# Lab 1 - Revisited

- Display signals on scope
- Measure the time, frequency, voltage visually and with the scope
- *Voltage measurement**
- *Build simple circuits on a protoboard.**

- Oscilloscope demo

# RMS Voltage

- 0-5v square wave (50%) duty cycle has a rms value of $5 / \sqrt{2}$ = 3.54v
- 5v peak-peak square wave (-2.5v to +2.5v 50% duty cycle) has a rms value of 2.5v

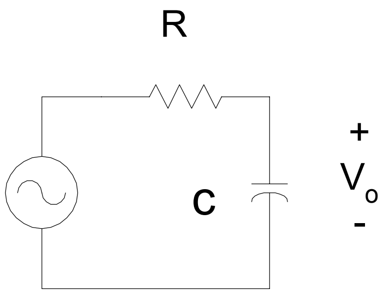
# General Conventions

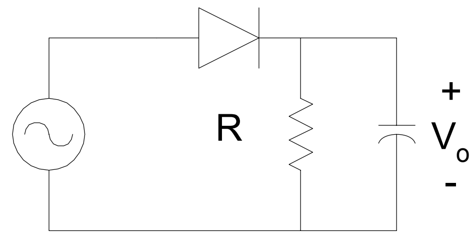
- Wire coding
  - red: positive or signal source
  - black: ground or common reference point
- Circuit flow, signal flow left to right
- Higher voltage on top, ground negative voltage on bottom

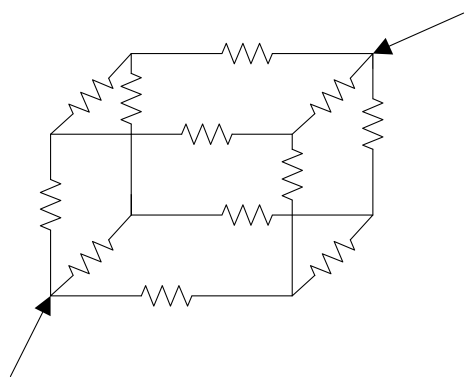
# Lab Hints & Cautions

- Current measure must be taken in series – not parallel.
- There are tools for most situations: wire strippers, de-soldering tool, etc..
- Power ratings of components must not be exceeded
- Polarity of electrolytic capacitors must be observed.

# Lab 1 Circuits

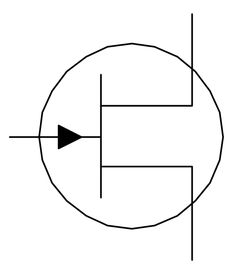


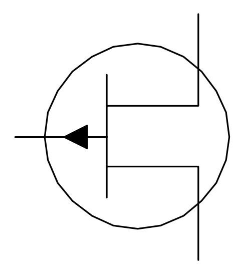



# Field Effect Transistors (FET)

- MOSFET: Metal Oxide Semiconductor FET
- JFET: Junction FET
- FETs are voltage controlled device with very high input impedance (little current)

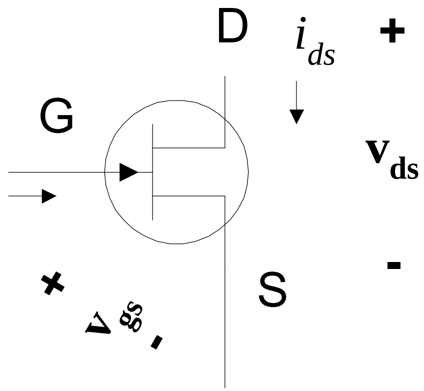


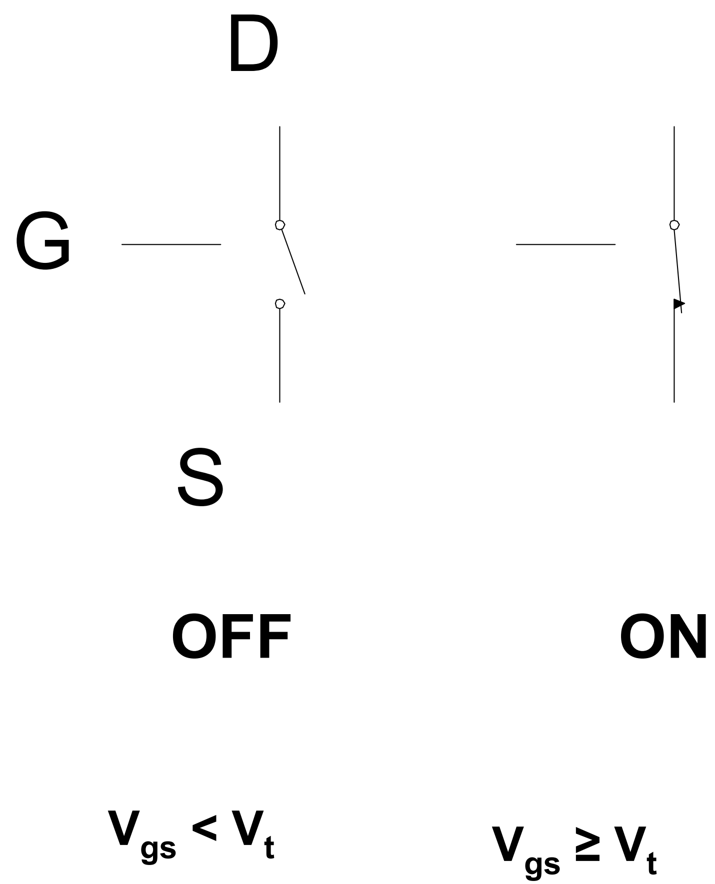
N channel JFET



P channel JFET

# Simple Model of MOSFET




MOSFET made VSLI (microprocessors and memories) possible.

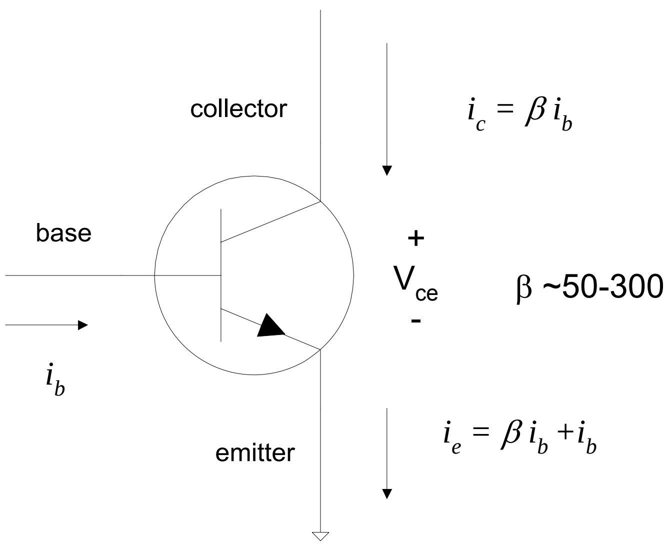
Very high input resistance

Voltage controlled device

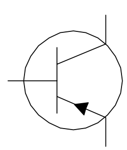
~25 V max operating

# Bipolar Junction Transistors

NPN

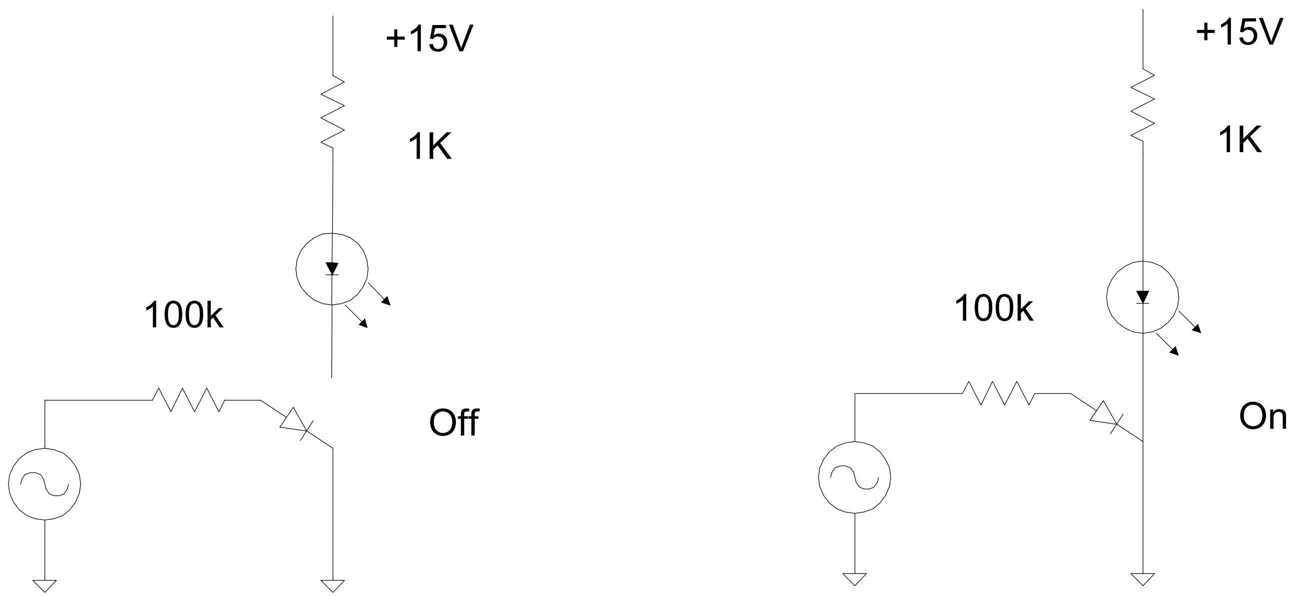



PNP



- BJT can operate in a linear mode (amplifier) or can operate as a digital switch.
- Current controlled device
- Two families: npn and pnp.
- BJT's are current controlled devices
- NPN – 2N2222
- PNP – 2N2907
- $V_{CE}$ ~30V, 500 mw power

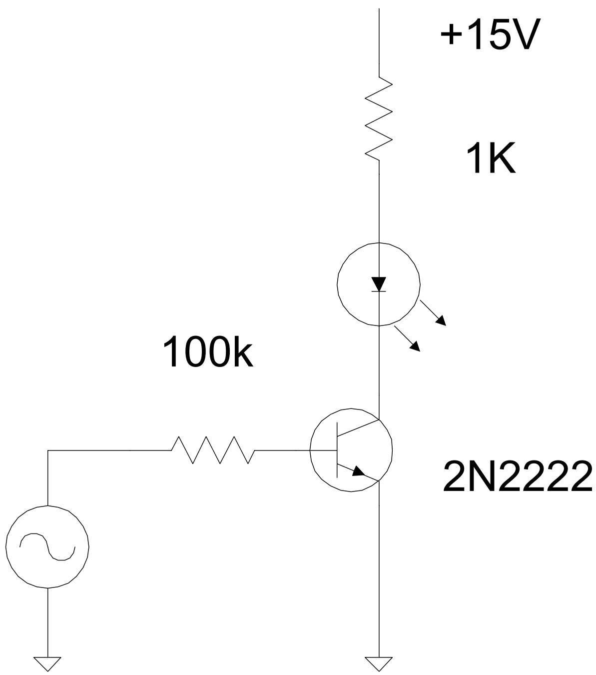
# BJT Switching Models



# Light Emitting Diode

- LED’s are pn junction devices which emit light. The frequency of the light is determined by a combination of gallium, arsenic and phosphorus.
- Red, yellow and green LED’s are in the lab
- Diodes have polarity
- Typical forward current 10-20ma

# Lab Exercise




- Wire up protoboard.
- Turn on function generator and using a ramp signal try to get a pulsing light

# Optical Isolators

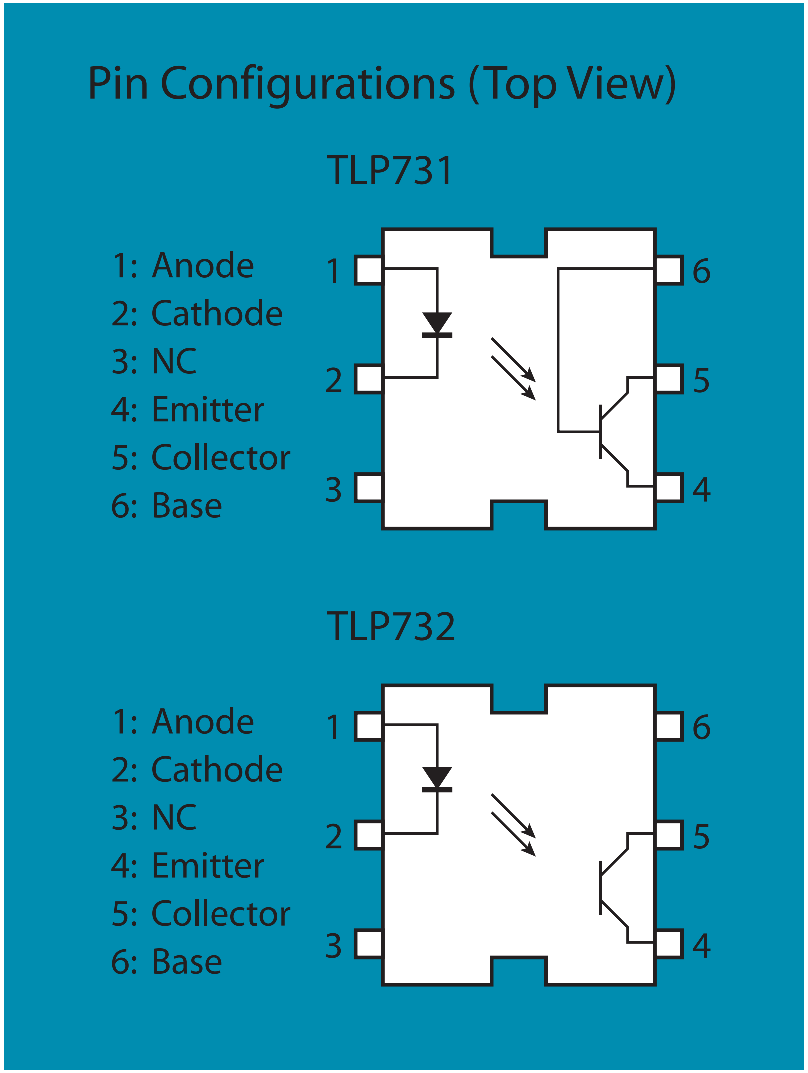
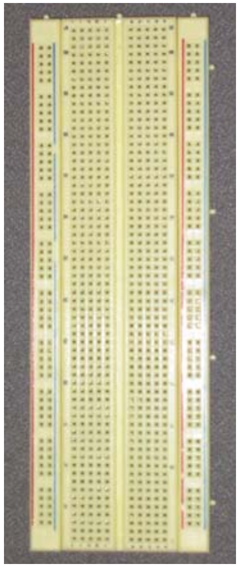


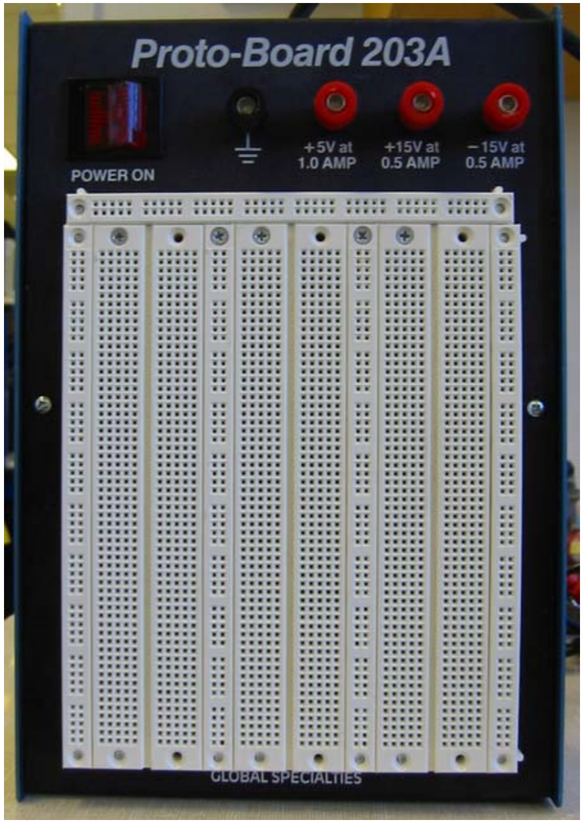

Figure by MIT OpenCourseWare.

- Optical Isolators are used to transmit information optically without physical contact.
- Single package with LED and photosensor (BJT, thyristor, etc.)
- Isolation up to 4000 Vrms

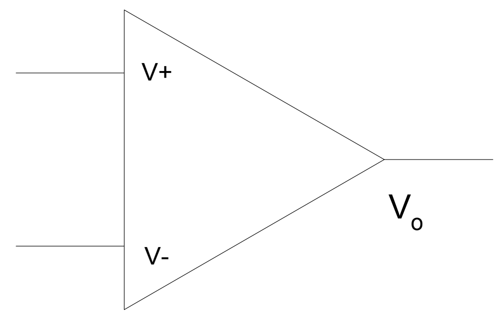
# Proto-Board

- +5v, +15v, -15v available
- Pins within row or column connected
- Use bypass capacitors liberally



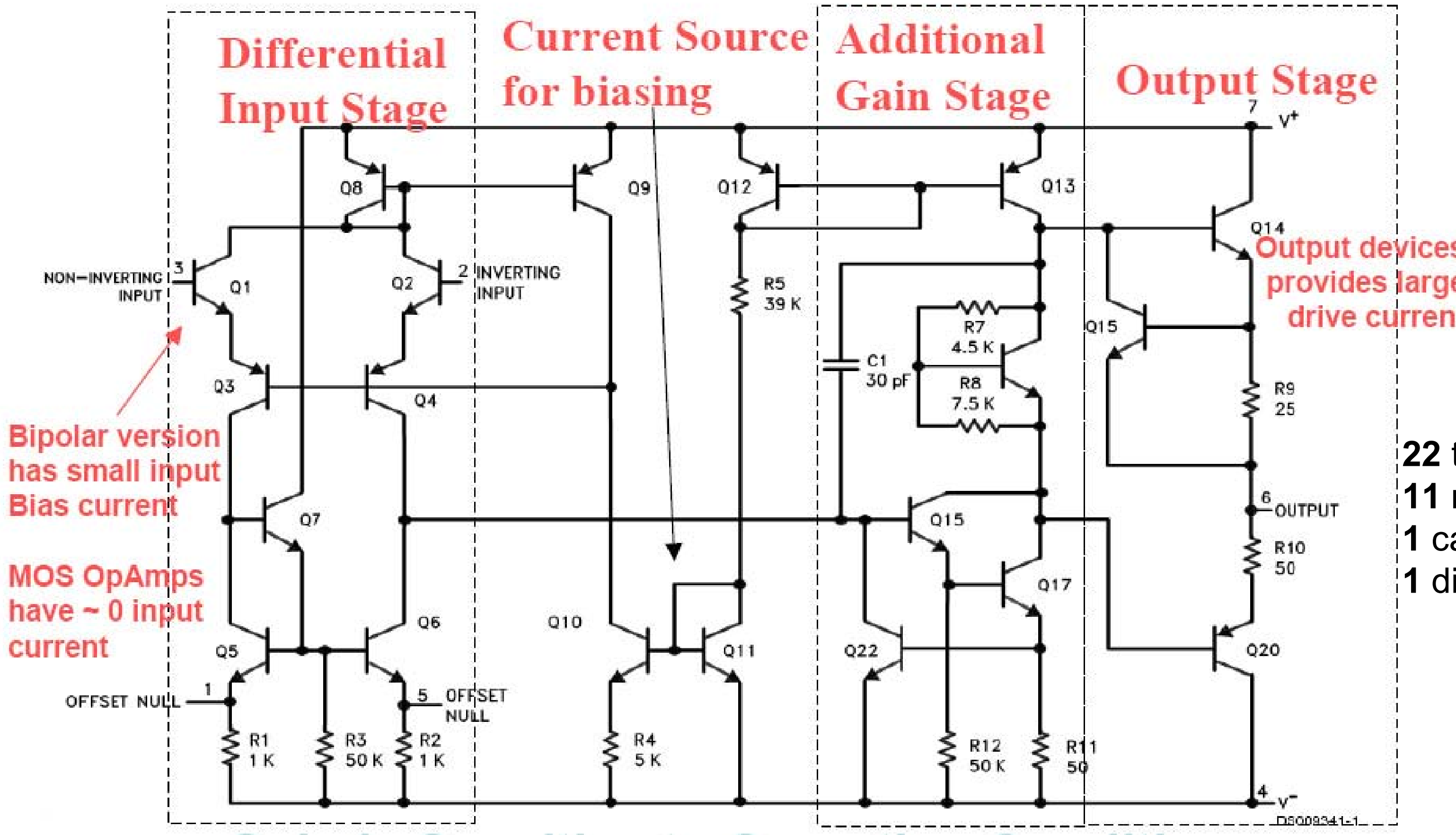


# Op-Amps




- Active device: $V_0 = A(V_+ - V_-)$; note that it is the difference of the input voltage!
- A=open loop gain ~ $10^5 - 10^6$
- Most applications use negative feedback.
- Comparator: no feedback
- Active device requires power. No shown for simplicity.
- Classics op-amps: 741, 357 ~ $0.20

# 741 Circuit




**22** transistors,
**11** resistors,
**1** capacitor,
**1** diode

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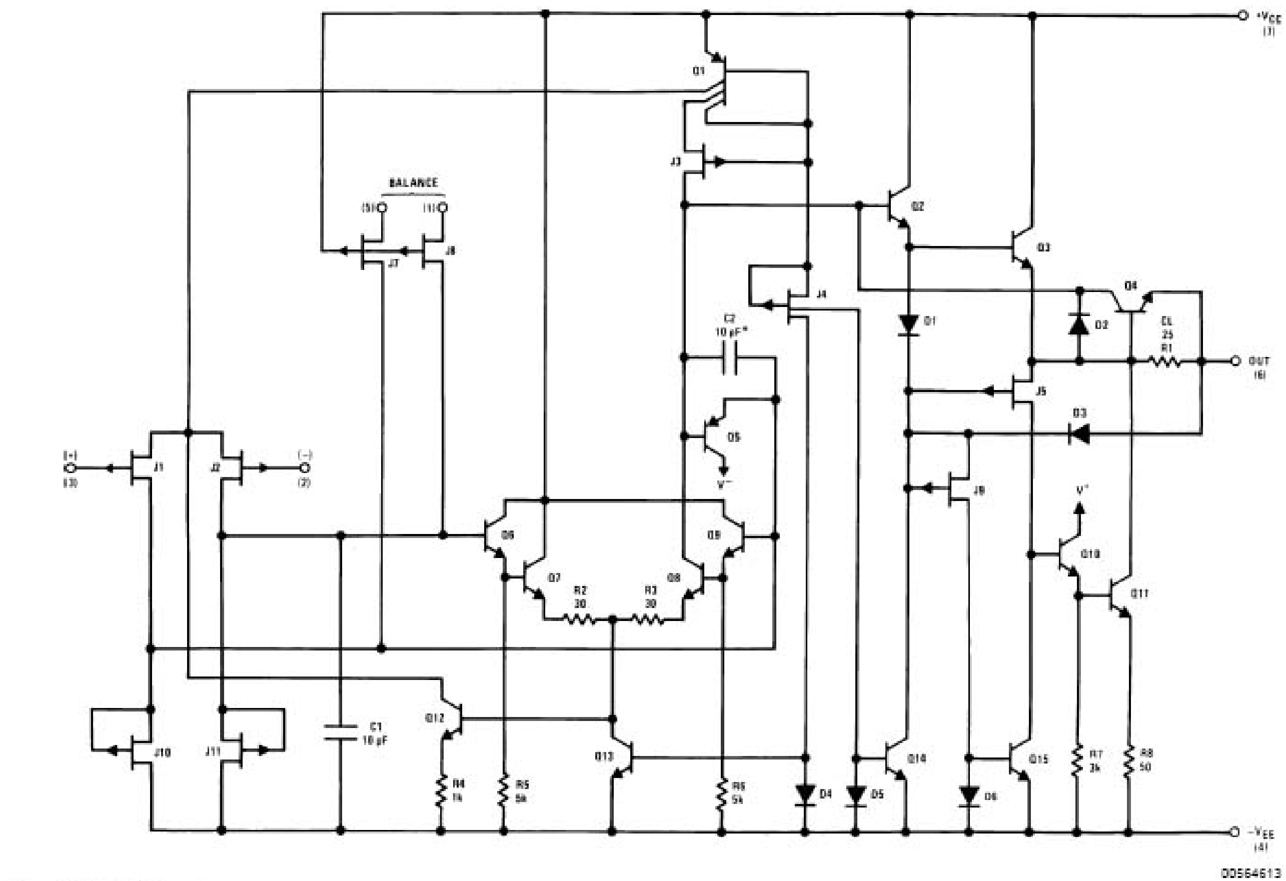
# 356 JFET Input Op-amp




*C = 3pF in LF357 series.

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# 741 Op Amp Max Ratings

**MAXIMUM RATINGS**

| Rating | Symbol | Value | Unit |
|---|---|---|---|
| Power Supply Voltage | $V_{CC}$, $V_{EE}$ | ±18 | Vdc |
| Input Differential Voltage | $V_{ID}$ | ±30 | V |
| Input Common Mode Voltage (Note 1.) | $V_{ICM}$ | ±15 | V |
| Output Short Circuit Duration (Note 2.) | $t_{SC}$ | Continuous | – |
| Operating Ambient Temperature Range | $T_A$ | 0 to +70 | °C |
| Storage Temperature Range | $T_{stg}$ | –55 to +125 | °C |

1. For supply voltages less than +15 V, the absolute maximum input voltage is equal to the supply voltage.
2. Supply voltage equal to or less than 15 V.

# 741 Electrical Characteristics

ELECTRICAL CHARACTERISTICS ($V_{CC}$ = +15 V, $V_{EE}$ = –15 V, $T_A$ = 25°C, unless otherwise noted.)

| Characteristic | Symbol | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| Input Offset Voltage ($R_S \le 10$ k) | $V_{IO}$ | – | 2.0 | 6.0 | mV |
| Input Offset Current | $I_{IO}$ | – | 20 | 200 | nA |
| Input Bias Current | $I_{IB}$ | – | 80 | 500 | nA |
| Input Resistance | $r_i$ | 0.3 | 2.0 | – | MΩ |
| Input Capacitance | $C_i$ | – | 1.4 | – | pF |
| Offset Voltage Adjustment Range | $V_{IOR}$ | – | ±15 | – | mV |
| Common Mode Input Voltage Range | $V_{ICR}$ | ±12 | ±13 | – | V |
| Large Signal Voltage Gain ($V_O = \pm 10$ V, $R_L \ge 2.0$ k) | $A_{VOL}$ | 20 | 200 | – | V/mV |
| Output Resistance | $r_o$ | – | 75 | – | Ω |
| Common Mode Rejection ($R_S \le 10$ k) | CMR | 70 | 90 | – | dB |
| Supply Voltage Rejection ($R_S \le 10$ k) | PSR | 75 | – | – | dB |
| Output Voltage Swing | $V_O$ | | | | V |
| ($R_L \ge 10$ k) | | ±12 | ±14 | – | |
| ($R_L \ge 2.0$ k) | | ±10 | ±13 | – | |
| Output Short Circuit Current | $I_{SC}$ | – | 20 | – | mA |
| Supply Current | $I_D$ | – | 1.7 | 2.8 | mA |
| Power Consumption | $P_C$ | – | 50 | 85 | mW |
| Transient Response (Unity Gain, Noninverting) | | | | | |
| ($V_I$ = 20 mV, $R_L \ge$ 2.0 k, $C_L \le$ 100 pF) Rise Time | $t_{TLH}$ | – | 0.3 | – | µs |
| ($V_I$ = 20 mV, $R_L \ge$ 2.0 k, $C_L \le$ 100 pF) Overshoot | os | – | 15 | – | % |
| ($V_I$ = 10 V, $R_L \ge$ 2.0 k, $C_L \le$ 100 pF) Slew Rate | SR | – | 0.5 | – | V/µs |

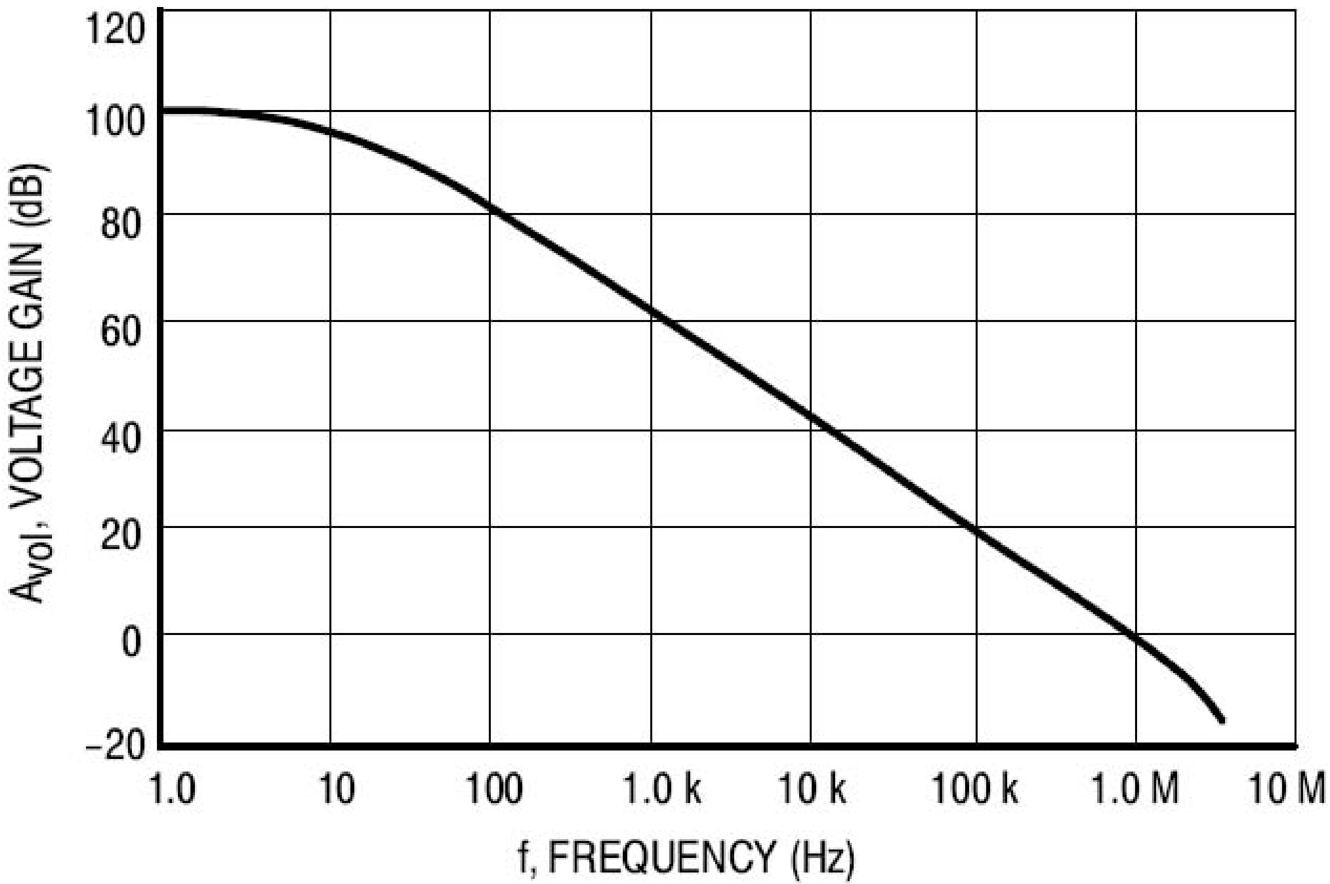
# Decibel (dB)

$$dB = 20\log\left(\frac{V_o}{V_i}\right) \qquad dB = 10\log\left(\frac{P_o}{P_i}\right)$$

$\log_{10}(2)=.301$

3 dB point = ?

# 741 Open Loop Frequency Gain



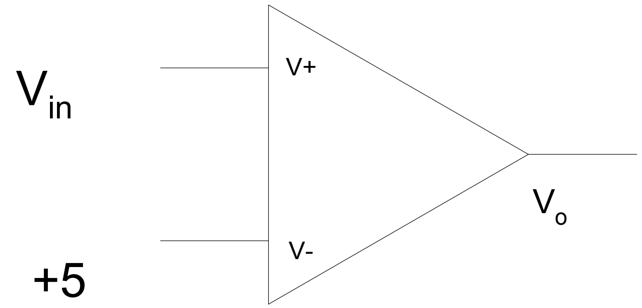
# 741 vs 356 Comparison

| | 741 | 356 |
|---|---|---|
| Input device | BJT | JFET |
| Input bias current | 0.5uA | 0.0001uA |
| Input resistance | 0.3 MΩ | $10^6$ MΩ |
| Slew rate* | 0.5 v/us | 7.5 v/us |
| Gain Bandwidth product | 1 Mhz | 5 Mhz |
| Output short circuit duration | Continuous | continuous |
| Identical pin out | | |

* comparators have >50 v/us slew rate

# Comparator Operation

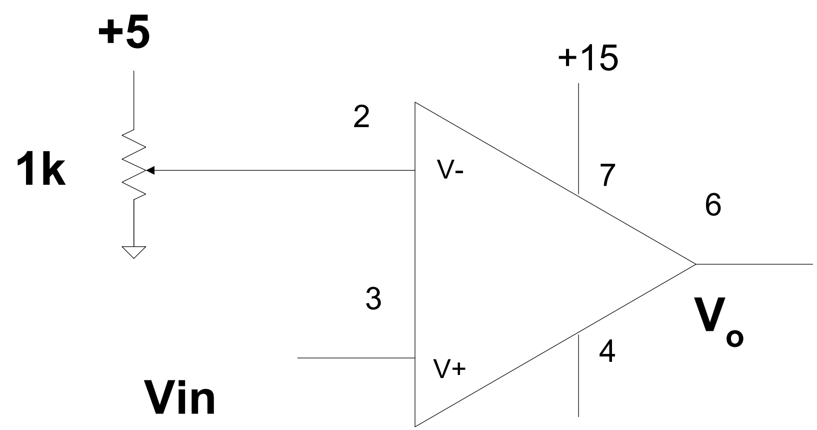
- Supply voltage = +15v, -15V
- V- = +5 V




- For $V_{in}$ = +4, $V_o$ = ?
- For $V_{in}$ = +5.1, $V_o$ = ?
- Comparators are design for fast response time and high slew rate.

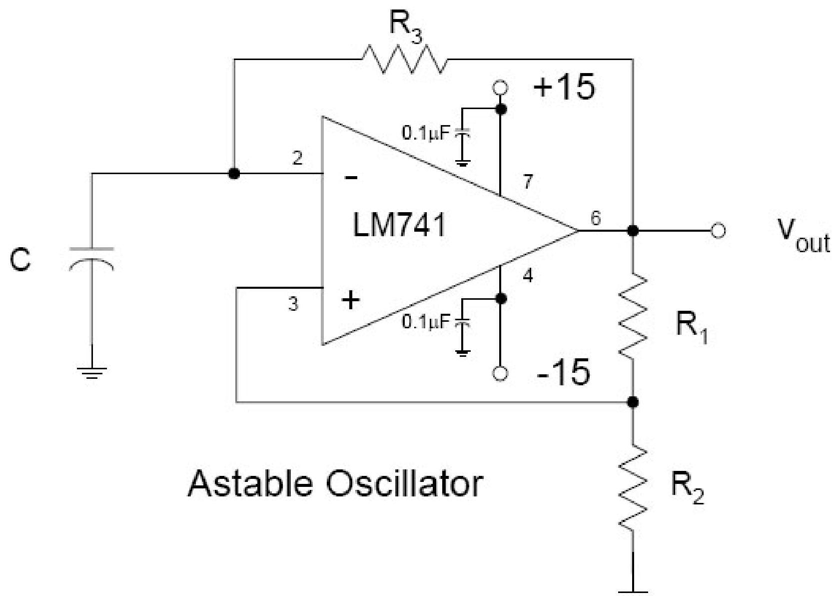
# Lab Exercise - Comparator

- Wire up a comparator on the proto-board using 741 op-amp. Be sure to supply power and ground.




- Turn on function generator using a ramp. Display both the input and the output on an oscilloscope. Describe what is happening.
- What is the maximum output voltage (the plus rail)?
- What is the minimum output voltage (negative rail)?

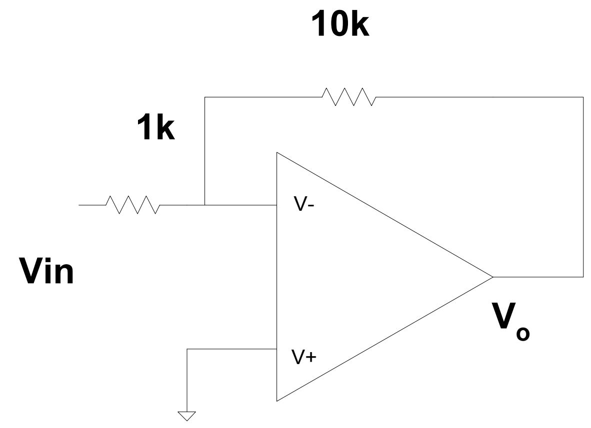
# Lab Exercise - Oscillator



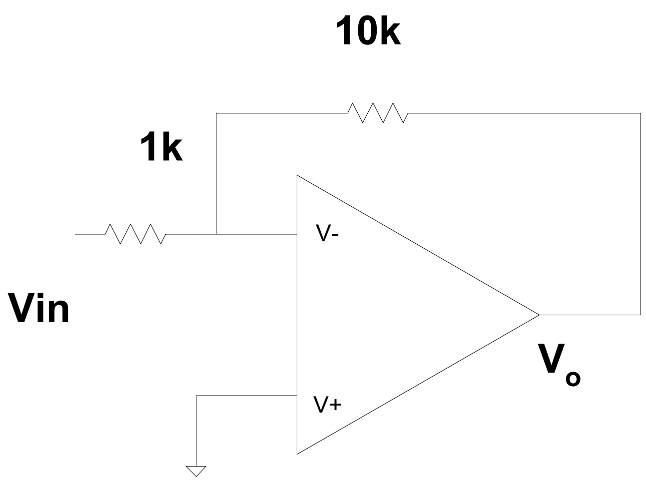

- Wire up a comparator on the proto-board using 741 op-amp. Be sure to supply power and ground.
- R1=10k, R2=4.7k, R3=10K, C=.33uf
- Display V- and $V_{out}$ on the scope. Describe what is happening. Set R3=4.7k. Predict what happens to the frequency.

# Lab Exercise – Inverting amplifier

- Wire up a comparator on the proto-board using 741 op-amp. Be sure to supply power and ground. Find the pin #
- Turn on function generator using a ramp. Display both the input and the output on an oscilloscope. How is the output related to the input?
- What is the peak output voltage?
- What is the minimum output voltage?
- What at frequency does the gain start to drop below ten?

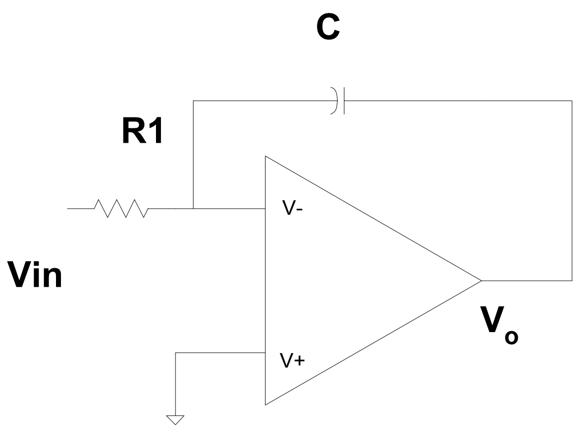


# Negative Feedback



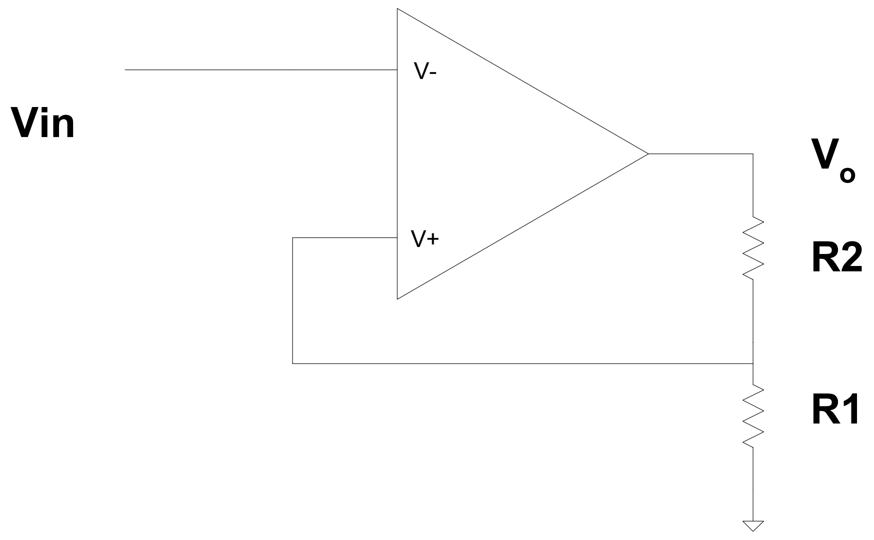

- Take product with 100,000 gain and reduce it to 10?

# Lab Exercise – Integrator




- Op-amps are frequently used as integrators. Wire up an integrator on the proto-board using a 741 op-amp. Be sure to supply power and ground. R1=47K, C=0.1uf
- Input a square wave to the integrator. What is the minimum frequency for for which the integrates? Display both the input and the output on an oscilloscope.
- Notice that for a square wave, the output voltage is proportional to the "on" time.

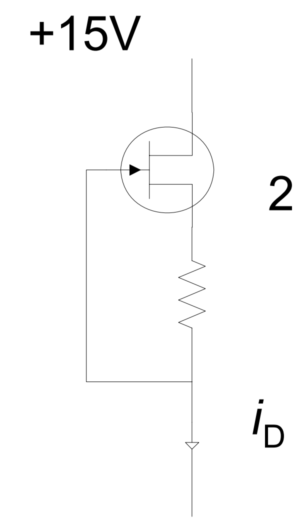
# Lab Exercise - Schmitt Trigger




- Schmitt trigger have different triggers points for rising edge and falling edge.
- Can be used to reduce false triggering
- This is NOT a negative feedback circuit.

# Current Source

- Household application: battery charger (car, laptop, mp3 players)
- Differential amplifier current source
- Ramp waveform generator
- High Speed DA converter using capacitors
- Simple circuit: 2N5459 Nchannel JFET




$I_{DSS}$ = current with $V_{GS}$=0

$V_P$ = pinchoff voltage

$$i_D = I_{DSS}\left(1 - \frac{v_{GS}}{V_P}\right)^2$$

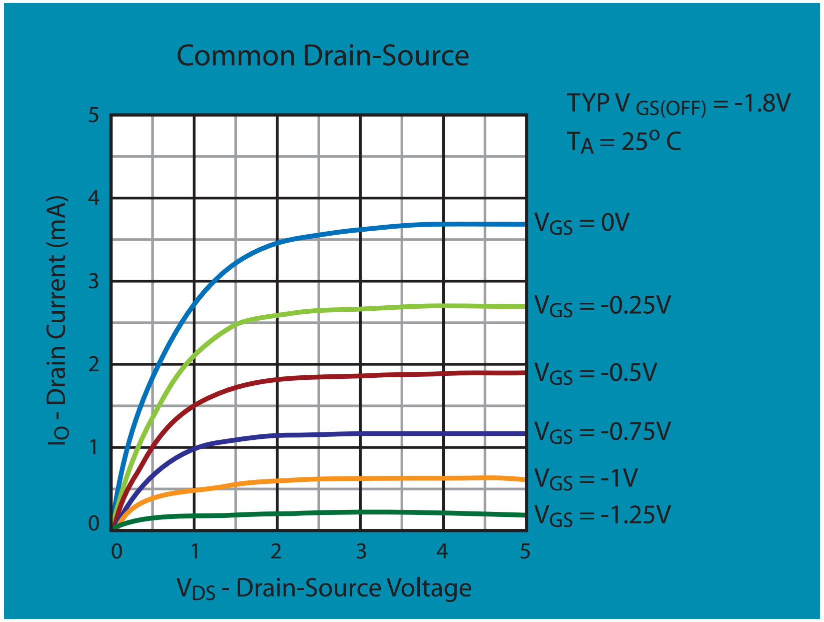
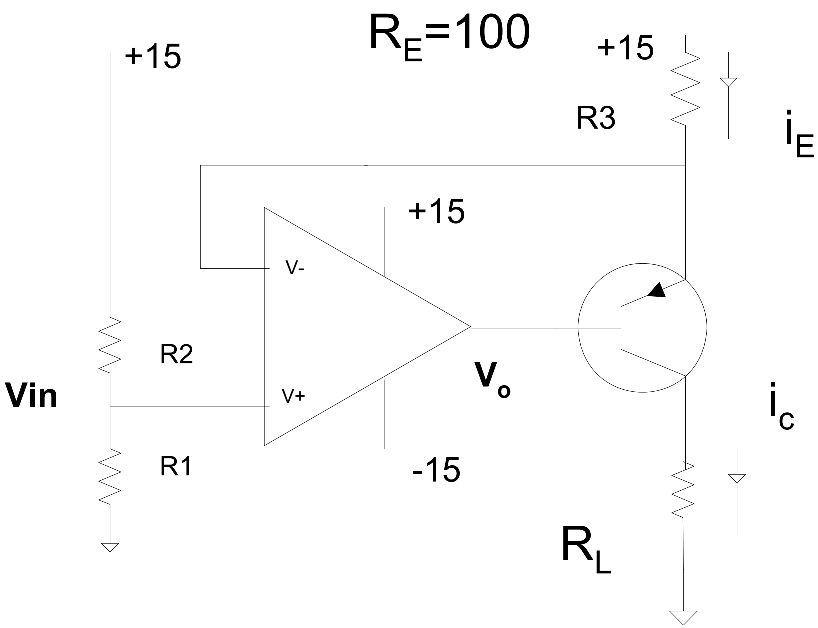



Figure by MIT OpenCourseWare.

# Voltage Control Current Source*




- Feedback forces $V_+ = V_-$.
- $R_E$=100, $\beta_F$=100, Vin=5
- $i_E \sim i_C$
- R1=10k, R2=4.7k, R3=10K, C=.33uf
- R1, R2 can be replaced with a pot.

* Fall 2006 6.101 lab exercise

# Lecture 2 Summary

- BJT, MOSFET
- Op Amp circuits
  - Comparator
  - Oscillator
  - Schmitt trigger
  - Current Source