2.996/6.971 Biomedical Devices Design Laboratory

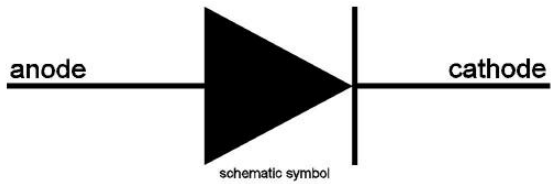
Lecture 3: Diodes and Transistors

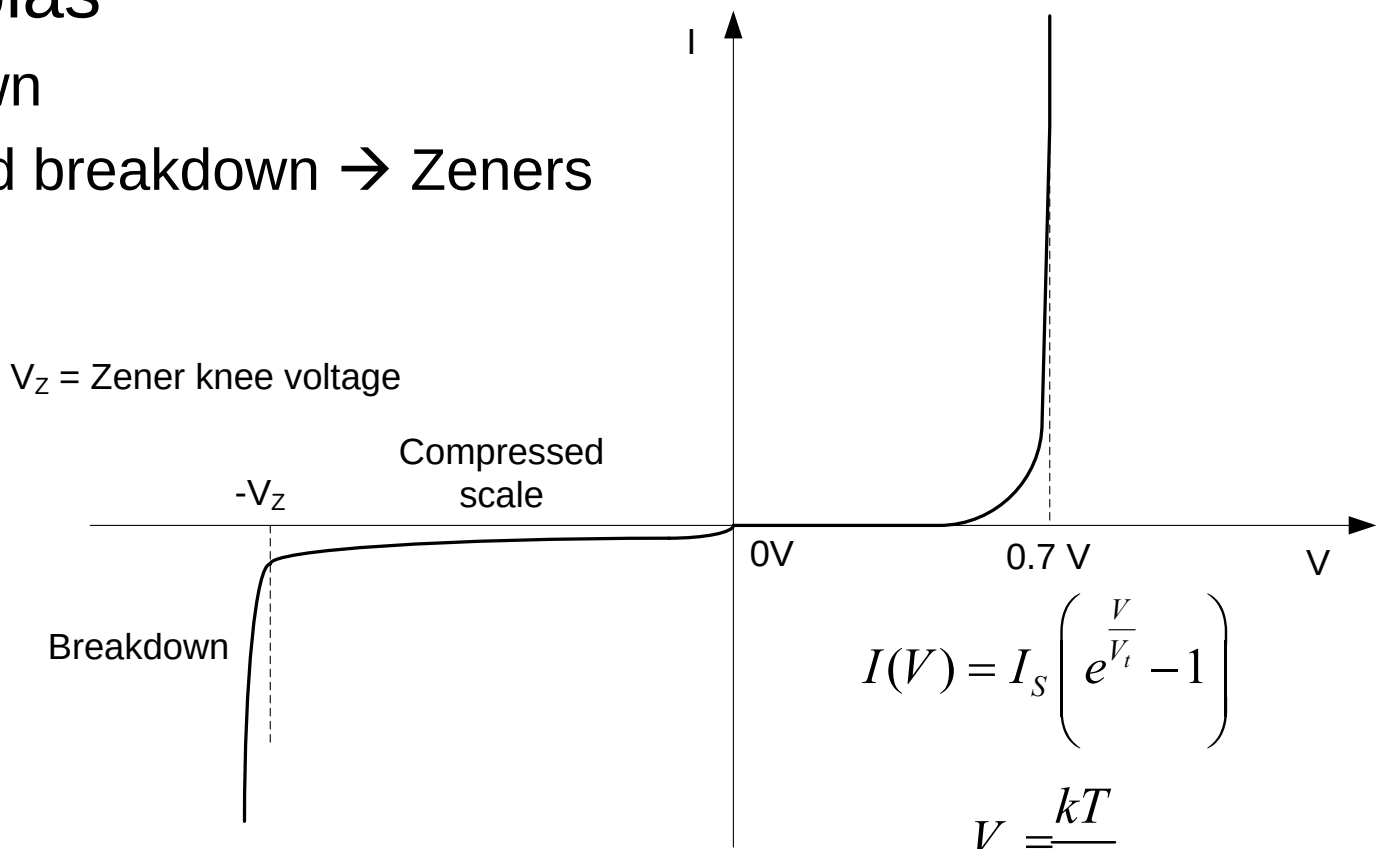
Instructor: Hong Ma

Sept. 17, 2007

Diode Behavior

- Forward bias
  - Exponential behavior
- Reverse bias
  - Breakdown
  - Controlled breakdown → Zeners





V_Z = Zener knee voltage

$$I(V) = I_S\left(e^{\frac{V}{V_t}} - 1\right)$$

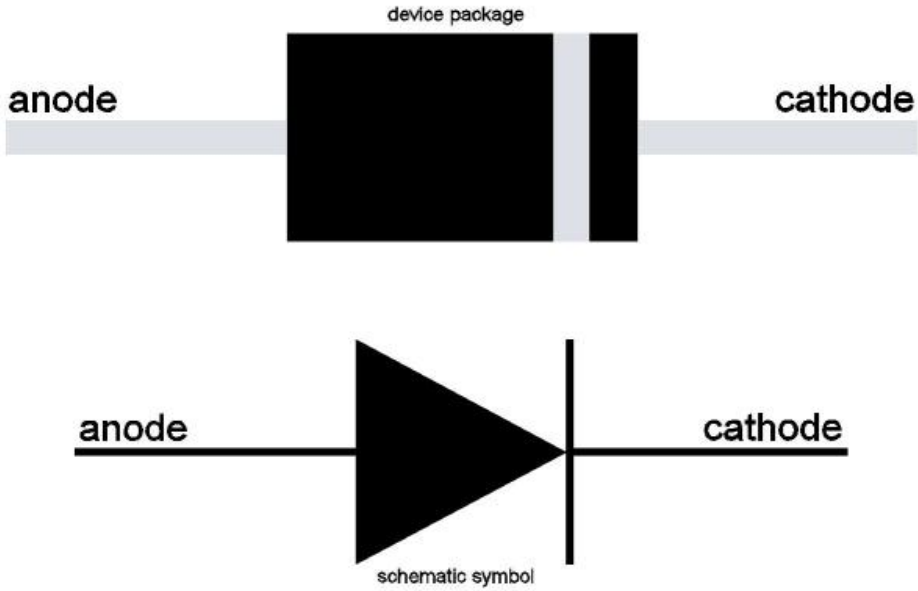
$$V_t = \frac{kT}{Q}$$

Types of Diode

- Silicon diode (0.7V turn-on)
- Schottky diode (0.3V turn-on)
- LED (Light-Emitting Diode) (0.7-5V)
- Photodiode
- Zener
- Transient Voltage Suppressor

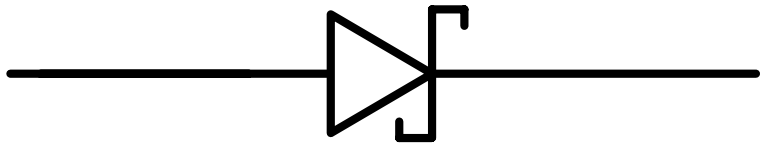
Silicon Diode

- 0.7V turn-on
- Important specs:
  - Maximum forward current
  - Reverse leakage current
  - Reverse breakdown voltage
- Typical parts:



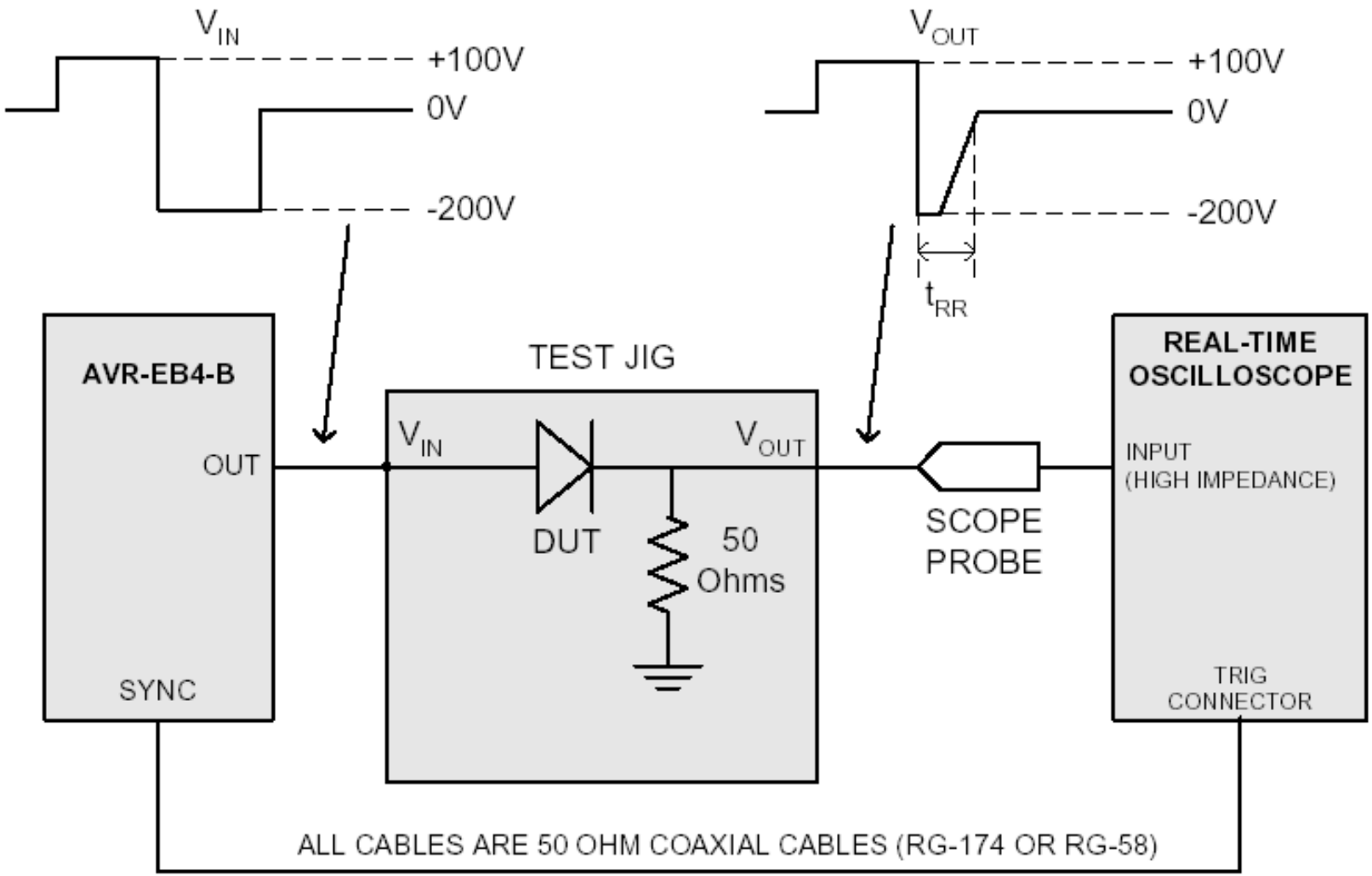
Part #	$I_{F,\,max}$	I_R	$V_{R,\,max}$	Cost
1N914	200mA	25nA at 20V	100	~$0.007
1N4001	1A	5µA at 50V	50V	~$0.02

Schottky Diode

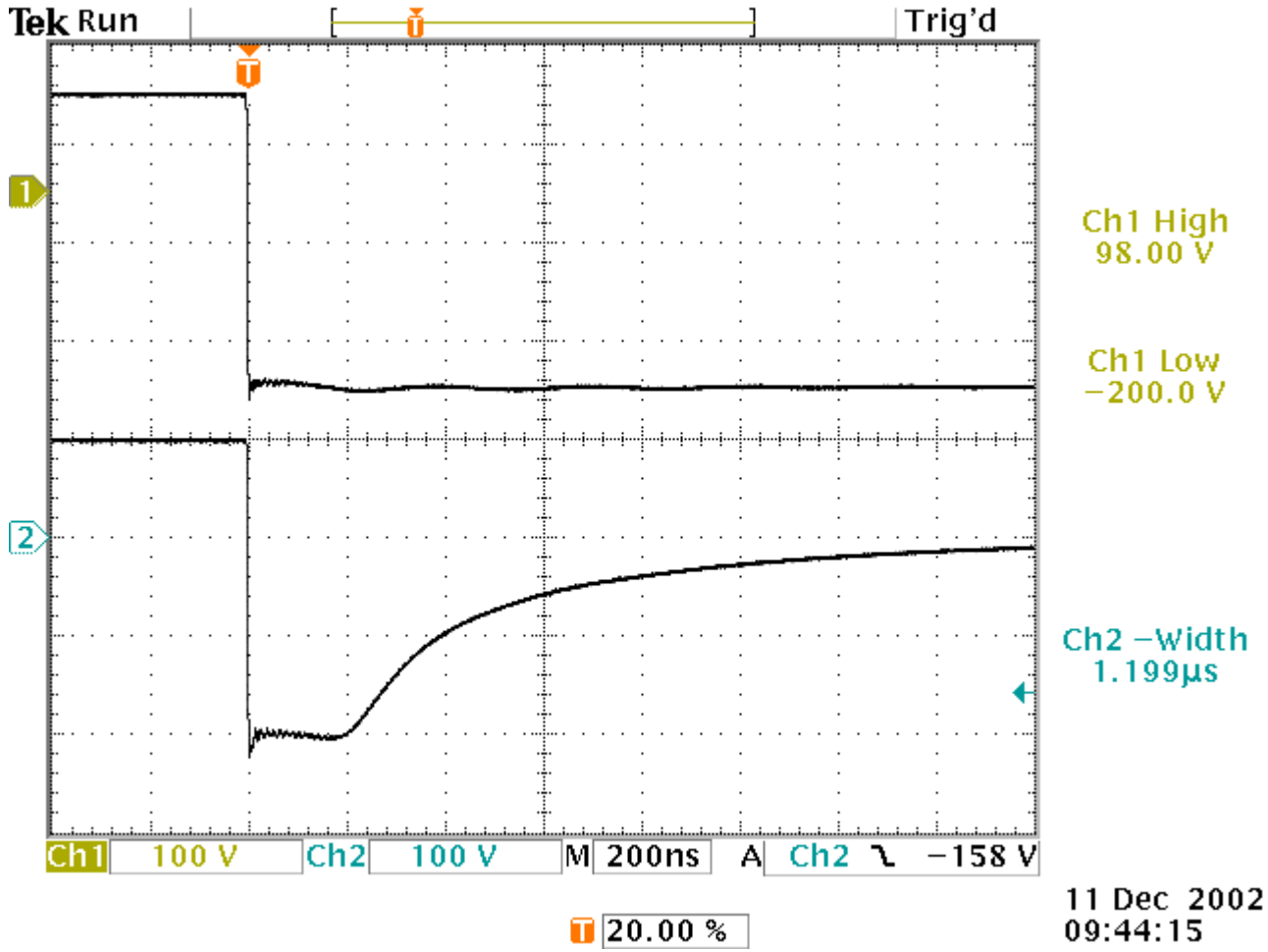


- Metal-semiconductor junction
- ~0.3V turn-on
- Often used in power applications
- Fast switching – no reverse recovery time
- Limitation: reverse leakage current is higher
  - New SiC Schottky diodes have lower reverse leakage

Reverse Recovery Time Test Jig



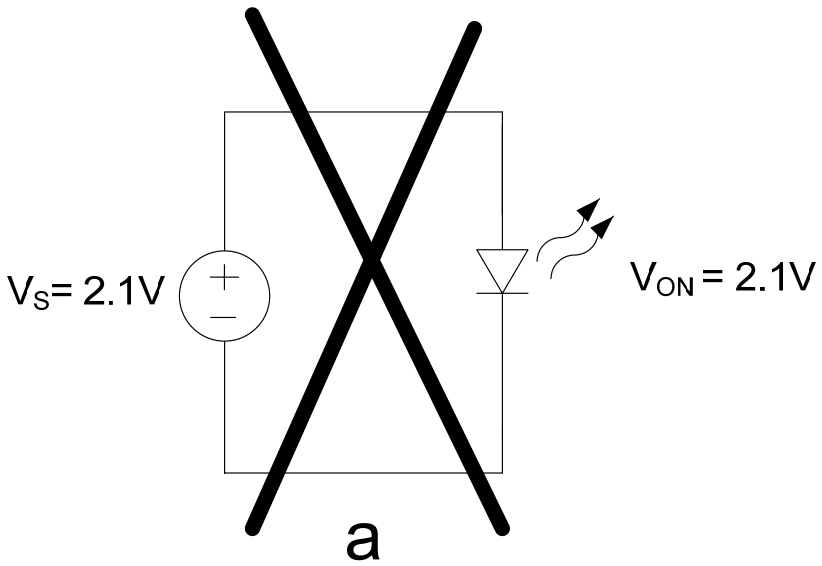
Reverse Recovery Test Results

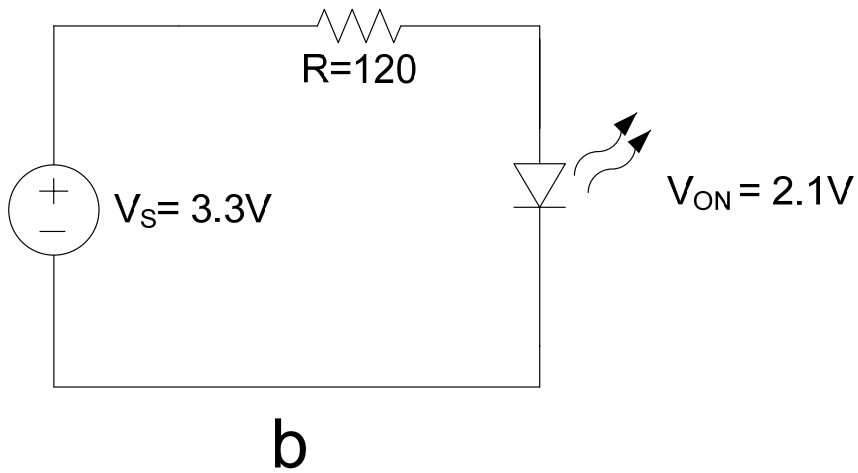


- Device tested: 2N4004 diode

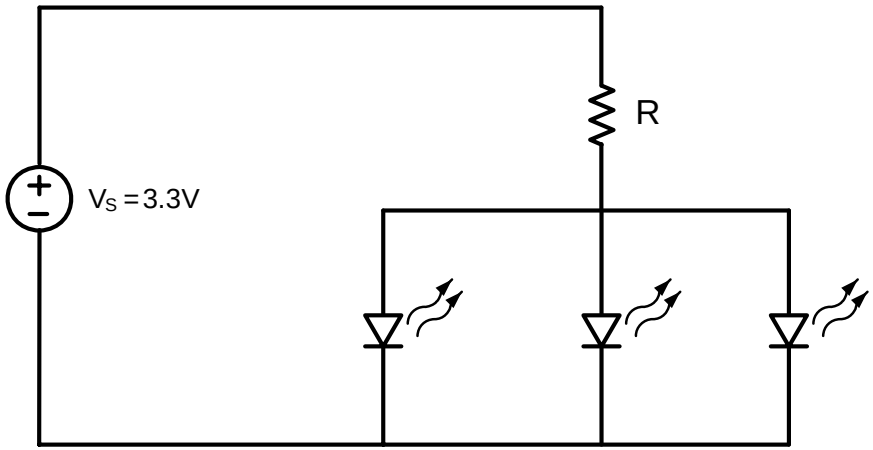
Light Emitting Diode (LED)

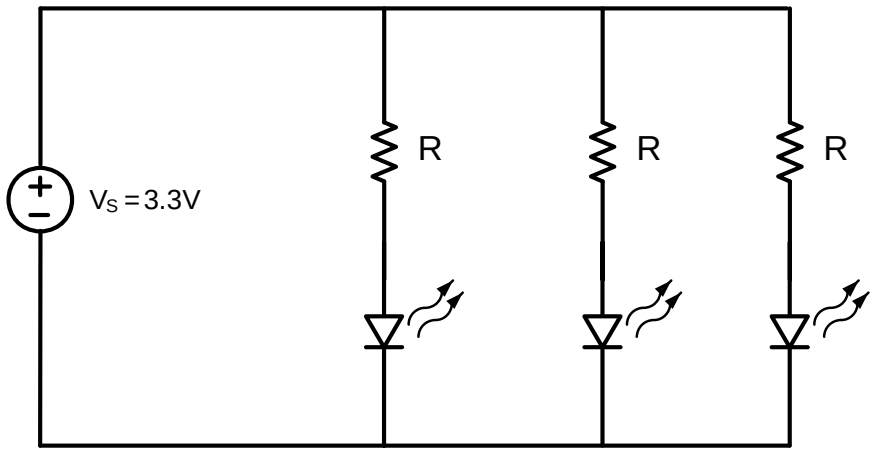
- Turn-on voltage from 0.7V to 5V
- ~5 years ago: blue and white LEDs
- Recently: high power LEDs for lighting
- Need to limit current





LEDs in Parallel



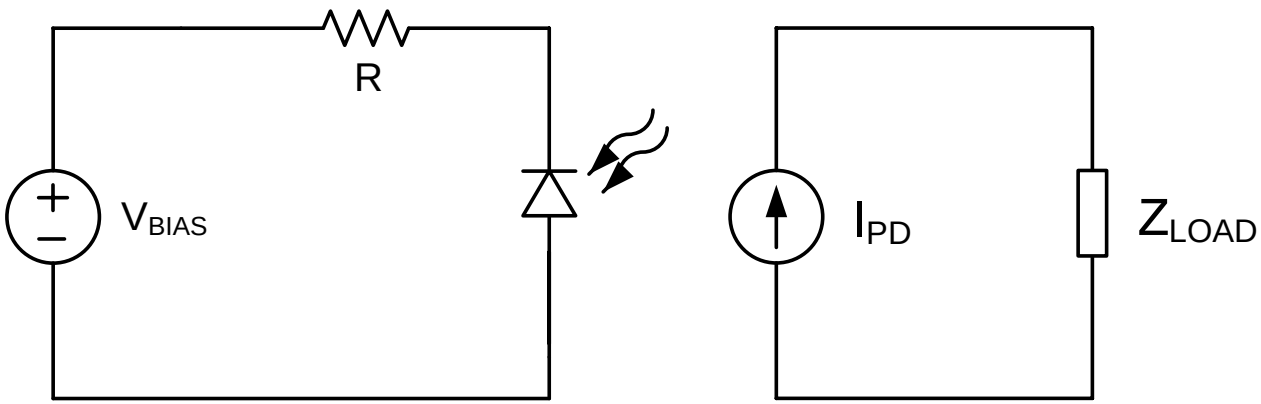


$$I(V) = I_S\left(e^{\frac{V}{V_t}} - 1\right)$$

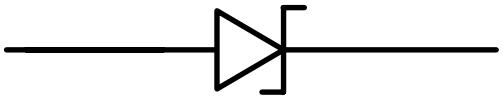
- I_S is strongly dependent on temp.
- Resistance decreases with increasing temperature
- “Power Hogging”

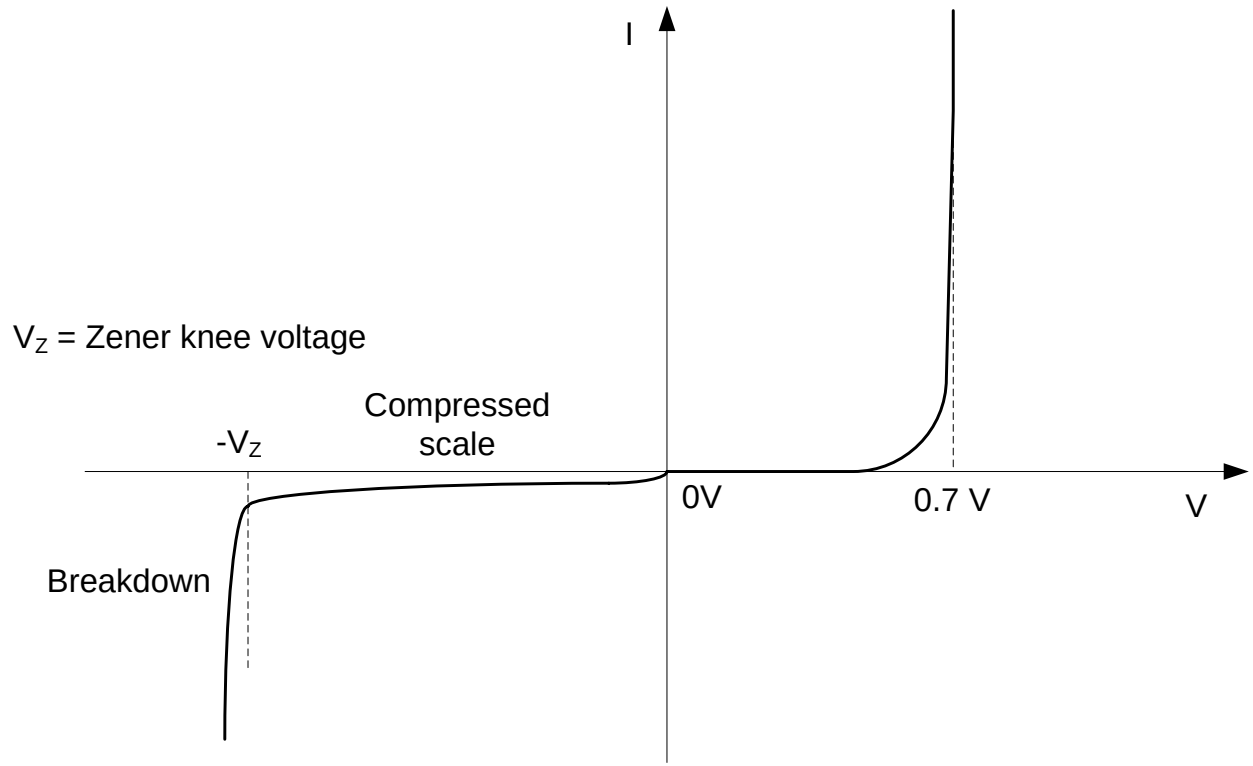
Photodiode

- Photons generate electron-hole pairs
- Apply reverse bias voltage to increase sensitivity
- Key specifications:
  - Sensitivity (short-circuit current for a given light level)
  - Spectral response
  - Reverse breakdown voltage
  - Dark current



Zeners

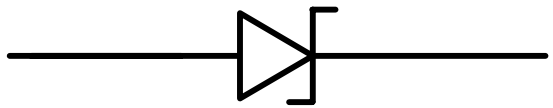


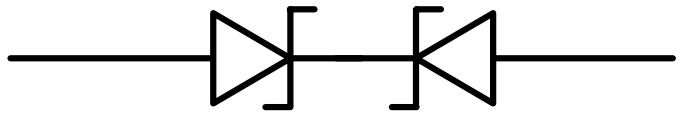


- Utilize reverse breakdown mechanism
- Sharper transition than forward biased diode
- Knee Voltages range from 1.8V to 200V to kV
- Reverse leakage current is higher
- Applications
  - Limiter
  - Voltage reference

Transient Voltage Suppressor

- TVS or TransOrb
- Place in parallel with power supply
- Absorbs over-voltage
- Unipolar or bipolar
- Typical specs:
  - Absorb 1000W for 1ms
  - Breakdown voltage (V_{BR})
  - Standoff voltage (~0.9V_{BR})
  - V_{supply} <= $V_{standoff}$



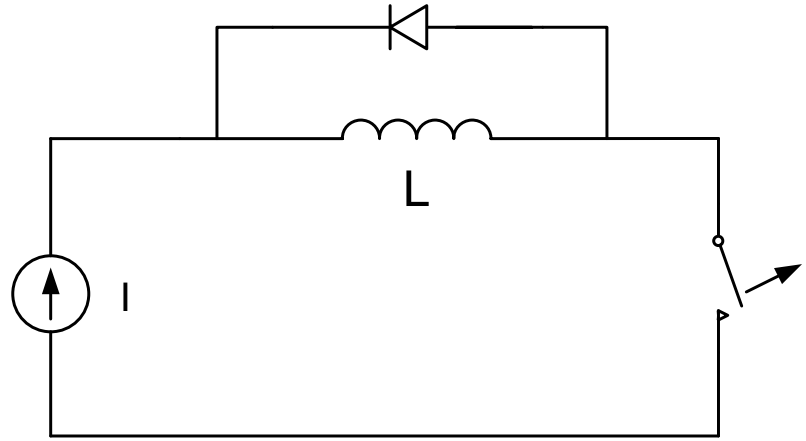


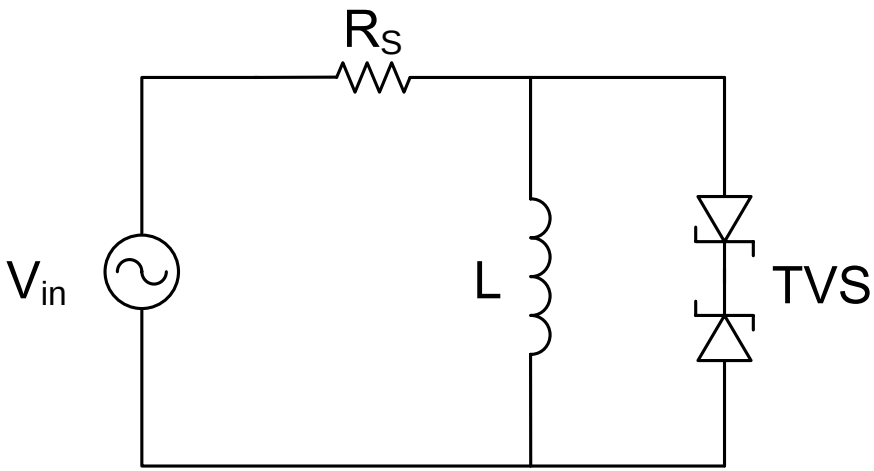
Diode Application: Preventing Inductive Kickback

- From Maxwell's equations:

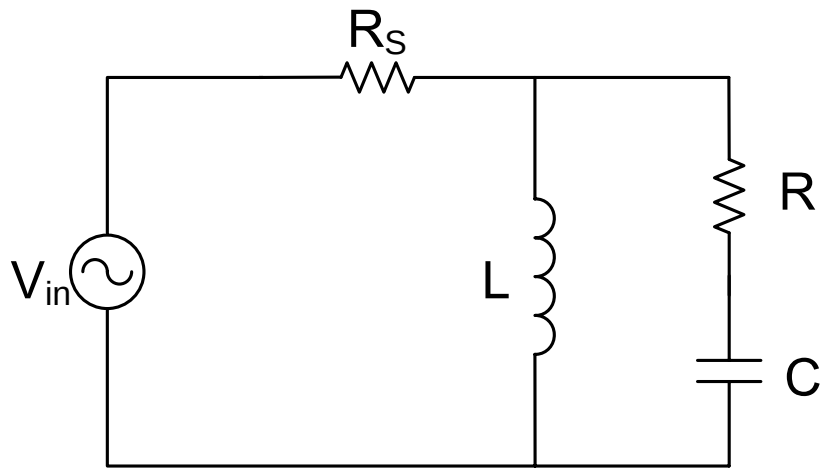
$$V = -L\frac{dI}{dt}$$

- Instantaneous current switching produces very large voltages!





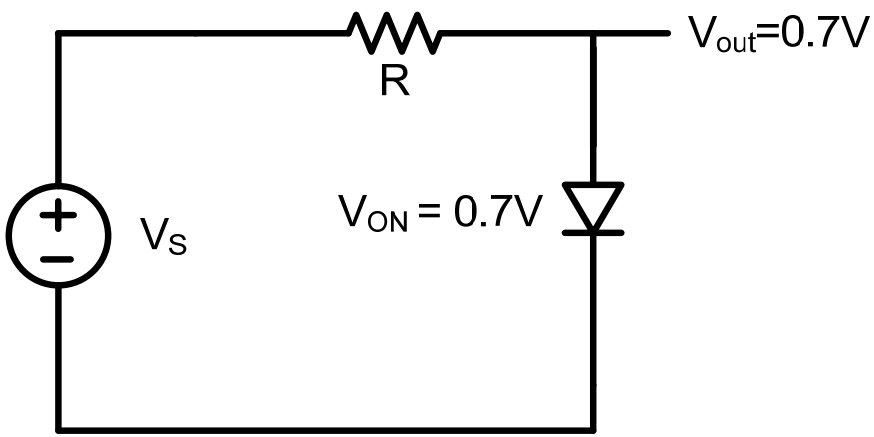
Bi-directional TVS

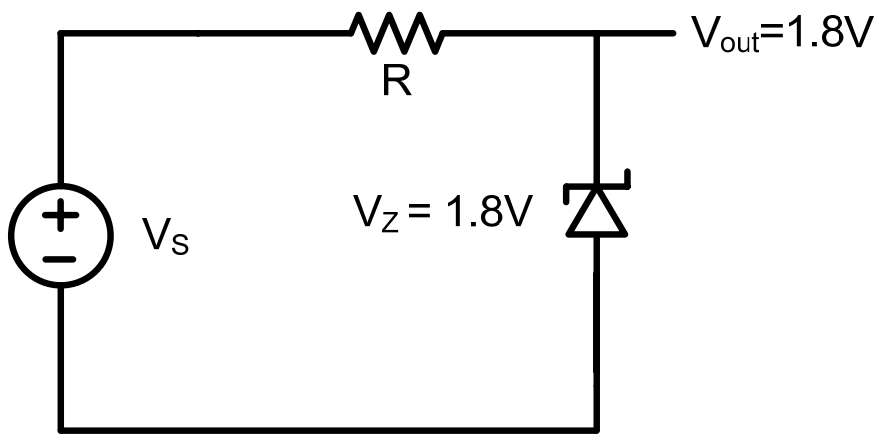


Snubber

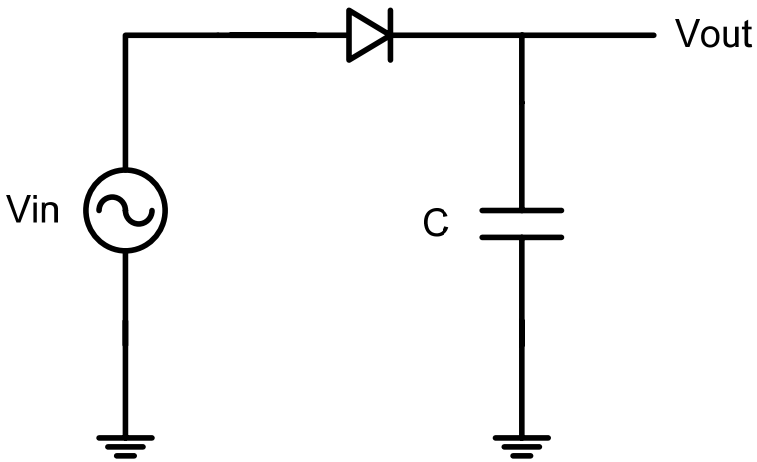
Voltage References

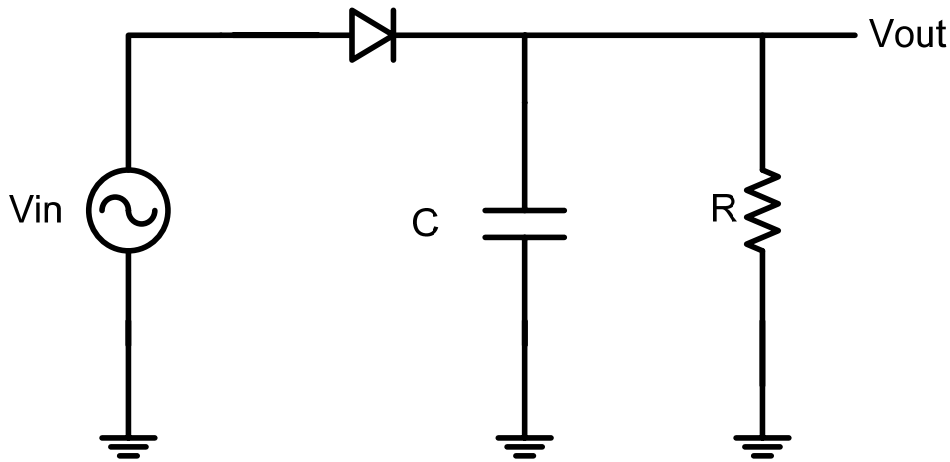
- With forward biased diode
- With Zener
- Temperature compensated reference – bandgap reference





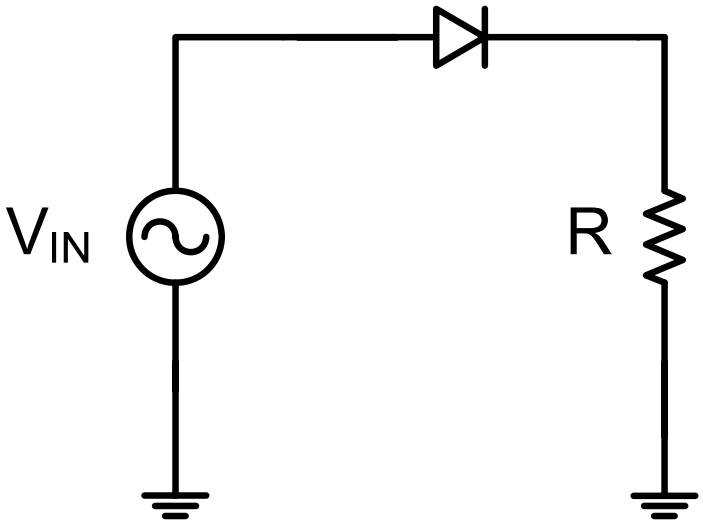
Peak Detector



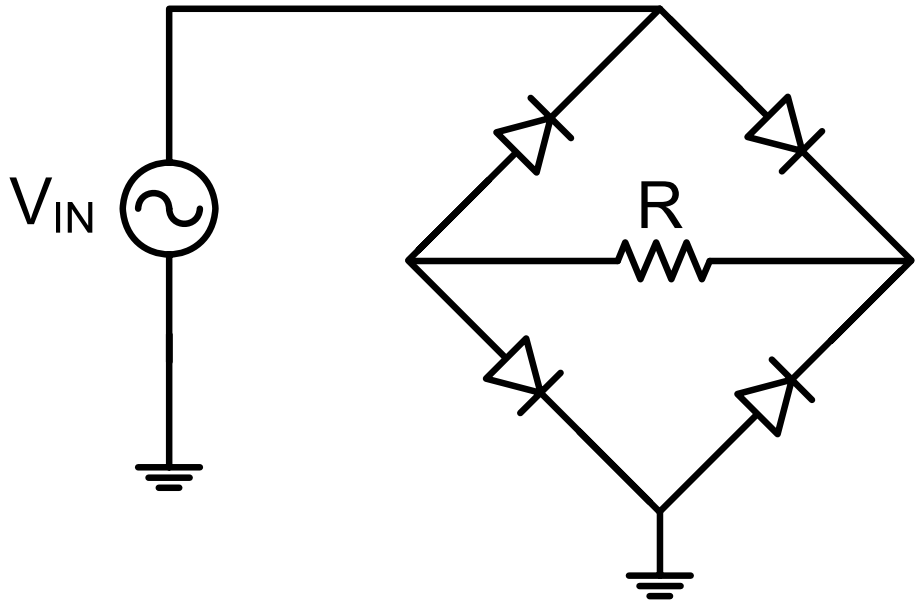


- AKA: Envelop detector

Rectifier

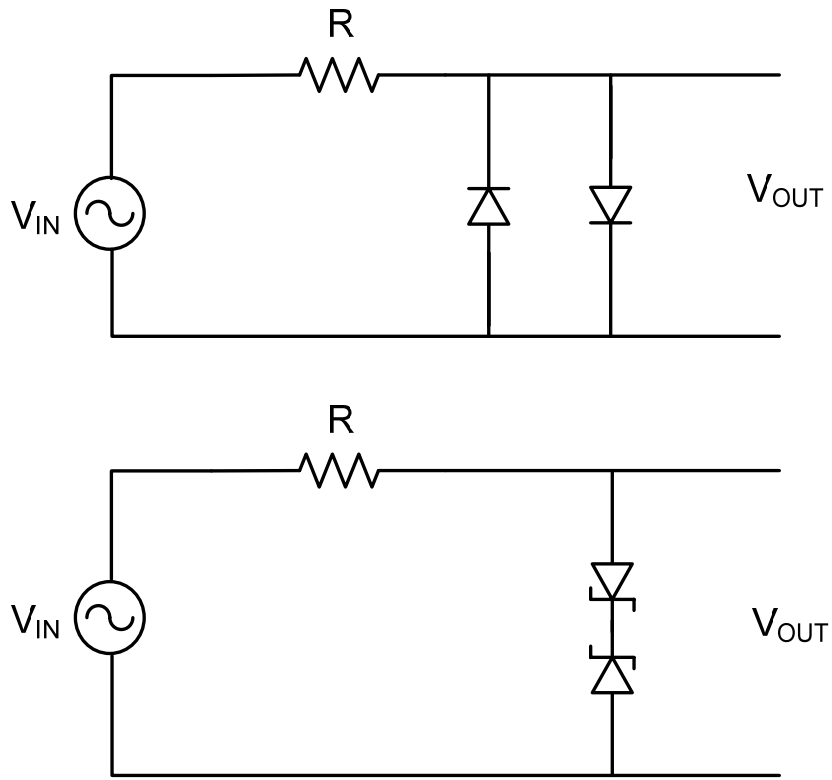


Half-wave



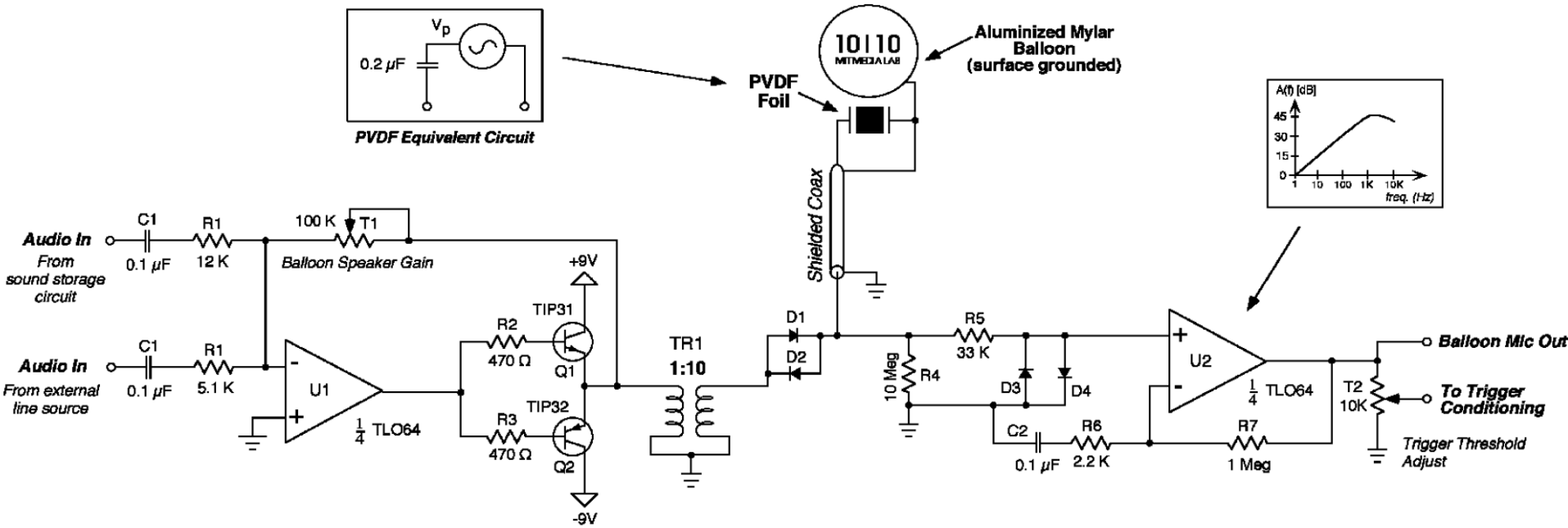
Full-wave

Diode Clamper



- Zener has bad leakage
- Don’t forget about failure mode

Diode Tx-Rx Switch



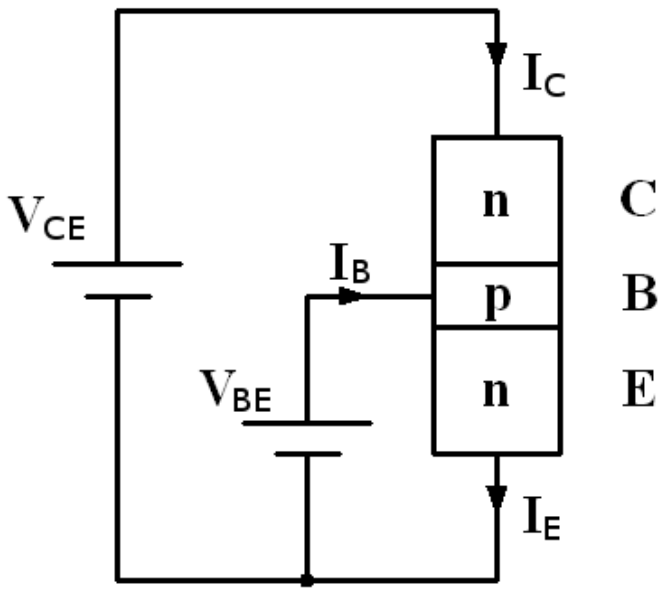
- Mylar balloon used both as a speaker and a microphone
- D3 and D4 limit the voltage at the input of U2

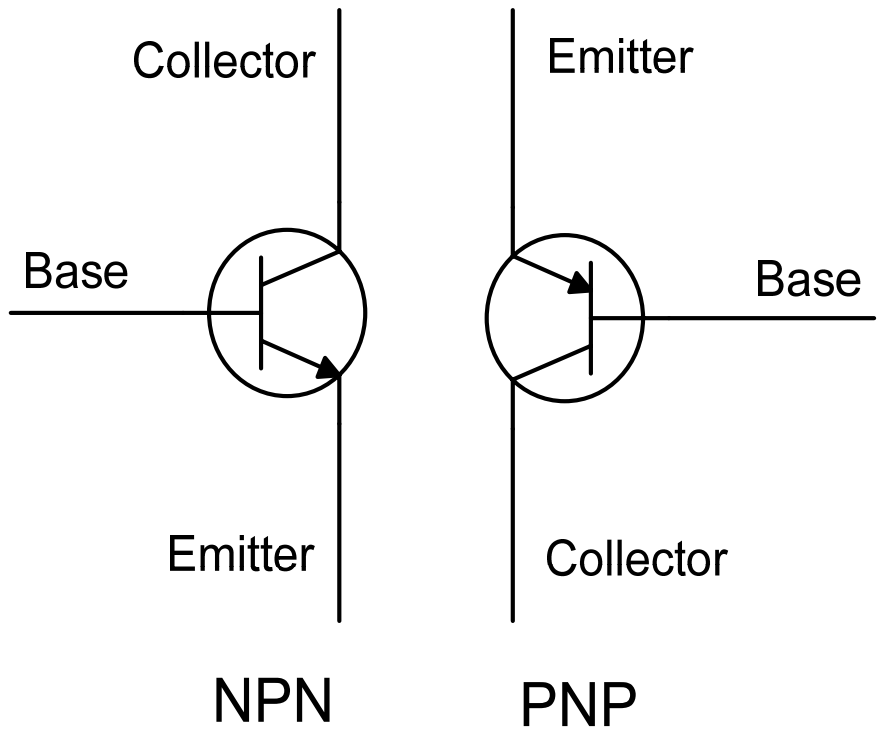
Transistors

(as switches)

BJT

- Three-terminal device: base, emitter, collector
- Two types: NPN and PNP
- $I_C = \beta I_B, \beta \approx 100$

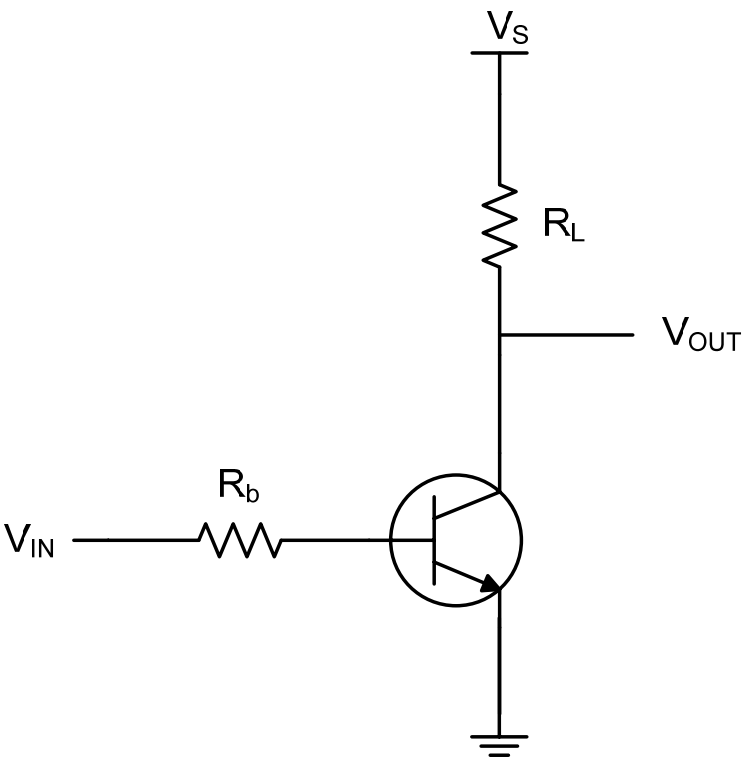




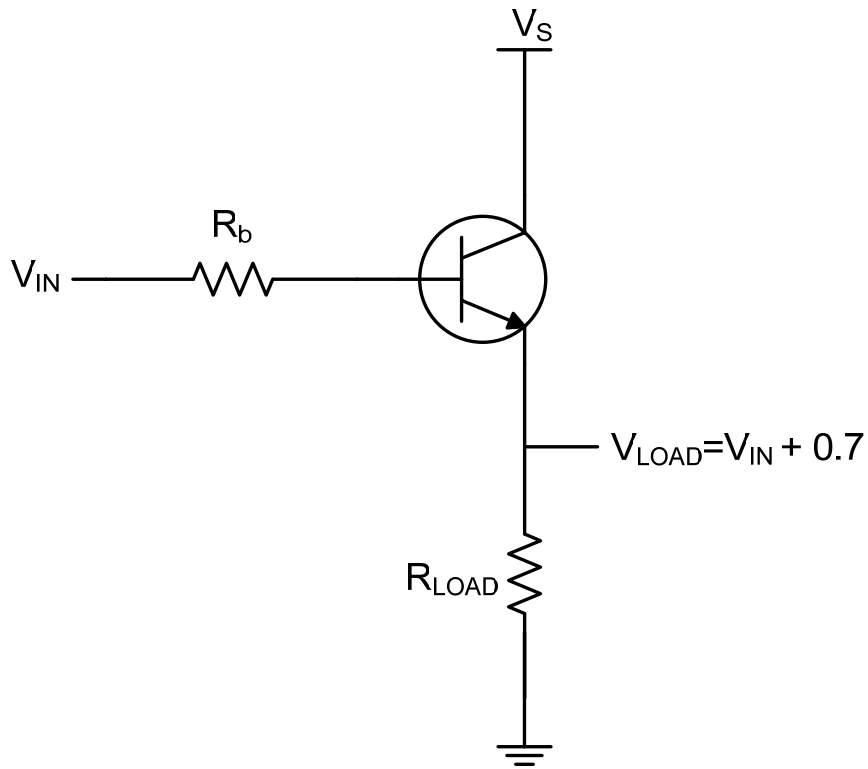
Typical parts: 2N3904 (NPN), 2N3906 (PNP)

BJT as a Switch

- Need a resistor to limit base current
- Many IC's leave R_L unconnected – open collector output
- Emitter follower: output tracks input with 0.7V offset

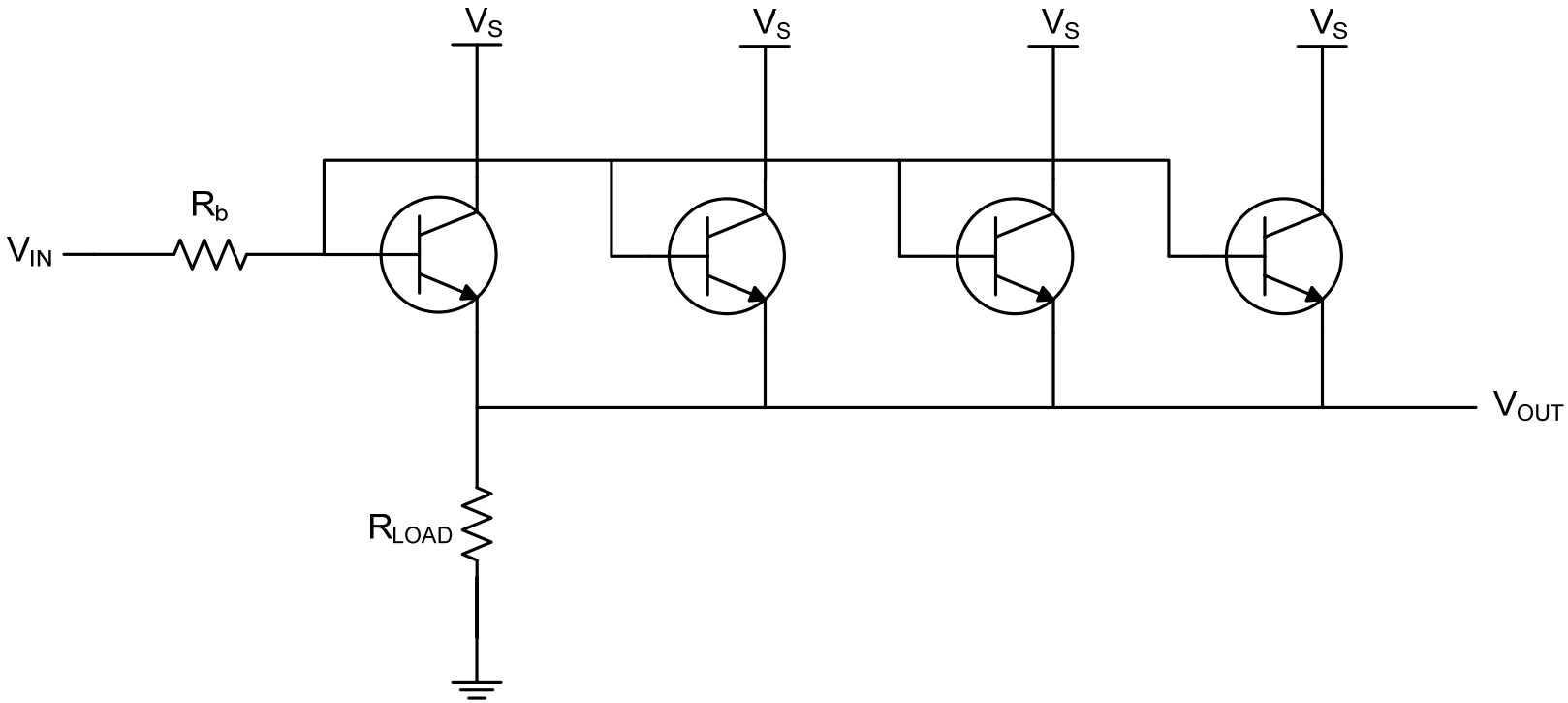


Common-Emitter



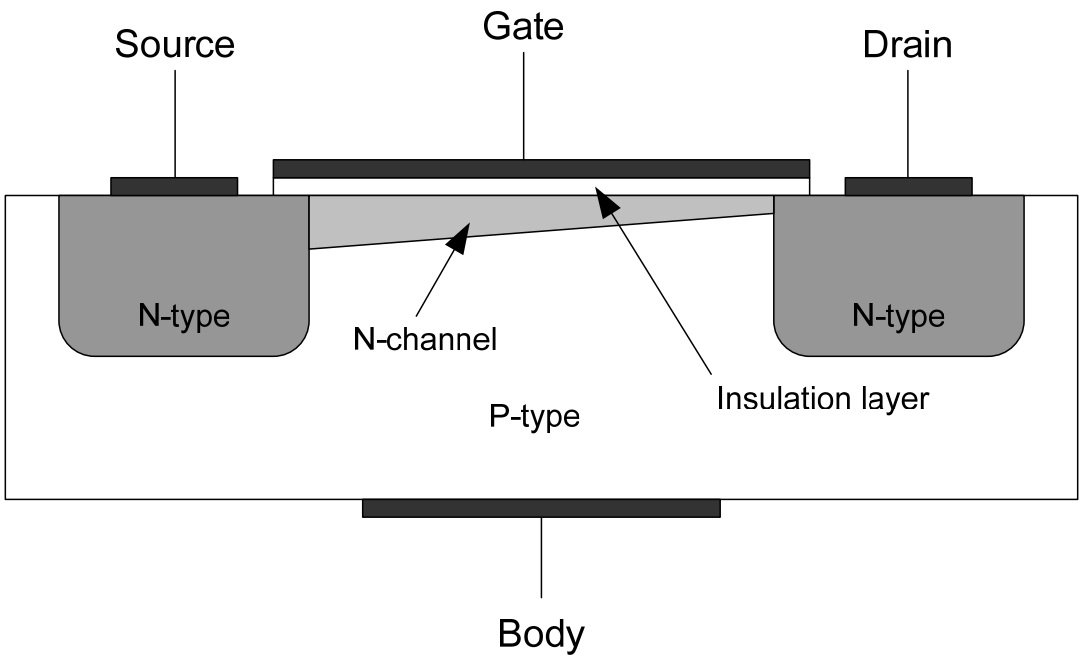
Emitter follower

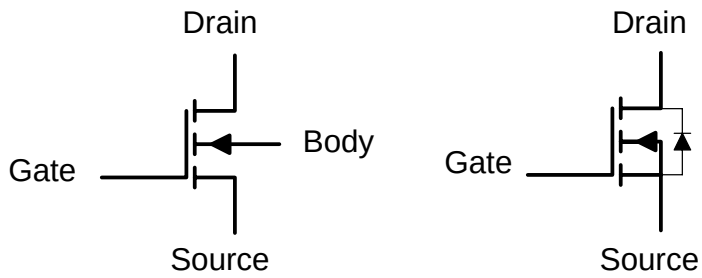
Problems with BJTs



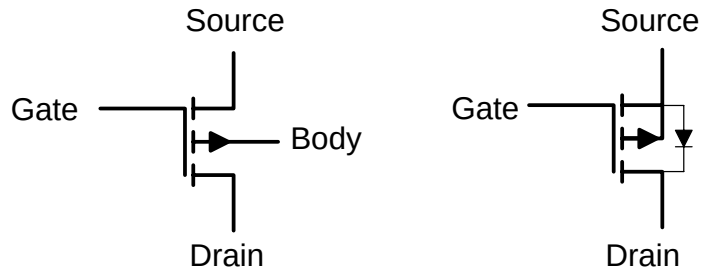
- Negative temperature coefficient
- Parallel BJTs: Power hogging
- Large BJTs: secondary breakdown

MOSFET





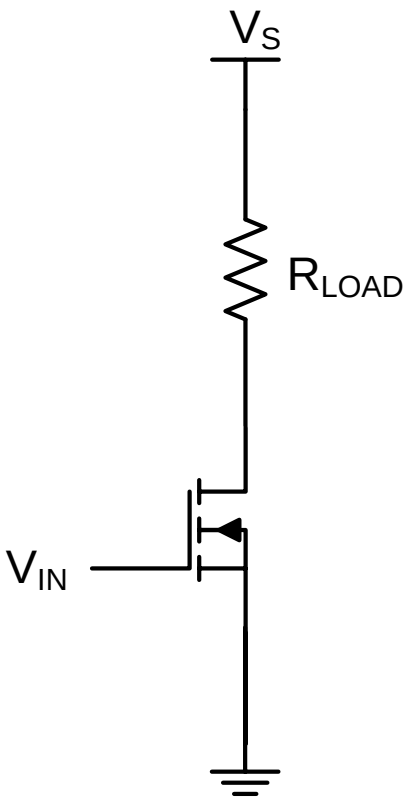
N-channel MOSFET



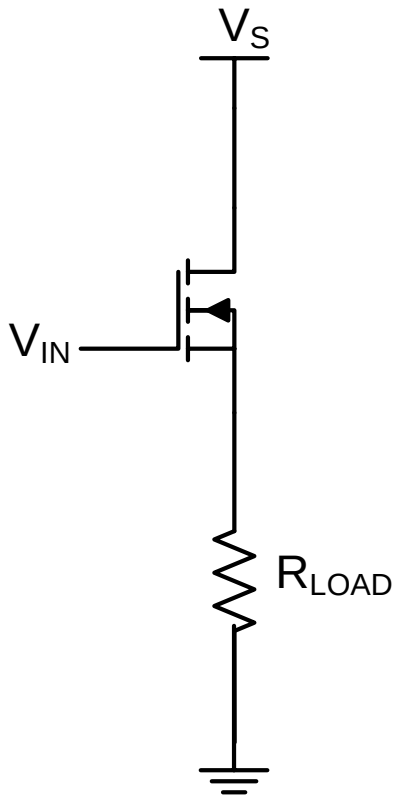
P-channel MOSFET

- Four-terminal device: gate, source, drain, and body
- N-type and P-type
- **Negative temperature coefficient → can be parallelized**
- Bidirectional - so long as body-drain diode remain reverse biased

MOSFET as Switches



Low-side Switch



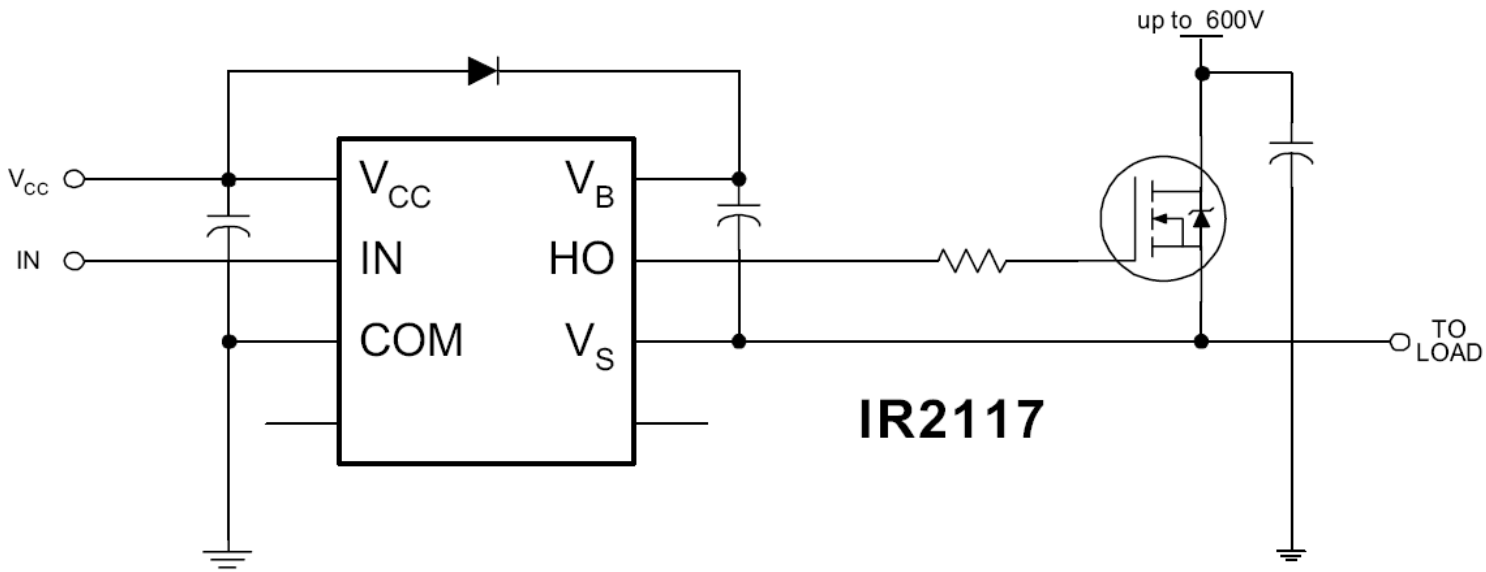
High-side Switch

Important Specs

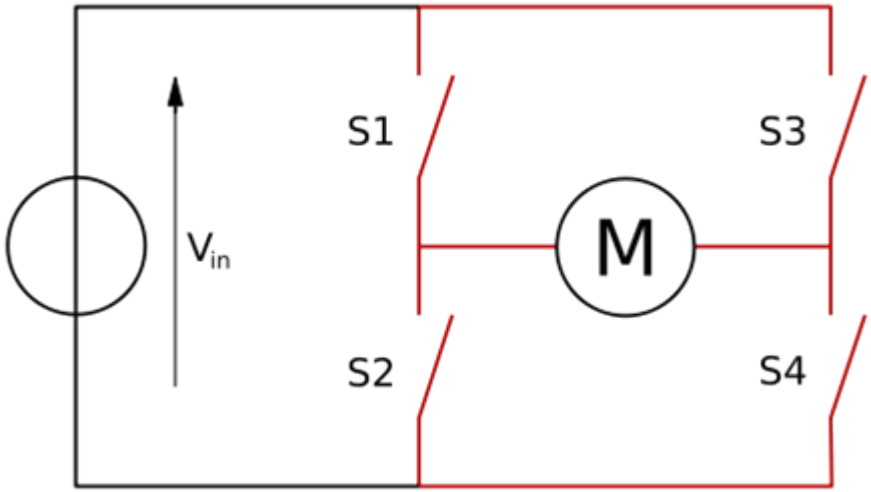
- Gate capacitance (C_G)
  - Hundreds of pF
- On resistance ($R_{DS(on)}$)
  - R_{DS} N-ch < R_{DS} P-ch
  - Use N-channel whenever possible
- Threshold voltage (V_{TH})
  - As low as 1.8V
- Drain-source breakdown voltage (V_{DSS})

Gate Drivers

- Efficiency dependent on transition time
- Low-side driver – low impedance drive
- High-side driver – charge pump to create gate voltage above the source voltage



H-Bridges



Key Issue

- Shoot through current

LMD18200

- High, low gate drivers
- Current sensing
- Current limiting
- Thermal shutdown

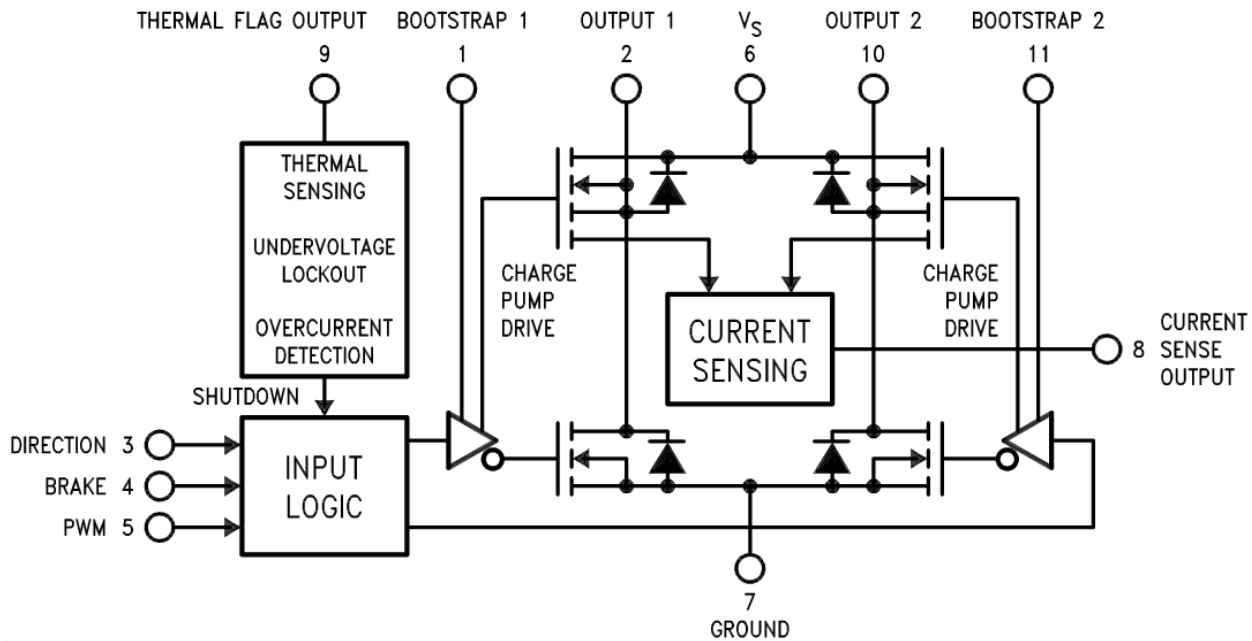
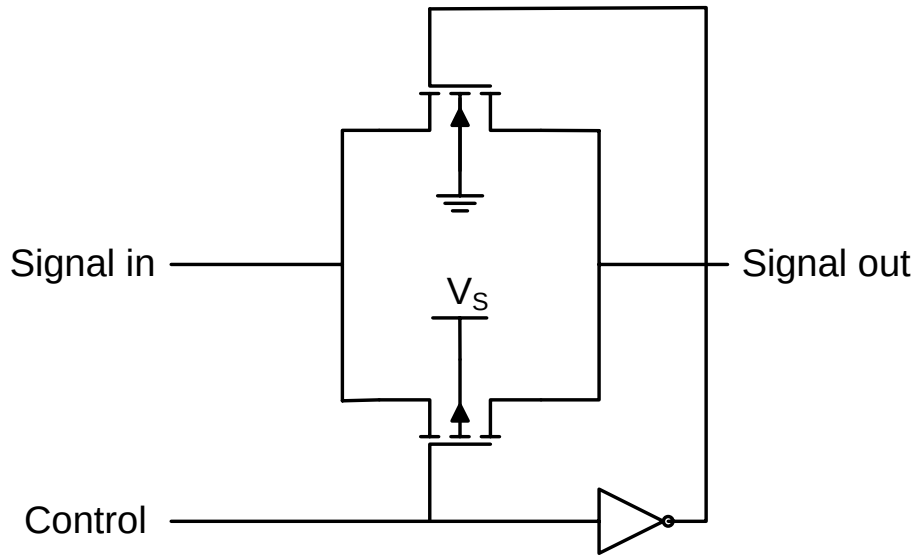


FIGURE 1. Functional Block Diagram of LMD18200

Reprinted with permission of the National Semiconductor Corporation.

CMOS Analog Switches

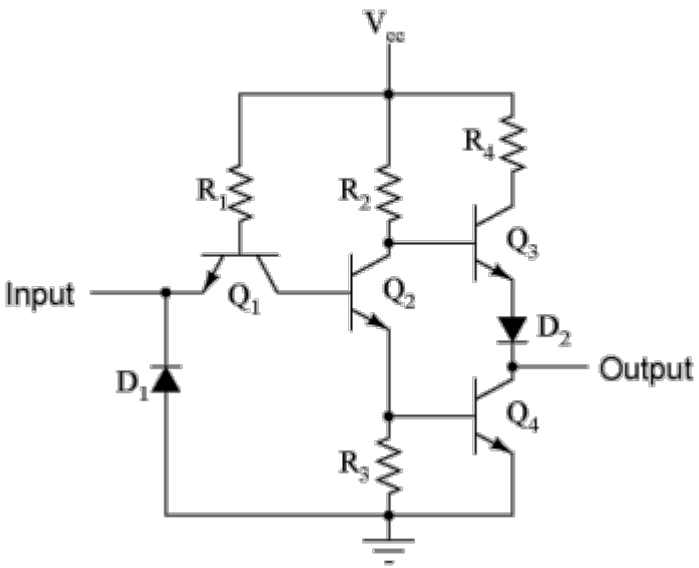


Key Issues for Analog Circuits

- Signal range
- Switch on-resistance
- Resistance matching

Logic Gates

Practical inverter (NOT) circuit



Logic Family Conversion Table

TO / *FROM*	**TTL**	**HCT ACT**	**HC AC**	**HC, AC @3.3V**	**NMOS LSI**	**4000B, 74C @5V**	**4000B, 74C @10V**
TTL	OK	OK	A	OK	OK	A	B
HCT, ACT	OK	OK	OK	NO	OK	OK	B
HC, AC	OK	OK	OK	NO	OK	OK	B
HC, AC @3.3V	OK	OK	NO	OK	OK	B	B
NMOS, LSI	OK	OK	A	OK	OK	A	B
4000B, 74C @5V	OK[a]	OK	OK	NO	OK	OK	B
4000B, 74C @10V	C	C	C	C	C	C	OK

(a) with limited fanout.

A - pullup to +5V, or use HCT as interface.

B - use *i)*OC pullup to +10V, or *ii)*40109, 14504, or LTC1045 level translator.

C - use 74C901/2, 4049/50, 14504, or LTC1045 level translator.