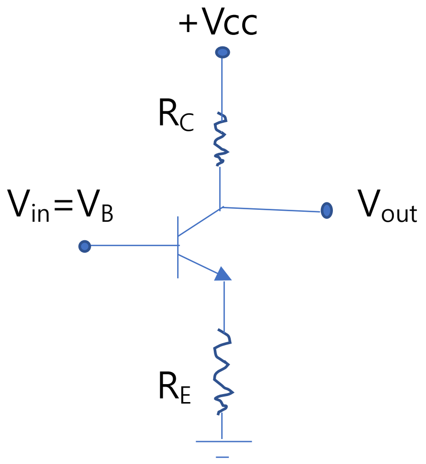
Lecture 11; Transistor2

6. Common-Emitter Follower

: Current is amplified, and Voltage is also amplified.



$V_{out}=Vcc-R_CI_C$ and $I_C=I_E=V_E/R_E=(V_{in}-0.6)/R_E$

Thus $V_{out}=Vcc-R_C(V_{in}-0.6)/R_E$ ∴ $\Delta V_{out}=-\Delta V_{in}R_C/R_E$

Therefore ΔV_{out} is amplified from ΔV_{in} with Gain$=-R_C/R_E$

Current (I_C) is also amplified by β times ($=\beta I_B$)

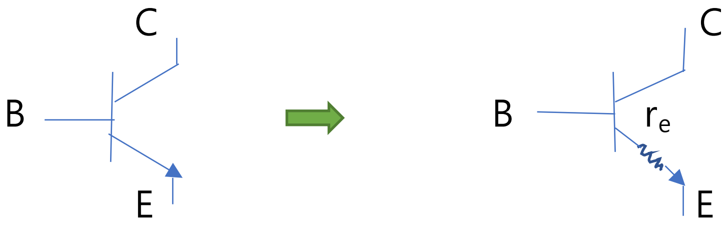
To check the impedance of Z_{in} and Z_{out}

$Z_{in}=\Delta V_B/\Delta I_B=\Delta V_E/(\Delta I_E/\beta)=\beta R_E$

$\Delta V_{out}=-R_C\Delta I_C$ thus $Z_{out}=Z_C=|\Delta V_C/\Delta I_C|=|\Delta V_{out}/\Delta I_C|=R_C$

∴ $Z_{out} \ll Z_{in}$ if R_E and R_C are appropriately chosen, thus the common emitter amplifier can be a good device to drive or to be driven

Let's introduce the Ebers-Moll model of Transistor for precise design



(1) $I_C=I_S\{\exp(V_{BE}/V_T)-1\}$: Ebers-Moll eqn

It indicates current I_C is a function of $V_{BE}(=V_B-V_E)$

where $V_T=kT/q$ and k=Boltzmann const.=1.38E-23 [J/°K]

T=Kelvin Temp. and q=one electron charge=1.60E-19 C

Thus V_T=25.3mV at 20°C room temp.

I_S=Saturation current of TR, or reverse leakage current

(2) Intrinsic Emitter Resistance, r_e , between B and E

As $V_{BE}/V_T \fallingdotseq 0.6/0.0253 (\gg 1)$, E-M eqn can be simplified as

$I_C= I_S\{\exp(V_{BE}/V_T)-1\} \fallingdotseq I_S\exp(V_{BE}/V_T)$

$\partial I_C/\partial V_{BE}=I_S\exp(V_{BE}/V_T)/V_T=I_C/V_T$

thus $r_e=\partial V_{BE}/\partial I_C=1/(\partial I_C/\partial V_{BE})=V_T/I_C=25.3/I_C$ in [mV/mA] or [Ω]

$1/r_e=r_m$=Trans-conductance

(3) Temperature dependence of V_{BE}

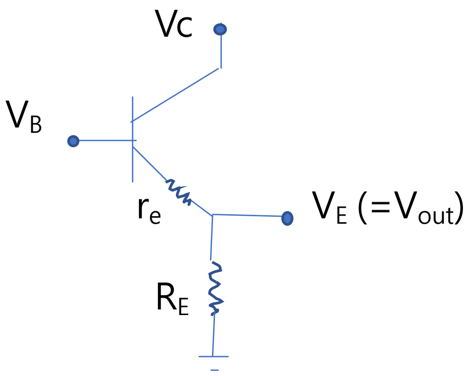
$\Delta V_{BE}/\Delta T = -2.1 mV/°C$

(4) Early effect

V_{BE} slightly varies with V_{CE}

Thus $\Delta V_{BE} = -\alpha \Delta V_{CE}$ and $\alpha \fallingdotseq 0.01\%$

Emitter-Follower (revisited)



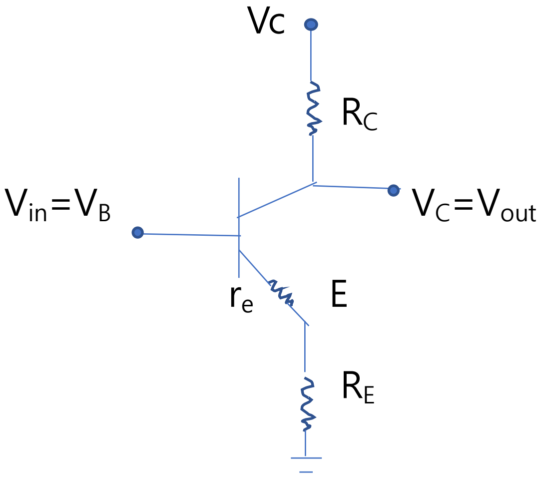
In previous model, $\Delta V_E = \Delta V_B$ and Gain=1

$Z_{in} = \beta R_E$ and $Z_{out} = R_E$

In E-M model, $\Delta V_E = \Delta V_B R_E/(r_e + R_E)$ and Gain=$R_E/(r_e + R_E) < 1$

$Zin = \beta(r_e + R_E)$ and $Z_{out} = R_E$

Common Emitter Follower (revisited)



In previous model

$\Delta V_{out}=-\Delta V_{in}R_C/R_E$ and Gain$=-R_C/R_E=-\infty$ if $R_E=0$

$Z_{in}=\beta R_E$ and $Z_{out}=|-R_C|=R_C$

In E-M model

$\Delta V_{out}=-\Delta V_{in}R_C/(r_e+R_E)$ and Gain$= -R_C/(r_e+R_E)$

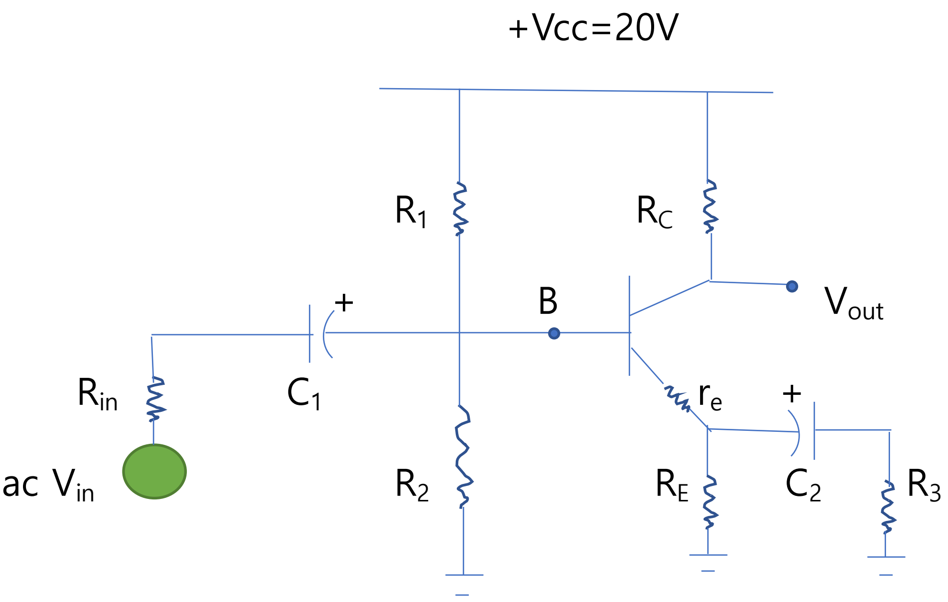
$Z_{in}=\beta(r_e+R_E)$ and $Z_{out}=|-R_C|=R_C$

Note that the Gain $=-R_C/(r_e+R_E)= -R_C/r_e$ when $R_E=0$, and it is called 'Grounded Common Emitter Follower'

Ex) Design a AC coupled common emitter follower

Vcc=20V, f_{3dB}=100Hz, Gain=-100 for ac, $I_{quiescence}$=0.5mA

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



(1) For DC component

Centering V_{out} in quiescence, and V_{out}=10V=Vcc-$I_C R_C$ and I_C=0.5mA

Thus Rc=(Vcc-V_{out})/I_C=(20-10)V/0.5mA=20KΩ

Choosing R_E , so as to give V_E as 1V (for temperature stability),

$R_E=V_E/I_E$=1V/0.5mA=2KΩ

r_e=25.3mV/0.5mA≒50Ω

$V_B/Vcc=R_2/(R_1+R_2)=(1+0.6)/20$ eq(1)

$R_1 \parallel R_2$ drives Z_B ; and $Z_B=\beta(r_e+R_E)\fallingdotseq\beta R_E$=200(KΩ)

Thus $R_1 \parallel R_2=R_1R_2/(R_1+R_2)=Z_B/10$=20 (KΩ)   eq(2)

From eq(1) (2); R_1=220KΩ and R_2=20KΩ

(2) For AC component

Gain=$-R_C/\{r_e+R_E \parallel R_3\}=-100$

Thus $r_e+R_E \parallel R_3=200\Omega$ and $R_E \parallel R_3=150=(2000)R_3/(2000+R_3)$

$\therefore R_3=162\Omega \fallingdotseq 150\Omega$ from commercial choice

C_2 is the DC blocking capacitor, and its location does not matter in general (in frequency domain), although it is better to locate close to the receiver or driver (in time domain), where the AC current flows back and forth.

The relevant R_{eq} for C_2 is $R_3+r_e \parallel R_E \fallingdotseq R_3+r_e=150+50=200(\Omega)$

This is also a cascaded HPF, thus excessive attenuation can be avoided by choosing $\omega2_{3dB}=\omega_{3dB}/2=(2\pi)(100)/2=314$ (rad/s)$=1/(R_3+r_e)C_2$

Thus $C_2=1/\{(314)(200)\}=16\mu F$

For C_1 of the biasing circuit; the relevant R_{eq} for back and forth, $R_{eq}=(R_1 \parallel R_2) \parallel \beta(r_e+R_E \parallel R_3)+R_{in}$(if any), and $R_1 \parallel R_2$=20KΩ,

$r_e+R_E \parallel R_3 \fallingdotseq r_e+R_3=200\Omega$; Thus R_{eq}=20K$\parallel$20K=10K and

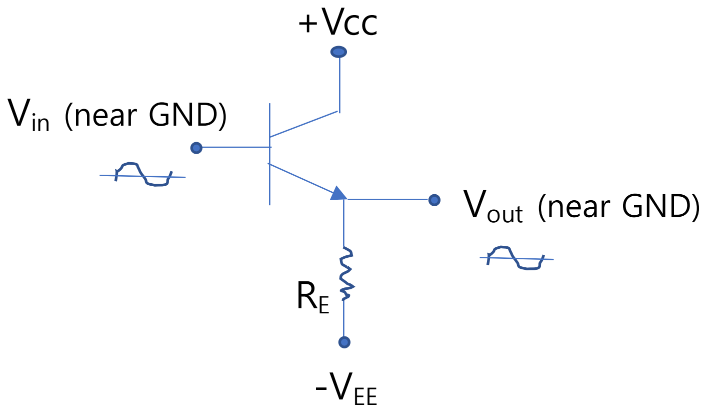
$\omega1_{3dB}=\omega_{3dB}/2=314(rad/s)=1/R_{eq}C_1$, and thus $C_1 \fallingdotseq 0.33\mu F$

HW8) Design a AC coupled common emitter follower

Vcc=24V, f_{3dB}=100Hz, Gain=-100 for ac, $I_{quiescence}$=0.5mA.

(Hint: Use an alternative method for cascaded DC blocking capacitors)

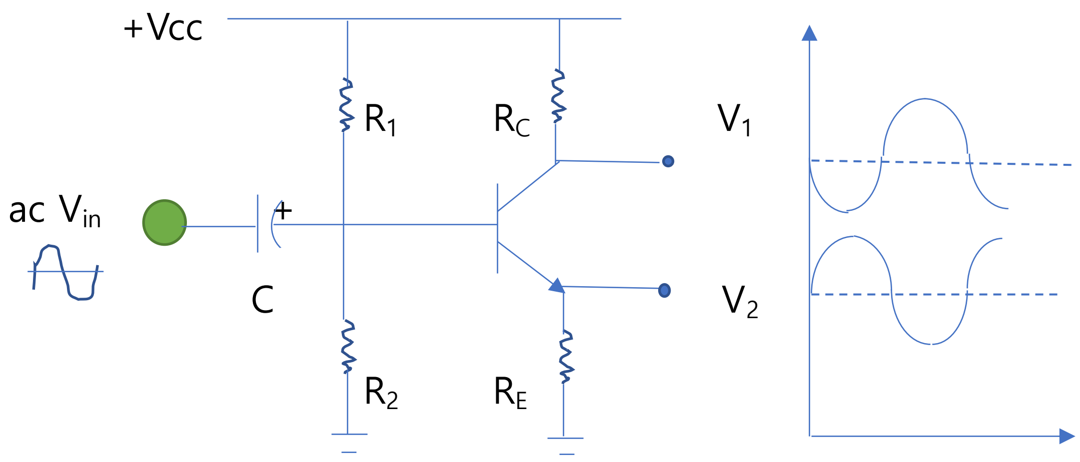
7. Emitter Follower with split supply, or "DC Coupled Emitter Follower" with split supply



This TR circuit can accept the negative swing of the Vin, thus can be used for current amplification with voltage replica

8. Unity-Gain Phase Splitter

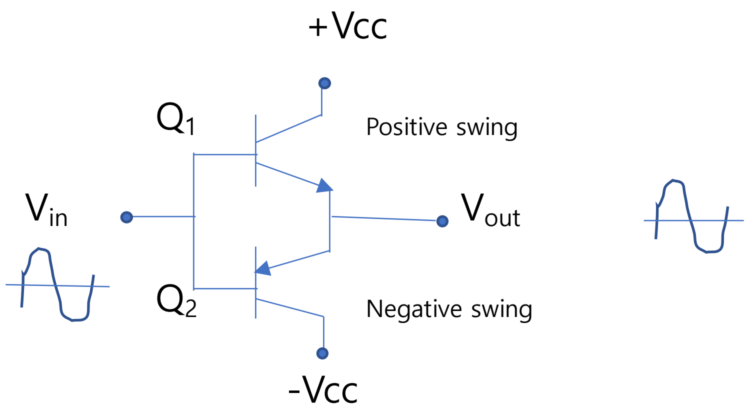
: For given input signal, V_{in} ; two output signals, V_1, V_2 of 180° phase difference



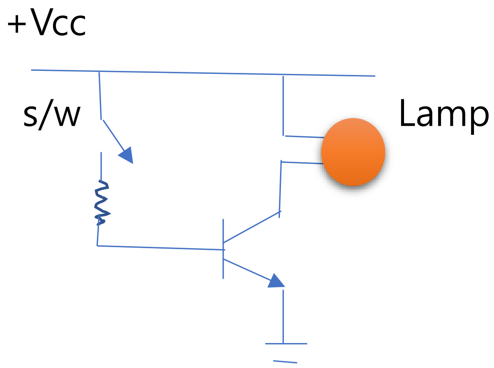
Ex) Design a unity-gain phase splitter such as;

Vcc=20V, and $I_{quiescence}$=1mA, V_1=15V, V_2=5V

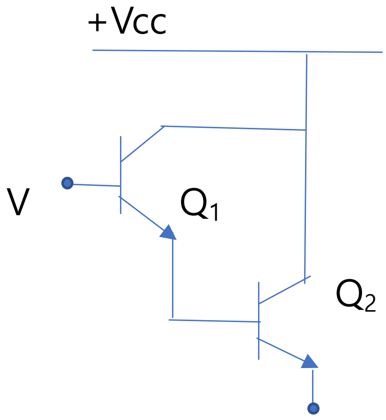
9. Push-Pull Amplifier



10. Transistor Switch



11. Darlington Connection



$\beta_{TOT} = \beta_1 \beta_2$

∴ Very High Gain of current amplification