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
- $E = \frac{V}{d}$
- As you move closer to a positive charge, the voltage increases

![Diagram of a capacitor with a metal dielectric and two plates, one positively charged and the other negatively charged.](image)

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
  \[ R = \frac{V}{I} \]
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

Resistor Combination

Series resistance

\[
\begin{align*}
R_1 & \quad R_2 \\
\hline
R_1 & \quad R_2 \\
\hline
\end{align*}
\]

Parallel resistance

\[
R = \frac{R_1 R_2}{R_1 + R_2} = R_1 || R_2
\]

\[
1/R = 1/R_1 + 1/R_2
\]
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

\[
V_2 = \frac{V \times R_1}{R_1 + R_2}
\]

Solution:
Goal: Find \( V_2 \) given \( V \)
- Find \( V_2 \) in terms of \( I \)
- Current through \( R_2 \) in terms of \( I \)
- Voltage across \( R_1 \)
- Find voltage across \( R_1 \) and \( R_2 \) using two different methods
Potentiometer (Variable Resistor)

\[ V_X = V \times \frac{\text{Distance AX}}{\text{Distance AB}} \]

(linear potentiometer)

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

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
Output Transducers

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

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
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
- 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 = \( C = \frac{Q}{V} \)
- 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

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.

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

![Silicon atom and valence electrons diagram]

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

![Diode Diagram]

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

\[ I = I_0 e^{bV} \]  
(Strictly \( I = I_0 (e^{bV} - 1) \))

**Reverse bias**

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

\[ I = -I_0 \]
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 $V_R = V - 0.6$
For LEDs $V_D$ is about 1.8 - 4.0 $V$, depending on colour

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
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 as heat
- In gallium arsenide it produces a photon

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

\[
\begin{align*}
I &= 9 - \frac{2.0}{680} \\
&= 10.29 \text{ mA}
\end{align*}
\]
Introduction to AVR

Atmel AVR Microcontroller

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
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

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
General T/C 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 Canceler
- PWM
16 Bit T/C Block Diagram

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.
PWM Features

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

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
MegaLoad

AVR websites and mail

- ATMELE website www.atmel.com
  - Datasheets
  - Application Notes
  - FAQ
- Unofficial AVR websites
  www.avrfreaks.net
  www.avr-forum.com