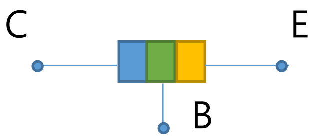
Lecture 10 - Transistor : 3 Legged device of semiconductor

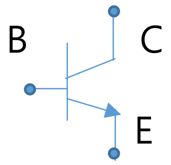
: To give <u>current amplification</u> with voltage following

C(Collector), E(Emitter), B(Base)

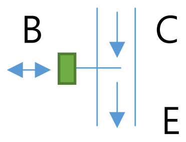
NPN type



Symbol



Direction control V/V



Rules: (for NPN type)

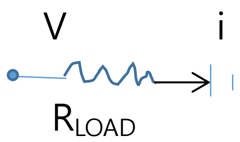
1. $V_C > V_E$ (or $V_C - V_E \geq 0.2V$) for flowing
2. $V_B - V_E \fallingdotseq 0.6V$ when flowing
3. $I_C = \beta I_B$ where $\beta \fallingdotseq 100$, and $I_E = I_C + I_B = (\beta+1) I_B \fallingdotseq \beta I_B = I_C$

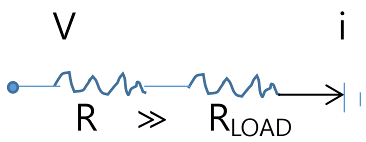
<u>Application:</u>

1. Current source or current supply

   : To provide *constant current* into circuit, regardless of R_{LOAD}

(1) Big R



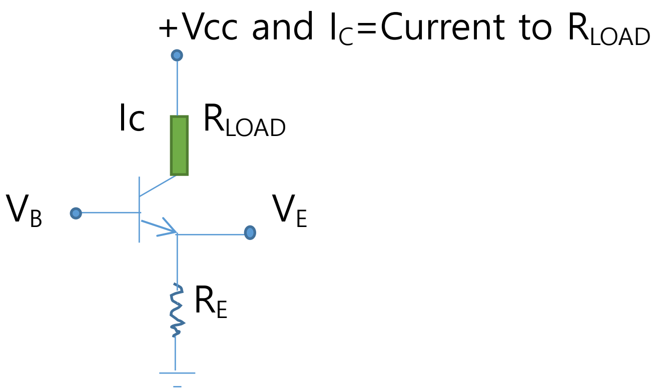


$i = V/R_{LOAD}$

$i = V/(R + R_{LOAD}) = V/R(1 + R_{LOAD}/R)$

$\fallingdotseq V/R = const$ $\therefore$ Big $R (\gg R_{LOAD})$ needed

(2) Transistor Current Source



When $V_B \geq 0.6V$, $V_E = V_B - 0.6$ and

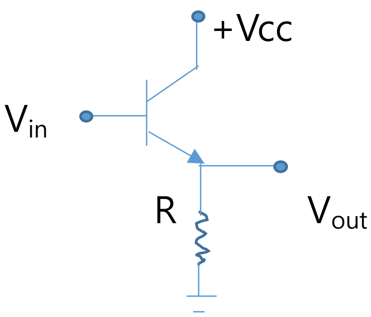
$I_C = I_E = V_E/R_E = (V_B - 0.6)/R_E$

Thus I_C is supplied to R_{LOAD} that is regardless of R_{LOAD}

∴ Current Source or Current Supply

2. Emitter Follower

: Current is amplified by β times while voltage is following



$V_{out} = V_E = V_{in} - 0.6$ ∴ $\Delta V_{out} = \Delta V_{in}$; Replica of Input voltage,

where Gain= $\Delta V_{out} / \Delta V_{in} = 1$

And $I_E \fallingdotseq I_C = \beta I_B$; Thus current is amplified while voltage is following.

∴ Emitter Follower

Emitter follower is to be driven or to drive a device.

Thus input impedance, Z_{in} , is of interest at the Vin point.

Impedance is defined as the ratio of ΔV to ΔI at any point within circuit.

$Z_{out}=Z_E=\Delta V_E/\Delta I_E=R$

$Z_{in}=Z_B\equiv\Delta V_B/\Delta I_B=\Delta V_E/(\Delta I_E/\beta)=\beta\Delta V_E/\Delta I_E=\beta R=\beta Z_{out}$

As $Z_{out} \ll Z_{in}$, Emitter follower is a very nice device to drive

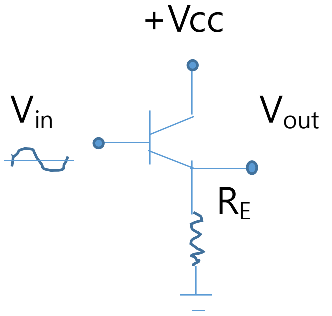
or to be driven.

Note that very big or infinite Z_{in} is an ideal to be driven by any circuit.

Also very small or zero Z_{out} is an ideal to drive any circuit.

3. AC coupled Emitter Follower

In the above Emitter Follower, TR is not active when V_{in} < 0.6V



How to cope with the AC voltage signal for Vin? Answer is to use

1) Biasing :

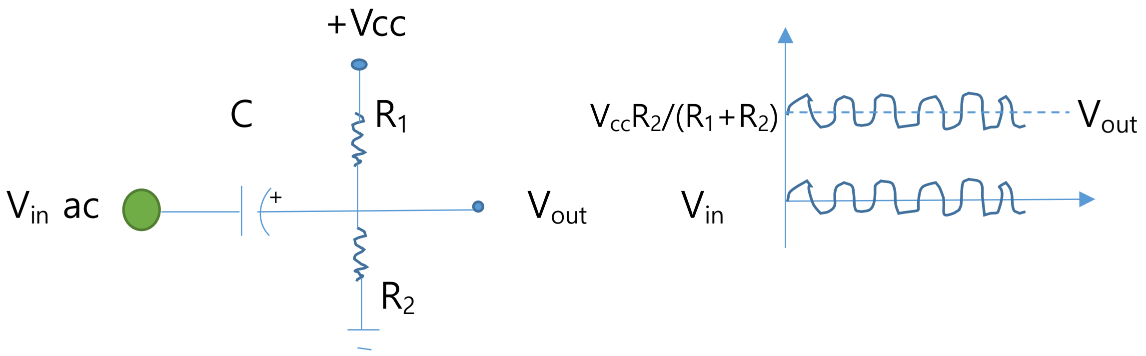
To pull TR's quiescent voltage to midpoint between Vcc and GND

where the quiescent voltage is when no AC signal is applied.

Then the TR becomes active, and Emitter following is possible.

⇒ AC signal is to ride over the pulled TR's quiescent voltage(DC)

A good method of biasing or DC offsetting is to add capacitor together with the voltage divider as follows;



Electrons from V_{in} ac is getting into the charged capacitor, then overflown (or discharged) electrons are flowing to the voltage divider, riding over the DC offset voltage given by R_1, R_2 voltage divider.

Thus V_{in} ac signal is adding to the DC voltage of $VccR_2/(R_1+R_2)$, then leads to V_{out}

Note the symbol + where + sign is higher voltage (or biased) direction.

Q: V_{in} ac can have Impedance?

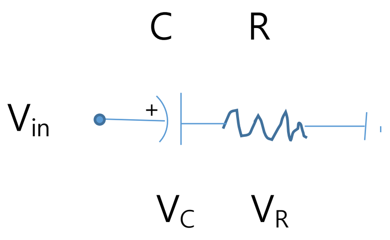
Yes. It can be a signal from a sensor that can have impedance Z_{in}, that is viewed from the sensor output.

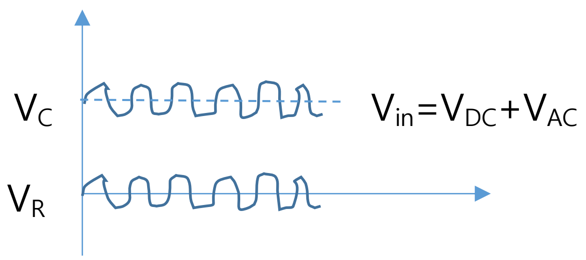
Thus $Z_{in} \ll Z_{TOTAL}$ also should be checked.

2) DC Blocking

To remove the biased DC component from the signal

by adding the blocking capacitor.





$V_{in} = V_C+V_R$ and $Z_C=1/j\omega C$, $Z_R=R$

$V_C=V_{in}Z_C/(Z_C+Z_R)=V_{in}/(1+j\omega RC)$

$\Rightarrow$Low freq. part ($V_C=V_{DC}$ if $\omega=0$)

$V_R=V_{in}Z_R(Z_C+Z_R)=V_{in}\{j\omega RC/(1+j\omega RC)\}$

$\Rightarrow$High freq. part ($V_R=V_{in}-V_C=V_{AC}$, when $\omega=0$)

$\therefore$ V_R is the AC voltage signal after the V_{DC} is removed.

(Q: What happen if the sequence of C, R is changed?)

This is a DC blocking capacitor or a kind of HPF with $\omega_{3dB}=1/R_{eq}C$

where R_{eq} is the total equivalent resistor including *back and forth* resistors relevant to C.

Also note the symbol + for biased direction.

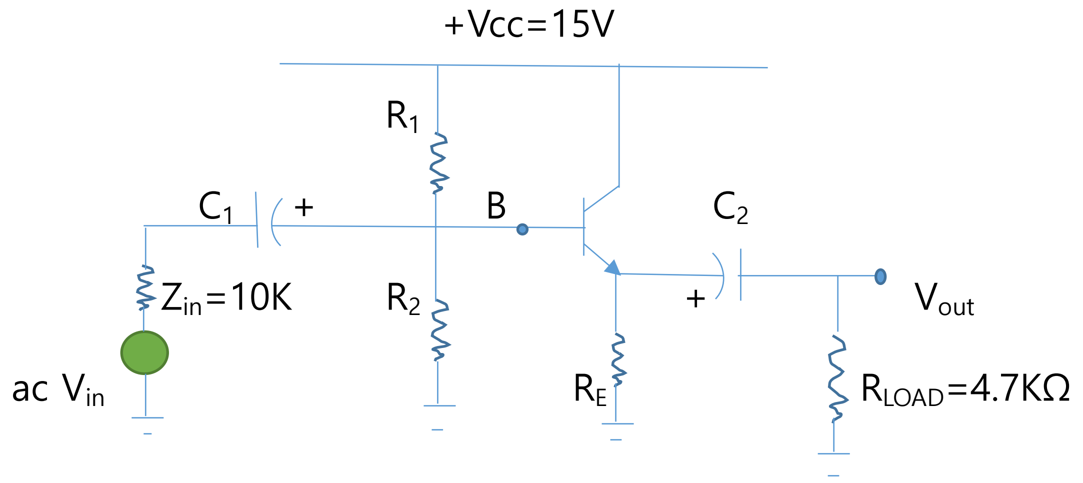
Ex) Design a AC coupled Emitter Follower that drives AC coupled load.

Design Spec:

Vcc=+15V, TR's $I_{quiescent}$=0.5mA, R_{LOAD}=4.7KΩ, V_{in} is ac voltage signal from a sensor of 10KΩ input impedance. Choose f_{3dB}=100Hz

(Source: Student Manual for The Art of Electronics, Thomas C. Hayes, Paul Horowitz, Cambridge University Press, 1989)

AC coupled Emitter Follower



1) V_E centering in quiescence of TR

In quiescence, V_E=15V/2=7.5V (chosen)

Thus $R_E=V_E/I_{quiescence}$=7.5/0.5E-3=15KΩ

V_B=7.5+0.6 (Diode drop)=8.1(V)

(1) DC component

When quiescence, Voltage divider gives

$V_B=V_{CC}R_2/(R_1+R_2)$, thus $8.1/15=R_2/(R_1+R_2)$ eq(1)

When quiescence, the voltage divider should drive the circuit below B,

Thus $R_1 \| R_2 \ll Z_B$ and $Z_B=\beta(R_E \| \infty)=\beta R_E$

∴ $R_1R_2/(R_1+R_2)=Z_B/10=10(15)=150K\Omega$ eq(2)

From eq(1),(2); $R_1=277K\Omega$ and $R_2=325K\Omega$

(2) AC component

For the ac signal, the DC component is added by the biasing circuit; and removed by the blocking capacitor, respectively. Thus we need a DC blocking capacitor (or a kind of HPF passing over 100Hz), to block the DC component, and the relevant $R_{eq} = R_E \parallel 0 + R_{LOAD} = 4.7K$

This is a kind of Cascaded HPF, and ω_{3dB} adjustment is needed to prevent excessive attenuation near the ω_{3dB} frequency range. Thus ω_{3dB} can be adjusted such as $\omega1_{3dB}=\omega_{3dB}=100Hz$ and $\omega2_{3dB} = \omega_{3dB}/3=33Hz$

For the DC blocking capacitor, $\omega2_{3dB}=(2\pi)(100/3)=1/R_{eq}C_2$

$\therefore C_2=1/\{2\pi(33)(4700)\}\fallingdotseq 1\mu F$ from the commercial choice

For the biasing circuit, $\omega1_{3dB}=(2\pi)(100Hz)=1/R_{TOT}C_1$

where R_{TOT} is the total resistance relevant for C_1.

$R_{TOT}=10K+R_1 \parallel R_2 \parallel \beta(R_E \parallel R_{LOAD})$ and $R_E \parallel R_{LOAD}=(15)(4.7)/(15+4.7)=3.58K\Omega$

As $R_1 \parallel R_2=150K\Omega$, thus $R_{TOT}=10K+(150)(358)/(150+358)=115.7K\Omega$

Thus $C_1=1/\{(115.7)(2\pi)(100)\}\fallingdotseq 0.02\mu F$

Quick check for Z_{in} (=10KΩ) ≪ $Z_{emitter\ follower}$ (=105.7KΩ) and it is OK!!

Thus design is completed for the AC coupled Emitter follower.

HW7) Design a AC coupled Emitter follower such that

$V_{cc}=+12V$, TR's $I_{quiescent}=0.5mA$, $R_{LOAD}=10K\Omega$, V_{in} is ac voltage signal from a sensor of $10K\Omega$ input impedance. Choose $f_{3dB}=100Hz$ and use alternative method for preventing excessive attenuation at ω_{3dB}