Lecture/Laboratory #4 & #5

Outline

1. Review transistors from previous lecture
2. Discussion laboratory work
3. Transistors (cont.)
    - Common Emitter Ampl., Emitter Follower
    - Differential ampl.
    - "Rule of Thumb" for transistors use
    - Data for 2N 3904 transistor (npn silicon trans.)
4. Operational Amplifiers and Servos (Introduction)
    - General about Op-Amps
    - General about Servos

Laboratory work:

1. (a) Transistor switch (driving lamp)

   (b) Darlington pair (driving motor)

2. "O-order" servo with op-amp
    - Introduction to Data Table of "747" Op-Amp
    - Current in motor (measurements); damping time.

Bipolar Transistor

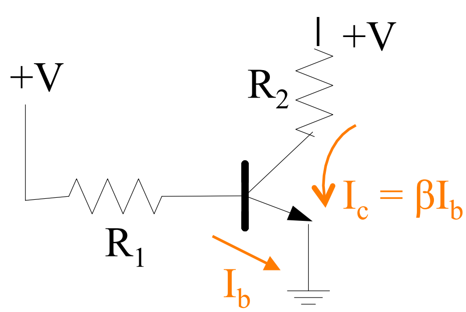
The basic rules for npn transistors (for pnp polarity is reversed):

1. Collector – must be more positive than emitter
2. Base – emitter and base-collector circuits behave like diodes (normally base-emitter diode is conducting and base-collector diode is reverse-biased). However collector current changes a little with applied voltage, whereas diode current changes strongly with voltage.
3. For given transistor → max. values of I_c, I_b, and V_{ce}
4. Relation between I_c and I_b:

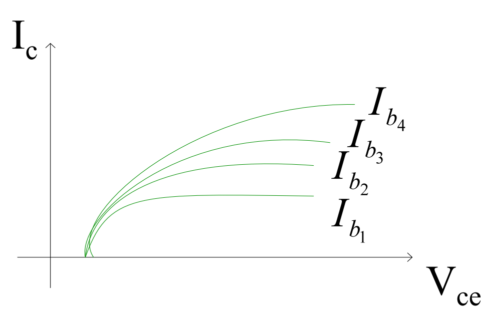
$$I_c = h_{fe} I_b = \beta I_b \leftarrow$$ small changes in $I_b \Rightarrow$ large changes in I_c

h_{fe} (or β) is gain (≈ 100)

Both I_c and I_b are flowing to the emitter: $I_e = I_c + I_b = (\beta + 1) I_b$



"Saturation" – collector saturation voltage at given I_b



$V_{ce}(\text{sat.}) \approx 0.05 - 0.2$ V

Transistors (cont.)

Example: $V = +5V$, $R_1 = 1\ M\Omega$

$I_b = 5\ \mu A$ (actually $4.4\ \mu A$,

because 0.6 V drop on base-emitter trans.)

$$V_{be} \approx 0.6\ V \Rightarrow V_e = V_b - 0.6\ V$$

If $R_2 = 0 \Rightarrow I_c = 500\ \mu A$

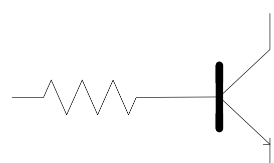
If $R_2 = 10\ k\Omega \Rightarrow I_c = 500\ \mu A$ – just at saturation ($V_{ce} \cong V_e$)

If $R_2 = 1\ M\Omega \Rightarrow I_c = 5\ \mu A \rightarrow V_{ce} \Rightarrow 0$

<u>Bipolar transistors are current devices</u>

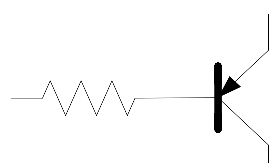
Most digital logic outputs are current sink (pnp – transistors)

current <u>source</u>



npn

current <u>sink</u>



pnp

TYPES 2N3903, 2N3904, A5T3903, A5T3904
N-P-N SILICON TRANSISTORS

BULLETIN NO. DL-S 7311576, NOVEMBER 1971 – REVISED MARCH 1973

SILECT† TRANSISTORS‡

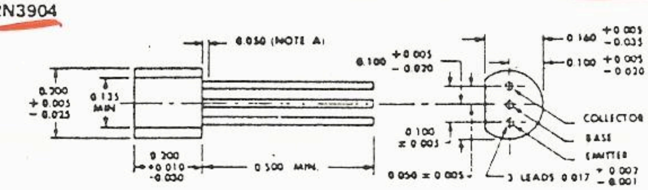
FOR GENERAL PURPOSE SATURATED-SWITCHING AND AMPLIFIER APPLICATIONS

- For Complementary Use with P-N-P Types 2N3905, 2N3906, A5T3905, and A5T3906
- Rugged One-Piece Construction with In-Line Leads or Standard TO-18 100-mil Pin-Circle Configuration

mechanical data

These transistors are encapsulated in a plastic compound specifically designed for this purpose, using a highly mechanized process developed by Texas Instruments. The case will withstand soldering temperatures without deformation. These devices exhibit stable characteristics under high-humidity conditions and are capable of meeting MIL-STD-202C, Method 106B. The transistors are insensitive to light.

2N3903, 2N3904

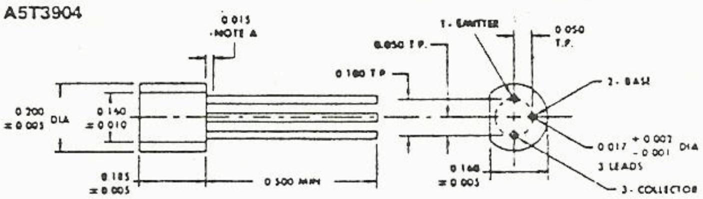


NOTES: A. Lead diameter is not controlled in this area.
B. All dimensions are in inches.

*ALL JEDEC TO-92 DIMENSIONS AND NOTES ARE APPLICABLE

EBC

A5T3903, A5T3904



NOTES: A. Lead diameter is not controlled in this area.
B. Leads having maximum diameter (0.019) shall be within 0.007 of their true positions measured in the gaging plane 0.054 below the seating plane of the device relative to a maximum-diameter package.
C. All dimensions are in inches.

absolute maximum ratings at 25°C free-air temperature (unless otherwise noted)

Collector-Base Voltage	60 V*
Collector-Emitter Voltage (See Note 1)	40 V*
Emitter-Base Voltage	6 V*
Continuous Collector Current	200 mA*
Continuous Device Dissipation at (or below) 25°C Free-Air Temperature (See Note 2)	625 mW§ 310 mW*
Storage Temperature Range	−65°C to 150°C§ −55°C to 135°C*
Lead Temperature 1/16 Inch from Case for 60 Seconds	260°C§ 230°C*

NOTES 1. This value applies between 10 μA and 200 mA collector current when the base-emitter diode is open-circuited.
2. Derate the 625-mW rating linearly to 150°C free-air temperature at the rate of 5 mW/°C. Derate the 310-mW (JEDEC registered) rating linearly to 135°C free-air temperature at the rate of 2.81 mW/°C.

*The asterisk identifies JEDEC registered data for the 2N3903 and 2N3904 only. This data sheet contains all applicable registered data in effect at the time of publication.

†Trademark of Texas Instruments

‡U.S. Patent No. 3,439,238

§Texas Instruments guarantees these values in addition to the JEDEC registered values which are also shown.

USES CHIP N14

TYPES 2N3903, 2N3904, A5T3903, A5T3904
N-P-N SILICON TRANSISTORS

√ 2N 3904

*electrical characteristics at 25°C free-air temperature

PARAMETER		TEST CONDITIONS		2N3903, A5T3903 MIN	2N3903, A5T3903 MAX	2N3904, A5T3904 MIN	2N3904, A5T3904 MAX	UNIT
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	$I_C = 10\ \mu A$, $I_E = 0$		60		60		V
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	$I_C = 1\ mA$, $I_B = 0$,	See Note 3	40		40		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 10\ \mu A$, $I_C = 0$		6		6		V
I_{CEV}	Collector Cutoff Current	$V_{CE} = 30\ V$, $V_{BE} = -3\ V$			50		50	nA
I_{BEV}	Base Cutoff Current	$V_{CE} = 30\ V$, $V_{BE} = -3\ V$			−50		−50	nA
h_{FE}	Static Forward Current Transfer Ratio	$V_{CE} = 1\ V$, $I_C = 100\ \mu A$		20		40		
		$V_{CE} = 1\ V$, $I_C = 1\ mA$		35		70		
		$V_{CE} = 1\ V$, $I_C = 10\ mA$	See Note 3	50	150	100	300	
		$V_{CE} = 1\ V$, $I_C = 50\ mA$		30		60		
		$V_{CE} = 1\ V$, $I_C = 100\ mA$		15		30		
V_{BE}	Base-Emitter Voltage	$I_B = 1\ mA$, $I_C = 10\ mA$	See Note 3	0.65	0.85	0.65	0.85	V
		$I_B = 5\ mA$, $I_C = 50\ mA$			0.95		0.95	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	$I_B = 1\ mA$, $I_C = 10\ mA$	See Note 3		0.2		0.2	V
		$I_B = 5\ mA$, $I_C = 50\ mA$			0.3		0.3	
h_{ie}	Small-Signal Common-Emitter Input Impedance	$V_{CE} = 10\ V$, $I_C = 1\ mA$, $f = 1\ kHz$		1	8	1	10	kΩ
h_{fe}	Small-Signal Common-Emitter Forward Current Transfer Ratio			50	200	100	400	
h_{re}	Small-Signal Common-Emitter Reverse Voltage Transfer Ratio			0.1×10^{-4}	5×10^{-4}	0.5×10^{-4}	8×10^{-4}	
h_{oe}	Small-Signal Common-Emitter Output Admittance			1	40	1	40	µmho
$\lvert h_{fe} \rvert$	Small-Signal Common-Emitter Forward Current Transfer Ratio	$V_{CE} = 20\ V$, $I_C = 10\ mA$, $f = 100\ MHz$		2.5		3		
f_T	Transition Frequency	$V_{CE} = 20\ V$, $I_C = 10\ mA$,	See Note 4	250		300		MHz
C_{obo}	Common-Base Open-Circuit Output Capacitance	$V_{CB} = 5\ V$, $I_E = 0$, $f = 100\ kHz$ to $1\ MHz$			4		4	pF
C_{ibo}	Common-Base Open-Circuit Input Capacitance	$V_{EB} = 0.5\ V$, $I_C = 0$, $f = 100\ kHz$ to $1\ MHz$			8		8	pF

NOTES: 3. These parameters must be measured using pulse techniques. $t_w = 300\ \mu s$, duty cycle ≤ 2%.

4. To obtain f_T, the $\lvert h_{fe} \rvert$ response with frequency is extrapolated at the rate of −6 dB per octave from f = 100 MHz to the frequency at which $\lvert h_{fe} \rvert = 1$.

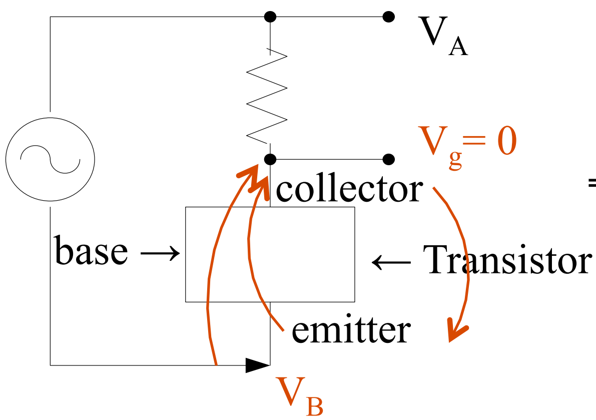
*operating characteristics at 25°C free-air temperature

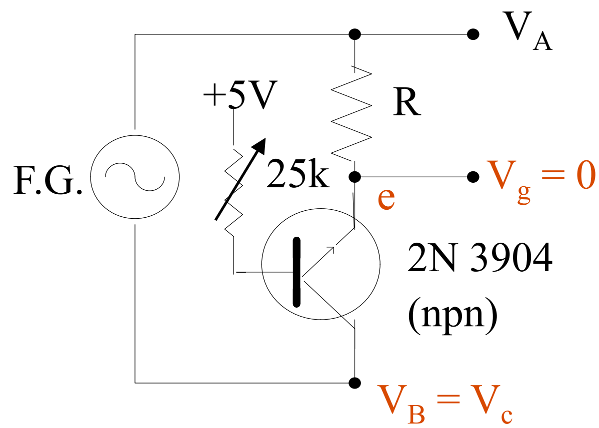
PARAMETER		TEST CONDITIONS	2N3903, A5T3903 MIN	2N3903, A5T3903 MAX	2N3904, A5T3904 MIN	2N3904, A5T3904 MAX	UNIT
$\overline{NF}$	Average Noise Figure	$V_{CE} = 5\ V$, $I_C = 100\ \mu A$, $R_G = 1\ k\Omega$, Noise Bandwidth = 15.7 kHz, See Note 5		6		5	dB

NOTE 5: Average Noise Figure is measured in an amplifier with response down 3 dB at 10 Hz and 10 kHz and a high-frequency rolloff of 6 dB/octave.

*The asterisk identifies JEDEC registered data for the 2N3903 and 2N3904 only.

Transistors : Load Curve → Curve Tracer

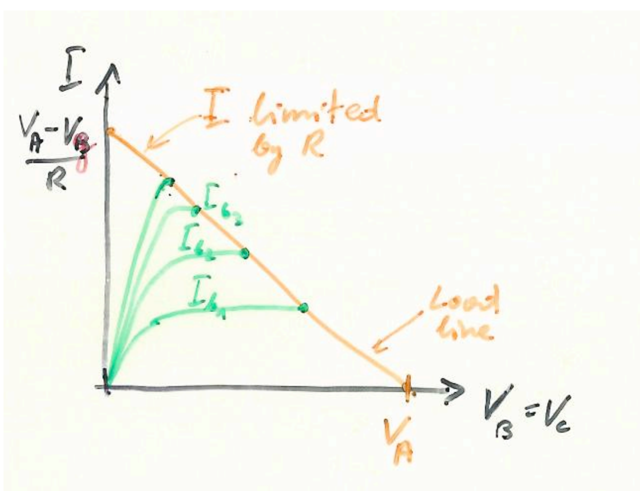




$V_{be} = 0.6$ V $\quad V_e = 0$

$V_b = 0.6$ V

$V_c = V_A - I_c R$



$I_b = .2$ mA

$h_{fc} = 100 \rightarrow I_c = I = 20$ mA

$h_{fe} = 10 \rightarrow I_c = 10$ mA

In Laboratory

(a) Build simple circuit with npn transistor ⇒ choose R and obtain curve tracers

(b) Look for sensitivity of I_c vs I_b

(c) Establish conditions for saturations

Voltage Amplifier

$V_b = V_e + 0.6$ V

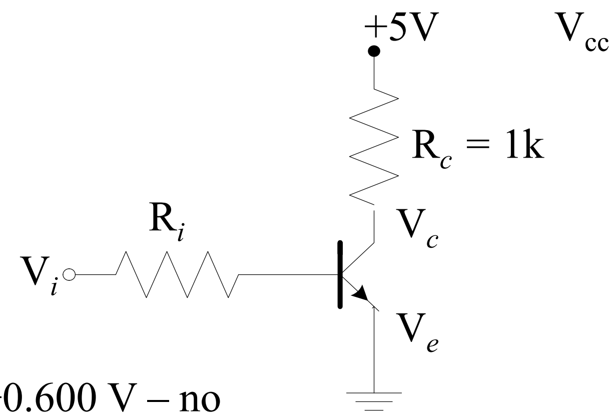
$\Delta V_b = +0.005$ V

$\Delta I_b = \Delta V_b / R_i =$

$$= \frac{0.005V}{1\times10^{+3}\Omega} = 5\mu A$$

$\Delta I_c = \beta \, \Delta I_b \approx 500$ µA

$-\Delta V_c = R_c \, \Delta I_c = 0.5$ V



$V_b = +0.600$ V – no transmission

$= + 0.605$ V - open

Note: Reverse voltage change between base and collector

$\Delta V_{base} = \underline{0.005\text{ V}}$ leads to

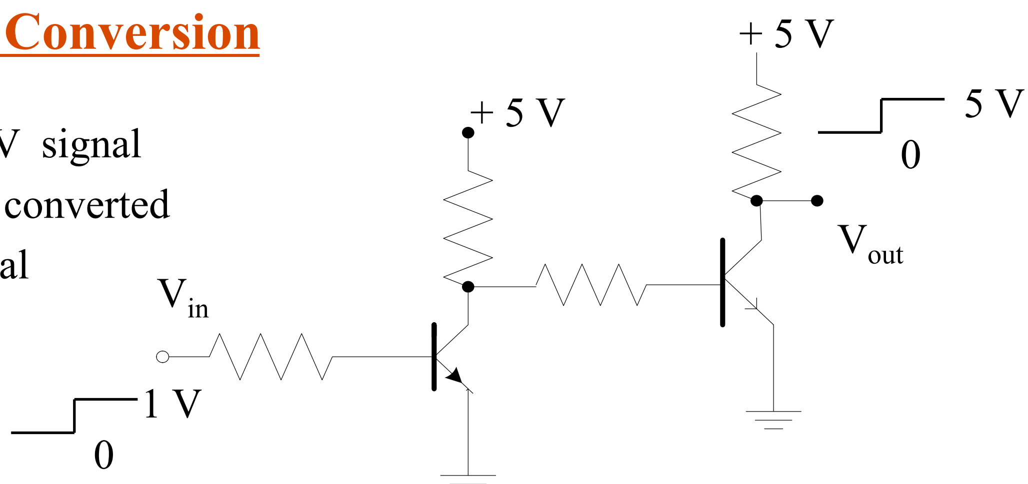
$\Delta V_{coll.} = -\underline{0.5\text{ V}}$

Voltage amplification

(amplification 100, which is equal to gain $\beta = 100$)

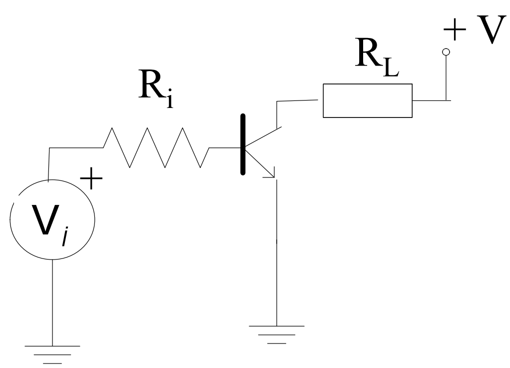
- Voltage Conversion

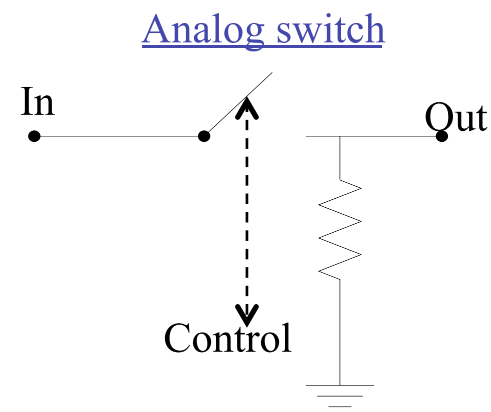
We have 0 – 1 V signal which has to be converted to 0 – 5 V signal



Transistor Switch

Transistor switch is most common use of bipolar transistor





Use to switch analog signal "ON" and "OFF"

Conduction: $V_i > +0.6V \quad ("ON")$

$V_i \leq +0.6V \quad ("OFF")$

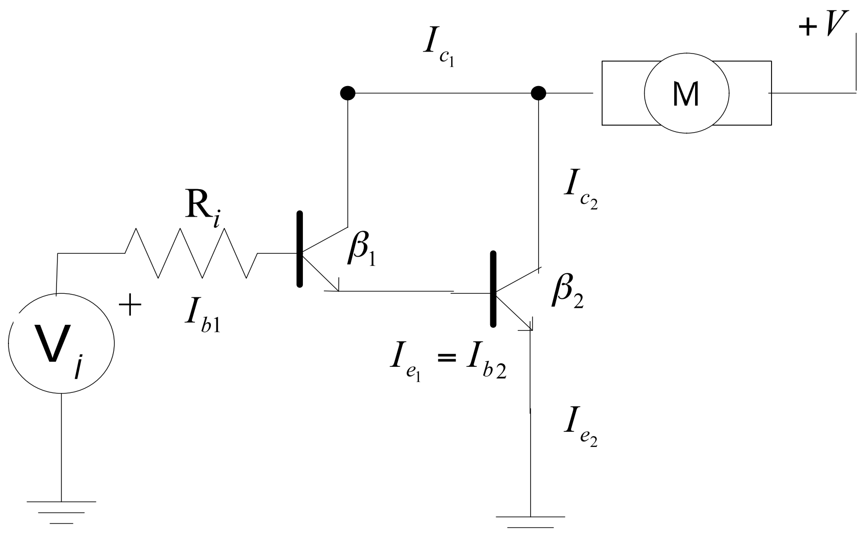
$$I_{c\max} = \frac{V}{R_L} \qquad I_b = \frac{V_i}{R_i} \Rightarrow \underline{\text{ON}} \quad \text{if} \quad \frac{V_i}{R_i} \leq \frac{V}{R_L}\frac{1}{\beta}$$

$$\underline{\text{OFF}} \qquad \text{Else}$$

Laboratory:

Build Transistor switch with R_L as a lamp. Observe conditions on transistor with lamp "ON" and "OFF".

Darlington Pair



$$I_{b_1} = \frac{V_i}{R_i}$$

$$I_{c_1} = \beta_1 I_{b_1}$$

$$I_{e_1} = (\beta_1 + 1) I_{b_1}$$

$$I_{e_1} = I_{b_2}$$

$$I_{e_2} = (\beta_2 + 1) I_{b_2} =$$

$$= (\beta_2 + 1)(\beta_1 + 1) I_{b_1}$$

$$\beta_1 >> 1 \qquad \beta_2 >> 1$$

$$I_{e_2} \approx I_{c_2} \approx \beta_2 \beta_1 I_{b_1}$$

$$I_M = I_{c_2} + I_{c_1} \approx (\beta_2 \beta_1 + \beta_1) I_{b_1}$$

$$I_M \approx \beta_2 \beta_1 I_{b_1}$$

Motor impedance $\mathrm{R_M}$

$$I_{c_2\ \max} = \frac{+V}{R_M}$$

npn - Darlington

Darlington pair – when you need power, and single transistor would burn (e.g. running motor) Darlington transistors are available as single packages.

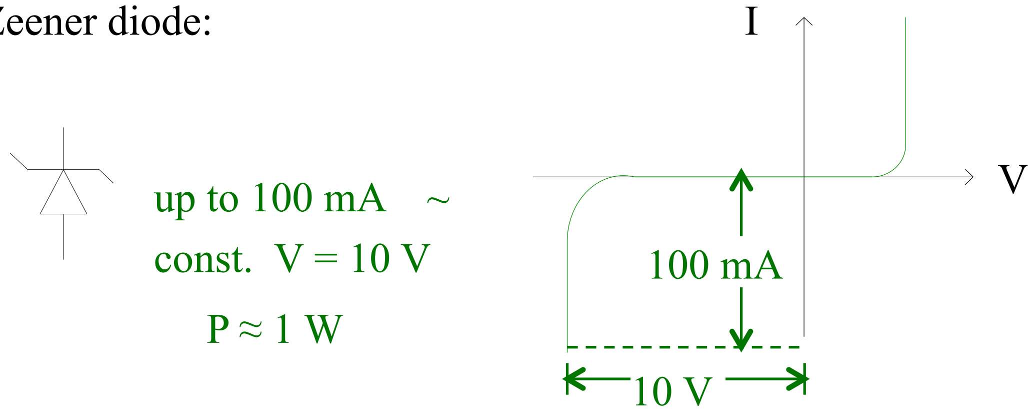
<u>Example</u>: npn power Darlington 2N6285 with $\beta_2\ \beta_1 \approx 4000$ and $I_{c_2} \approx 10\ A$

Laboratory

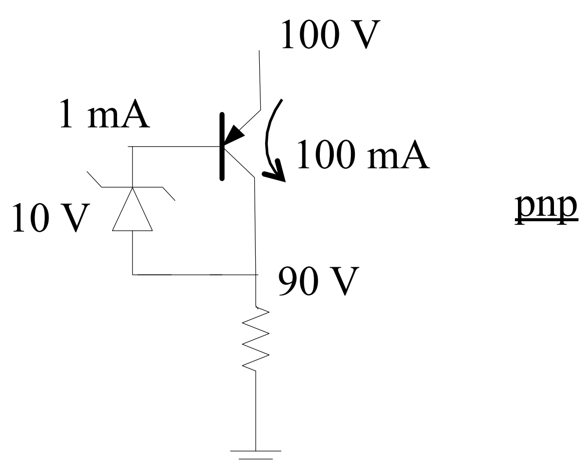
Use Darlington Pair to drive motor. Measure current on motor.

By-Pass Transistor with Zeener Diode

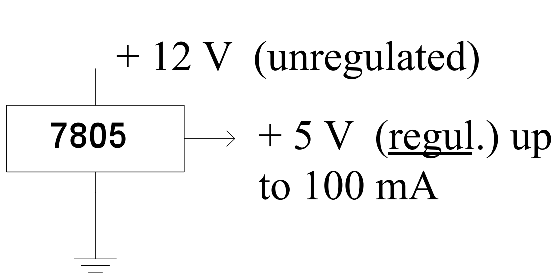
Zeener diode:

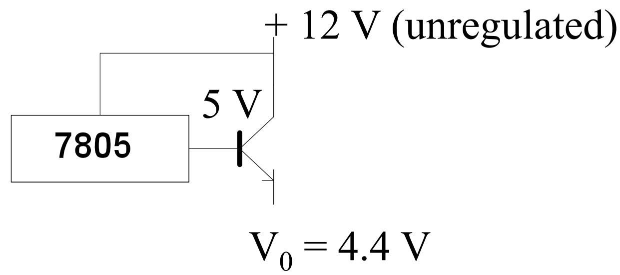


Zeener provides constant 10 V drop for different base currents.



Voltage Regulator



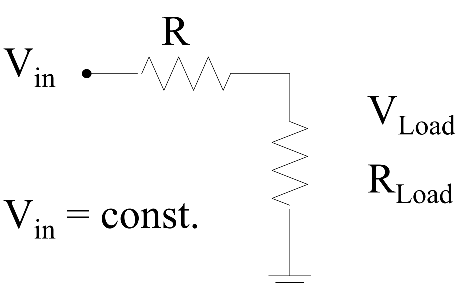


$$if\ \ \mathrm{V}_0 < 4.4V \ \Rightarrow I_b \uparrow \ \Rightarrow V_0 \uparrow$$

$$if\ \ \mathrm{V}_0 > 4.4V \ \Rightarrow I_b \downarrow \ \Rightarrow V_0 \downarrow$$

Transistor Current Source

The simplest approximation



Very poor current source (most power dissipates in R – lost)

If $V_{Load} << V_{in}$ I is nearly constant (small load effect) and

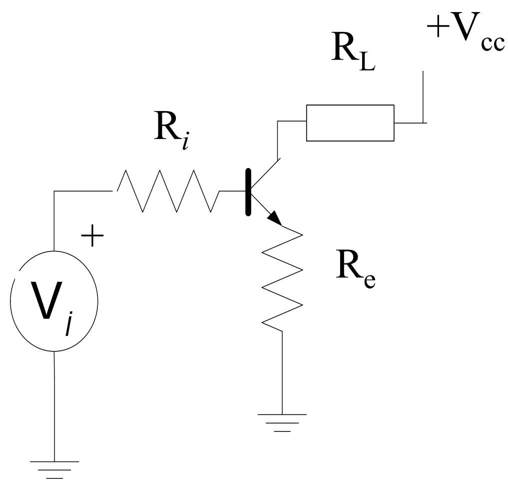
$$I = \frac{V_{in} - V_{Load}}{R} \approx \frac{V_{in}}{R} = const.$$

Transistor Current Source (cont.)

With transistor:

V_{cc} – source voltage on collector side

V_c – collector voltage



Transistor : for $V_b > 0.6$ V emitter conducting

$$V_e = V_b - 0.6\ V \quad \Rightarrow \quad I_e = V_e / R_e$$

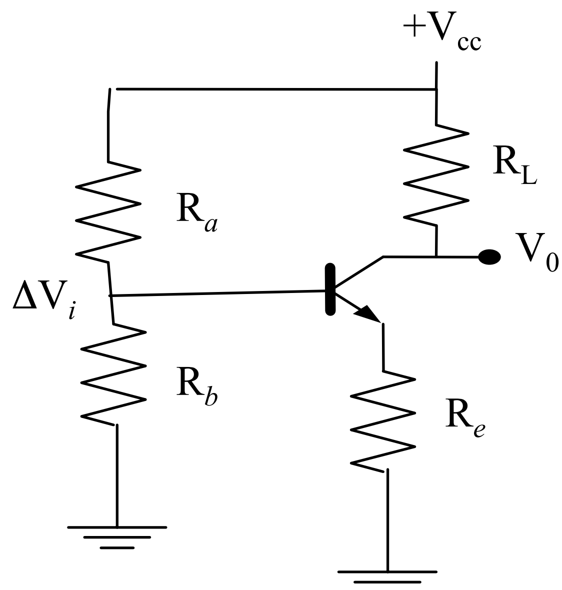
For large β : $\quad I_c \approx I_e = \left(V_b - 0.6\,V\right) / R_e \quad \Rightarrow \quad I_c \neq f(V_{cc})$

current source

Current source for <u>unsaturated</u> transistor $\quad (V_c > V_e + 0.2\ V)$

Common Emitter Amplifier

If in transistor current source circuit we replace load by resistor R_L and use voltage divider R_a / R_b for base voltage $\Rightarrow$ we will have so called Common Emitter Amplifier



$$V_b = \frac{R_b}{R_a + R_b} V_{cc}$$

$$V_e = V_b - 0.6\ V \qquad I_e = V_e / R_e \qquad I_e \approx I_c$$

$$V_0 = V_{cc} - I_c R_L = V_{cc} - \left[\left(V_b - 0.6V \right) / R_e \right] R_L$$

$$\Delta V_0 = -\Delta V_b \frac{R_L}{R_e} = -\Delta V_i \frac{R_L}{R_e}$$

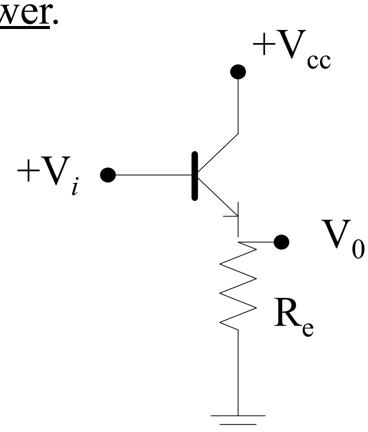
$$\boxed{\frac{\Delta V_0}{\Delta V_i} = gain = -\frac{R_L}{R_e}}$$

If $R_e = 0 \rightarrow$ internal dynamic intrinsic (r_e) resistance of transt. becomes important ($r_e \approx 25\ \Omega$)

For $R_e = 0 \rightarrow$ called Grounded Emitter Amplifier

Emitter Follower

When you need input impedance much higher than output impedance ⇒ you can use emitter follower.



It is called E.F. because output is emitter, which follows the input (base) with one diode drop (0.6 V)

$$V_e = V_b - 0.6\text{ V} \;\; ; \;\; V_0 \approx V_i - 0.6\text{ V}$$

$$(\Delta V_0 \approx \Delta V_i)$$

and $V_i > 0.6$ V for $V_0 > 0$

(If instead of grounded resistor R_e in emitter we would use negative voltage supply, we could use $V_i < 0$)

No collector resistance

$$\Delta I_e = \Delta V_0 / R_e \approx \Delta V_i / R_e \;\Rightarrow\; \Delta V_0 = \Delta I_e R_e \;\; and \;\; \Delta V_0 = (\beta + 1)\Delta I_b R_e$$

$$\Delta V_i = \Delta I_b R_{eff} \Rightarrow \Delta V_i = \frac{\Delta V_0 R_{eff}}{(\beta+1)R_e} \Rightarrow \Delta V_i \approx \Delta V_0$$

R_{eff} – effective input impedance

$$\boxed{R_{eff} = (\beta+1)R_e \approx \beta R_e}$$

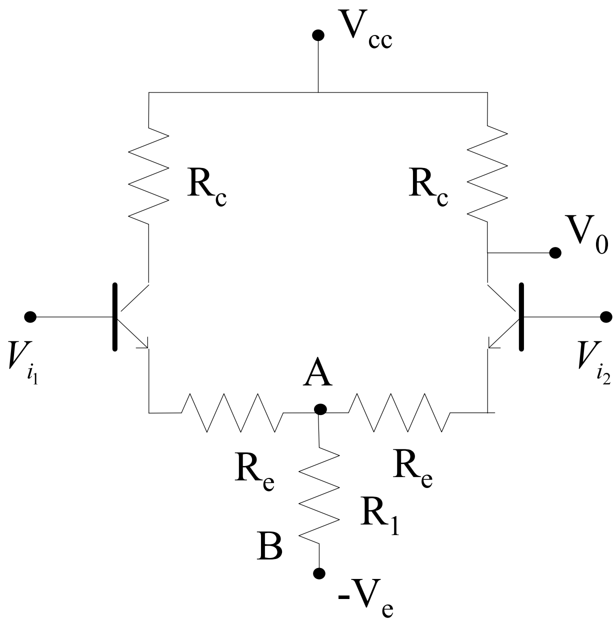
Effectively high input impedance for not so high output impedance R_e (for $R_e = 1$ kΩ → $R_{eff} \approx 100$ kΩ !)

Differential Amplifier

Differential amplifier (DA) → to amplify the voltage difference between two input signals. In ideal DA only difference between two input signals is important.

Common-mode input change → when both inputs change levels together.

Normal-mode (differential mode) → differential change



Common-mode rejection ratio (CMRR) → the ratio of response for a normal-mode signal to the common-mode signal of the same amplitude. Good DA has high CMRR

Gain G_{diff} of DA in normal mode:

Let have $\Delta V_{i_1} = -\Delta V_{i_2}$

$$G_{diff} = \frac{\Delta V_{0(out)}}{\Delta(V_{i_1} - V_{i_2})_{in}} = \frac{\Delta V_0}{2\Delta V_i} \quad \leftarrow \text{ Pt } \underline{A} \text{ fixed}$$

Differential Amplifier (cont.)

$$I_c = \frac{V_{cc} - V_0}{R_c} \rightarrow \Delta I_c = -\frac{\Delta V_0}{R_c}$$

$$\Delta I_c \approx \Delta I_e = \frac{\Delta V_i}{R_e + r_e}$$

$$\Longrightarrow \frac{\Delta V_0}{\Delta V_i} = -\frac{R_c}{R_e + r_e}$$

$$\underbrace{G_{diff} = -\frac{R_c}{2(R_e + r_e)}}$$

$$\underbrace{G_{CM} = -\frac{R_c}{2R_1 + R_e + r_e}} \quad \leftarrow \text{ Pt } \underline{\text{B}} \text{ fixed}$$

$$CMRR = G_{diff} \Big/ G_{CM} = \frac{2R_1 + R_e + r_e}{2(R_e + r_e)}$$

$$G_{CM} = \frac{\Delta V_0}{\Delta V_i^*} \qquad I_c = \frac{V_{cc} - V_0}{R_c}, \quad I_e = \frac{V_i^* - V_A}{R_e + r_e}, \quad I = \frac{V_A - V_e}{R_1} = 2I_e$$

$$\Delta I_c = -\frac{\Delta V_0}{R_c} \approx \Delta I_e, \quad \Delta I_e = -\frac{\Delta V_i^* - \Delta V_A}{R_e + r_e}, \quad \Delta I = -\frac{\Delta V_A}{R_1} = 2\Delta I_e$$

Differential Amplifier (cont.)

$$\frac{\Delta V_i^* - \Delta V_A}{R_e + r_e} = \frac{\Delta V_A}{2R_1} \quad \Rightarrow \quad \Delta V_i^* = \Delta V_A \frac{2R_1 + R_e + r_e}{2R_1}$$

$$where \quad \Delta V_A = -\Delta V_0 \frac{2R_1}{R_c}$$

$$\boxed{G_{CM} = \frac{\Delta V_0}{\Delta V_i^*} = -\frac{R_c}{2R_1 + R_e + r_e}}$$

"Rule of Thumb" for Transistors Use

Ebers-Moll model: transistor is transconductance device → collector current (I_c) is determined by base current (I_b) or by base-to-emitter voltage (V_{be})

Ebers-Moll Equation:

$$I_c = I_s \left[\exp\left(\frac{V_{be}}{V_T}\right) - 1 \right]$$

I_s → saturation current for given T

T is absolute temperature (°K = °C + 273.16)

$V_T = kT/q = 25.3$ mV , q – electron charge

k – Boltzmann constant

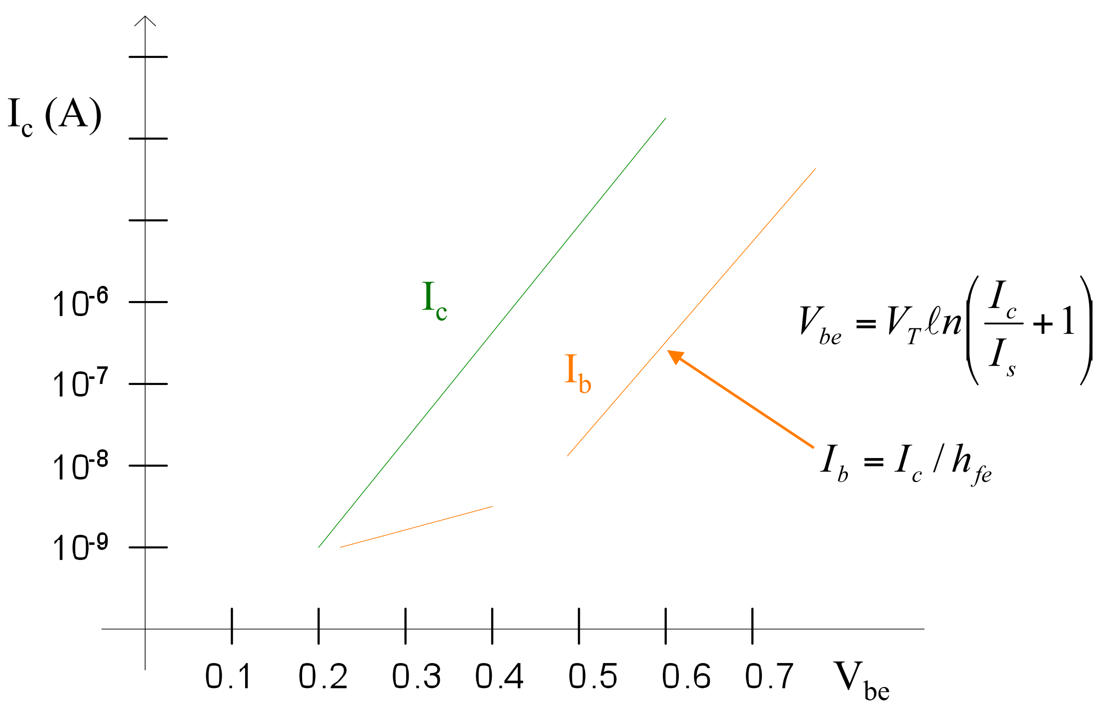
"Rule of Thumb" for Transistors Use (cont.)

Because $I_c = h_{fe}\, I_b \quad \rightarrow \quad I_b = I_c / h_{fe}$

I_s is reverse leakage current, and $I_c >> I_s$ in the active region.

Hence 1 can be neglected in Eq. (Above eq. also describes I vs V for diode). From E – M Eq. $\Rightarrow\ I_c = f(V_{be})$, and $I_b = I_c / h_{fe}$

Exponential law of E – M eq. is correct for very large range of currents $\Rightarrow$ <u>nA → mA</u> $(10^{-9}\,A \rightarrow 10^{-3}\,A)$



“Rule of Thumb” for Transistors Use (cont.)

From E – M Eq.:

(1) The steepness of I_c curve (how much we have to increase V_{be} to increase I_c by 10x ?)

$V_{be} = V_T \ell n (10 + 1) \approx 60$ mV

(2) The small – signal impedance (internal impedance) r_e :

$$r_e = \frac{dV_{be}}{dI_c} = \frac{V_T}{(I_c/I_s)+1}\frac{1}{I_s} \approx \frac{V_T}{I_c} \approx \underline{25/I_c\ \Omega}$$

Intrinsic emitter resistance

(I_c in mA) in room temperature

(3) The temperature dependence of V_{be}:

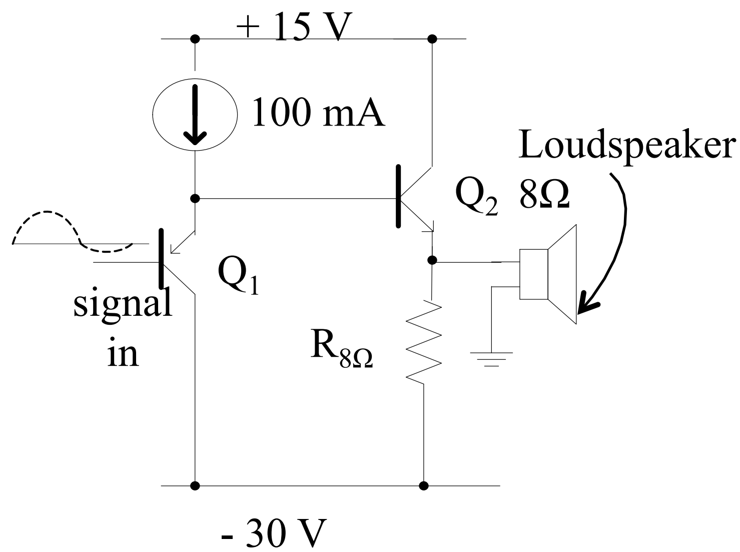
$$I_s = f(T) \Rightarrow V_{be} \sim \frac{1}{T_{abs.}} \Rightarrow \Delta V_{be} \sim -2.1\, mV/{}^\circ K$$

(4) V_{be} varies slightly with changing V_{ce} at constant I_c (Early effect) due to changing effective base width

Approximately: $\Delta V_{be} \approx -0.001\ \Delta V_{cc}$

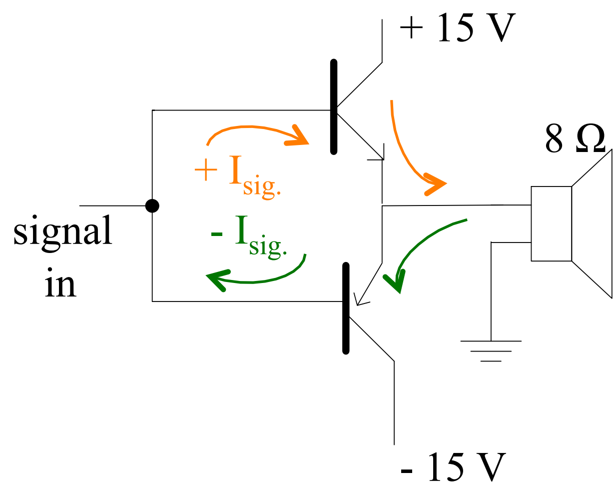
Push-Pull Follower

Single emitter follower with +/- voltage supplies and a ground-returned load require high quiescent current → high quiescent power is dissipated in emitter follower ground resister R and in transistor (Q_2) as well. In example shown: $\underline{P_R = 110\text{ W}}$, $\underline{P_{Q2} = 55\text{W}}$ for <u>10 W</u> in speaker!



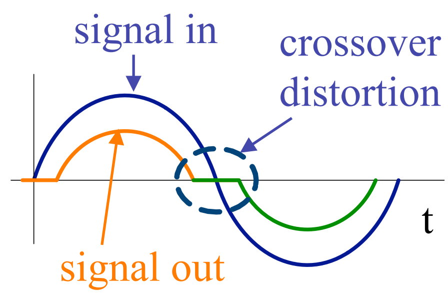
Class A amplifier → dissipates large quiescent power – <u>no good</u>

Much better solution by using push-pull follower ⇒ 10 W in speaker and less than 10 W on each transistor with no dissipation of quiescent power.

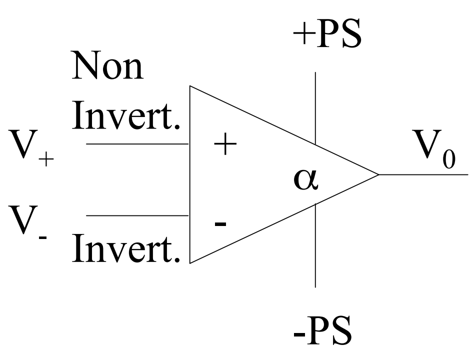


Push-Pull Follower (cont.)

Some crossover distortion



Operational Amplifiers (Op-Amp) and Servos



Very high gain α

$$V_0 = \alpha(V_+ - V_-)$$

$\alpha \sim 10^5 - 10^6$ (or higher)

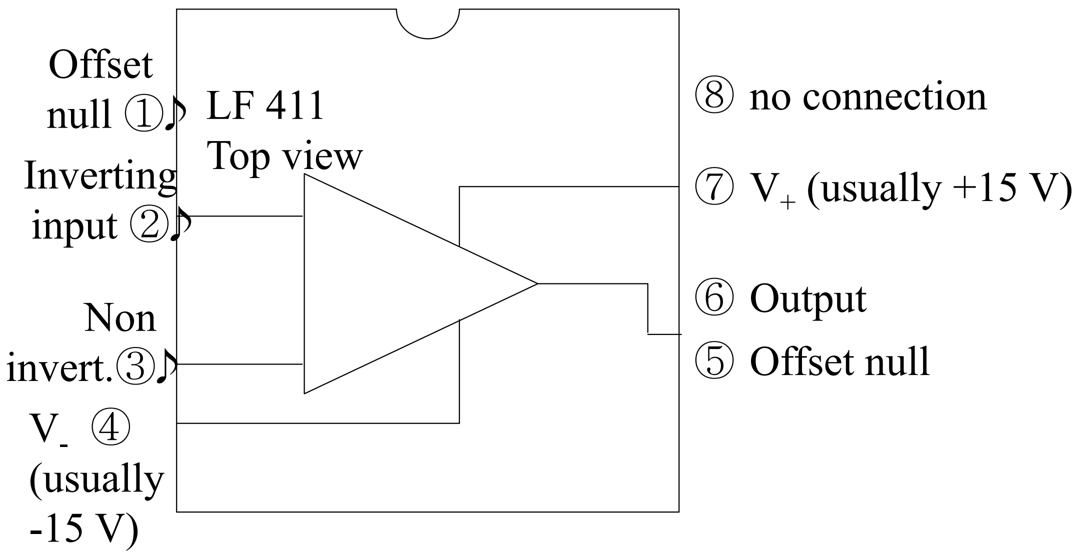
Because so high α Op-amp working almost always with feedback

High input impedance > 1 MΩ

Low output impedance < 1 kΩ (can be very low)

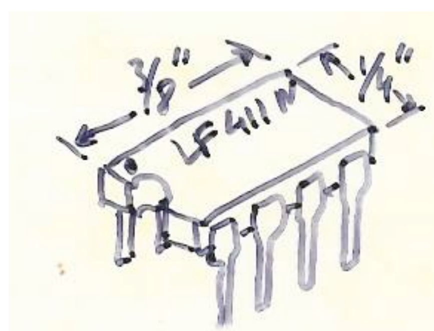
Operational Amplifiers (Op-Amp) and Servos (cont.)

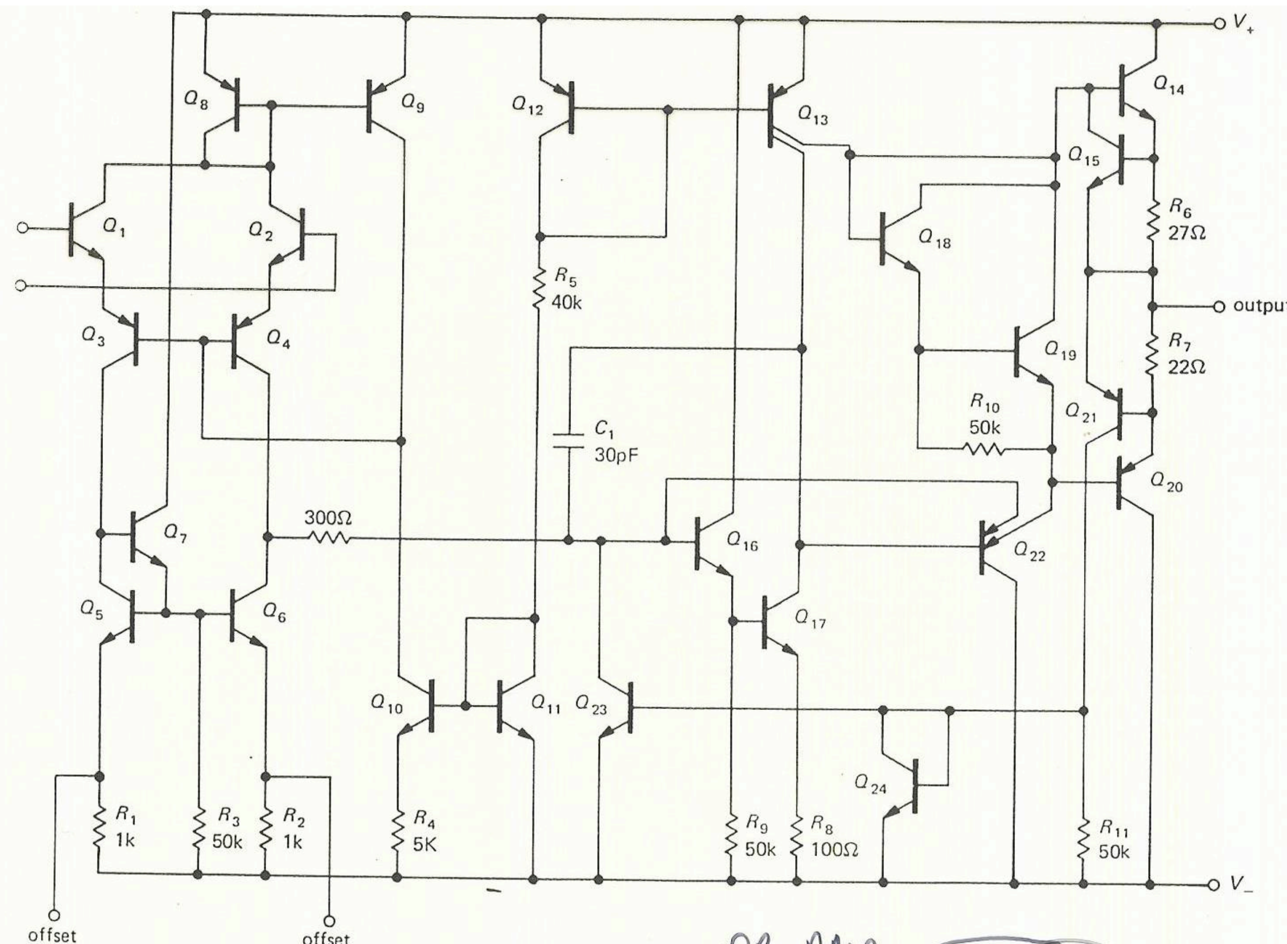
Slow Op-amp consists of a number of elements (example)



Mini-DIP Integrated ckt. (1 C)

DIP → dual-in-line package





of the p· lar 741 op-amp. (Fairchild Camera and Instrument Corp

OP-AMP Example

μA747/747C-F,H,N
SA747C-N
μA747C-D

DESCRIPTION

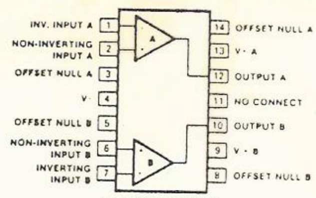
747 is a pair of high performance monolithic operational amplifiers constructed on a single silicon chip. High common mode voltage range and absence of "latch-up" make the 747 ideal for use as a voltage follower. The high gain and wide range of operating voltage provides superior performance in integrator, summing amplifier, and general feedback applications. The 747 is short-circuit protected and requires no external components for frequency compensation. The internal 6dB/octave roll-off insures stability in closed loop applications. For single amplifier performance, see μA741 data sheet.

FEATURES

- No frequency compensation required
- Short-circuit protection
- Offset voltage null capability
- Large common-mode and differential voltage ranges
- Low power consumption
- No latch-up

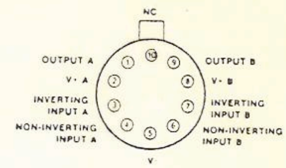
PIN CONFIGURATIONS

D,F,N PACKAGE



ORDER PART NO.
μA747CN, μA747CF, μA747N,
μA747F, SA747CN
μA747CD

H PACKAGE*

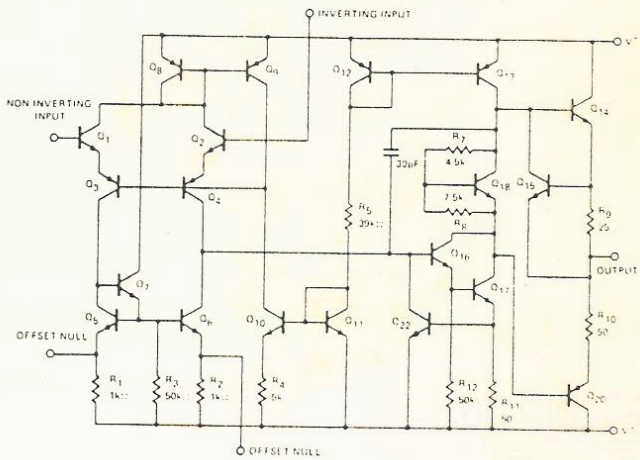


ORDER PART NO.
μA747CH, μA747H

*Metal cans (H) not recommended for new designs

EQUIVALENT SCHEMATIC

EQUIVALENT CIRCUIT (EACH SIDE)



ABSOLUTE MAXIMUM RATINGS

PARAMETER	RATING	UNIT
Supply voltage		
μA747	±22	V
μA747C	±18	V
SA747C	±18	V
Internal power dissipation		
H Package	500	mW
N,F Packages	670	mW
Differential input voltage	±30	V
Input voltage	±15	V
Voltage between offset null and V-	±0.5	V
Storage temperature range	-65 to +155	°C
Operating temperature range		
μA747	-55 to +125	°C
μA747C	0 to +70	°C
SA747C	-40 to +85	°C
Lead temperature (soldering, 60 sec)	300	°C
Output short-circuit duration	indefinite	

µA747/747C-F,H,N
SA747C-N
µA747C-D

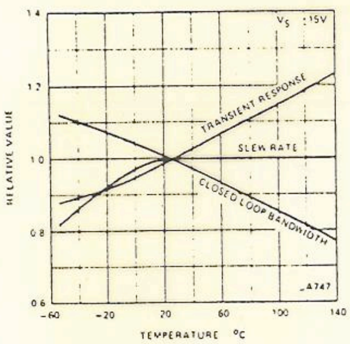
DC ELECTRICAL CHARACTERISTICS $T_A = 25°C$, $V_S = \pm15V$ unless otherwise specified.

	PARAMETER	TEST CONDITIONS	µA747			µA747C			UNIT
			Min	Typ	Max	Min	Typ	Max	
V_{OS}	Offset voltage	$R_S \leq 10k\Omega$		2.0	5.0		2.0	6.0	mV
		$R_S \leq 10k\Omega$, over temp		3.0	6.0		3.0	7.5	mV
I_{OS}	Offset current			20	200		20	200	nA
		$T_A = +125°C$		7.0	200				nA
		$T_A = -55°C$		85	500				nA
		Over temp					7.0	300	nA
I_{BIAS}	Input current			80	500		80	500	nA
		$T_A = 125°C$		30	500				nA
		$T_A = -55°C$		300	1500				nA
		Over temp					30	800	nA
V_{OUT}	Output voltage swing	$R_L \geq 2k\Omega$, over temp	±10	±13		±10	±13		V
		$R_L \geq 10k\Omega$, over temp	±12	±14		±12	±14		V
I_{CC}	Supply current each side			1.7	2.8		1.7	2.8	mA
		$T_A = 125°C$		1.5	2.5				mA
		$T_A = -55°C$		2.0	3.3				mA
		Over temp					2.0	3.3	mA
	Power consumption			50	85		50	85	mW
		$T_A = 125°C$		45	75				mW
		$T_A = -55°C$		60	100				mW
		Over temp					60	100	mW
	Input capacitance			1.4			1.4		pF
	Offset voltage adjustment range			±15			±15		V
	Output resistance			75			75		Ω
	Channel separation			120			120		dB
P_{SRR}	Supply voltage rejection ratio	$R_S \leq 10k\Omega$, over temp		30	150		30	150	µV/V
A_{VOL}	Large signal voltage gain (DC)	$R_L \geq 2k\Omega$ $V_{OUT} = \pm10V$	50,000			25,000			V/V
		Over temp	25,000			15,000			V/V
C_{MRR}		$R_S \leq 10K\Omega$, V_{CM} ±12V over temp	70			70			dB

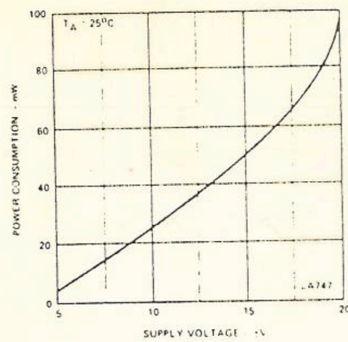
μA747/747C-F,H,N
SA747C-N
μA747C-D

TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)

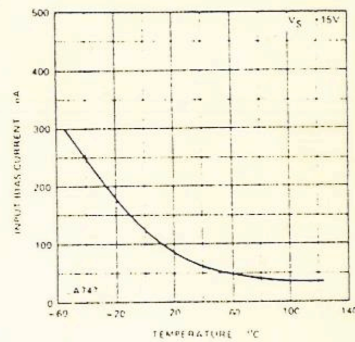
FREQUENCY CHARACTERISTICS AS A FUNCTION OF AMBIENT TEMPERATURE



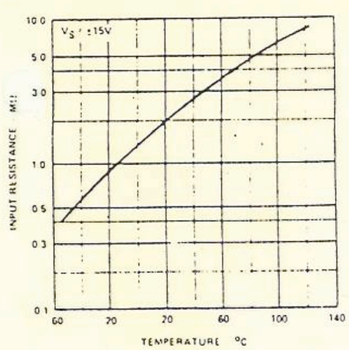
POWER CONSUMPTION AS A FUNCTION OF SUPPLY VOLTAGE



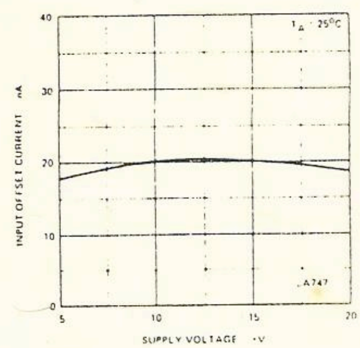
INPUT BIAS CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



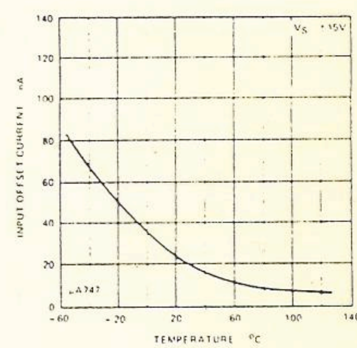
INPUT RESISTANCE AS A FUNCTION OF AMBIENT TEMPERATURE



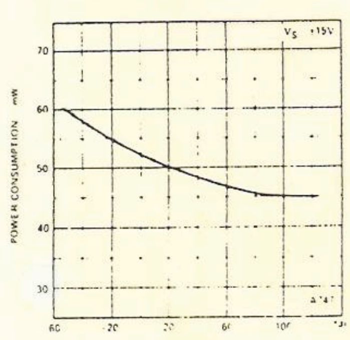
INPUT OFFSET CURRENT AS A FUNCTION OF SUPPLY VOLTAGE



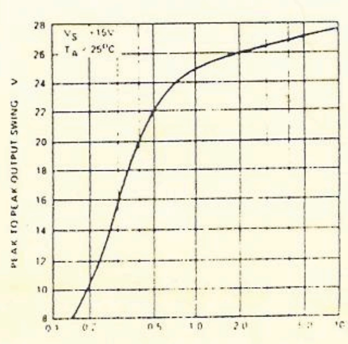
INPUT OFFSET CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



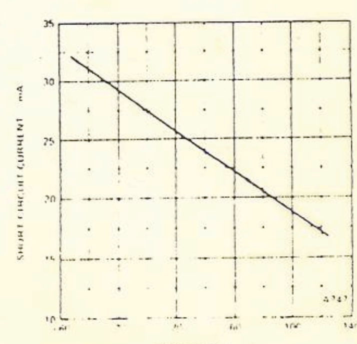
POWER CONSUMPTION AS A FUNCTION OF AMBIENT TEMPERATURE



OUTPUT VOLTAGE SWING AS A FUNCTION OF LOAD RESISTANCE



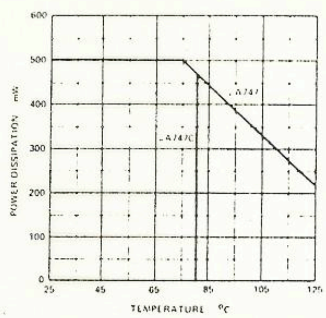
OUTPUT SHORT-CIRCUIT CURRENT AS A FUNCTION OF AMBIENT TEMPERATURE



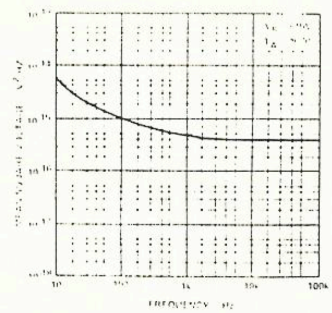
μA747/747C-F,H,N
SA747C-N
μA747C-D

TYPICAL PERFORMANCE CHARACTERISTICS (Cont'd)

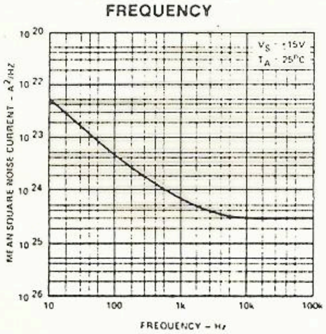
ABSOLUTE MAXIMUM POWER DISSIPATION AS A FUNCTION OF AMBIENT TEMPERATURE



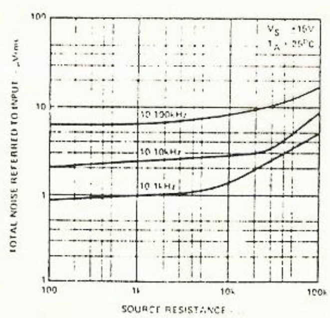
INPUT NOISE VOLTAGE AS A FUNCTION OF FREQUENCY



INPUT NOISE CURRENT AS A FUNCTION OF FREQUENCY

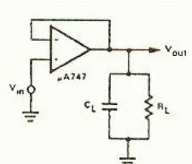


BROADBAND NOISE FOR VARIOUS BANDWIDTHS

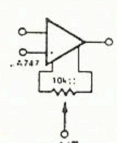


TEST CIRCUITS

TRANSIENT RESPONSE TEST CIRCUIT



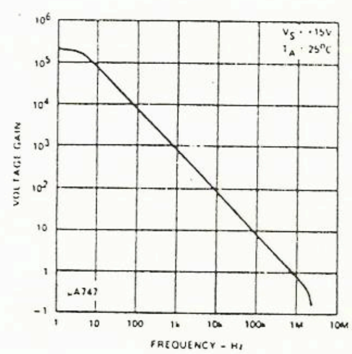
VOLTAGE OFFSET NULL CIRCUIT



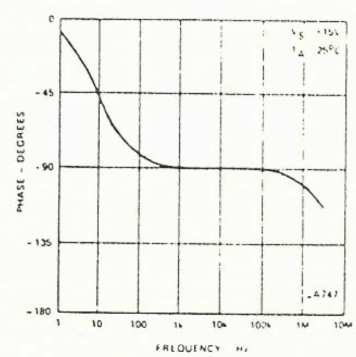
μA747/747C-F,H,N
SA747C-N
μA747C-D

TYPICAL PERFORMANCE CHARACTERISTICS

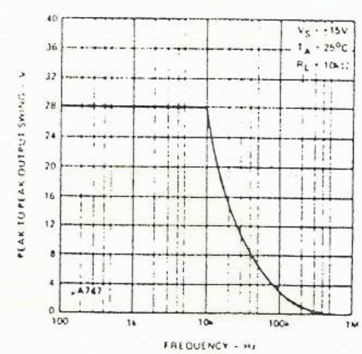
OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF FREQUENCY



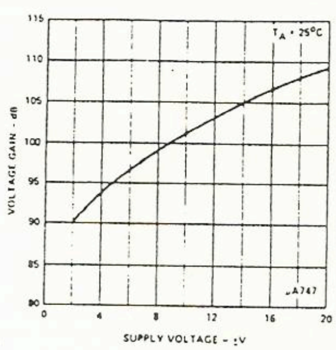
OPEN LOOP PHASE RESPONSE AS A FUNCTION OF FREQUENCY



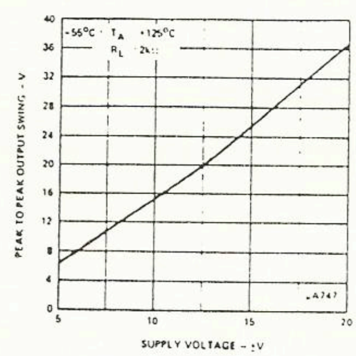
OUTPUT VOLTAGE SWING AS A FUNCTION OF FREQUENCY



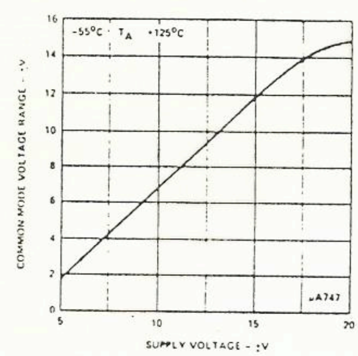
OPEN LOOP VOLTAGE GAIN AS A FUNCTION OF SUPPLY VOLTAGE



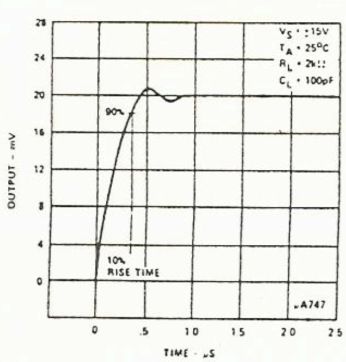
OUTPUT VOLTAGE SWING AS A FUNCTION OF SUPPLY VOLTAGE



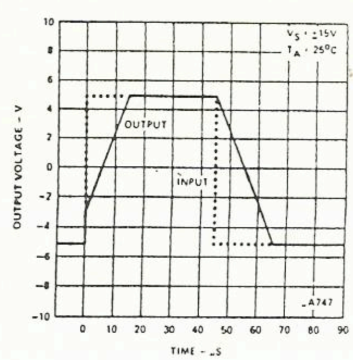
INPUT COMMON MODE VOLTAGE RANGE AS A FUNCTION OF SUPPLY VOLTAGE



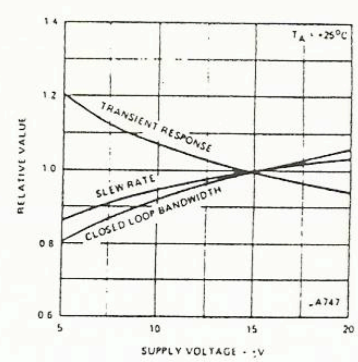
TRANSIENT RESPONSE



VOLTAGE FOLLOWER LARGE SIGNAL PULSE RESPONSE



FREQUENCY CHARACTERISTICS AS A FUNCTION OF SUPPLY VOLTAGE



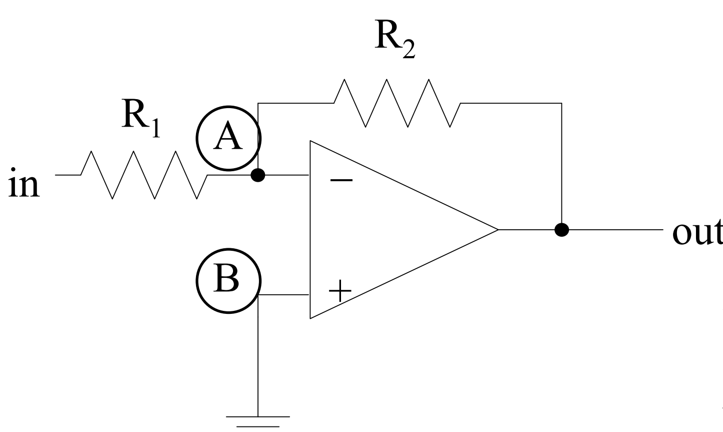
Basic Rules for Op-Amp

The so called "golden rules", which are two simple rules for working out op-amp behavior with external feedback. They are quite universal and probably sufficient for almost everything you'll do with op-amps. The first one is related (result) to a very high gain, and second one to very high input impedance:

1. The output attempts to do whatever is necessary to make the voltage difference between the inputs zero.
2. The inputs draw no current.

Note, that rule 1 doesn't mean that op-amp changes input voltage (it would contradict rule 2). Its output change in such a way that feedback can bring the input differential to zero (or as close as possible to zero).

Example

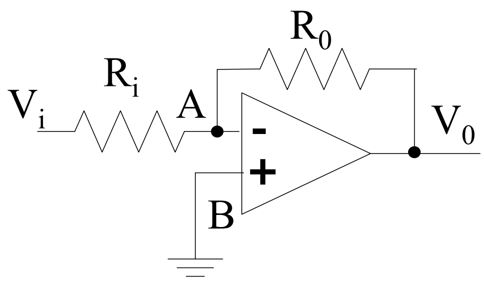


B – ground, hence A –also (from 1)

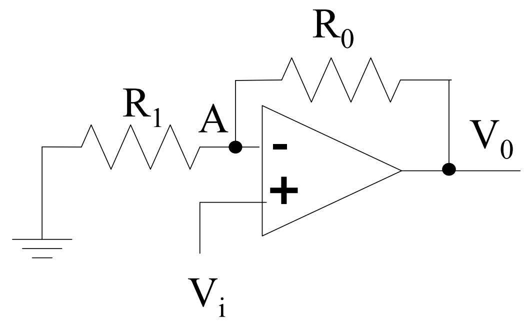
V_{in} on R_1 ; V_{out} on R_2

From 2: $\sum I_A = 0 \rightarrow \frac{V_{in}}{R_1} + \frac{V_{out}}{R_2} = 0 \rightarrow \frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2}$

Inverting and Non-Inverting Amplifiers



Inverting amplifier



Non-inverting amplifier

Inverting amplifier:

$V_A = V_B = 0$ A-virtual ground

$$\sum I_A = 0 \Rightarrow \frac{V_0}{R_0} = -\frac{V_i}{R_i}$$

Gain: $\boxed{\dfrac{V_0}{V_i} = -\dfrac{R_0}{R_i}}$

Relatively low input impedance $R_i \Rightarrow Z_i$

Non-inverting amplifier:

$V_A = V_i$

From voltage divider

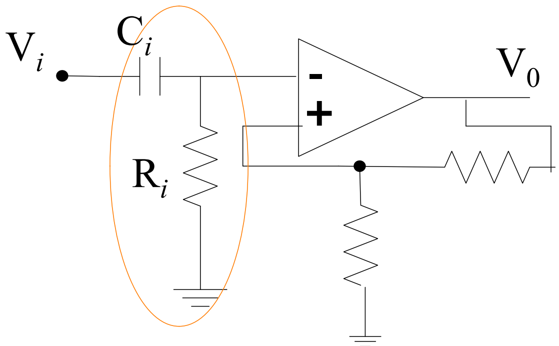
$$\frac{V_A}{R_1} = \frac{V_0}{R_1 + R_0} = \frac{V_i}{R_1}$$

Gain: $\boxed{\dfrac{V_0}{V_i} = 1 + \dfrac{R_0}{R_1}}$

High input impedance

Inverting and Non-Inverting Amplifiers (cont.)

These are DC amplifiers. For AC → input through capacitor (and high resistor to ground)

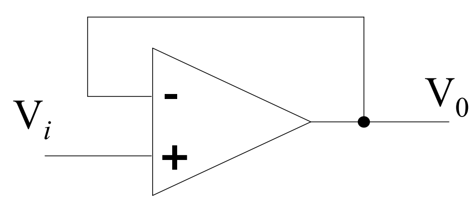


e.g.: $C_i \approx 0.1\ \mu F$

$R_i \approx 100\ k\Omega$

Voltage follower: "Buffer"

Non-inverting voltage follower



When we need high input impedance for matching low load impedance.

It is just non-inverting amplifier with $R_1 \Rightarrow \infty \Rightarrow V_0/V_i = 1$

From direct analysis:

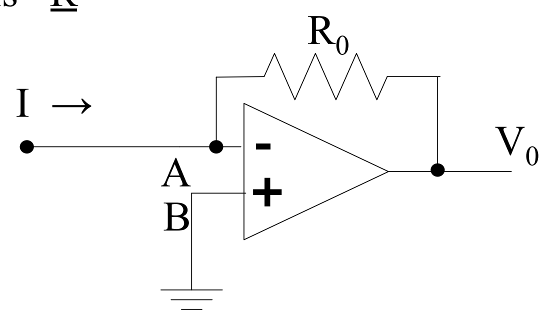
$$V_0 = \alpha(V_i - V_0) \Rightarrow \frac{V_i}{V_0} - 1 = \frac{1}{\alpha} = 0$$

10^6

$$\frac{V_i}{V_0} = 1 \quad \Rightarrow \quad \boxed{V_0 = V_i}$$

Current Amplifier/Current-to-Voltage Converter

The simplest I → V converter is R



$V_A = 0$ (virtual ground)

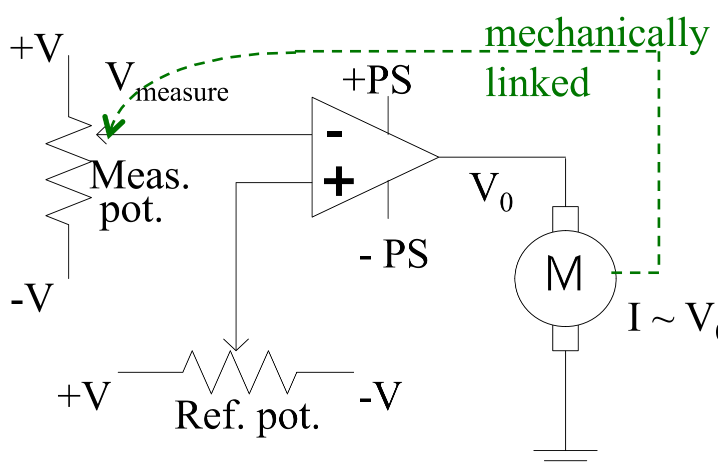
$$V_A - V_0 = IR_0$$

$$V_0 = -R_0 I$$

Servos

Servo means to “slave” something to something else.

We will servo potentiometer (pot) to another potentiometer using an op-amp:



Angle position servo

$I \sim V_0 \Rightarrow$ more voltage $\rightarrow$ faster/or more torque/ motor

O-order servo (O-approsx.)

$$V_0 = \alpha(V_+ - V_-)$$

$$\alpha \sim 10^5 - 10^6$$

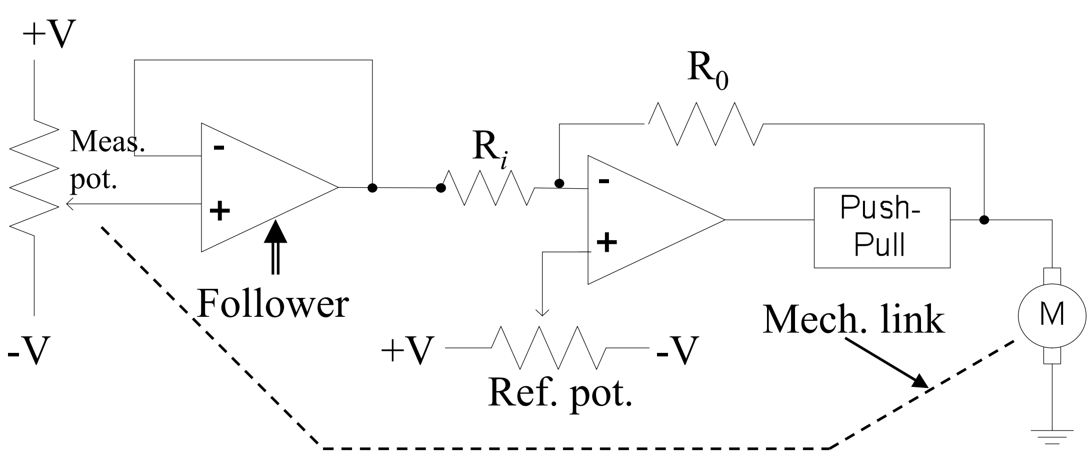
$$Z_{input} > 10^6 \ \ \Omega \ \ (like\ oscill.)$$

If direction of motor rotation is such, that with increasing V_0 motor mechanically is decreasing $V_+ - V_-$ by changing $pot_{meas.} \Rightarrow$ stable operation. Changing leads of motor will make unstable operation. Above servo in its O–approximation is poorly damped (like spring). Any change in ΔV cause oscillation. Add resistors for damping.

Servo – 1st Order

Now we can use some of the devices with op-amps to improve performance of servos. We will add follower for better match impedance and push-pull for higher power in motor. We will add additional resistors for better damping.

We will make 1st order servo:



Follower → for better matching input impedance

Push-Pull → for high current (high power)

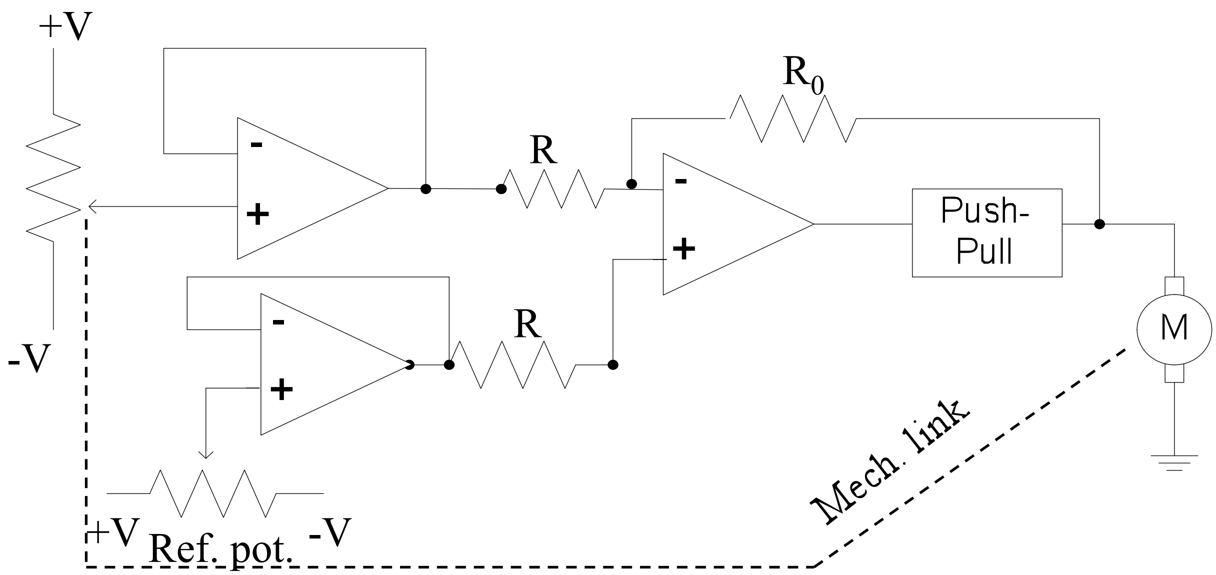
$R_0 = 10\ R_i$

Note: it will not work at ends of limit of $V_{Ref.}$ where $V_{Ref.}$ is far from 0.

We can farther improve by adding follower in Ref. Pot. Ckt

$\Rightarrow$ 2nd order servo

Servo – 2nd Order



$R_0 = 10\ R$

Laboratory:

- Build 2nd order servo.
- Measure current through motor vs. $V_{Ref.}$
- Remove push-pull and observe difference
- Install back push-pull and change $R_0 \rightarrow$ see effect on current in motor