P45 - SWITCHING CHARACTERISTICS AND DATA SHEET REALISATION OF MOSFET

B.Tech Project

Department of Electrical Engineering

By

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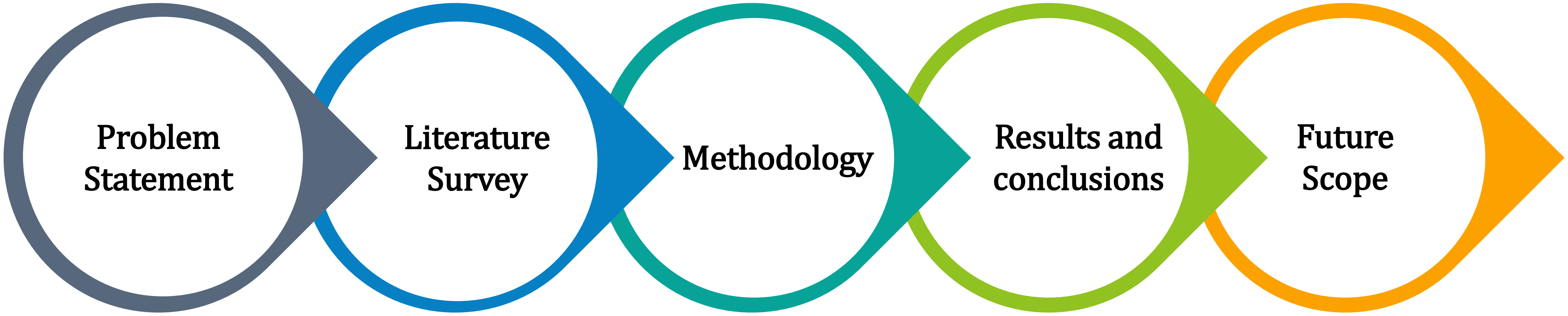
PROJECT OUTLINE



Tracing the evolution of gate drivers and MOSFET dynamics.

From simulation to soldering — bridging theory and hardware.

Turning waveforms into insights

PROBLEM STATEMENT AND MOTIVATION

Motivation

Understanding practical switching characteristics by analysing

"Switching Control"
"Switching Performance"
"Efficiency"

Practical application of Datasheet realisation:
- Smart component selection
- Design validation & troubleshooting
- Optimized switching & driver design

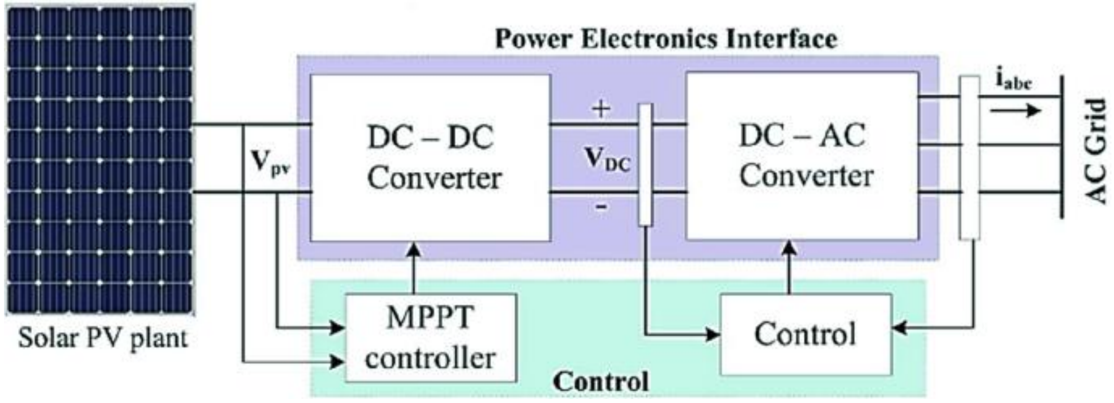


Fig : Use of power electronic converters in inverter

Tasks/Goals of P.S :

1. Analyze MOSFET switching behavior (delays, losses)
2. Optimize gate driver design
3. Measure switching waveforms experimentally
4. Validate datasheet parameters through testing
5. Apply to real-world power electronics applications

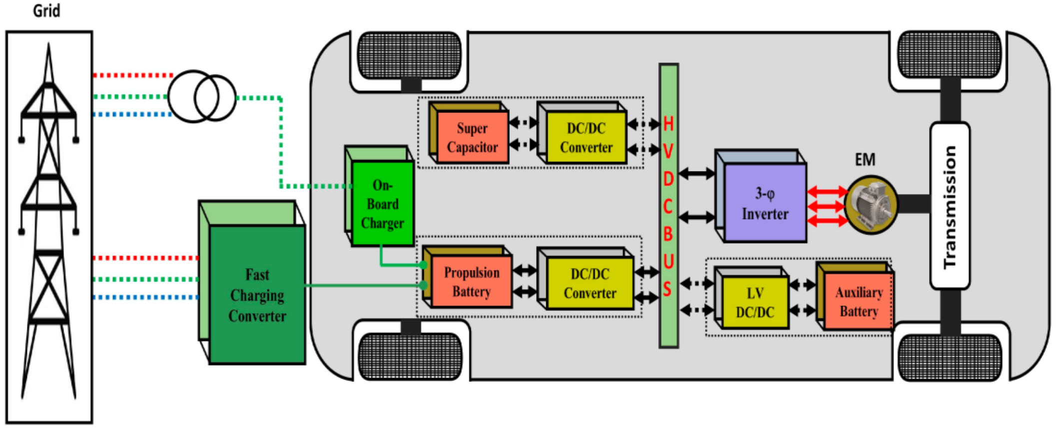
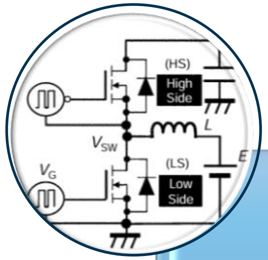


Fig : Use of power electronic converters in electric vehicles

[1]https://share.google/images/1McGvcscESnt15JA6
[2]https://share.google/images/J48pioUbL19TCVagN

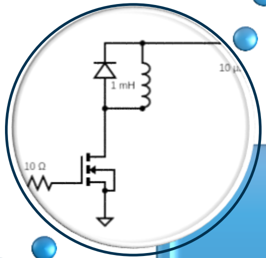
How to approach the problem statement ?

Application to real-world power electronics



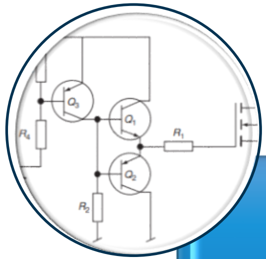
Buck converter

- Asynchronous Buck converter
- Synchronous buck converter



Double pulse test

Validation datasheet parameters using these methods



Gate driver circuit

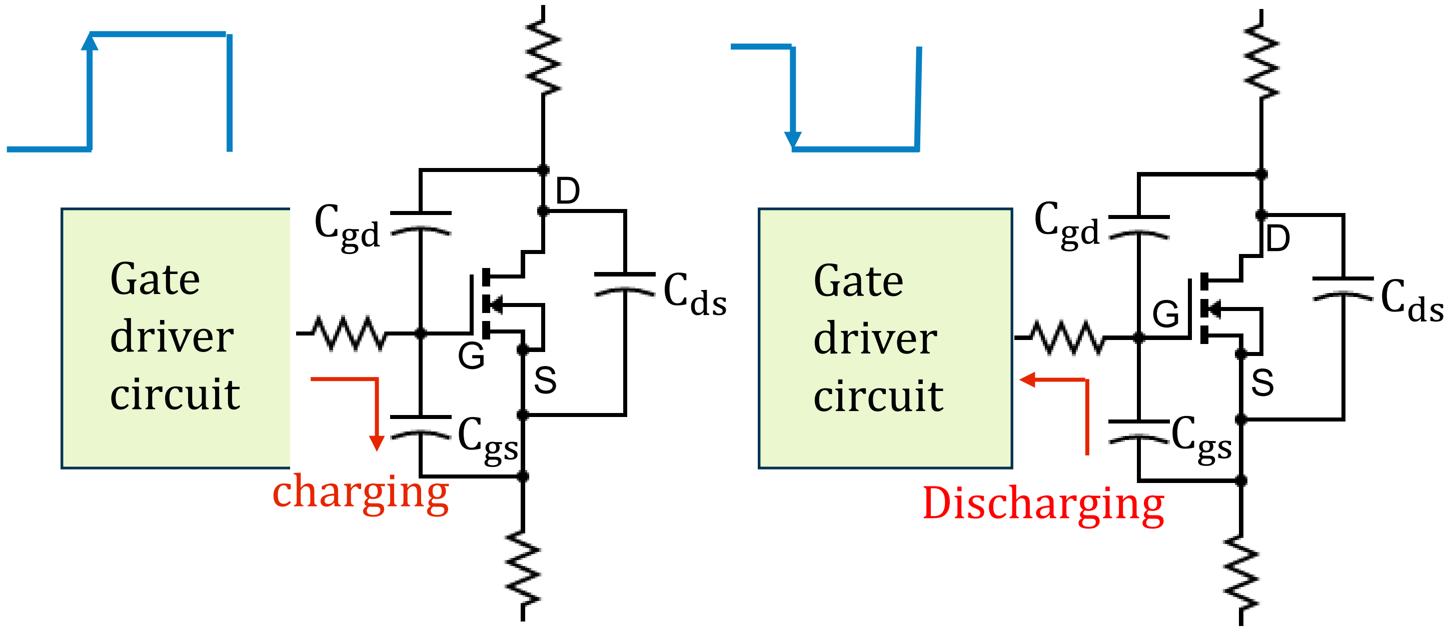
- Non-isolated gate driver
- Isolated gate driver (TLP250)
- Advanced gate driver (TLP5214)

LITERATURE REVIEW

Switching of MOSFET:

MOSFET TURN-ON

MOSFET TURN-OFF



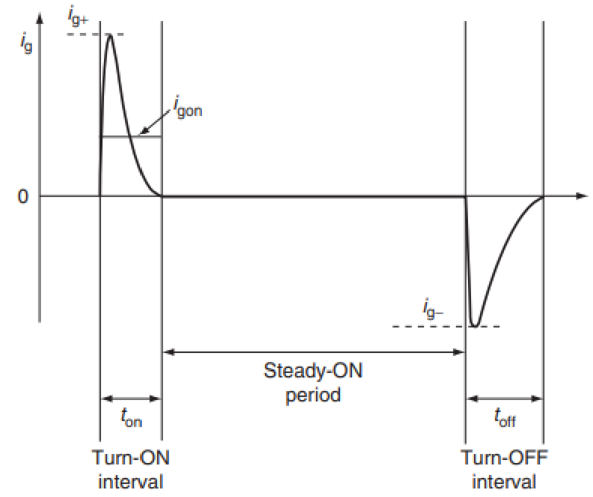


Fig : Gate current waveform

Gate driver circuit:

- Connected to the gate terminal of the MOSFET
- Power amplifier that converts low-power control signals to high-current gate drive signals
- Protect sensitive control circuits from high-voltage power stage noise

Gate charging and discharging depends on:

- Gate-source voltage
- Gate resistance
- Gate Driver Strength (Drive Current)
- Gate capacitance
- Gate charge

Non-Isolated Gate Driver Circuit

Design:

- Non-isolated gate drivers share the common ground on both sides
- **Input: 3.3V** pulse from microcontroller
- **Output: 15V** at the gate of the MOSFET
- Push-pull circuit with 2 NPN and 1 PNP transistors.

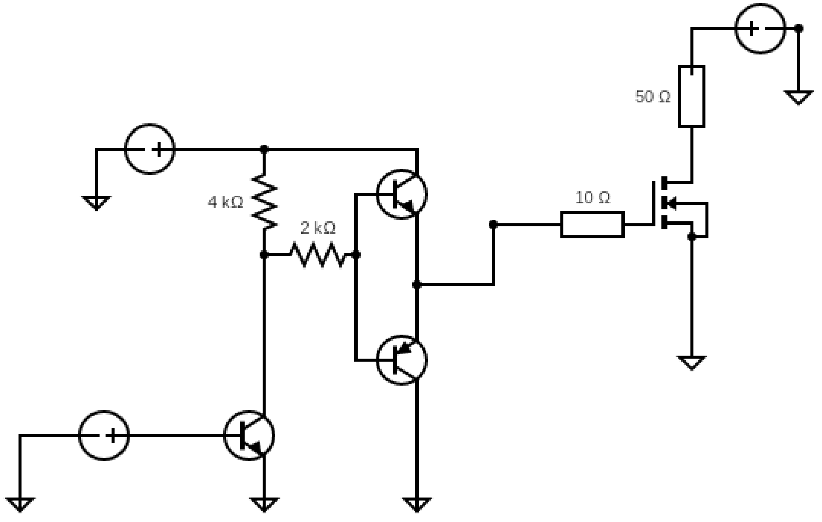


Fig : Non-isolated gate driver circuit

Calculations

- ❑ The values of gate/limiting resistance is calculated assuming Ton=0.5us

$$Q_g = (I_g) \text{ x } t_{on}$$
$$I_g = 63nC/0.5\mu s$$
$$I_g = 126mA$$

$$\text{Peak } I_g = I_g \text{ x } 2 = 252mA$$

$$R_g = V_{cc}/\text{peak } I_g$$
$$R_g = 15V/252mA$$
$$R_g = 59.5\Omega$$

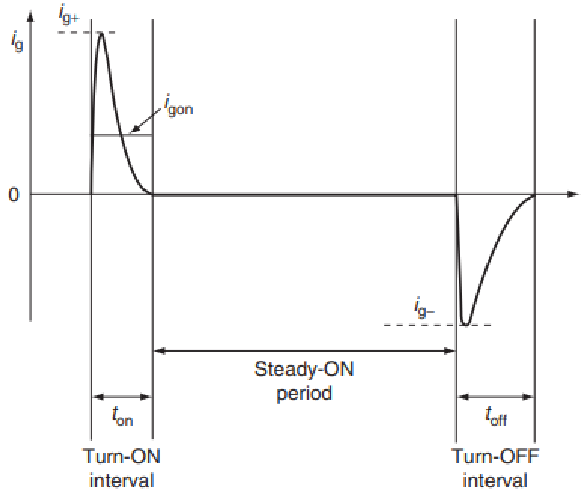


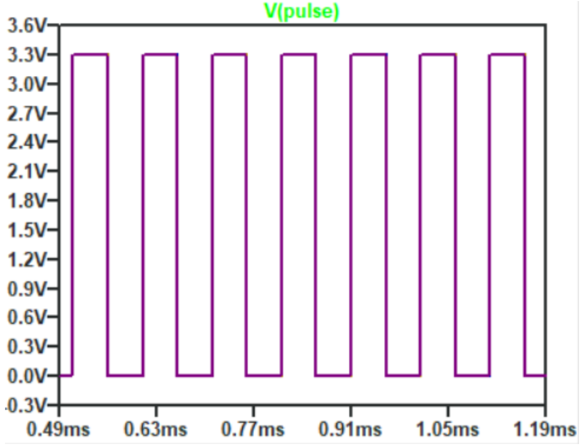
Fig : Gate current waveform

Table : Datasheet values of IRF840

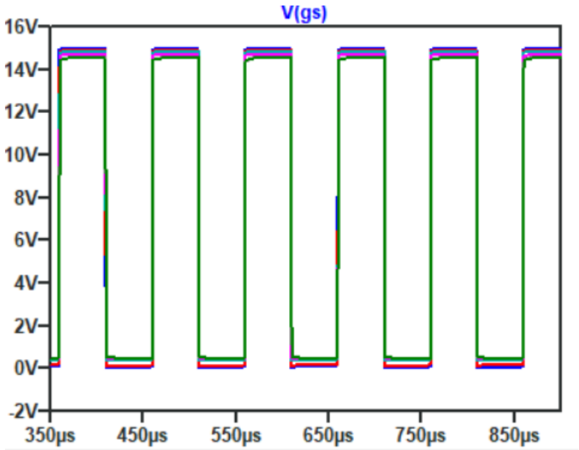
Parameter	Value
V_{ds}(max)	500V
Q_g(max)	63nC
V_{gs}(max)	20V

L.Umanand, "Power Electronics Essentials and Applications," New Delhi, India: Wiley India, 2009.

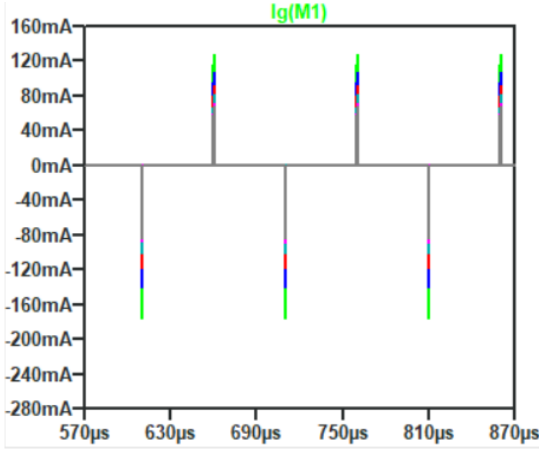
Simulation results



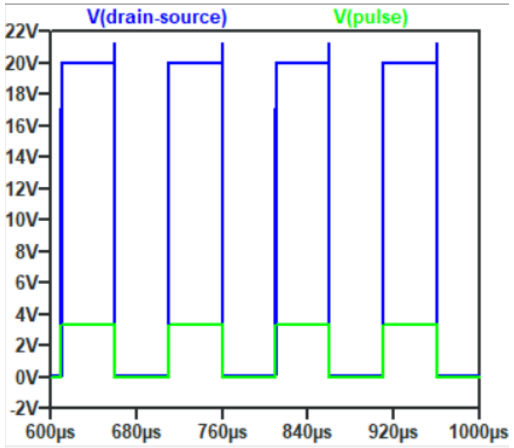
V_{in}=3.3V



V_{gs} =15V



Gate current



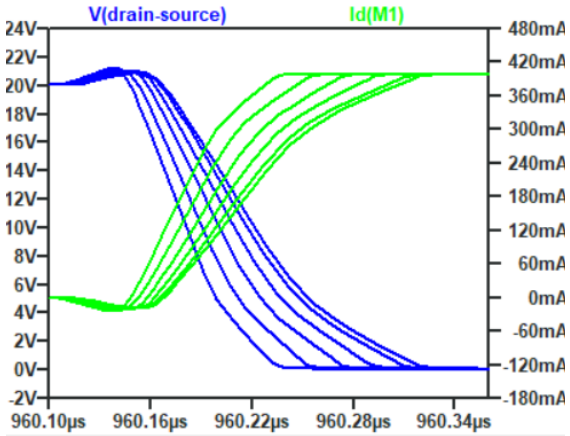
Drain-source voltage and input pulse

1.Variation of gate resistance

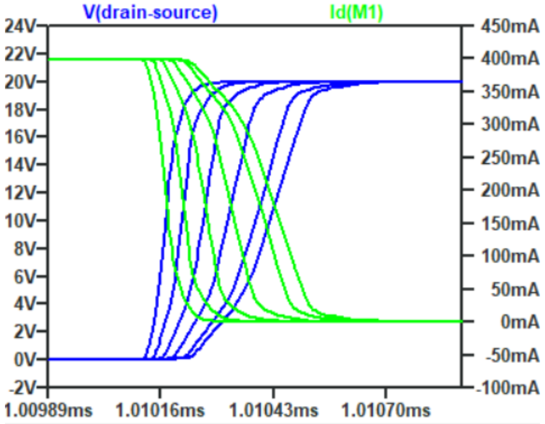
- Gate resistance is varied keeping all other parameters constant

  10 <R <100

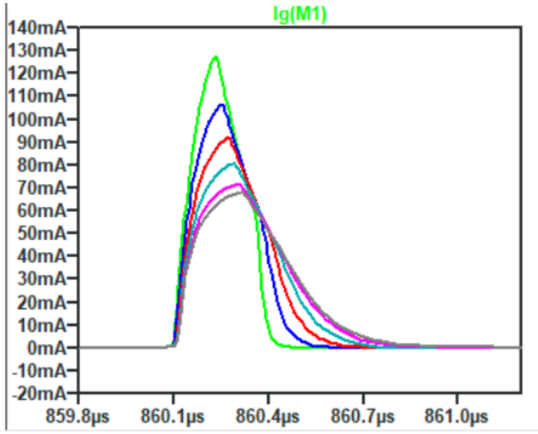
  V_{gs} = 15V



V_{ds} decreases and I_d increases during turn-on



V_{ds} increases and I_d decreases during turn-off



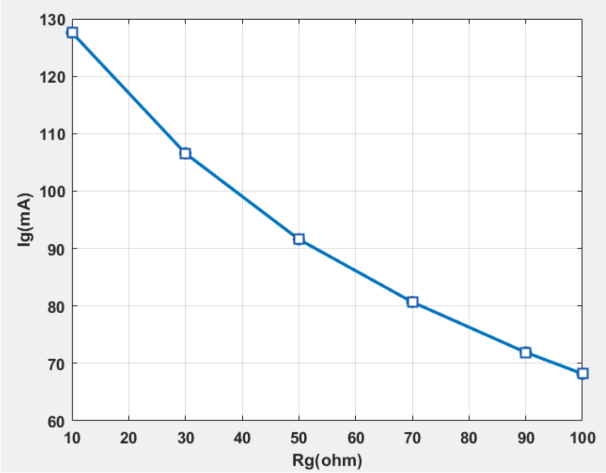
Waveform of gate current

Table : Variation of parameters with gate resistance

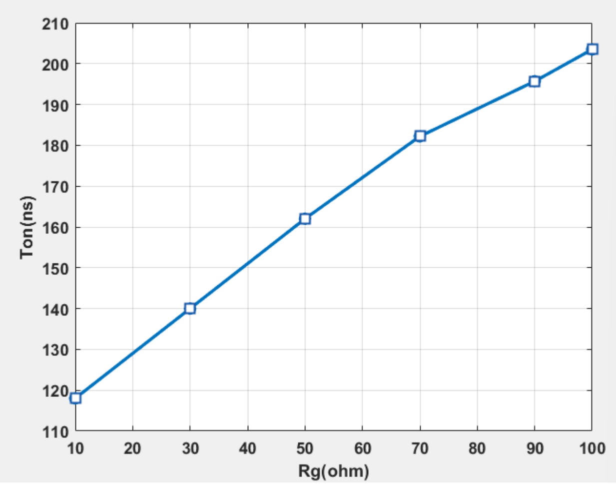
Gate resistance(Ω)	Peak current(mA)	Turn-on time(ns)	Turn-off time(ns)
10	127.6	118	151.4
30	106.57	140	189
50	91.6	162	247
70	80.68	182.2	306.5
90	71.92	195.7	374
100	68.19	203.5	390.4

As gate resistance increases

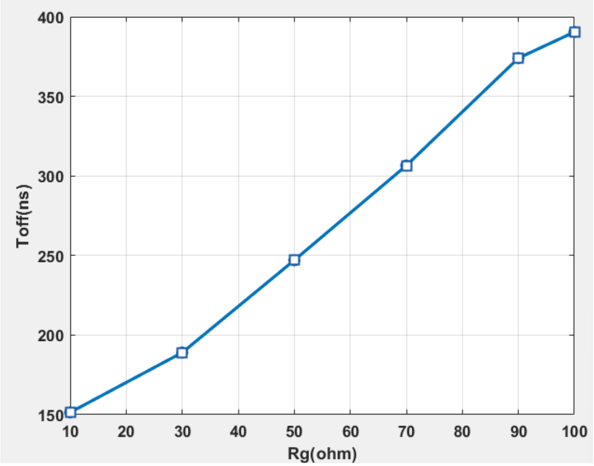
- Peak gate current decreases
- Turn-on time increases
- Turn-off time increases



Variation of Peak gate current with gate resistance



Variation of Turn-on time with gate resistance



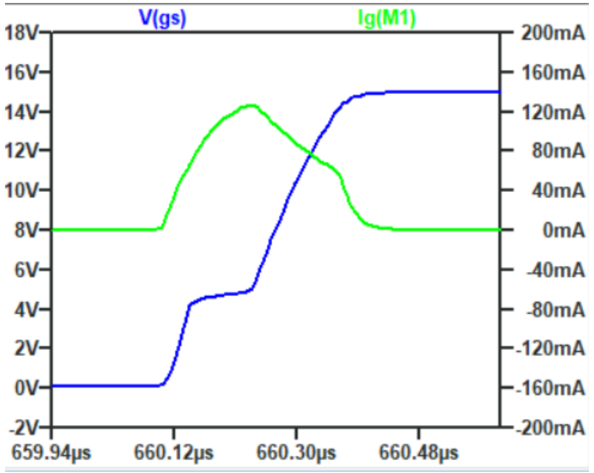
Variation of Turn-off time with gate resistance

Calculation of gate charge :

$$Q_{gs} = I_{avg} \cdot \Delta t$$
$$Q_{gs} = 80 \text{ mA} \times 0.12\mu s$$
$$Q_{gs} = 9.6nC$$

$$Q_{gd} = 85 \text{ mA} \times 0.24\mu s$$
$$Q_{gd} = 20.4 \text{ nC}$$

$$Q_g = Q_{gs} + Q_{gd} = 9.6 + 20.4 = 30nC$$



V_{gs} vs I_g

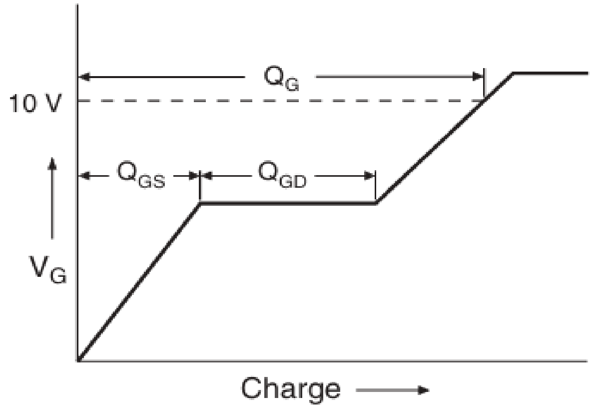
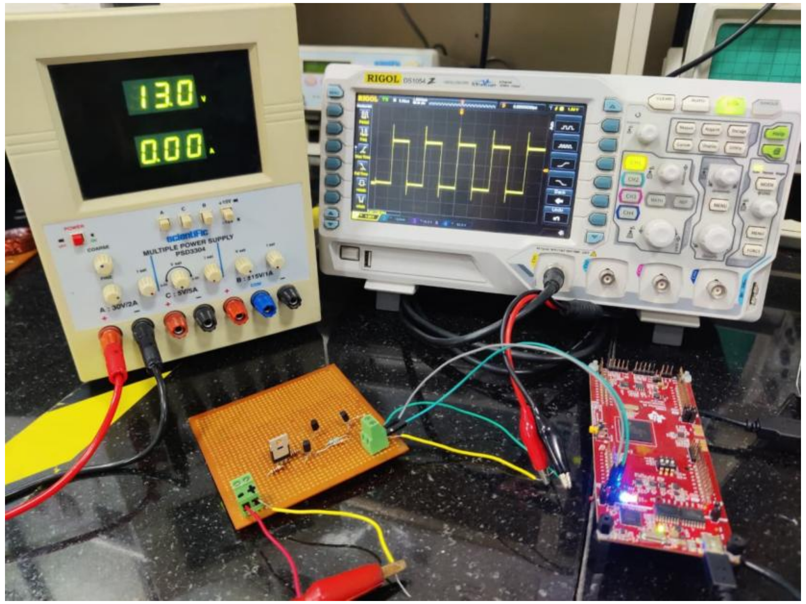


Fig : Gate charge waveform

Hardware



Hardware Results

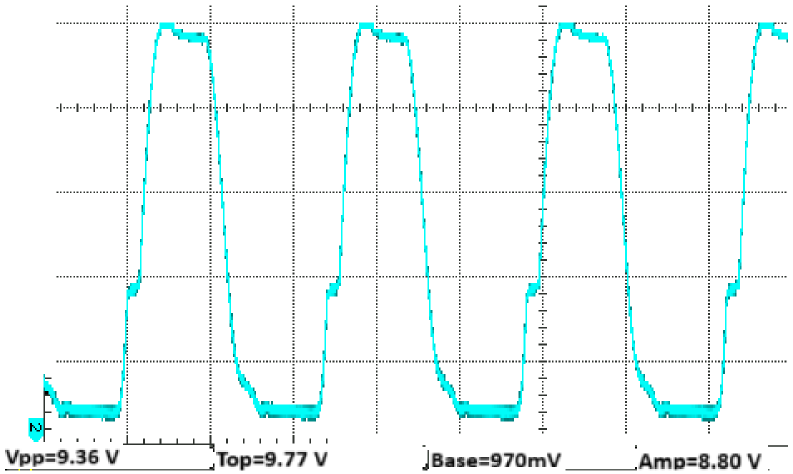


Fig : Waveform of gate-source voltage

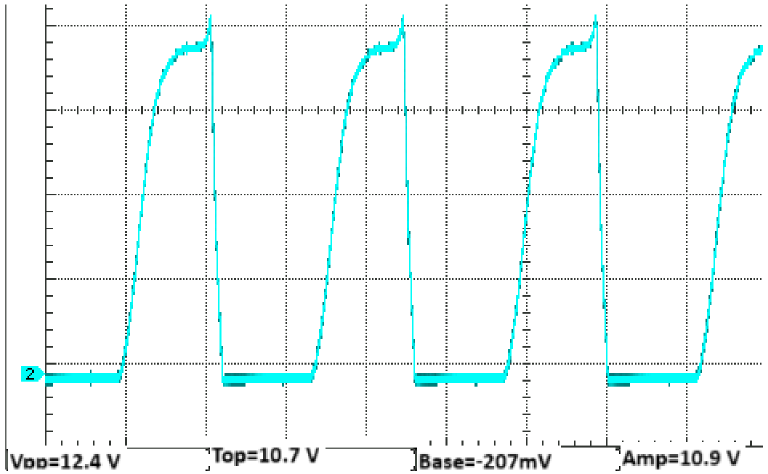


Fig : Waveform of drain-source voltage

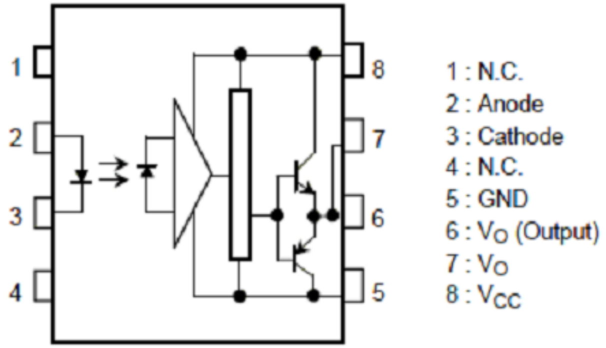
[1]*L.Umanand, "Power Electronics Essentials and Applications," New Delhi, India: Wiley India, 2009.*

Gate driver with TLP250

TLP250

- 8 pin DIP
- Provides galvanic isolation
- Protects control circuits from high voltages and noise.

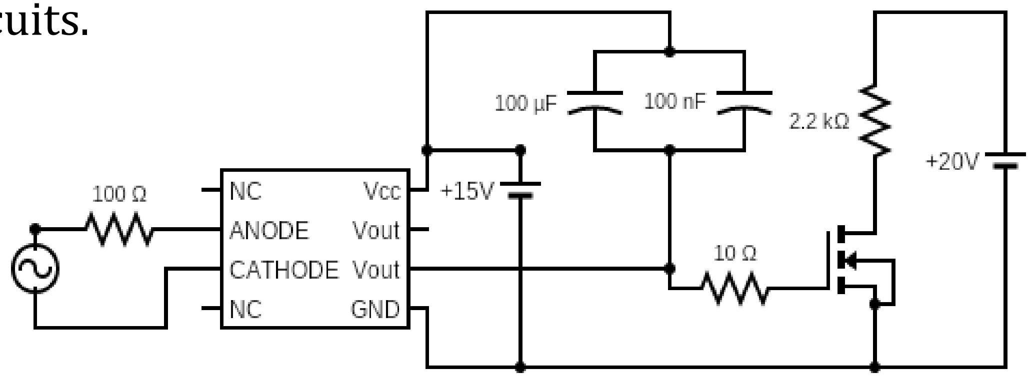
Pin Configuration (top view)



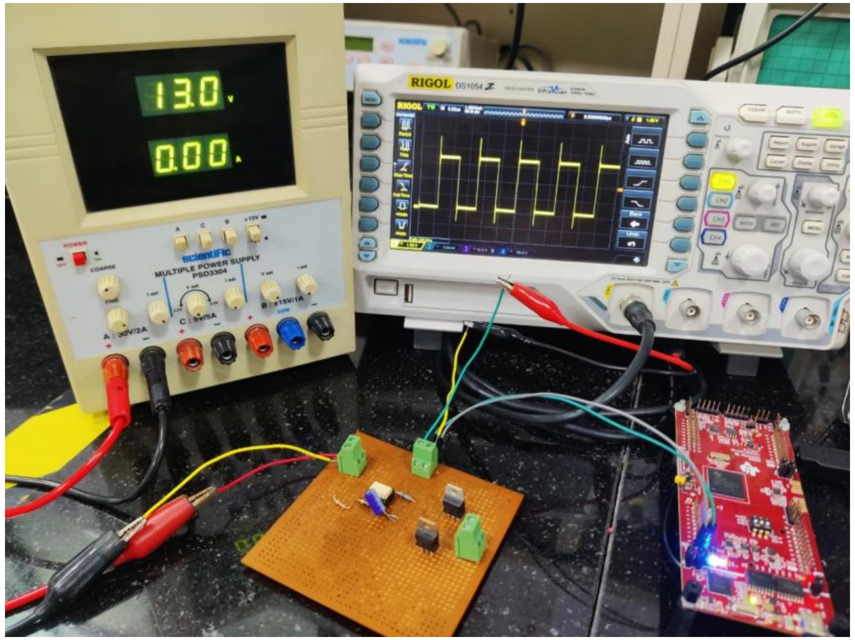
- Input supply voltage range: 10–35 V
- Output drive current: 1.5 A (max)
- Operating frequency: up to 25 kHz

Design and Simulation

- Include the .subckt model in LTspice to simulate realistic gate driver behavior.
- Use L7905,L7815 regulators to generate isolated voltage supplies for the gate driver stage
- Separate supply and ground domains for control and power circuits.



Hardware



[1] Toshiba, “TLP250: Gate Drive Optocoupler Datasheet,” Toshiba Semiconductor & Storage Products, 2020.

Smart Gate Driver using TLP5214

TLP5214

FEATURES:

1. Overcurrent protection
2. Desaturation (DESAT) detection
3. Miller clamping function
4. Fault outputting function
5. UVLO (under voltage lockout) function
6. Gate driver coupler

Specifications

- Output current: ±4.0 A peak
- Supply voltage 15–30 V

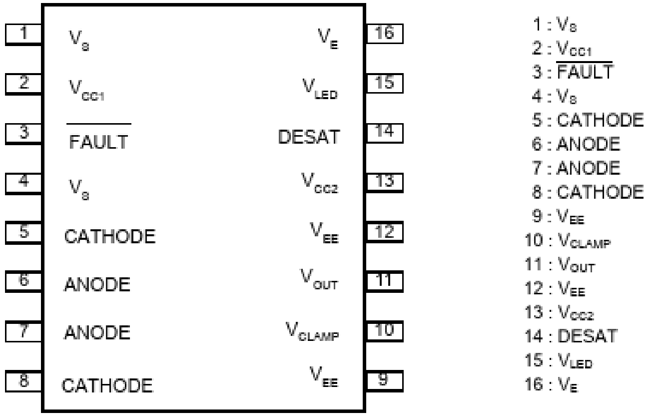
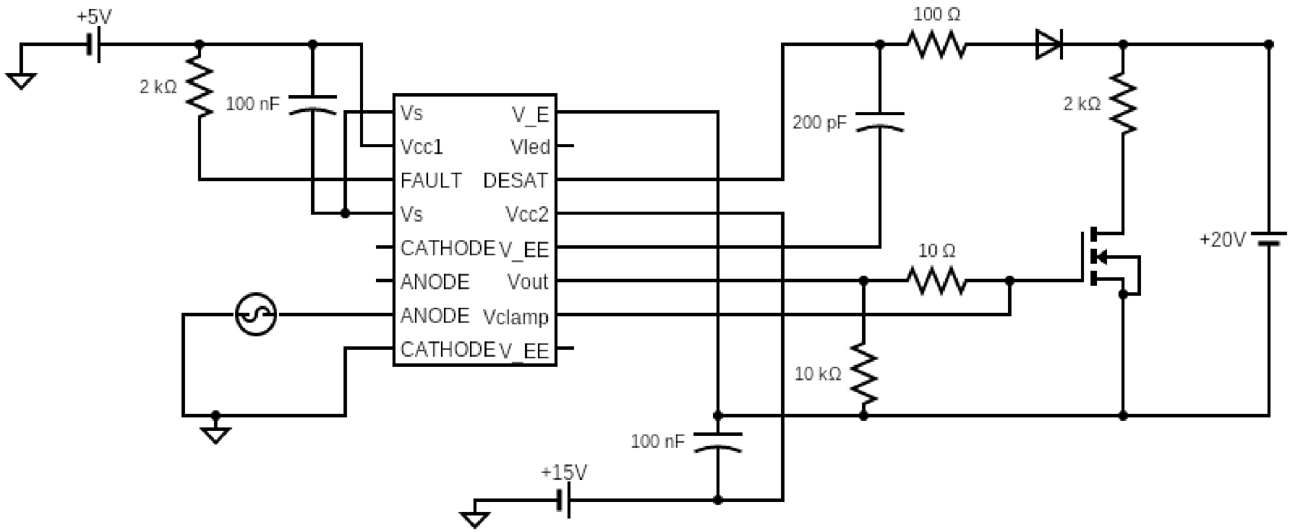


Fig : Pinout of TLP5214

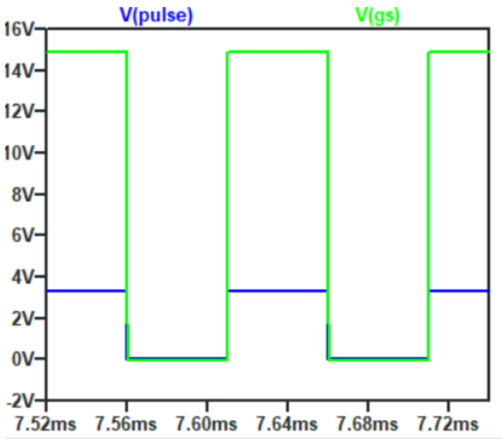
Design

- Include the .subckt model in LTspice to simulate realistic gate driver behavior.
- Use L7905, L7815 regulators to generate isolated voltage supplies for the gate driver stage
- Separate supply and ground domains for control and power circuits.

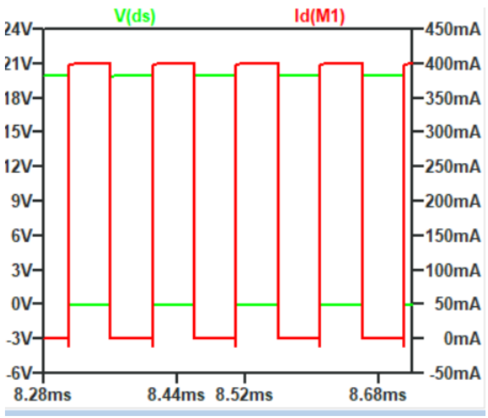


[1] Toshiba, "TLP5214: Gate Drive Optocoupler Datasheet," Toshiba Semiconductor & Storage Products, 2020.

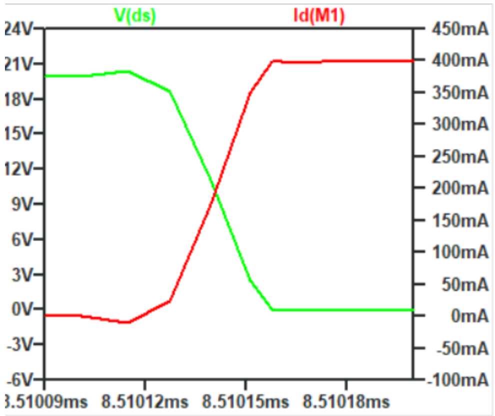
Simulation results



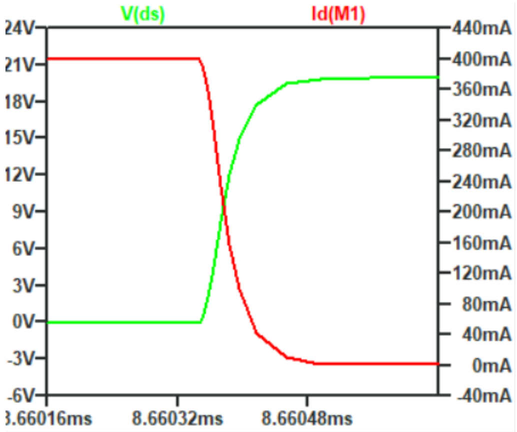
V_{pulse}=3.3V ; V_{gs}=15V



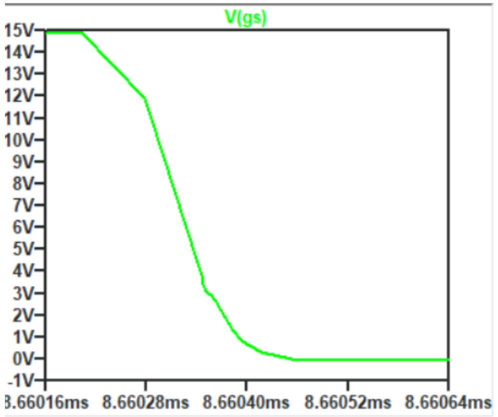
V_{ds}=20V ; I_d =400mA



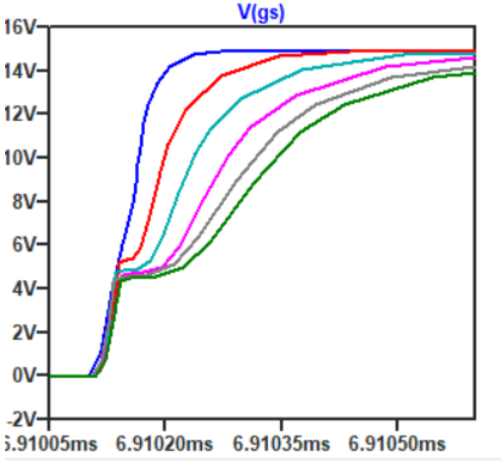
Turning-on transient



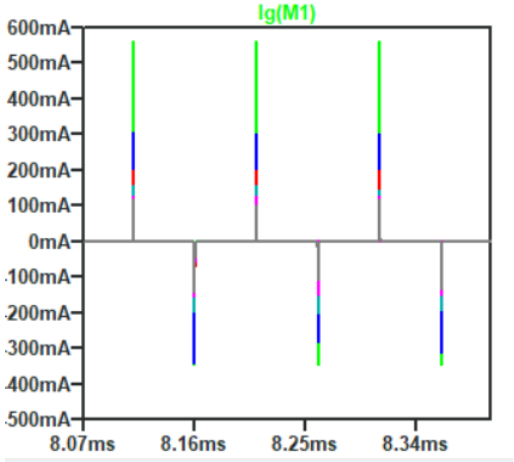
Turning-off transient



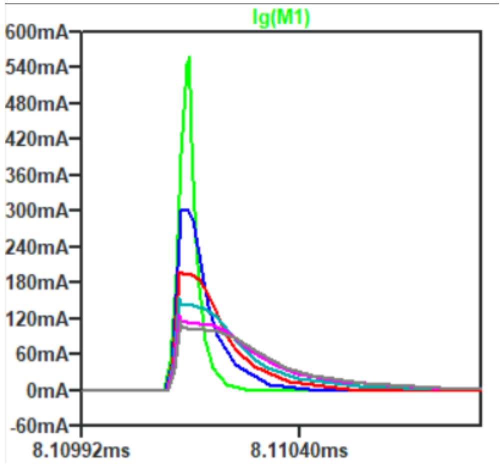
Waveform of V_{gs} during turn-off



V_{gs} waveform with miller plateau



Waveform of gate current



Waveform of positive gate current

HOW OPTOCOUPLERS EFFECT SWITCHING?

2. Variation of Gate driver

Comparison of peak gate current

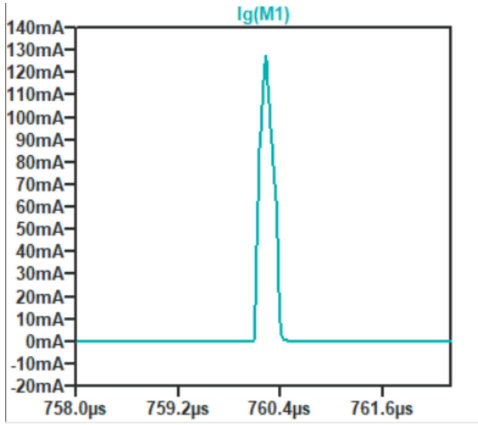


Fig : Gate current of Non-isolated driver

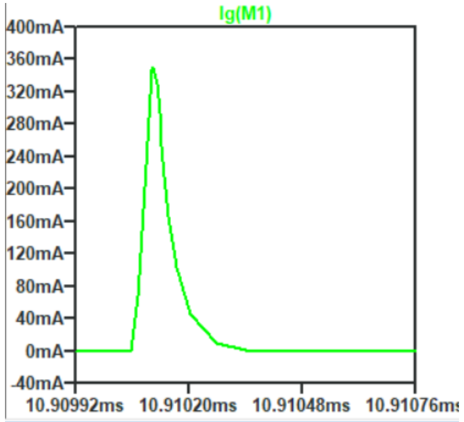


Fig : Gate current of TLP250

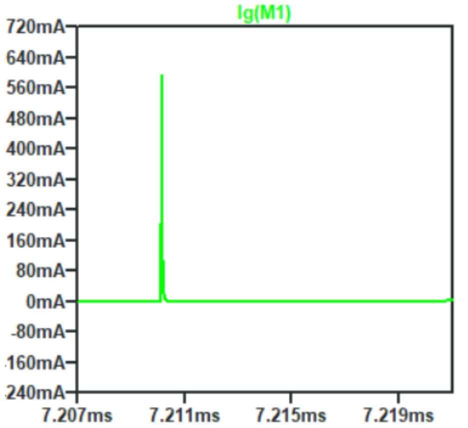
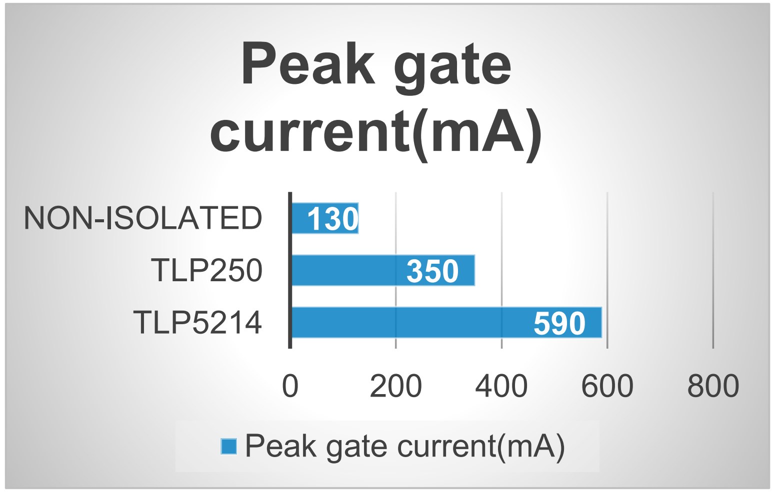
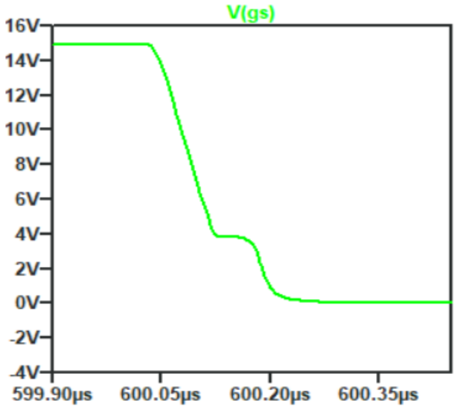


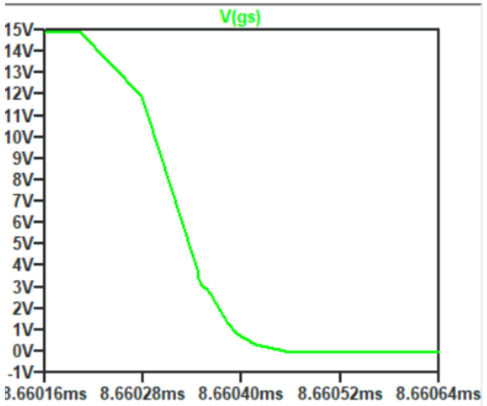
Fig : Gate current of TLP5214



Turn-off

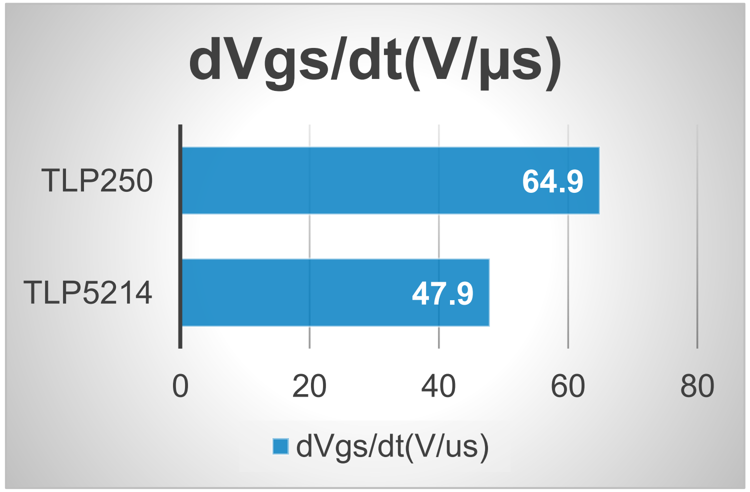


Drop of V_{gs} during turn-off in TLP250



Drop of V_{gs} during turn-off in TLP5214

- TLP5214 has higher gate driver strength during turn –on
- It delivers less gate current during turn-off to reduce stress on MOSFET at high switching frequencies



Double Pulse Test

Experimental Approach to Switching Evaluation

- Double Pulse Test(DPT) is the standard test for measuring switching losses and dynamics.
- Determines dv/dt and di/dt limitations.
- Used for validating MOSFET models in converters.

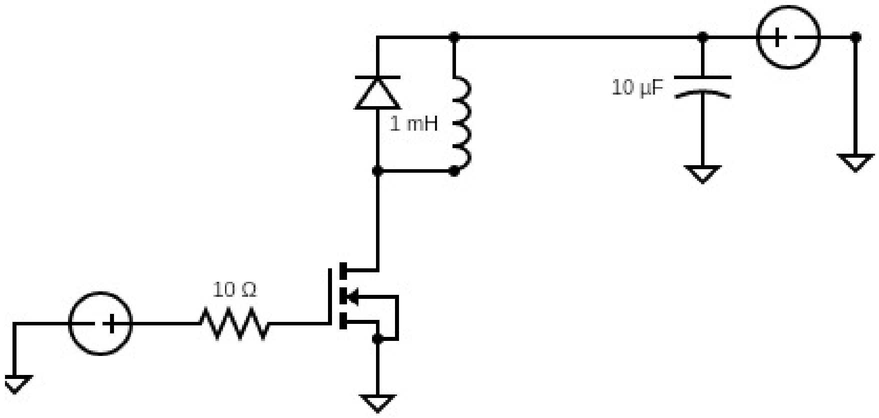
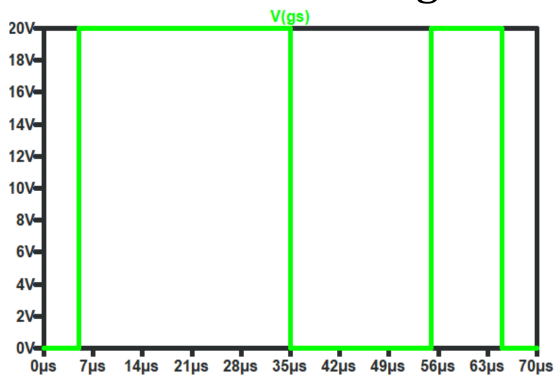


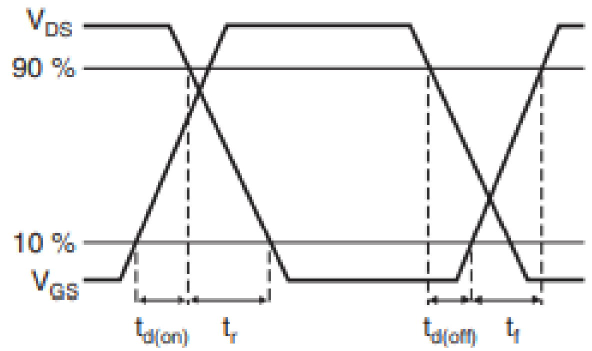
Fig : Double pulse test circuit



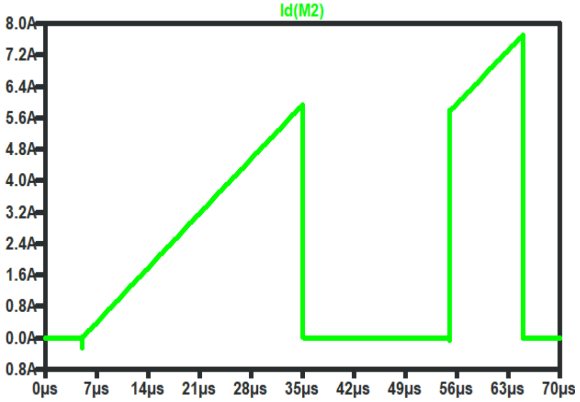
The test uses two gate pulses:

1. First Pulse – establishes load current through the inductor.
2. Second Pulse – measures switching behavior when current commutates through the freewheeling diode and back.

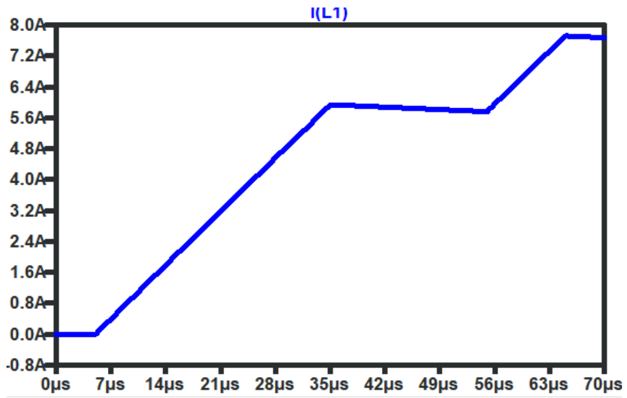
Width of Pulse1 = 30μs ; Gap Width = 20μs ; Width of Pulse2 = 10μs



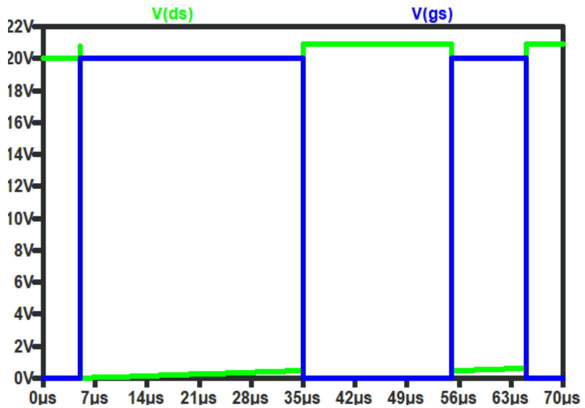
Simulation results



Waveform of Drain current



Waveform of Inductor current



Turning on and off transient

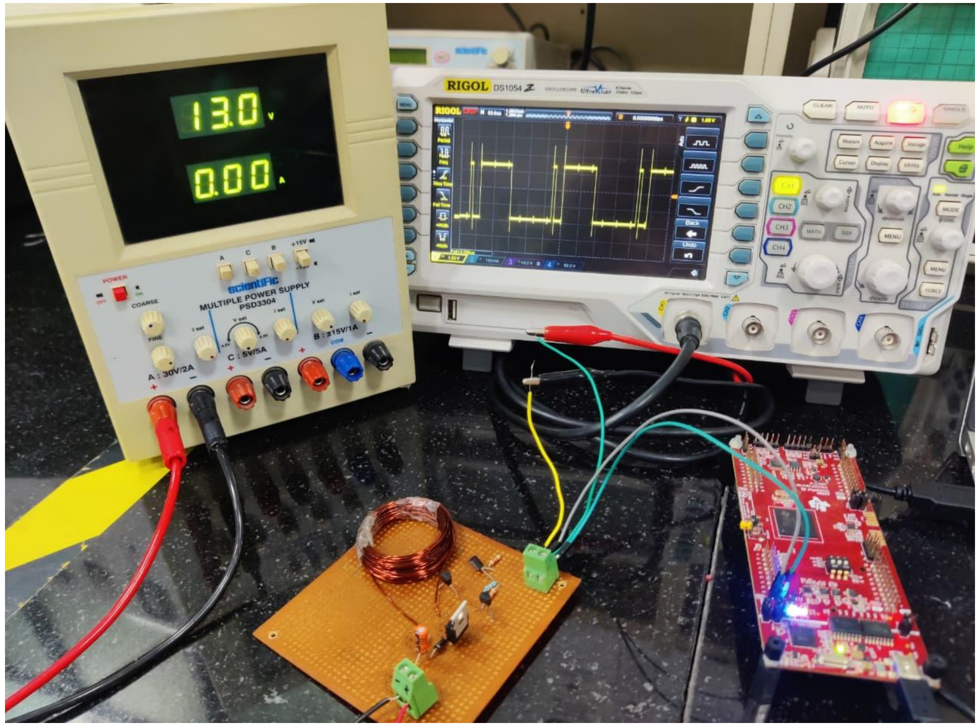
Turn-on delay time($t_d(on)$)=6.0109ns
Rise time(t_r)=7.1035ns
Turn-on time(t_{on})=13.1144ns
Turn-off delay time($t_d(off)$)=7.122ns
Fall time(t_f)=9.406ns
Turn-off time(t_{off})=16.528ns

Hardware

- TMS320F28379D Launchpad generates precise double pulses using ePWM
- Dual-core 200 MHz processor ensures real-time switching control
- Interfaced with non-isolated gate driver for safe MOSFET triggering

Input Voltage = 3.3V
Supply Voltage Range = 10V-15V

TMS320F28379D Launchpad Specifications:
Voltage = 3.3V
GPIO drive strength = Max 8mA per pin
EPWM modules = 24
Frequency = 200MHz CPU



Air core Inductor
Wheeler's formula:
L=r^2N^2/(9r+10l)=94µH
where
Radius of coil(r)=1inch
Length of coil(l)=0.8inch
No.of turns(N)=40

Results

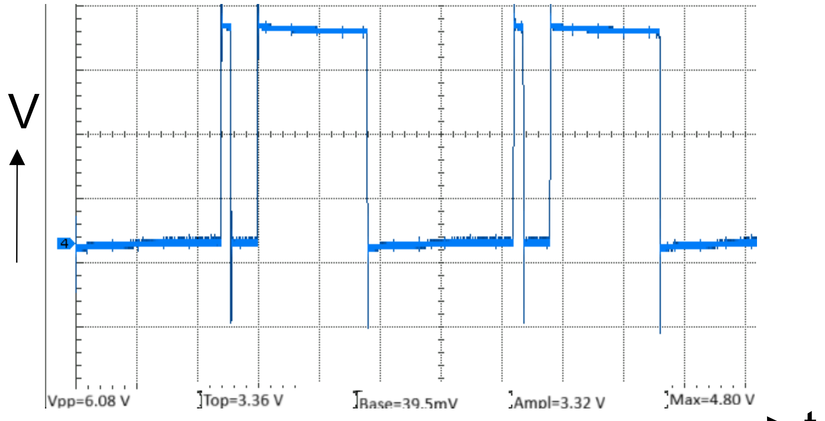


Fig : Waveform of pulse input

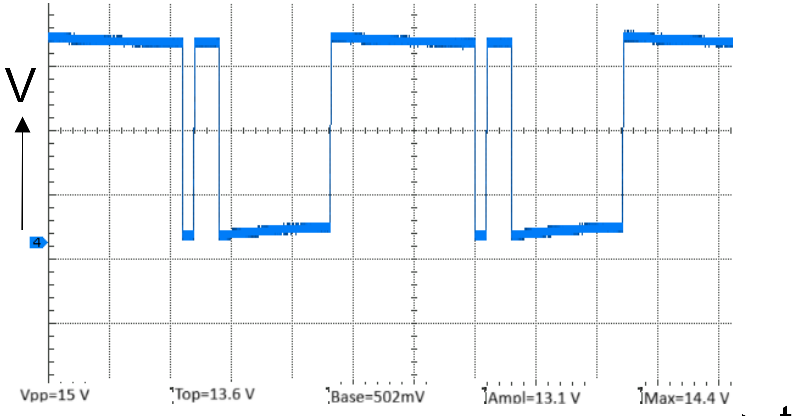


Fig : Waveform of gate-source voltage

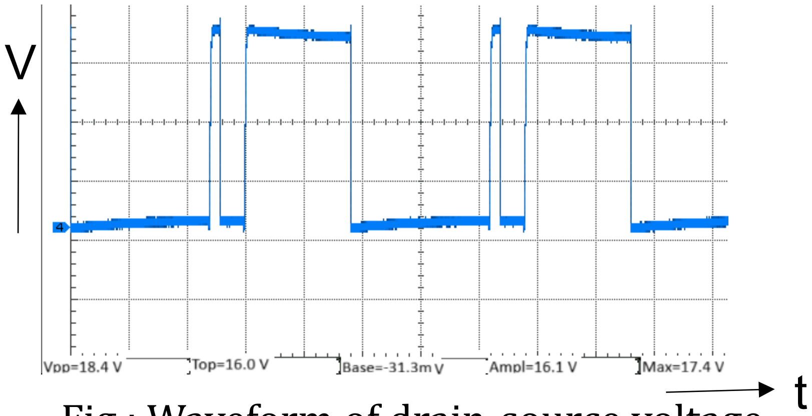
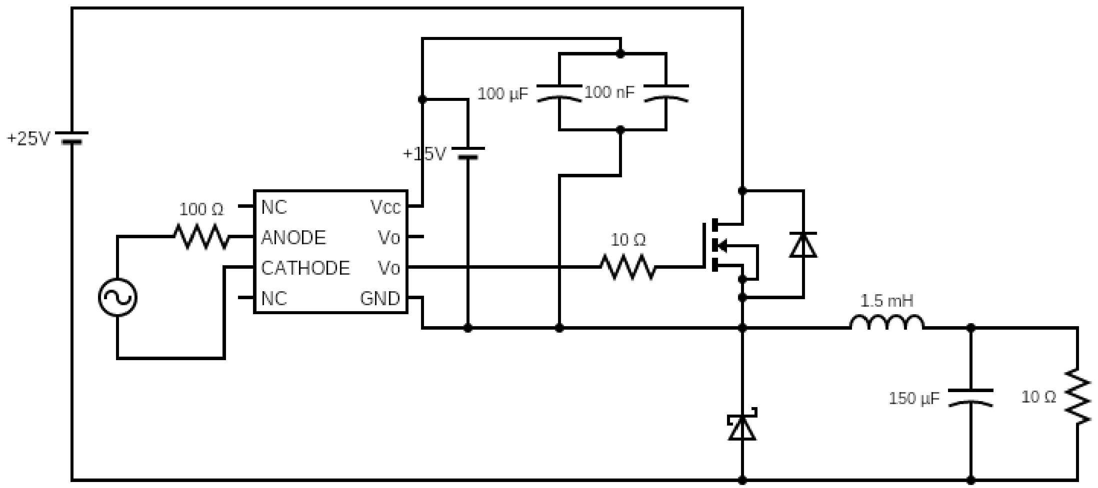


Fig : Waveform of drain-source voltage

Asynchronous Buck Converter

- An asynchronous buck converter consists of a high-side switch and a freewheeling diode
- MOSFET ON - energy stored in the inductor
- MOSFET OFF - diode conducts, releasing inductor energy to the load



Design and simulation

- Modeled in LTspice to step down the input DC voltage using a MOSFET switching stage.
- TLP250 optocoupler gate driver is used

CALCULATIONS

Given:
- $V_{in} = 25$ V
- Output Power=10W
- Duty cycle D=0.4
- Switching Frequency $f_s = 20$ kHz

$V_{out} = V_{in} \text{ x } D = 25 \text{ x } 0.4 = 10V$

$I_{out} = 1A$

$\Delta I_L = 0.2 \times I_{out} = 0.2 \times 1 \text{ A} = 0.2 \text{ A}$

CCM

Inductance Calculation:

$L = (V_{in} - V_{out}) \times D / (\Delta I_L \times f_s)$

L=1.5mH

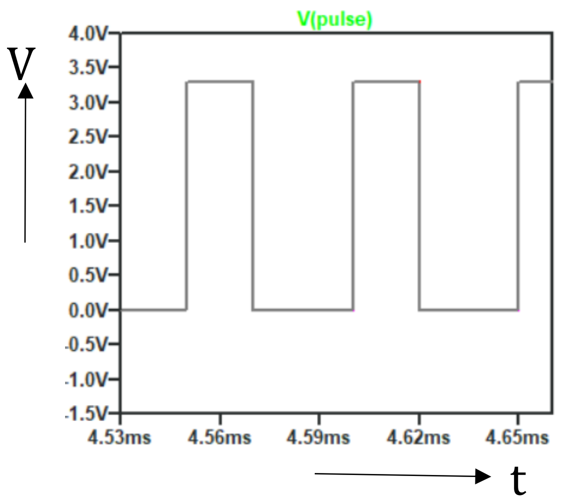
Capacitance Calculation (5% Ripple):

$C = \Delta I_L / (8 \times f_s \times \Delta V_{out})$

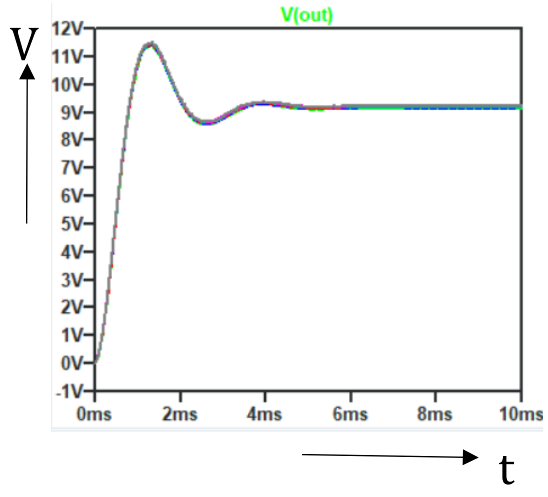
C=150µF

Diode:
- Schottky diode
- $I_{avg} = 1A$

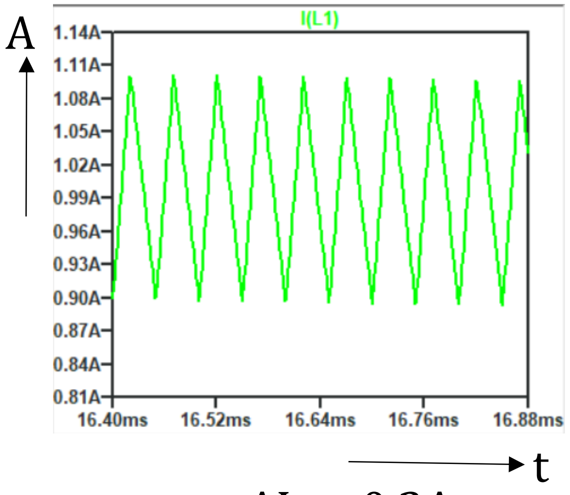
Simulation results



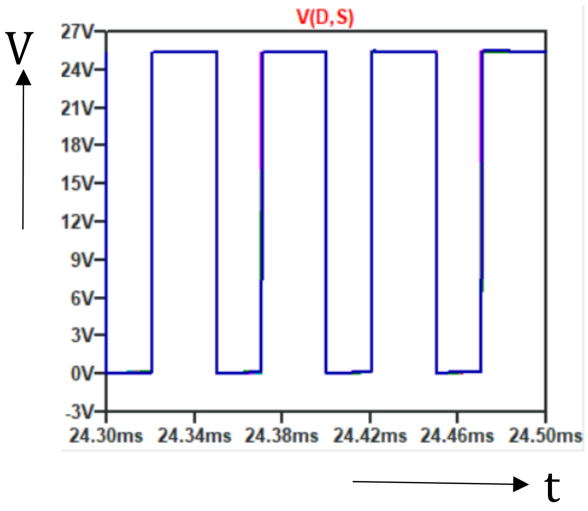
Input pulse=3.3V



V_{out} = D x V_{in} =10V



ΔI_L= 0.2A



V_{ds} = 25V

Losses in MOSFET

Switching losses

- Occur during the MOSFET's transitions between ON and OFF states.
- $P_{sw} = (E_{on} + E_{off}) \times f_{sw}$

Conduction losses

- Occur when the MOSFET is in the ON state.
- Caused by the non-zero on-resistance (R_DS(on))
- $P_{con} = I_d rms^2 \times R_{ds}\ (on)$

Turn-On Energy (Eon) : $E_{on} = \frac{V_{ds} \text{ x } I_d \text{ x } t_{on}}{2}$

Energy dissipated during transition from OFF to ON

Turn-Off Energy (Eoff) : $E_{off} = \frac{V_{ds} \text{ x } I_d \text{ x } toff}{2}$

Energy dissipated during the transition from ON to OFF

Losses in DIODE

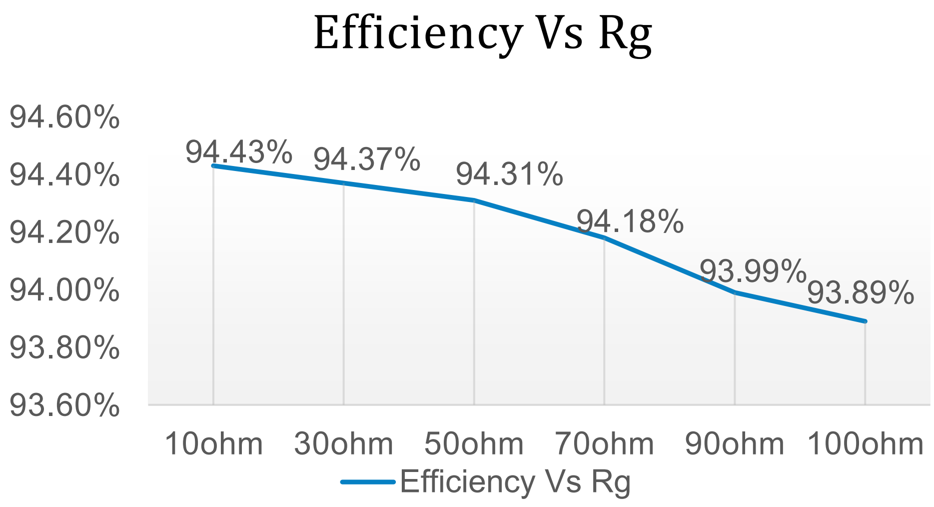
P= (1-D)I_{diode} x V

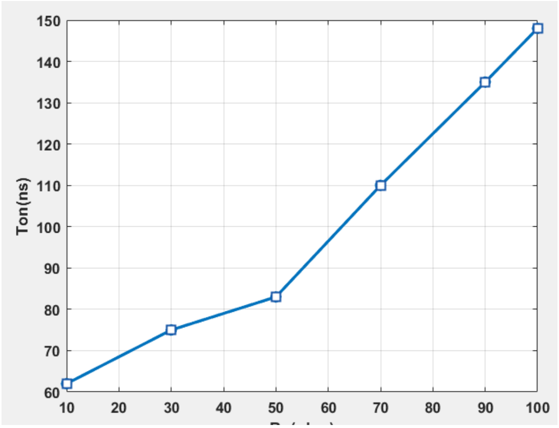
P=0.6x1x0.7=420mW

Total losses = $P_{sw} + P_{con} + P_{diode}$

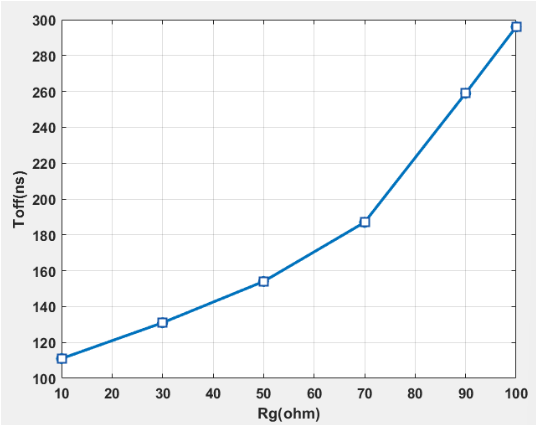
Table : Variation of different parameters with gate resistance

R_g (Ω)	t_{on} (ns)	t_{off}(ns)	E_{on} (μJ)	E_{off}(μJ)	P_{sw}(W)	P_{con}(W)
10	62	111	0.697	1.248	0.039	0.1296
30	75	131	0.843	1.437	0.0463	0.1296
50	83	154	0.933	1.732	0.0533	0.1296
70	110	187	1.237	2.103	0.0668	0.1296
90	135	259	1.518	2.913	0.0886	0.1296
100	148	296	1.665	3.33	0.1	0.1296

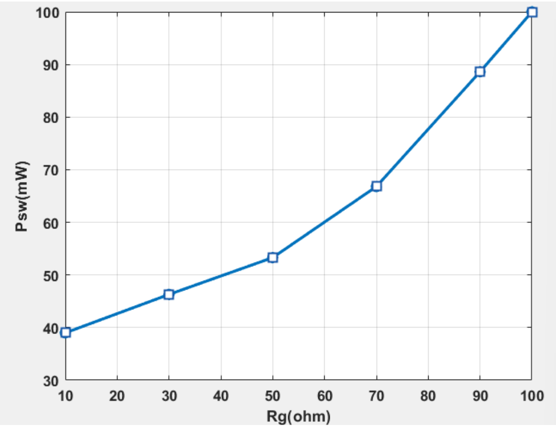




Turn-on time increases with increase in gate resistance



Turn-off time increases with increase in gate resistance



Switching losses increases with increase in gate resistance

R_g (Ω)	Efficiency(%)
10	94.43
30	94.37
50	94.31
70	94.18
90	93.99
100	93.89

Table : Variation of efficiency with gate resistance

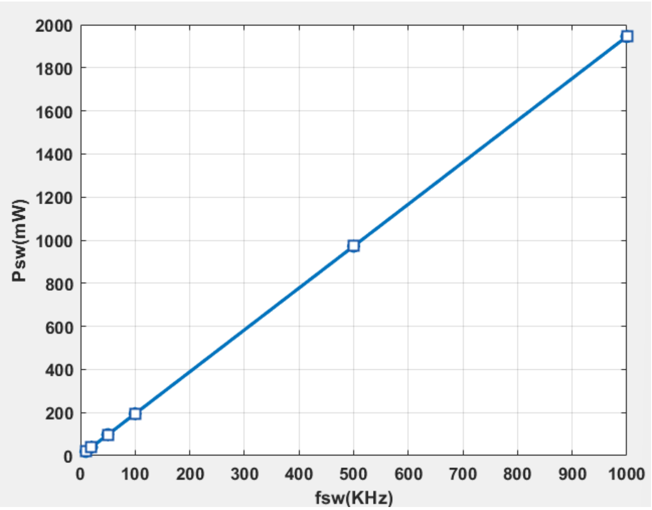
Gate resistance increases → Losses increases → Efficiency decreases

Variation of switching frequency

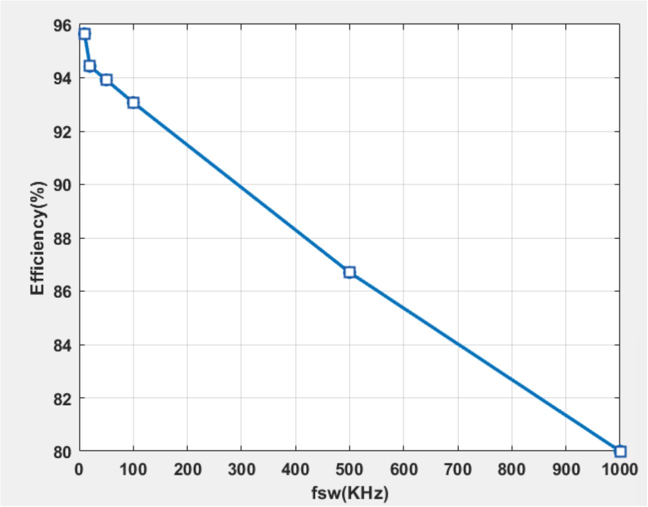
Table : Variation of efficiency with switching frequency

Switching frequency f_s	P_{sw}(mW)	Efficiency(%)
10KHz	19.45	95.67
20KHz	39	94.43
50KHz	97.25	93.92
100KHz	194.5	93.07
500KHz	972.1	86.7
1MHz	1945	80.00

- Switching frequency is varied keeping gate resistance constant($R_g = 10\Omega$)
- As switching frequency increases, switching losses increases almost linearly
- Which further decreases the efficiency
- Increase in switching frequency decreases the efficiency



Switching lossses Vs switching frequency



Efficiency Vs switching frequency

Synchronous Buck Converter

- Replaces the free-wheeling diode with a low-side MOSFET, reducing conduction losses.
- Dead time : Small delay inserted between turning OFF one MOSFET and turning ON the other.
  - ➢ Prevents shoot-through
  - ➢ Ensures stable switching transitions
- Losses are due to both MOSFETs(No diode)

PULSE 1: D_{hs} =0.4
PULSE 2: D_{ls} =0.596
Dead time= 0.2μs; D=0.004

As dead time is short
$V_{out} \approx D_{hs}V_{in}$.
$V_{out} = 10V$

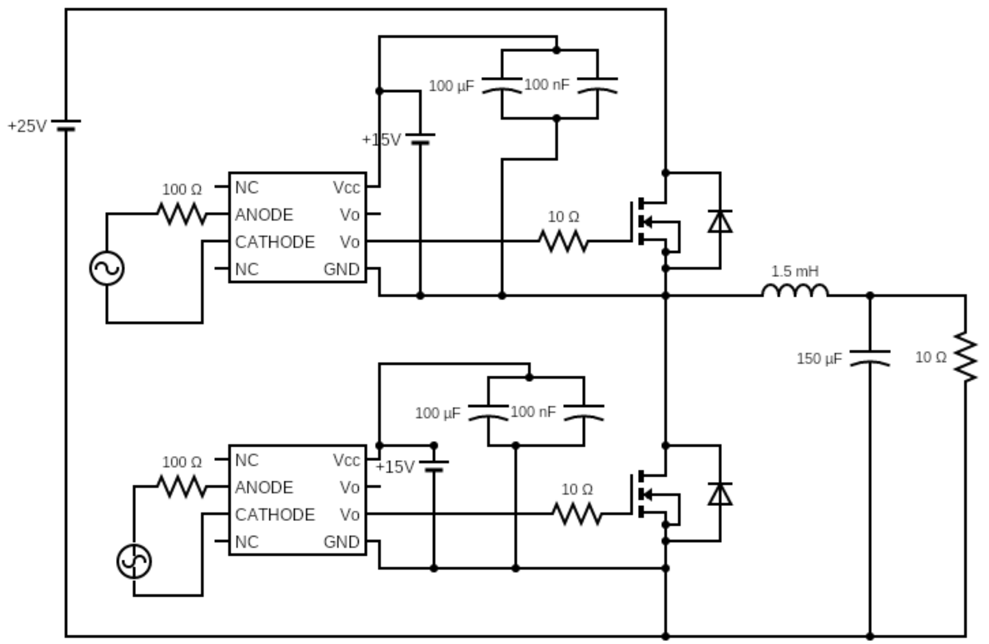
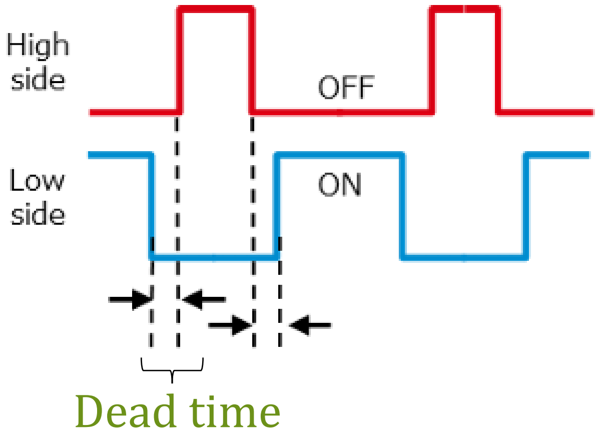


Fig : Synchronous buck converter



LOSSES
- ➢ Conduction losses
- ➢ Switching losses
- ➢ Body diode losses(neglected)

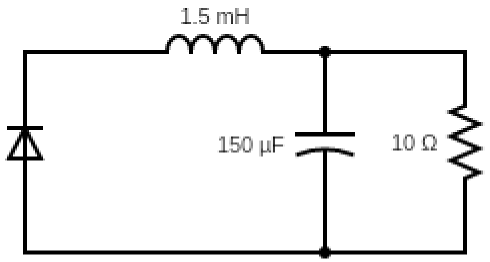
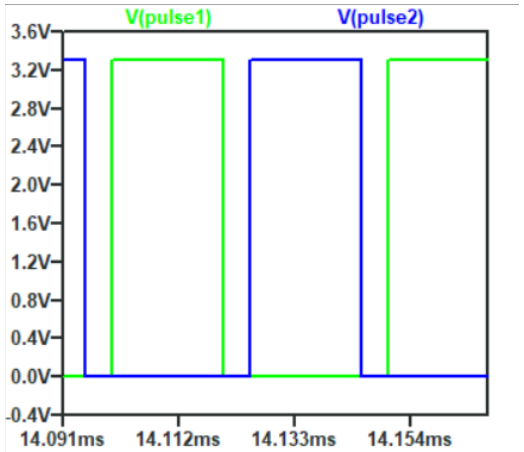


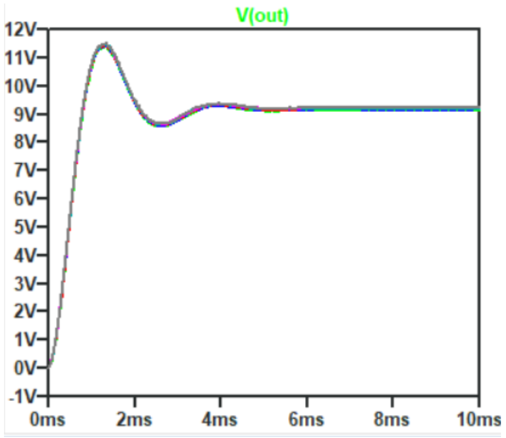
Fig : Circuit during dead time

[1] ROHM Co., Ltd., "Gate-source voltage behaviour in a bridge configuration," Application Note No. 60AN135E Rev.002, April 2020.

Simulation results

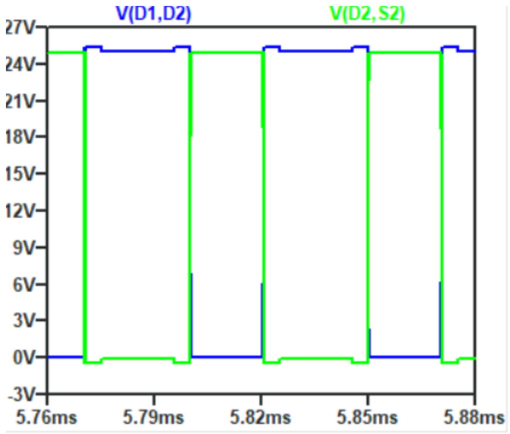


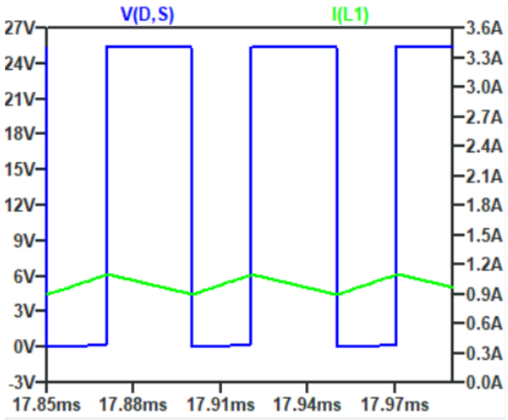
Pulse with dead time



$V_{out} = 10$ V

V





t

Drain-source volage of both MOSFETs

Charging and discharging of inductor current with V_{ds} of the low-side MOSFET

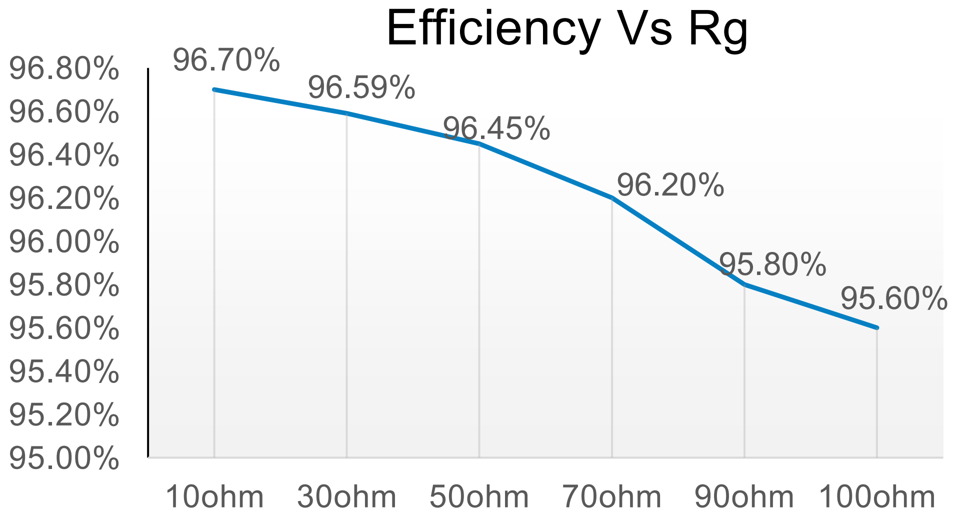
Efficiency

$$P_{losses} = P_1 + P_2$$
$$P_{losses} = 2(P_{sw} + P_{con})$$

$$\text{Efficiency} = P_{out} / (P_{out} + P_{losses})$$
$$P_{out} = 10\text{W}$$

Table: Variation of efficiency with gate resistance

R_g (Ω)	Efficiency(%)
10	96.7
30	96.59
50	96.45
70	96.2
90	95.8
100	95.6



RESULTS AND CONCLUSIONS

SWITCHING CHARACTERISTICS

1. Gate drive strength

- Higher gate current → faster turn-on/off → lower losses but higher EMI.
- Lower gate current → softer transitions

2. MOSFET Gate charge and Gate capacitance

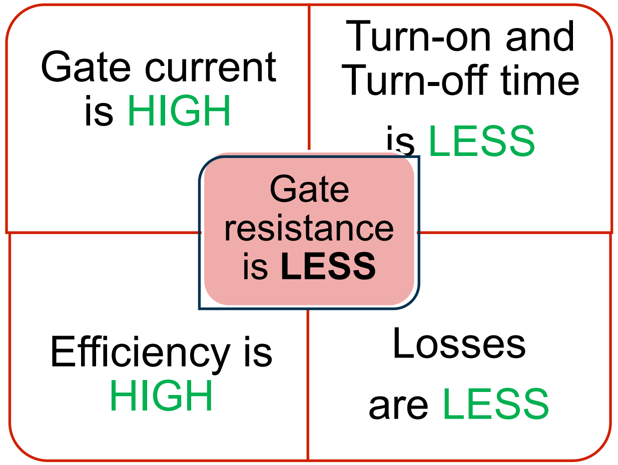
- Higher Q_g requires a stronger gate driver for fast switching.
- C_{gd} (Miller capacitance) strongly affects turn-on/turn-off

3. Dead-time plays

- Too little dead-time → shoot-through
- Too much dead-time → diode conduction + reverse recovery losses

4. Switching frequency

- Higher switching frequency increases switching losses and decreases efficiency



LOWER gate resistance is preferred

Preffered values:

- $R_g = 10ohm$
- $V_{gs} = 15V$
- TLP5214 gate driver
- Low f_{sw} (<100KHz)

DATASHEET REALISATION

MOSFET - IRF 840

Specification	Method	Conditions	Obtained value	Datasheet value	Remark
Gate-Source charge(Q_{gs})	MOSFET gate driver	V_{gs} =10V, V_{ds} =400v, I_d =8A	9.6nC	9.3nC	✓ Valid
Gate-Drain charge(Q_{gd})	MOSFET gate driver	V_{gs} =10V, V_{ds} =400v, I_d =8A	20.4nC	32nC	✓ Valid
Gate charge (Q_g)	MOSFET gate driver	V_{gs} =10V, V_{ds} =400v, I_d =8A	30nC	63nC(max)	✓ Valid
Turn-on delay time (t_d (on))	Double pulse test	V_{DD}= 250V, I_d = 8A, R_g = 9.1 Ω, R_d = 31 Ω	6.0109ns	14ns	✓ Valid
Rise time (t_r)	Double pulse test	V_{DD}= 250V, I_d = 8A, R_g = 9.1 Ω, R_d = 31 Ω	7.1035ns	23ns	✓ Valid
Turn-off delay time (t_d (off))	Double pulse test	V_{DD}= 250V, I_d = 8A, R_g = 9.1 Ω, R_d = 31 Ω	7.122ns	49ns	✓ Valid
Fall time (t_f)	Double pulse test	V_{DD}= 250V, I_d = 8A, R_g = 9.1 Ω, R_d = 31 Ω	16.528ns	20ns	✓ Valid
Body diode reverse recovery time(t_{rr})	Double pulse test	I_f = 8 A, dI/dt = 100 A/μs b	800ns	970ns(max)	✓ Valid
Diode reverse recovery charge(Q_{rr})	Double pulse test	I_f = 8 A, dI/dt = 100 A/μs b	1.2μC	4.2μC	✓ Valid

FUTURE SCOPE

- Development of an intelligent algorithm capable of estimating a MOSFET's datasheet parameters based on experimental switching test inputs, such as gate driver evaluation and double pulse testing.

- This approach can automate datasheet realization, enable faster device characterization and reduce manual analysis.

- The algorithm can further be extended for predictive modelling and optimization of power semiconductor devices in real-time applications.

- Hardware modelling of synchronous buck converter and estimating the losses, efficiency.

THANK YOU

BACKUP SLIDES

Optocouplers

- Electronic device that enables electrical signals to be transmitted between two isolated circuits
- It consist of 2 parts: LED and a photosensitive device(phototransistor)

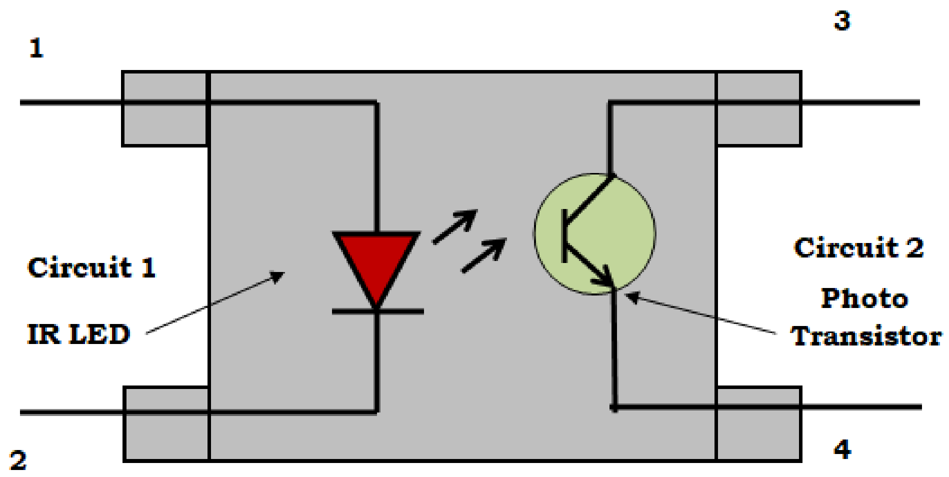


Fig : Optocoupler

USES

1. Provides galvanic isolation
2. Eliminates noise

Optocouplers are used in the design of MOSFET gate driver circuits

- ❑ General-purpose gate driver(TLP250)
- ❑ Smart gate driver (TLP5214)

HOW IT EFFECTS SWITCHING?

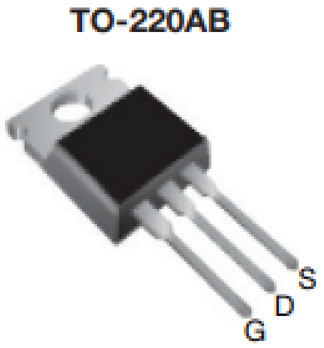
- ➢ Isolation avoids false triggering and ensures clean switching at high dV/dt.
- ➢ Better turn-off safety

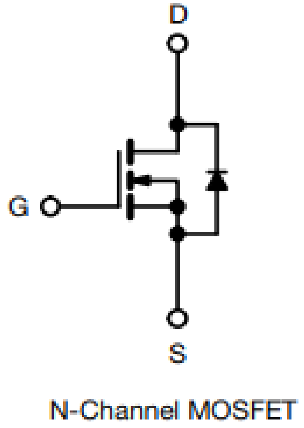
[1]https://share.google/images/l3pfivJpXmUlK7x1f

MOSFET

Understanding MOSFET Switching Studies

- MOSFETs are key devices in power conversions and switching applications.
- Research focuses on switching speed, losses and reliability.
- Switching behavior determines efficiency and thermal performance in converters.





Switching Dynamics in Power MOSFETs

Key parameters:
- Turn-on / Turn-off delay times
- Rise / Fall times
- Switching energy losses (E_{on}, E_{off})

Switching performance depends on:
- Gate resistance
- Drain current
- Junction temperature

- Switching characteristics
- Gate drive circuits
- Double pulse testing
- Converter-level studies

Vishy siliconix, "IRF840 N-Channel Power MOSFET Datasheet,"PDF file, 2017.

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