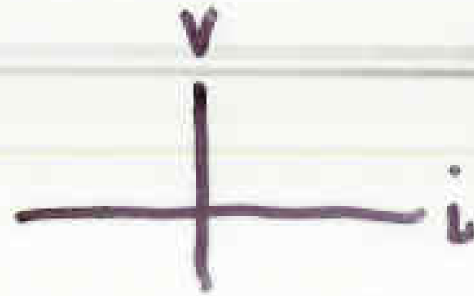
Chapter 4. Switch Realization

slow 4 quad
wire switch
vs
semiconductor
fast 1-2 quads



4.1. Switch applications

Single-, two-, and four-quadrant switches. Synchronous rectifiers

4.2. A brief survey of power semiconductor devices

Power diodes, MOSFETs, BJTs, IGBTs, and thyristors

4.3. Switching loss

Two parts are?

Transistor switching with clamped inductive load. Diode recovered charge. Stray capacitances and inductances, and ringing. Efficiency vs. switching frequency.

4.4. Summary of key points

Total Loss = Sw loss + Core losses + i^2R

Chapter 4. Switch Realization

bipolar $R_{on} = 0$

Not yet in solid state → Mechanical Switch: $R_{off} = \infty$

Back to the Future: μ Mechanical Switches @ ~100 KHz MEMS

4.1. Switch applications

Mechanical: all 4 V-I quadrants

Single-, two-, and four-quadrant switches. Synchronous rectifiers

MOSFET fast but limited quadrants

4.2. A brief survey of power semiconductor devices

10 nS switch time, f_{sw} · 1 MHz

Power diodes, MOSFETs, BJTs, IGBTs, and thyristors

4.3. Switching loss

Total Loss = DC loss + Switch Loss

Transistor switching with clamped inductive load. Diode recovered charge. Stray capacitances and inductances, and ringing. Efficiency vs. switching frequency.

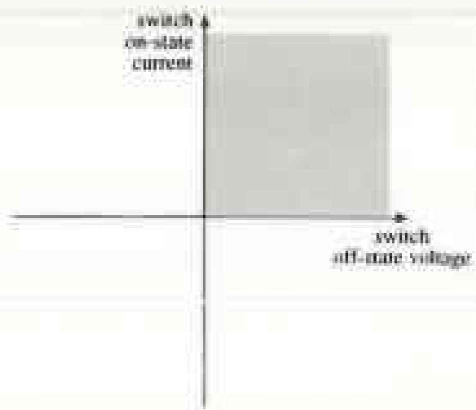
$f_{sw}\left[\frac{1}{2}CV^2 + \frac{Li^2}{2}\right]$

4.4. Summary of key points

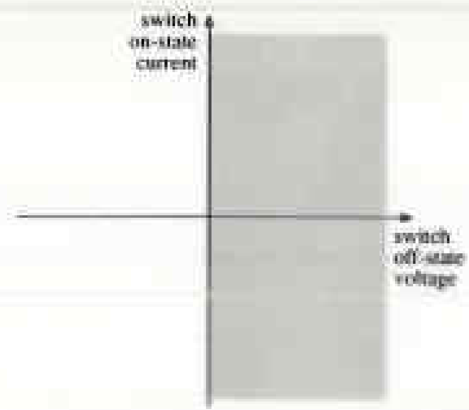
? I_{rr} V_{off} meaning

Some basic switch applications

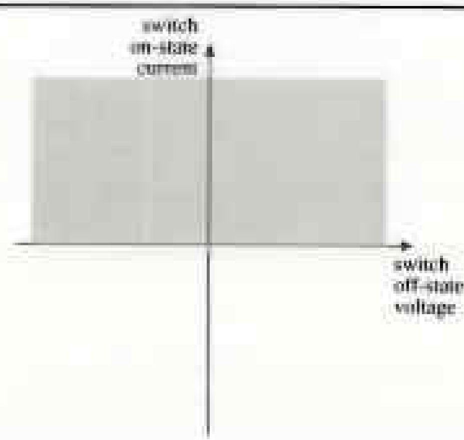
Single-quadrant switch



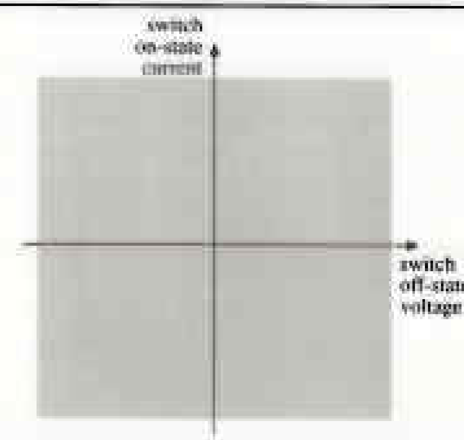
Current-bidirectional two-quadrant switch



Voltage-bidirectional two-quadrant switch

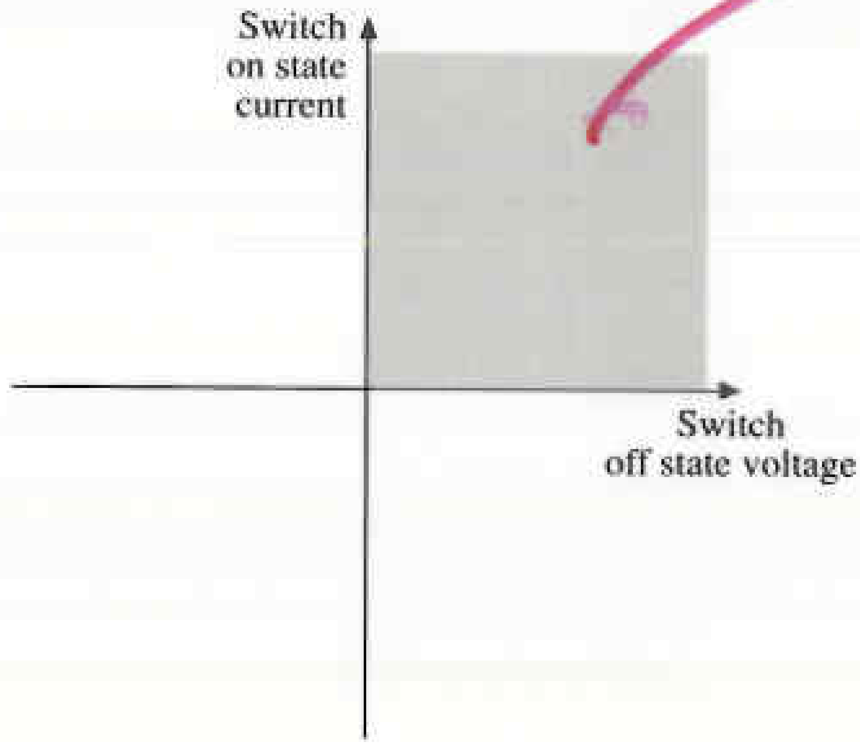


Four-quadrant switch



Quadrants of SPST switch operation

Solid state has limits



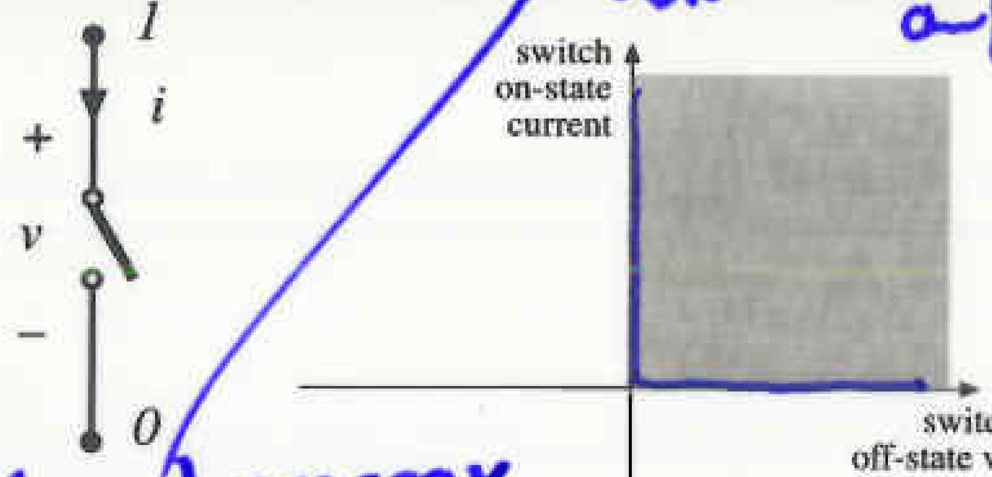
A single-quadrant switch example:

ON-state: $i > 0$

OFF-state: $v > 0$

Fig 4.3

Quadrants of SPST switch operation



BJT

A single-quadrant switch example:

ON-state: $i > 0$

OFF-state: $v > 0$

i_{ON} V_{off}

"ON" stored energy $\frac{1}{2} L (i_{ON})^2$

Causes ON → off only losses

Got it?

← compare →

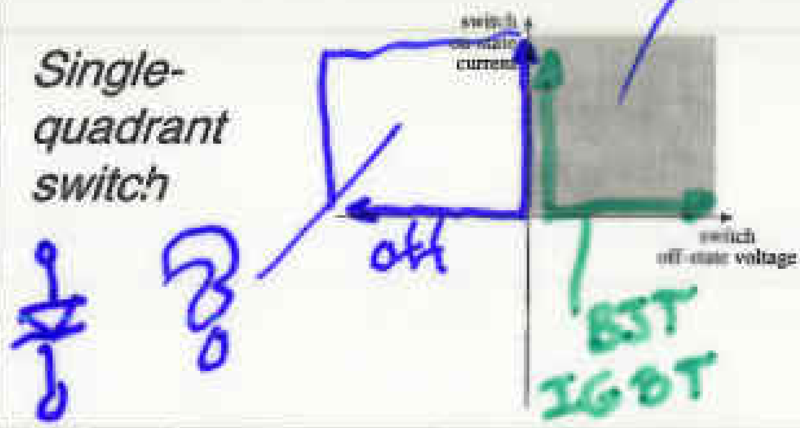
"off" stored energy $\frac{1}{2} C(\text{device}) V_{off}^2$

Causes off → ON losses only

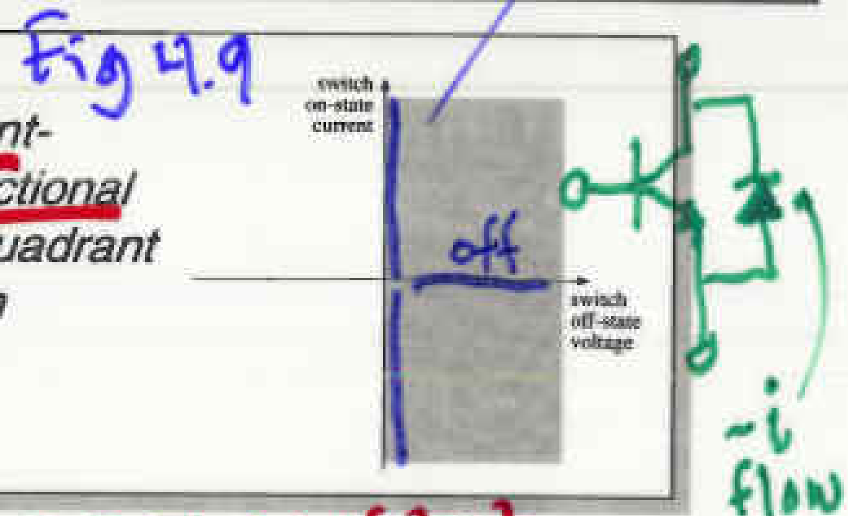
Got it!

Some basic switch applications

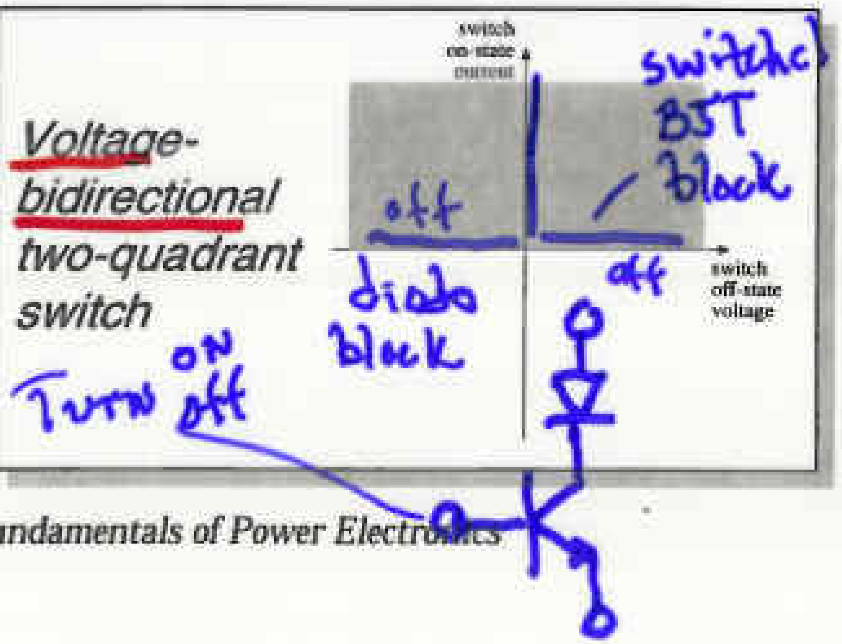
Single-quadrant switch



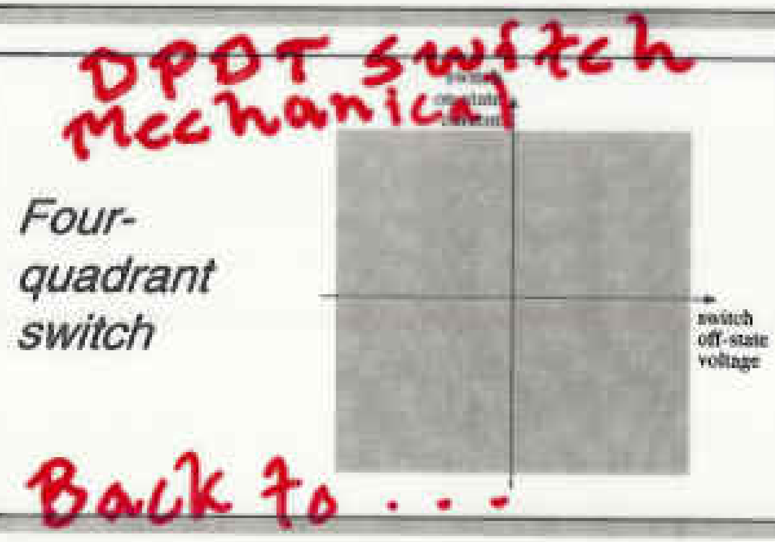
Current-bidirectional two-quadrant switch



Voltage-bidirectional two-quadrant switch



Four-quadrant switch



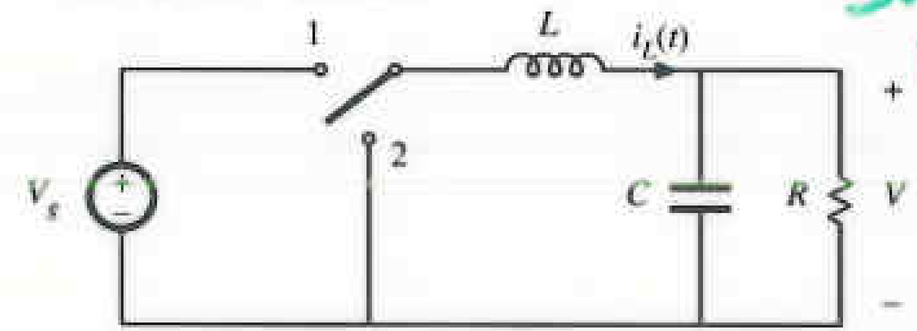
SPST (single-pole single-throw) switches

SPST switch, with voltage and current polarities defined

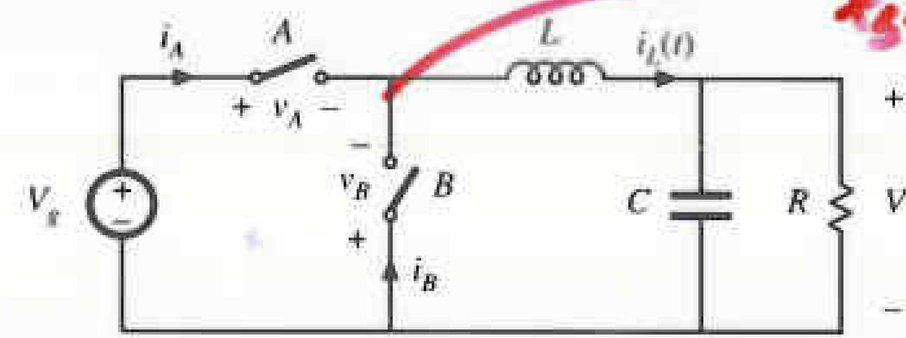
All power semiconductor devices function as SPST switches.

Buck converter

with SPDT switch:



with two SPST switches:



New MEMS Sw 10kHz

Semicond f_{sw} → MHz

SPST (single-pole single-throw) switches

Start Fig 4.2 p 64

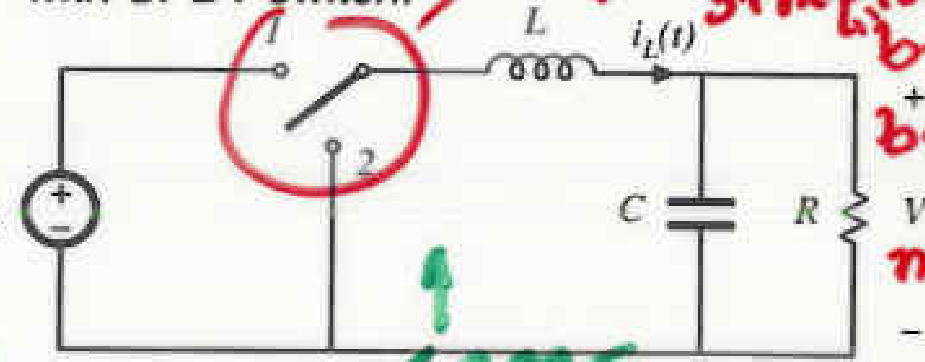
SPST switch, with voltage and current polarities defined

Voff air arc 30kV / cm

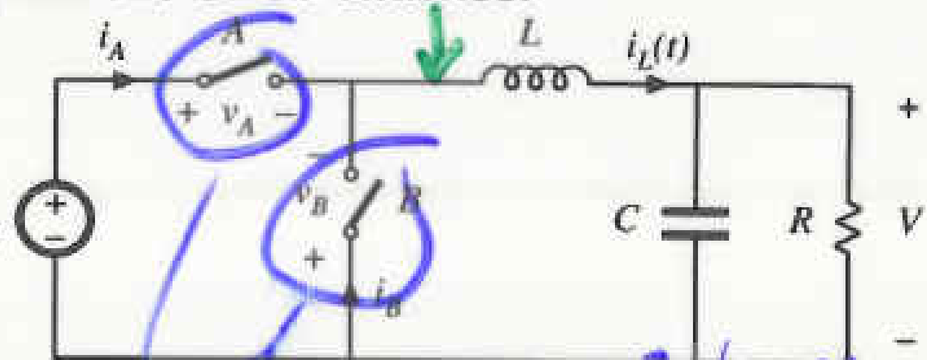
All power semiconductor devices function as SPST switches.

Buck converter

with SPDT switch:



with two SPST switches:



Realization of SPDT switch using two SPST switches

- A nontrivial step: two SPST switches are not exactly equivalent to one SPDT switch
- It is possible for both SPST switches to be simultaneously ON or OFF
- Behavior of converter is then significantly modified
  —discontinuous conduction modes (chapter 5)
- Conducting state of SPST switch may depend on applied voltage or current —for example: diode

Q_{rr}, t_{rr}

Realization of SPDT switch using two SPST switches

limited V-I quadrants causes

- A nontrivial step: two SPST switches are not exactly equivalent to one SPDT switch
- It is possible for both SPST switches to be simultaneously ON or OFF sw. drive synch
- Behavior of converter is then significantly modified —discontinuous conduction modes (ch. 5) diode is not bipolar cause $I_L = 0$
- Conducting state of SPST switch may depend on applied voltage or current —for example: diode

"Break before make" requires a deadtime interval, Δt with both off

OR ?

4.1.1. Single-quadrant switches

Active switch: Switch state is controlled exclusively by a third terminal (control terminal).

Passive switch: Switch state is controlled by the applied current and/or voltage at terminals 1 and 2.

SCR: A special case — turn-on transition is active, while turn-off transition is passive.

Single-quadrant switch: on-state $i(t)$ and off-state $v(t)$ are unipolar.

i zero crossing by Thy → 0

4.1.1. Single-quadrant switches

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Passive switch: Switch state is controlled by the applied current and/or voltage at terminals *1* and *2*.

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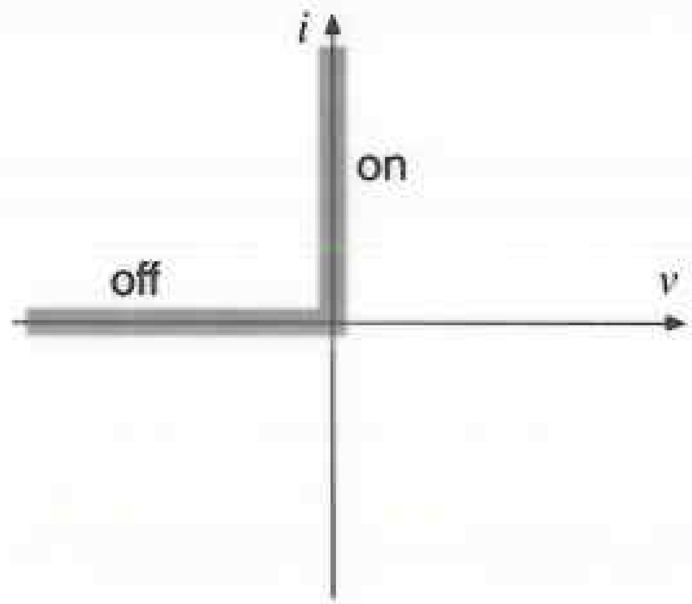
Single-quadrant switch: on-state $i(t)$ and off-state $v(t)$ are unipolar.

FET
Bipolar
ON Thyristor
diode
off thyristor

When Thyristor off?

The diode

Symbol

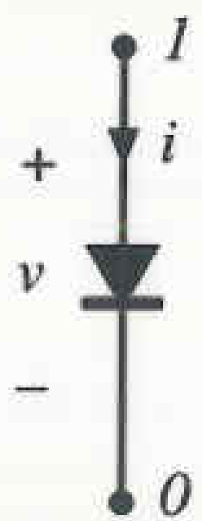


instantaneous i-v characteristic

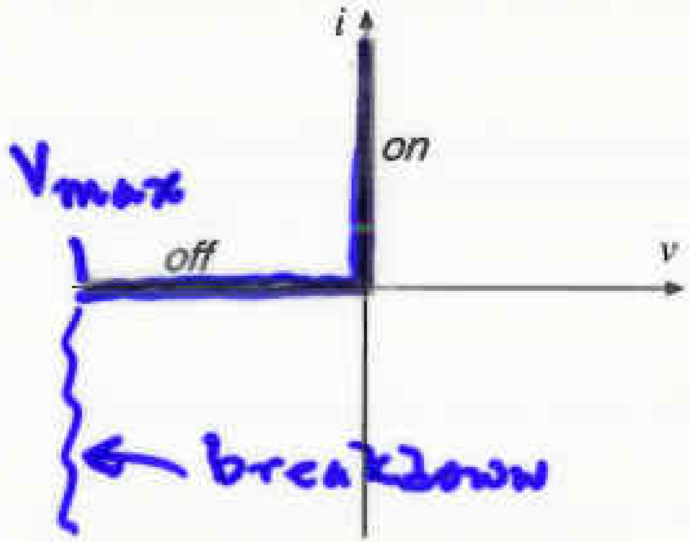
- *A passive switch*
- *Single-quadrant switch:*
- *can conduct positive on-state current*
- *can block negative off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the diode i-v characteristic, then switch can be realized using a diode*

Figure 4.4 p 85

The diode



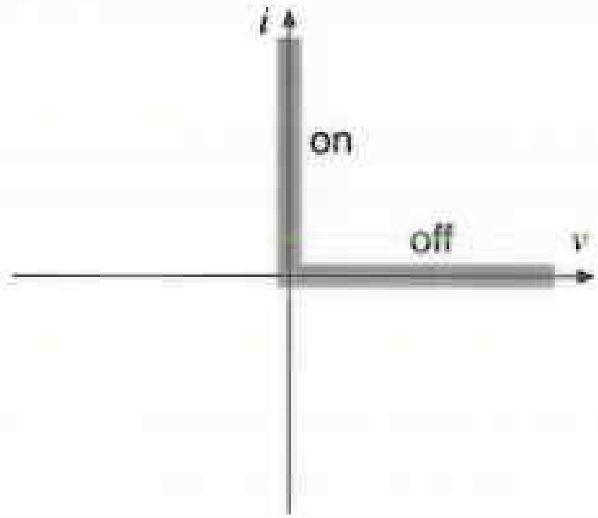
Symbol



instantaneous i-v characteristic

- *A passive switch*
- *Single-quadrant switch:*
- *can conduct positive on-state current*
- *can block negative off-state voltage* } Vmax
- *provided that the intended on-state and off-state operating points lie on the diode i-v characteristic, then switch can be realized using a diode*

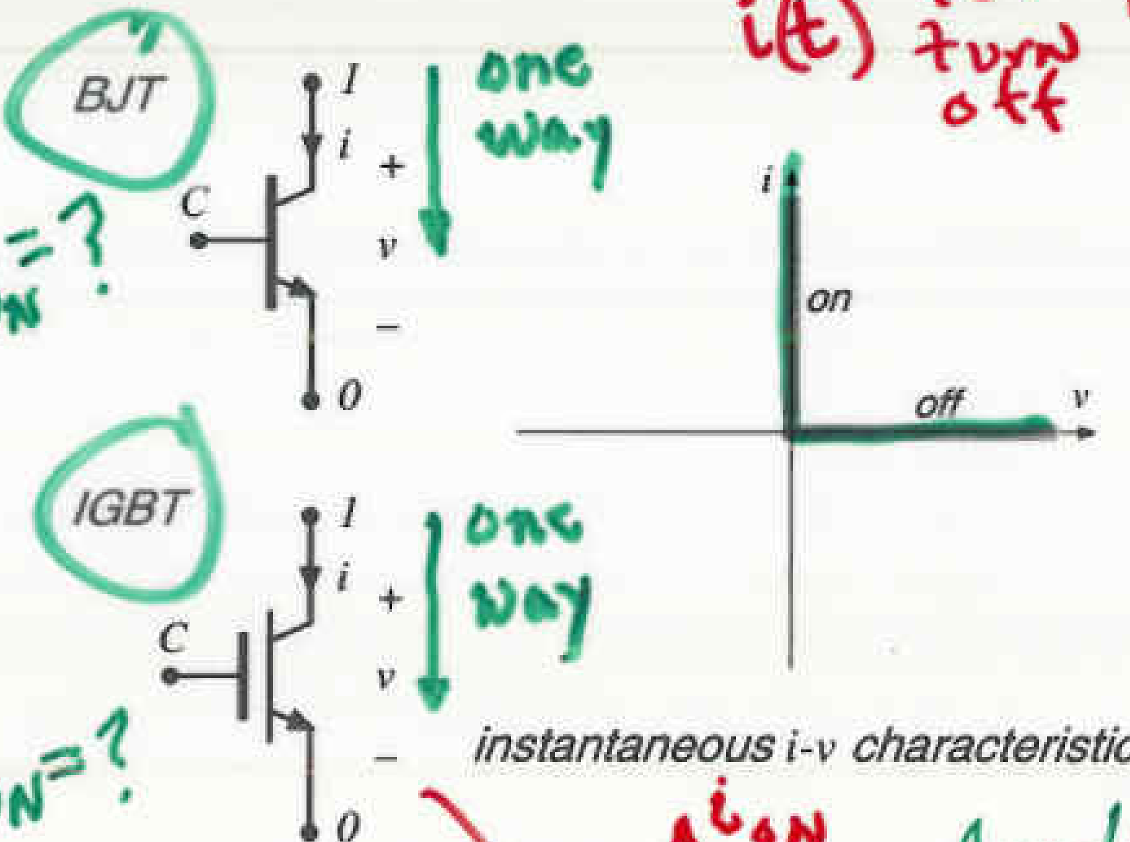
The Bipolar Junction Transistor (BJT) and the Insulated Gate Bipolar Transistor (IGBT)



instantaneous i-v *characteristic*

- *An active switch, controlled by terminal C*
- *Single-quadrant switch:*
- *can conduct positive on-state current*
- *can block positive off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the transistor* i-v *characteristic, then switch can be realized using a BJT or IGBT*

The Bipolar Junction Transistor (BJT) and the Insulated Gate Bipolar Transistor (IGBT)

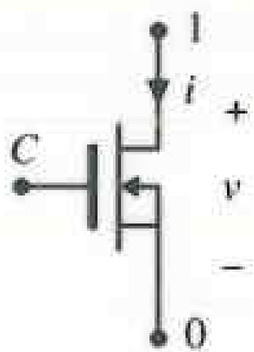


instantaneous i-v characteristic

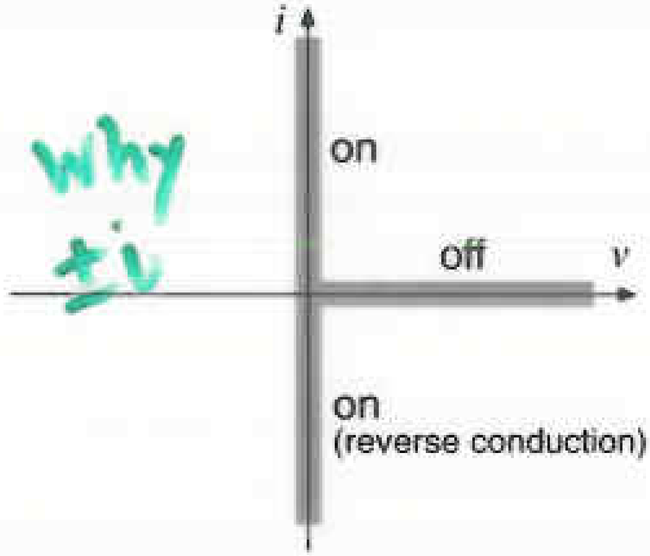
- *An active switch, controlled by terminal C*
- *Single-quadrant switch:*
- *can conduct positive on-state current*
- *can block positive off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the transistor i-v characteristic, then switch can be realized using a BJT or IGBT*

The Metal-Oxide Semiconductor Field Effect Transistor (MOSFET)

Exam
V_{GS} Polarities



Symbol



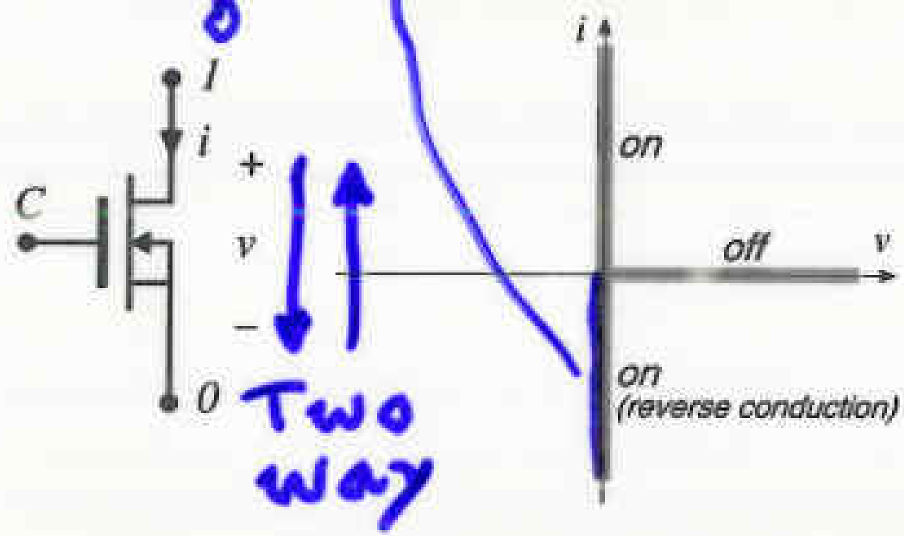
instantaneous *i-v* characteristic

- *An active switch, controlled by terminal C*
- *Normally operated as single-quadrant switch:*
- *can conduct positive on-state current (can also conduct negative current in some circumstances)*
- *can block positive off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the MOSFET i-v characteristic, then switch can be realized using a MOSFET*

Figure 4.10 pg 38

The Metal-Oxide Semiconductor Field Effect Transistor (MOSFET)

body diode is inherent to MOSFET "Parasitic"



Symbol instantaneous i-v characteristic

- An active switch, controlled by terminal C
- Normally operated as single-quadrant switch:
- can conduct positive on-state current (can also conduct negative current in some circumstances)
- can block positive off-state voltage
- provided that the intended on-state and off-state operating points lie on the MOSFET i-v characteristic, then switch can be realized using a MOSFET