Basic Electronics

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- Basic JITPCB

```scala
val sob = 50b()
val iop0 = IOP(sob)
val iop1 = IOP(sob)
add(iop0, bool_in('SW0, Switch))
add(iop0, bool_out('LED0, PullUpLED))
add(iop1, bool_in('SW1, Switch))
add(iop1, bool_out('LED1, PullUpLED))

void main (void) {
    init();
    while(true) {
        pull();
        LED0.value = SW1.value;
        LED1.value = SW0.value;
        push();
        step();
    }
}
```
Basic Electronics
- Loop of conductive material
- Graph of electrical *components*
- Edges are *wires*
- Vertices are components
- Points on edges between on components are called *nodes*
Loop from power source to itself
Beware as dangerous in heat and fire
Use circuit breaker to prevent damage
Open Circuit

- Break in loop
- No circuit at all
- Broken circuit
- Can detect with multimeter
Electrons moving between atoms
Atoms have equal number of protons and electrons
Some materials have more and freer electrons
Mobility of electrons is related to conductivity
Outer electrons are valence electrons and are easy to free
Like charge repels and different charge attracts
Amount of force depends on how far they are from each other
Basis for electric current
Also causes lightning and sparks
Network of components that transform electricity
- Basics are electrons moving through conductive material
- Information processing and power delivery
- **Voltage** is difference in charge between two points
- **Current** is rate at which current is flowing at a point
- **Resistance** is degree to which a material slows down current
Current

- Current is flow of electric charge through material
- Usually carried by negatively charged particles called electrons
- Like water flowing down pipes w/ water as charge + flow as current
- Rate at which electric charge flows through a point in circuit
- Needs a closed loop to flow
- Flow from high potential energy to low
- Represented by $I$ or $i$ in equations
- Measured in Amperes or amps for short
- 1 Amp = 1 Coulomb / sec passing point in circuit, where
- 1 Coulomb = $6.241 \times 10^{18}$ electrons
Current Facts

- Fork and joins in circuits divide or sum current flow like pipes
- Unlike voltage don’t need to consume only what it needs
- Too little or much current can cause circuit to fail
- Good to use power supply that provides more current than you need

\[ I_1 + I_2 + I_3 = I_4 + I_5 \]
Voltage

- Difference in electronic charge between two points
- Makes current flow
- Like water pressure in pipes
- Need two points to define voltage
  - No absolute voltages only relative ones
  - Difference in electric potential energy between two points
  - Reference is called “ground” and is set to zero volts
- Represented by V in equations
- Measured in terms of energy per unit charge called Volts
Voltage Facts

- All available voltage will be used in a circuit
- Can increase voltage by putting multiple power sources in series
- 5V is common for embedded electronics
- Operating voltage is desired voltage value circuit wants
- Often circuits can run with higher voltage up to some limit
- Components can be damaged with too little or too much voltage
- Voltage regulator takes range of voltage inputs and produces steady voltage output
- Circuits can have multiple voltage inputs
Ability to resist the flow of electrical charge
Materials with high resistance are often used as insulators
Like size of pipes in water pipes analogy
Can regulate flow by increasing or decreasing resistance
Proportion factor R, is known as the resistance
Resistance has units of ohms (Ω)
If voltage across the element is held constant, then increasing the resistance will limit the current going through the element
Ohm’s Law

- Describes relationship between voltage, current and resistance
- Says current is directly proportion to voltage

\[ V = IR \]
Calculate current through 50 ohm resistor using 5V

\[ I = \frac{V}{R} = \frac{5.0\, \text{v}}{50\, \Omega} = 0.1\, \text{amps} = 100\, \text{mA} \]
I-V Curves

- Common way to characterize electrical elements is plotting current by voltage
- Can develop equations that relate current and voltage
- Simplest I-V curve is for a resistor: $V = IR$ (Ohm’s law)
- Inverse of the slope, $R$, is known as the resistance
Kirchhoff Laws

- Basically conservation of energy
- Sum of voltages in circuit loop adds to zero
- Sum of currents going in equal sum of currents going out
Node is point in circuit between components
Components share one node
Components share two nodes
Two resistors in series

Harder for current to flow

\[ R = R_1 + R_2 \]
Equivalent Parallel Circuit

- Two paths but same voltage
- Draws more current

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

\[ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \]
Voltage Divider Circuit

- Two resistors in series with output in middle
- Used as potentiometer
- Used to produce lower voltage (only low power though)

\[ V_{in} = I \times (R_1 + R_2) \]
\[ V_{out} = I \times (R_2) \]
\[ V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \]
Components either consume or produce electric energy

Energy in Joules

Voltage is measure of energy that unit charge will dissipate when flowing through device

Current is number of coulombs that flow through device in 1 sec

Power is rate at which energy is dissipated

Power \((P)\) = joules per second = watts \((W)\) = volts \(*\) amps

\[ P = VI \]

\[ P = \frac{V^2}{R} \]

\[ P = I^2R \]
Some resistors are built to handle larger power drops

Can calculate power drop based on equations

Calculate current through resistor: \( I = \frac{V}{R} = \frac{5\,\text{V}}{100\,\Omega} = 0.05\,\text{A} \)

Calculate power: \( P = IV = 0.05\,\text{A} \times 5\,\text{V} = 0.25\,\text{W} \)

Also \( P = \frac{V^2}{R} = I^2R \)
- Add voltages in series same current
- Add currents in parallel same voltage
Calculating Power Needs

- Calculate or measure current draw in circuit
- Look up battery capacity in Amp Hours
- Divide capacity by current draw
- Be conservative with capacity
Components

- resistor
- potentiometer
- capacitor
- switch
- diode
- led
- transistor
Resistors

- Slow down current – like rocks in river
- Follow Ohm’s law, $V = IR$
- Variable resistors adjusted by force, temperature and knob called potentiometers
Different Resistance Values

- Fixed set of values and their powers of 10
- Values 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, and 82
- Color on them codes their value and their accuracy
- Accuracy as deviation like +-1, +-5, +-10
- Can create exact values by adding resistors in series
- Resistors in parallel produce $\frac{r_1 \times r_2}{r_1 + r_2}$

Resistor Color Code Guide

<table>
<thead>
<tr>
<th>COLOR</th>
<th>1st BAND</th>
<th>2nd BAND</th>
<th>3rd BAND</th>
<th>MULTIPLIER</th>
<th>TOLERANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1Ω</td>
<td>± 1%</td>
</tr>
<tr>
<td>Brown</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>10Ω</td>
<td>± 1%</td>
</tr>
<tr>
<td>Red</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>100Ω</td>
<td>± 2%</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1kΩ</td>
<td>± 5%</td>
</tr>
<tr>
<td>Yellow</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>10kΩ</td>
<td>± 10%</td>
</tr>
<tr>
<td>Green</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>100kΩ</td>
<td>± 0.5%</td>
</tr>
<tr>
<td>Blue</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>1MΩ</td>
<td>± 0.25%</td>
</tr>
<tr>
<td>Violet</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>10MΩ</td>
<td>± 0.1%</td>
</tr>
<tr>
<td>Grey</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td></td>
<td>± 0.05%</td>
</tr>
<tr>
<td>White</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.1Ω</td>
<td>± 5%</td>
</tr>
<tr>
<td>Silver</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.01Ω</td>
<td>± 10%</td>
</tr>
</tbody>
</table>

0.1%, 0.25%, 0.5%, 1%

5-Band-Code

source: www.elexp.com/t_resist.htm
Pull-up Resistor

- Pulls value up to 5V in default state
- When button depressed input goes to ground
- Value determines how much current flows when pressed
- R2 determines R1 so that Vin is high enough (10x)

\[
V_{out} = V_{in} \frac{R_2}{R_1 + R_2} = 5 \times \frac{10R}{R + 10R} = 5 \times \frac{10}{1 + 10} \approx 5 \times 0.9
\]
Capacitors

- Two metal plates separated by space
- Essentially they keep voltage constant
- Like a small rechargeable battery
- Measured in farads, F, most common ones in micro farad range
- Non-polarized ones which are weaker and usually ceramic
- Polarized ones are stronger and you need to hook up correctly or they might explode
- Capacitance values add in parallel $c_1 + c_2$
- Capacitance values inversely add in series $\frac{c_1 \cdot c_2}{c_1 + c_2}$

Eric Schrader

Jwratner1
- Filter out voltage changes for remove noise
- Decoupling capacitors near ICs
- Debouncing buttons
- Energy storage
Beware as capacitors hold onto charge and can be dangerous when high voltage.
Diodes

- Make sure that current goes only one way
- Avoid reverse voltage or voltage spikes
- The current follows the arrows direction
- LEDs are actually diodes (also laser diodes)
- Have non zero voltage drop
- Breakdown voltage is reverse voltage when diode fails
Diodes IV Curve
Diode Uses

- Used to prevent voltage spikes and reverse voltages
- Example: Protect against batteries inserted incorrectly
- Example: Prevent voltage spikes from solenoids + motors
- Can rectify signal
- Example: change AC to DC
- Have voltage drop
- Have current operating range
- Pins can source 20mA
- Can use multiple pins to source more current
Transistors

- Electrical switches controlled by a voltage applied to third terminal
- Base is switch control, collector is in, and emitter is out
- Can switch moderate power components with low voltage signal
- Threshold voltage controls switch
- NMOS turns on when above threshold
- PMOS turns on when below threshold
Transistor Uses

- Using transistor for switching higher voltage higher current
- First example is a higher power LED
- Second example is a high voltage motor
Physical Switches

- Either Normally Closed (NC) or Normally Open (NO)
- Pole is a set of contacts or independent circuits
- Throw determines number of positions it can be in
- SPST is single pole single throw
- DPST is double pole single throw
Example Switches

<table>
<thead>
<tr>
<th>Switch Type</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPST</td>
<td>![SPST Diagram]</td>
</tr>
<tr>
<td>SPDT</td>
<td>![SPDT Diagram]</td>
</tr>
<tr>
<td>DPST</td>
<td>![DPST Diagram]</td>
</tr>
<tr>
<td>DPDT</td>
<td>![DPDT Diagram]</td>
</tr>
</tbody>
</table>
Multimeters can measure resistance, voltage, current and continuity

Continuity determines if two points are connected – mode with beep

Resistance can be measured in unpowered circuit using $\Omega$ setting

Voltage can be measured in powered circuit by putting probes in parallel with circuit

Current can be measured in series

Make sure not to exceed current limits of multimeter

Debug using continuity and voltage checks to compare against circuit diagram
## Multimeter Usage

<table>
<thead>
<tr>
<th>mode</th>
<th>function</th>
</tr>
</thead>
<tbody>
<tr>
<td>dc volts</td>
<td>measure voltage between probes</td>
</tr>
<tr>
<td>dc current</td>
<td>measure current flowing through probes</td>
</tr>
<tr>
<td>resistance</td>
<td>measures resistance between probes</td>
</tr>
<tr>
<td>continuity</td>
<td>checks if probed points are electrically connected</td>
</tr>
<tr>
<td>diodes</td>
<td>measures voltage drop across a diode – continuity mode</td>
</tr>
</tbody>
</table>
Datasheet is like user manual for component

- Find through vendor webpage or googling part number + datasheet
- Reading pinout to find out what pins do and where they are
- Top left is pin 1
- Electrical parameters say max supply voltage (Vss is ground) and input current, temperature
- Exceeding limits will break component

### Electrical Characteristics (Tamb = 25 °C, unless otherwise specified)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITION</th>
<th>SYMBOL</th>
<th>MIN.</th>
<th>TYP.</th>
<th>MAX.</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward voltage</td>
<td>I_P = 10 mA</td>
<td>V_F</td>
<td>1000</td>
<td>mV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse current</td>
<td>V_R = 20 V</td>
<td>I_R</td>
<td>25</td>
<td>nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V_R = 20 V, T_J = 150 °C</td>
<td>I_R</td>
<td>50</td>
<td>µA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>V_R = 75 V</td>
<td>I_R</td>
<td>5</td>
<td>µA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakdown voltage</td>
<td>I_Z = 100 µA, V_T = 0.01, t_D = 0.8 ms</td>
<td>V_ZBR</td>
<td>100</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diode capacitance</td>
<td>V_D = 0 V, f = 1 MHz, V_D = 50 mV</td>
<td>C_D</td>
<td>4</td>
<td>pF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectification efficiency</td>
<td>V_D = 2 V, f = 100 MHz</td>
<td>η_R</td>
<td>45</td>
<td>%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reverse recovery time</td>
<td>I_R = I_Z = 10 mA, I_S = 1 mA</td>
<td>t_R</td>
<td>8</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>I_R = 10 mA, V_R = 8 V, I_S = 0.1 x I_Z, R_L = 100 Ω</td>
<td>t_R</td>
<td>4</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Absolute Maximum Ratings (Tamb = 25 °C, unless otherwise specified)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITION</th>
<th>SYMBOL</th>
<th>VALUE</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetitive peak reverse voltage</td>
<td>V_RPM</td>
<td>100</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Reverse voltage</td>
<td>V_R</td>
<td>75</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Peak forward surge current</td>
<td>I_F = 1 µs</td>
<td>I_FSM</td>
<td>2</td>
<td>A</td>
</tr>
<tr>
<td>Repetitive peak forward current</td>
<td>I_FPM</td>
<td>500</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Forward continuous current</td>
<td>I_F</td>
<td>300</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Average forward current</td>
<td>V_F</td>
<td>I_FAV</td>
<td>150</td>
<td>mA</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>I = 4 mm, T_L = 45 °C</td>
<td>P_Tot</td>
<td>440</td>
<td>mW</td>
</tr>
<tr>
<td></td>
<td>I = 4 mm, T_L ≤ 25 °C</td>
<td>P_Tot</td>
<td>500</td>
<td>mW</td>
</tr>
</tbody>
</table>
Sizing Resistor for LED

- Voltage drop across LED say 1.7V
- Need certain current to drive LED and too much will destroy it
- Want to match voltage drop by taking up remainder by resistor
- Calculate using Ohm’s law:
  \[ R = \frac{V}{I} = \frac{(5V - 1.7V)}{0.2A} = \frac{3.3V}{0.2A} = 16.5\Omega \]

- Pins can drive up to 20mA
- Use transistors for more
Want non-zero range of resistor values for reasonable currents but Potentiometer goes to zero
What circuit handles this?
Current is what kills you not voltage
Current above 15 to 100mA AC is lethal
Still can get burned without getting electrocuted
Shut off things that shocked person before giving first aid
Don’t allow yourself to become connection between a live wire and ground especially through heart
Circuits can be damaged by too much current or voltage
  - electrostatic discharge (ESD) will damage or destroy sensitive circuit components
  - polarized components may explode if reversed
- Milling lab due Thursday
- Soldering lab out Thursday
Communication Protocols

JITPCB Circuit Design
Calsol – basic electronics lab

learn.sparkfun.com