ICICT 2022 February 21(Mon) – 24(Thu)
London, United Kingdom

Zoom : Virtual Room D

Feb. 24, 2022 GMT
10:46am - 11:00am

Current-Driven IGBT Gate Driver Circuit Considering Four Operation Regions

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OUTLINE

- **Research Background and Objective**
- **IGBT Evaluation Circuit**
- **IGBT Current Drive Simulation**
  - **Current Gate Driver Circuit**
  - **Simulation Results**
- **Gate Current Automatic Control**
  - **Analog Value**
  - **Digital Value**
- **Conclusion and Challenges**

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Research Background

IGBTs have advantages of both MOSFETs and bipolar transistors

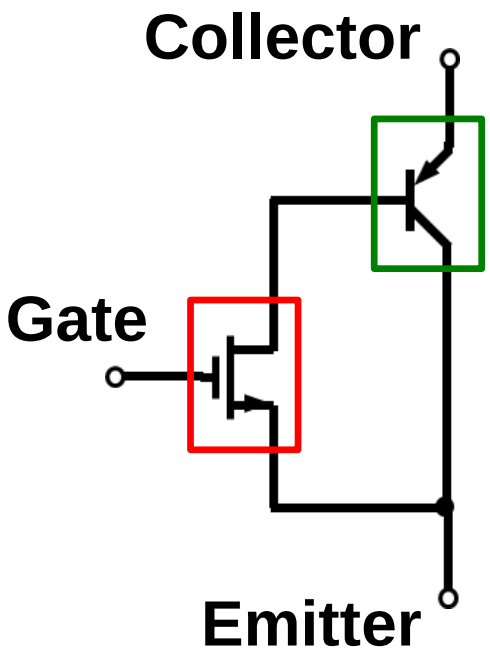
Used in wide range of applications as power semiconductor devices

Development of IGBT and its driver circuit is important

IGBT and Driver Circuit

IGBT

(Insulated Gate Bipolar Transistor)



Input part is MOSFET
Output part is bipolar transistor

Advantages

- **Fast operating speed**
- **Large current amplification factor (~1.2kA)**
- **High withstand voltage (~3.3kV)**

Disadvantage

Large gate capacitance → Driver design is difficult

Objective

IGBT circuit

Parasitic capacitance and tail current → Switching loss

Parasitic inductance → Excessive overshoot

Change drive resistance during switching → Complex control

Objective

Current Drive →

Reduction of Switching loss and Excessive overshoot

Simplification of control design

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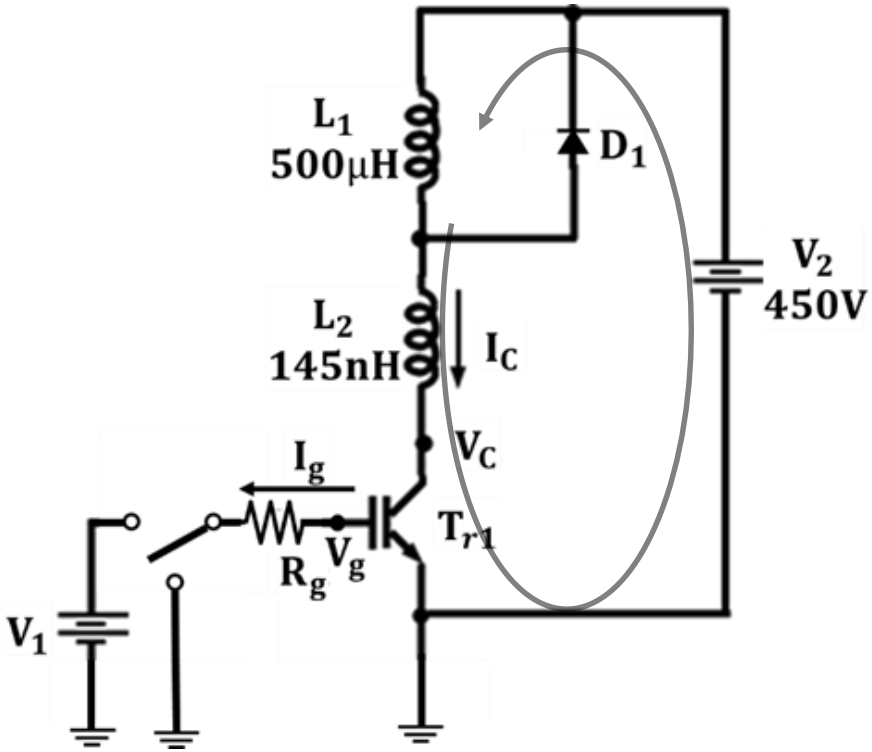
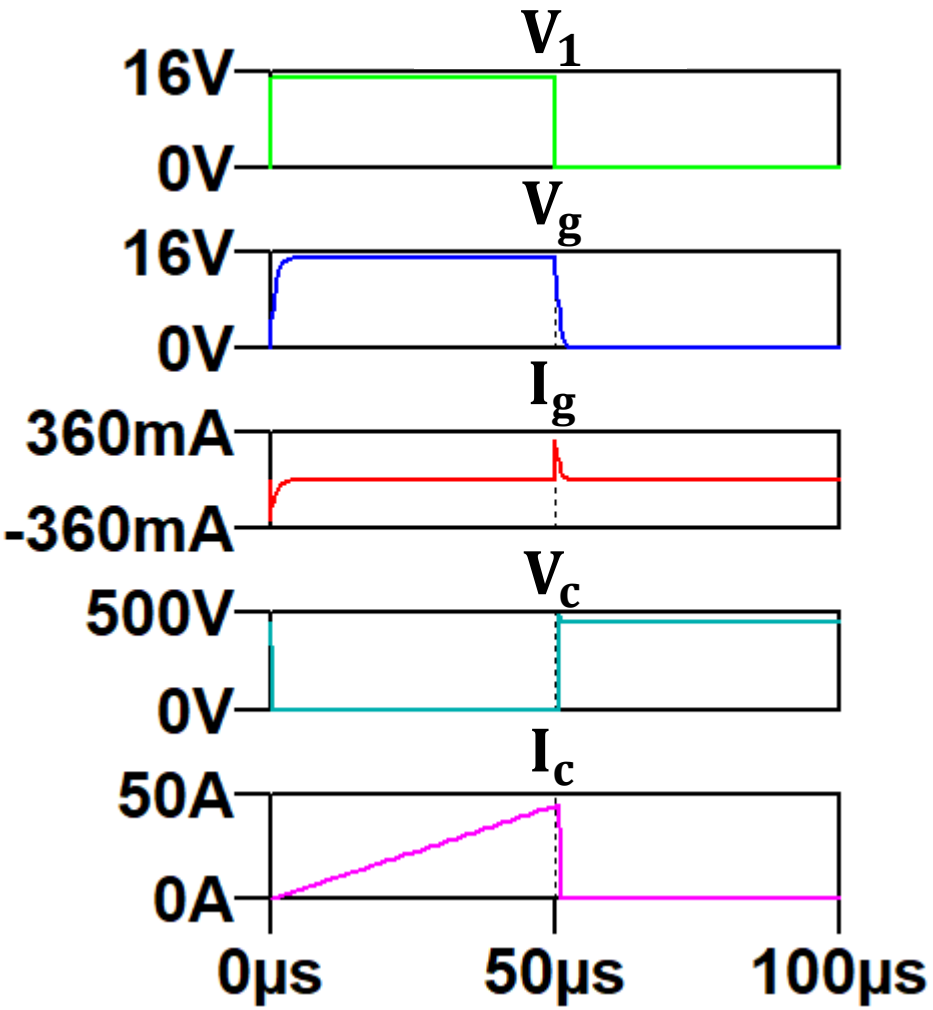
Voltage-Driven IGBT Evaluation Circuit (1/2)

Input voltage V_1

V_g turns on IGBT

I_c gradually flows



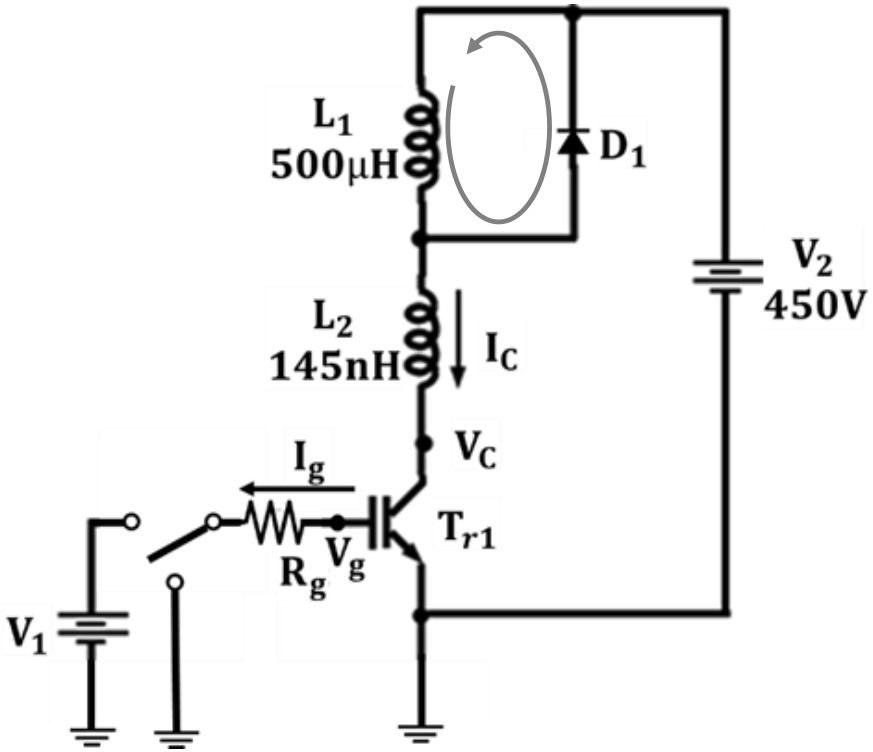


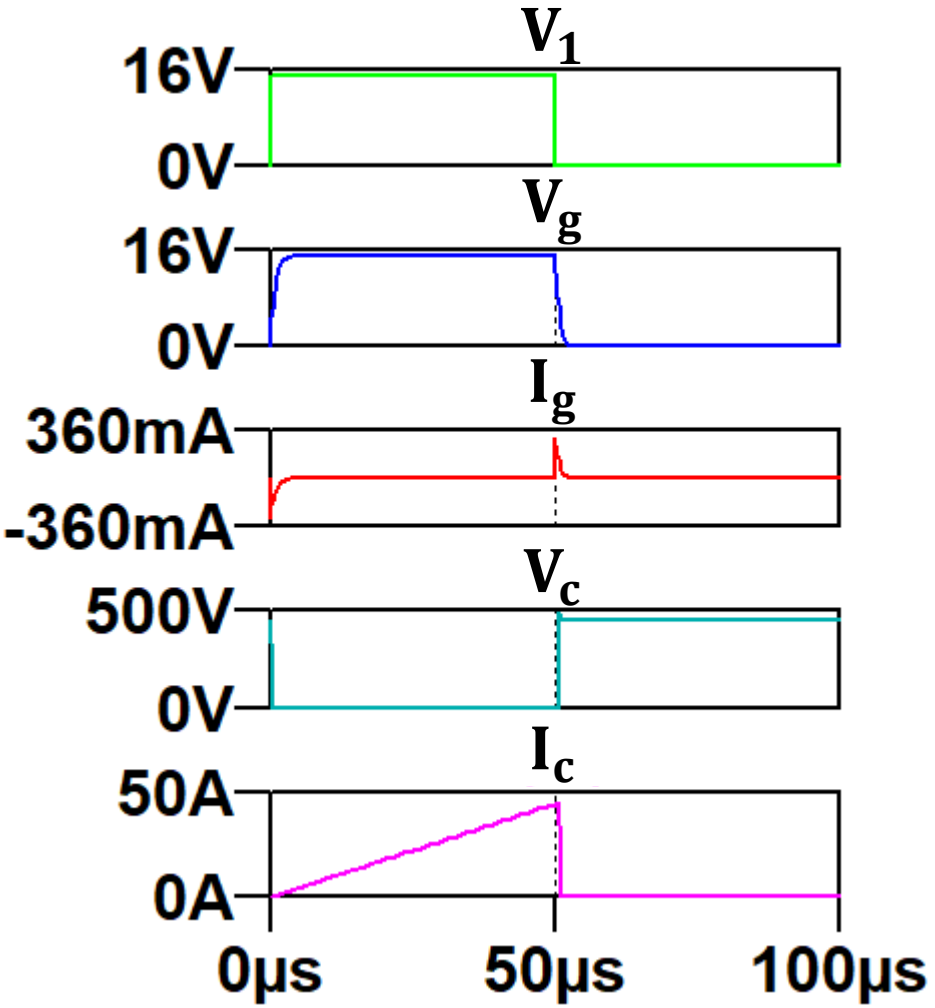
Voltage-Driven IGBT Evaluation Circuit (2/2)

V_1 becomes 0

V_g turns off IGBT

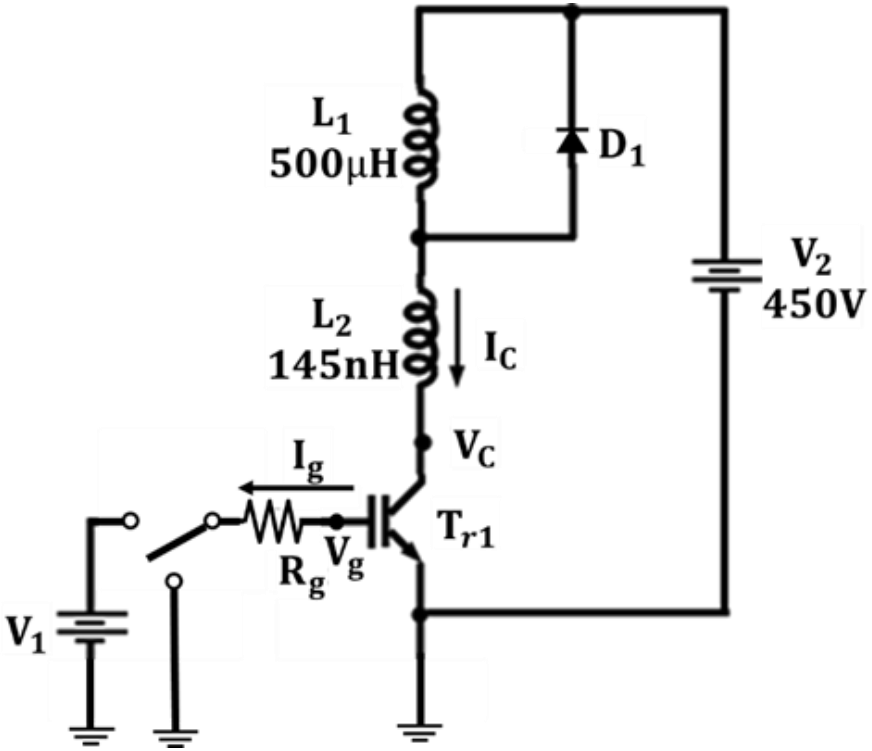
I_c rapidly decreases

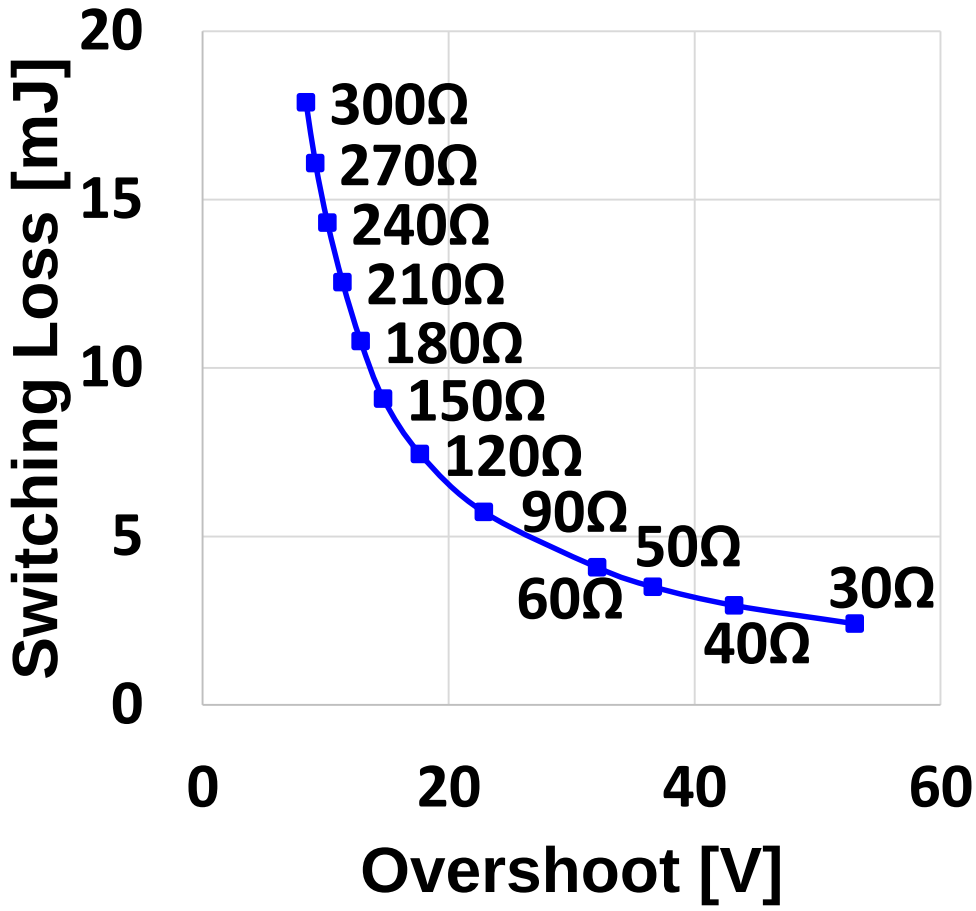




Overshoot and Switching Loss during Turn-off

Change gate resistance R_g from 30Ω to 300Ω





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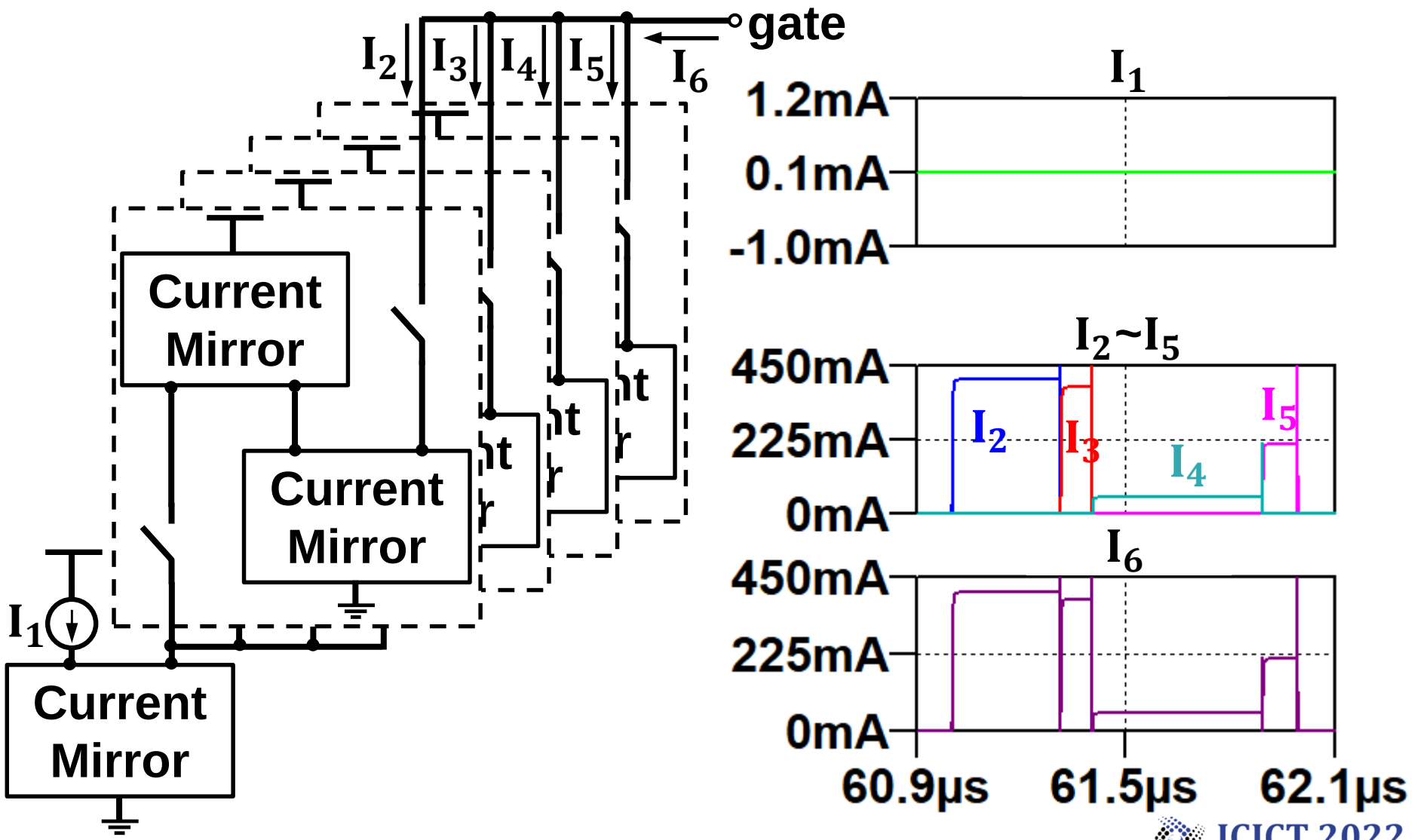
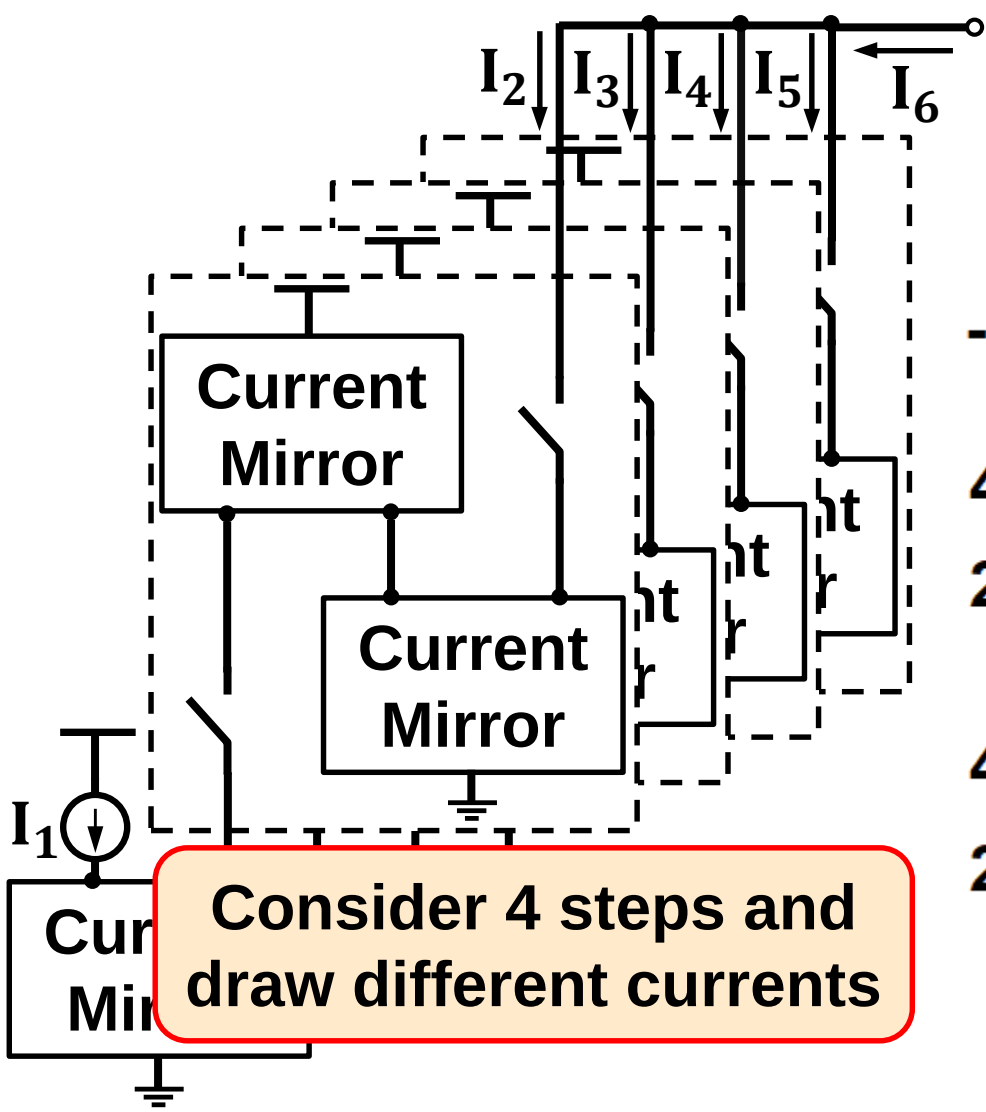
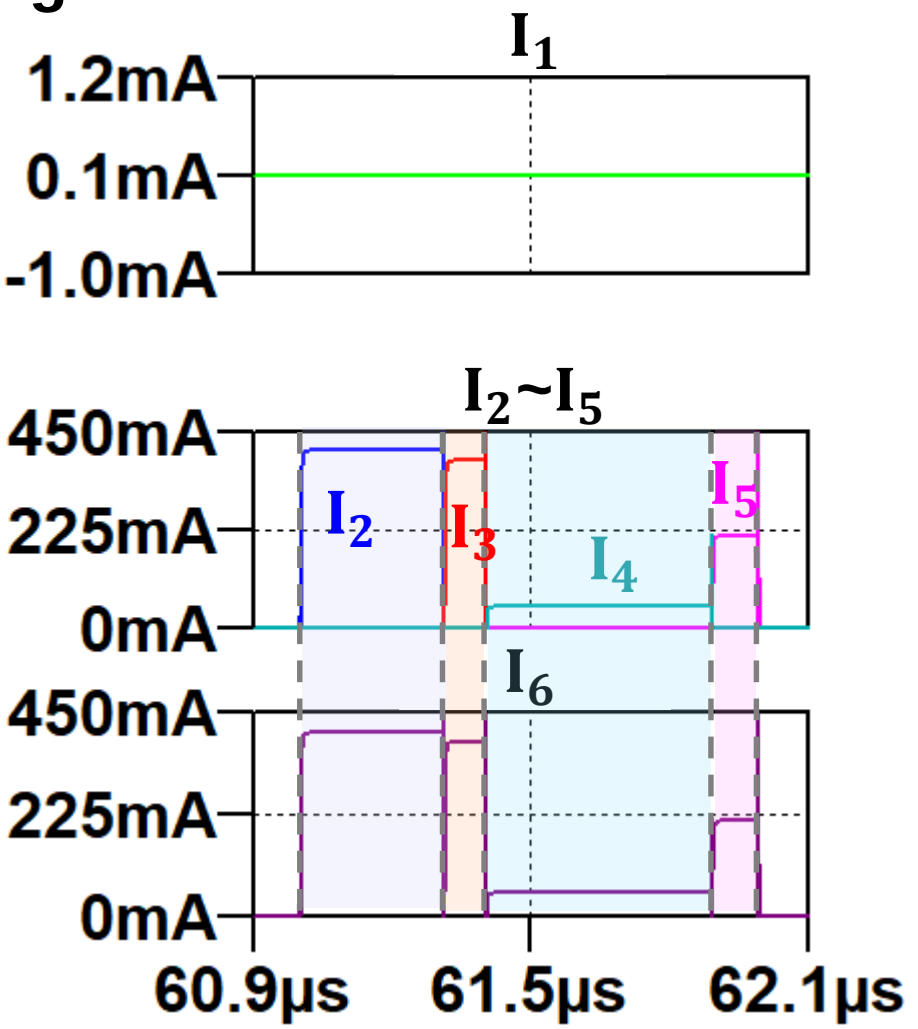
Current Gate Driver Circuit（1/2）



Current Gate Driver Circuit（2/2）



Consider 4 steps and draw different currents



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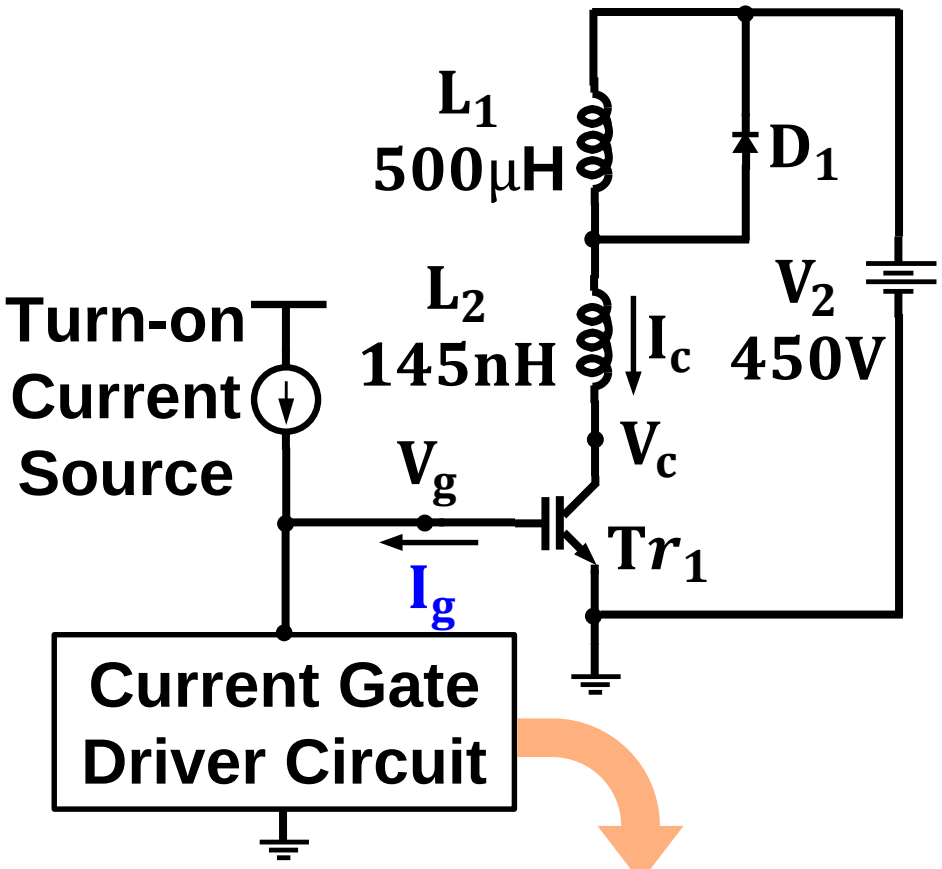
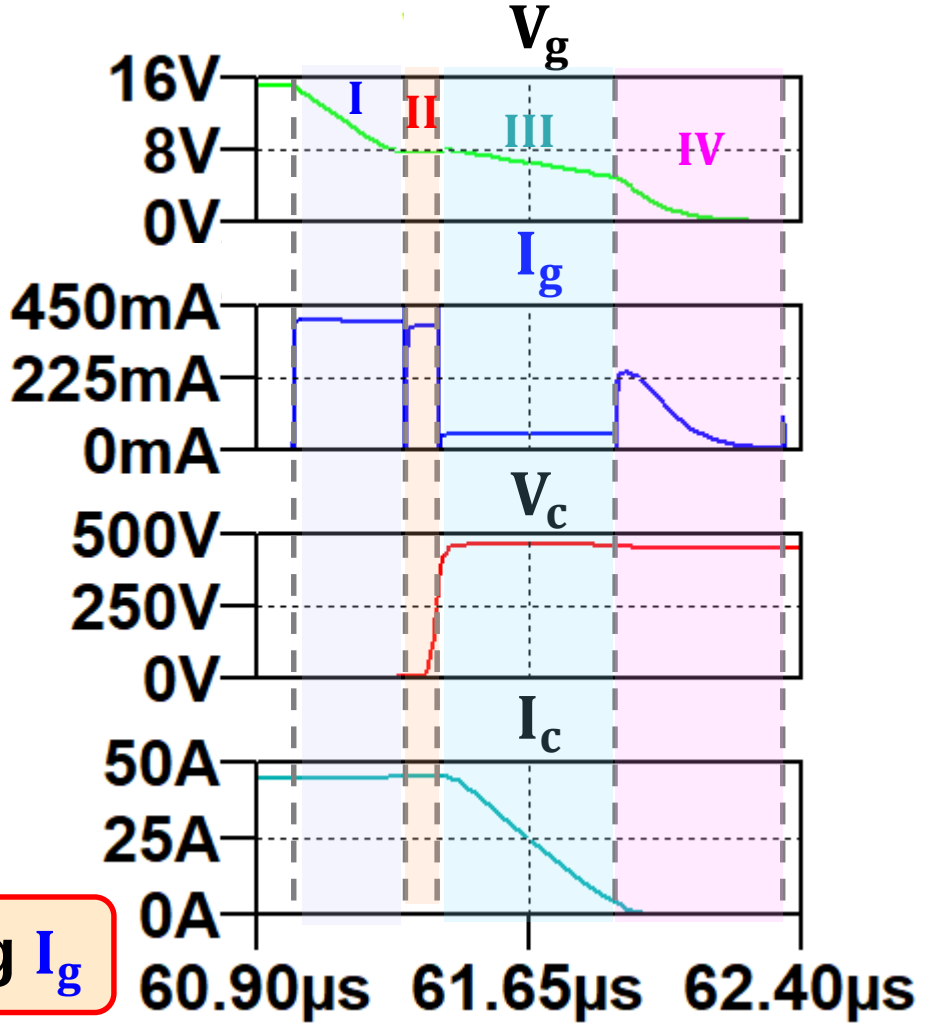
IGBT Turn-off Characteristics





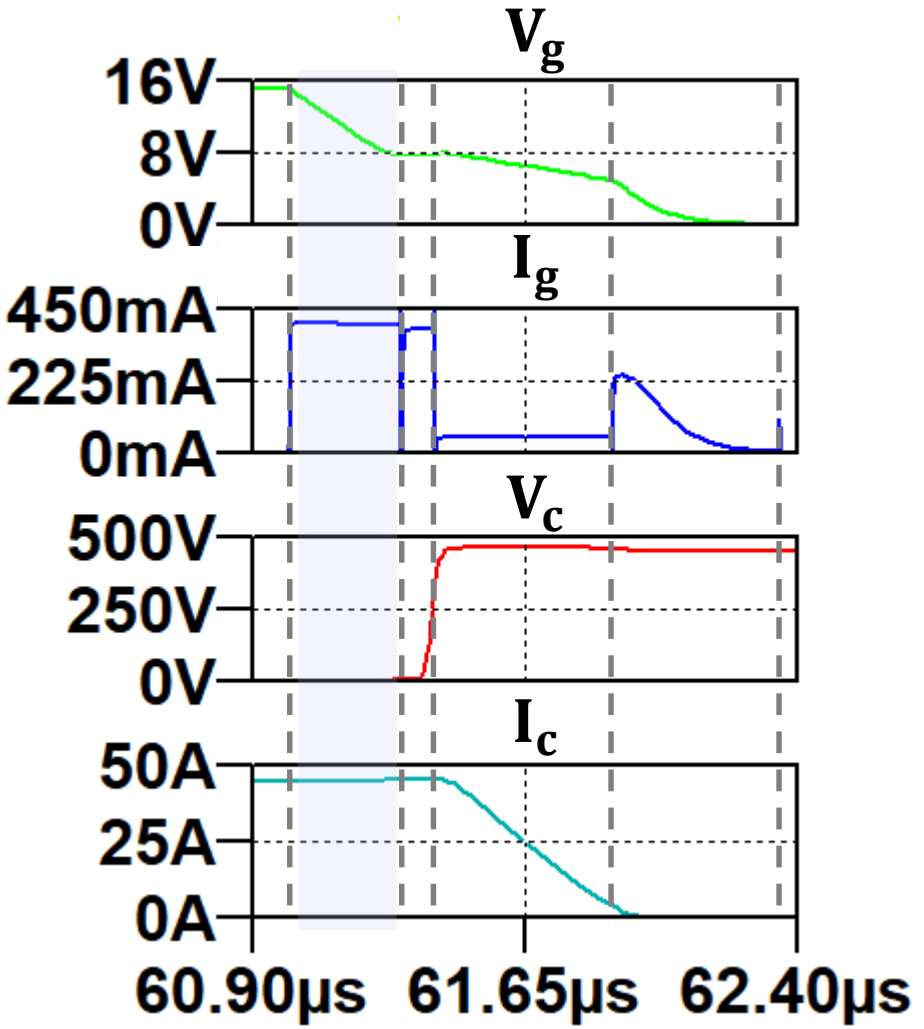
Control gate voltage by flowing I_g

Control of Gate Voltage by Gate Current (Region I)

Region I

V_g : Saturation voltage to Miller voltage

No effects on switching loss and overshoot



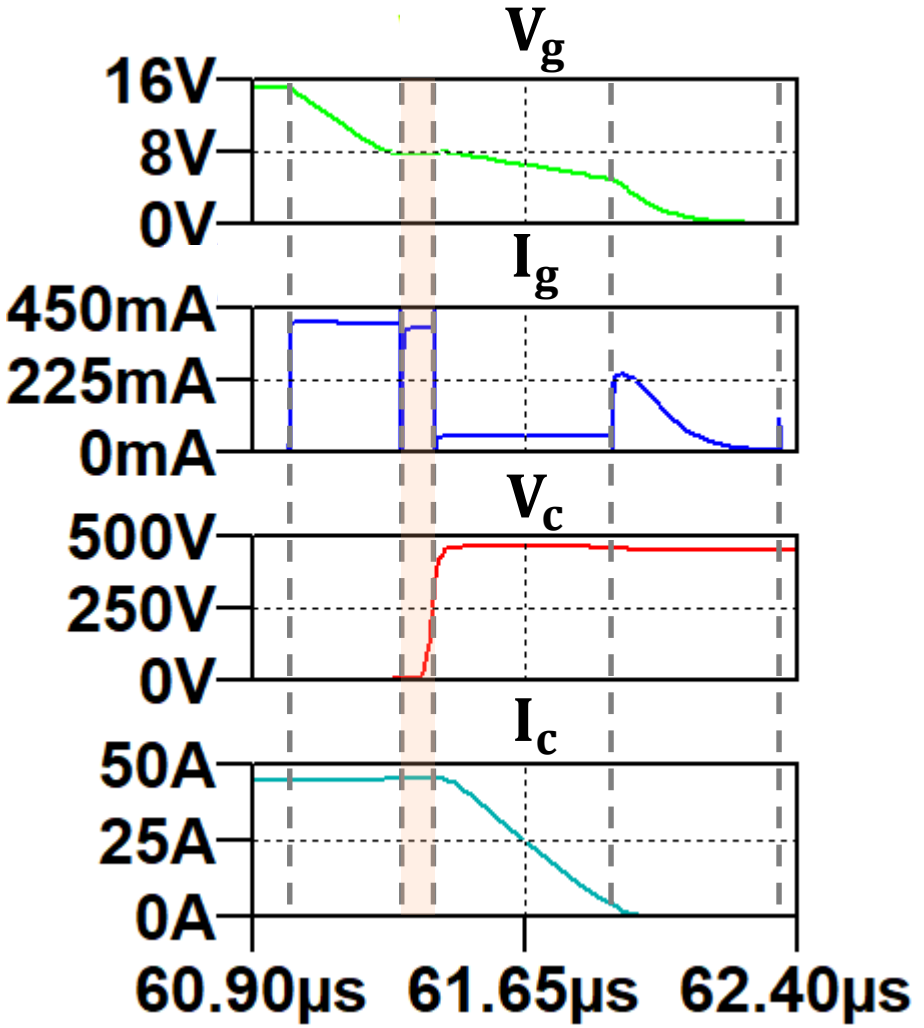
Control of Gate Voltage by Gate Current (Region II)

Region II

V_g : Miller period of IGBT

Trade-off between switching loss and slew rate

Switching loss can be reduced



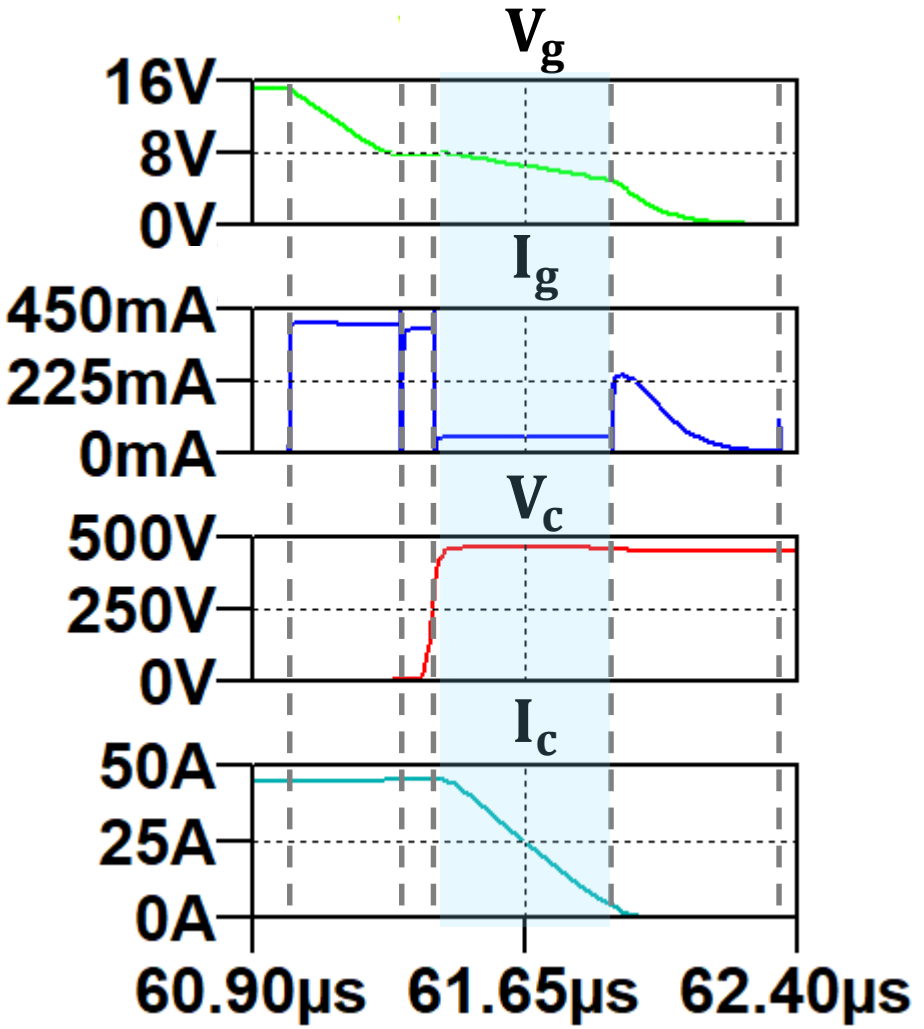
Control of Gate Voltage by Gate Current (Region III)

Region III

V_g : Miller voltage to threshold voltage

Trade-off between switching loss and overshoot

Overshoot can be reduced



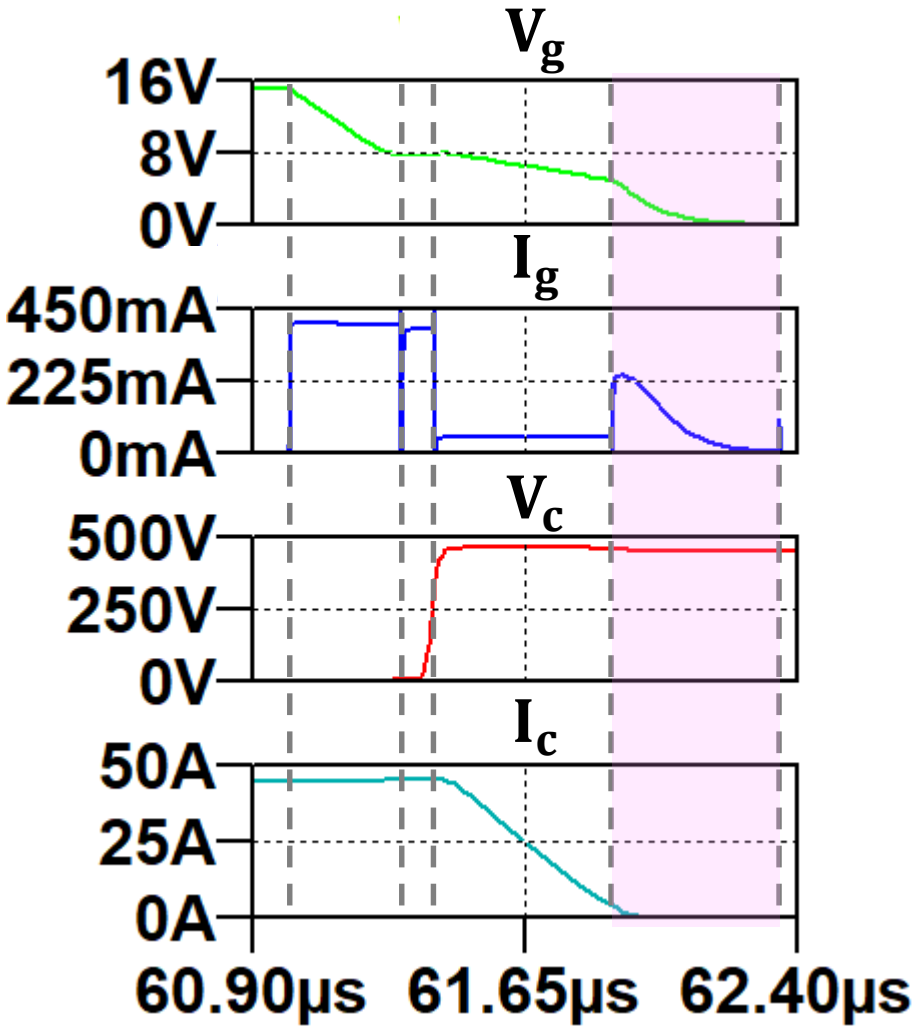
Control of Gate Voltage by Gate Current (Region IV)

Region IV

V_g : Threshold voltage to 0

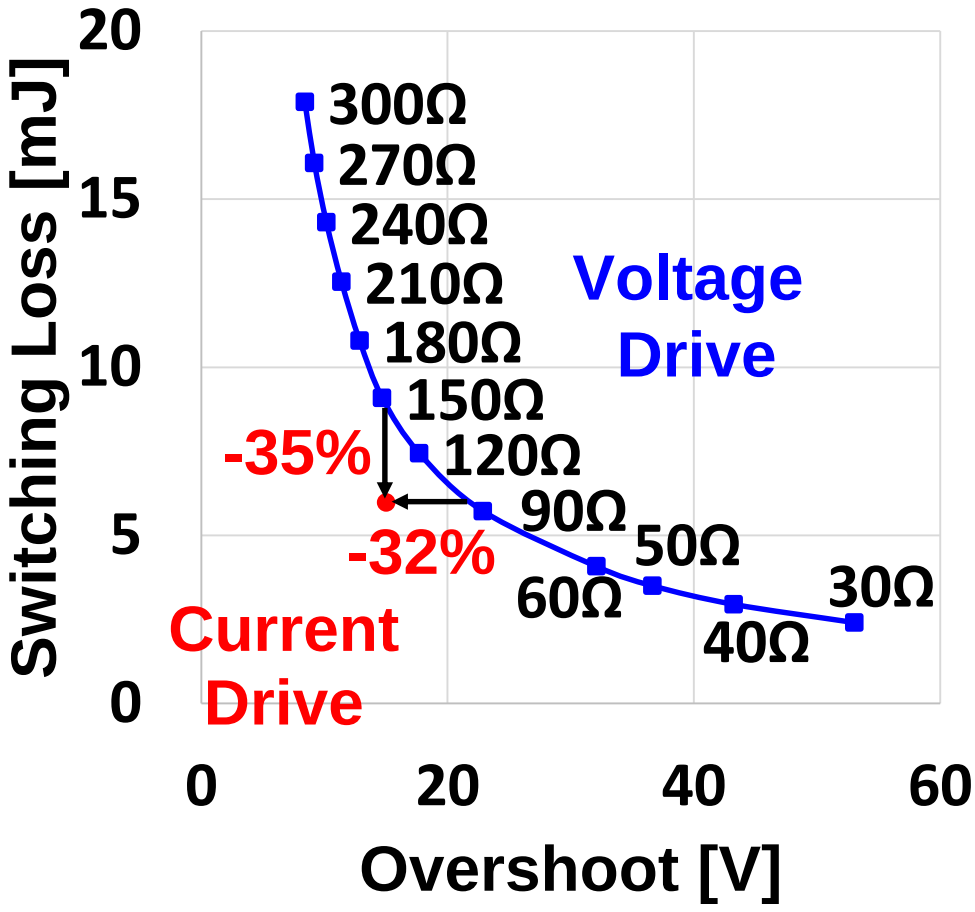
I_g : Uncontrollable due to I-V characteristics of MOSFETs

No effects on switching loss and overshoot



Comparison with Voltage Drive

Switching Loss : -35%, Overshoot : -32%



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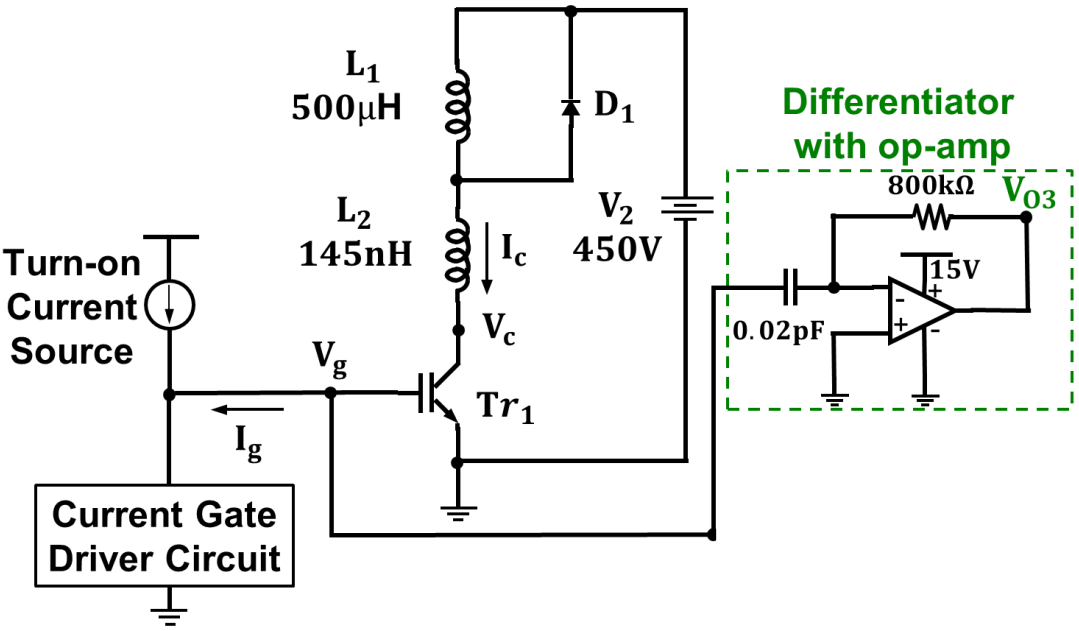
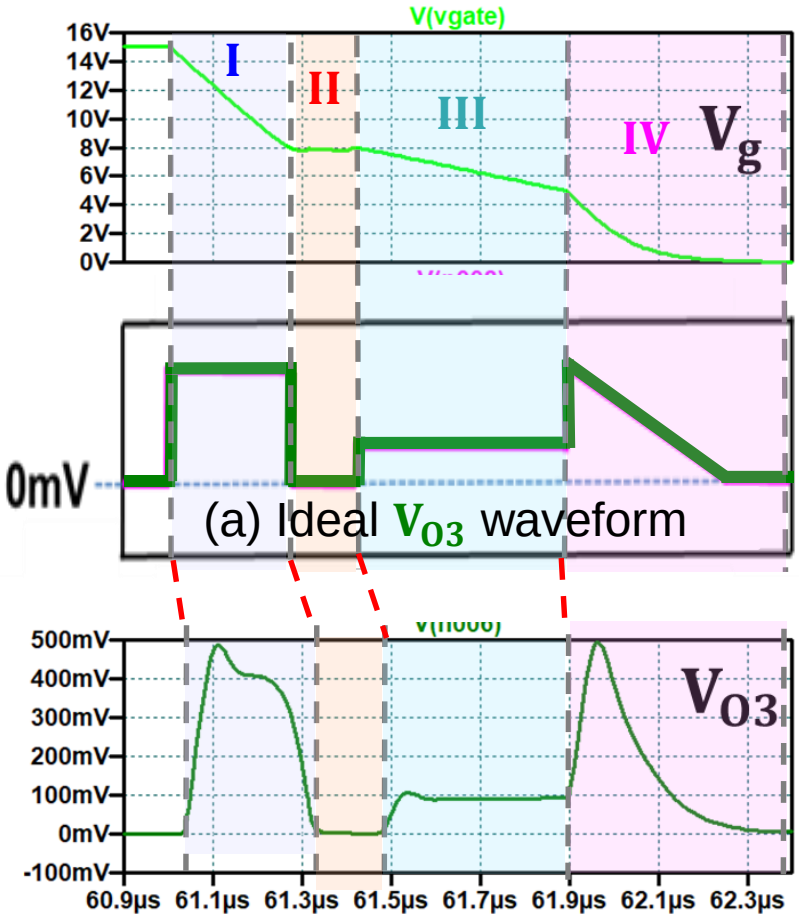
Addition of an active differentiator with an operational amplifier





Add operational amplifier differentiator
Model: UniversalOpamp2 (LTspice)

Observe the change in the slope of V_g

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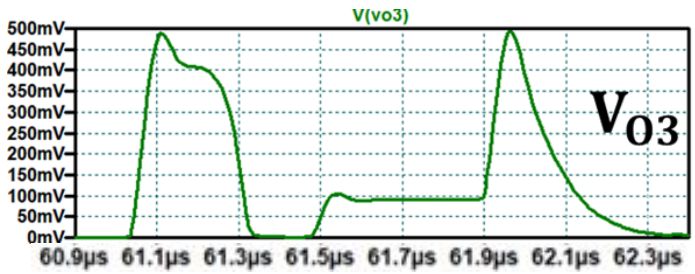
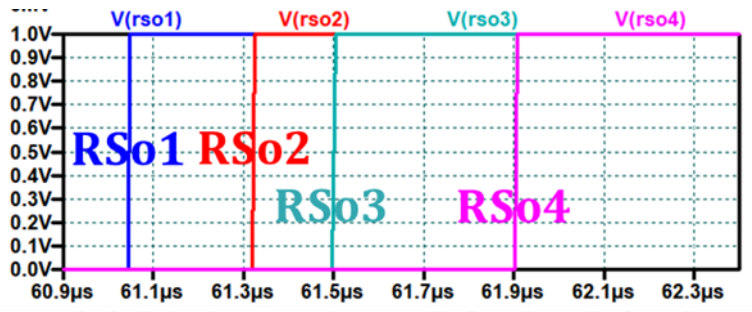
Automatic Discrimination of Operation Regions (Digital value)





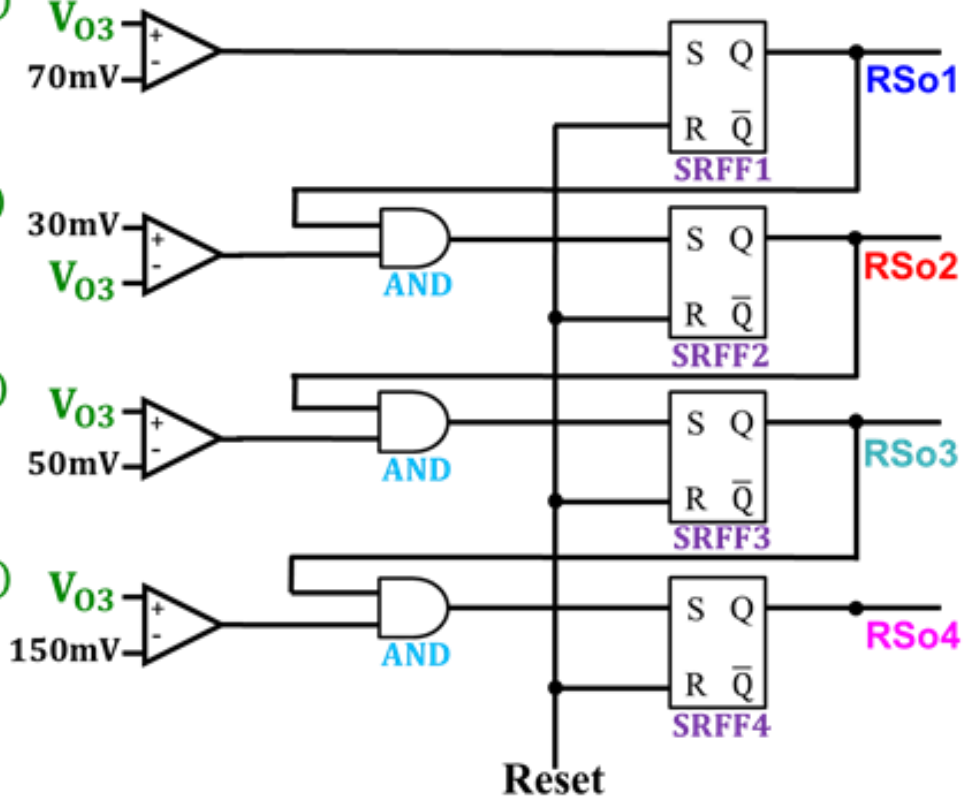
Analog Value

Comparator1(Cp1)
If $V_{O3} > 70mV$
Output Cp1 = 1

Comparator2(Cp2)
If $30mV > V_{O3}$
Output Cp2 = 1

Comparator3(Cp3)
If $V_{O3} > 50mV$
Output Cp3 = 1

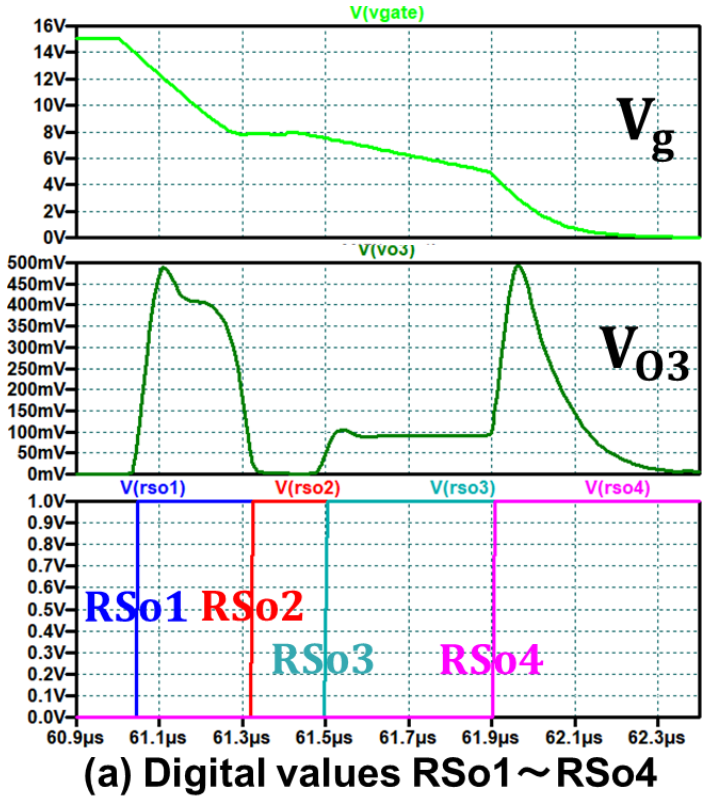
Comparator4(Cp4)
If $V_{O3} > 150mV$
Output Cp4 = 1



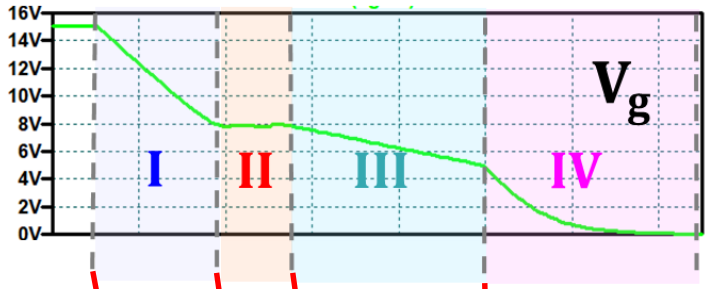
Digital value

The detected values (V_{O3}) are used to discriminate the operating region using a comparator and SRFF.

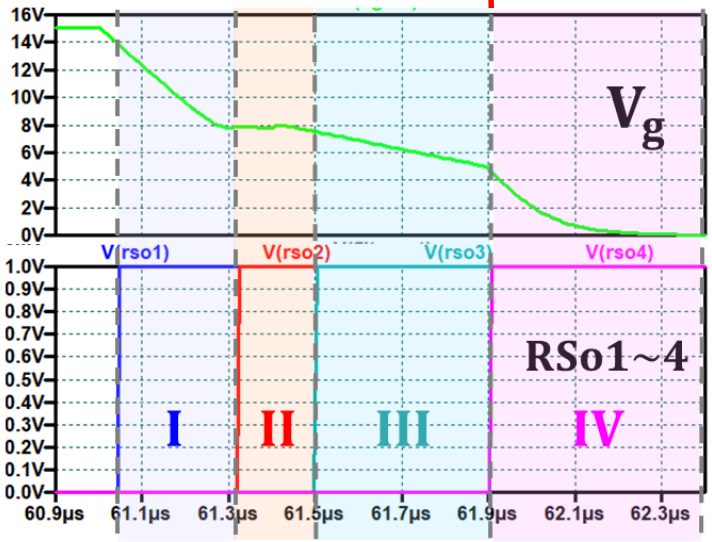
Digital Value ⇒ Operation Regions



(a) Digital values RSo1～RSo4



(b) Actual operating region



(c) Detected operating region

Delay in response speed of V_{O3} to variation in V_g

☹

Detection timing of operating region transitions delayed than actual operating region

Operation Regions

Digital Value

	RSo1	RSo2	RSo3	RSo4
Reg I	1	0	0	0
Reg II	1	1	0	0
Reg III	1	1	1	0
Reg IV	1	1	1	1

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Conclusion and Challenges

Conclusion

- **Proposal of current drive circuit to control gate voltage of IGBT**

- **During turn-off, when compared to conventional voltage drive :**

Current Drive → switching loss (-35%), overshoot (-32%)

- **Automatic discrimination of the operating region of current-driven IGBT gate driver circuits.**

Challenges

- **To verify the effect of detection delay in the operating region change on switching loss and overshoot.**

Thank you very much