Electronics 101 – v2.0

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Recitation Plan

- Introduction & goal

- Essential Laws

- Simulation

- Microcontrollers

- Input Devices

- Output Devices

- Design cycle overview

- Pseudocode

- Questions

Teaching Objective

- To give you an overview of the electronics design process, from idea to functional circuit/product.

- You will not learn:

  - Exactly how to do your assignment. Check the resources linked in the last slide, Neil's page, etc.

  - How to use a specific software tool

  - How to design a good electronics product

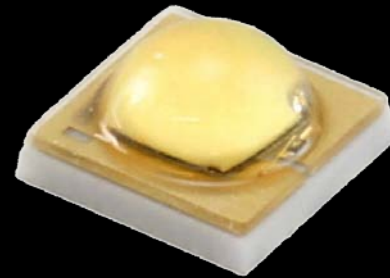 *Focus your attention on the big picture, not on technical details!*
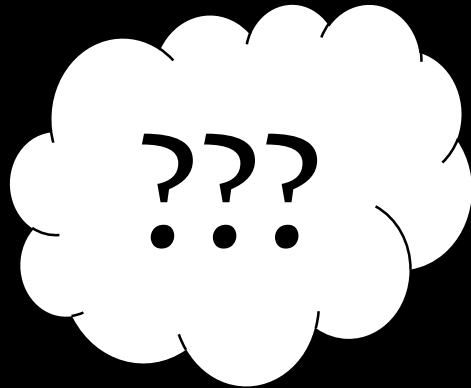
The Project

- Together we will design an LED "flashlight"*

- Input devices:
  - Pushbutton to turn the flashlight ON or OFF
  - Potentiometer to adjust the brightness

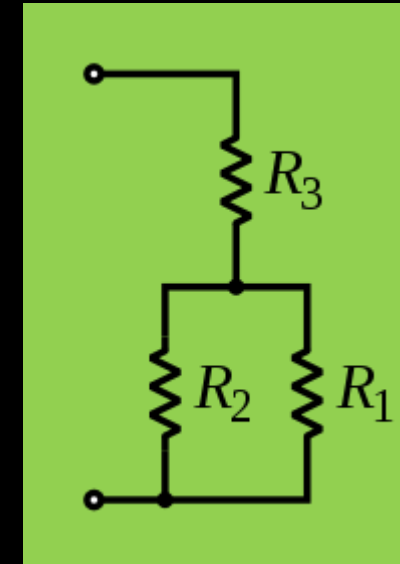- Output devices:
  - LED

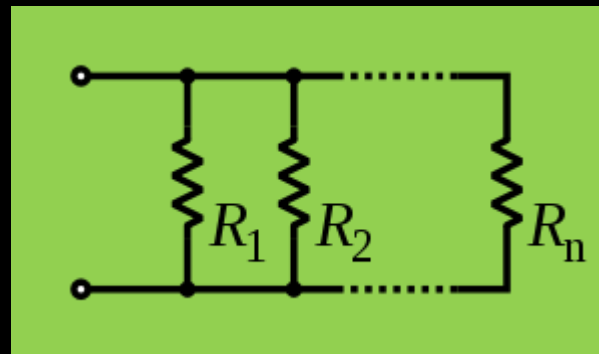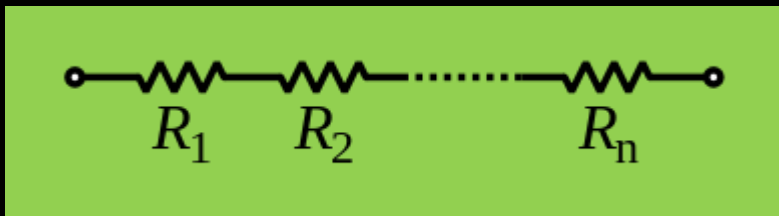- Microcontroller, voltage regulator, …

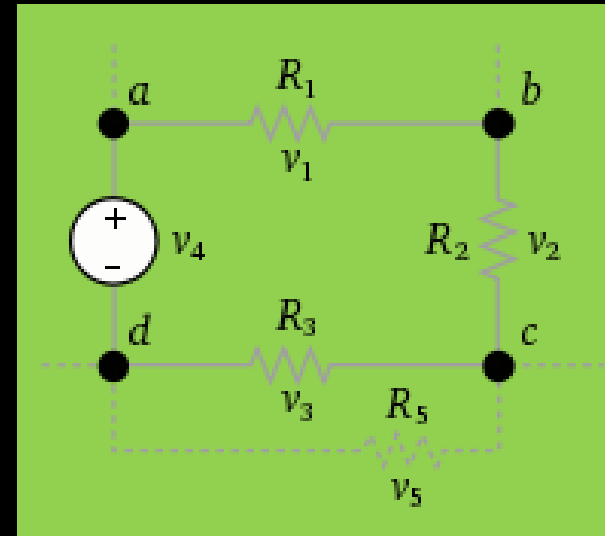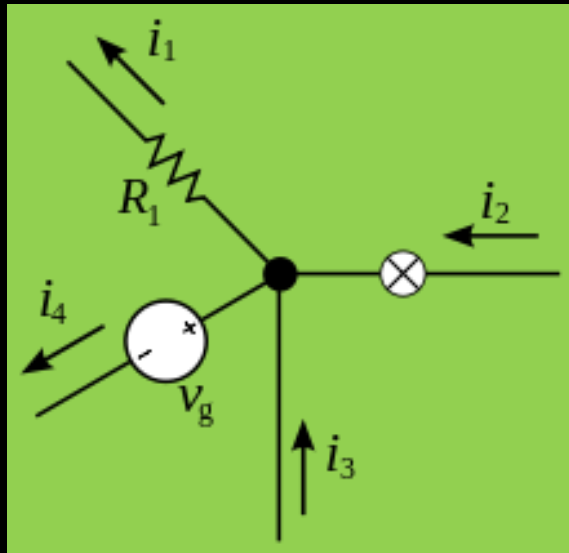*It won't be very bright…

Understanding the requirements

Ohm's Law

- V = R*I

- Series: $R_{EQ} = R_1 + R_2 + \ldots + R_n$

- Parallel: $1/R_{EQ} = 1/R_1 + 1/R_2 + \ldots + 1/R_n$

Kirchoff's Laws

- Kirchhoff's current law (KCL): The sum of currents in a network of conductors meeting at a point is zero.

- Kirchhoff's voltage law (KVL): The voltage drop around a closed loop is 0.

Let's SPICE it up

- **SPICE** (*Simulation Program with Integrated Circuit Emphasis*) was invented in 1973 and it's still in use, impressive!

- You can use SPICE to confirm your math, your circuit understanding, to test for extreme cases, etc.

- My favorite free options are LTSpice and Tina-TI. It's also included in many CAD packages such as Altium.
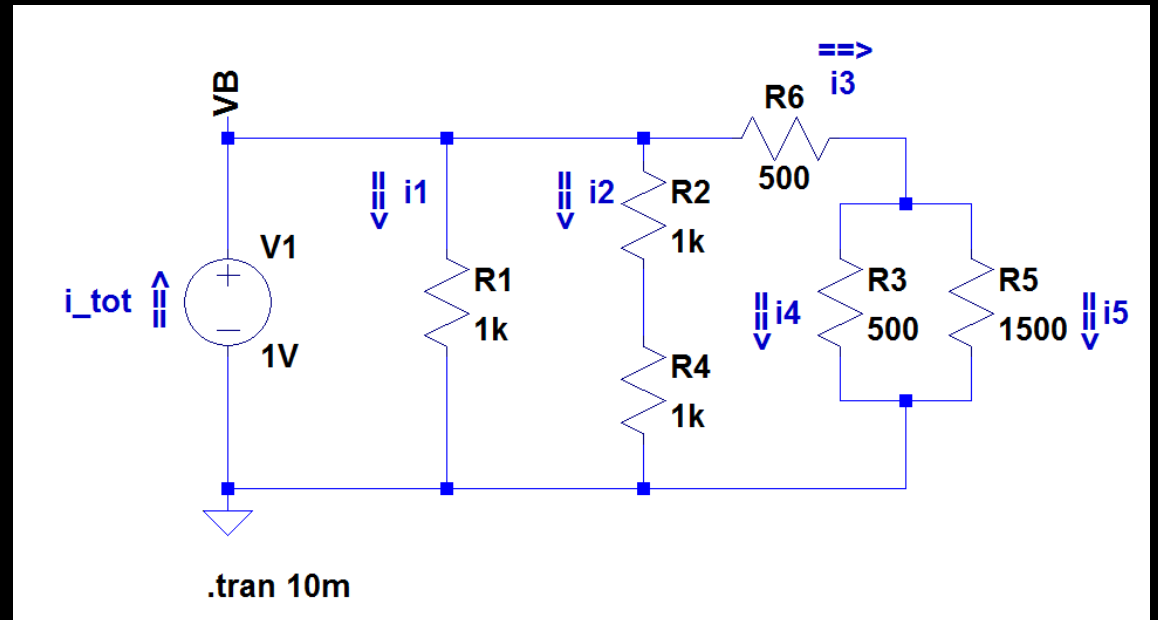
The first attempt
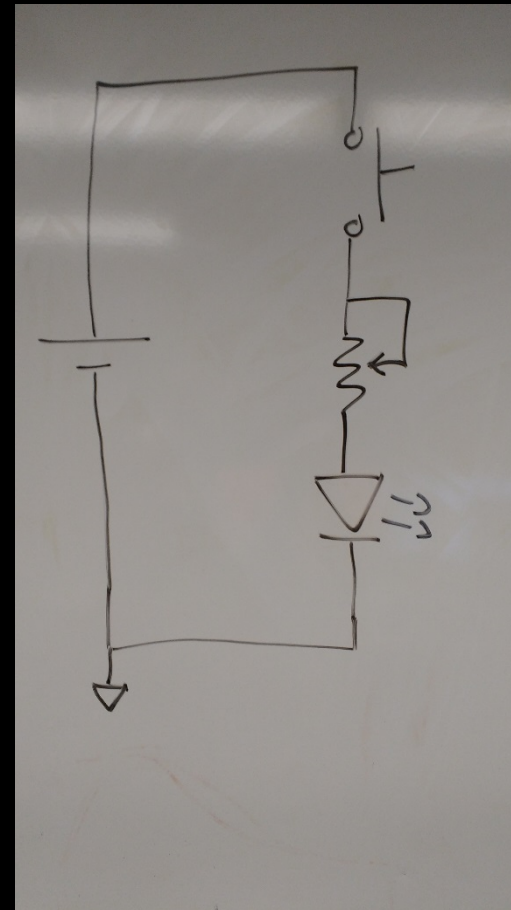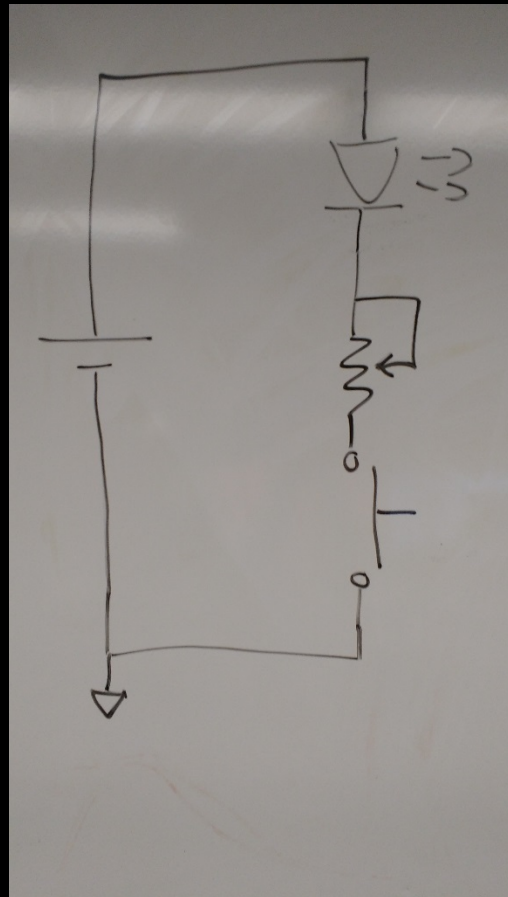
What's wrong with that circuit?

- Bad efficiency. If VB = 5V and VL = 2V we need 3V across the potentiometer. Only 40% of the energy is going to the LED!

- LED brightness will vary with battery voltage

- No mechanism to prevent over discharging the battery

Let's add a microcontroller!

- Microcontrollers are everywhere!
  - Hundreds of µC in your car
  - All the "smart objects" around you...
  - ... and sometimes inside you.

World's Smallest Microcontroller — MICROCHIP PIC10F
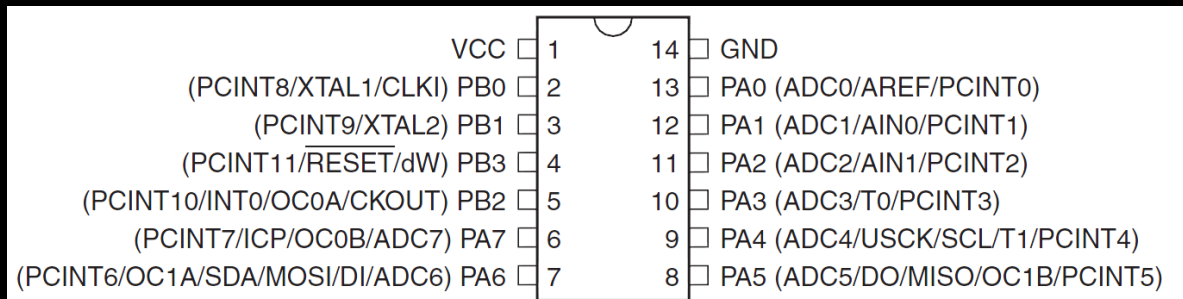
What µC should you use?

- Start with the ATTiny or ATMega chips
  - Simpler parts, simple programming environment
  - More than enough for 90% of the projects in this class

- Smooth transition to a higher power chip? Look at the Xmega

- Are you looking to boost your resume? You should use ARM cores, such as the STM32
  - Setting up the toolchain can take a while
  - Complex chips
  - Unlimited possibilities

- Do you have a project that has a tight analog + digital integration? PSoC

- I want to connect my project to the cloud because it's not cool if it's not tweeting: Embedded computer

ATtiny44: datasheet

- Datasheet: http://www.atmel.com/Images/doc8006.pdf

- Pins (p. 2)
  - If you read further you'll find info such as "Port B is a 4-bit bi-directional I/O port with internal pull-up resistors (selected for each bit)."

- Everything you need to know is there (live overview)

```
                        VCC □ 1   14 □ GND
      (PCINT8/XTAL1/CLKI) PB0 □ 2   13 □ PA0 (ADC0/AREF/PCINT0)
          (PCINT9/XTAL2) PB1 □ 3   12 □ PA1 (ADC1/AIN0/PCINT1)
        (PCINT11/RESET/dW) PB3 □ 4   11 □ PA2 (ADC2/AIN1/PCINT2)
   (PCINT10/INT0/OC0A/CKOUT) PB2 □ 5   10 □ PA3 (ADC3/T0/PCINT3)
      (PCINT7/ICP/OC0B/ADC7) PA7 □ 6    9 □ PA4 (ADC4/USCK/SCL/T1/PCINT4)
(PCINT6/OC1A/SDA/MOSI/DI/ADC6) PA6 □ 7    8 □ PA5 (ADC5/DO/MISO/OC1B/PCINT5)
```

How should we connect all the pieces?

- On your desk you have a battery, a small microcontroller, a power LED, a potentiometer and a pushbutton… how do you link them together?

- There are many rules about how to power circuits, input voltages and currents, output currents, etc. It's impossible to cover everything here, but let's look at some important rules for our project:

  - Powering the µC

  - How to read input devices

  - How to control output devices

- Do not panic yet, we will go over all these aspects in the next slides

Input devices: push-button

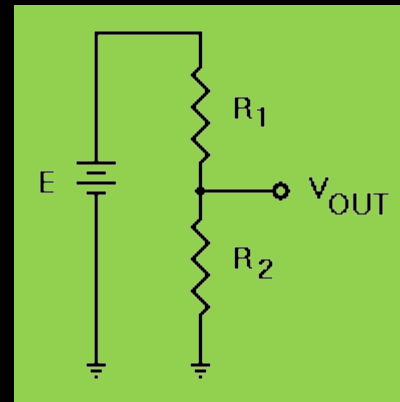- Push-button: pull-up and pull-down resistors. Digital input.
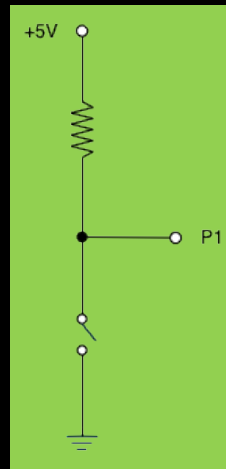
Input devices: potentiometer

- Potentiometer: voltage divider. ADC input.
  - One resistor with a cursor is the same as two variable resistors ($R_{TOT} = R_1 + R_2$)
  - $V_{OUT} = V_{IN}*(R_2/(R_1 + R_2))$
    - Ex.: 5V supply, $R_1 = 2k\Omega$, $R_2 = 8k\Omega$. $V_{OUT} = 5V*(8k\Omega/(8k\Omega+2k\Omega)) = 4.0V$
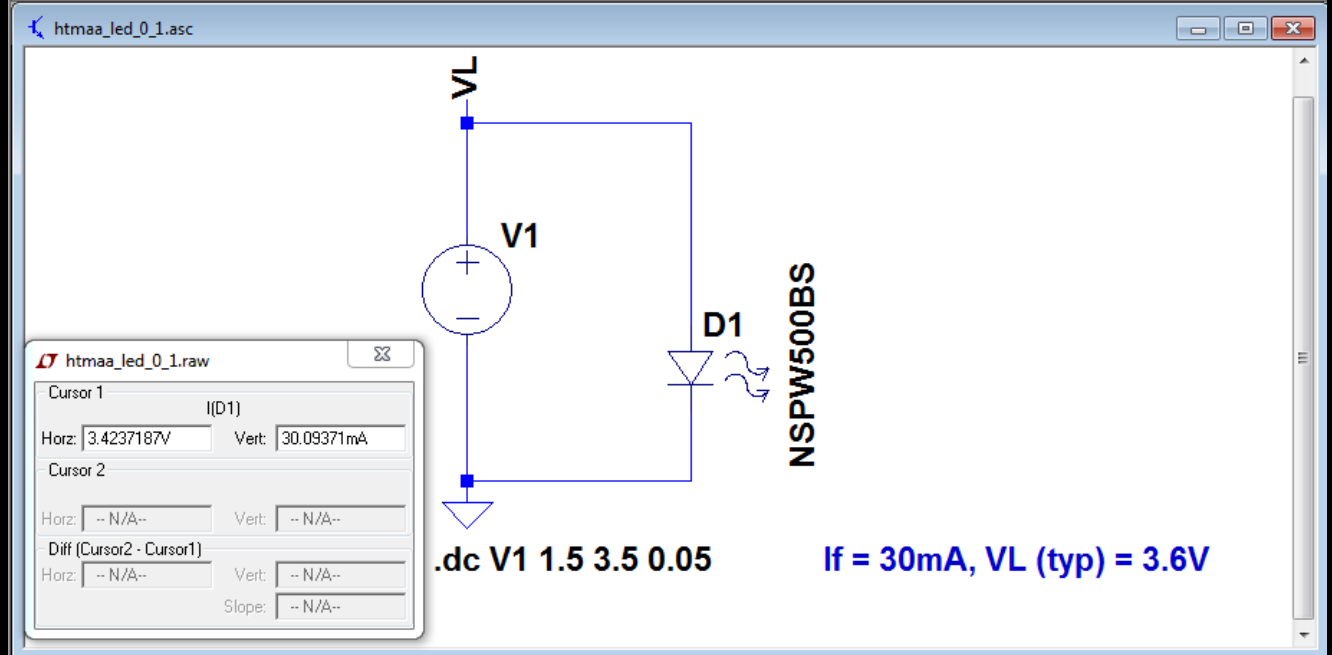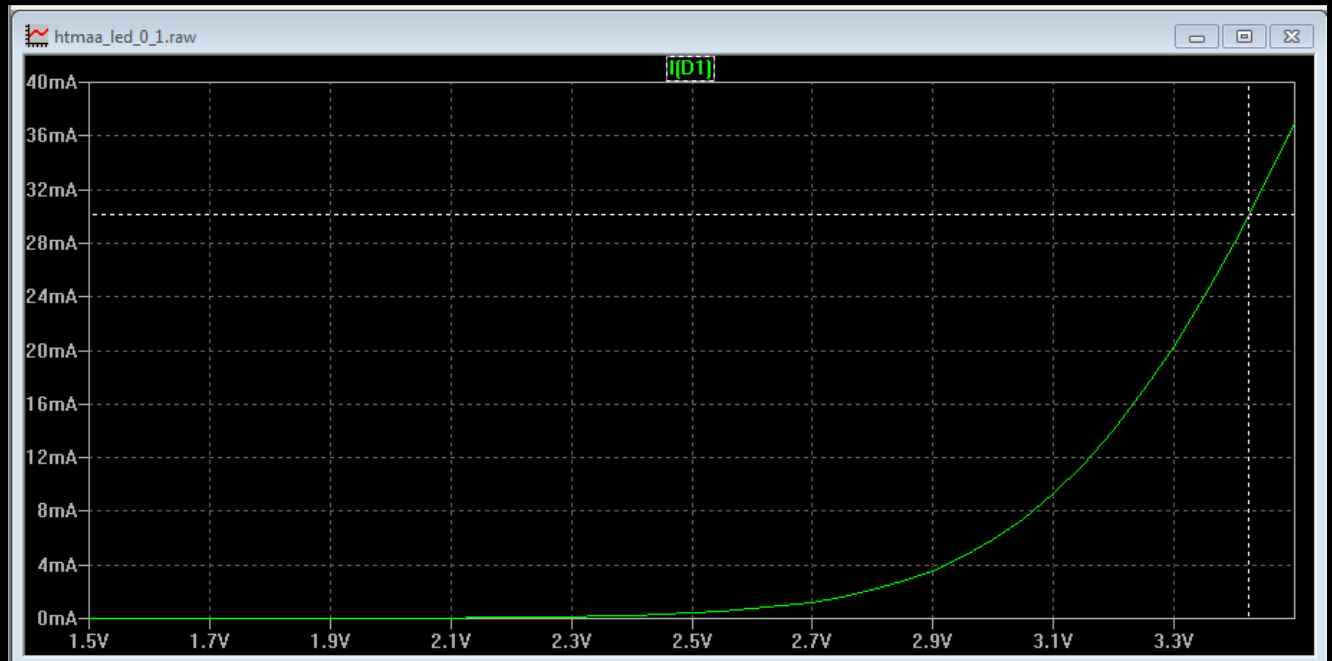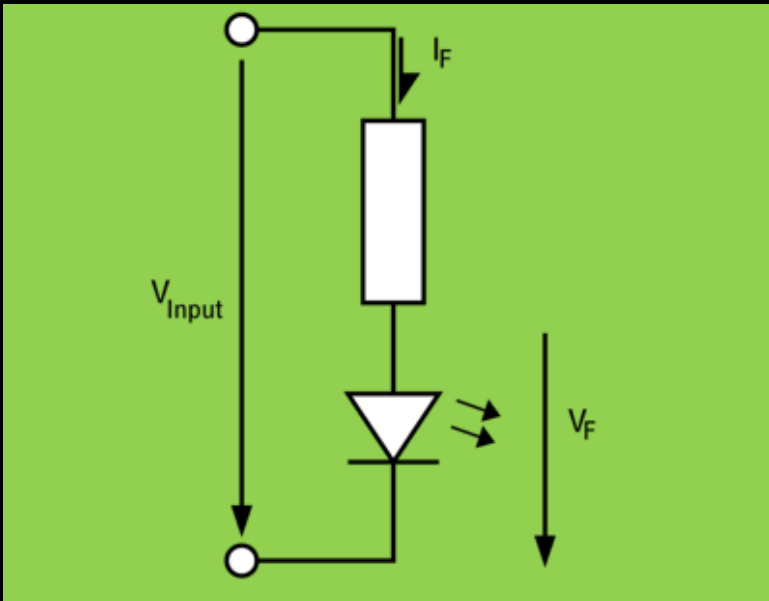
Output Devices

- LED resistor:

- $R = (V_{SUPPLY} - V_{LED})/I_{LED}$

- Ex.: 5V supply, 3.6V 30mA LED: $R = (5V - 2V)/5mA = 47\Omega$

Eagle Demonstration

- Schematic => Printed Circuit Board (PCB)

Pseudocode

```
2    //Initial conditions:
3    init_peripherals();
4
5    //Loop forever:
6    while(1)
7    {
8        //Read inputs:
9        brightness = read_adc();     //Read the potentiometer
10       on_off = read_pushbutton();
11
12       //Control output:
13       if(on_off == 1)       //Button is pressed
14       {
15           //LED proportional to the pot
16           led_output(brightness);
17       }
18       else
19       {
20           led_output(0);
21       }
22
23       //Waste some time
24       delay_ms(10);
25   }
26
```

Questions?

Extra material from last year:

- Provided for your own reference.

- No time to cover it all, but feel free to ask us any questions.

Operational Amplifier

- Best reference: "Op Amps For Everyone" by Ron Mancini (TI) (http://www.ti.com/lit/an/slod006b/slod006b.pdf)

- The Ideal Op Amp Assumptions:

PARAMETER NAME	PARAMETERS SYMBOL	VALUE
Input current	I_{IN}	0
Input offset voltage	V_{OS}	0
Input impedance	Z_{IN}	∞
Output impedance	Z_{OUT}	0
Gain	a	∞
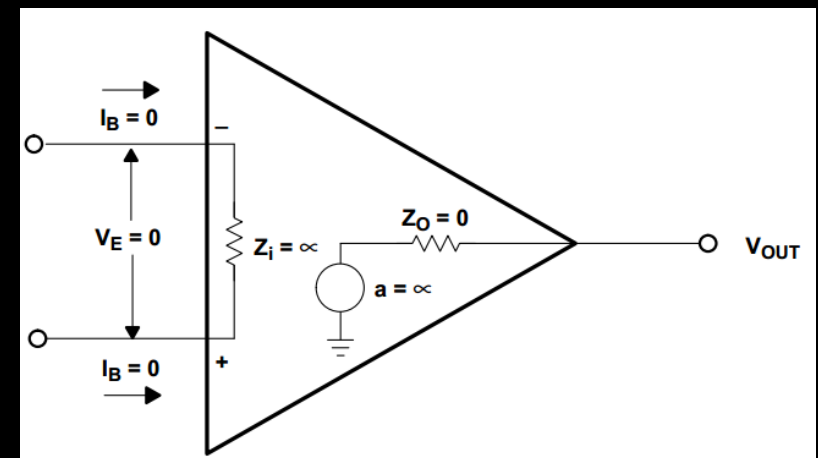
Operational Amplifier (2)

Figure 3–2. The Noninverting Op Amp
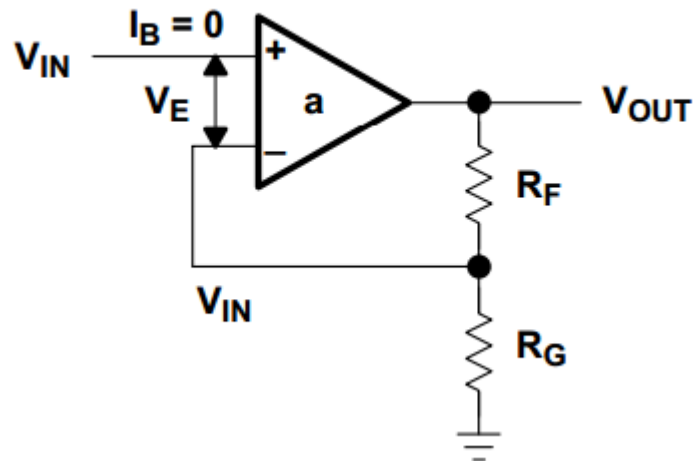
$$V_{IN} = V_{OUT} \frac{R_G}{R_G + R_F}$$

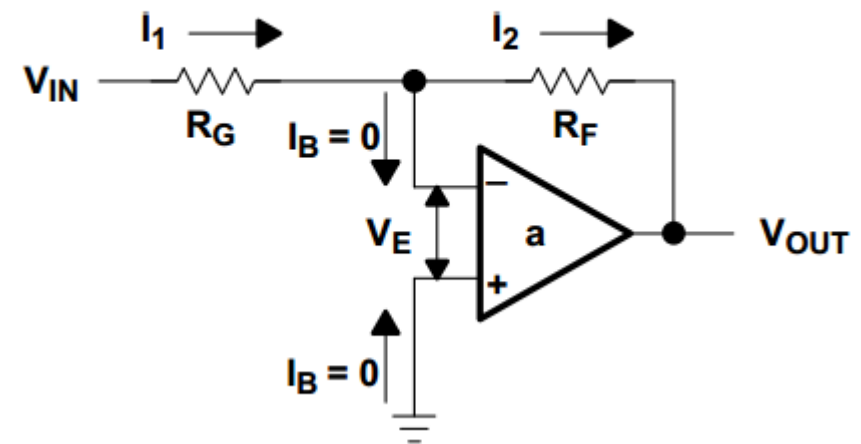$$\boxed{\frac{V_{OUT}}{V_{IN}} = \frac{R_G + R_F}{R_G} = 1 + \frac{R_F}{R_G}}$$

Figure 3–3. The Inverting Op Amp

$$I_1 = \frac{V_{IN}}{R_G} = -I_2 = -\frac{V_{OUT}}{R_F}$$

$$\boxed{\frac{V_{OUT}}{V_{IN}} = -\frac{R_F}{R_G}}$$

Operational Amplifier (3)

- Op amps can be used for/in/as:
  - Active filters
  - Oscillators
  - Inverting or non-inverting amplifier
  - Precision rectifier
  - Integrator
  - Trans-impedance amplifier (ex.: for photodiodes)
- PID loops used to be done only with op amps and passive components

Operational Amplifier (4)

- What to be aware of:
  - Not all op amps are rail-to-rail. Many references advertised as rail-to-rail are only r-r on the output. Read the specs carefully.
  - Always make sure that your op amp is qualified for the voltage of your system (Is it single supply? Are you trying to use a 5V op amp in a 24V system?)
  - Bandwidth is one thing, slew-rate is another. It's especially important to look at the SR if you use square waves.
    - Ex.: 20kHz sine wave, G=1, V_{peak} = 5V: SR_{MAX} = 2*pi*f*V_{peak} = 628e3 = 0.63V/μs

Passive filters

- Low pass filter:
  - fc = 1/(2*pi*R*C)
  - R = 1k, C = 100nF, fc = ?
  - fc = 1.59kHz

- At f=1.59kHz, the gain is -3dB (0.707)
  - 0.707? G = 10^(G_{dB}/20) = 10^(-3dB/20) = 0.707

- Need a high-pass? Swap R & C

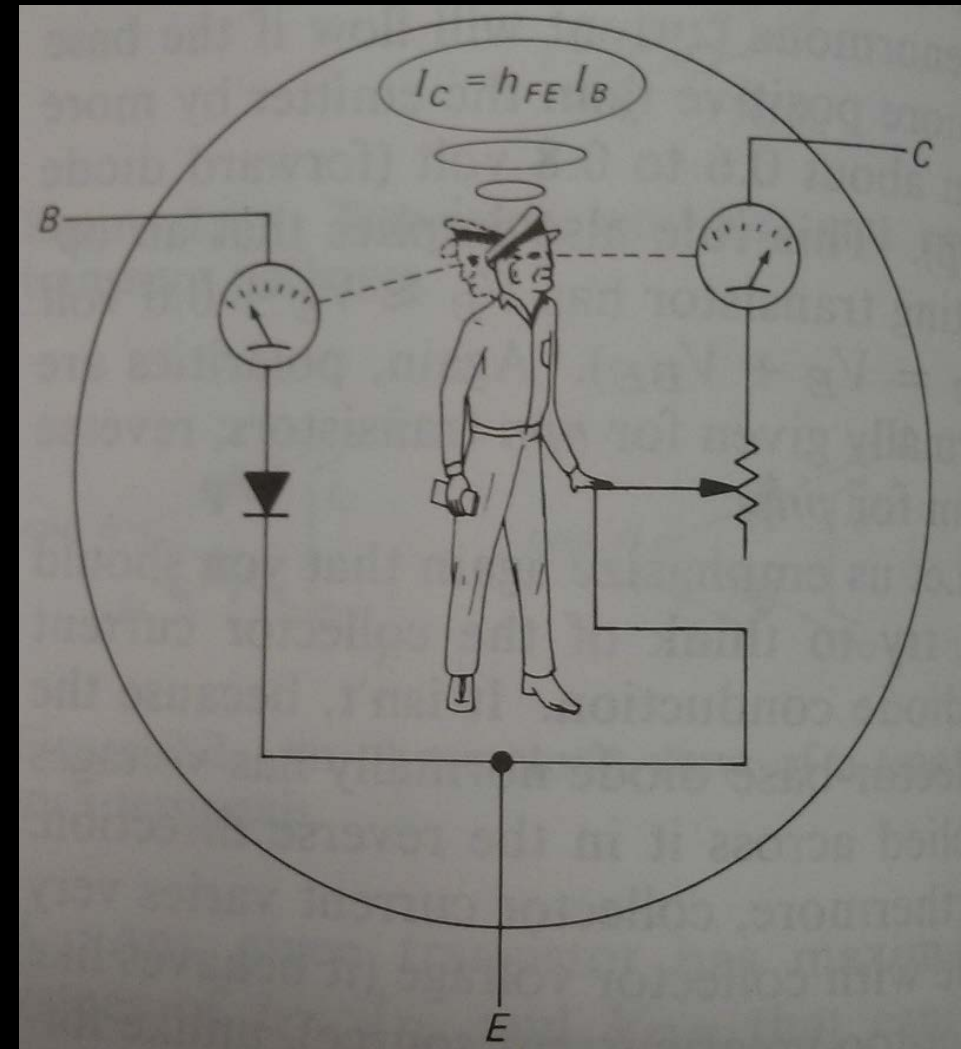- For better performances, look at active filters (filters with an op amp)
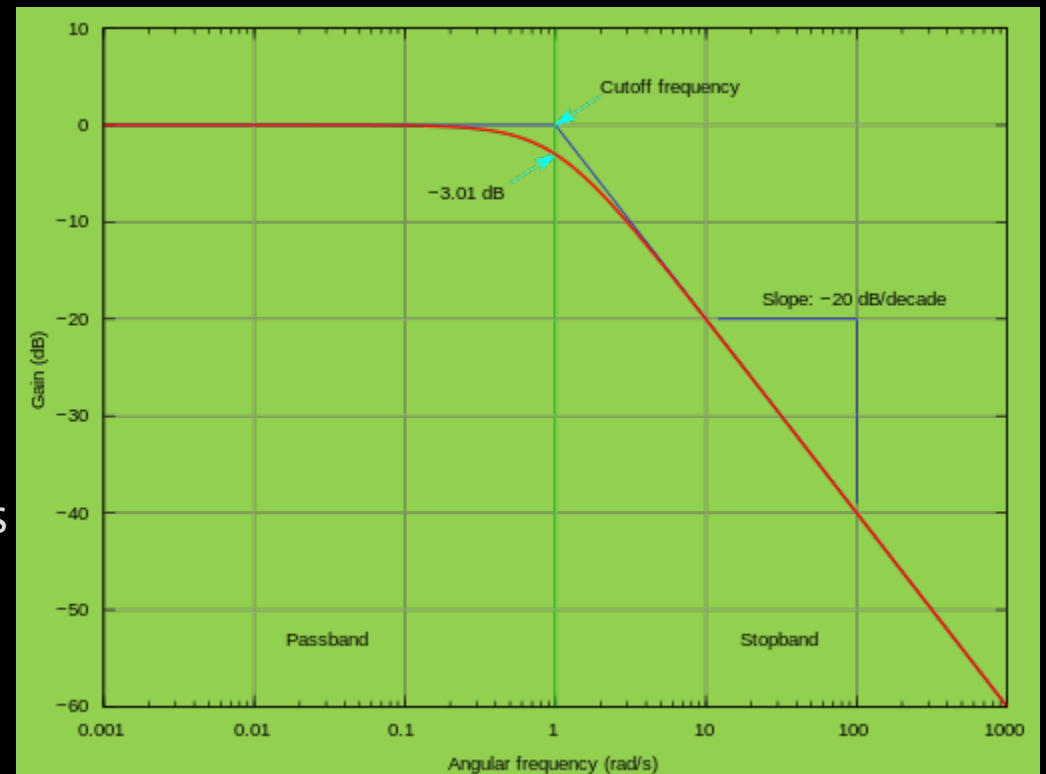
BJT Basics

- Current controlled device

- The Collector Current is proportional to the Base current.

- Can be used in the linear region, but nowadays we mostly use it as a switch

- Power LED and 2N2222 example

PNP   NPN
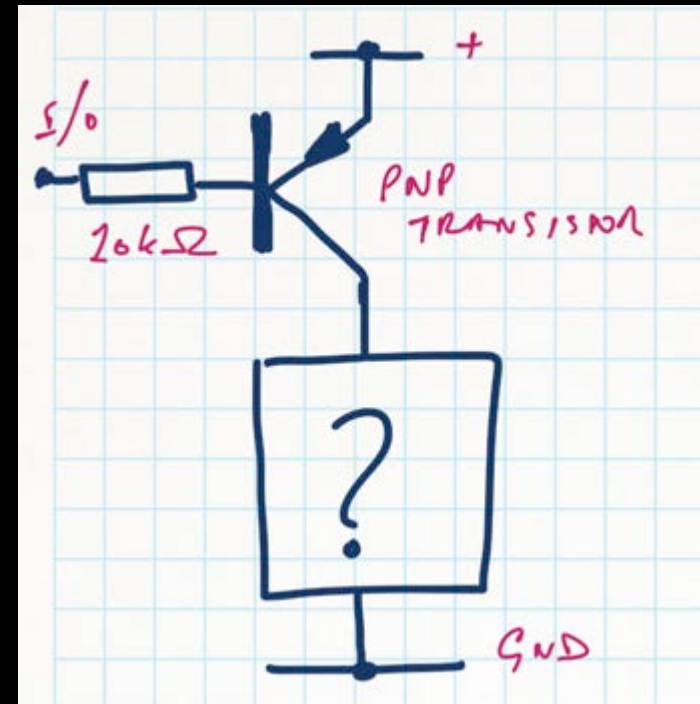

$I_C = h_{FE} I_B$

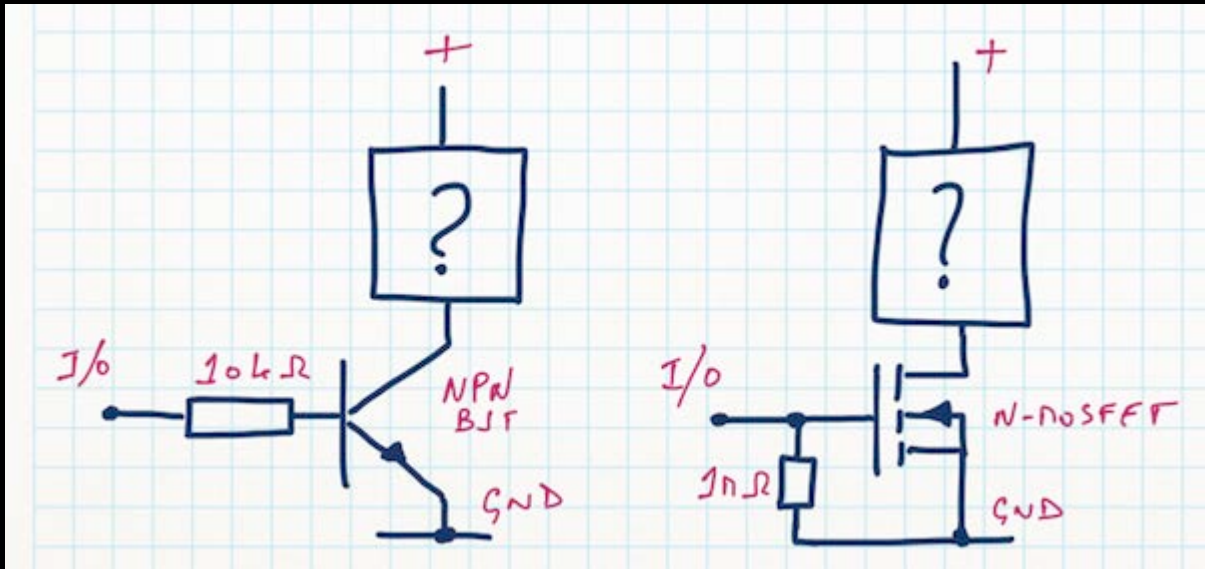# MOSFET basics

- Voltage controlled device

- Can be used in linear mode, but mostly used for switching applications

- When you apply a sufficient voltage to the gate (Vgs), the channel opens

- An open channel is like a tiny resistor

- Power LED example

P-
Channel

N-Channel

High-side vs low side switch

- General rule:
  - P-CH MOSFET or PNP BJT: High-Side
  - N-CH MOSFET or NPN: Low-Side

MOSFET, BJT or Relay?

- There is no general rule here, but always think about those factors:
  - If you use PWM, forget about relays
  - Some MOSFET require a Gate voltage higher than logic power supplies
  - Old power BJT transistors have really low gain (can be as low as 10). In that case, the base current is non negligible.
  - Relays are isolated
  - To drive most (if not all) relays you'll need a transistor
  - For low-power stuff, a small logic-gate MOSFET can be used most of the time

Voltage regulators

- Two main categories: linear or switching (also known as SMPS or switchers)

- Linear: there is a series pass element (usually a transistor). The "unwanted" voltage is converted to heat. Current out = current in.

  - Ex.: 12V in, 5V out 500mA. Vdrop = (12-5) = 7V. Pout = 2.5W, Pin = 6W. Efficiency: 42%, 3.5W to dissipate in heat.

  - LDO doesn't mean lower power! It simply means that you can use it with a lower input voltage

  - Pros: cheap, small, easy, low noise. Cons: inefficient, generates lots of heat

- Switching: a "switch" (usually a MOSFET) chops the input power. An inductor, a diode and a cap filter it. Power in = Power out. Theoretically 100% efficient.

 - Pros: efficient. Cons: usually bigger, more complex, noisier

Thermal

- "My MOSFET is rated for 260A, why would I need a heatsink? I'm only drawing 30A…"

- Let's look at a real part, IRLB3813. Continuous current drain at 25°C: 260A, $R_{DS(ON)}$ max: 1.95mΩ, Thermal resistance Junction to Ambient (R_{TJA}): 62°C/W

- $P = RI^2 = 1.95mΩ*(30A)^2 = 1.755W$

- $T_J = T_{ambient} + P* R_{TJA} = 25°C + 1.755W*62°C/W = 133.8°C$. Don't touch it.
  - For Americans: 272F

- (and I'm not including the derating. If you switch it (PWM), the dynamic losses are usually >= static losses)

- The same basic math applies to voltage regulators (to everything in fact…)

ESD

- Discharge yourself before touching electronics

- Always touch boards by the edges
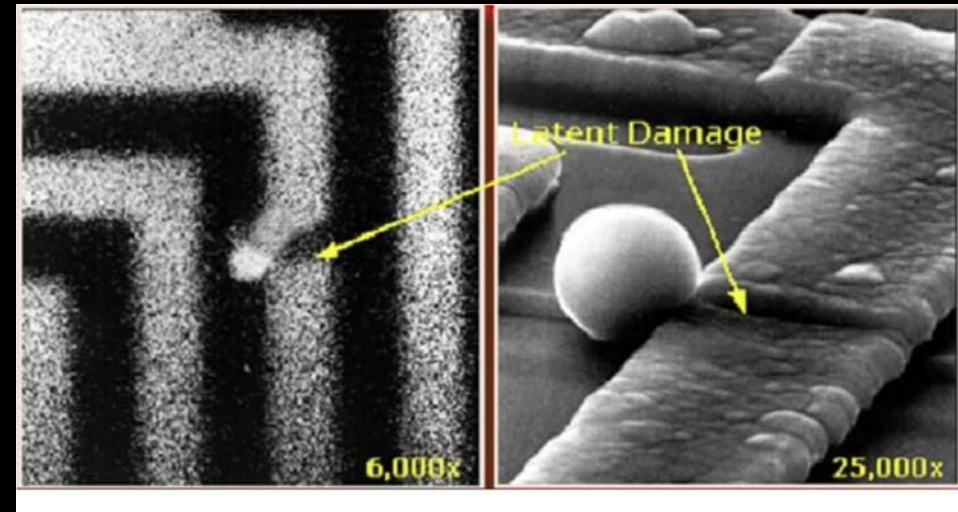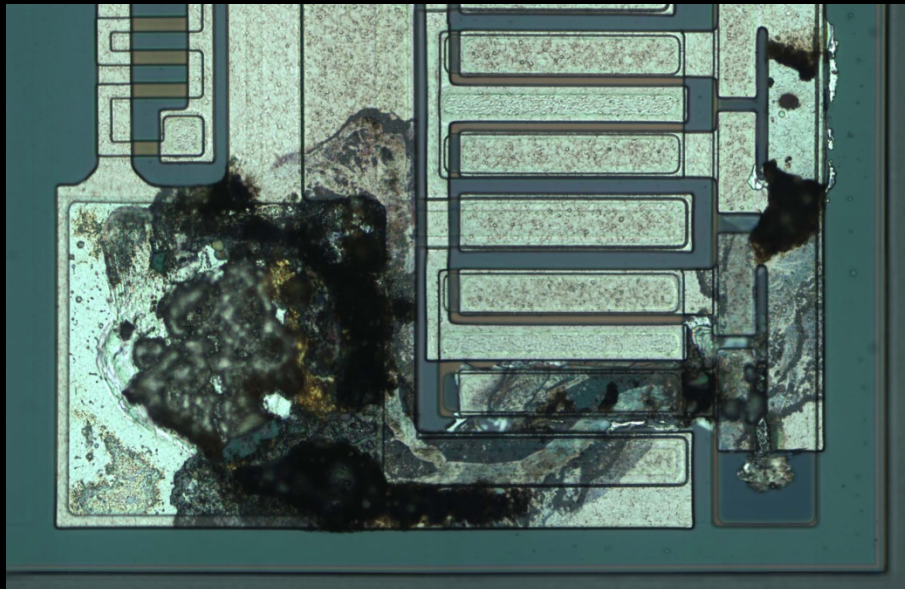
LiPO Battery

- Let's look at a real pack: "Turnigy 5000mAh 6S 20C Lipo Pack"
  - Each cell will be around 3.7V when fully charged
  - The minimum voltage is ~3V per cell
  - 5000mAh means that you can draw 5A for an hour, or 10A for 30 minutes
    - Faster discharge = less energy
  - Never over discharge! (Search "lipo fire" on Youtube…)
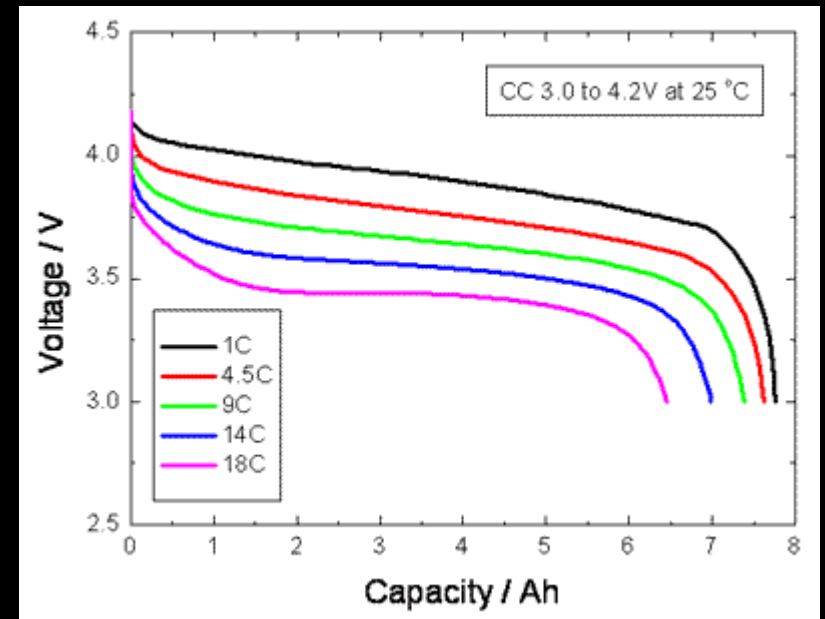
Misc. Tips, breaking some myths

- If you // LEDs, you need 1 resistor per LED (or string)

- Always think about power dissipation

- MOSFET's gate doesn't need current
  - It's only true when you reach steady state. At every transition you need to charge/discharge a capacitor. To give you an idea, most gate driver ICs can pump a couple amps in the gate to make it switch as fast as possible!

- Keep safety margins in your designs. A 24V MOSFET used to control a 24V motor WILL burn. Why? The inductive spikes can be twice as high as the supply voltage

Useful tools

- LTSpice, free SPICE simulator: http://www.linear.com/designtools/software/

- Filter Lab, active filter calculator:
  http://www.microchip.com/stellent/idcplg?IdcService=SS_GET_PAGE&nodeId=14
  06&dDocName=en010007&redirects=filterlab

- To spec SMPS (and many other circuits), use TI WeBench (used to be NI
  WeBench):
  http://www.ti.com/lsds/ti/analog/webench/overview.page?DCMP=PPC_Google_TI
  &k_clickid=7e5739d4-74cf-8188-3be9-000020f0b88c&247SEM=