Loss Analysis and Modeling of Asynchronous Buck-Converter

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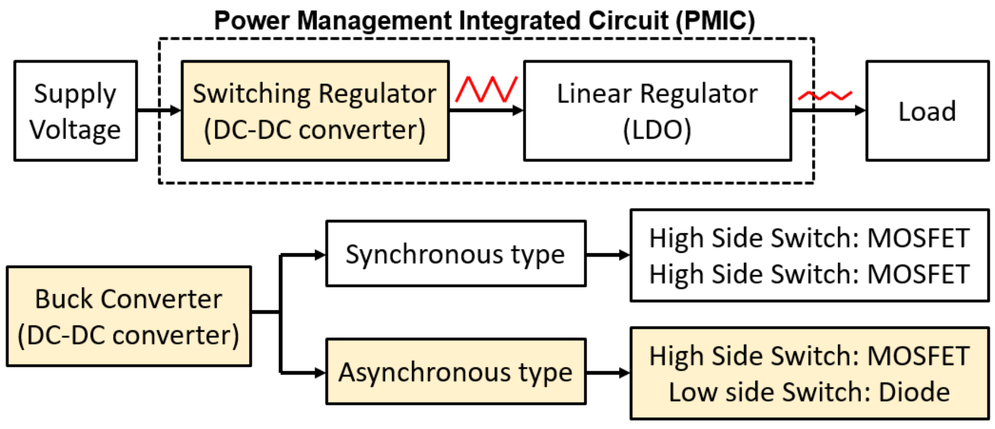
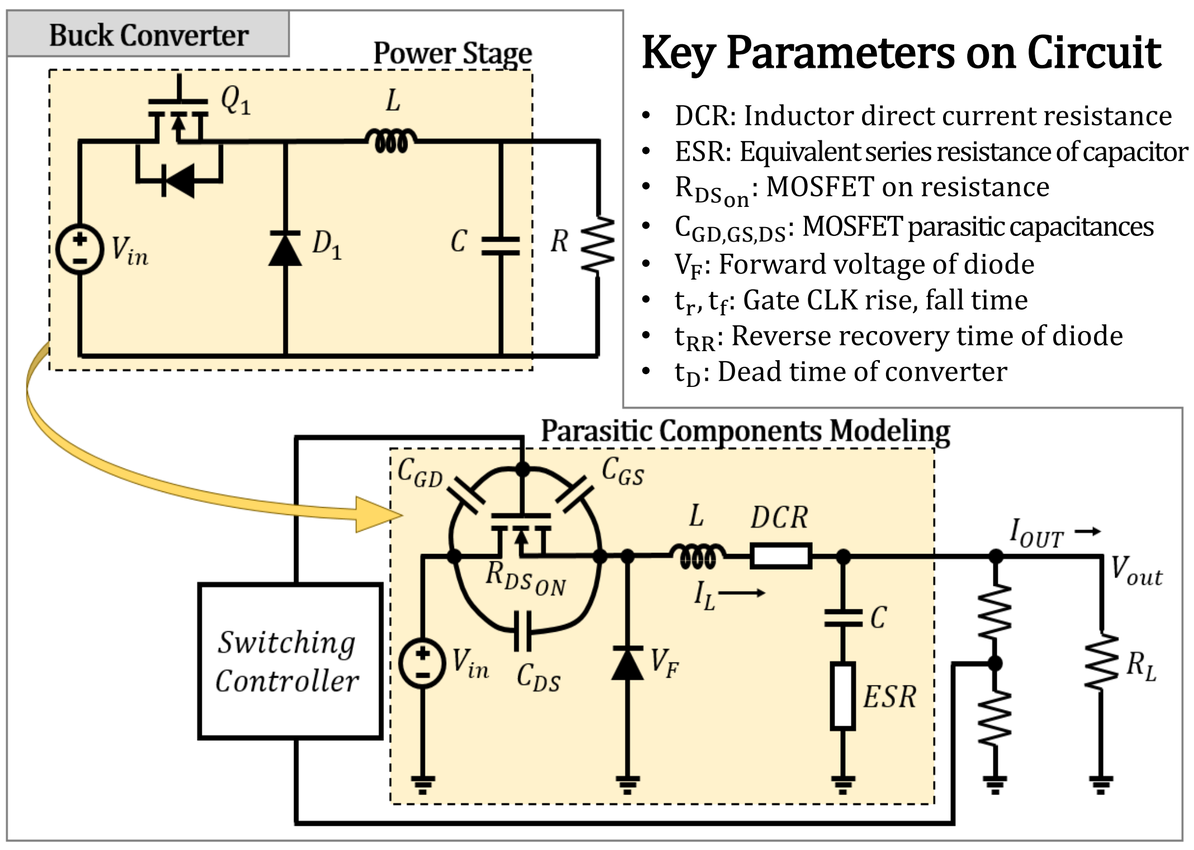
Introduction & Objectives



✓ **Asynchronous buck converter**
- Simpler structure than synchronous buck converter
- Poor power conversion efficiency

✓ **Loss analysis**
- Build a high-level behavior model
- Breakdown the loss by a quantitative order

Concept of Modeling



Key Parameters on Circuit

- DCR: Inductor direct current resistance
- ESR: Equivalent series resistance of capacitor
- $R_{DS_{on}}$: MOSFET on resistance
- $C_{GD,GS,DS}$: MOSFET parasitic capacitances
- V_F: Forward voltage of diode
- t_r, t_f: Gate CLK rise, fall time
- t_{RR}: Reverse recovery time of diode
- t_D: Dead time of converter

Quantitative Analysis

Asynchronous Topology

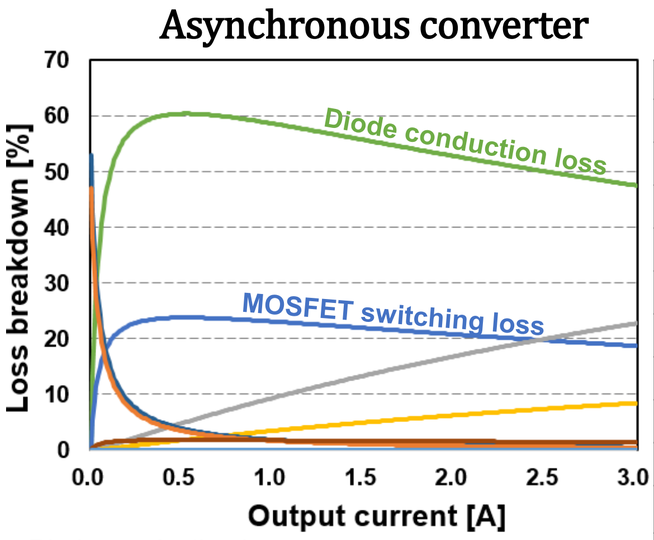
✓ Low-side switch(Diode) total loss
- Conduction loss $= (V_f \times I_{out}) \times (1 - D)$
- Reverse recovery loss $= Q_{rr} \times F_{sw} \times V_s$
- Dead-time loss $= V_f \times F_{sw} \times t_D \times I_{out}$

✓ High-side switch(MOSFET) total loss
- Conduction loss $= \left(I_{out}^2 + \frac{I_{ripple}^2}{12}\right) \times R_{ds_{on}} \times D$
- Switching loss $= (t_{r_H} - t_{f_H}) \times F_{sw} \times V_s \times \frac{I_{out}}{2}$

✓ Loss from other factors
- MOSFET's Output capacitance loss $= C_{oss} \times V_s^2 \times F_{sw}$
- Capacitor loss $= \frac{I_{ripple}^2}{12} \times ESR$
- Inductor loss $= I_{out}^2 + \frac{I_{ripple}^2}{12} \times DCR$

Results of the Analysis

Asynchronous converter



Parameters of the model

Parameters	Value	Explanation
V_{in}	12V	Input Voltage
V_{out}	3.3V	Output Voltage
I_{out}	0 ~ 3A	Output Current
ΔI_L	0.4 I_{out}	Ripple Current
f_{sw}	340kHz	Switching frequency
C	10μF	Capacitance
L	10μH	Inductance
ESR	0.015Ω	Equivalent series resistance
DCR	0.04Ω	Inductor DC resistance
$R_{DS_{on}}$	0.054Ω	MOSFET on resistance
V_F	0.35V	Forward voltage of diode
C_{oss}*	148pF	Parasitic Capacitance
Q_{RR}*	10nC	Reverse recovery Charge
$t_{r_{delay}}$, $t_{f_{delay}}$	9ns, 23ns	MOSFET Turn on delay
t_r, t_f	20ns, 29ns	Gate CLK rising, falling time
V_R	0.47V	Body diode forward voltage

* $C_{oss} = C_{GD} + C_{DS}$ * $Q_{RR} = \frac{1}{2} \times I_{RR} \times t_{RR}$

✓ MOSFET: MCH5809 (mfr. SANYO)

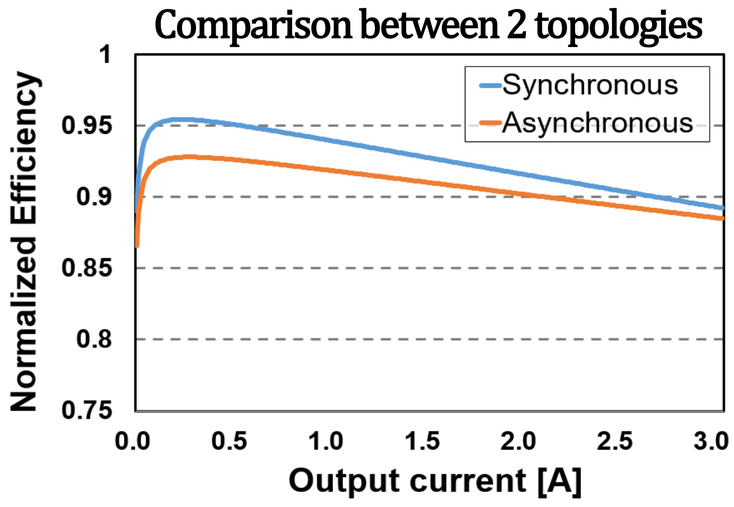
✓ Diode: IN5820 (Schottky) (mfr. CHENG-YI)
- to reduce its reverse recovery time and conduction loss

✓ The conduction loss of the diode: up to 60%

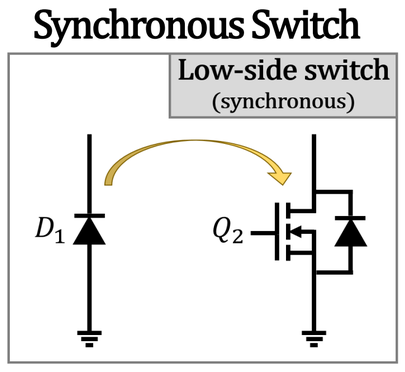
✓ Switching loss of MOSFET: up to 22%
- due to the rising and falling time of the MOSFET

Conclusion

Comparison between 2 topologies



Synchronous Switch



✓ Major elements causing losses
- Diode conduction loss (60%)
- MOSFET switching loss (22%)

✓ To reduce the Diode conduction loss
- Low-side switch → MOSFET* (synchronous)
  - Low-side MOSFET Conduction loss $= (V_R \times I_{out}) \times (1 - D)$
- **3%** more efficient than asynchronous

✓ To reduce the MOSFET switching loss
- Rising & falling time must be reduced
- Switches must be integrated

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