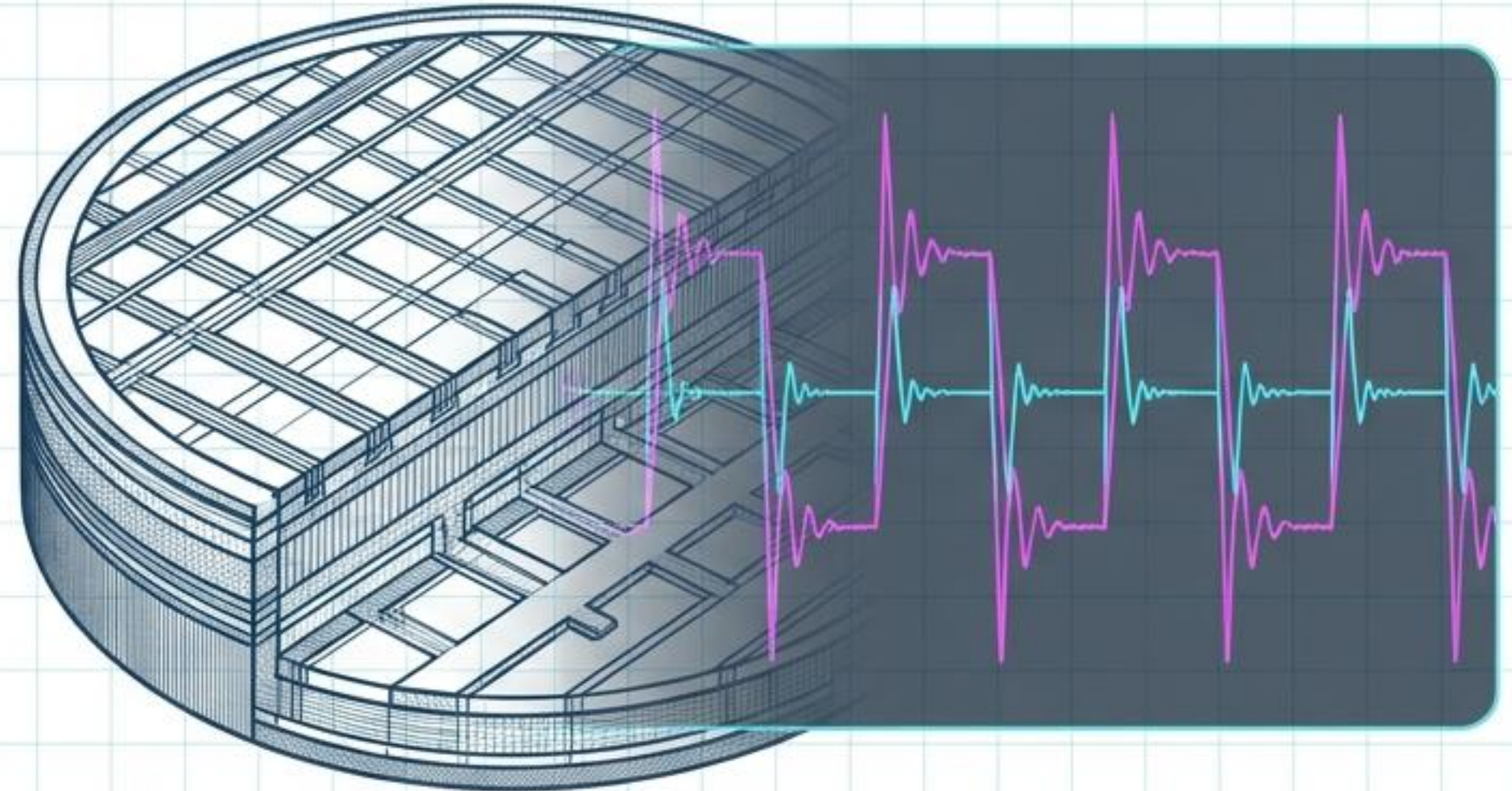


Power Transistors and Gate Drive Circuits

Power Semiconductor
Switching Devices and Their
Drive Techniques



Course: Power Electronics (Module-2)

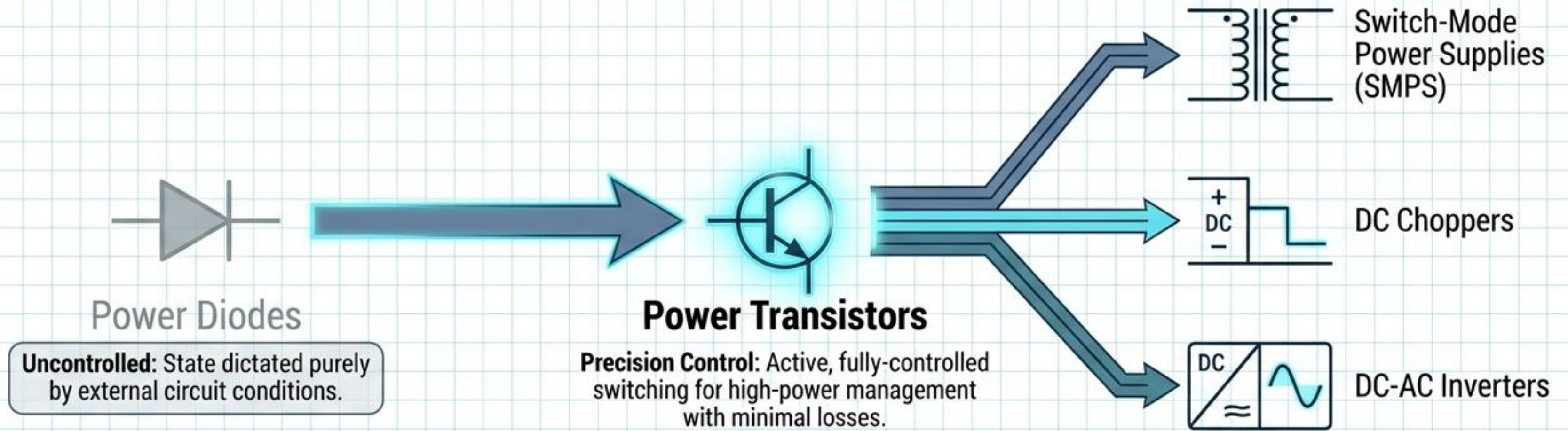
Presenter: Dr. Sathish K. R., Assistant Professor

Department of Electrical and Electronics Engineering (EEE)

Institution: ATME College of Engineering

Objective: Master the operational mechanics, dynamic switching characteristics, and drive circuit implementation of modern power semiconductor devices.

Introduction to Power Transistors



The Big Three Classification



BJT (Bipolar Junction Transistor) |
Current-controlled device.

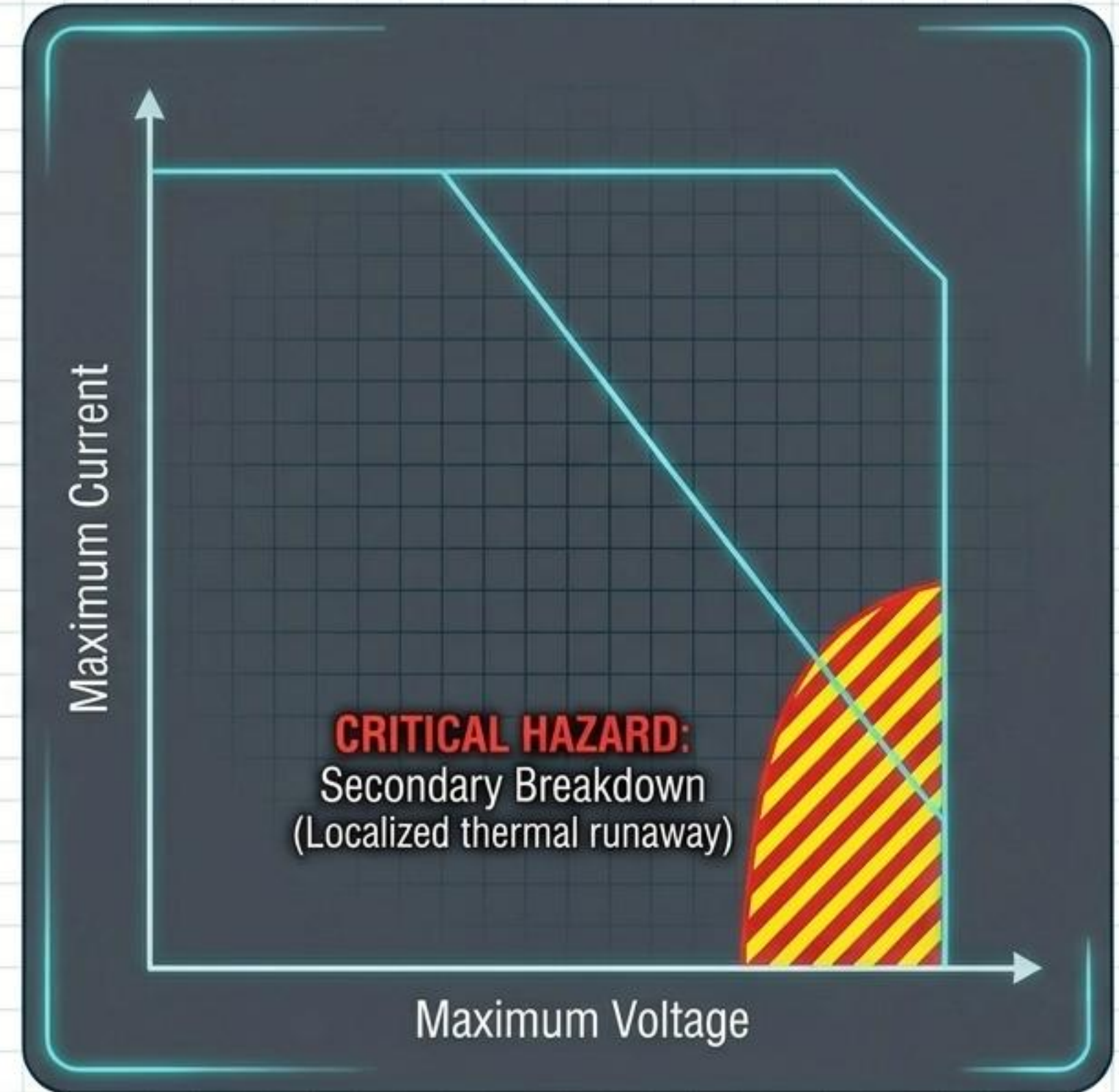
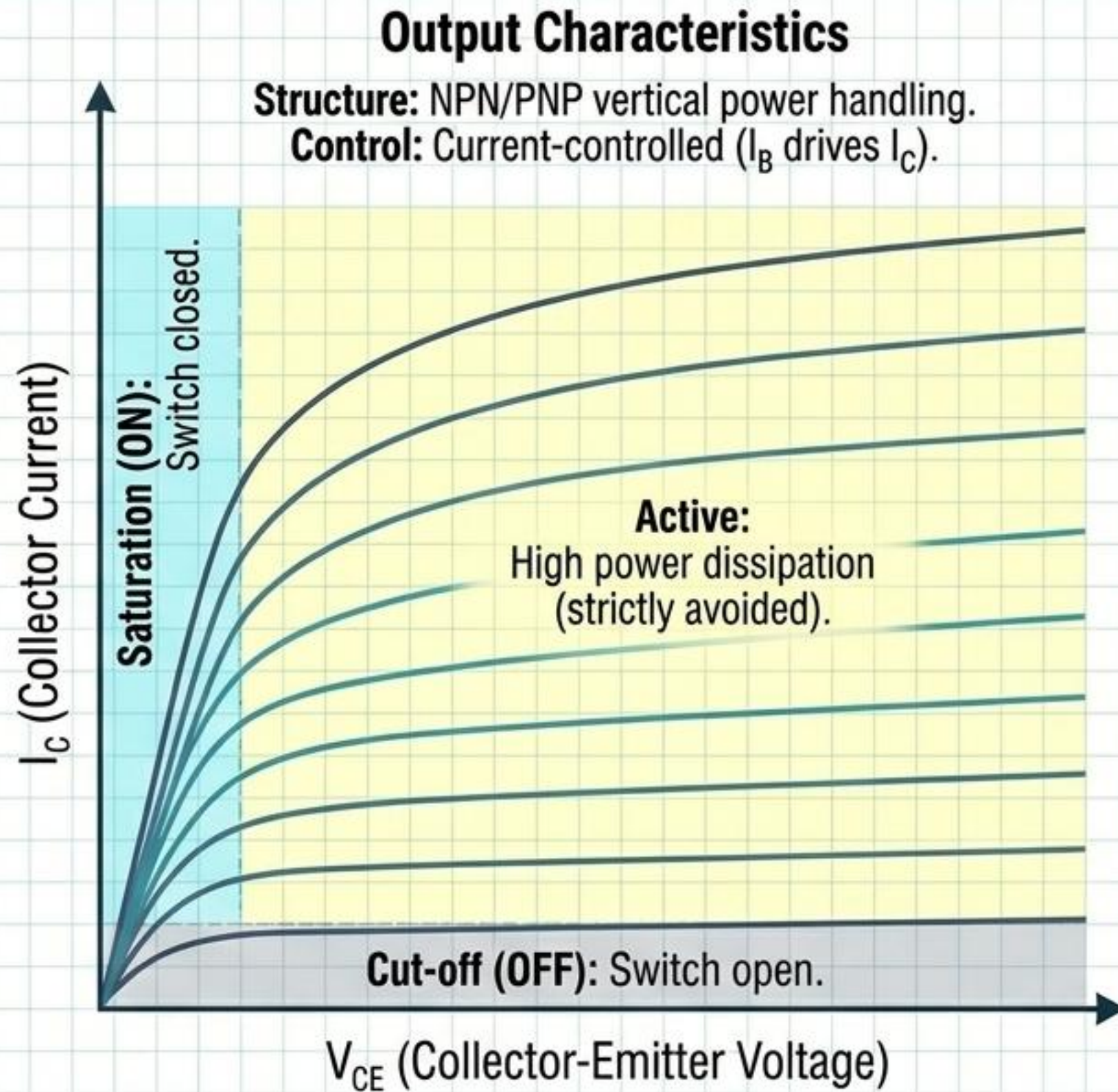


MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) | Voltage-controlled device.

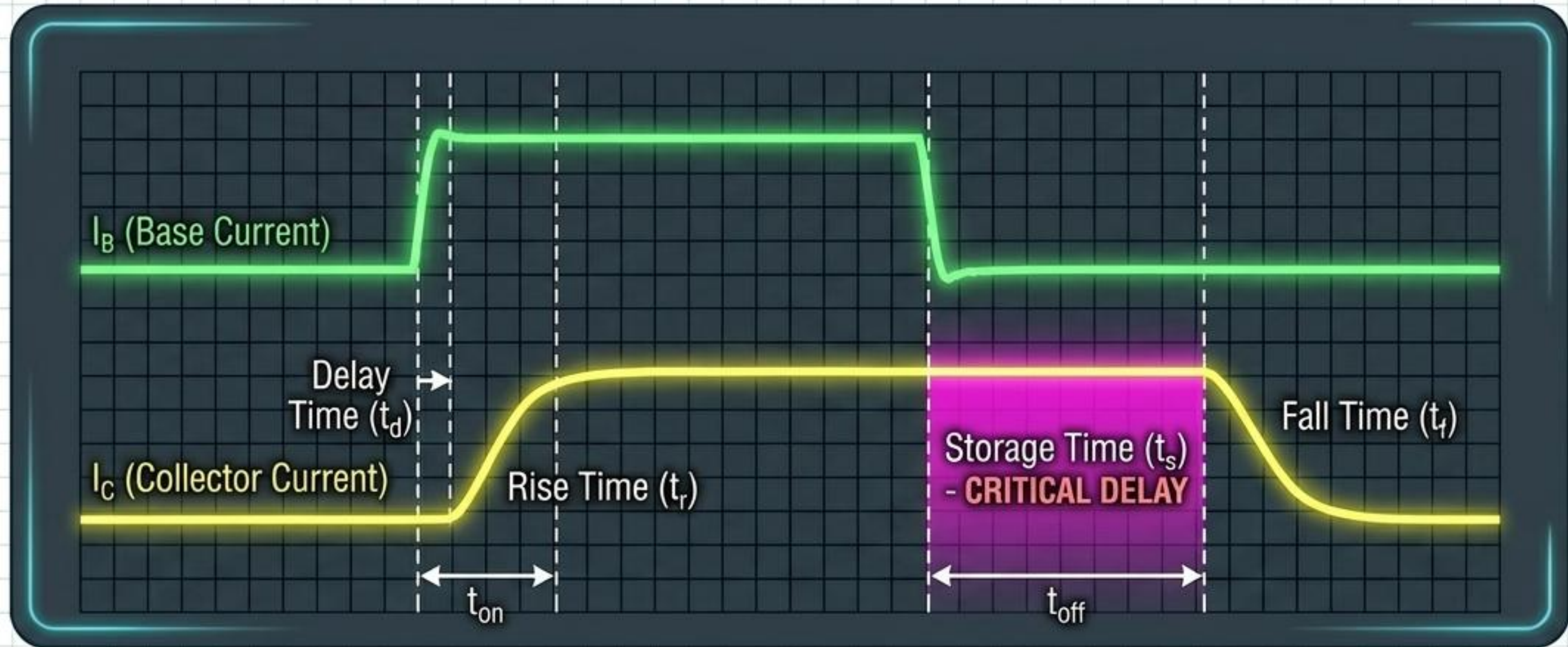


IGBT (Insulated Gate Bipolar Transistor) |
Hybrid voltage-controlled/high-current device.

Power BJTs: Characteristics & Switching Limits

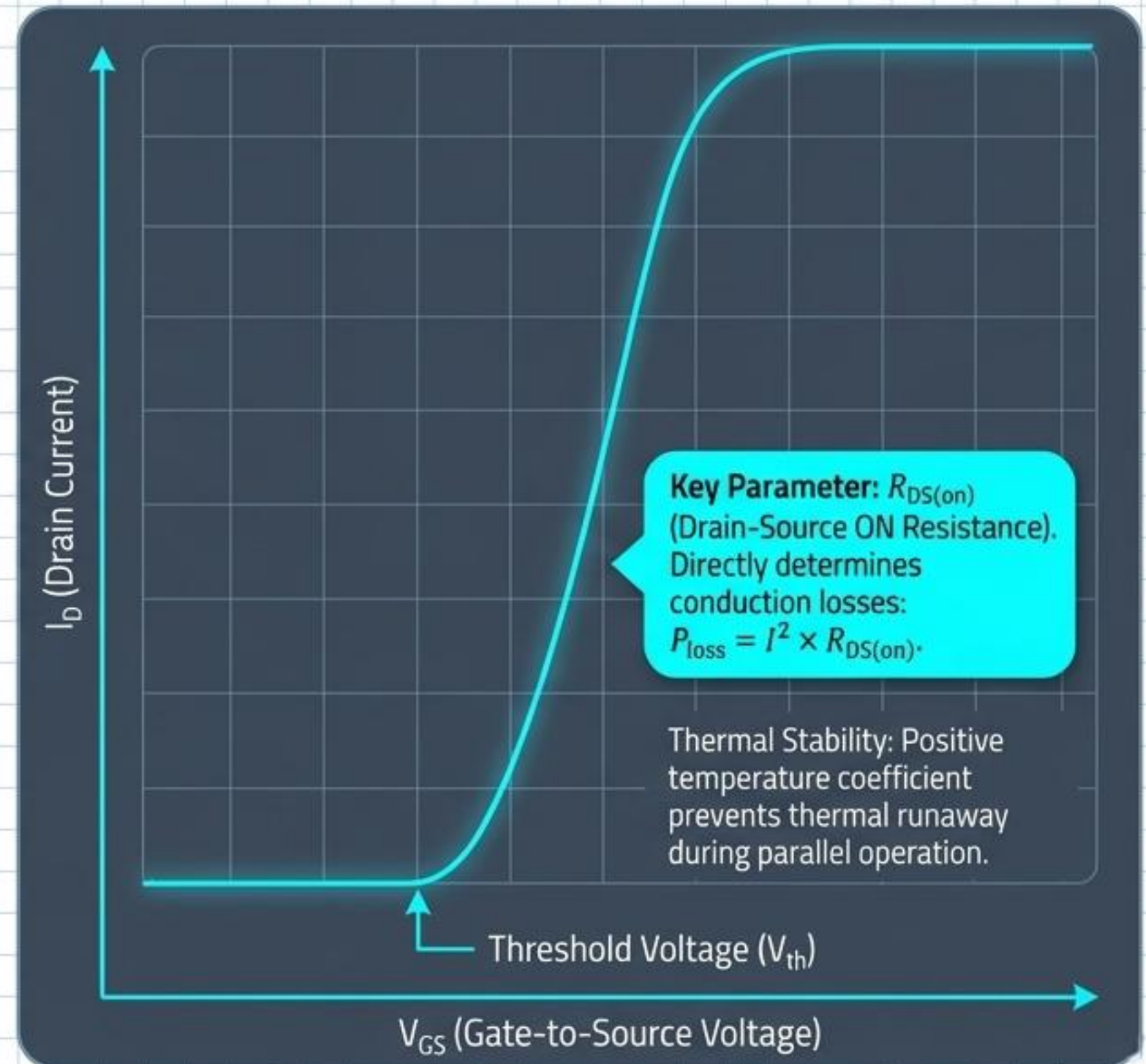
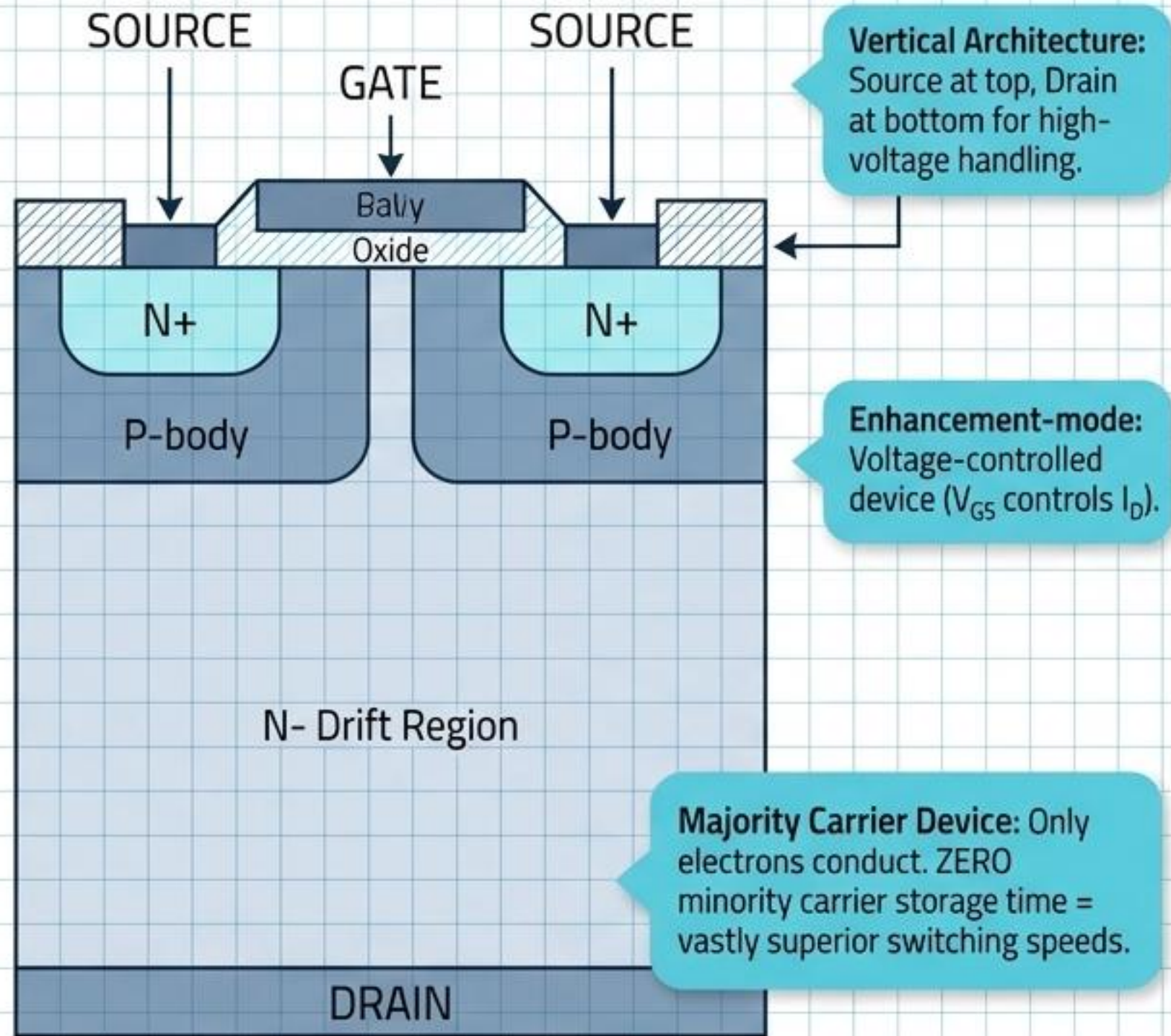


BJT Dynamic Switching Performance

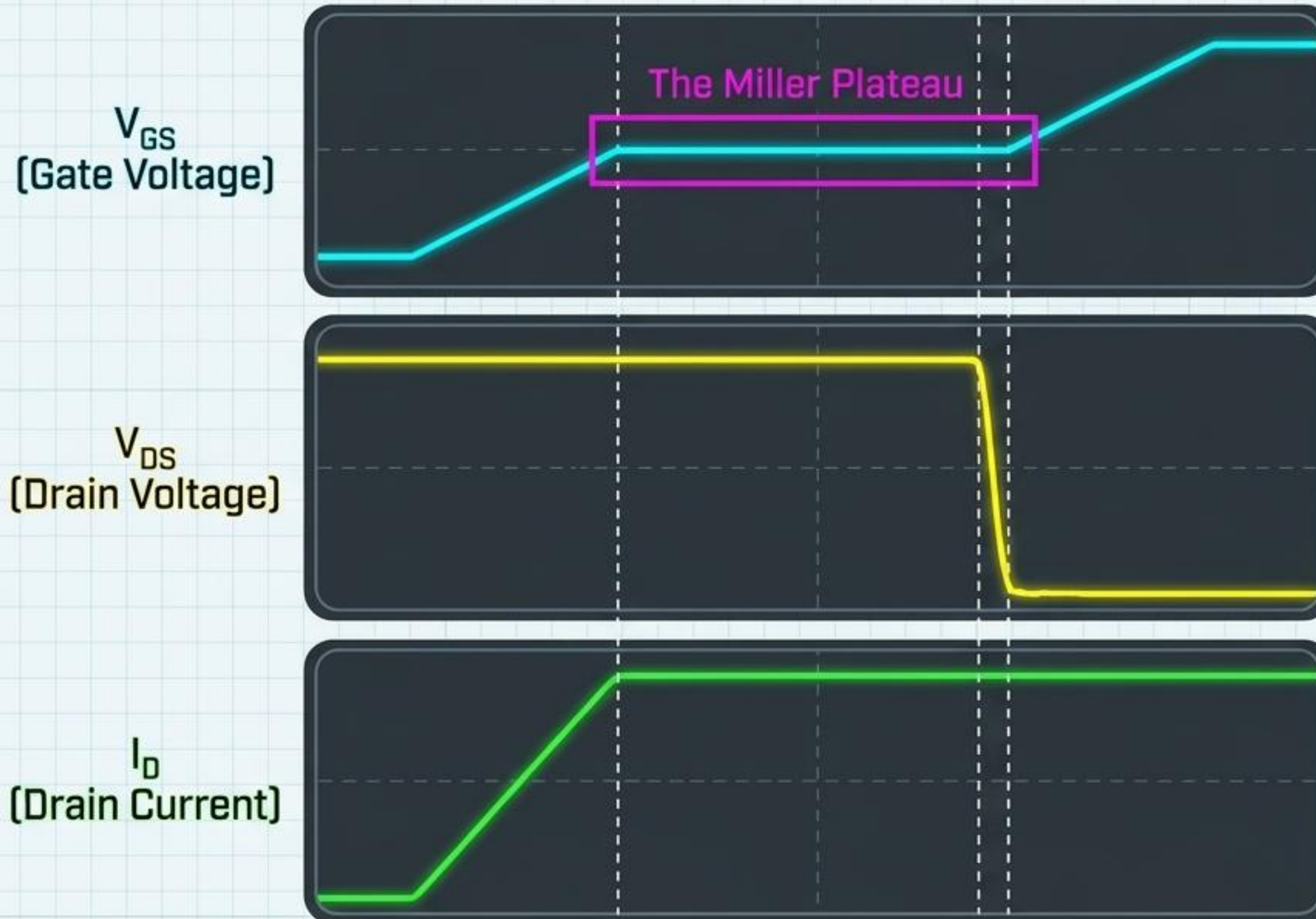


Engineering Takeaway: The BJT's reliance on minority carriers creates significant storage time (t_s)—the time required to sweep out excess carriers before I_C can drop. This heavily caps its maximum switching frequency to <10 kHz.

Power MOSFETs: Construction & Steady-State



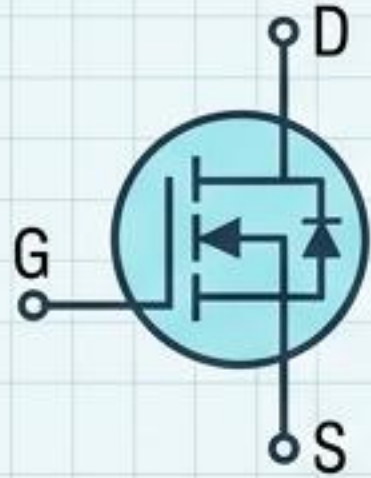
MOSFET Switching Characteristics & The Miller Plateau



The Gate Charging Process

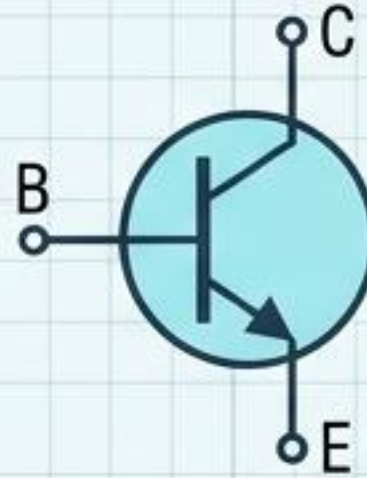
- Switching speed relies entirely on charging/discharging parasitic input capacitances [C_{gs} , C_{gd} , C_{ds}].
- Turn-ON Delay ($t_{d(on)}$): Charging C_{gs} up to the threshold voltage.
- Rise Time (t_r): V_{GS} rises past threshold, I_D ramps up to full load.
- The Miller Plateau Mechanism: Even though gate current flows, V_{GS} remains constant. The current is entirely diverted to discharge the Gate-Drain capacitance [C_{gd}] as V_{DS} rapidly falls.
- Performance Summary: Minimal delay allows ultra-high-frequency mastery (100 kHz to MHz range).

IGBTs: The Best of Both Worlds



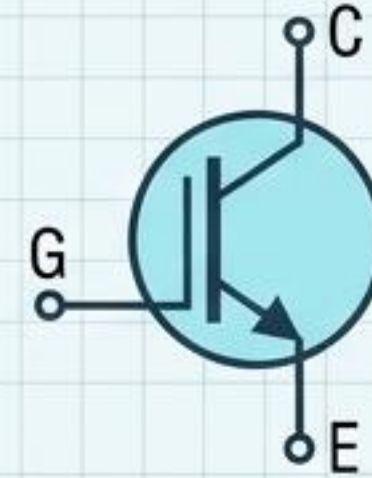
[MOSFET Input Stage]

Voltage-controlled gate. High input impedance = easy to drive.



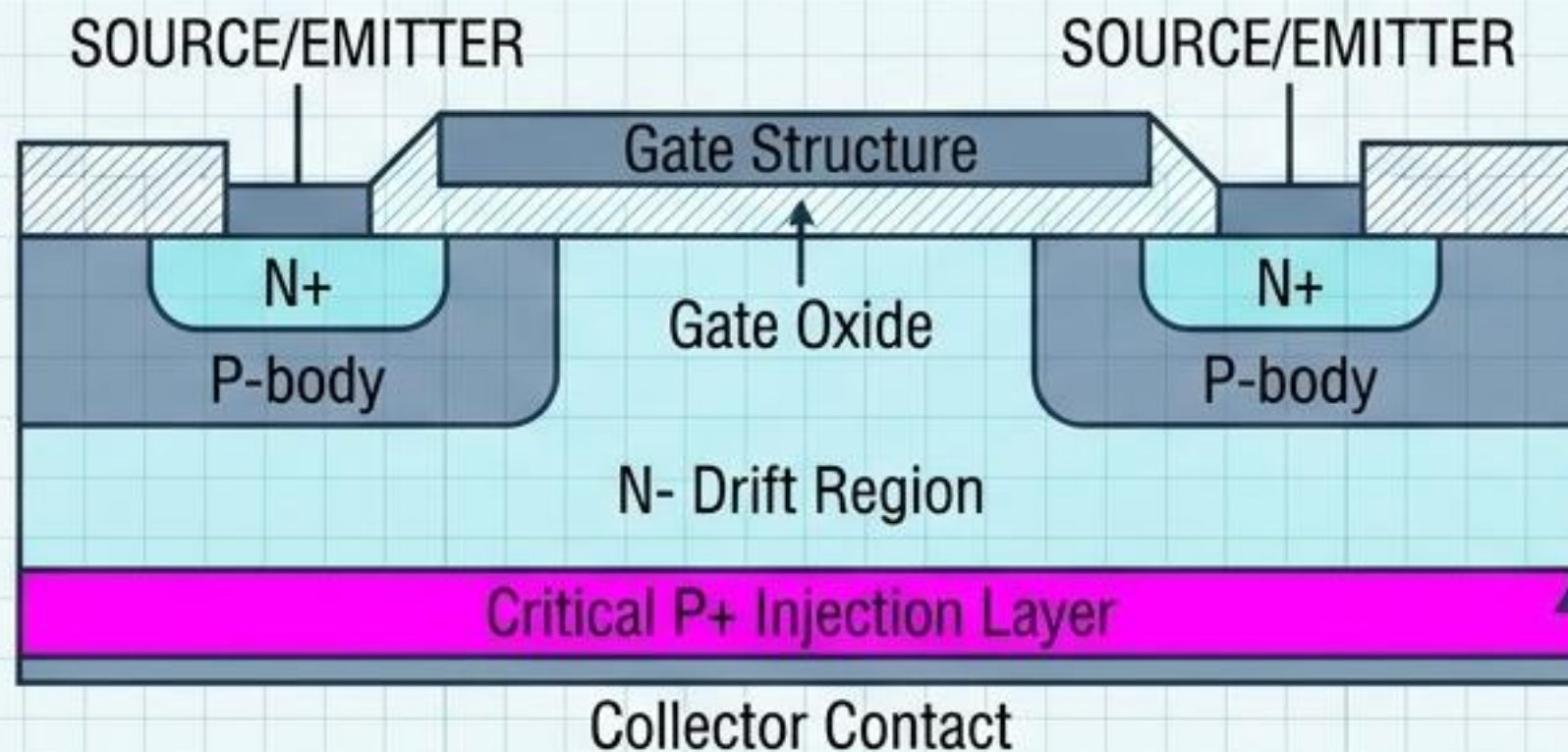
[BJT Output Stage]

High-current, low-saturation voltage.
Massive power handling capability.



[The IGBT Hybrid]

High voltage handling, low conduction loss, easily driven.



This layer injects minority carriers, drastically reducing the ON-state voltage drop at very high currents compared to a MOSFET. Exhibits a diode-like forward voltage drop.

IGBT Dynamic Behavior & The Current Tail



Turn-OFF Dynamics

Gate capacitance discharges quickly, causing the initial sharp drop in current.

The Cause of the Tail

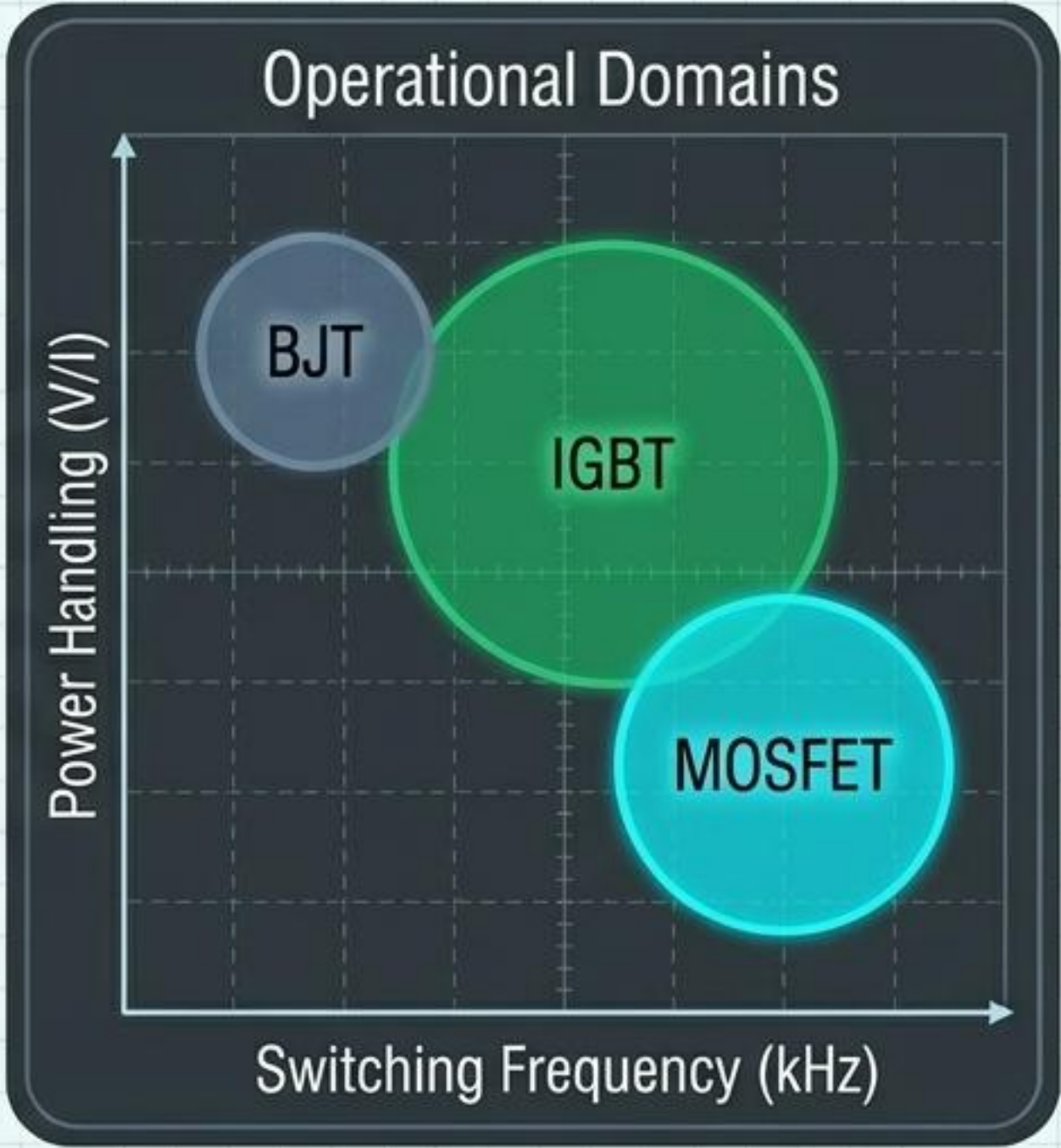
Because the IGBT uses a P+ injection layer, minority carriers flood the drift region. During turn-OFF, there is no negative gate connection to actively sweep them out. They must decay naturally through recombination.

The Consequence

Creates a trailing Collector Current (I_C) that prolongs total turn-OFF time. This increases switching losses, firmly capping the IGBT's practical switching frequency to the medium range (10-50 kHz).

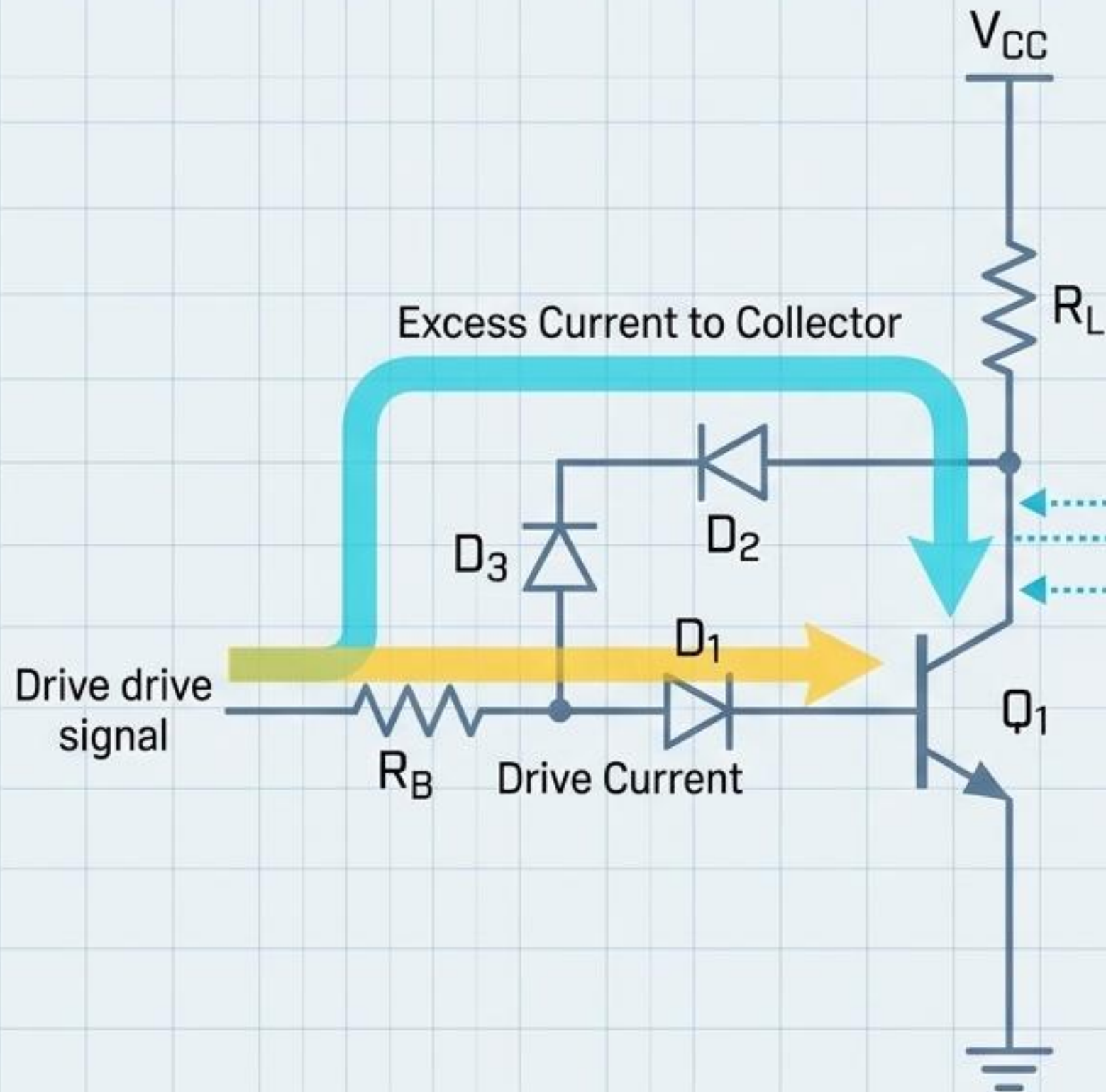
Comparative Analysis: Power Switch Selection Matrix

Characteristic	Power BJT	Power MOSFET	IGBT
Control Requirement	Current (High Power)	Voltage (Low Power)	Voltage (Low Power)
Switching Speed	< 10 kHz (Slow) 	> 100 kHz (Very Fast) 	10-50 kHz (Medium) 
Voltage/Current Rating	High	Low to Medium	Very High
Conduction Losses	Low	High at High Voltages	Low



Engineering Rule of Thumb: Use MOSFETs for High-Frequency / Low-Voltage. Use IGBTs for Low-Frequency / High-Voltage.

BJT Control: The Baker's Clamp Circuit



The Base Drive Challenge

Power BJTs require continuous, heavy base current (I_B) to stay in saturation.

Overdriving speeds up Turn-ON, but creates a massive storage time penalty during Turn-OFF.

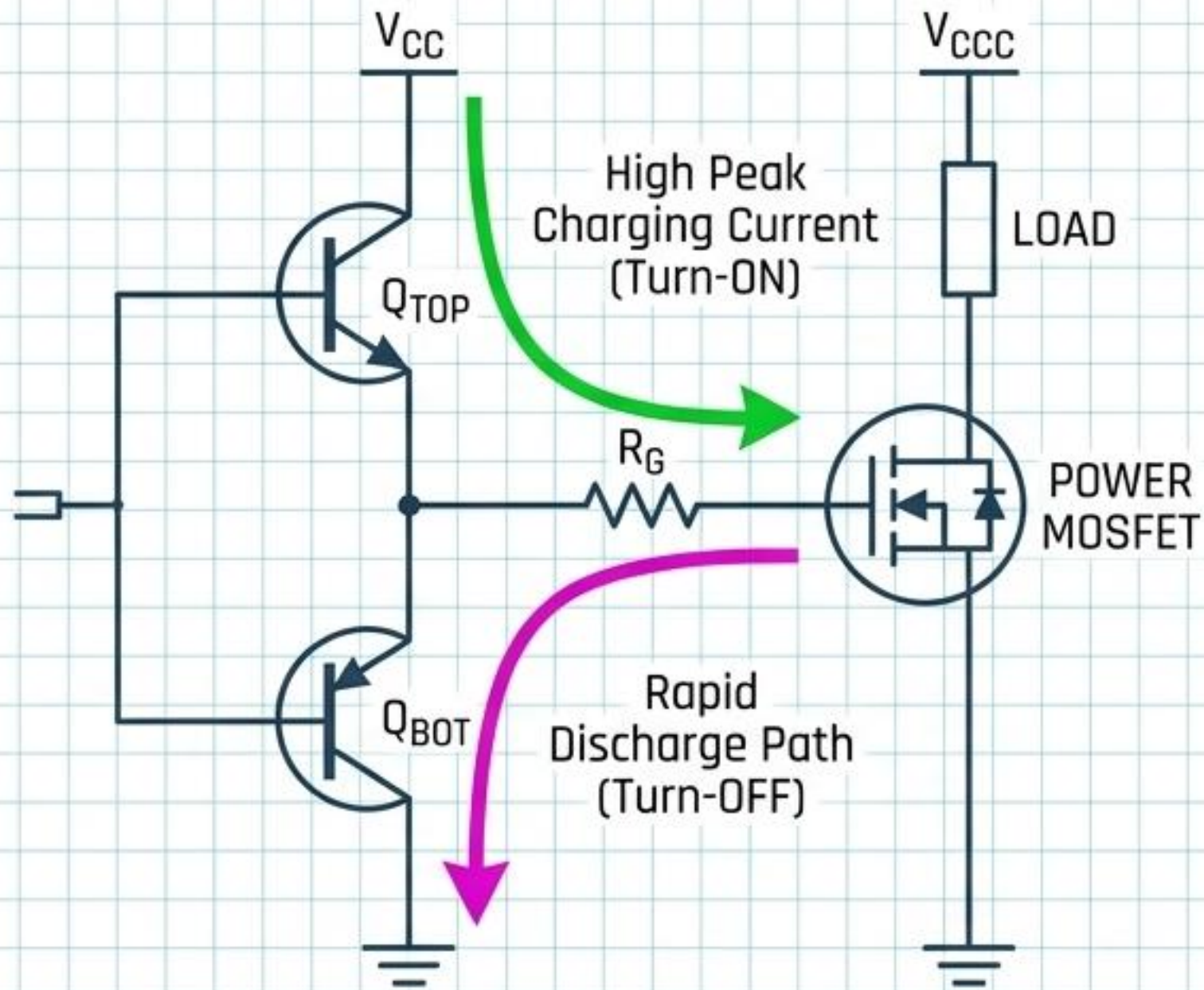
The Deep Saturation Problem

Pushing too much current into the base drives the BJT into deep saturation, making it extremely difficult to sweep out minority carriers quickly.

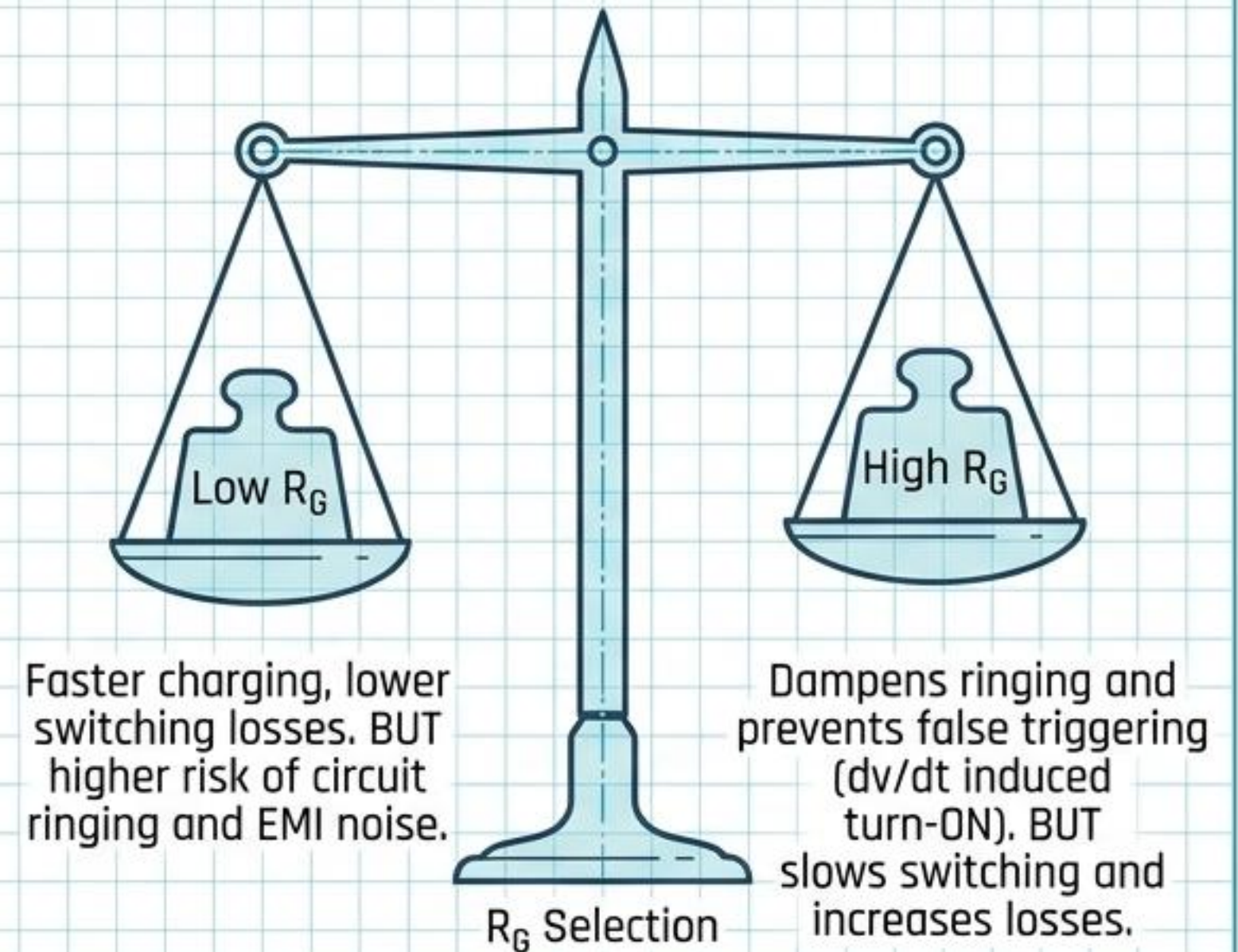
The Baker's Clamp Solution

Uses feedback diodes to implement proportional base control. Excess drive current is automatically routed to the collector. This keeps the BJT exactly at the edge of saturation, drastically cutting storage time and maximizing switching speed.

MOSFET/IGBT Control: Totem-Pole Gate Drives



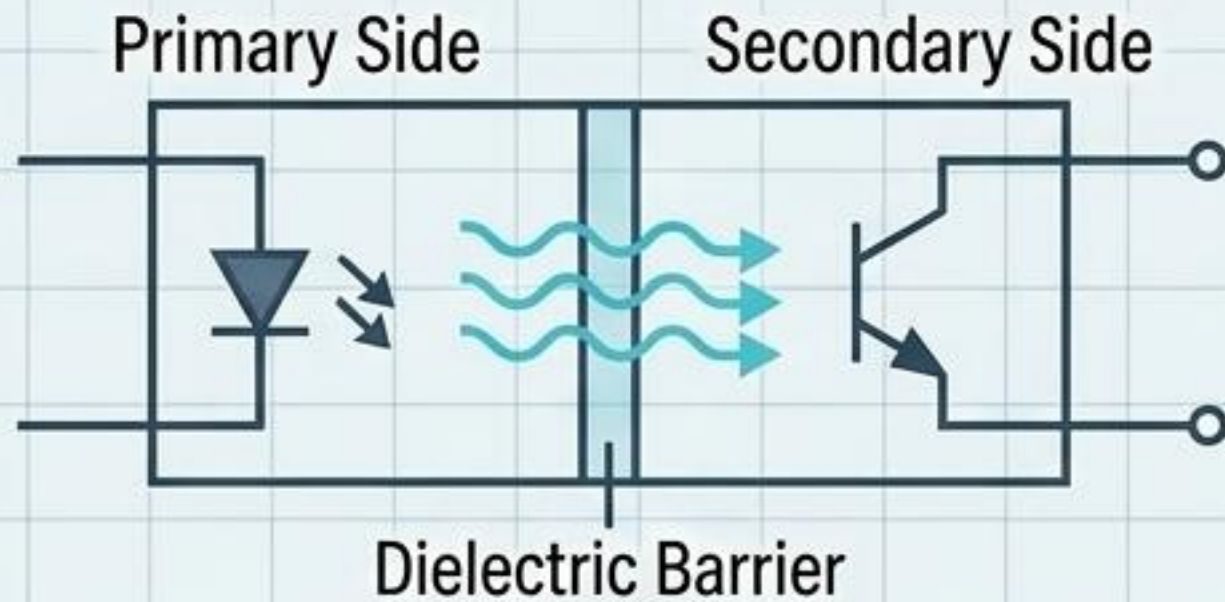
The Requirement: While "voltage controlled," parasitic capacitances demand huge transient current spikes (several amps) from the driver to switch states quickly.



Ensuring System Integrity: Galvanic Isolation

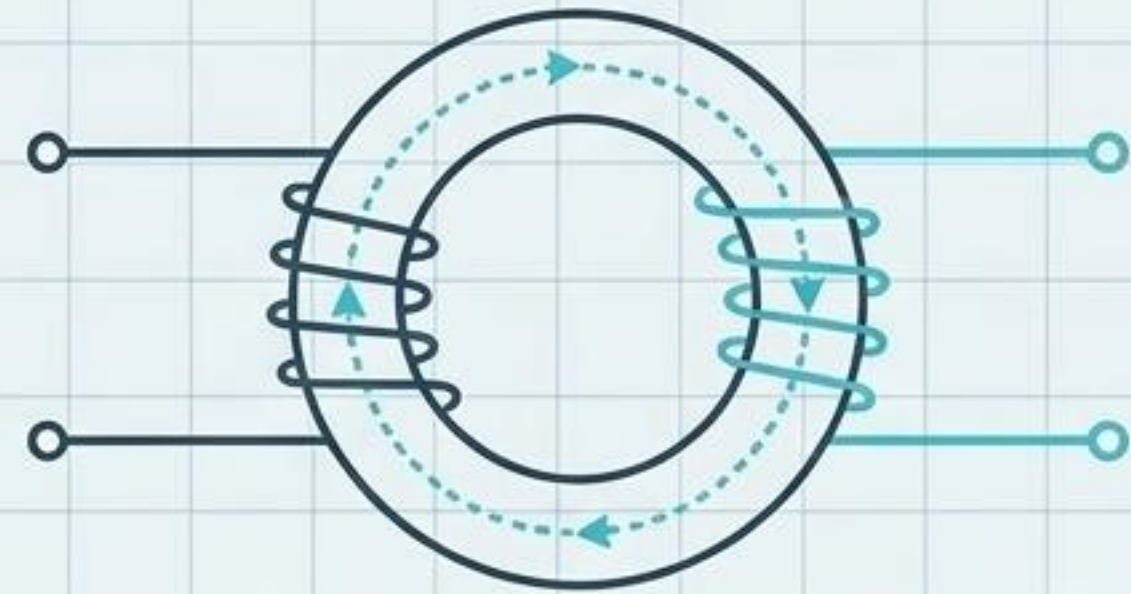
The Imperative: Isolate high-voltage power circuits from fragile low-voltage control microcontrollers. Prevents ground loops and catastrophic fault propagation.

Opto-Couplers (Optical Isolation)



- **Mechanism:** Light transmission across a physical dielectric barrier.
- **Pros:** Perfect for transmitting continuous low-frequency or DC signals (no duty cycle limits).
- **Cons:** Subject to propagation delays and LED degradation over time.
- **Application:** Industry standard for general industrial motor drives.

Pulse Transformers (Magnetic Isolation)



- **Mechanism:** Electromagnetic flux coupling across a transformer core.
- **Pros:** Excellent for ultra-high-frequency, instantaneous signal transfer.
- **Cons:** Cannot transmit continuous DC signals due to core saturation (strict duty cycle limitations).
- **Application:** Ideal for high-frequency Switch-Mode Power Supplies (SMPS).

Practical Device Selection Map

Converter Requirements

High Frequency ($>100\text{kHz}$) /
Low-to-Medium Power

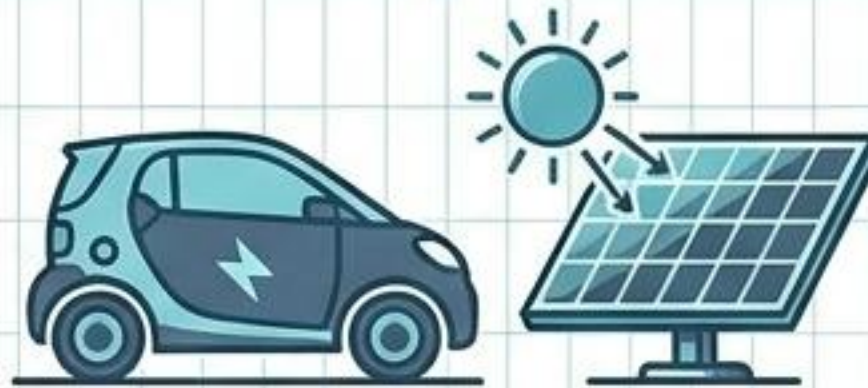
MOSFET + Pulse Transformers



Switch-Mode Power Supplies (SMPS).
High frequency shrinks magnetic
components, saving space.

Medium Frequency (10-50kHz) /
High Voltage & Power

IGBT + Opto-Couplers



EV Traction Inverters & Renewable
Solar Inverters. Balances efficiency
with high voltage capacity.

Low Frequency /
Extreme Overload Current

IGBT (or Heavy Duty BJT)



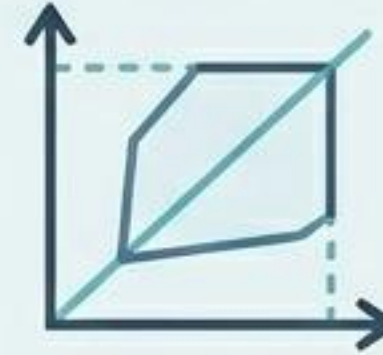
Heavy Industrial Motor Drives.
Requires maximum robustness
and thermal capacity.

Masterclass Summary & Key Exam Takeaways



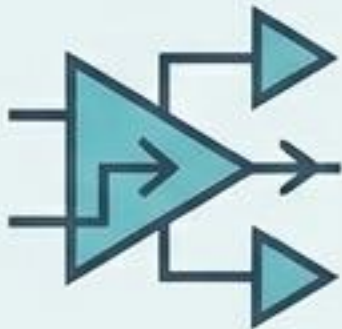
1. Device Physics

- **BJT:** Current-controlled, heavily limited by saturation storage time.
- **MOSFET:** Voltage-controlled majority carrier, zero storage time.
- **IGBT:** Hybrid structure, low conduction loss but exhibits a Turn-OFF current tail.



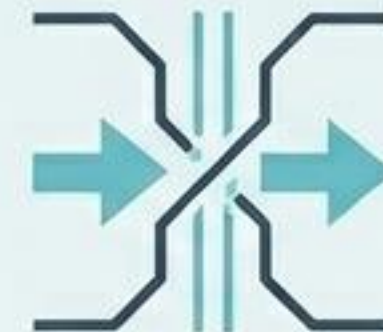
2. Diagnostic Curves

- **SOA (Safe Operating Area):** Always verify to avoid catastrophic secondary breakdown.
- **Waveforms:** Must be able to map the MOSFET Miller Plateau and BJT delay/storage times.



3. Drive Circuits

- **Base Drives (BJT):** Require anti-saturation techniques like the Baker's Clamp.
- **Gate Drives (MOSFET/IGBT):** Require Totem-Pole topologies to deliver massive transient charging currents.



4. Safety & Isolation

- Galvanic Isolation is universally mandatory.
- **Pulse Transformers:** Best for High Frequency/SMPS.
- **Opto-Couplers:** Best for DC capability/Motor Drives.

Are there any questions?