Charge

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

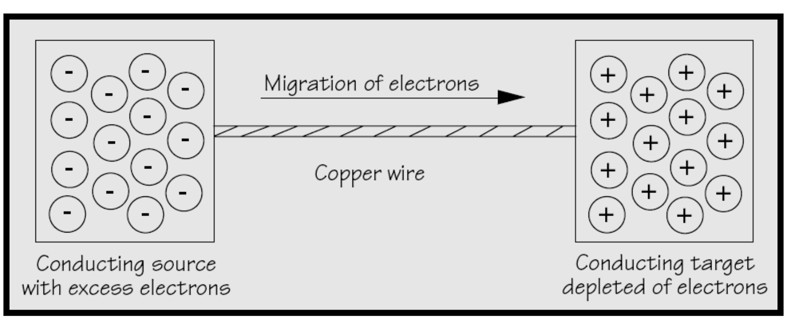
The other says "Are you sure?"

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

1

Basic Concepts of Electricity

- Voltage
- Current
- Resistance



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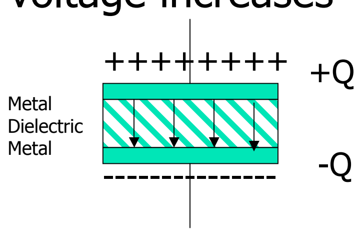
Electric Fields

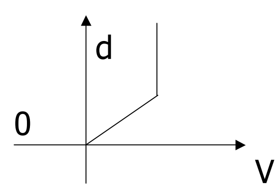
- An electric field applies a force to a charge
  - Force on positive charge is in direction of electric field, negative is opposite
- Charges move if they are mobile
- An electric field is produced by charges (positive and negative charges)
- Electric fields can be produced by time varying magnetic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

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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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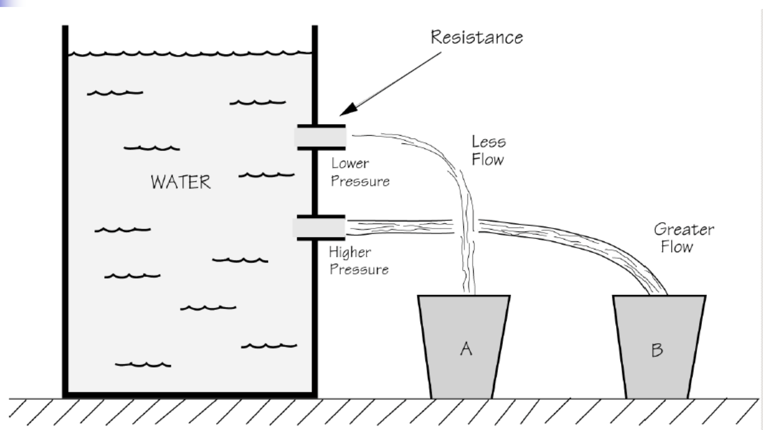
Voltage, Current, and Resistance



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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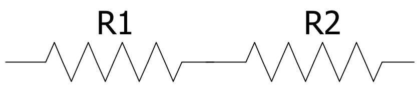
Resistor Combination

Series resistance



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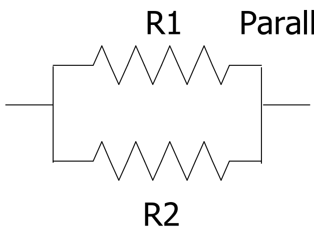
Parallel resistance



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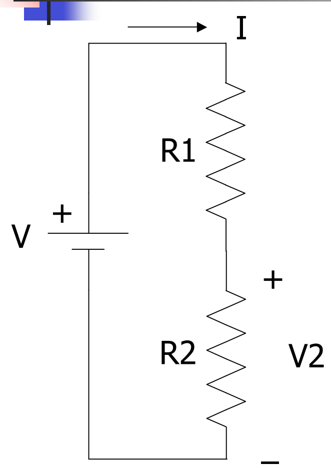
$$R = \frac{R1\ R2}{R1+R2} = R1||R2$$

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

Kirchoff's Voltage Law

- Kirchoff's voltage law (KVL)
  - The sum of voltage differences around any loop in a circuit equals 0
  - Equivalently, the voltage between two points is the same no matter what path is traversed

Voltage Divider



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

Solution:

Goal: Find V2 given V

- Find V2 in terms of I
- Current through R2 in terms of I
- Voltage across R1
- Find voltage across R1 and R2 using two different methods

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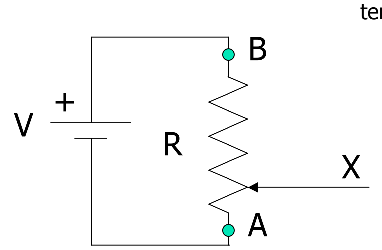
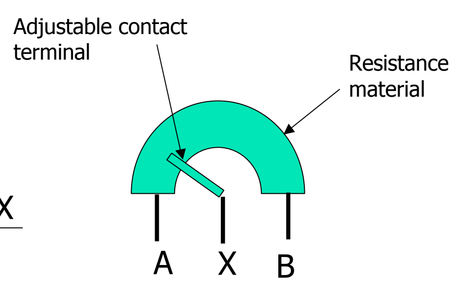
Potentiometer (Variable Resistor)





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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Input Transducers

- These are devices that produce electric signals in accordance with changes in some physical effect e.g. convert temperature, light level to a voltage level or resistance
- e.g. microphones, strain gauge, photo-detectors, ion-selective membranes, thermistors
- Sometimes the definition of transducer is that of a device that converts non-electrical energy to electrical energy

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Output Transducers

- Devices which convert an electrical quantity into some other physical quantity or effect e.g. relay, loudspeaker, solenoid

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Light Dependent Resistors (LDRs)

- Devices whose resistance changes (usually decreases) with light striking it
- (also called photocells, photoconductors)
- Light striking a semiconducting material can provide sufficient energy to cause electrons to break away from atoms.
- Free electrons and holes can be created which causes resistance to be reduced

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LDRs

- Typical materials used are Cadmium Sulphide (CdS), Cadmium Selenide (CdSe), Lead Sulphide
- With no illumination, resistance can be greater than 1 MΩ (dark resistance).
- Resistance varies inversely proportional to light intensity.
- Reduces down to 10-100s ohms
- 100ms/10ms response time

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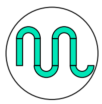
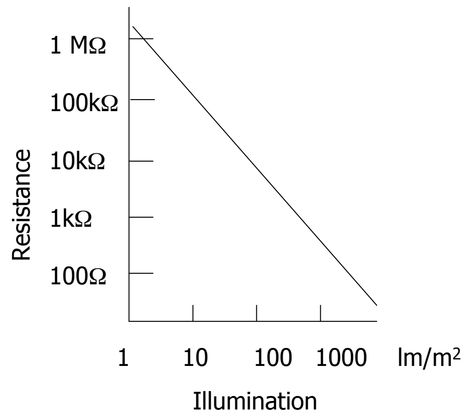
LDRs



CdS LDR
Top view



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LDRs

- LDRs have a low energy gap
- Operate over a wide wavelengths (some, into infrared)
- Indium antimonide is good for IR. When cooled is very sensitive, used for thermal scanning of earth's surface

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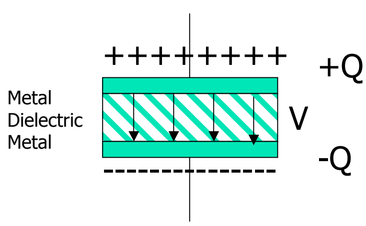
Capacitors

- 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

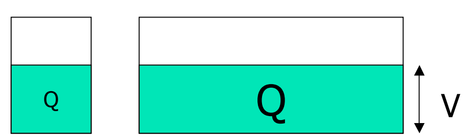
Capacitors



$C = Q/V$

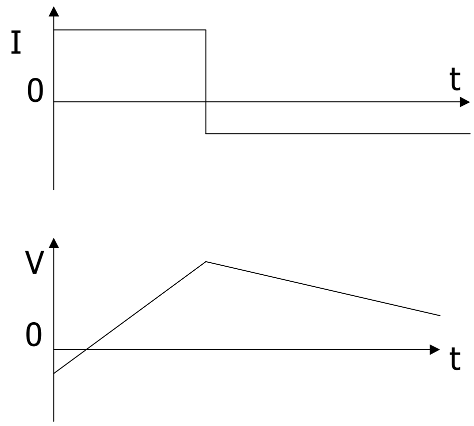
$(Q = CV)$

Bucket analogy



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

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

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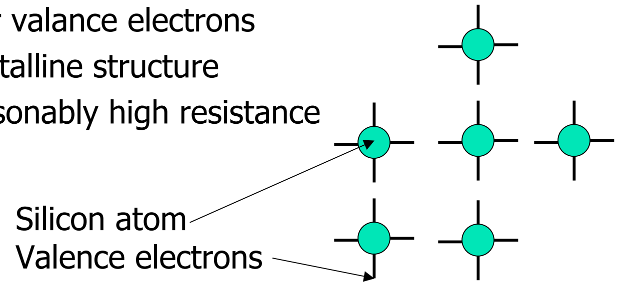
Semiconductors

- 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



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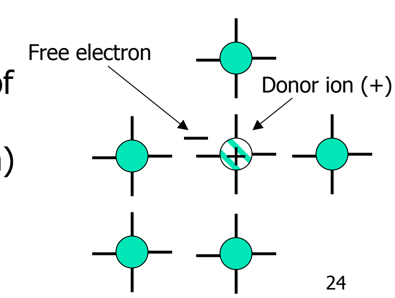
Electrons and holes

- 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

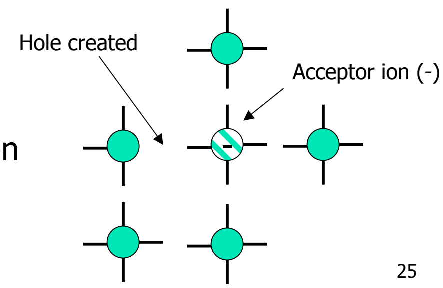
n-type silicon

- 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



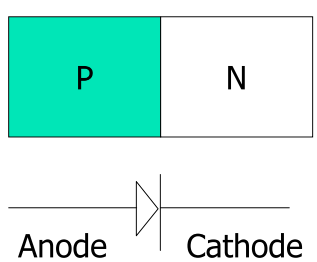
p-type silicon

- 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

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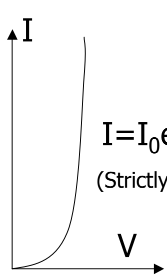
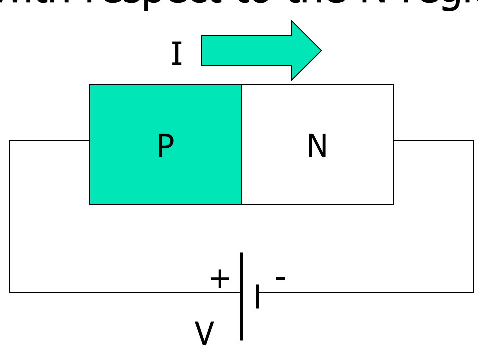
Forward bias

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



$I=I_0e^{bV}$

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



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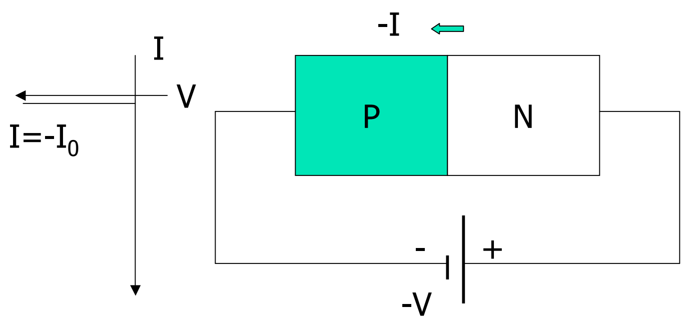
Reverse bias

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



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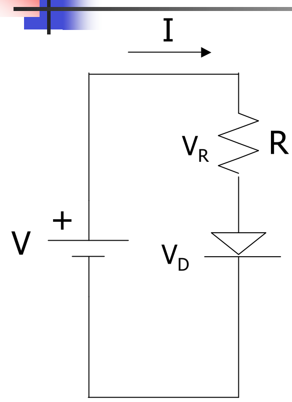
Diode and resistor circuit



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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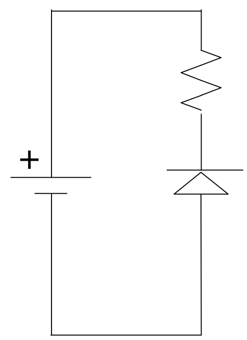
Diode and resistor circuit



Reverse biased diode

Assume no reverse-bias current flows (ideal case)

Therefore no voltage occurs across the resistor

Therefore the full supply voltage appears across the 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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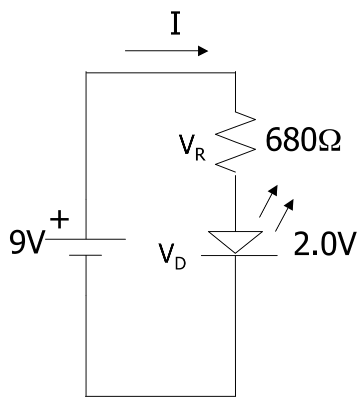
LEDs

- 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



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

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Introduction to AVR

Atmel AVR Microcontroller

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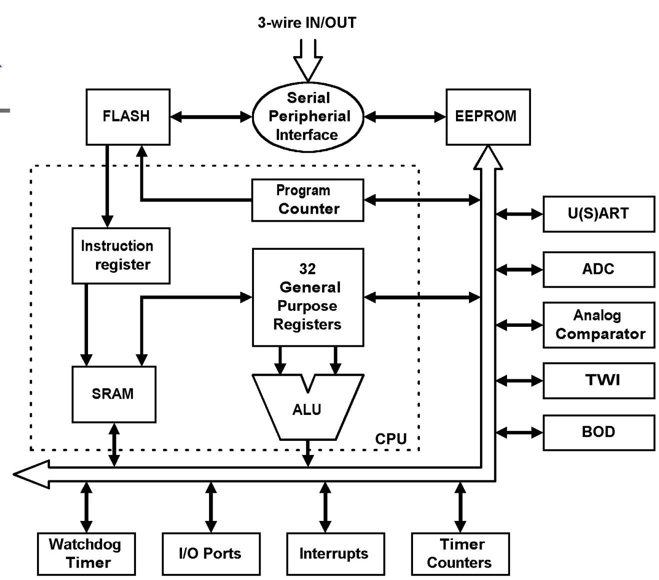
AVR Key Features

- High Performance 8-Bit MCU
- RISC Architecture
  - 32 Registers
  - 2-Address Instructions
  - Single Cycle Execution
- Low Power
- Large linear address spaces
- Efficient C Language Code Density
- On-chip in-system programmable memories

RISC Performance with CISC Code Density

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

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Typical Applications, ATmega16(L)

- Smart Battery
- Advanced Battery Charger
- Power Meter
- Temperature Logger
- Voltage Logger
- Tension Control
- Touch Screen Sensor
- Metering Applications
- UPS
- 3 Phase Motor Controller
- Industrial Control
- Power Management

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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

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3 Control/Status Bits per Pin

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

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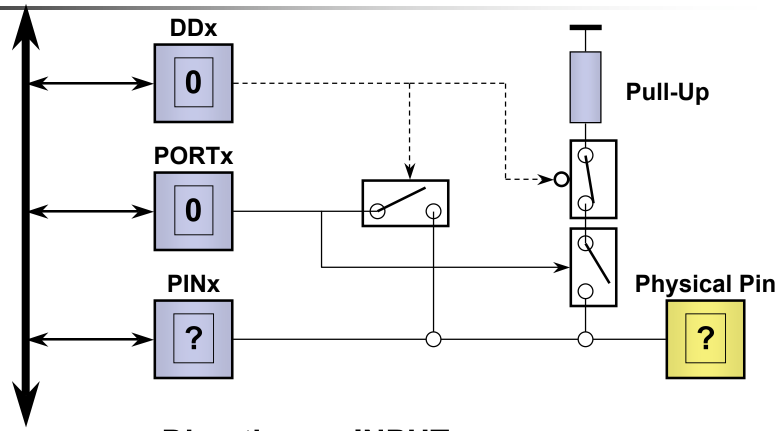
Default Configuration



Direction: INPUT
Pull-Up: OFF

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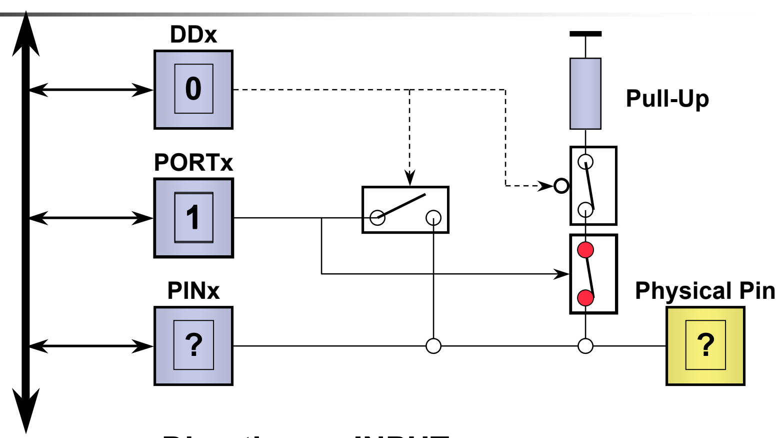
Switch On Pull-Up



Direction: INPUT
Pull-Up: ON

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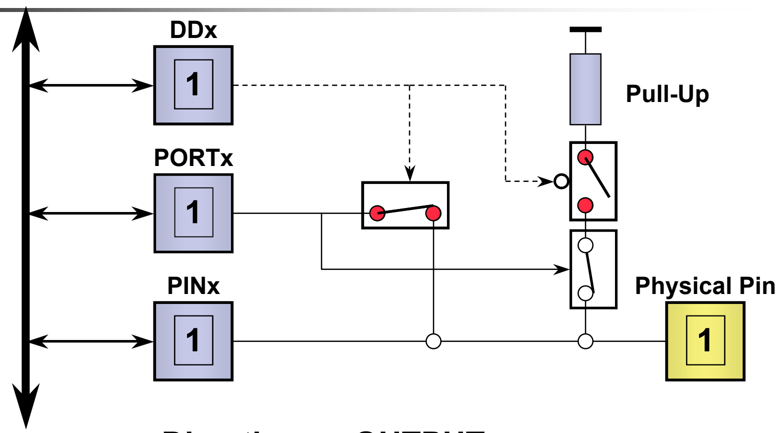
Port is Output



Direction: OUTPUT
Pull-Up: OFF

General Timer/Counter Features

- Various Clock Prescaling Options
- Can Run at Undivided XTAL Frequency (High Resolution)
- Can be Set to Any Value at Any Time
- Can be Clocked Externally by Signals with Transition Periods down to XTAL/2
- Can be Clocked Externally on both Rising and Falling Edge
- The features vary from device to device, see datasheets for details

16 Bit Timer/Counter

- Prescaler
- Overflow Interrupt
- Output Compare Function with Interrupt
- Input Capture with Interrupt and Noise Cancler
- PWM

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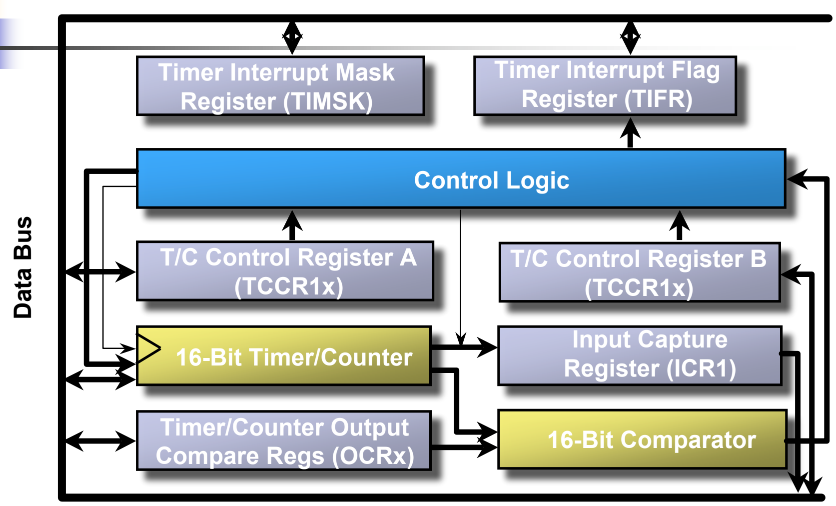
16 Bit T/C Block Diagram



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Output Compare Features

- Compare match can control an external pin (Rise, Fall or Toggle) even if the Interrupt is disabled.
- As an option, the timer can be automatically cleared when a compare match occurs.

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PWM (Pulse Width Modulator) Features

- Selectable 8, 9 or 10-Bit Resolution.
- Frequency @ 10 MHz (8-bit): 19 KHz
- Centered Pulses
- Glitch-Free Pulse Width Change
- Selectable Polarity

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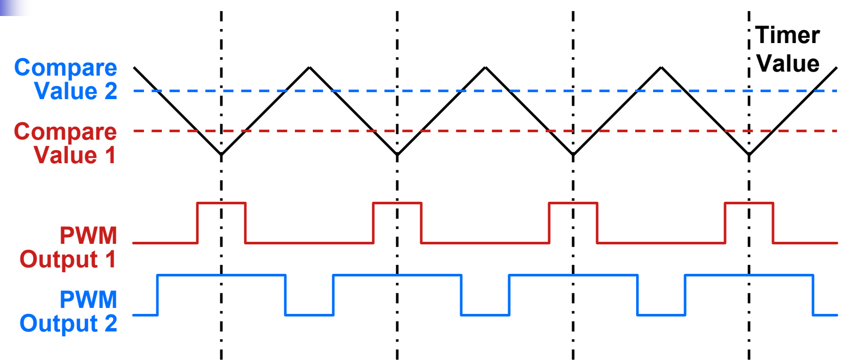
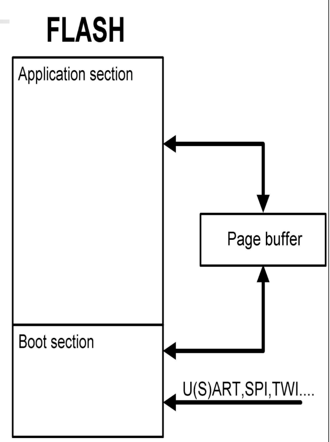
PWM Operation



Self Programming

- Dual memory areas
  - Application section
  - Boot section (optional)
- Read data from
  - Any communication interface
  - Application section
  - Boot section
- Write it to a page buffer
- Transfer the buffer to the Flash page in Application or Boot section



AVR websites and mail

- ATMEL website www.atmel.com
  - Datasheets
  - Application Notes
  - FAQ
- Unofficial AVR websites

  www.avrfreaks.net

  www.avr-forum.com

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