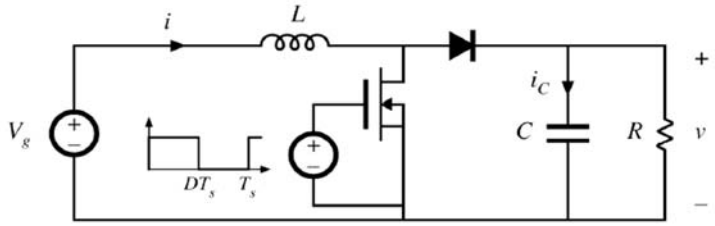
Semiconductor Conduction Loss Models

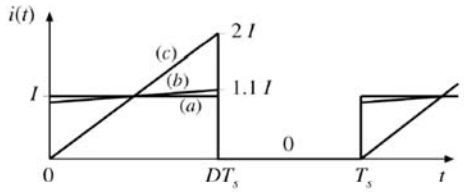
Boost Converter with Nonideal Semiconductors



Average vs RMS Currents

- Model uses average currents and voltages
- To correctly predict power loss in a resistor, use rms values
- Result is the same, provided ripple is small

MOSFET current waveforms, for various ripple magnitudes:



Inductor current ripple	*MOSFET rms current*	*Average power loss in R_{on}*
(a) $\Delta i = 0$	$I\sqrt{D}$	$D I^2 R_{on}$
(b) $\Delta i = 0.1\ I$	$(1.00167)\ I\sqrt{D}$	$(1.0033)\ D I^2 R_{on}$
(c) $\Delta i = I$	$(1.155)\ I\sqrt{D}$	$(1.3333)\ D I^2 R_{on}$

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Summary of Chapter 3

1. The dc transformer model represents the primary functions of any dc-dc converter: transformation of dc voltage and current levels, ideally with 100% efficiency, and control of the conversion ratio M via the duty cycle D. This model can be easily manipulated and solved using familiar techniques of conventional circuit analysis.
2. The model can be refined to account for loss elements such as inductor winding resistance and semiconductor on-resistances and forward voltage drops. The refined model predicts the voltages, currents, and efficiency of practical nonideal converters.
3. In general, the dc equivalent circuit for a converter can be derived from the inductor volt-second balance and capacitor charge balance equations. Equivalent circuits are constructed whose loop and node equations coincide with the volt-second and charge balance equations. In converters having a pulsating input current, an additional equation is needed to model the converter input port; this equation may be obtained by averaging the converter input current.

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Chapter 4: Switch Realization

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

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

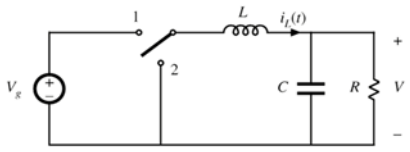
4.4. Summary of key points

THE UNIVERSITY OF TENNESSEE KNOXVILLE

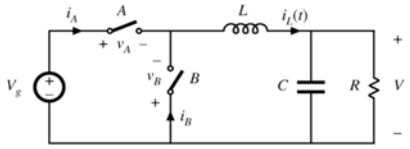
Implementing with SPST Switches

Buck converter

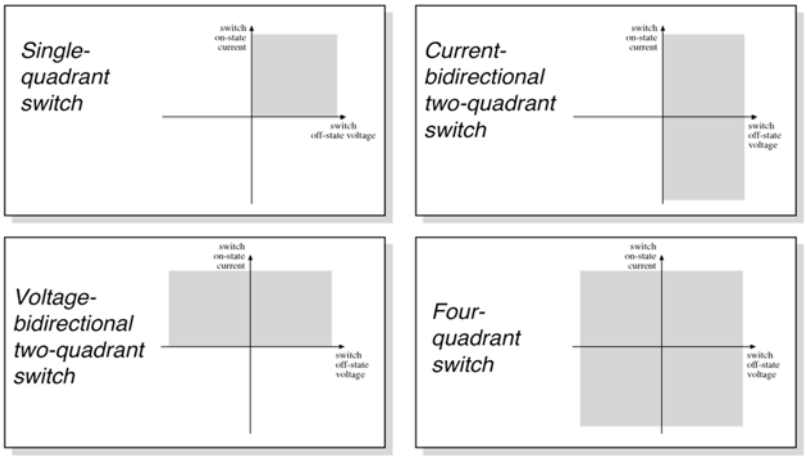
with SPDT switch:



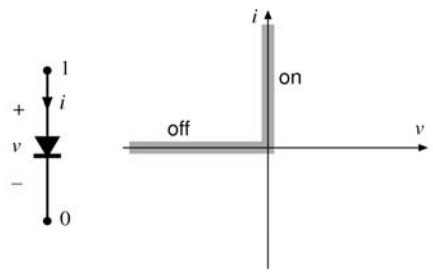
with two SPST switches:



SPST Operating Quadrants



The Diode

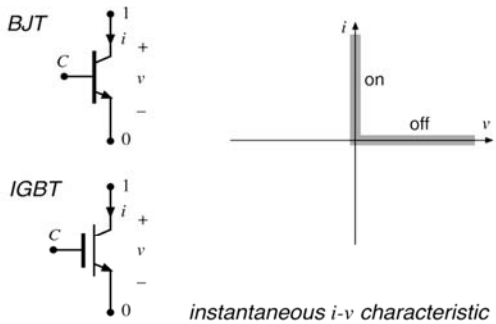


Symbol instantaneous *i-v* characteristic

- *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*

THE UNIVERSITY OF TENNESSEE KNOXVILLE

(Insulated Gate) Bipolar Junction Transistor

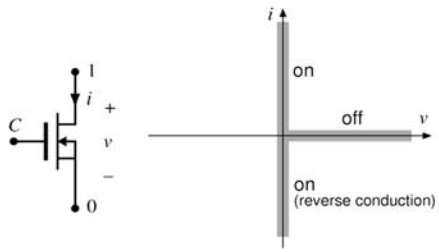


instantaneous *i-v* characteristic

- *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 UNIVERSITY OF TENNESSEE KNOXVILLE

MOSFET

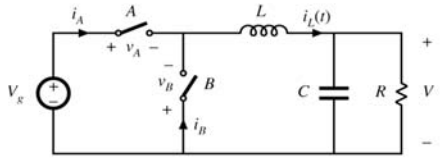


Symbol instantaneous *i-v* characteristic

- *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*

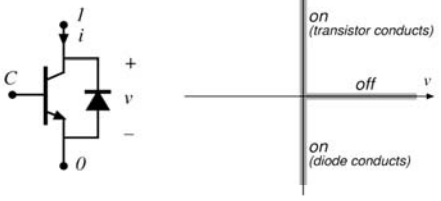
THE UNIVERSITY OF TENNESSEE KNOXVILLE

Buck Converter: Switch Realization



THE UNIVERSITY OF TENNESSEE KNOXVILLE

Current Bidirectional Two-Quadrant



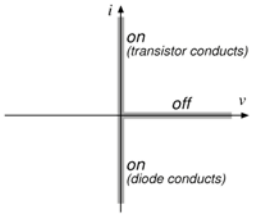
BJT / anti-parallel diode realization

instantaneous *i-v* characteristic

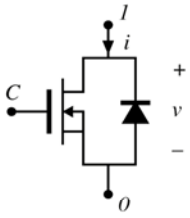
- *Usually an active switch, controlled by terminal C*
- *Normally operated as two-quadrant switch:*
- *can conduct positive or negative on-state current*
- *can block positive off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the composite i-v characteristic, then switch can be realized as shown*

THE UNIVERSITY OF TENNESSEE KNOXVILLE

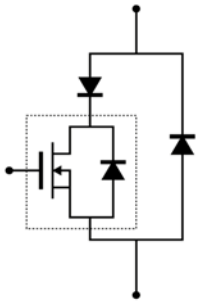
MOSFET Body Diode



Power MOSFET characteristics



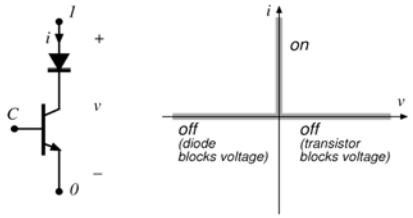
Power MOSFET, and its integral body diode



Use of external diodes to prevent conduction of body diode

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Voltage-bidirectional Two-Quadrant



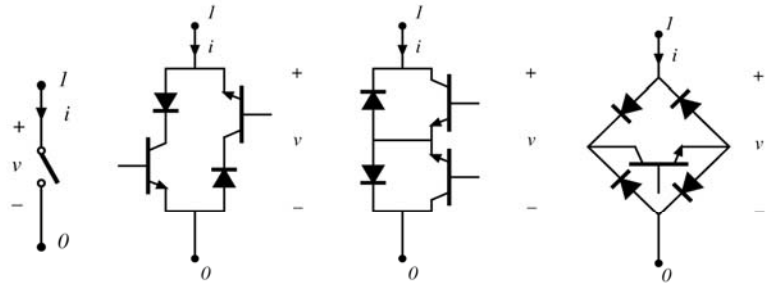
BJT / series diode realization

instantaneous *i-v* characteristic

- *Usually an active switch, controlled by terminal C*
- *Normally operated as two-quadrant switch:*
- *can conduct positive on-state current*
- *can block positive or negative off-state voltage*
- *provided that the intended on-state and off-state operating points lie on the composite i-v characteristic, then switch can be realized as shown*
- *The SCR is such a device, without controlled turn-off*

THE UNIVERSITY OF TENNESSEE KNOXVILLE

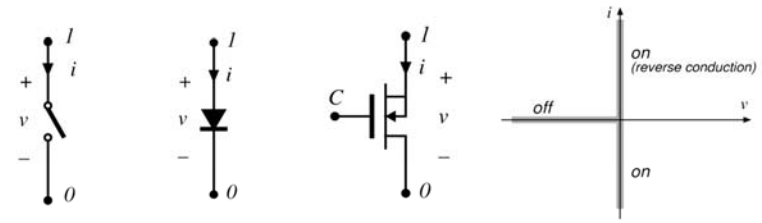
Four-Quadrant Switches



THE UNIVERSITY OF TENNESSEE KNOXVILLE

Synchronous Rectifiers

Replacement of diode with a backwards-connected MOSFET, to obtain reduced conduction loss



ideal switch | *conventional diode rectifier* | *MOSFET as synchronous rectifier* | *instantaneous i-v characteristic*