**ENPH 253 Introduction to Instrument Design**
**www.engphys.ubc.ca/enph253**

| | |
|---|---|
| Instruction | Andre Marziali, Jon Nakane |
| Technical | Bernhard Zender |
| TAs: | Matt Lam, Rob Stead, Yegor Rabets |

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## Focus in ENPH 253

- Basic electronics, mechanical design
- Prototyping skills
- Independent design

- Practical problem-solving
- Team work
- Prioritization of time, team effort
- Estimating time, effort for technical tasks

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## Tinkering vs. Design

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**Schedule**

**First six weeks:**

| | | |
|---|---|---|
| Lecture: | Tue 2:00 – 5:00 | IKBLC 182 |
| Lab: | Thurs 2:00 - ? (typically 9:30) | Hebb 42 |

**After week 6:**

Lab: Tue & Thurs 2:00 – 10pm
+ additional days and evenings as required.

**Machine Shop Course**

**ALL STUDENTS** take the machine shop course (10 hrs + lecture) if they have not completed the 40-hour shop course.
10-hr course for groups of 6 held on two afternoons (M/W/F), sign-up during Lab 1

**Wed May 9, 1pm-3pm, Hennings 201 (attendance required for all students)**
Machine Shop Intro and Safety

**Fri May 11, 1pm-2:30pm, Hennings 201 (attendance required for all students)**
Intro to Solidworks (Bernhard Zender)

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## Formal Labs (6 weeks)

1 – Microcontrollers and digital I/O
2 – Analog circuits and I/O
3 – PWM and Power circuits
4 – Mechanical Design
5 – PID control and tape following (2 weeks)

| | |
|---|---|
| **Design and design review** | (1 week) |
| **Construction** | (6-7 weeks) |
| **Individual time-trials** | ~week 12 |

| | | |
|---|---|---|
| **Competition:** | Thurs Aug 2nd, | 10am |
| **Cleanup** | Friday Aug 3rd, | 10am |
| **Final Report** | Friday August 10th | |

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## Team Mark

| | |
|---|---|
| Competition results | 25% |
| Robot design / construction: | 30% |
| Individual time-trials: | 25% |
| Design Review | 20% |
| Inappropriate lab practice | Max -20% |

(parts hoarding, unsafe practice, messy space, etc)

## Individual Mark

| | |
|---|---|
| Team self evaluation: | ± 10% |
| Lab performance: | ± 20% |

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## References

There is no required text. Lecture notes, labs and data sheets will be posted on web page:

- refer to Wiring programming website (wiring.org.co)
- **Horowitz and Hill**, Sedra and Smith
- MIT 2.007 Course Notes (link on course website)
- Online Component Vendors (Newark, McMaster)

## Logbooks

necessary for labs & construction, but not marked

## Circuit drawing and simulation

https://www.circuitlab.com/editor/

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## Class Activities

- Most "Teaching" will be done through in-class activities.
- Try to build circuit that we suggest
- Once you are successful, help people around you.
- Do not just build it for them. Explain how you did it instead.
- Bring laptop or smartphone

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**Ph253 final 2012:**

ENPH 253 – Introduction to Instrument Design summer 2012
projectlab.engphys.ubc.ca/enph253
Competition Rules

Block Stacking-Bots – are you faster than a pre-schooler?

Vs.

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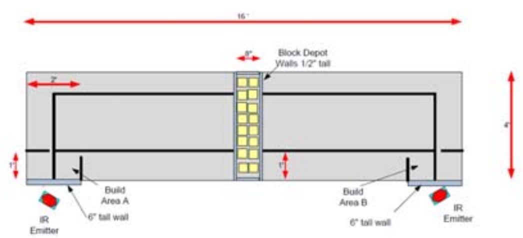


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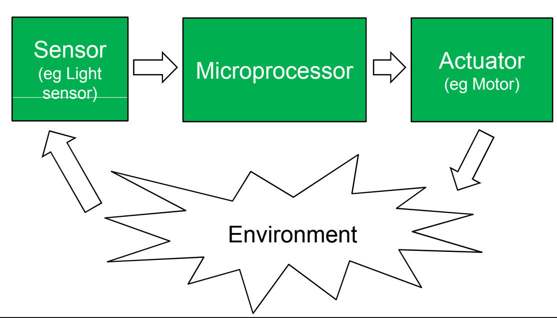
## "Smart" instruments

The use of microprocessors to replace mechanical systems leads to

- better performance
- higher reliability
- more complex behavior with a mechanically simpler instrument
- often lower total cost of instrument

Eg #1: mechanical vs. electronic thermostats

## "Smart" instruments



Rescue bot video

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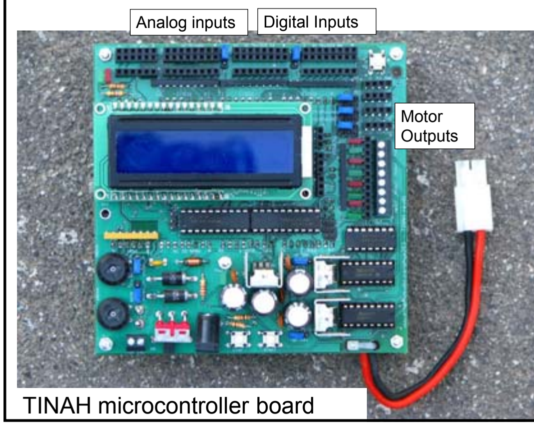


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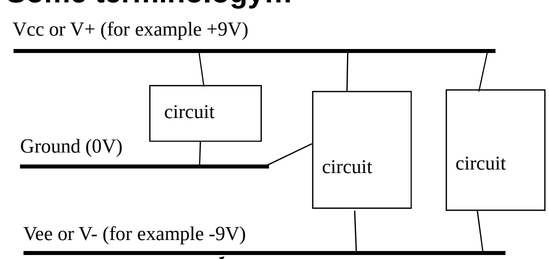
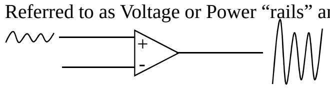
## Some terminology…




Referred to as Voltage or Power "rails" and **usually not shown**.




(This does not violate conservation of energy)

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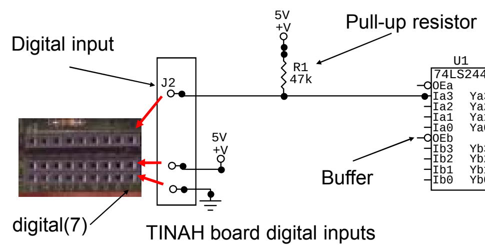
## Lab 1 - Digital Inputs – Getting information INTO your microprocessor

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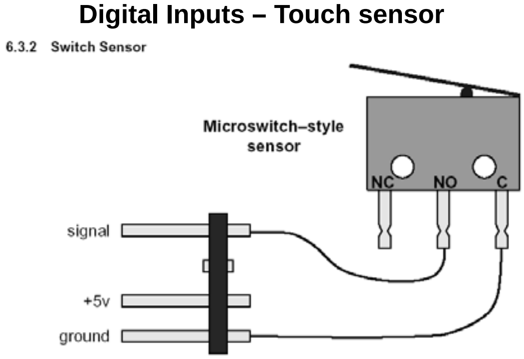
## Digital Inputs – Touch sensor




Wire to switch terminals labelled **C** (common) and **NO** (normally open)

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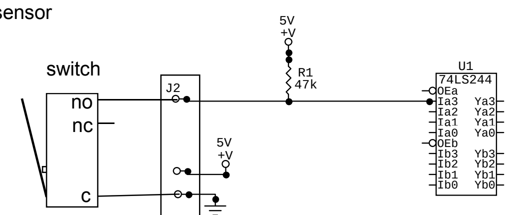
## Digital Inputs – Touch sensor

- A simple mechanical switch can be used as a collision or touch sensor




```
if (digital(7))
        print ("switch closed")
else
        print("switch open")
```

When switch is pressed, digital input is pulled low (0 V) by the switch.

When not pressed it is pulled high (5V) by the resistors

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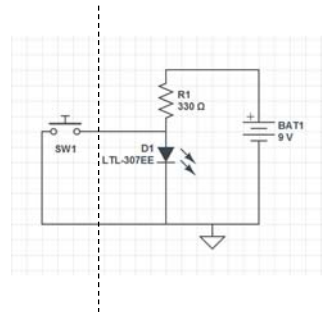
## Digital Inputs – Touch sensor

Build a circuit that has:

- An LED that is normally lit
- While a switch is pressed, the LED goes off

❖ Note: LED can only handle ~ 100 mA
❖ Design this so the battery is not badly drained when the switch is pressed
❖ If the battery or LED is getting hot, you're doing something wrong

## Digital Inputs – Touch sensor



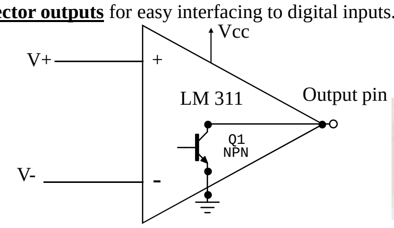

## Digital Inputs – Touch sensor

```
#include <phys253.h>
#include <LiquidCrystal.h>
#include <Servo253.h>

////////////////////////////////////////
// Physics 253 - Lecture 1
// 2009 May 4
////////////////////////////////////////

void setup()
{
  while(!startbutton())
  {
    LCD.clear();  LCD.home();
    LCD.print("Welcome to 253!");
    delay(1000) ;
    LCD.clear();  LCD.home();
    LCD.print("Come down to");
    LCD.setCursor(0,1) ;  LCD.print("pickup
kits....");
    delay(1000) ;
  }
 }

void loop()
{
while (!stopbutton())
{
 LCD.clear();  LCD.home();
 if (digitalRead(0))
  {    LCD.print("switch pressed.");   }
 else
  {  LCD.print("switch NOT pressed.");   }
 delay(100) ;
}

while (!startbutton())
{
 LCD.clear();  LCD.home();
 if (digitalRead(0))
 {    LCD.print("object detected."); }
 else
 {    LCD.print("object NOT detected.");   }
 delay(100) ;
}
}
```



## LM311 comparator – open collector output

• Comparators and other chips are sometimes provided with **Open Collector outputs** for easy interfacing to digital inputs.




When V+ < V- , Q1 is turned on (conducting). Output pin is grounded through Q1. When V+ >V- , Q1 is off, and output pin floats unless externally pulled up!!!. (but Q1 cannot sink any current to ground).

Remember: it takes very little charge to change the voltage of a disconnected wire!



## LM311 comparator – Example of a data sheet

**5.0 Absolute Maximum Ratings for the LM311** (Note 12)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Total Supply Voltage ($V_{84}$) | 36V |
| Output to Negative Supply Voltage ($V_{74}$) | 40V |
| Ground to Negative Supply Voltage ($V_{14}$) | 30V |
| Differential Input Voltage | ±30V |
| Input Voltage (Note 13) | ±15V |
| Power Dissipation (Note 14) | 500 mW |
| ESD Rating (Note 19) | 300V |
| Output Short Circuit Duration | 10 sec |
| Operating Temperature Range | 0° to 70°C |
| Storage Temperature Range | −65°C to 150°C |
| Lead Temperature (soldering, 10 sec) | 260°C |
| Voltage at Strobe Pin | $V^+$−5V |
| Soldering Information | |
| Dual-In-Line Package | |
| Soldering (10 seconds) | 260°C |
| Small Outline Package | |
| Vapor Phase (60 seconds) | 215°C |
| Infrared (15 seconds) | 220°C |

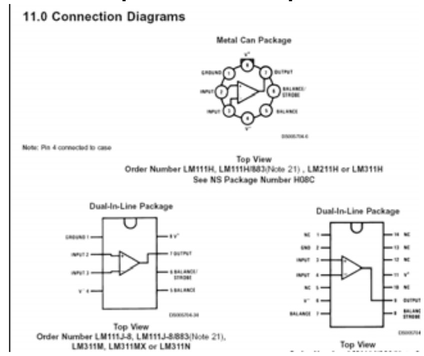
See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

DANGER LEVELS: Exceeding these voltages / currents will blow up the chip.



## LM311 comparator – Example of a data sheet

**11.0 Connection Diagrams**




The most often used page – how to hook up the chip.

## LM311 comparator – Example of a data sheet

**Electrical Characteristics** (Note 15)
for the LM311

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Input Offset Voltage (Note 16) | $T_A$=25°C, $R_S$≤50k | | 2.0 | 7.5 | mV |
| Input Offset Current(Note 16) | $T_A$=25°C | | 6.0 | 50 | nA |
| Input Bias Current | $T_A$=25°C | | 100 | 250 | nA |
| Voltage Gain | $T_A$=25°C | 40 | 200 | | V/mV |
| Response Time (Note 17) | $T_A$=25°C | | 200 | | ns |
| Saturation Voltage | $V_{IN}$≤−10 mV, $I_{OUT}$=50 mA<br>$T_A$=25°C | | 0.75 | 1.5 | V |
| Strobe ON Current (Note 18) | $T_A$=25°C | | 2.0 | 5.0 | mA |
| Output Leakage Current | $V_{IN}$≥10 mV, $V_{OUT}$=35V<br>$T_A$=25°C, $I_{STROBE}$=3 mA<br>$V^-$ = Pin 1 = −5V | | 0.2 | 50 | nA |
| Input Offset Voltage (Note 16) | $R_S$≤50K | | | 10 | mV |
| Input Offset Current (Note 16) | | | | 70 | nA |
| Input Bias Current | | | | 300 | nA |
| Input Voltage Range | | −14.5 | 13.8,−14.7 | 13.0 | V |
| Saturation Voltage | $V^+$≥4.5V, $V^-$=0<br>$V_{IN}$≤−10 mV, $I_{OUT}$≤8 mA | | 0.23 | 0.4 | V |
| Positive Supply Current | $T_A$=25°C | | 5.1 | 7.5 | mA |
| Negative Supply Current | $T_A$=25°C | | 4.1 | 5.0 | mA |

Important operating characteristics: these numbers will tell you how the chip will behave.

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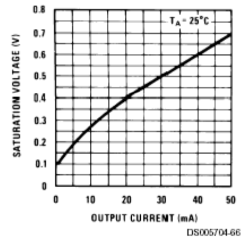
## LM311 comparator – Example of a data sheet

7.0 LM311 Typical Performance Characteristics

Output Saturation Voltage




LM 311 can only sink a limited amount of current

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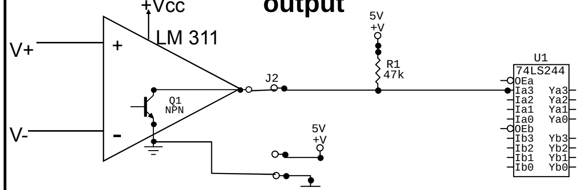
## LM311 comparator – open collector output




**Unlike an OP-amp, the 311 is NOT a source of power! You cannot drive a load with the output pin.**

Now, when Q1 is off, digital input J2 is pulled high by R1. When Q1 is on, J2 is pulled low (~ 0.1 or 0.2 V) by Q1. Note that the LM311 and the TINAH **must share ground** for this to work, but DO NOT NEED TO SHARE POWER RAILS.

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## LM311 comparator – open collector output

Build a circuit that has:

- An LED that is normally lit
- While a switch is pressed, the LED goes off
- The LED is connected to switch through a 311

❖ Note: Can use both batteries or only one

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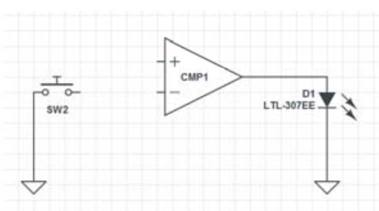
## LM311 comparator – open collector output

Start with this circuit and fill in:

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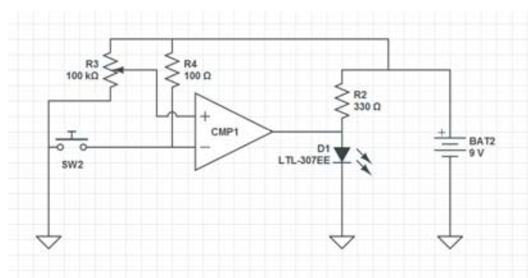
## LM311 comparator – open collector output

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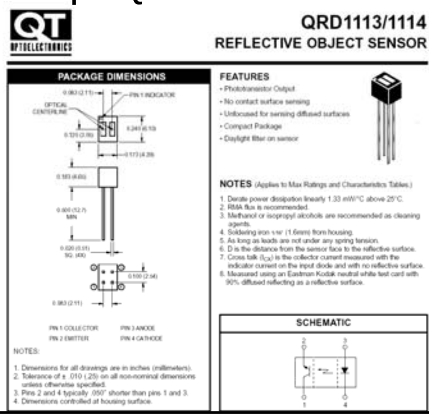
## Example: QRD1114 reflectance sensor

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## Example: QRD1114 reflectance sensor

Build a circuit that has:

- An LED that is normally lit
- When your finger comes near the QRD sensor, the LED goes off

- ❖ Note: Use a comparator
- ❖ Note: Use a potentiometer to allow you to vary the threshold distance of your finger to the sensor

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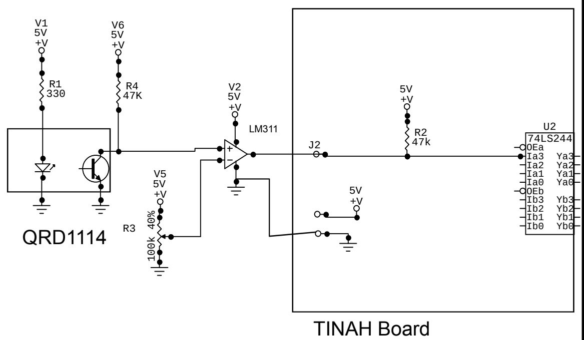
## Example: QRD1114 reflectance sensor

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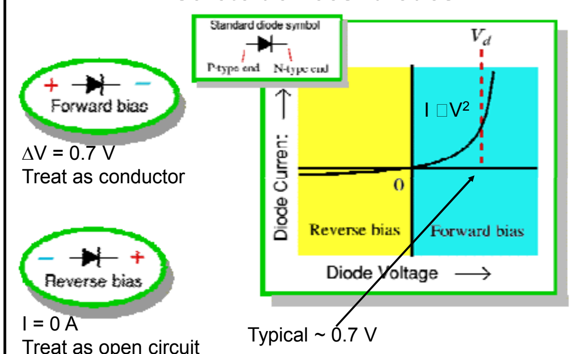
## Discrete devices: diodes




Diagrams courtesy of: University of St. Andrews, St Andrews, Fife KY16 9SS, Scotland

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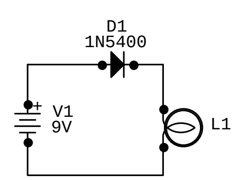
## Discrete devices: diodes

Build a circuit that has:

- A lamp that is lit
- When you reverse the battery polarity the lamp goes off

## Discrete devices: diodes

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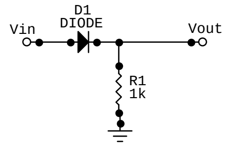
$V_{in}$ = 5V DC, $V_{out}$ is connected to scope only.




a) $V_{out}$ = 5 V if R1 = 1K
b) $V_{out}$ = 4.3 V regardless of R1
c) $V_{out}$ = 4.3 V if R1 = 1K
d) $V_{out}$ = 5 V if R1 is removed
e) $V_{out}$ = 4.3 V if R1 is removed

The following are true: (Try it with your own meter)

1. a
2. b,c,e
3. c,d
4. a,e
5. c

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## Discrete devices: Transistors

Transistors are semiconductor devices used to **amplify** a signal (e.g. small current/voltage to large current/voltage).

In ENPH 253, we use transistors as switches to turn on and off larger amounts of current.

Two major types of transistors:

Bipolar Junction Transistors
MOSFETs

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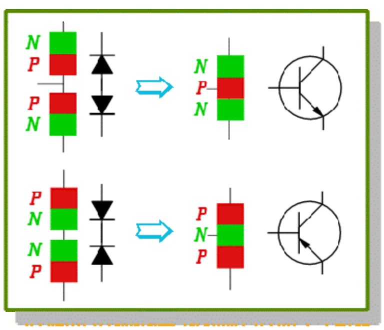
## Discrete devices: BJT

Bipolar Junction Transistors




Diagrams courtesy of: University of St. Andrews, St Andrews, Fife KY16 9SS, Scotland

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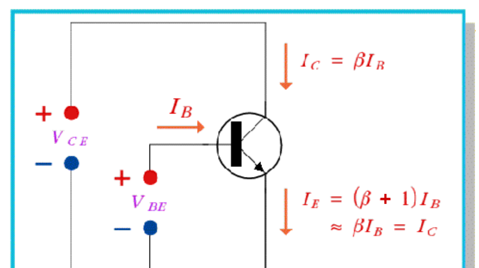
## Discrete devices: BJT

Bipolar Junction Transistors




'Conventional' view of the NPN Bipolar Transistor

Diagrams courtesy of: University of St. Andrews, St Andrews, Fife KY16 9SS, Scotland

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## Discrete devices: BJT

**General Purpose Transistors**
**NPN Silicon**

**2N3903**
**2N3904***

*Motorola Preferred Device



CASE 29–04, STYLE 1
TO–92 (TO–226AA)

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Collector–Emitter Voltage | $V_{CEO}$ | 40 | Vdc |
| Collector–Base Voltage | $V_{CBO}$ | 60 | Vdc |
| Emitter–Base Voltage | $V_{EBO}$ | 6.0 | Vdc |
| Collector Current — Continuous | $I_C$ | 200 | mAdc |
| Total Device Dissipation @ $T_A$ = 25°C<br>Derate above 25°C | $P_D$ | 625<br>5.0 | mW<br>mW/°C |
| Total Device Dissipation @ $T_C$ = 25°C<br>Derate above 25°C | $P_D$ | 1.5<br>12 | Watts<br>mW/°C |
| Operating and Storage Junction Temperature Range | $T_J$, $T_{stg}$ | –55 to +150 | °C |

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## Discrete devices: BJT

Bipolar Junction Transistors

**ELECTRICAL CHARACTERISTICS** ($T_A$ = 25°C unless otherwise noted) (Continued)

| Characteristic | | Symbol | Min | Max | Unit |
|---|---|---|---|---|---|
| **ON CHARACTERISTICS** | | | | | |
| DC Current Gain[1] | | $h_{FE}$ | | | — |
| ($I_C$ = 0.1 mAdc, $V_{CE}$ = 1.0 Vdc) | 2N3903<br>2N3904 | | 20<br>40 | —<br>— | |
| ($I_C$ = 1.0 mAdc, $V_{CE}$ = 1.0 Vdc) | 2N3903<br>2N3904 | | 35<br>70 | —<br>— | |
| ($I_C$ = 10 mAdc, $V_{CE}$ = 1.0 Vdc) | 2N3903<br>2N3904 | | 50<br>100 | 150<br>300 | |
| ($I_C$ = 50 mAdc, $V_{CE}$ = 1.0 Vdc) | 2N3903<br>2N3904 | | 30<br>60 | —<br>— | |
| ($I_C$ = 100 mAdc, $V_{CE}$ = 1.0 Vdc) | 2N3903<br>2N3904 | | 15<br>30 | —<br>— | |
| Collector–Emitter Saturation Voltage[1]<br>($I_C$ = 10 mAdc, $I_B$ = 1.0 mAdc)<br>($I_C$ = 50 mAdc, $I_B$ = 5.0 mAdc | | $V_{CE(sat)}$ | —<br>— | 0.2<br>0.3 | Vdc |
| Base–Emitter Saturation Voltage[1]<br>($I_C$ = 10 mAdc, $I_B$ = 1.0 mAdc)<br>($I_C$ = 50 mAdc, $I_B$ = 5.0 mAdc) | | $V_{BE(sat)}$ | 0.65<br>— | 0.85<br>0.95 | Vdc |

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## Discrete devices: Transistors (NPN)

Build a circuit that :

- Uses a 3904 (NPN) transistor to light a lamp

❖ Check: when the 3904 is turned on, the Base-Emitter voltage should be ~ 0.7V

❖ Limit the current into the base!!

❖ Note: arrange the 3904 so the emitter voltage to ground does not change when the lamp is lit (it needs to be stable as a reference for the base voltage)

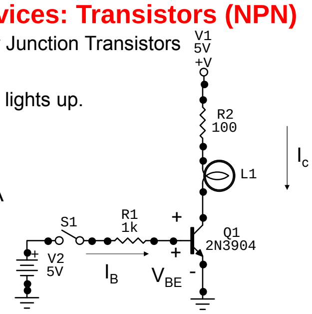
## Discrete devices: Transistors (NPN)

Bipolar Junction Transistors

Typical circuit (NPN):
When S1 is closed, lamp lights up.

$I_B$ = (5-0.7)/1k = 4.3 mA
$\beta$= 30
$I_c$ = (30)4.3 mA = 130 mA

$V_{BE}$ = 0.7 V
$V_{CE}$ = 0.3 V




Checking $V_{BE}$ is a quick way to test a transistor. If $V_{BE}$ >> 0.7 V, the transistor is dead.

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## Discrete devices: Transistors (PNP)

Build a circuit that :

- Uses a 3906 (PNP) transistor to light a lamp

❖ Check: when the 3906 is turned on, the Base-Emitter voltage should be ~ 0.7V

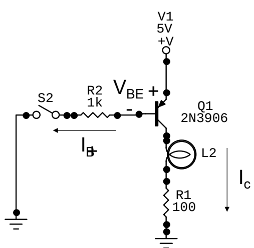
❖ Note: arrange the 3906 so the emitter voltage to ground does not change when the lamp is lit (it needs to be stable as a reference for the base voltage)

## Discrete devices: Transistors (PNP)

Bipolar Junction Transistors

Typical circuit (PNP):

When S2 is closed, lamp lights up.

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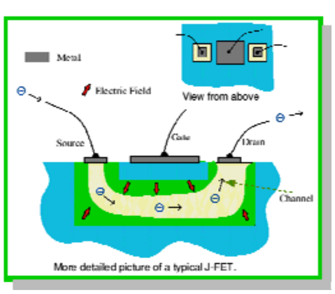
## Discrete devices: FETs

Field Effect Transistors




Gate voltage either ENHANCES or DEPLETES the conduction channel.

JFET = Junction FET
MOSFET = Metal Oxide Semiconductor FET

MOSFETS have an insulating layer at gate so draw less current.

Current passing from source to drain now controlled by VOLTAGE at the gate
(rather than by CURRENT into the base as in a BJT).

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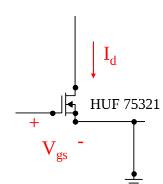
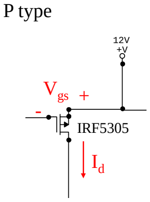
## Discrete devices: FETs

Field Effect Transistors

There are FOUR kinds of MOSFETs:

Enhancement Mode: N type P type




Increasing $V_{gs}$ increases $I_d$.

Depletion : Increasing $V_{gs}$ decreases $I_d$

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**FAIRCHILD SEMICONDUCTOR®**

**HUFA75321P3, HUFA75321S3S**

**Data Sheet** **December 2001**

### 35A, 55V, 0.034 Ohm, N-Channel UltraFET Power MOSFETs

These N-Channel power MOSFETs are manufactured using the innovative UltraFET® process. This advanced process technology achieves the lowest possible on-resistance per silicon area, resulting in outstanding performance. This device is capable of withstanding high energy in the avalanche mode and the diode exhibits very low reverse recovery time and stored charge. It was designed for use in applications where power efficiency is important, such as switching regulators, switching converters, motor drivers, relay drivers, low-voltage bus switches, and power management in portable and battery-operated products.

Formerly developmental type TA75321.

### Ordering Information

| PART NUMBER | PACKAGE | BRAND |
|---|---|---|
| HUFA75321P3 | TO-220AB | 75321P |
| HUFA75321S3S | TO-263AB | 75321S |

NOTE: When ordering, use the entire part number. Add the suffix T to obtain the TO-263AB variant in tape and reel, e.g., HUFA75321S3ST.

### Features

- 35A, 55V
- Simulation Models
  - Temperature Compensated PSPICE® and SABER™ Models
  - Thermal Impedance SPICE and SABER Models Available on the WEB at: www.fairchildsemi.com
- Peak Current vs Pulse Width Curve
- UIS Rating Curve
- Related Literature
  - TB334, "Guidelines for Soldering Surface Mount Components to PC Boards"

### Symbol

### Packaging

JEDEC TO-220AB

JEDEC TO-263AB



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## Discrete devices: MOSFETS

Build a circuit that :

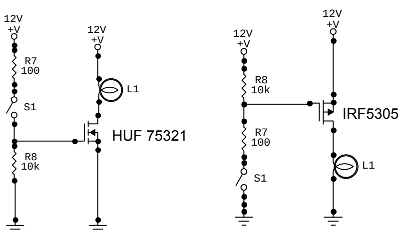
- Uses a MOSFET to light a lamp

❖ Note: no current is required to flow into the gate to switch on or off the MOSFET

❖ Make this circuit for both N and P type FETs

## Discrete devices: MOSFETs

Enhancement: N type P type

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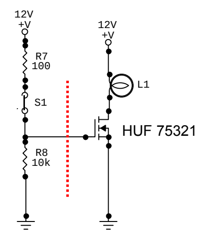
## Discrete devices: MOSFETs

If after closing S1 (and turning on the LED) we cut the circuit at the red line:

1. The LED will stay lit
2. The LED will go off

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## Things to keep in mind for Lab 1

- Bring a Lab Notebook!
- Circuit (LM311) and TINAH are not connected to a common ground.
- The LM311 comparator output pin is not pulled up.
- The power rail break in the proto board is not bridged.
- The strobe pin of the LM311 is pulled low.
- The ground pin of the LM311 is not grounded.
- Blowing up the TINAH. Please use LM311 to interface to the frequency generator.

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