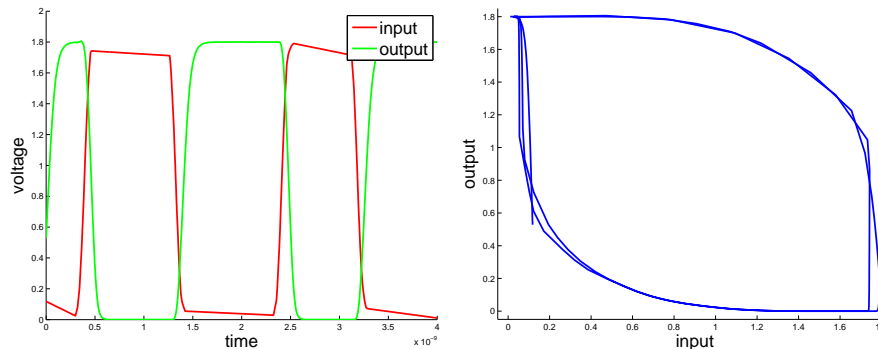
- Account for large percent of critical bugs
- Sandy bridge chipset
- Rambus ring oscillator

- Formal Methods

- Simulations: incomplete coverage
- Reachability analysis
- Theorem proving

Reachability Analysis

- Verification as Reachability
 - Phase-space view of circuit behavior



- Verification Flow
 - Model circuits as ODEs
 - Formally specify properties
 - Reachability computation
 - Verify properties based on reachable regions.

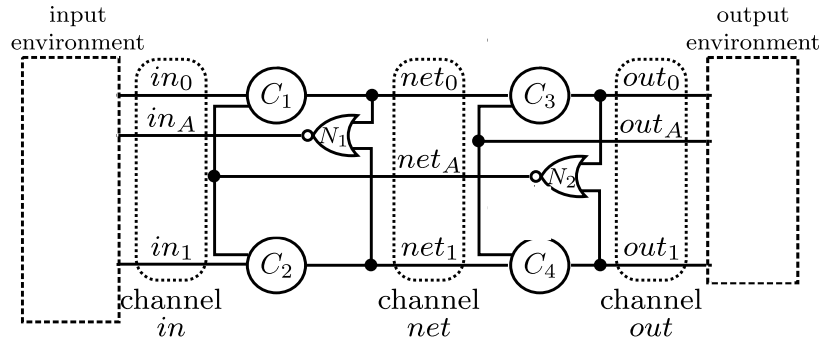
Real Applications?

- Related Tools & “Verified” Circuits
 - LEMA, D/DT, SpaceEx, CheckMate, AMT, Phaver, ...
 - Voltage controlled oscillator, Low-pass filter, Tunnel diode oscillator, ...
- Challenges
 - Reachability computation is expensive → small circuits (2-3 variables)
 - Difficult to solve nonlinear dynamics → simple dynamic (linear or quasi-linear)
 - Specification? → does not satisfy verification need of designers
- Two examples from Industry
 - Full-buffer circuit from ST Microelectronics
 - Differential ring oscillator from Rambus Inc.

Our Approach

- Requirements
 - High dimensional: > 5 -dim
 - Non-convex reachable regions
 - Complex dynamics
- Efficient Reachability Analysis Tool: COHO
 - Modeling a circuit by ODEs automatically
 - Representing and manipulating high dimensional space: [projectagon](#)
 - Solving dynamic systems: [linear differential inclusions](#).
 - `http://coho.sourceforge.net`
- Avoid expensive computations as possible: reachability computation is still expensive
- Combine with other methods: reachability analysis can not verify all circuit properties

Full-Buffer



● Circuit

- From ST Microelectronics
- Quasi-delay insensitive circuit, dual-rail encoded
- Four-phase handshake protocol

● Does It Work for Low Power Design?

- Delay insensitive does not mean slope insensitive [ASYNC 2010].
- Capacitances of internal nodes matter.
- Sufficient condition to ensure the handshake protocol.

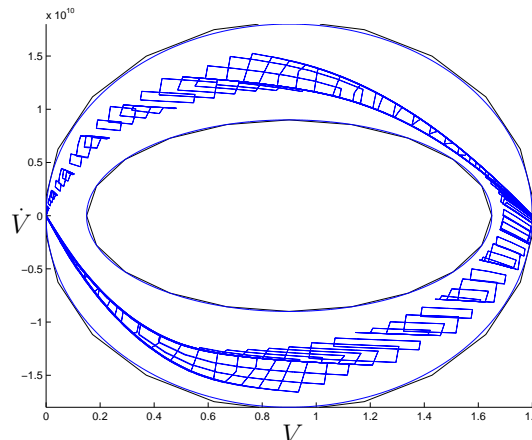
Verification of Full-buffer Circuit

● Decomposition

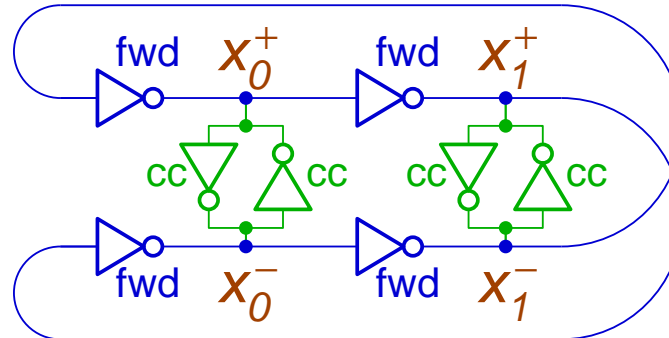
- Partition the circuit to C-elements, NORs, and inverters.
- Compute reachable regions of C-element circuits.
- Parallel computation using assume-guarantee strategy.

● Brockett annulus based verification

- Apply the same Brockett's annulus to specify inputs of C-elements, NORs, and inverters.
- Verify outputs of C-elements, NORs and inverters satisfy the same Brockett's annulus.
- All internal signals oscillate properly.

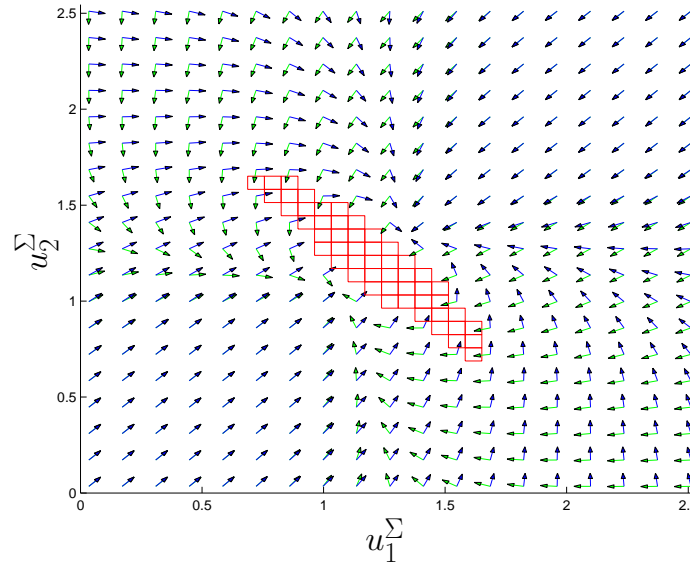


Rambus Ring Oscillator



- Circuit
 - Even-stage differential oscillator
 - Forward inverters (**fwd**), cross-couple inverters (**cc**).
 - Generates multiple, evenly spaced, differential phases.
- Will it start-up reliably?
 - Failures have been observed for real chips
 - Small Signal Analysis [GLSVLSI08]
 - Sufficient condition?

Verification of Rambus Ring Oscillator



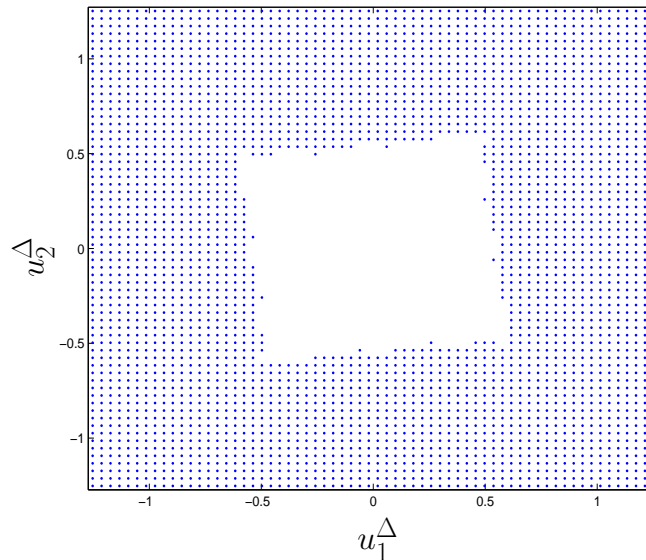
- Differential Operation

- Let

$$u_i^{\Delta} = \frac{x_i^{+} - x_i^{-}}{\sqrt{2}}, \quad \text{"differential" component}$$
$$u_i^{\Sigma} = \frac{x_i^{+} + x_i^{-}}{\sqrt{2}}, \quad \text{"common mode" component}$$

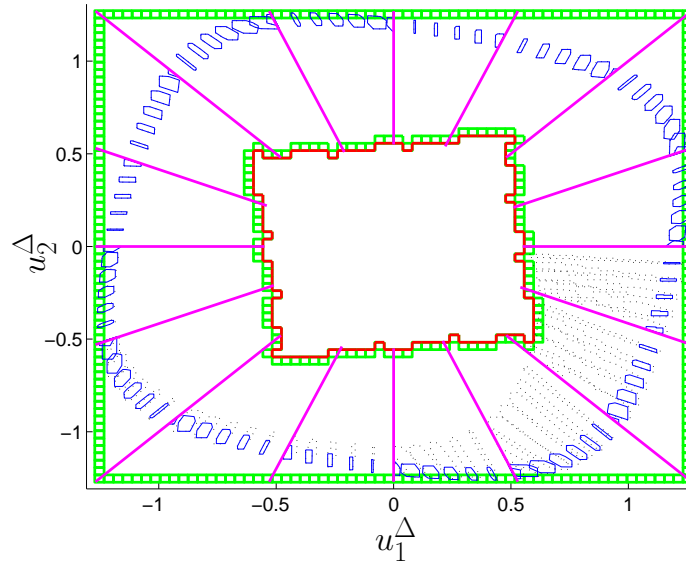
- Partition u space into small boxes
 - Determine flows between boxes

Verification of Rambus Ring Oscillator



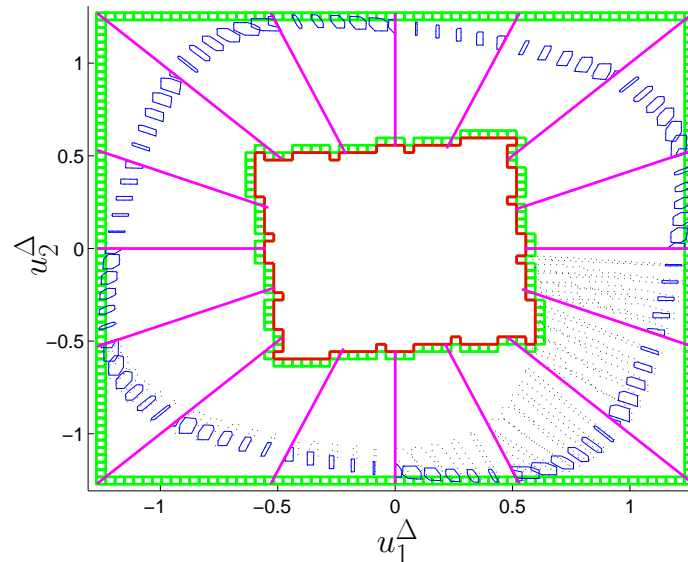
- Differential Operation
- Divergence from Metastability
 - Metastability: any oscillator must fail on a set of measure zero.
 - Show the failure set is negligible by dynamical system theory.

Verification of Rambus Ring Oscillator



- Differential Operation
- Divergence from Metastability
- Reachability Check
 - Show that all remaining initial conditions lead to correct oscillation.
 - $4D \rightarrow 2D$ by constructing 2-dim differential inclusions
 - Only check trajectories starting from boundaries.

Verification of Rambus Ring Oscillator



- Differential Operation
- Divergence from Metastability
- Reachability Check
- Results
 - Free from DC lock-up ($0.625 \leq r \leq 2.25$)
 - Oscillate from all (almost) initial conditions when ($0.875 \leq r \leq 2$).

Conclusion

- Formal methods are powerful enough to verify some practical circuits
 - Full-buffer circuit: C-element based circuits
 - Rambus ring oscillator: other oscillators
- Reachability analysis can not solve all problems
 - Dynamical theory for metastability
- Reachability computations are still very expensive
 - Use reachability analysis only necessary
 - Reduce problem size: decomposition
 - Abstraction: simplified models
 - Parallel computation: assume-guarantee
- Future Work
 - Specification
 - Parameterized verification
 - Point verification: not too many analog circuits!