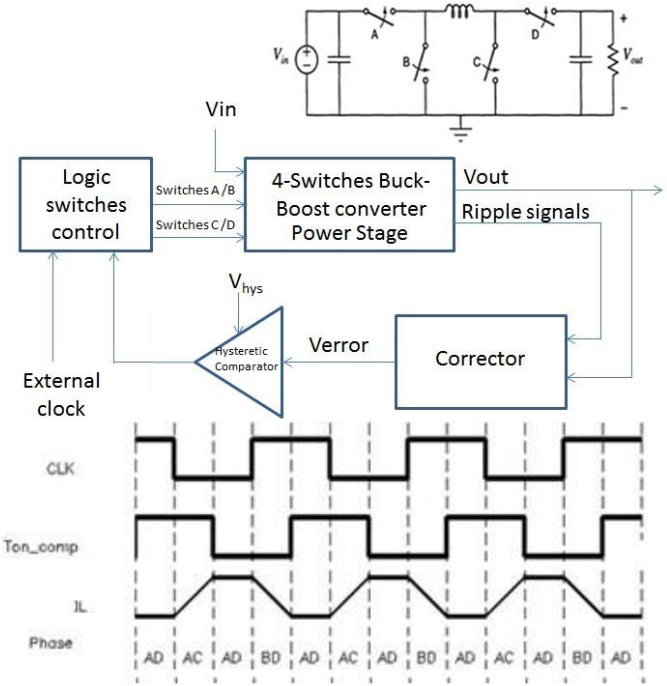
# Augmented Sampled-Data Modeling for Stability Analysis of A 4-Switch Buck-Boost Power SoC

Amokrane Malou[1,2], Bruno Allard[1], Alaa Hijazi[1] Xuefang Lin-Shi[1],

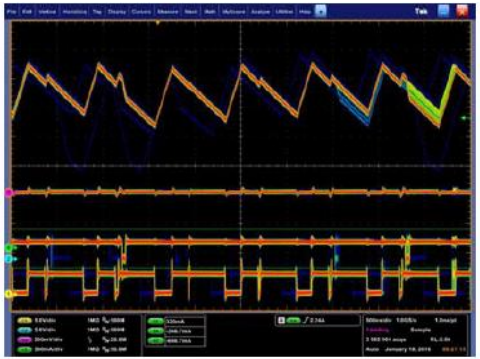
(1) Univ. Lyon, INSA Lyon, Ampère, UMR CNRS 5005, France; (2) ON Semiconductor, Toulouse, France

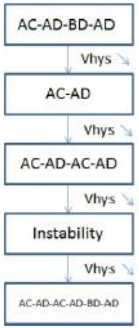
## IoT → interest for 4-switch buck-boost



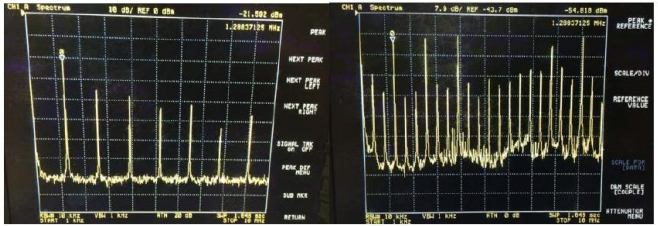

Focus on Buck-Boost mode → problem of stability when changing switching scheme

## Stability Issue





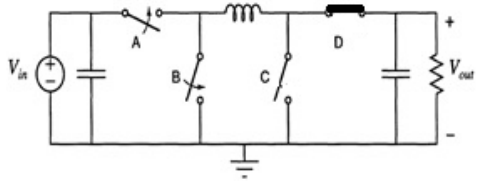

Experimental buck-boost converter: bifurcation when reducing the hysteretic comparator window



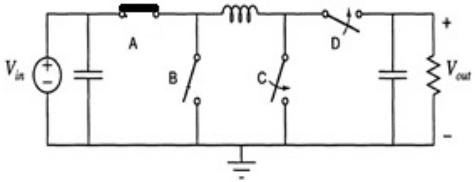
Spectrum of the inductor current in normal operating condition in transition mode (left) and after installation of a bifurcation (right)

## Power Stage Architecture

Buck mode : $V_{in} > V_{out} + V_{th1}$

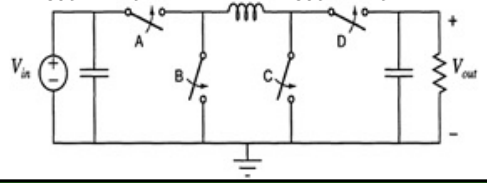



Boost mode : $V_{in} < V_{out} - V_{th2}$




Transition mode :

$V_{out} + V_{th1} > V_{in} > V_{out} - V_{th2}$





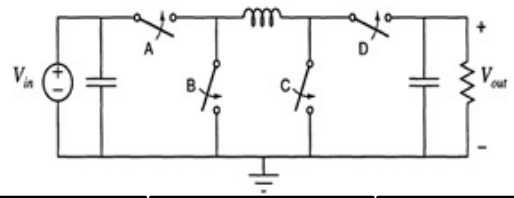

ON Semiconductor®

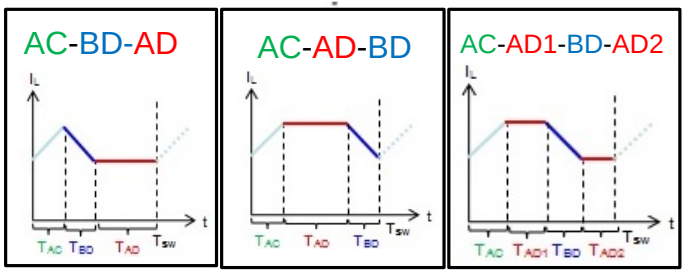
# Augmented Sampled-Data Modeling for Stability Analysis of A 4-Switch Buck-Boost Power SoC

Amokrane Malou[1,2], Bruno Allard[1], Alaa Hijazi[1] Xuefang Lin-Shi[1],

(1) Univ. Lyon, INSA Lyon, Ampère, UMR CNRS 5005, France; (2) ON Semiconductor, Toulouse, France

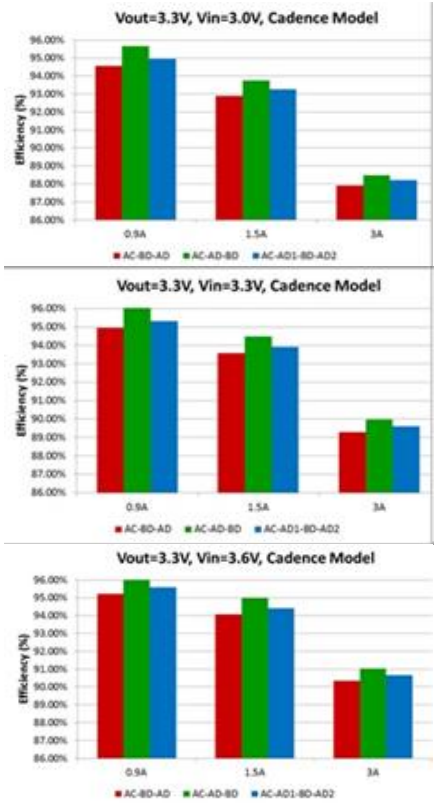
## Transition Mode Switching Schemes



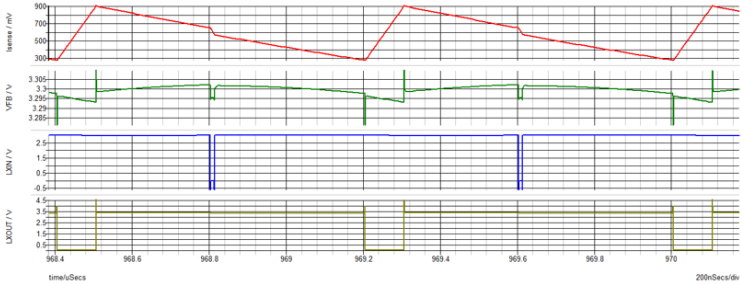

| Switching Scheme | Efficiency | CCM/DCM Transition | Comment |
|---|---|---|---|
| AC-AD-BD | +++ | + | Variable Frequency (DCM at high Iload) |
| AC-BD-AD | + | + | Degraded Efficiency (DCM at low Iload) |
| AC-AD1-BD-AD | ++ | +++ | Good trade-off |

## Cadence Model Efficiency Comparison




## Classical design approach

- Phase/gain margin: stability issue undetected
- Floquet's approach [1]: analysis of growth or decay of a perturbation in a periodic system
- Stability issue : a needle in a haystack
- No systematic approach existing to determine critical operating points



# Augmented Sampled-Data Modeling for Stability Analysis of A 4-Switch Buck-Boost Power SoC

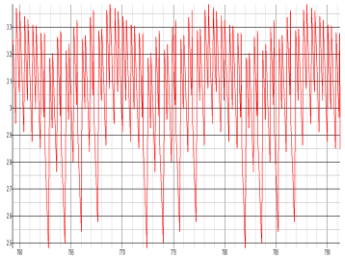
Amokrane Malou[1,2], Bruno Allard[1], Alaa Hijazi[1] Xuefang Lin-Shi[1],

(1) Univ. Lyon, INSA Lyon, Ampère, UMR CNRS 5005, France; (2) ON Semiconductor, Toulouse, France

## Transition Mode Sampled-Data modeling

1. Topology State-Space Model
2. Recurrence equation
3. Initial Point numerical calculation
4. Saltation Matrices establishment
5. Monodromy Matrices establishment
6. Stability analysis through Monodromy Matrix eigenvalues modulus study

| |
|---|
| 0.3202 |
| 0.3202 |
| 0.9622 |
| 0.7663 |
| 0.7663 |
| 0.6335 |
| 0.0000 |
| 0.0000 |



No eigenvalues with modulus above 1 !

## Sampled-Data Modeling Stability Analysis Shortcomings

- **Floquet's approach [2]: does not apply** when change in switching scheme during switching period
- **Possible solution** : Take into account the transition between switching schemes

## Modified Sampled-Data Modeling Stability Analysis

- Use of **Filippov Convex continuation method**

$\Phi_1$ : monodromy matrix for switching scheme AC-AD-AC-AD-BD-AD

$\Phi_2$ : monodromy matrix for switching scheme AC-AD-AC-AD

$$\Phi_F = q \cdot \Phi_1 + (1-q) \cdot \Phi_2, 0 \leq q \leq 1$$

## Case study: $V_{hys}$

Steady SDM before boundary crossover

Vhys

Loss of Initial Point determination

Vhys smaller

From last initial point calculation, **recursively perturb the last initial point** calculation and **observe the eigenvalues modulus of $\Phi_F$**

One eigenvalues modulus is above 1

No convergence or No eigenvalues modulus above 1

END

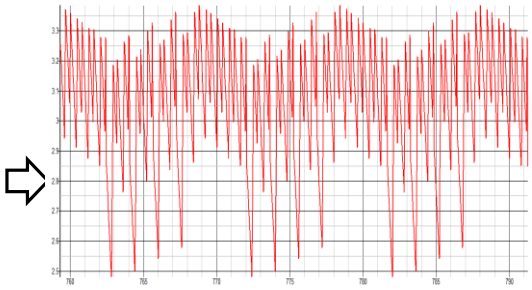
# Augmented Sampled-Data Modeling for Stability Analysis of A 4-Switch Buck-Boost Power SoC

Amokrane Malou[1,2], Bruno Allard[1], Alaa Hijazi[1] Xuefang Lin-Shi[1],

(1) Univ. Lyon, INSA Lyon, Ampère, UMR CNRS 5005, France; (2) ON Semiconductor, Toulouse, France

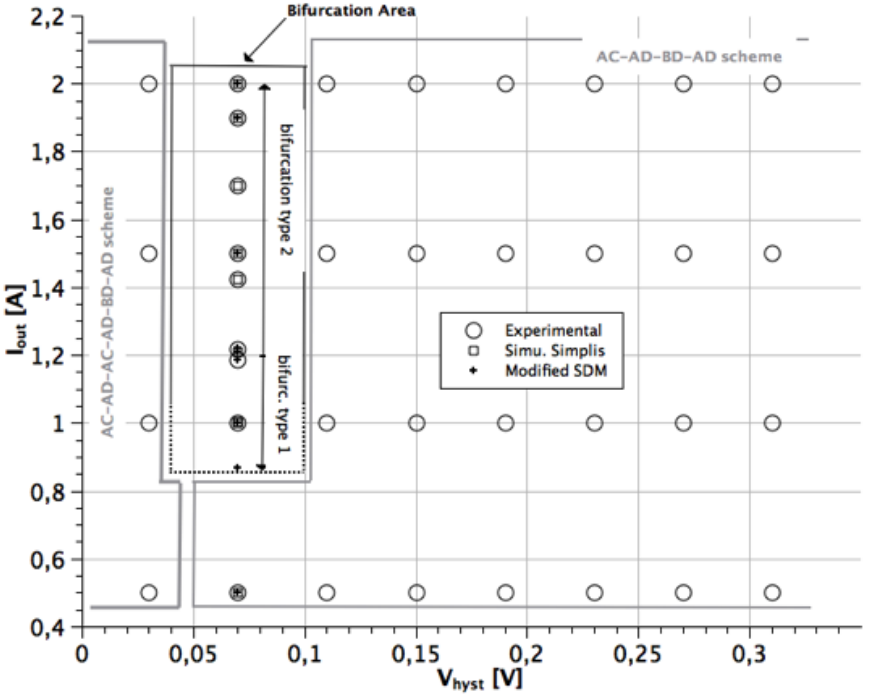
## Modified Sampled-Data Modeling Stability Analysis Result

| |
|---|
| 7.62 |
| 0.77 |
| 0.46 |
| 0.19 |
| 0.19 |
| 0.00 |
| 0.00 |
| 0.00 |
| 0.00 |



One eigenvalue modulus above 1 !

## Application




## Conclusion

- Case study of stability issue wrt Vhys in a 4-switch buck-boost
- Experimental support of instability when changing switching scheme over switchin period
- Modified Sampled-data Modeling introduced to provide a systematic approach
- Help for detecting conditions of bifurcation: parameters, operating points
- Help for evaluation of stable operating conditions

## References

[1] Cortés, J.; Šviković, V.; Alou, P.; Oliver, J. A.; Cobos, J. A. & Wisniewski, R, *IEEE Transactions on Power Electronics,* **2015**, *30*, 1005-1018

[2] Cliquennois, S. 2010 IEEE 12th Workshop on Control and Modeling for Power Electronics (COMPEL), **2010**