CSEP567: **Design and Implementation of Digital Systems– Focus on Embedded Design**

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- Course web:
  - http://www.cs.washington.edu/education/courses/csep567/05au/
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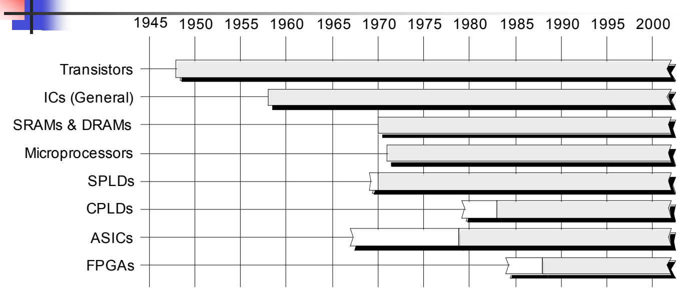
- Today
  - Grading
  - Technology Timeline
  - Electrical basics
  - AVR I/O

Grading (our current thinking)

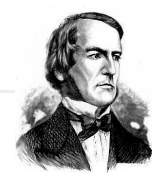
- Lab Completion: 50%
- Assignments: 30%
- Take-home exam/report/class participation: 20%

Technology timeline



1854

- George Boole
  - Boolean algebra
- Number system with 2 values
  - 0/1 ⇔ false/true
  - Do math on logic statements
  - 3 operations (NOT, AND, OR)



All computers use Boolean algebra

NOT

A	Out
0	1
1	0

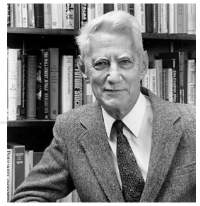
AND

A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1

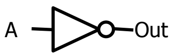
OR

A	B	Out
0	0	0
0	1	1
1	0	1
1	1	1

1938

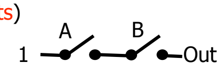


- Claude Shannon
  - Implemented Boolean algebra using switches
  - Described information using binary digits (bits)



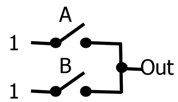
NOT

A	Out
0	1
1	0



AND

A	B	Out
0	0	0
0	1	0
1	0	0
1	1	1



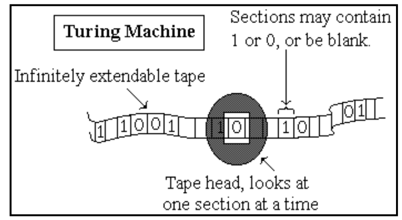
OR

A	B	Out
0	0	0
0	1	1
1	0	1
1	1	1

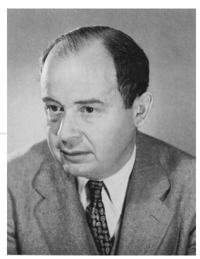
1937

- Alan Turing
  - Turing Machines
- Simple computer model
  - Can something be computed?

Also pioneered artificial intelligence



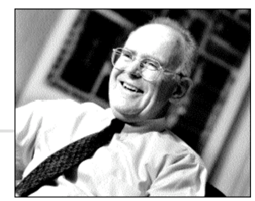
1945



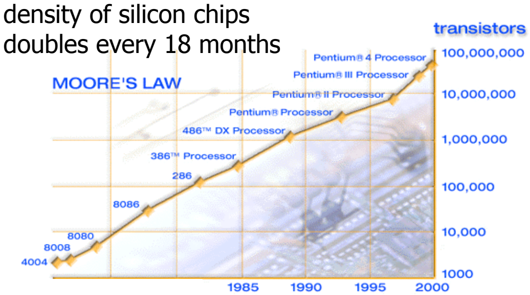
- John von Neumann
  - First stored computer program
- A sequence of operations
  - Read from memory
  - Operate using logic gates
  - Store result into memory

Other contributions:
Quantum Mechanics
Cellular Automata
Game Theory

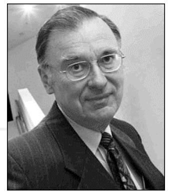
1965



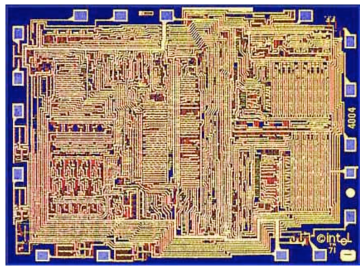
- Gordon Moore
  - Moore's Law: The transistor density of silicon chips doubles every 18 months



1971



- Ted Hoff invents the microprocessor



- Intel 4004
- 2,300 transistors
- 3 mm by 4 mm
- As powerful as the ENIAC

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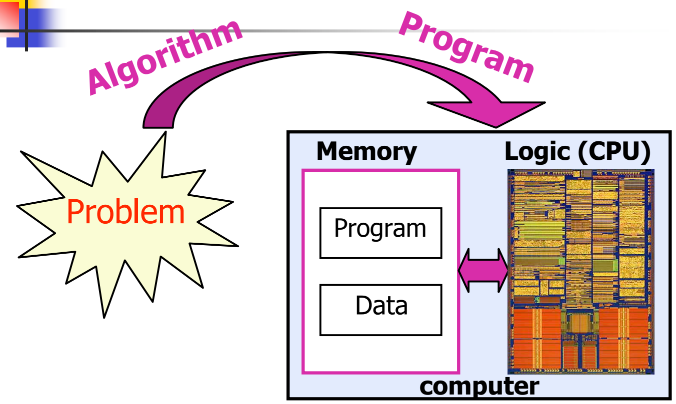
Hardware + Software + Technology



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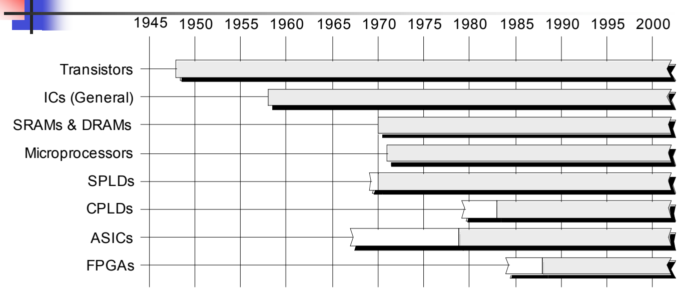
Technology timeline



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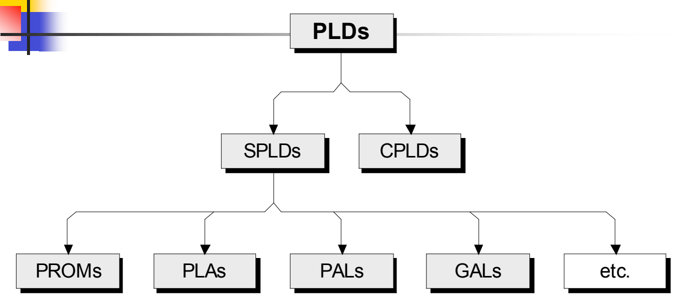
Programmable Logic Devices



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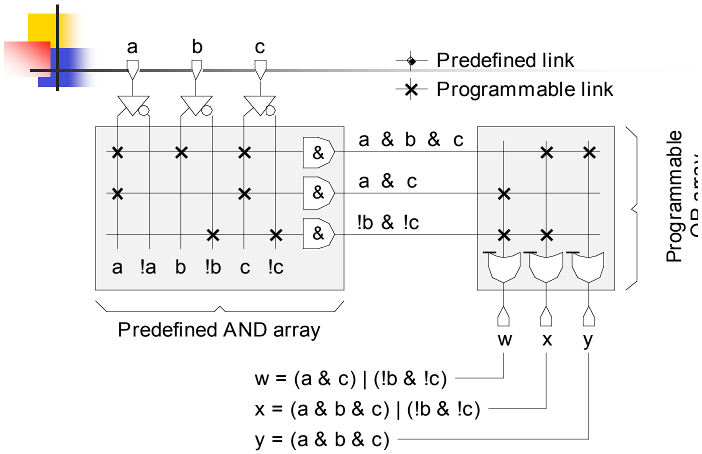
Programmed PLA



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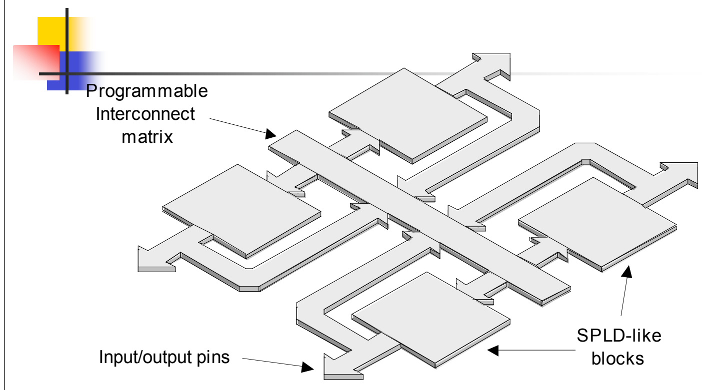
Generic CPLD Structure



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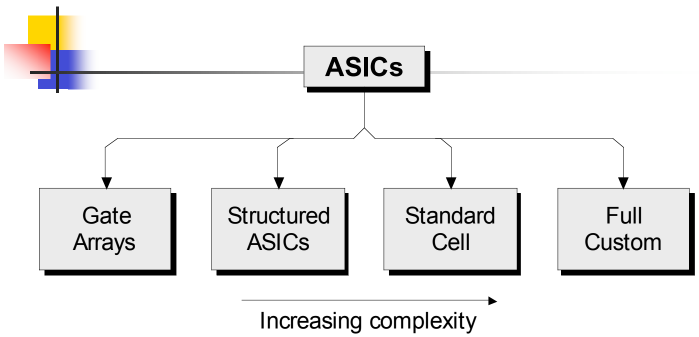
Different Types of ASICs



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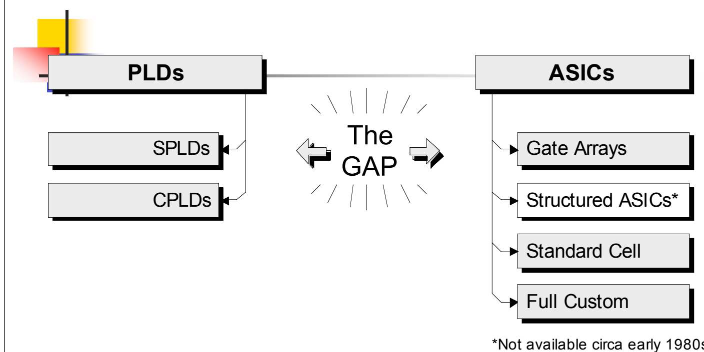
The Gap-- FPGAs



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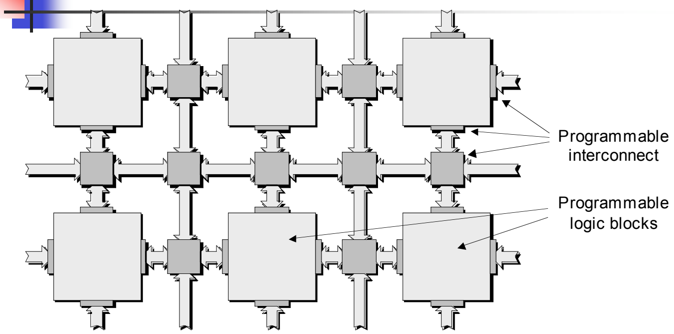
Simple generic FPGA architecture



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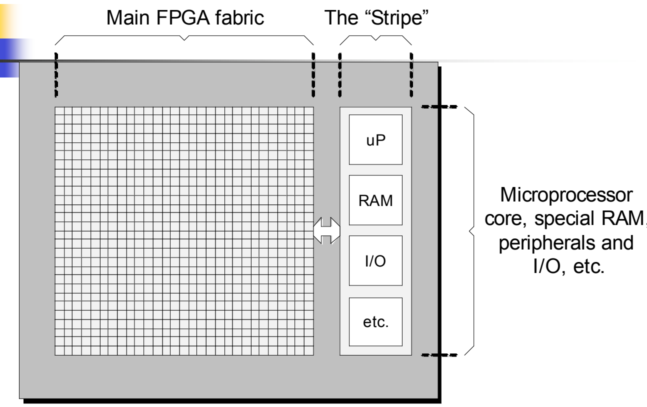
Embedded Microprocessor core



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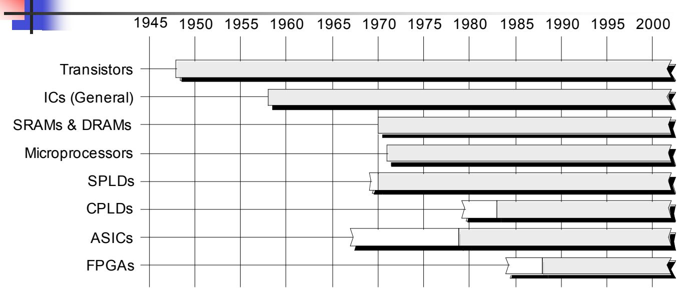
Technology timeline



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Charge

Two hydrogen atoms meet. One says "I've lost my electron."

The other says "Are you sure?"

The first replies "Yes, I'm positive."

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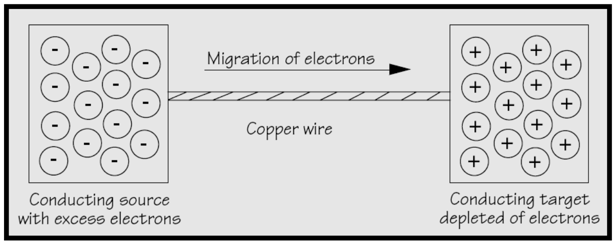
Basic Concepts of Electricity

- Voltage
- Current
- Resistance



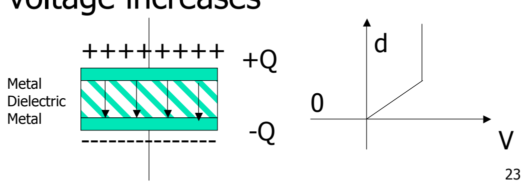
Electric Fields

- An electric field applies a force to a charge
  - Force on positive charge is in direction of electric field, negative is opposite
- Charges move if they are mobile
- An electric field is produced by charges (positive and negative charges)
- Electric fields can be produced by time varying magnetic fields (generator, antenna radiation)

Voltage Difference

- Voltage difference is the difference in potential energy in an electric field
- $E = V/d$
- As you move closer to a positive charge the voltage increases

Capacitor (electric field constant between parallel plates)



Current

- An electric current is produced by the flow of electric charges
- Current = rate of charge movement
  = amount of charge crossing a surface per unit time
- In conductors, current flow is due to electrons
- Conventional current is defined by the direction positive charges will flow
- Direction of electron flow is opposite to direction of conventional current

Resistance

- In materials electrons accelerate in an electric field
- Electrons lose energy when they hit atoms - lost energy appears as heat and light
- The result is that electrons drift with constant velocity (superimposed on random thermal motion)
- Resistance is the ratio Voltage/current

  $R = V/I$

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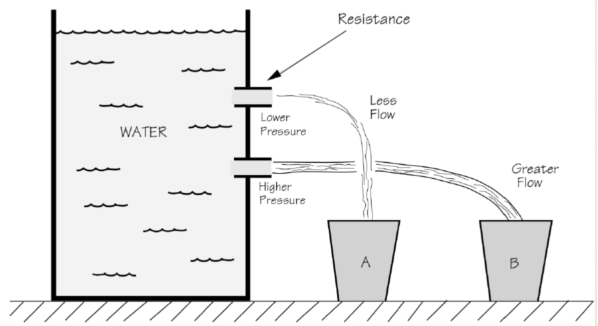
Voltage, Current, and Resistance



Flow = current Pressure = voltage

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Material Conductivity

- Conductors - negligible resistance
- Insulators - extremely large resistance
- Semiconductors - some resistance
- Resistors - are devices designed to have constant resistance across a range of voltages

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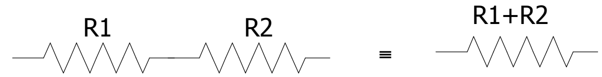
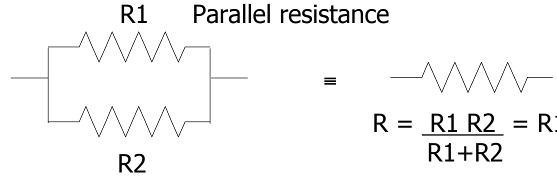
Resistor Combination

Series resistance



Parallel resistance



$$R = \frac{R1\,R2}{R1+R2} = R1||R2$$

$$1/R = 1/R1 + 1/R2$$

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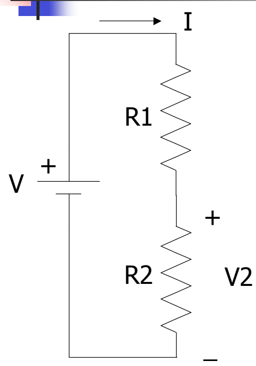
Voltage Divider



$$V2 = \frac{V\ R1}{R1 + R2}$$

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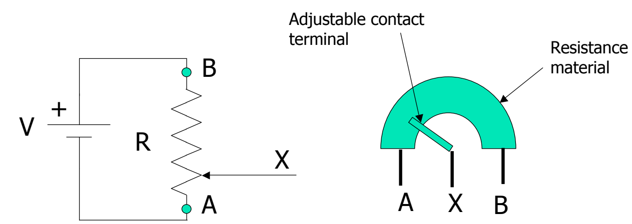
Potentiometer (Variable Resistor)



VX = V * Distance AX/Distance AB
(linear potentiometer)

A trimpot is a small variable resistor mounted on a printed circuit board that can adjusted by a small screwdriver to make semi-permanent adjustments to a circuit

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Capacitors

- A component constructed from two conductors separated by an insulating material (dielectric) that stores electric charge (+Q, -Q)
- As a consequence there is a voltage difference across the capacitor, V
- Capacitance = C = Q/V
- The dielectric material operates to reduce the electric field between the conductors and so allow more charge to be stored for a given voltage

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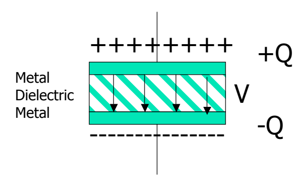
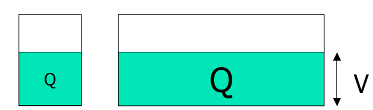
Capacitors

Bucket analogy





C = Q/V

(Q = CV)

A small bucket (capacitor, C)
holds less charge (Q)
for given level (voltage V)
than a large bucket

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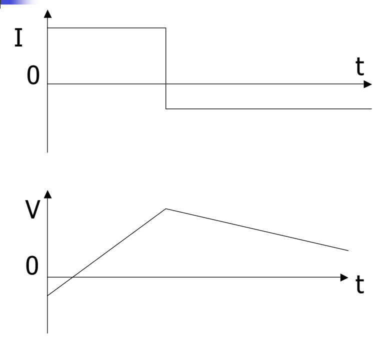
Charging a Capacitor

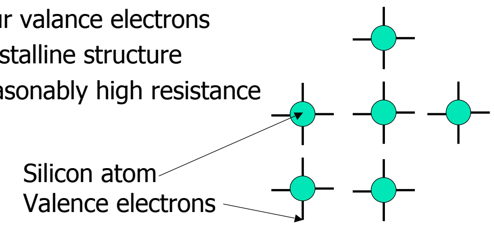


The bucket analogy can be used to describe capacitor charging

When current flows in at a constant rate the voltage increases linearly and vice versa for current flowing out

Semiconductors

- Silicon is used as an example (other semiconductors include Germanium, Gallium Arsenide, Gallium phosphide, indium arsenide, indium phosphide)
- Pure silicon (intrinsic semiconductor)
  - Four valance electrons
  - Crystalline structure
  - Reasonably high resistance

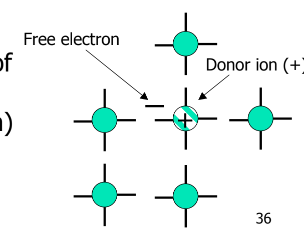


Electrons and holes

- Due to thermal energy some electrons in the valance shell become free
- Create:
  - One free electron +
  - One hole in the valence band that can be filled by electrons from the valance band in an adjacent silicon atom
- Current in silicon can flow due to both movement of electrons and holes

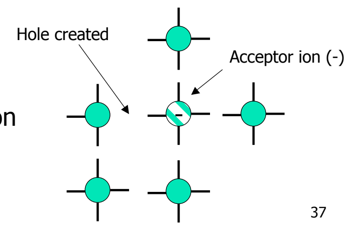
n-type silicon

- Add donor impurities (e.g. Phosphorus, arsenic, indium) with 5 electrons in the valance band
- As only four electrons can bond with neighbouring silicon atoms one free electron is left
- Increases concentration of free electrons
- Reduces concentration of holes (due to increased chance of recombination)
- Resistance reduced



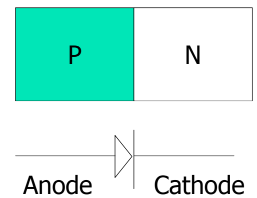
p-type silicon

- p-type silicon is created by adding acceptor impurities which have three valance electrons (e.g. boron)
- This leaves an unbound valance electron in an adjacent silicon atom creating a hole
- Increases concentration of holes
- Reduces concentration of free electrons
- P-type silicon has lower resistance than pure silicon



Diodes

- If a piece of n-type silicon and p-type silicon are joined directly together a diode (di - electrode) device is created

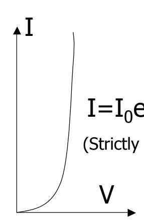


Macro-behaviour

- A diode is a device that allows current flow easily in one direction easily and allows hardly any current flow in the opposite direction

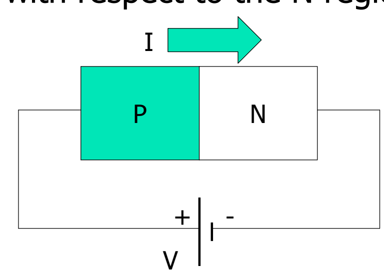
Forward bias

- Current flows easily if the P region is positive with respect to the N region



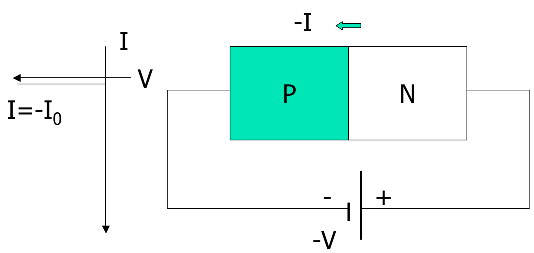
$I=I_0e^{bV}$

(Strictly $I=I_0(e^{bV}-1)$)



Reverse bias

- Current hardly flows if the P region is negative with respect to the N region



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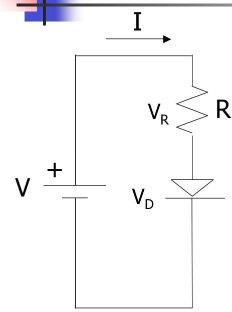
Diode and resistor circuit



Currents and voltages determined by:
(work backwards to find V_D)
1. V_D related to I by diode equation
2. Current in resistor and diode equal
3. V_R = IR
4. voltage across diode and voltage resistor add up to voltage source V

Short cut rule of thumb, V_D is approx 0.6-0.7 volts and $V_R \approx V - 0.6$
For LEDs V_D is about 1.8 - 4.0 V, depending on color

Forward biased diode

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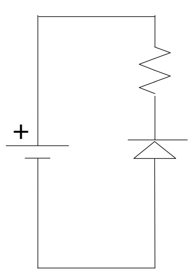
Diode and resistor circuit



Assume no reverse-bias current flows (ideal case)

Therefore no voltage occurs across the resistor

Therefore the full supply voltage appears across the diode

Reverse biased diode

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LEDs

- Light emitting diode
- When an electron moves down from the conduction band to the valence band it loses energy
- In silicon and germanium the energy-momentum relationships mean that this energy is lost heat
- In gallium arsenide it produces a photon

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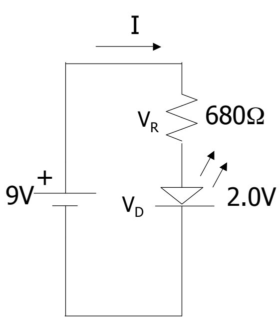
LEDs

- The light intensity is proportional to current
- Pure gallium arsenide produces infrared light
- GaAsP produces red or yellow light
- GaP produces red or green

Circuit design using LEDs

- LEDs behave just like normal diodes except that the forward bias voltages are greater (typically 1.8 - 4.0 V)
- A typical forward bias current of 10-20 mA is used.

Example

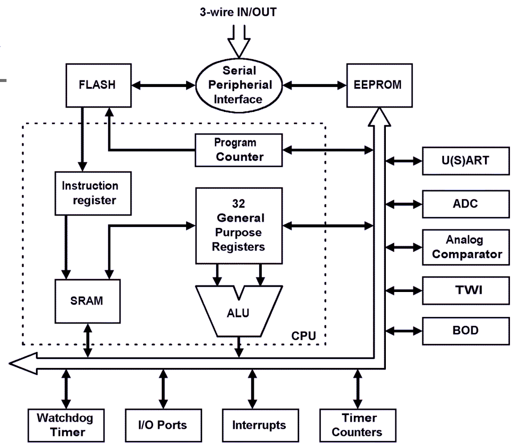


$$I = \frac{9 - 2.0}{680} = 10.29 \text{ mA}$$

AVR I/O

Atmel AVR Microcontroller

AVR



ATmega16(L)

- 40/44 pin packages
- 16 KBytes ISP Flash, Self Programmable
- 512 Bytes ISP EEPROM
- 1 KBytes SRAM
- Full Duplex UART
- SPI – Serial Interface
- TWI – Serial Interface
- 8- and 16-bits Timer/Counters with PWM
- 2 External Interrupts
- 10-bit ADC with 8 Multiplexed Inputs
- RTC with Separate 32 kHz Oscillator
- Analog Comparator
- JTAG Interface with On-Chip Debugger

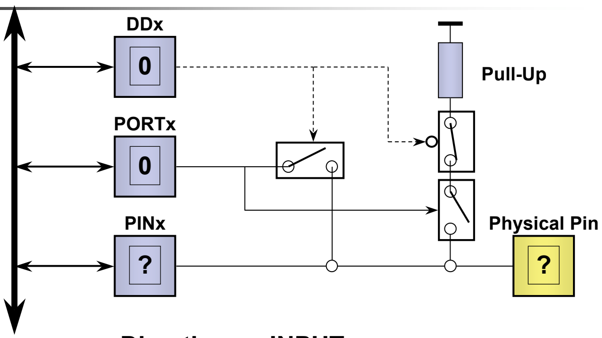
I/O Ports General Features

- Push-Pull Drivers
- High Current Drive (sinks up to 40 mA)
- Pin-wise Controlled Pull-Up Resistors
- Pin-wise Controlled Data Direction
- Fully Synchronized Inputs
- Three Control/Status Bits per Bit/Pin
- Real Read-Modify-Write

3 Control/Status Bits per Pin

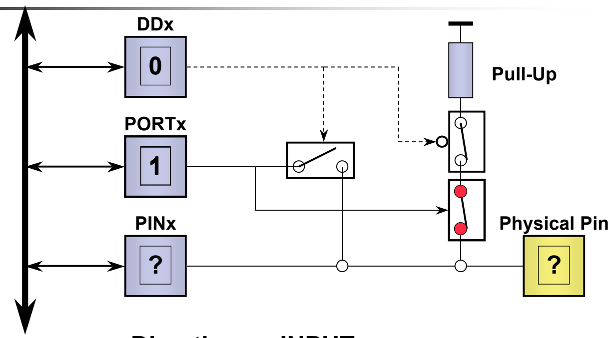
- DDx Data Direction Control Bit
- PORTx Output Data or Pull-Up Control Bit
- PINx Pin Level Bit

Default Configuration



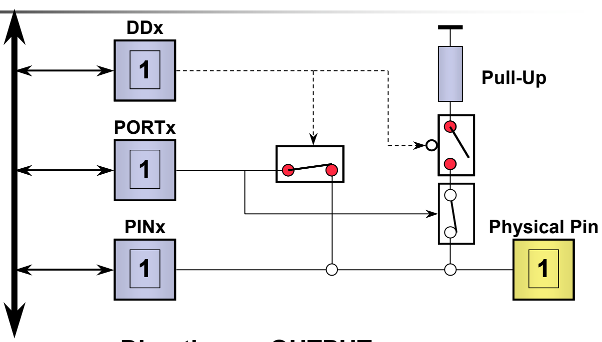
Direction: INPUT
Pull-Up: OFF

Switch On Pull-Up



Direction: INPUT
Pull-Up: ON

Port is Output



Direction: OUTPUT
Pull-Up: OFF

I/O Port Registers

Port A Data Register – PORTA

Bit	7	6	5	4	3	2	1	0	
	PORTA7	PORTA6	PORTA5	PORTA4	PORTA3	PORTA2	PORTA1	PORTA0	PORTA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port A Data Direction Register – DDRA

Bit	7	6	5	4	3	2	1	0	
	DDA7	DDA6	DDA5	DDA4	DDA3	DDA2	DDA1	DDA0	DDRA
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Port A Input Pins Address – PINA

Bit	7	6	5	4	3	2	1	0	
	PINA7	PINA6	PINA5	PINA4	PINA3	PINA2	PINA1	PINA0	PINA
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Sample Code from Lab 1

```
.include "C:\Program Files\Atmel\AVR
  Tools\AvrAssembler\Appnotes\m16def.inc"
.cseg
ldi r16, 0xff
out DDRB, r16
ldi r16, 0x00
out PORTB, r16
loop:
jmp loop
```