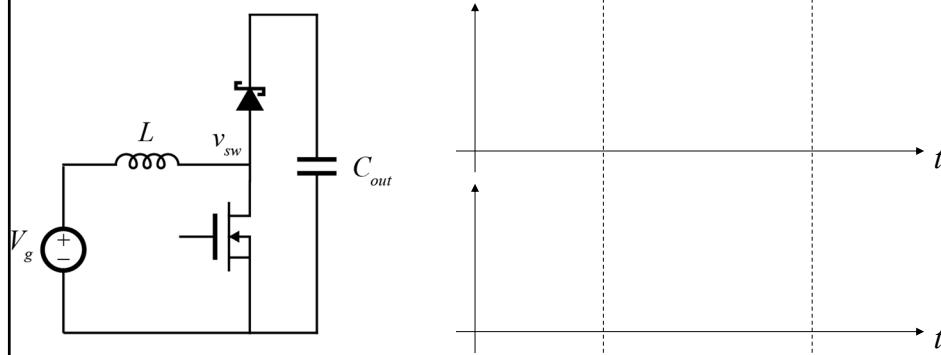
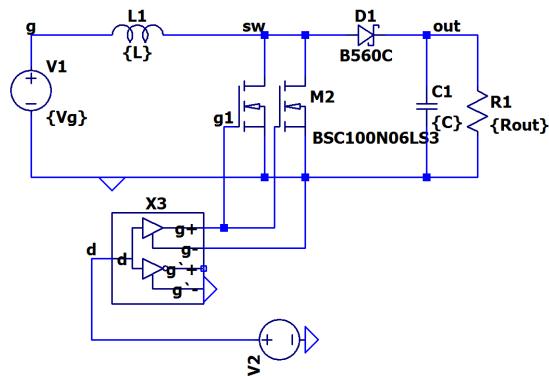


Device Capacitances



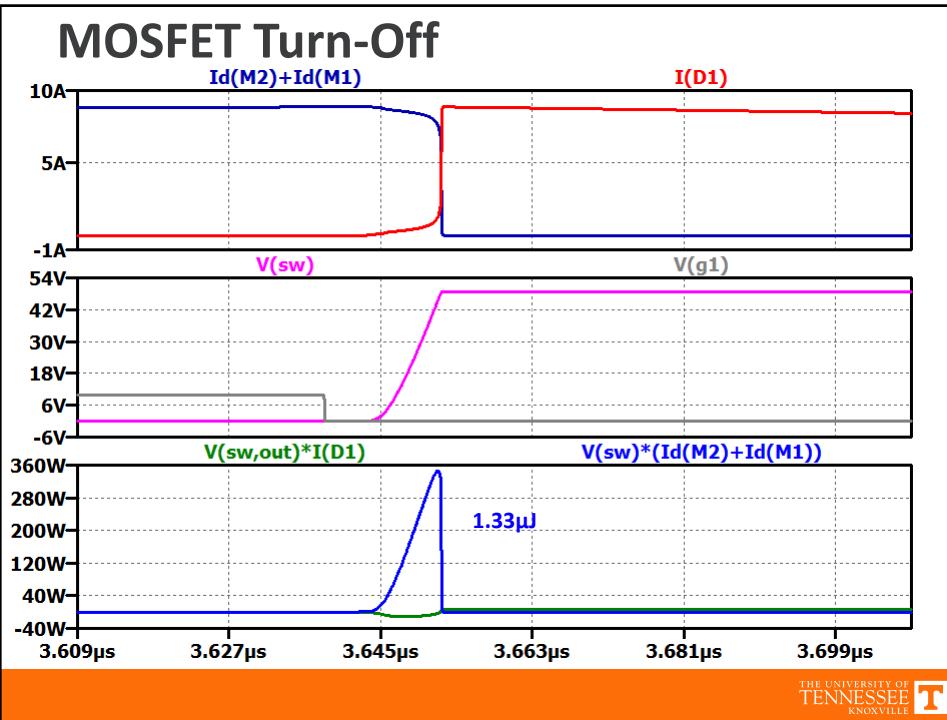
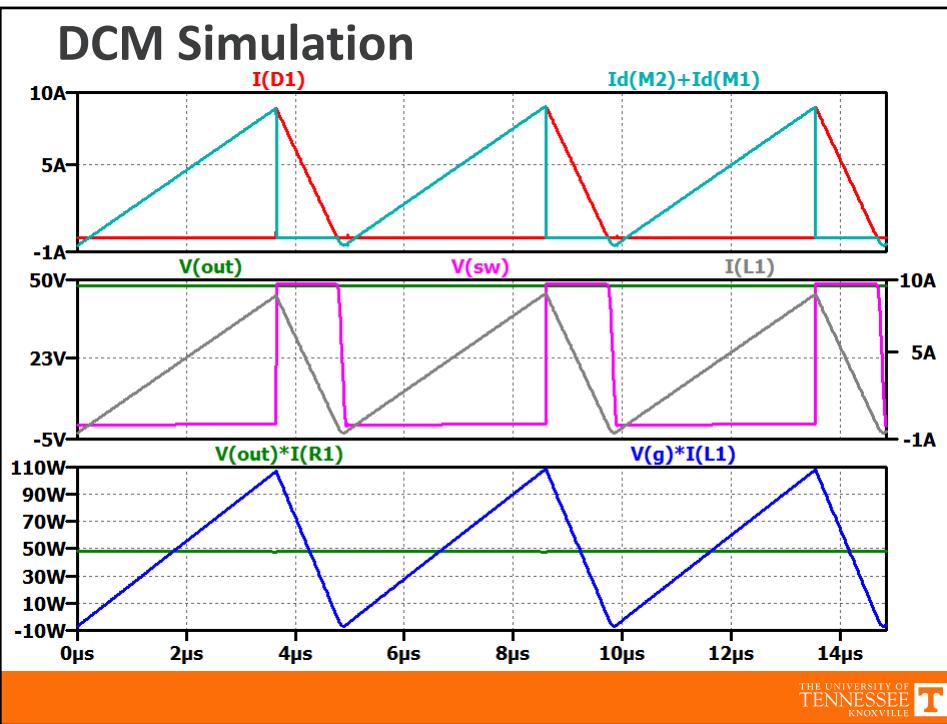
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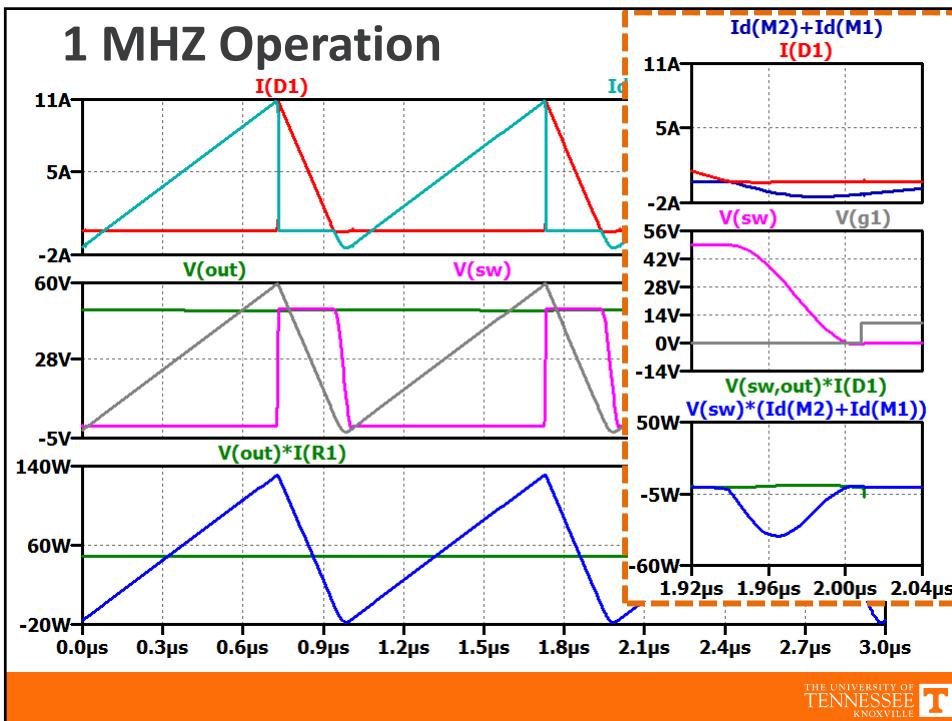
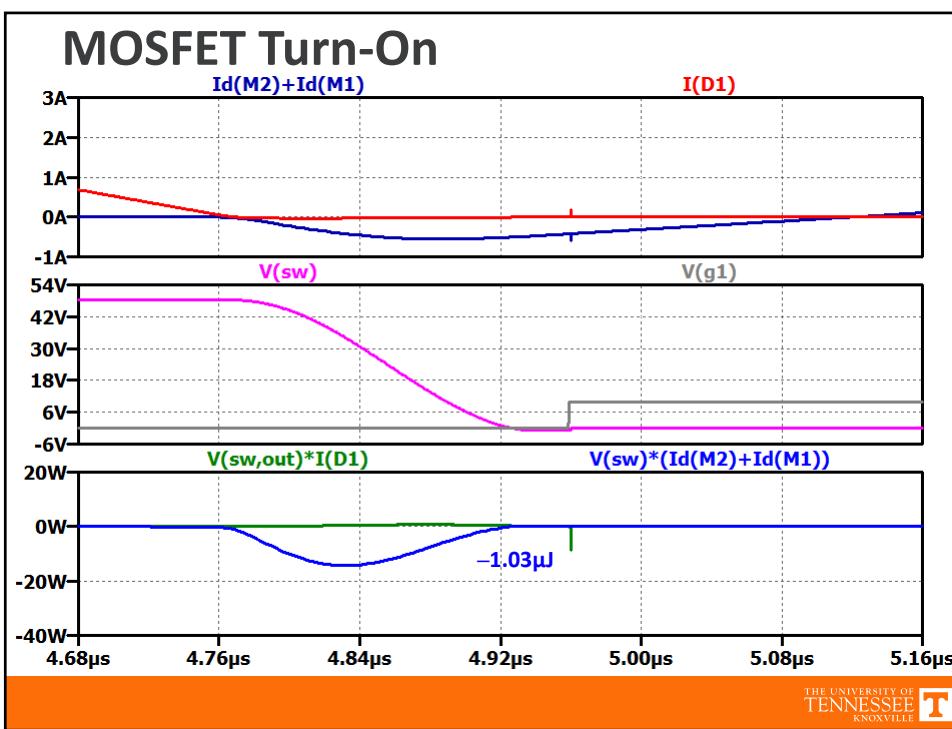
DCM: Soft Switching



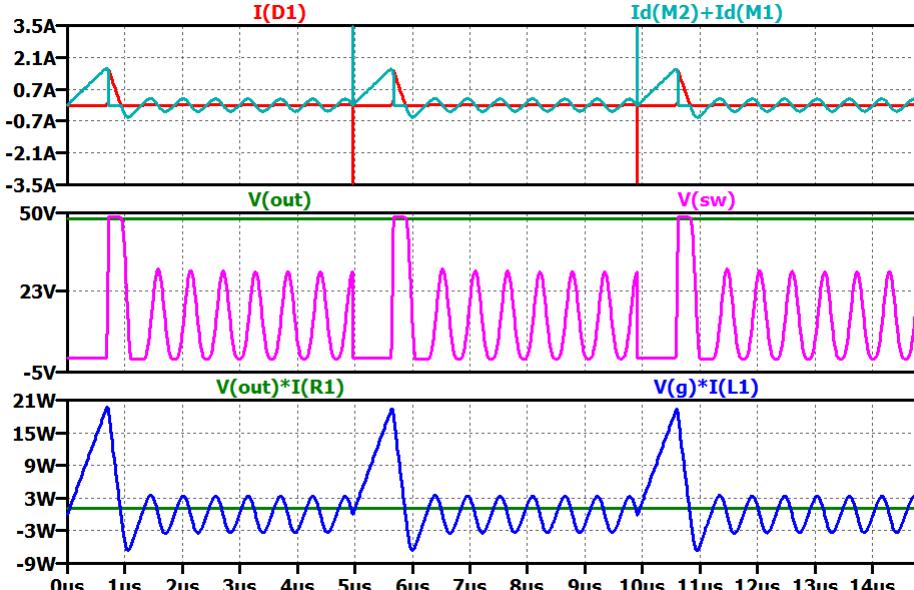
L	C_{out}	f_s	Diode	η (Sim)
22uH	22uF	202k	Si (FR)	93.9%
22uH	22uF	202k	Si Schottky	95.8%
4.6uH	22uF	202k	Si Schottky	98.2%

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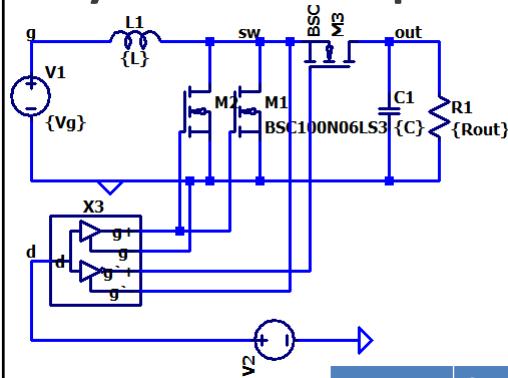


Low Power Operation



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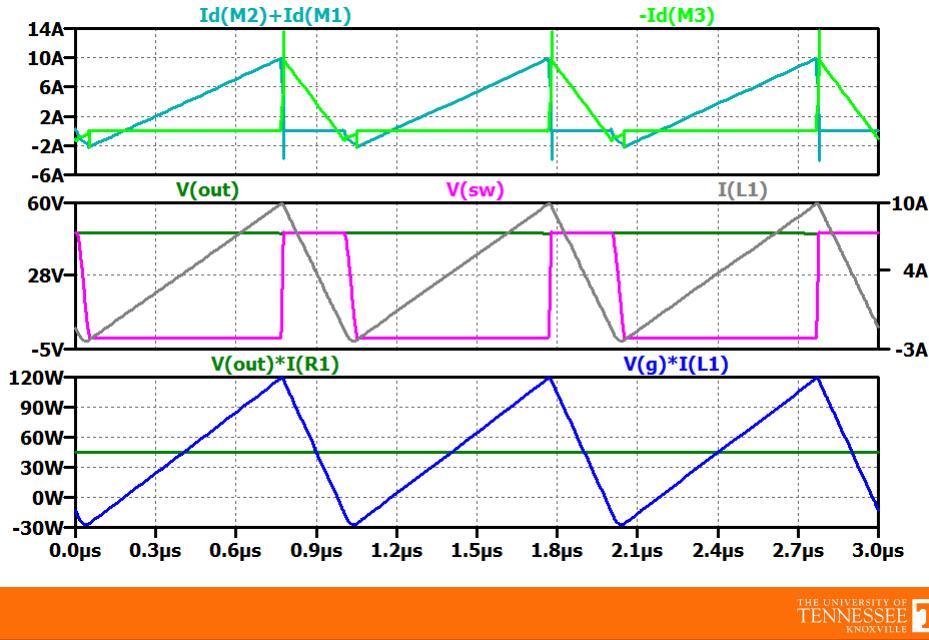
Synchronous Operation



L	C_{out}	f_s	Diode	η (Sim)
22uH	22uF	202k	Si (FR)	93.9%
22uH	22uF	202k	Si Schottky	95.8%
4.65uH	22uF	202k	Si Schottky	98.4%
710nH	4.4uF	1 MHz	Si Schottky	98.2%
710nH	4.4uF	1 MHz	MOSFET	99.6%

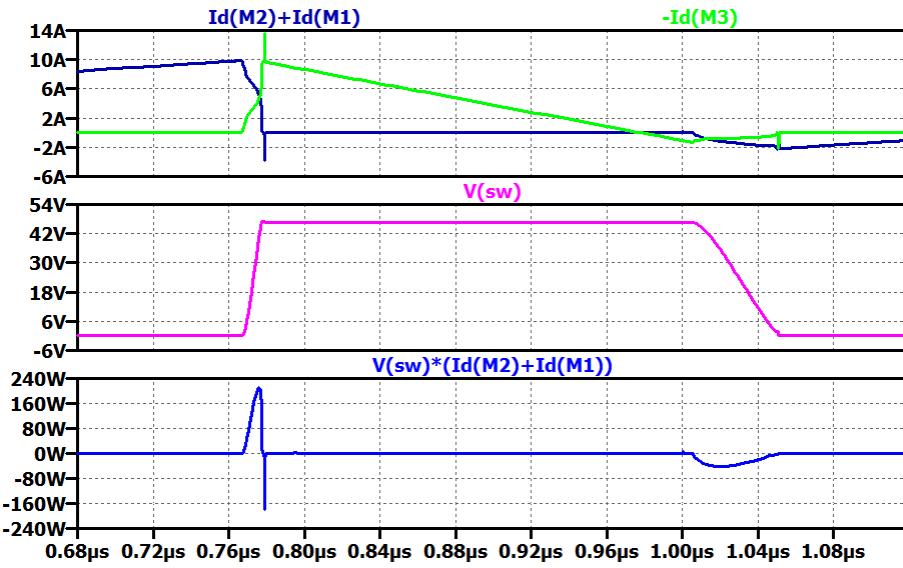
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Synchronous Simulation



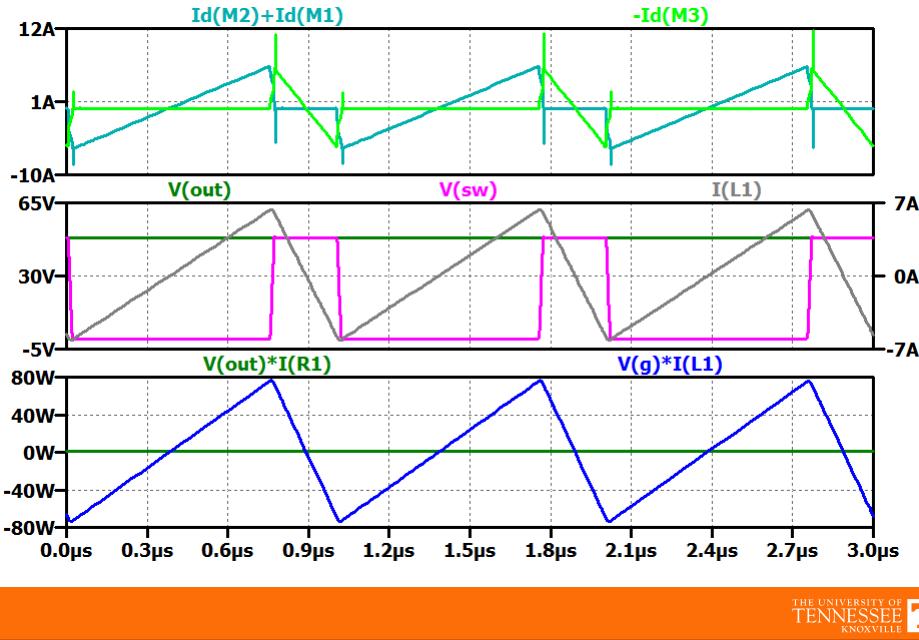
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Switching Transitions



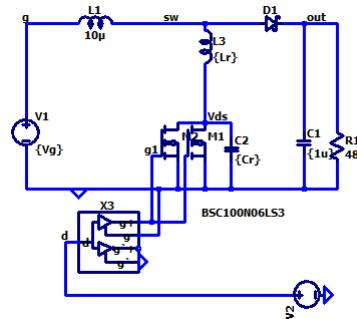
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Low Power Operation



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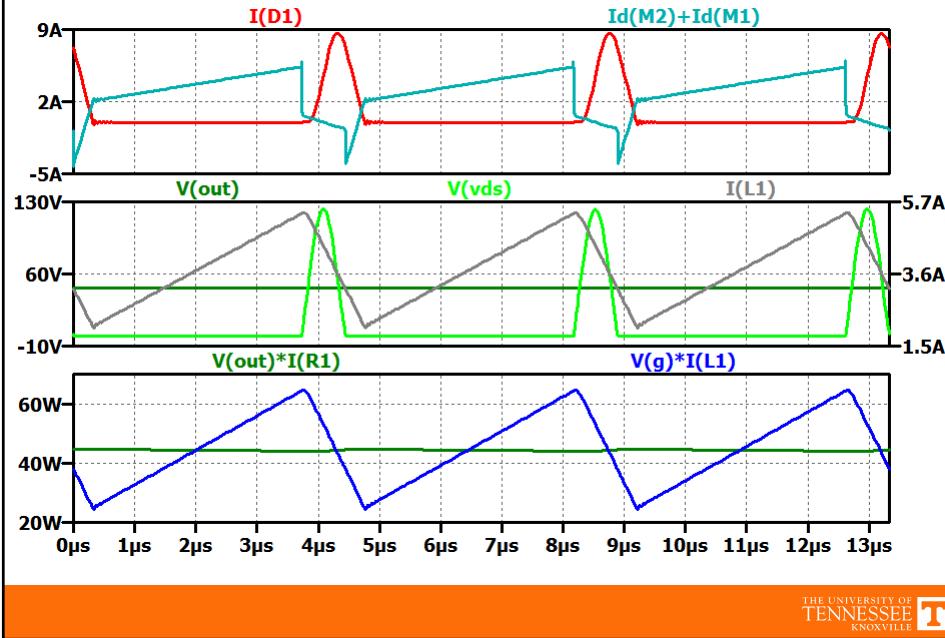
Resonant Operation



Switching	L	C_{out}	f_s	Diode	η (Sim)
Hard	22uH	22uF	202k	Si (FR)	93.9%
Hard	22uH	22uF	202k	Si Schottky	95.8%
Soft	4.65uH	22uF	202k	Si Schottky	98.4%
Soft	710nH	4.4uF	1 MHz	Si Schottky	98.2%
Soft	710nH	4.4uF	1 MHz	MOSFET	99.6%
Resonant	10uH + 2.4uH	1uF + 10nF	225 kHz	Si Schottky	98.6%

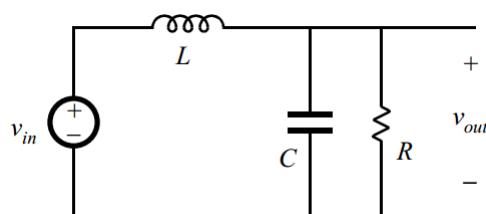
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Resonant Boost Converter



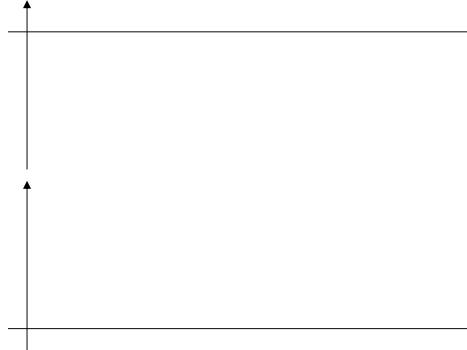
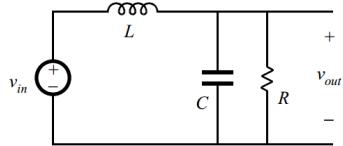
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Resonant Circuits



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Resonant Circuit Analysis

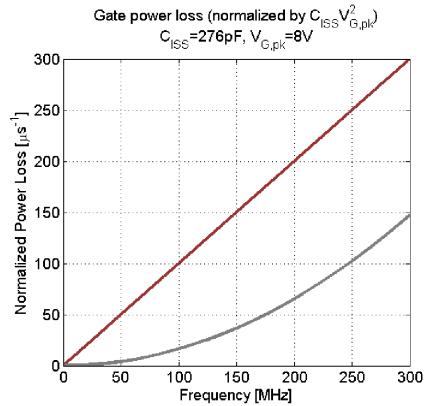
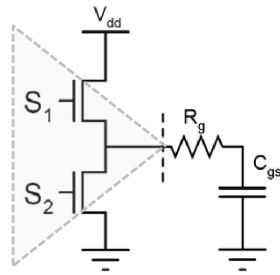


Soft Switching

- Advantages
 - Reduced switching loss
 - Possible operation at higher switching frequency
 - Lower EMI
- Disadvantages
 - Increased current and/or voltage stresses due to circulating current
 - Higher peak and rms current values
 - Complexity of analysis and modeling

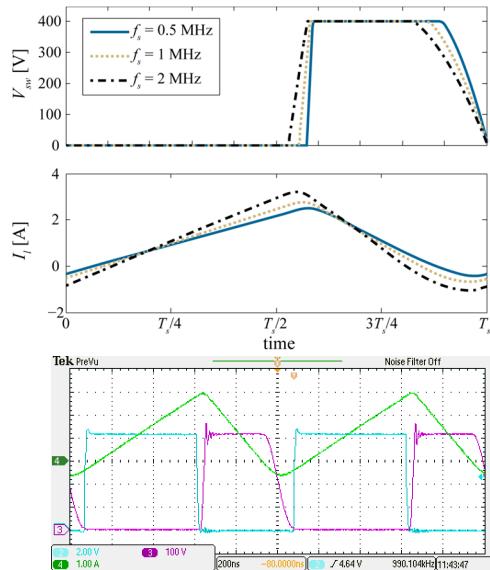


Limitations: Gate Drive



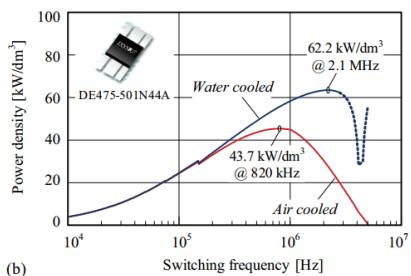
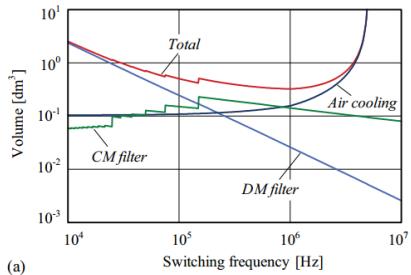
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Limitations: t_d/T_s



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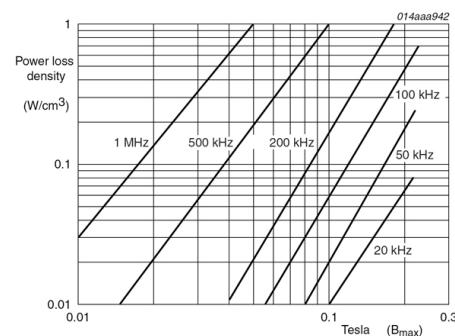
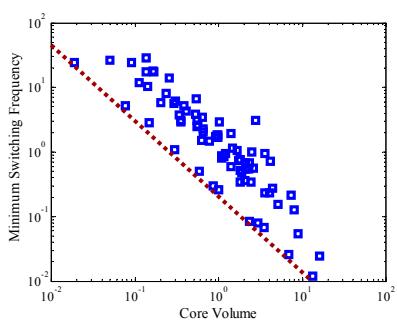
Limitations: Thermal



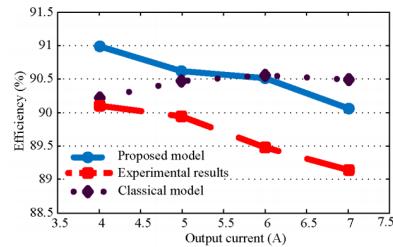
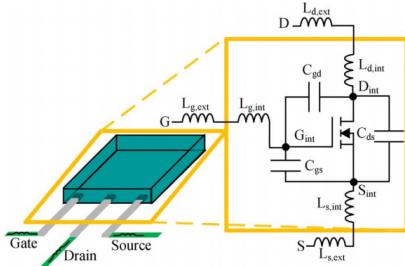
Kolar, J.W.; Drofenik, U.; Biela, J.; Heldwein, M.L.; Ertl, H.; Friedl, T.; Round, S.D., "PWM Converter Power Density Barriers," *Power Conversion Conference - Nagoya, 2007. PCC '07*, vol. no., pp.P-9,P-29, 2-5 April 2007



Limitations: Magnetics Design



Limitations: Circuit Modeling



Rodríguez, M.; Rodríguez, A.; Mijaya, P.F.; Lamar, D.G.; Zúñiga, J.S., "An Insight into the Switching Process of Power MOSFETs: An Improved Analytical Model," *Power Electronics, IEEE Transactions on*, vol.25, no.6, pp.1626-1640, June 2010

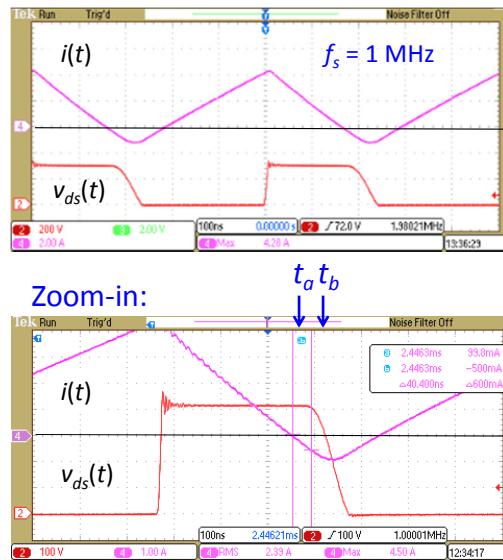


150-to-400V, 150W Boost

EXPERIMENTAL EXAMPLE



ZVS with Si diode



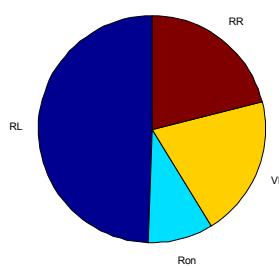
- **ZVS turn-ON**
 - Eliminated losses due to C_{sw} discharge during turn-ON transient
 - Eliminated losses due to MOSFET di_f/dt during turn-ON transient
- **Diode reverse recovery still impacts the waveforms and losses**
- **Increased current ripple**
 - Increased conduction losses (by >30%)
 - Increased dv_{ds}/dt upon turn-OFF, MOSFET turn-OFF speed is more important

D. Costinett, D. Maksimovic, R. Zane, A. Rodriguez and A. Vázquez, "Comparison of reverse recovery behavior of silicon and wide bandgap diodes in high frequency power converters"



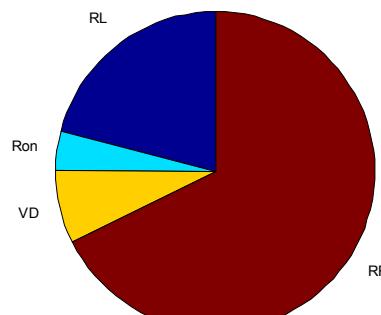
Loss Breakdown: Soft-Switched Si Boost

$$f_s = 100 \text{ kHz} \\ P_{loss} = 5.7 \text{ W}, \eta = 98.1\%$$



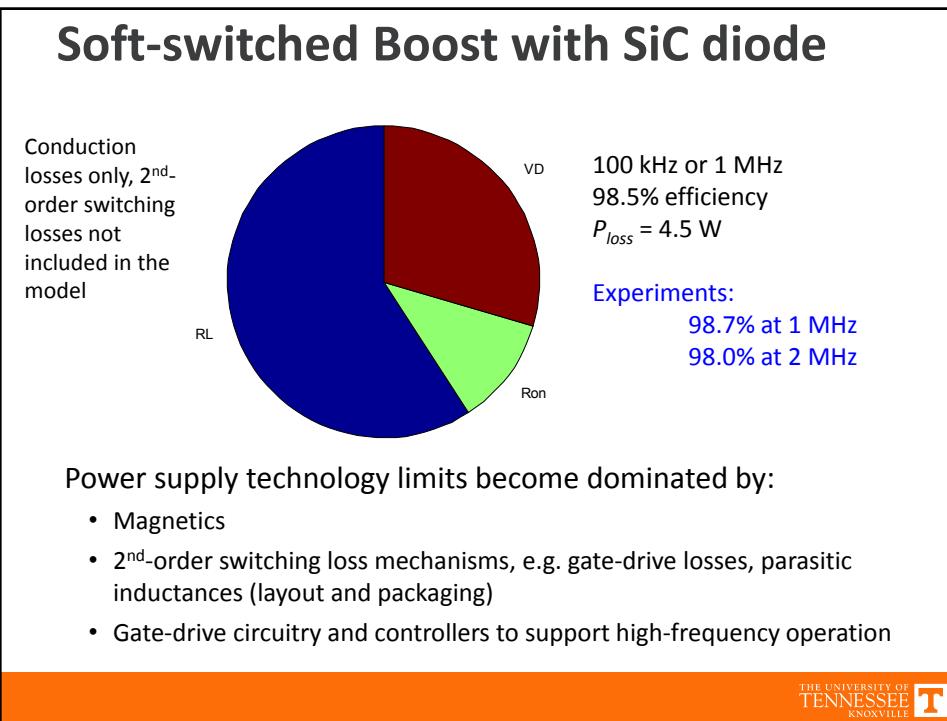
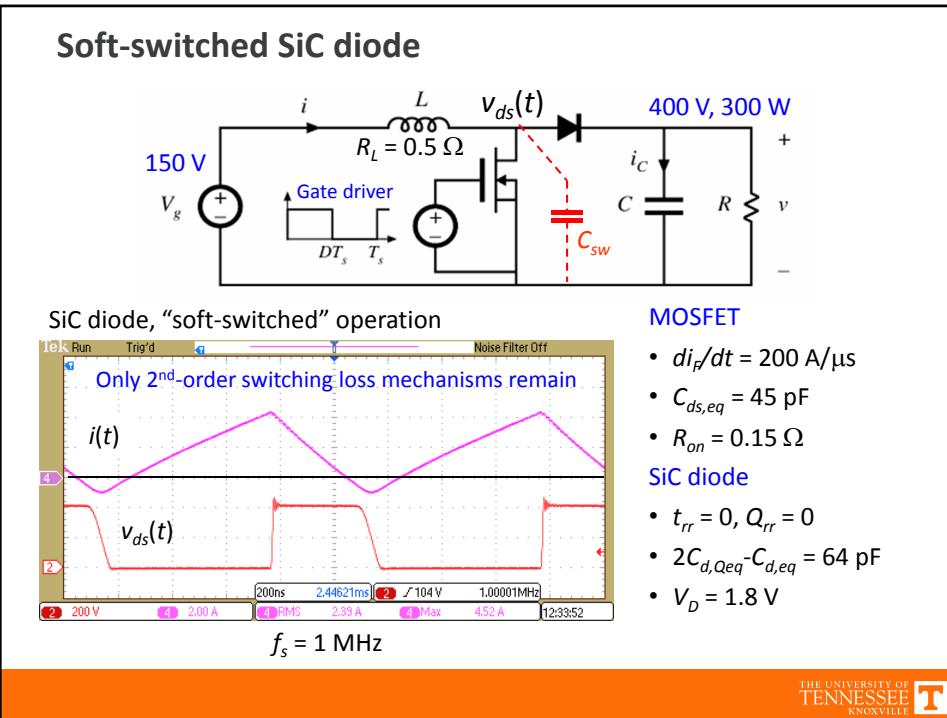
Reverse-recovery:
21% of the total loss

$$f_s = 1 \text{ MHz} \\ P_{loss} = 17.7 \text{ W}, \eta = 94.4 \% \\ \text{Experiment: } \eta = 95.1 \%$$



Reverse-recovery:
68% of the total loss





VHF power electronics [11]

Component	Resonant Design Value	Type
L_F	33 nH	Coilcraft 1812SMS
L_{2F}	12.5 nH	Coilcraft A04TG
L_{rect}	22 nH	1812SMS
C_{2F}	39 pF	ATC100A
C_{rect}	10 pF	ATC100A
C_{out}	75 μ F	Multilayer Ceramics
C_{in}	22 μ F	Multilayer Ceramics
S_{main}		Freescale MRF69090
D		Fairchild S310

Component	Conventional Design Value	Type
L_{boost}	10 μ H	Coilcraft D03316T-103ML
C_{out}	75 μ F	Multilayer Ceramics
C_{in}	22 μ F	Multilayer Ceramics
S_{main}		LT1371HV
D		Fairchild S310

Converter Efficiencies vs. Output Power

[11] D.J. Perreault, et.al. "Opportunities and challenges in very high frequency power conversion," IEEE APEC 2009.

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WBG Devices

Standard hard-switched PWM operation at 50 MHz
 dv_{ds}/dt dominated by probe (4 pF) capacitance

TriQuint TGF2023-02
12W, DC-to-18 GHz
RF/microwave HEMT

FOM for switching applications
 $C_{ds}R_{on} \approx 1 \Omega pF$
 $C_gR_{on} \approx 10 \Omega pC$

Emerging GaN HEMT devices may enable completely new RF-based design approaches in power electronics

M. Rodríguez, G. Stahl, D. Costinett and D. Maksimović, "Simulation and characterization of GaN HEMT in high-frequency switched-mode power converters,"

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Topics Covered

- **Course Topics**

- High Frequency Power Conversion
 - Switching losses and device selection
 - Resonance in power electronics
 - Soft switching (ZVS and ZCS)
 - Magnetics design
- Non-resonant soft switching converters
 - Constant frequency control
 - State-plane analysis
 - Resonant switches
 - Modeling and Simulation
 - Discrete time models
- Resonant Converters
 - Resonant converter topologies
 - Sinusoidal analysis
 - AC-modeling and frequency modulation
 - State-plane analysis
- Applications and practical issues of high frequency converters

