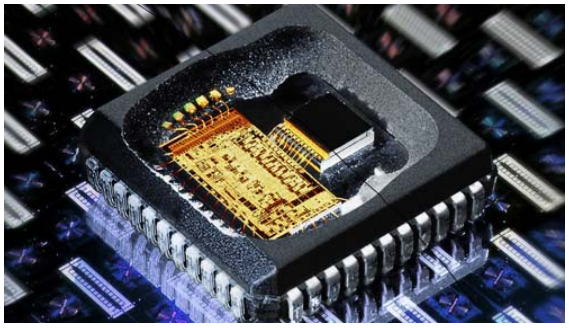
Lecture 6

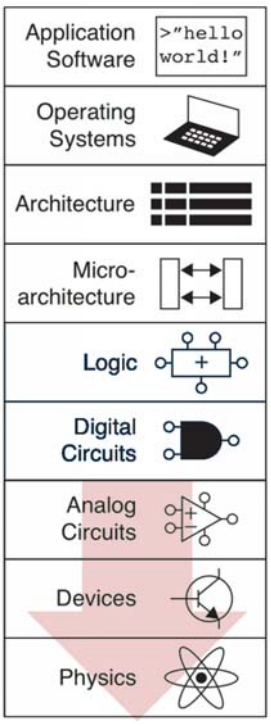
Electronics beyond the Logic Switches

Junrui Liang
ShanghaiTech University



Outline

- Beneath the digital abstraction
  - » Physical embodiment of digital logics
  - » Noise margins
- Analog electronics
  - » Definition
  - » Diode & MOSFET
  - » Operational amplifier
  - » A/D and D/A conversion
  - » Example: audio systems
- Power electronics
- MEMS



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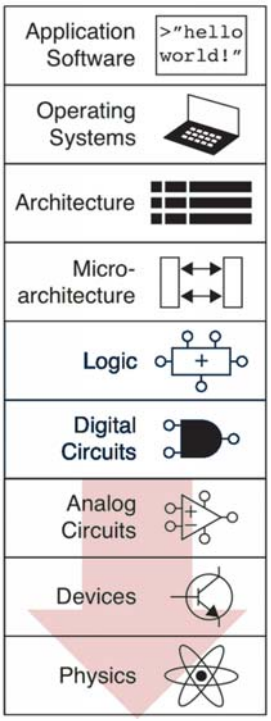

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Digital abstraction

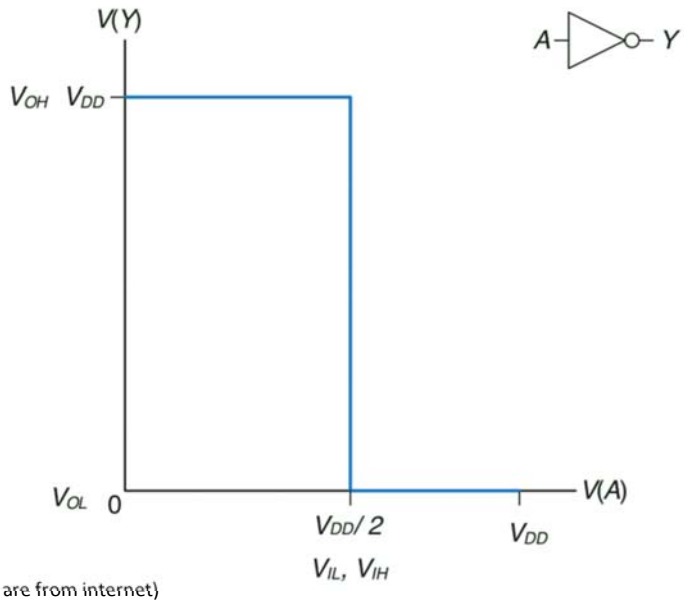
- Digital systems
  - » Representing information with discrete-valued variables
  - » Binary (two-valued) representation in modern computers

Physical variable	Binary variable		
Positive voltage	"1"	TRUE	HIGH
Zero voltage	"0"	FALSE	LOW

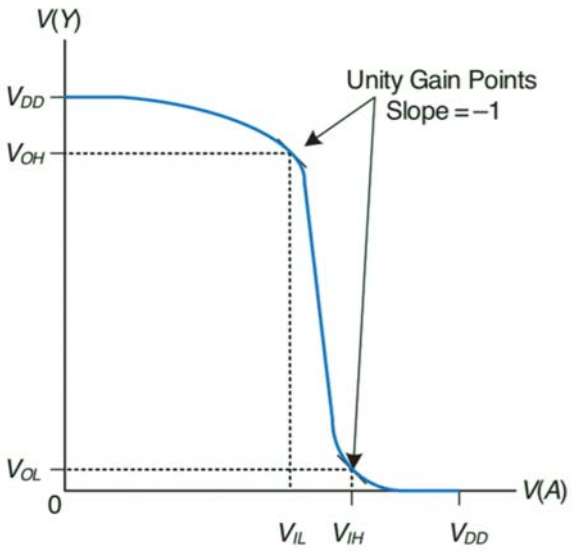
  - » Boolean logic: AND, OR, XOR, ….
  - » Other operations: addition, subtraction, comparison, ….

Characteristics of a NOT gate

- Ideal



- Practical



(Figures are from internet)

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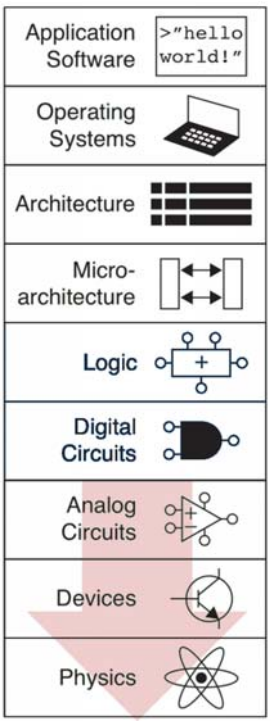
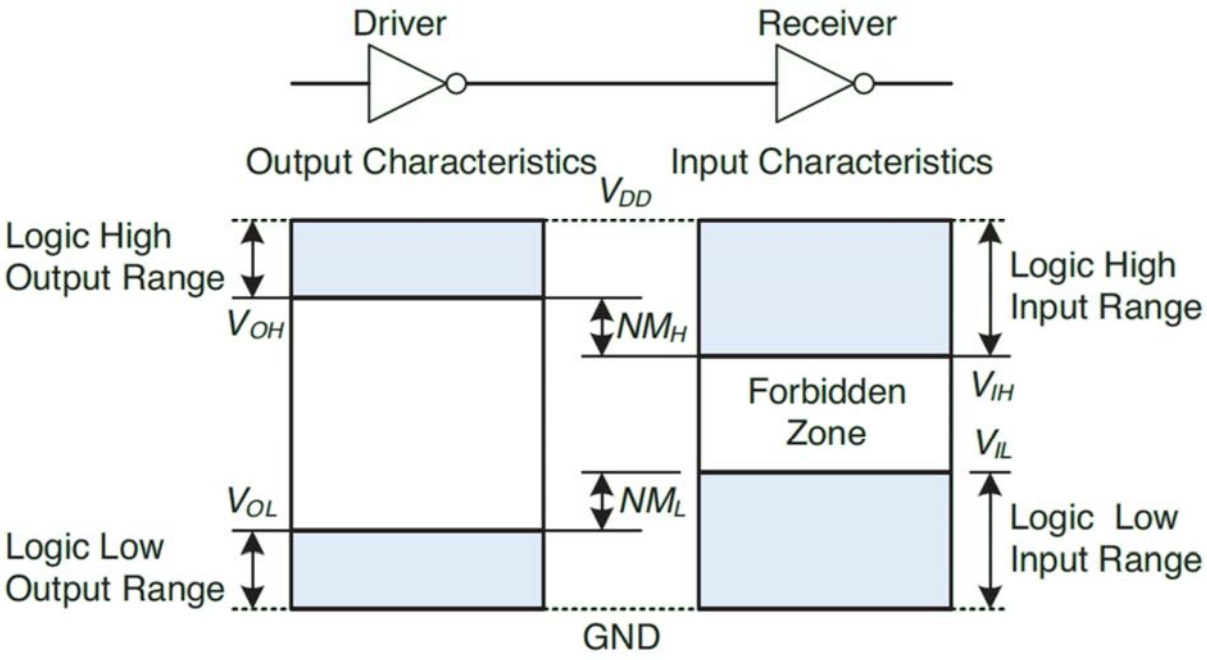


Noise margins



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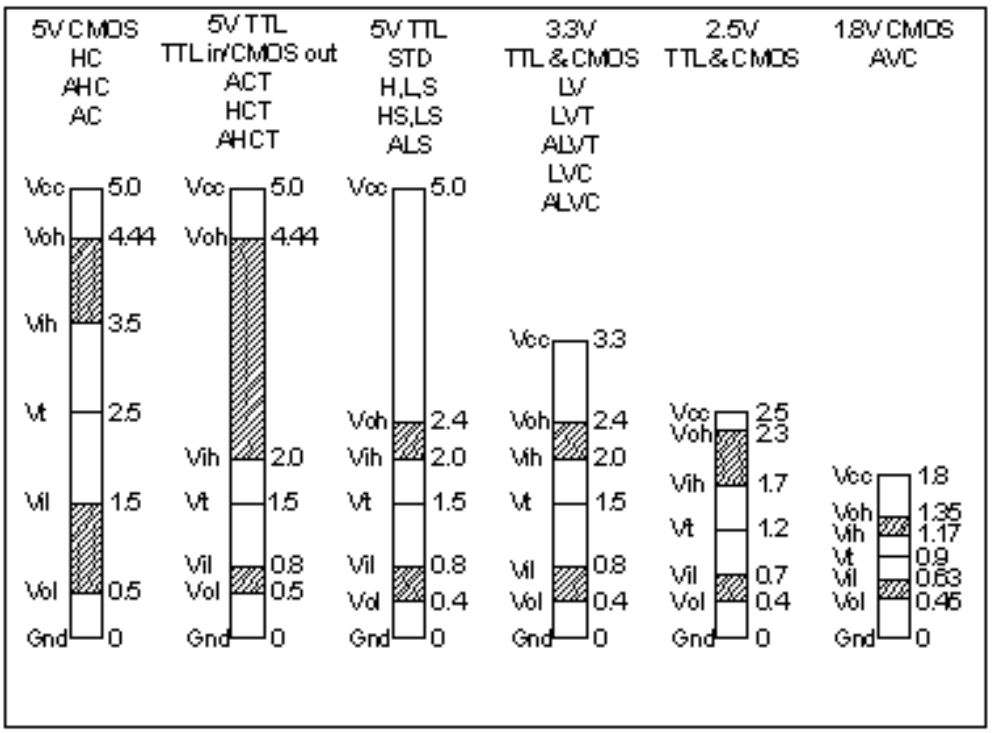
Logic family



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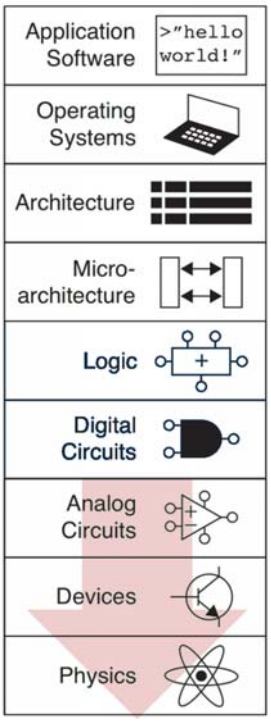

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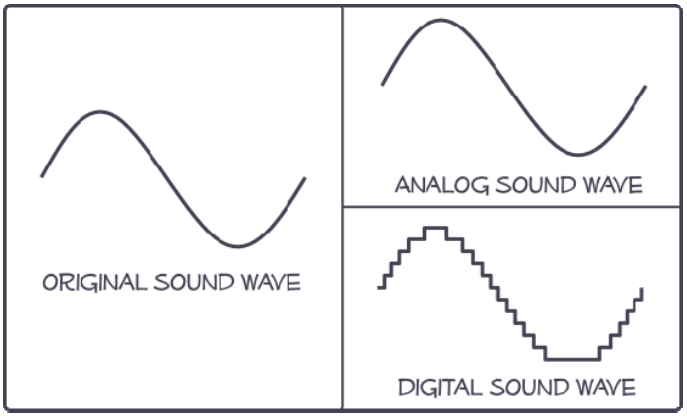
Definition

- Electronic systems with a continuously variable signal
- The term "analog", derived from the Greek word ανάλογος (analogos), describes the proportional relationship between a signal and a voltage or current that represents the signal



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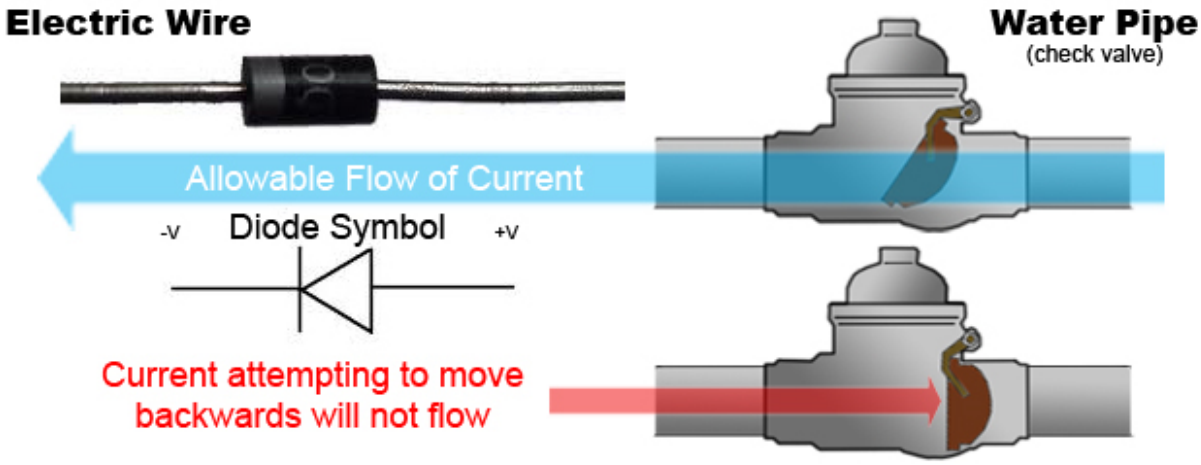
Diode *vs.* one way valve



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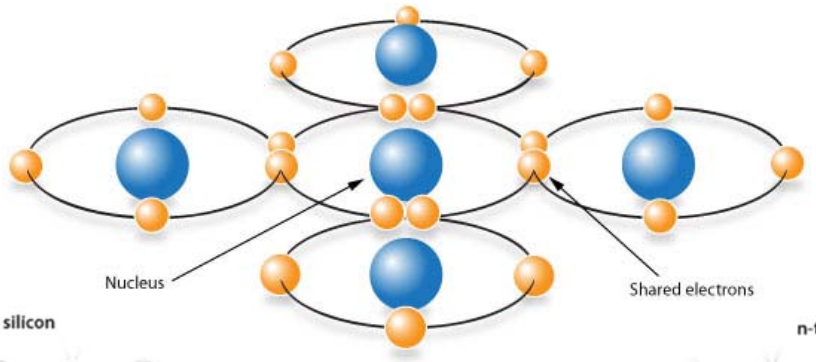
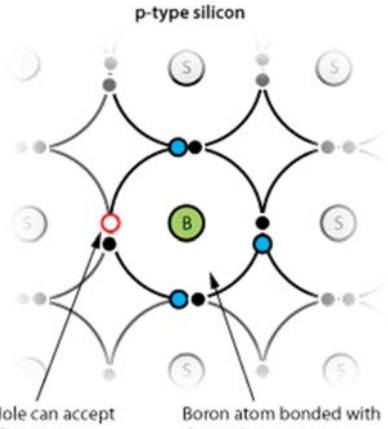
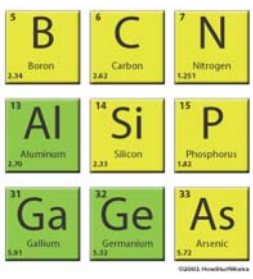
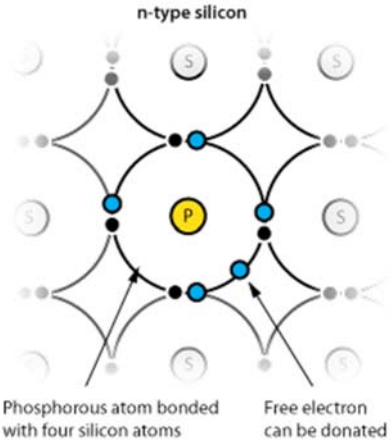
Semiconductors









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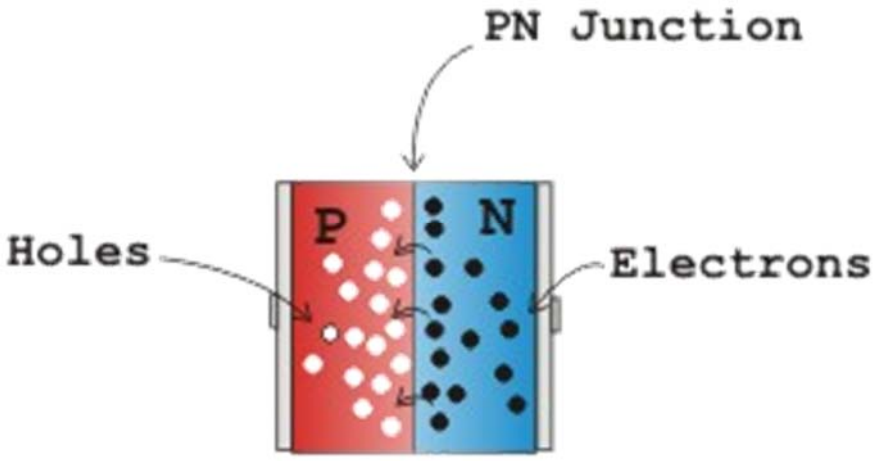
PN junction



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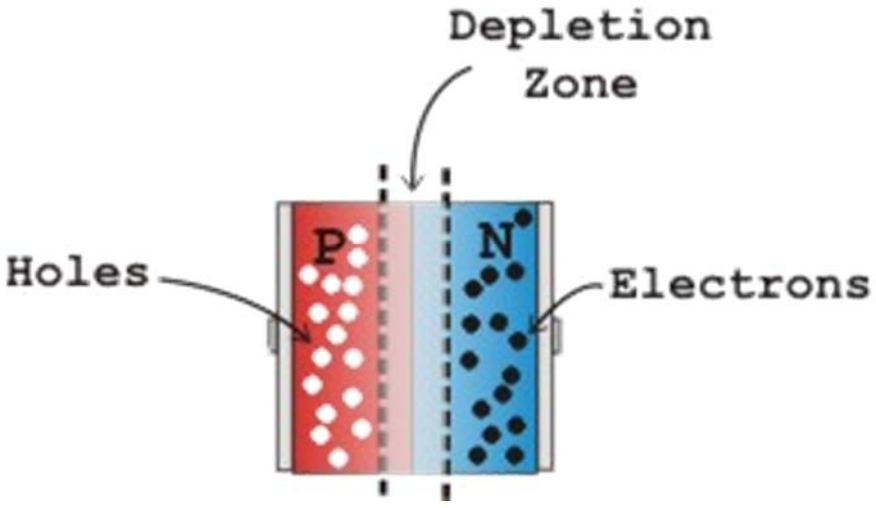
PN junction



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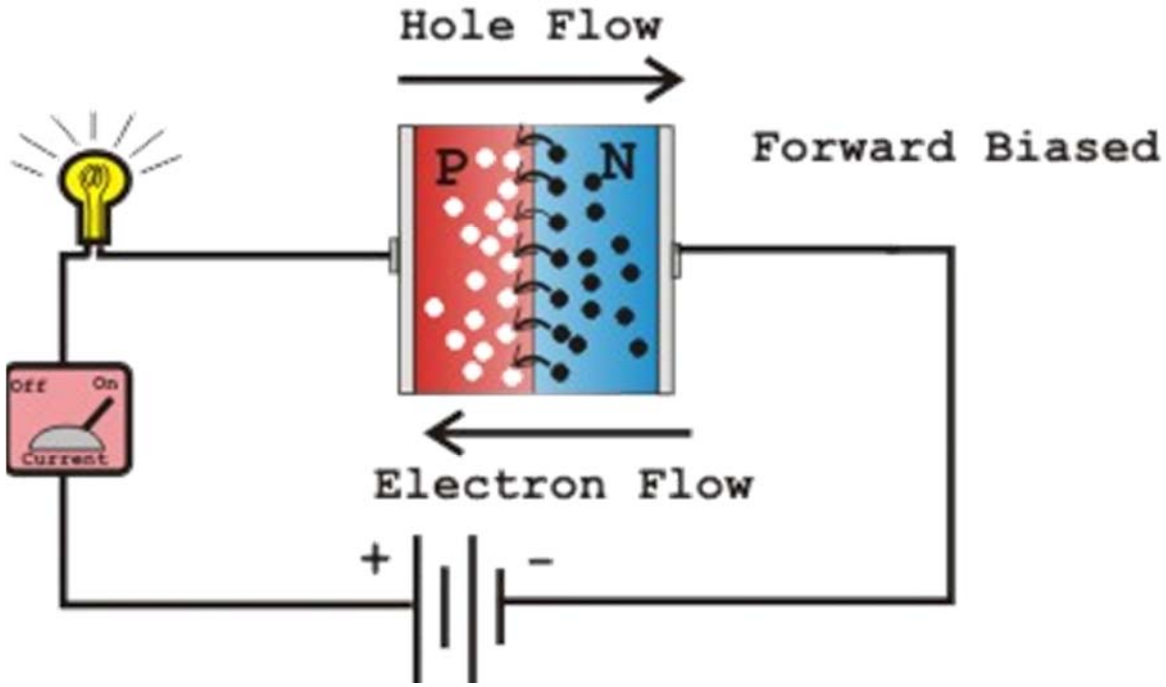
Forward Biased



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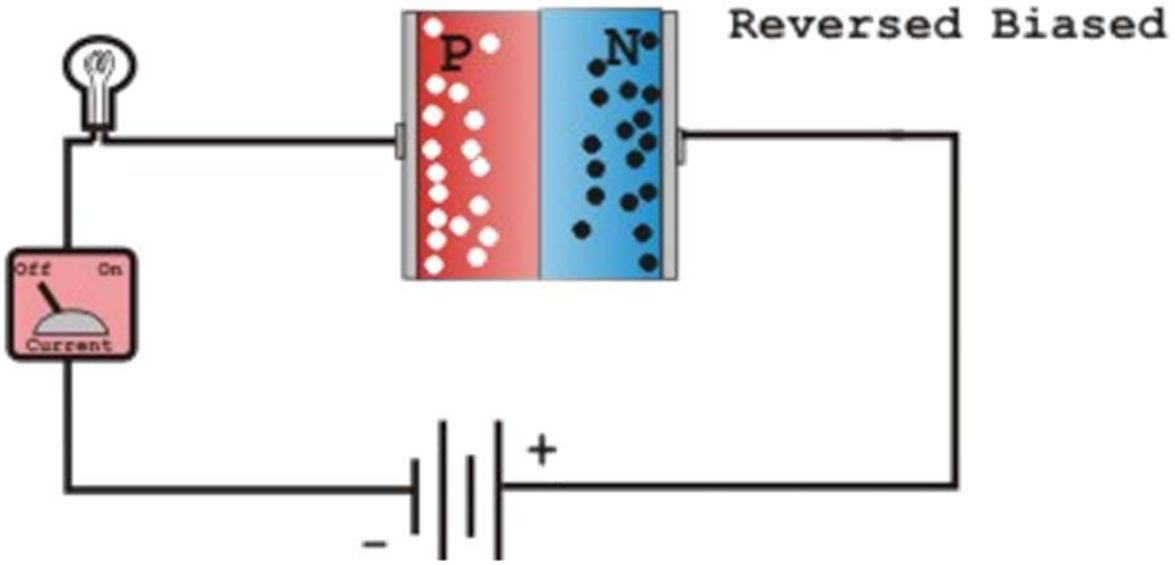
Reverse Biased



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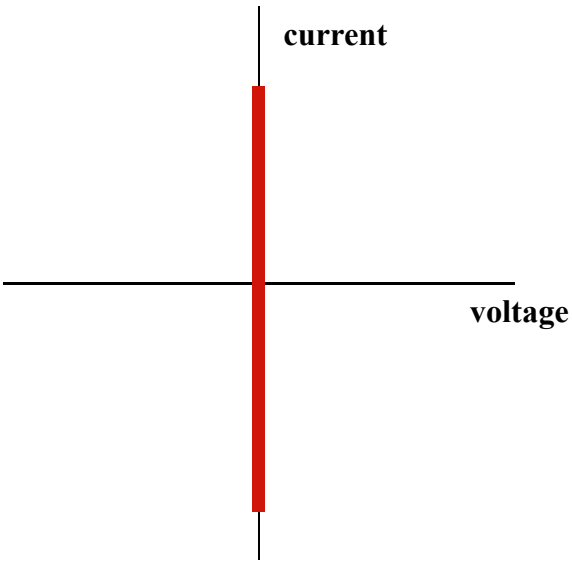
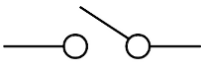
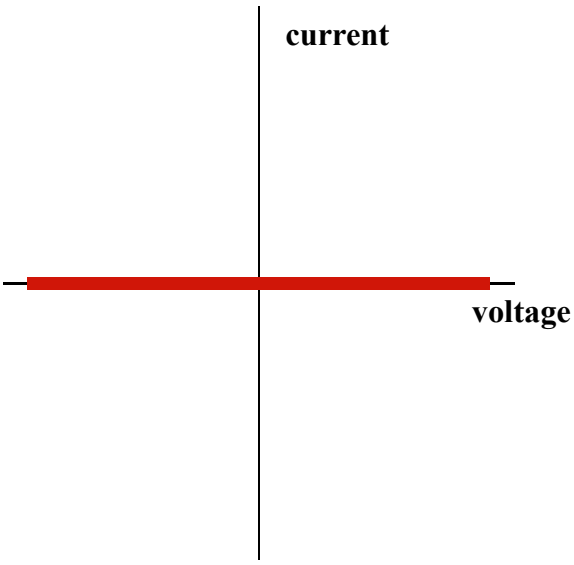
Electrical behavior of a switch

- Switch on 



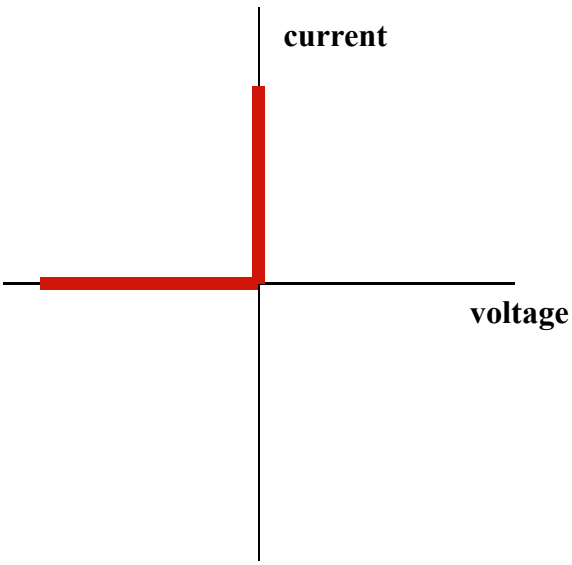
- Switch off 



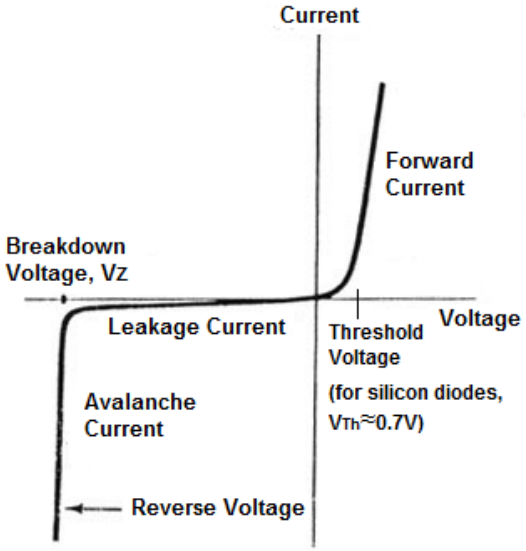
(Figures are from internet)

Electrical behavior of an diode

- Ideal diode



- Practical diode



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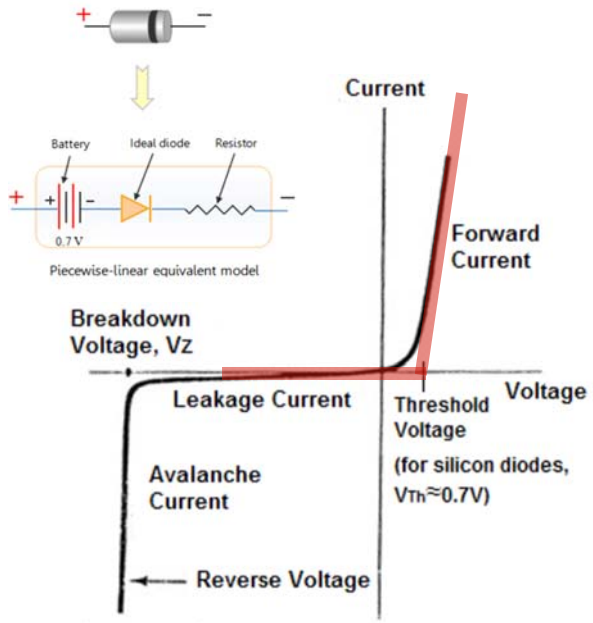
Diode modeling

- Piecewise-linear model



(Figures are from internet)

- I/V characteristics

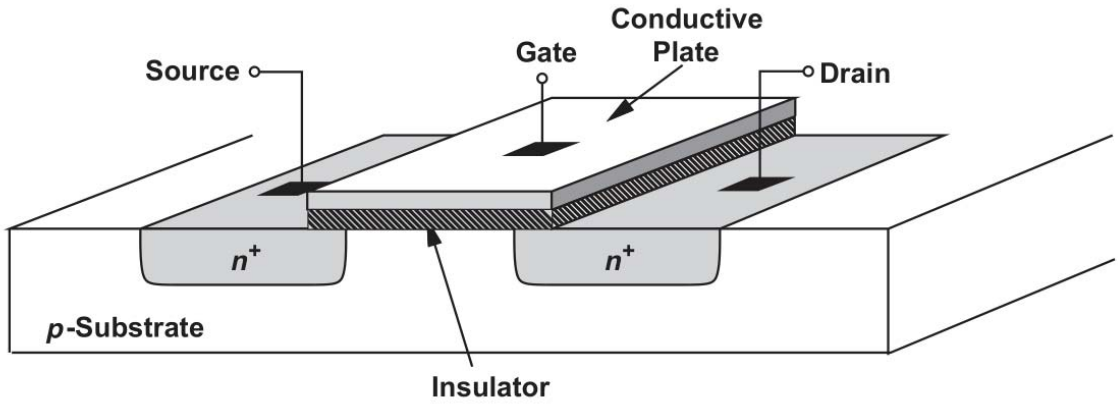
$$I = I_S\left[e^{\left(\frac{V_D}{nV_T}\right)} - 1\right]$$

I_S: saturation current

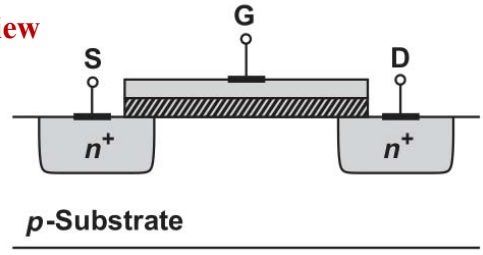
$V_T = kT/q$: thermal voltage

n: diode ideality factor (1~2 for silicon diodes)

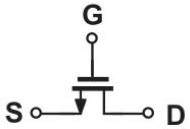
MOSFET



Sideview

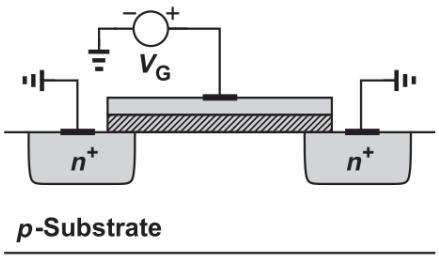


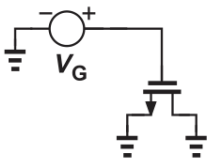
Symbol

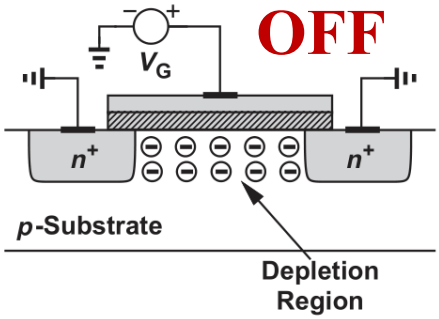


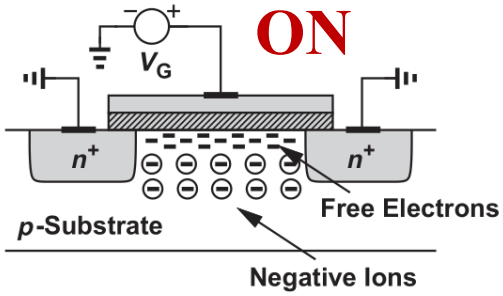
(Razavi, Fundamentals of Microelectronics)

Applying gate voltage







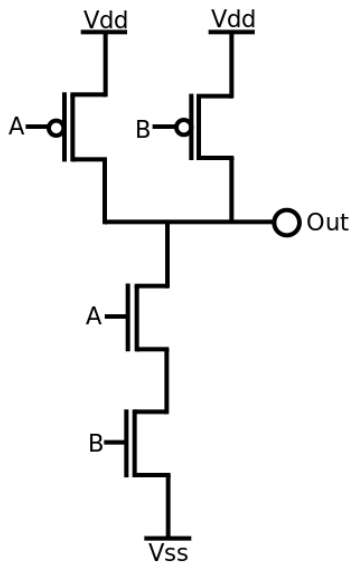


Formation of depletion region **Formation of channel**

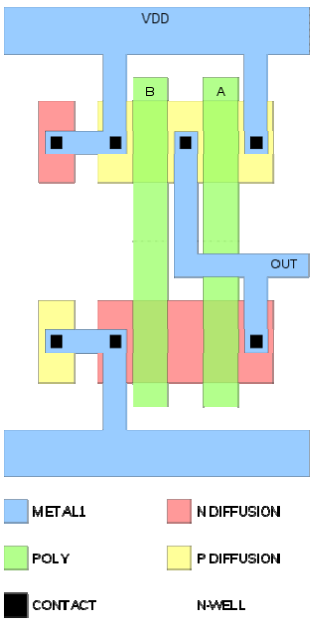
(Razavi, Fundamentals of Microelectronics)

Physical layout of MOS NAND gate

- CMOS NAND gate



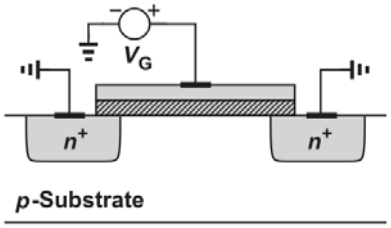
- Physical layout



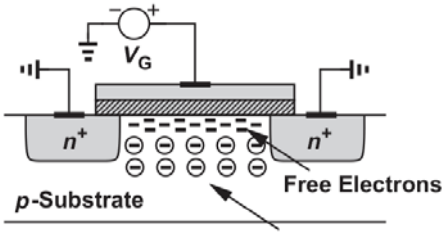
(Razavi, Fundamentals of Microelectronics)

Beyond the on/off states

- For digital electronics

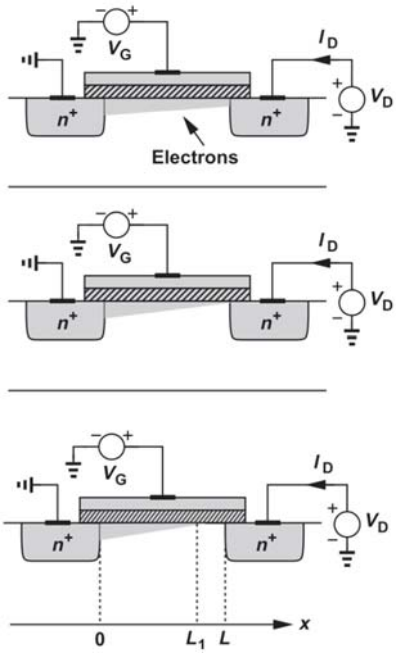


Cut off



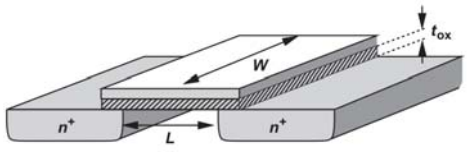
Conducting

- For analog electronics



(Razavi, Fundamentals of Microelectronics)

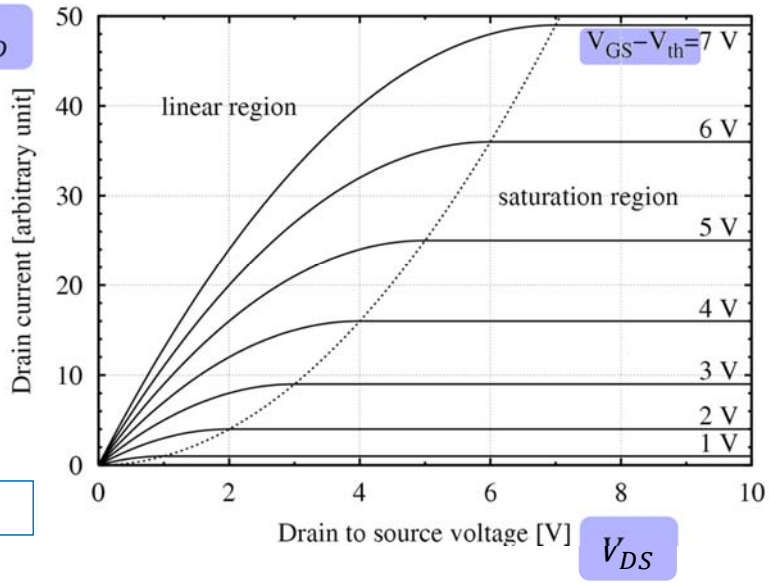
I/V characteristics



Linear region:

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}[2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2]$$

A voltage-controlled resistor



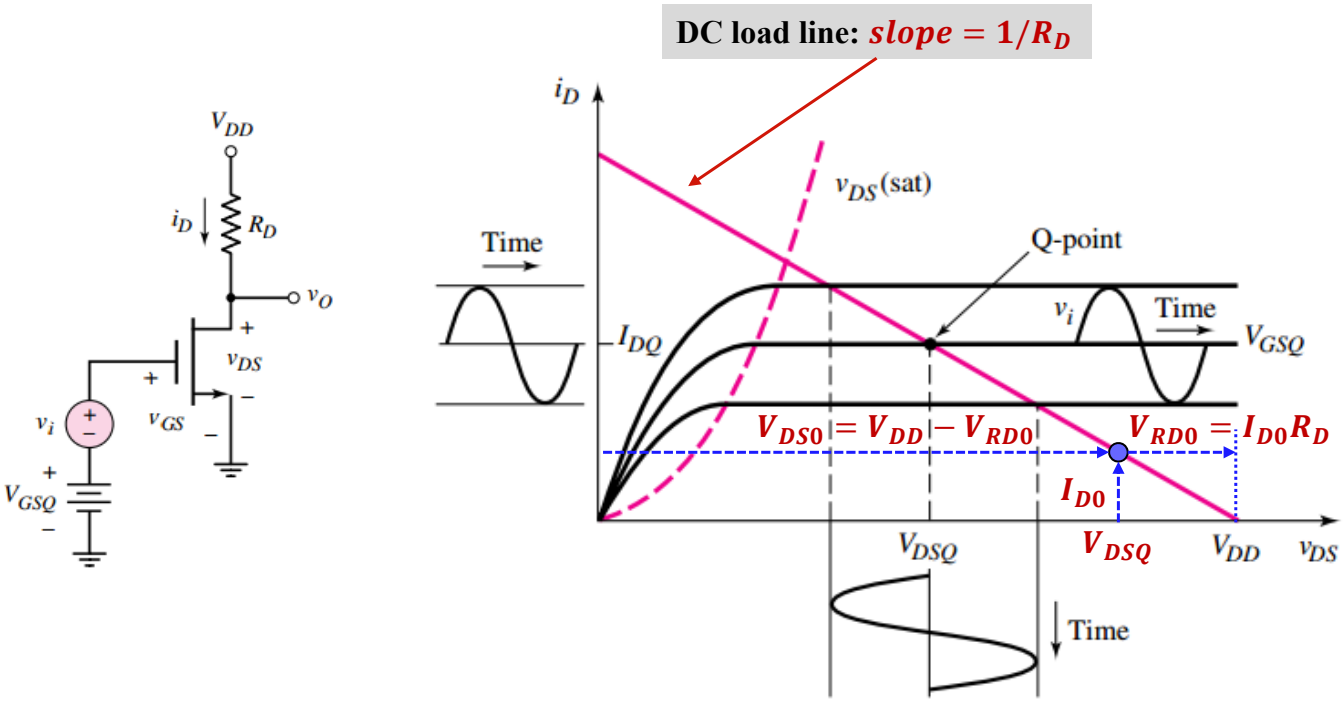
Saturation region:

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})^2(1 + \lambda V_{DS})$$

A voltage controlled current source

(Razavi, Fundamentals of Microelectronics)

Basic MOS amplifier



(Neamen, Electronic Circuit Analysis and Design)

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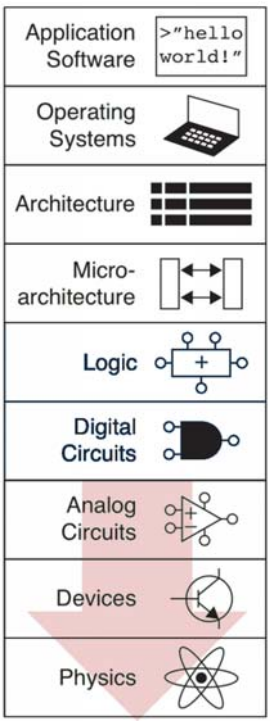
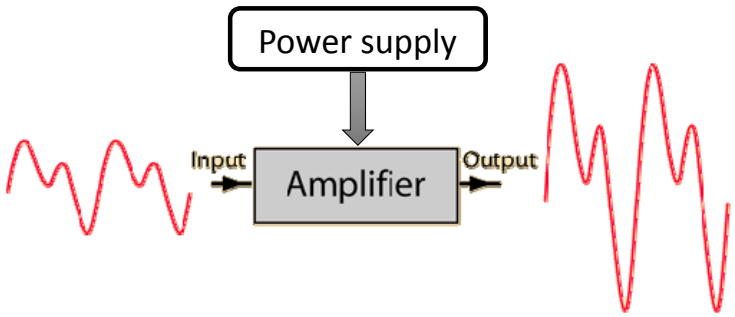


Amplifier

- An electronic device that increases the power of a signal
  - » Taking energy from a power supply
  - » controlling the output to match the input signal shape but with a larger amplitude
  - » The opposite of an attenuator
  - » An amplifier provides gain, an attenuator provides loss



(Figures are from internet)

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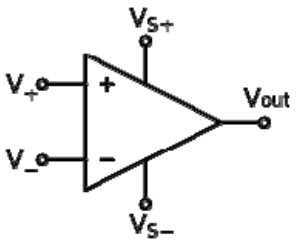
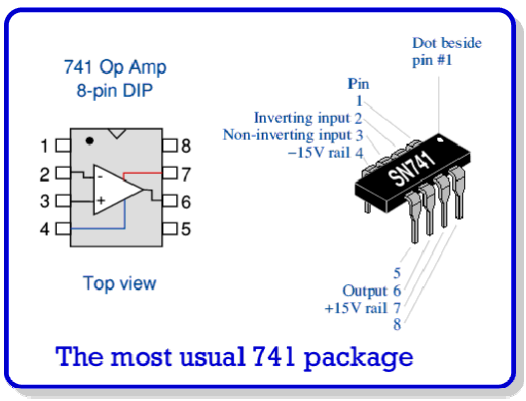
Operational amplifier (运算放大器)

- Characteristics
  - » DC-coupled
  - » Voltage amplifier
  - » High gain $(A \to \infty)$
  - » A differential input $(V_+ - V_-)$
  - » A single-ended output (V_{out})
- Originally from analog computers for doing mathematical operations
- One of the most widely used electronic devices



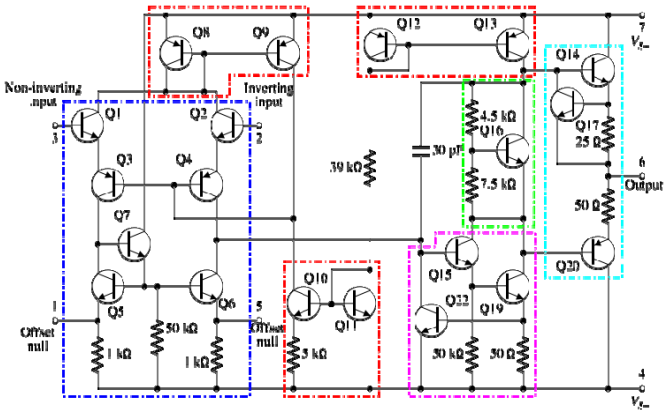
$$V_{out} = A(V_+ - V_-)$$



(Figures are from internet)

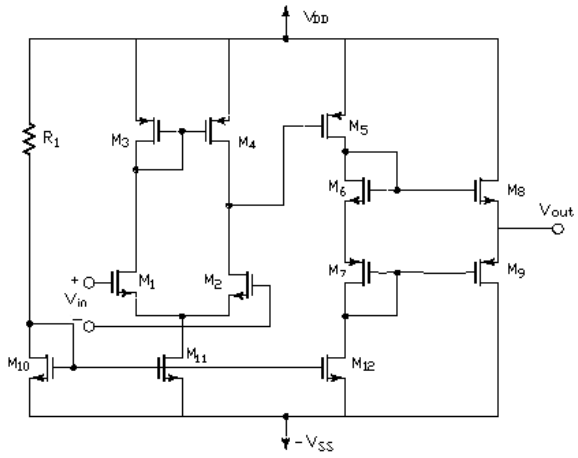
Realization

- BJT Technology



A component-level diagram of the common 741 op-amp. Dotted lines outline: current mirrors (red); differential amplifier (blue); class A gain stage (magenta); voltage level shifter (green); output stage (cyan).

- CMOS Technology



(Figures are from internet)

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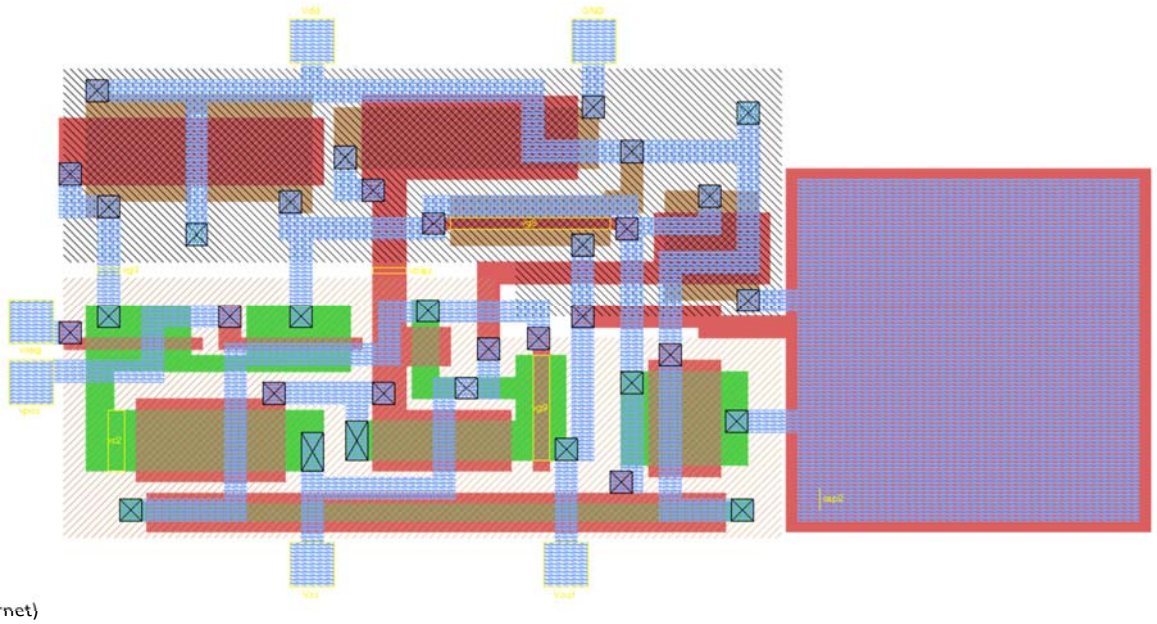
Realization

- Layout view of a simple CMOS operational amplifier



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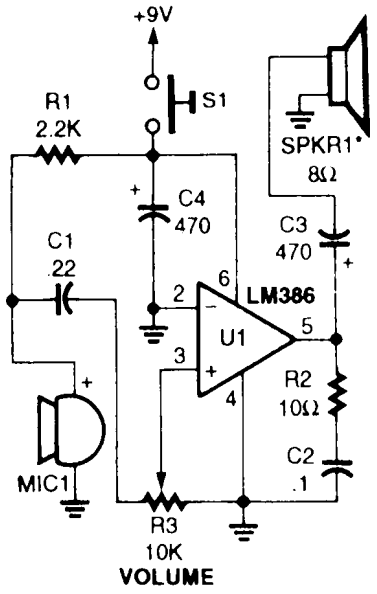
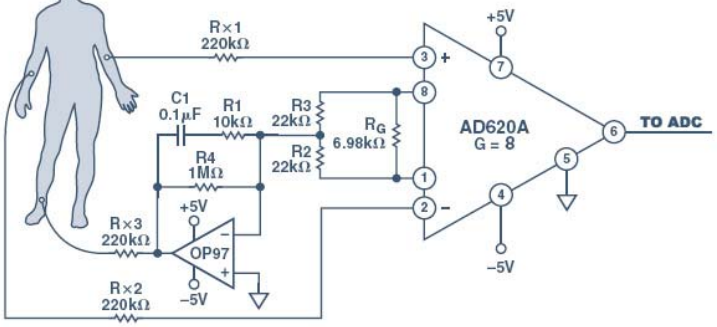
Applications

- Audio system



- Bio-electric signal



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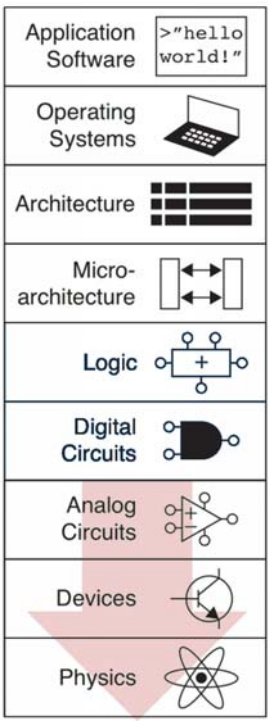
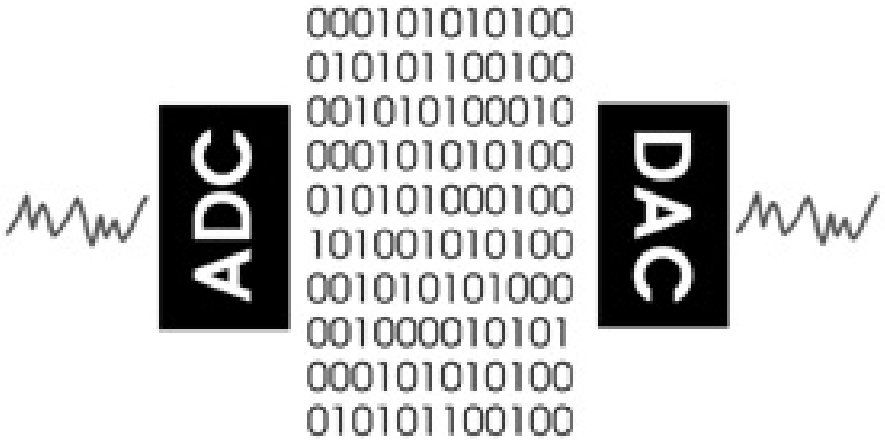
- Power electronics
- MEMS



Applications

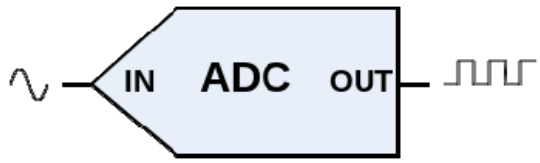
- Connecting the digital computers and physical world

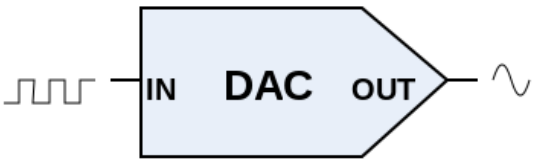


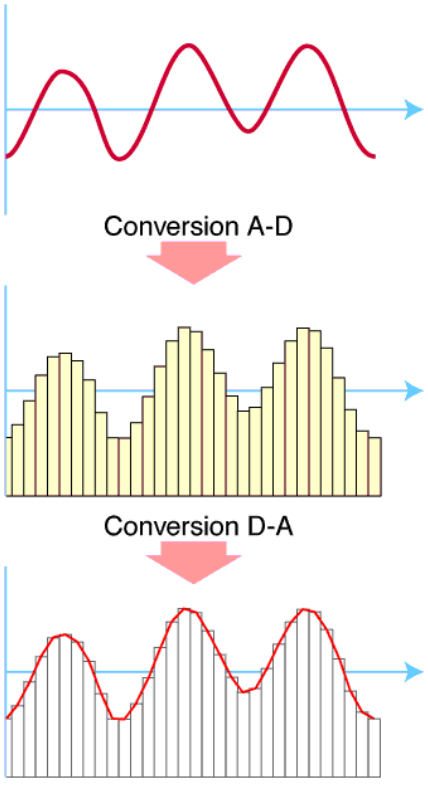
(Figures are from internet)

A/D and D/A conversions

- Symbols



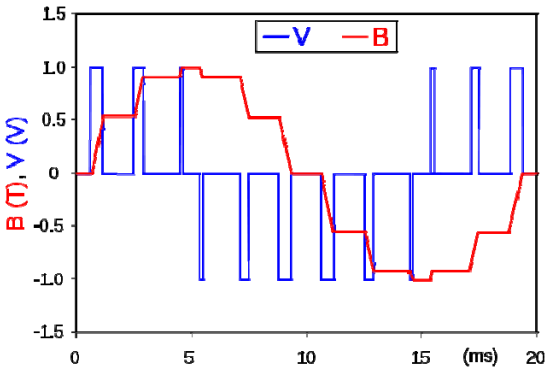


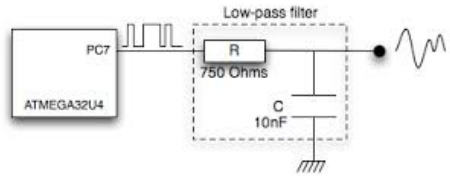


(Figures are from internet)

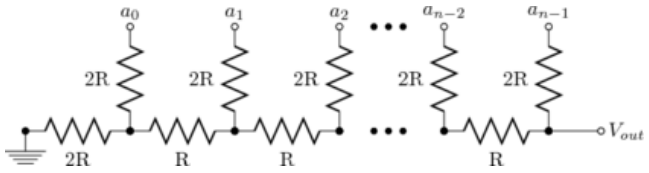
Digital-to-analog converters

- Pulse-width modulation





- The R-2R ladder DAC



$$V_{out} = \frac{a_{n-1}}{2} + \frac{a_{n-2}}{4} + \cdots + \frac{a_2}{2^{n-2}} + \frac{a_1}{2^{n-1}} + \frac{a_0}{2^n}$$

(Figures are from internet)

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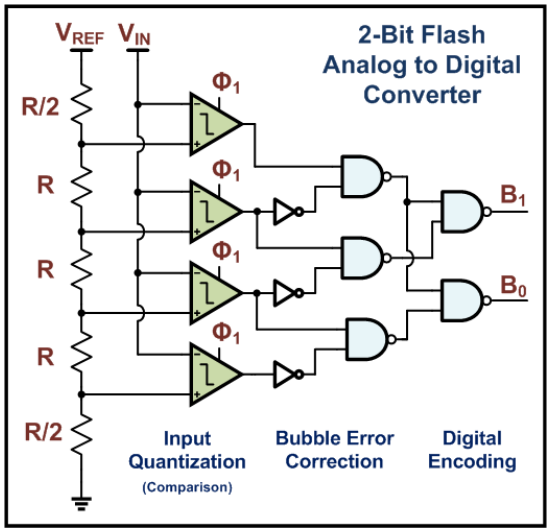
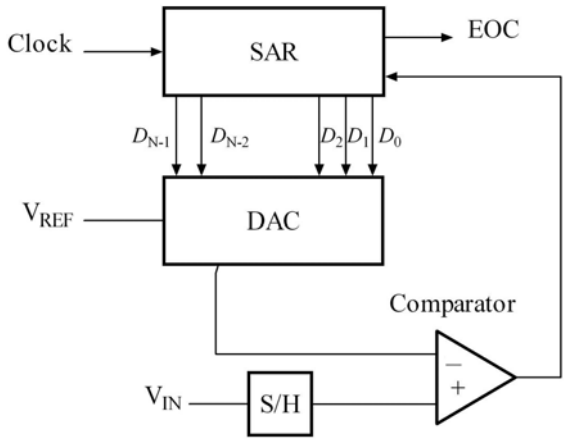
Analog-to-digital converters

- Flash ADC (also known as a Direct conversion ADC)

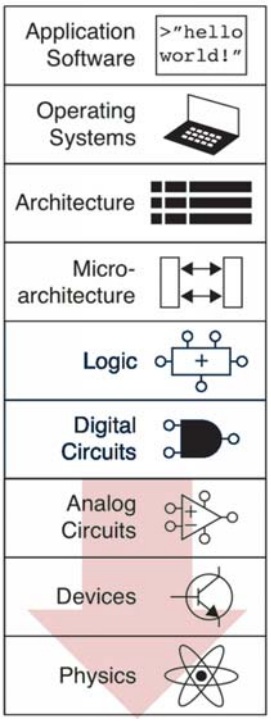


- Successive approximation ADC



Outline

- Beneath the digital abstraction
  - » Digital abstraction
  - » Noise margins
- **Analog electronics**
  - » Definition
  - » Diode & MOSFET
  - » Operational amplifier
  - » A/D and D/A conversion
  - » **Example: audio systems**
- Power electronics
- MEMS



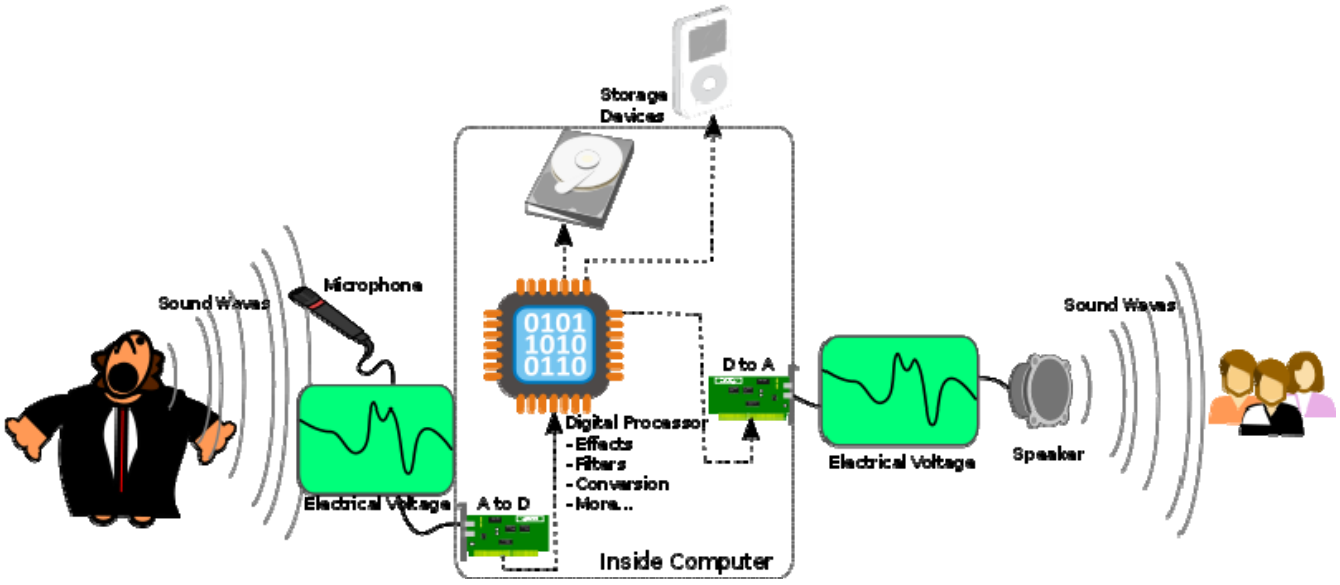
Analog *vs.* digital audio systems

Signals in analog amplifier

Signals in digital amplifier

(Figures are from internet)

Digital audio system



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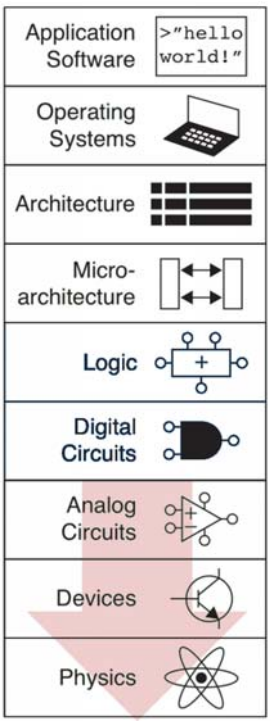
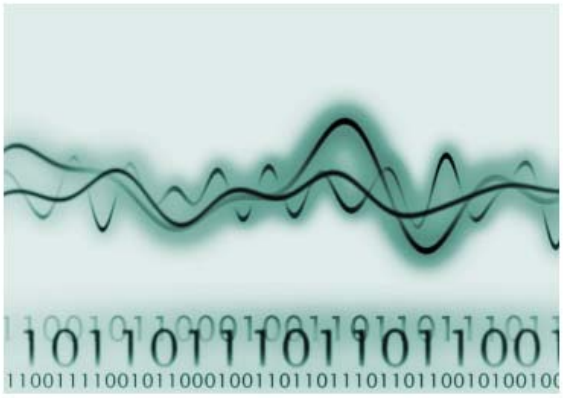


Relations between signal and power



Signal – a function that conveys information about the behavior or attributes of some phenomenon

Power is a necessity for the acquisition, conditioning, transmission, storage, and visualization of signals (data)

(Figures are from internet)

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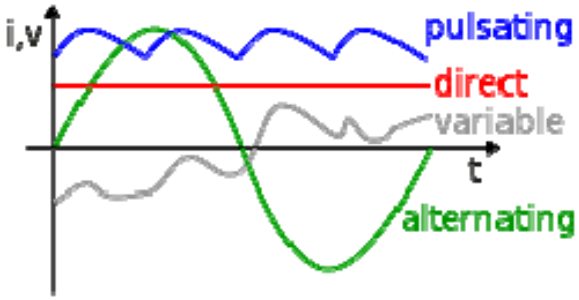
Different forms of electric power



- Direct current (DC) power

- Alternating current (AC) power

(Figures are from internet)

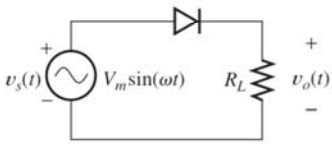
Power electronics

- The application of solid-state electronics to the control and conversion of electric power
- Conversions among different forms
  - » AC to DC (rectifier)
  - » DC to AC (inverter)
  - » DC to DC (DC-to-DC converter)
  - » AC to AC (AC-to-AC converter)

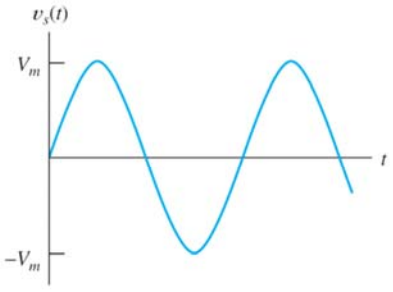
(Figures are from internet)

Example: half-wave rectifier

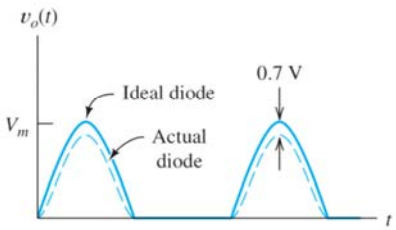
Without filter capacitor



(a) Circuit diagram

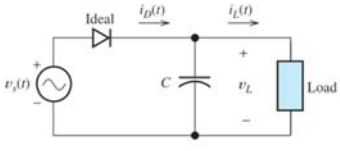


(b) Source voltage versus time

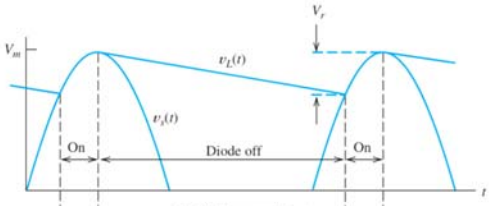


(c) Load voltage versus time

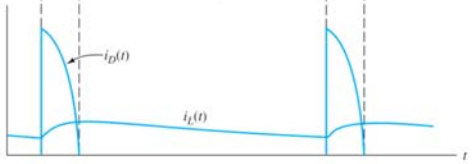
With filter capacitor



(a) Circuit diagram



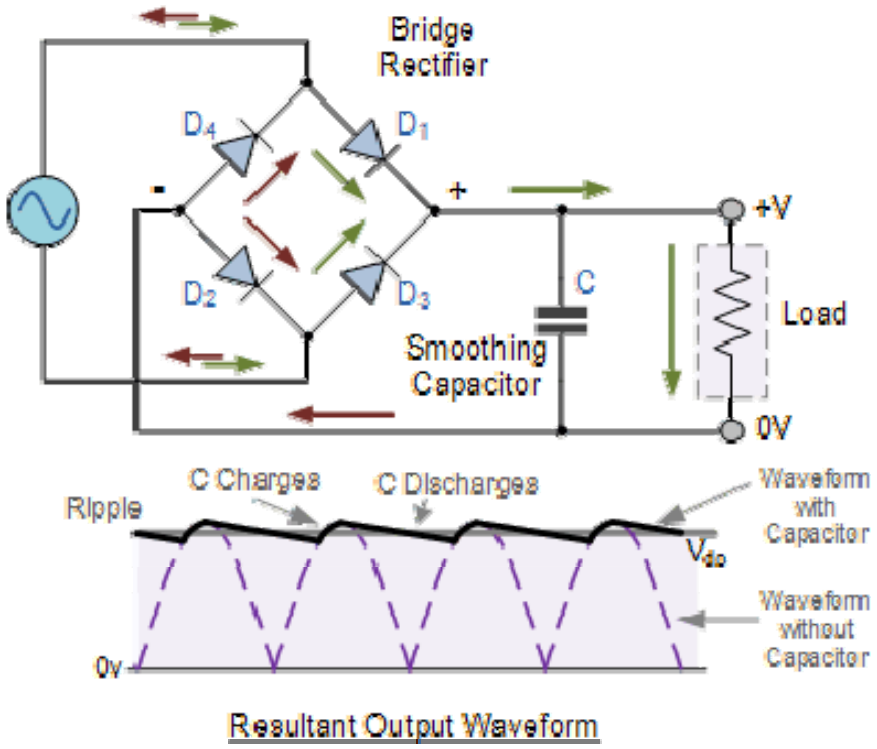
(b) Voltage waveforms



(c) Current waveforms

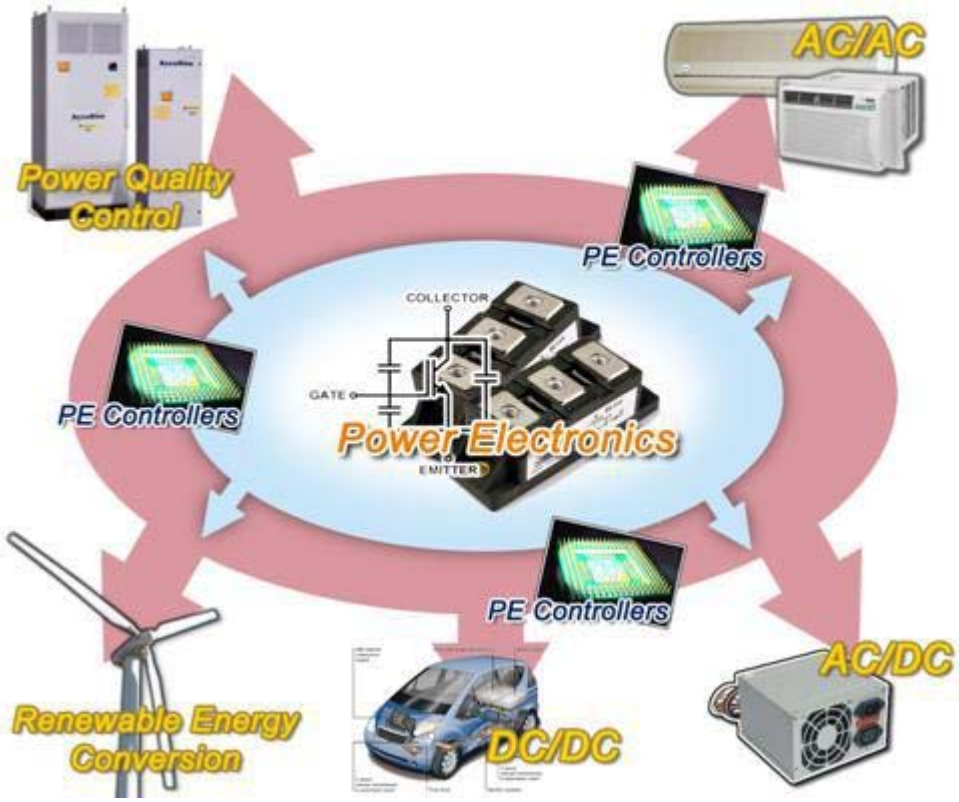
(Figures are from internet)

Example: full-wave rectifier



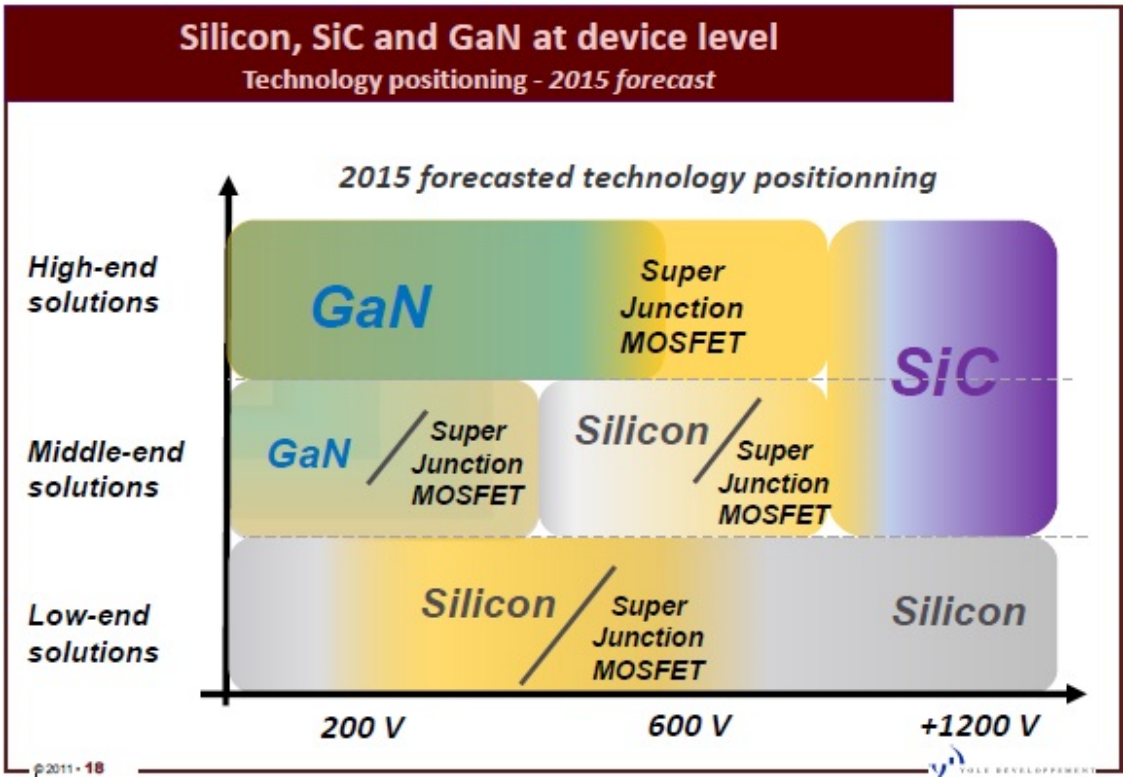
(Figures are from internet)

PE applications



(Figures are from internet)

PE devices



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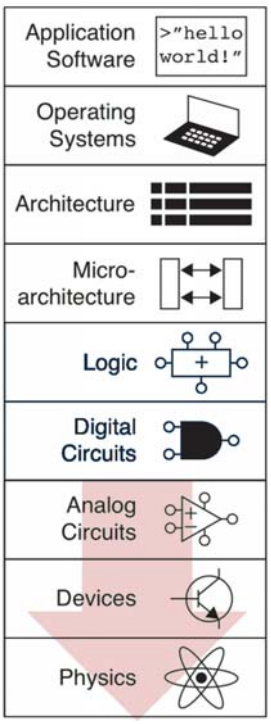
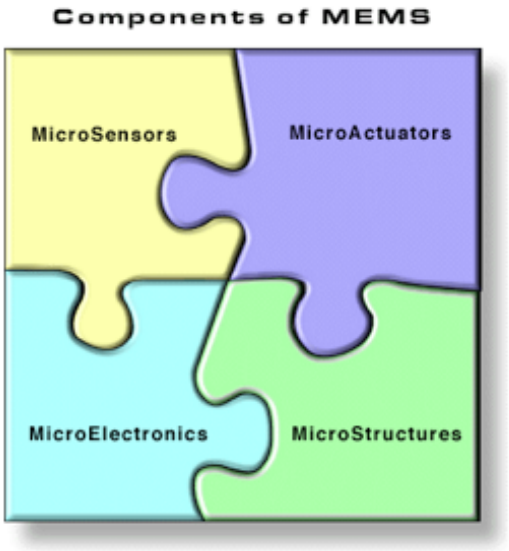


MEMS

- Microelectromechanical systems
  - » miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication
  - » it merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology

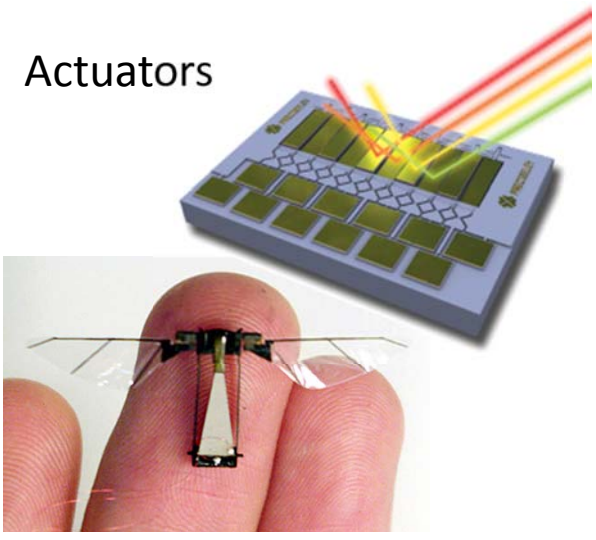


(Figures are from internet)

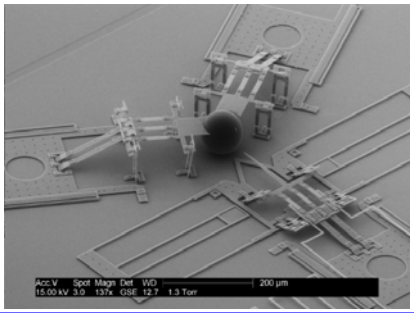
MEMS applications

- Sensors

- Actuators



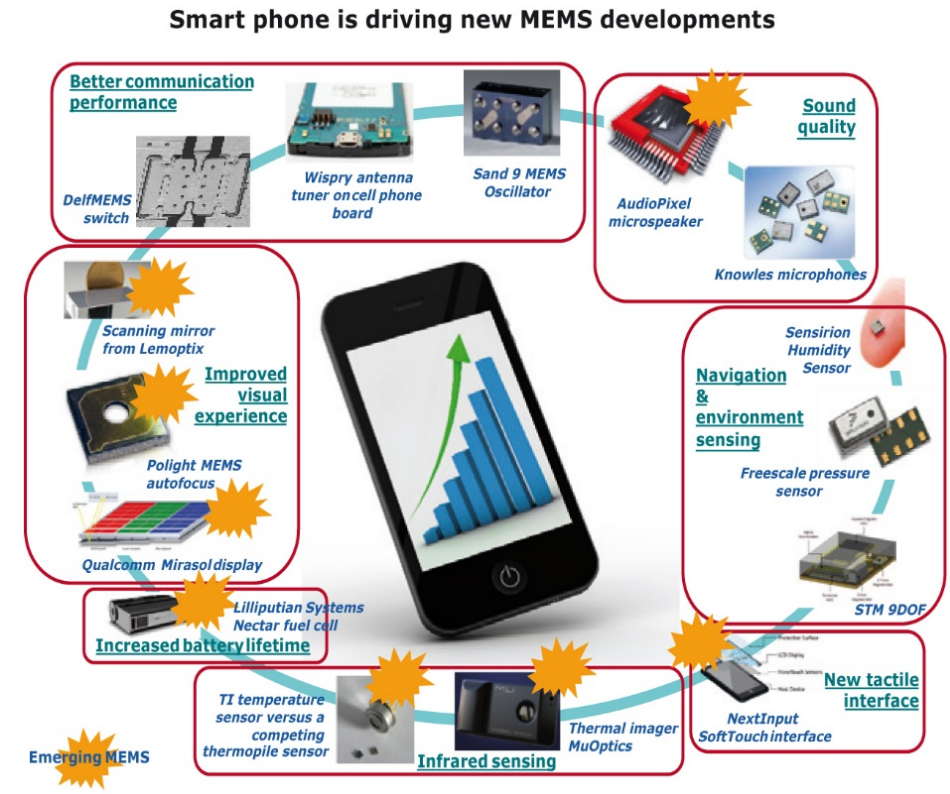
- Structures



- Etc.

(Figures are from internet)

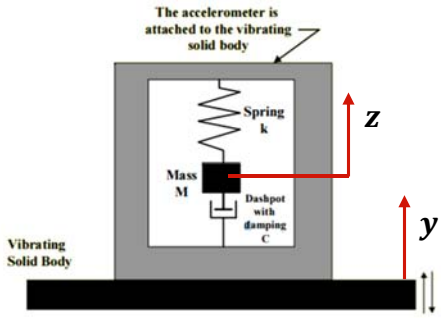
MEMS in smart phone



(http://smartphoneworld.me)

Example: MEMS accelerometer

- Principle



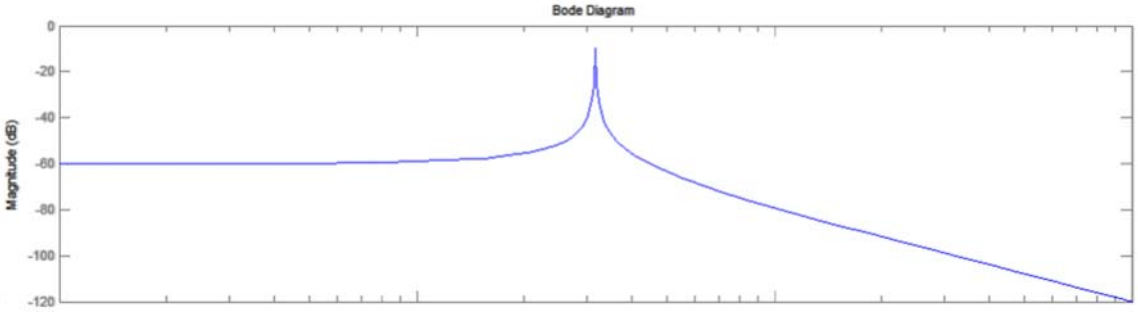
Relative displacement

$$x = z - y$$

$$\rightarrow \ddot{x} + \frac{C}{m}\dot{x} + \frac{k}{m}x = -\ddot{y} = -a(t)$$

In the frequency domain

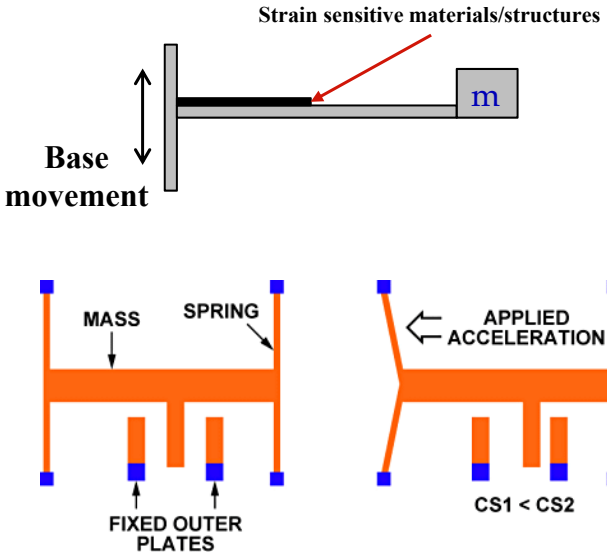
$$\frac{X(j\omega)}{A(j\omega)} = \frac{m}{k - m\omega^2 + j\omega c}$$



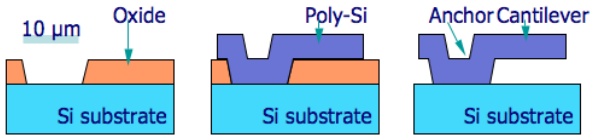
(Figures are from internet)

Example: MEMS accelerometer

- Measurement



- Manufacturing process



(Figures are from internet)