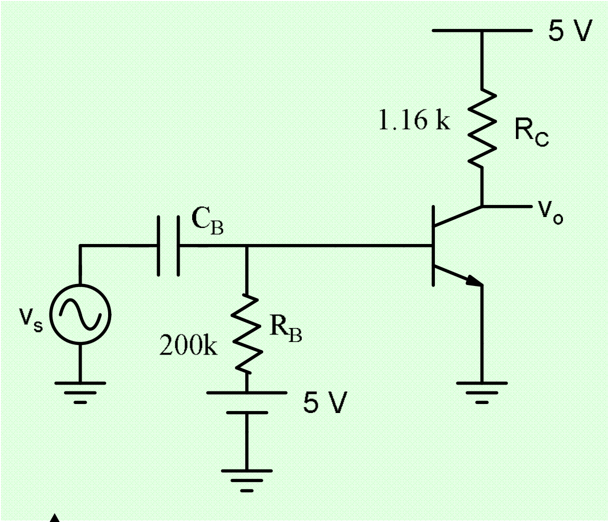
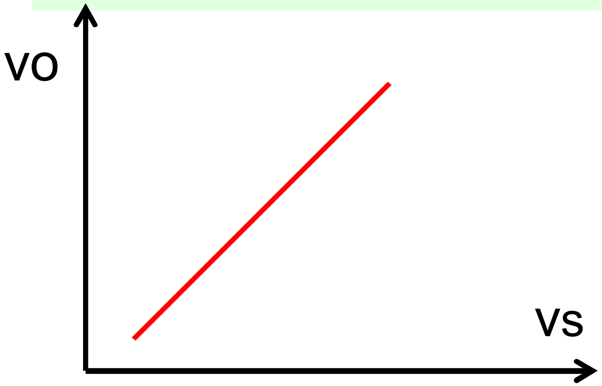
EE210: Microelectronics-I

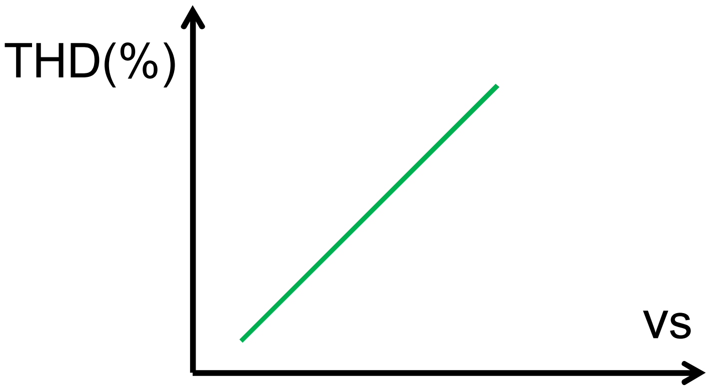
Lecture-15 :BJT Amplifier-part-4

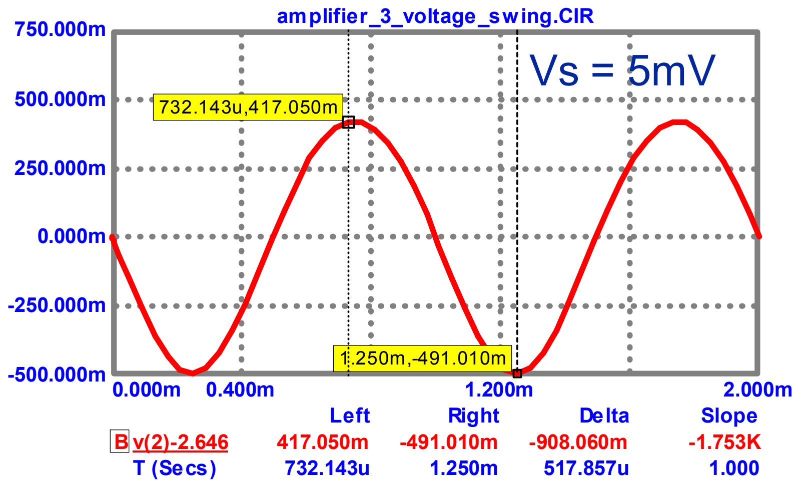
Instructor - Y. S. Chauhan

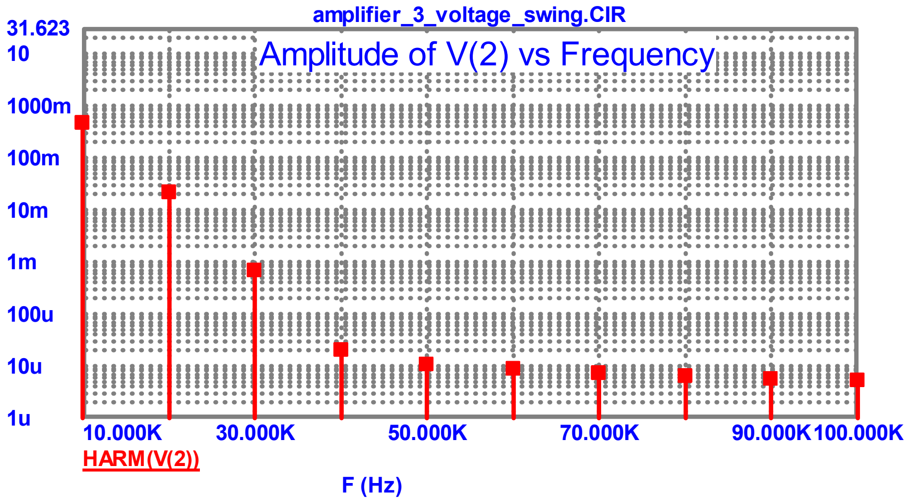
Slides from: B. Mazhari
Dept. of EE, IIT Kanpur





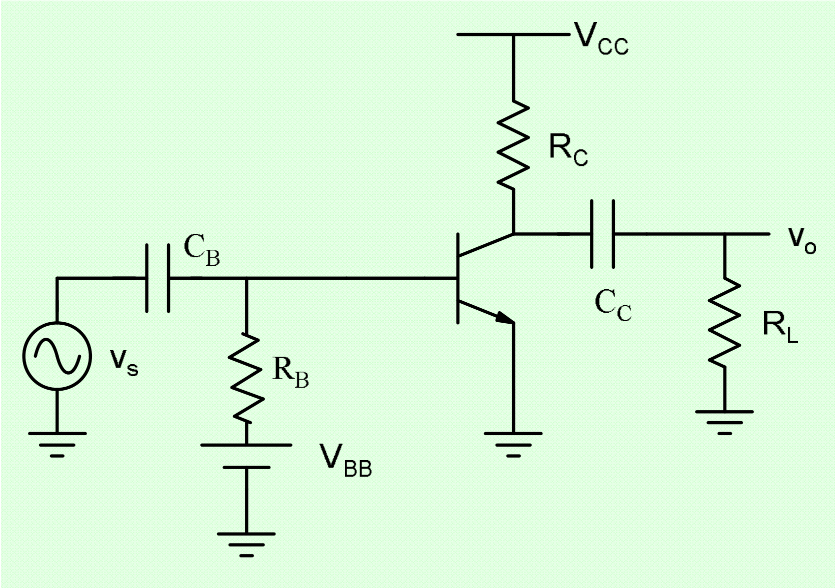


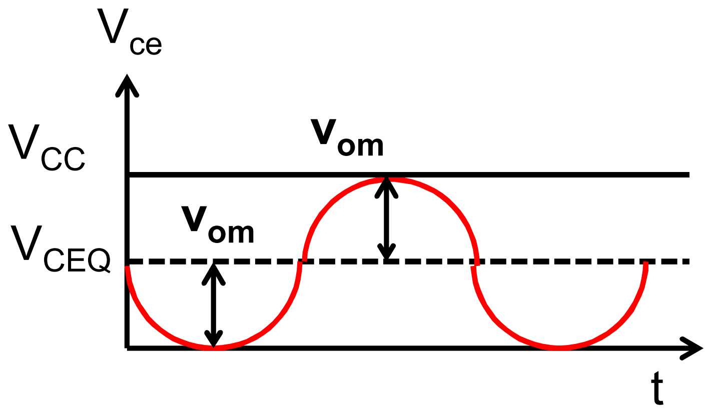




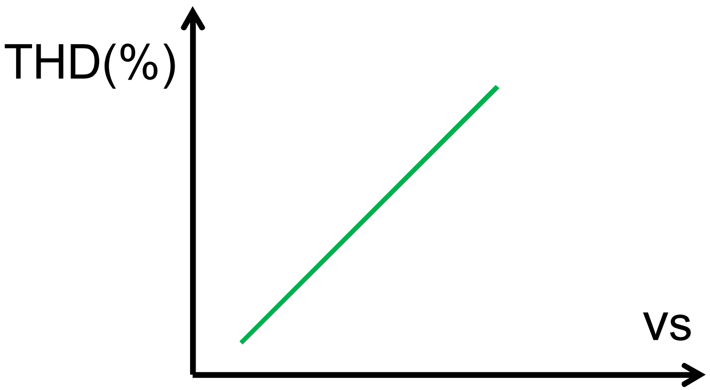
Vo (p-p) ~0.91V, THD~4.8%

Design for Maximum Output Voltage Swing





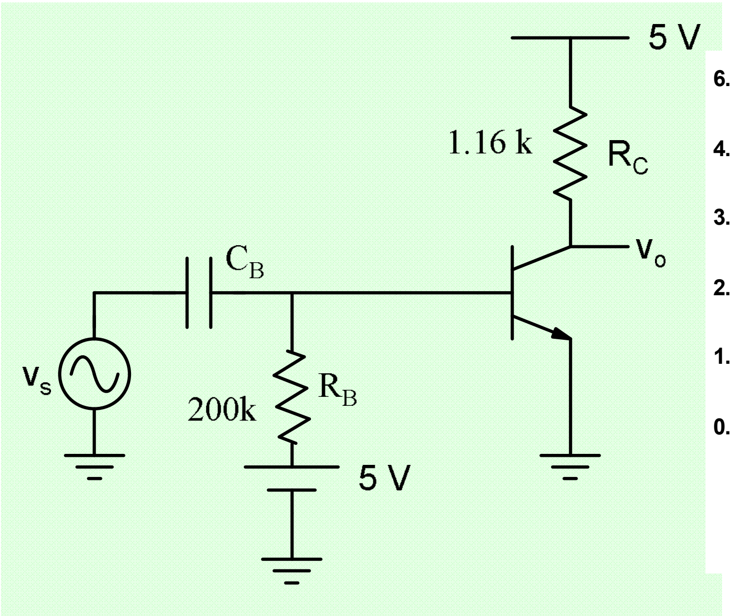
$$V_{CEQ} \sim \frac{V_{CC}}{2} \sim v_{om}$$

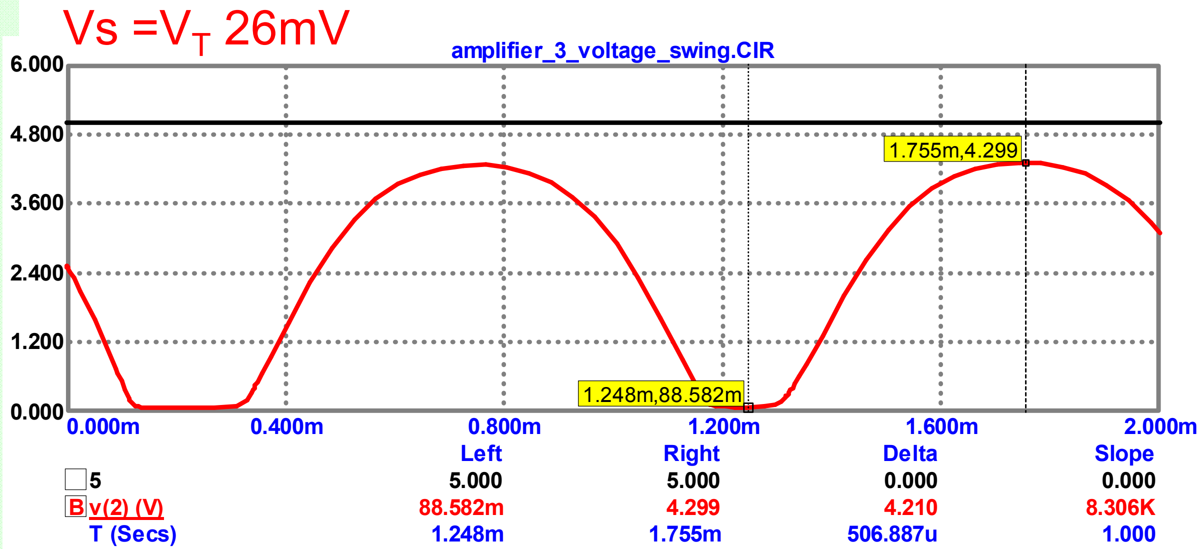


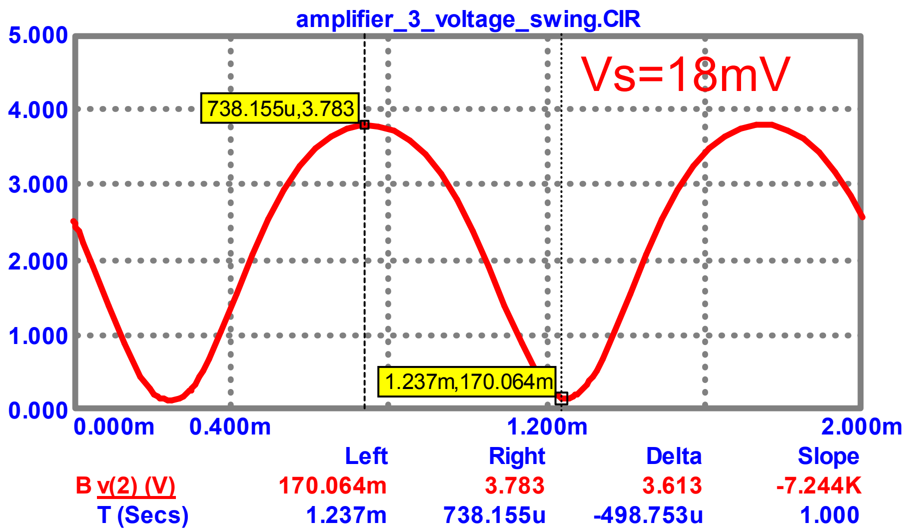
$$A_V = \frac{V_{CC} - V_{CEQ}}{V_T} \sim \frac{V_{CC}}{2V_T}$$

$$A_V = \frac{v_{om}}{v_s} \sim \frac{V_{CC}}{2V_T} \Rightarrow v_S = V_T$$

High Distortion begins to occur well before V_{ce} approaches V_{CC}





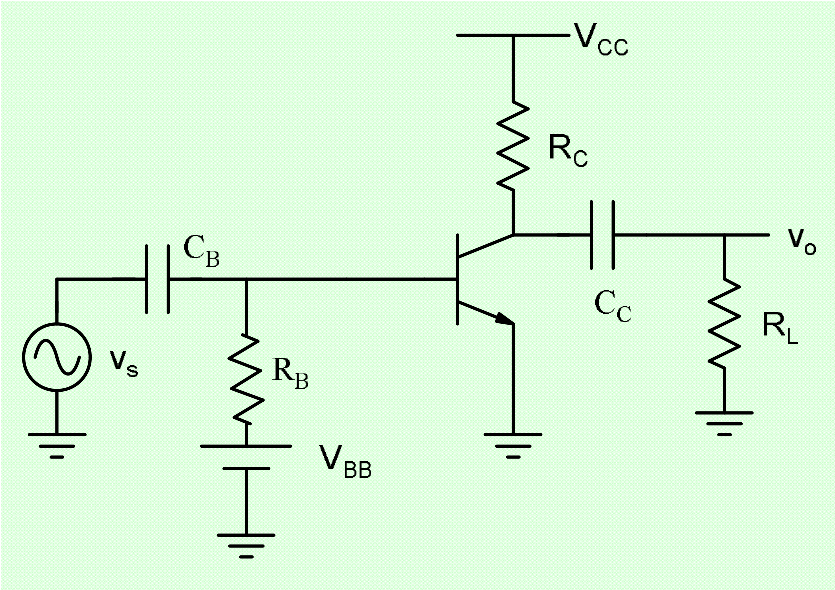


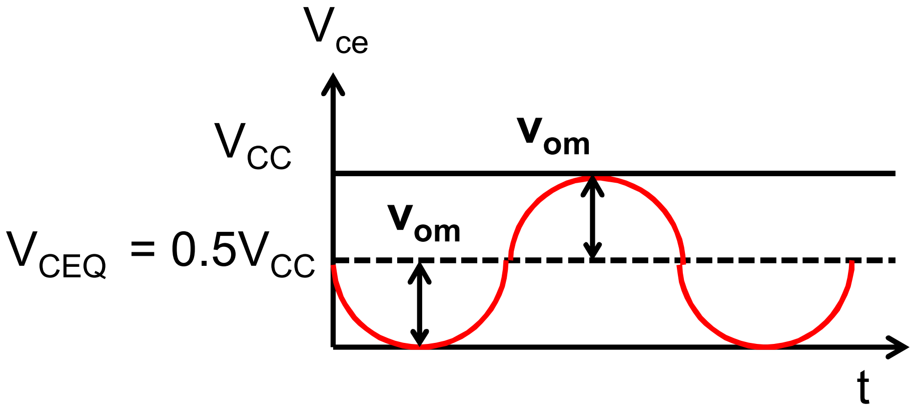
Vo (p-p) ~3.6V THD~16.9%

Must take harmonic distortion into account to calculate swing

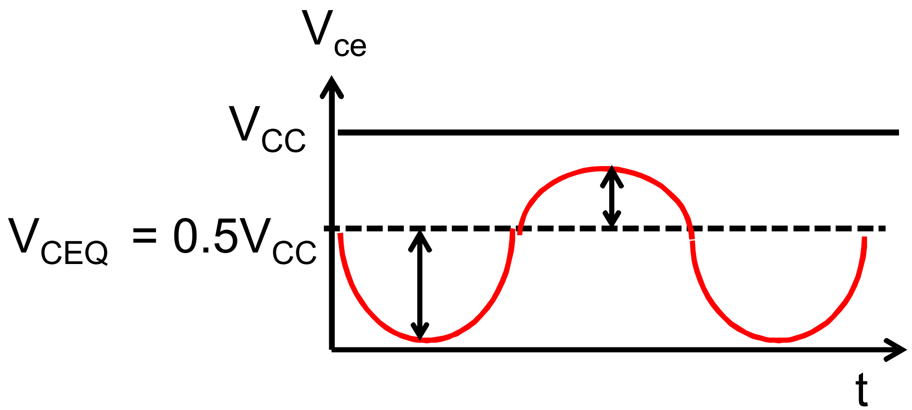
G-Number

Design for Maximum Output Voltage Swing



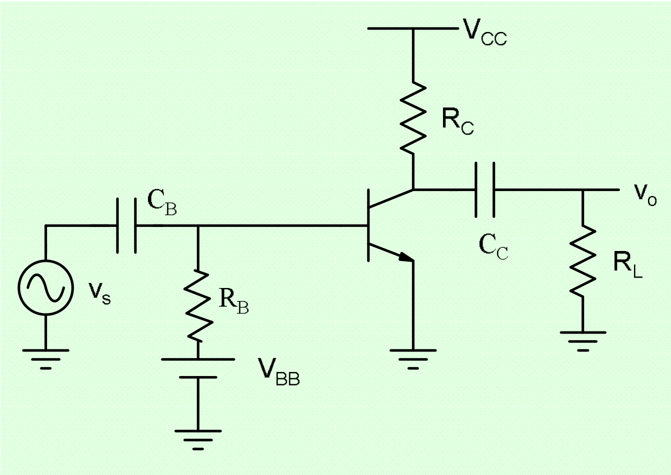


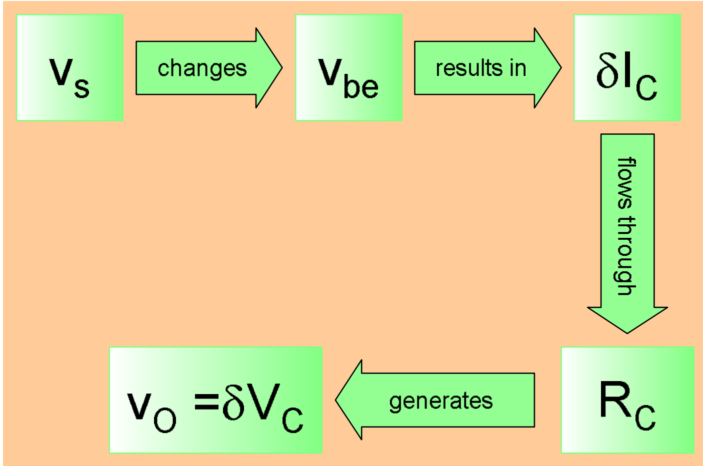
$$v_{om} = Min\{V_{CEQ} - V_{CEsat}; V_{CC} - V_{CEQ}\}$$



Should $V_{CEQ} \sim \frac{V_{CC}}{2}$ for maximum output swing ?

Output Voltage Swing limited by Distortion





$$I_c = I_{CQ} + i_c = I_S \times \exp\left(\frac{V_{BEQ} + v_{be}}{V_T}\right) \qquad i_c = I_{CQ} \times \exp\left(\frac{v_{be}}{V_T}\right) - I_{CQ}$$

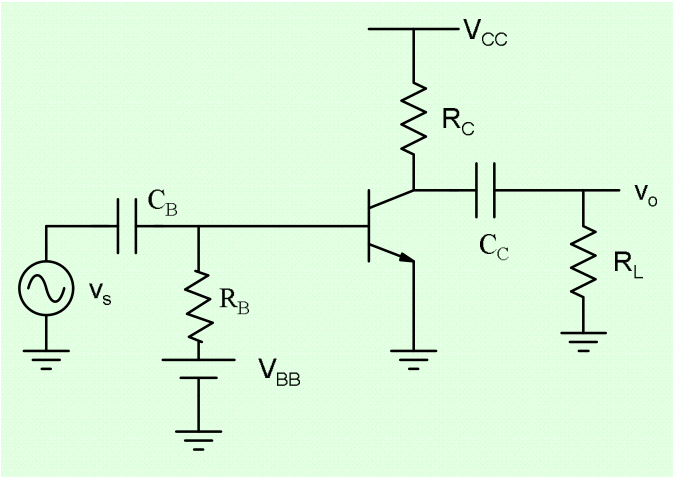
$$v_s = v_{be} = v_{beo} \times Sin(\omega t)$$

$$\frac{i_c}{I_{CQ}} = \exp\{m \times Sin(\omega t)\} - 1 \qquad \frac{v_{beo}}{V_T} = m$$

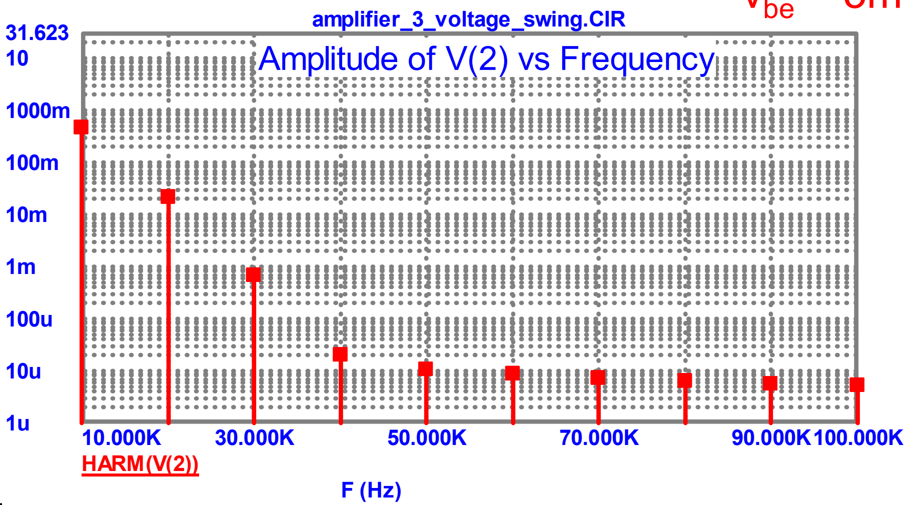
$$\frac{i_c}{I_{CQ}} = m \times Sin(\omega t) + \frac{(m \times Sin(\omega t))^2}{2} + \dots\dots\dots\dots$$

$$\frac{i_c}{I_{CQ}} = m \times Sin(\omega t) + \frac{(m \times Sin(\omega t))^2}{2} + \ldots\ldots\ldots\ldots \qquad \frac{v_{beo}}{V_T} = m$$

$$\frac{i_c}{I_{CQ}} = m \times Sin(\omega t) - \frac{m^2}{4} Cos\left(2\omega t\right) + \ldots\ldots.$$



$v_{be} = 5\text{mV}$



Second Harmonic Distortion HD_2

$$\text{HD}_2 \cong \frac{m}{4} = \frac{v_{beo}}{4 \times V_T} \qquad \text{HD}_2(\%) = \frac{v_{beo}}{V_T} \times 25$$

$$v_{om} \cong A_v \times v_{beo} \Rightarrow V_{om} \le V_T \times \frac{HD_2}{25} \times A_V$$

$$V_{om} \le \left(I_{CQ} \times R_C \| R_L\right) \times \left(\frac{HD_2}{25}\right)$$

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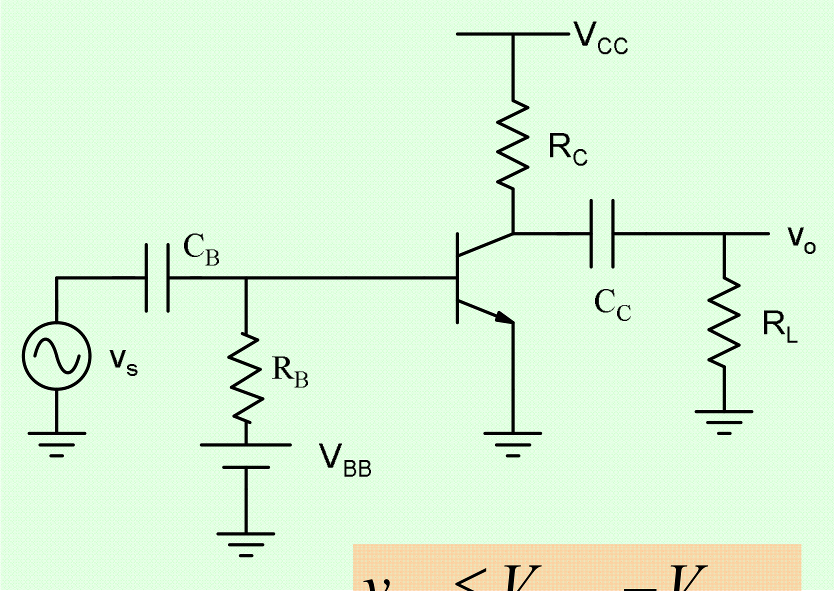
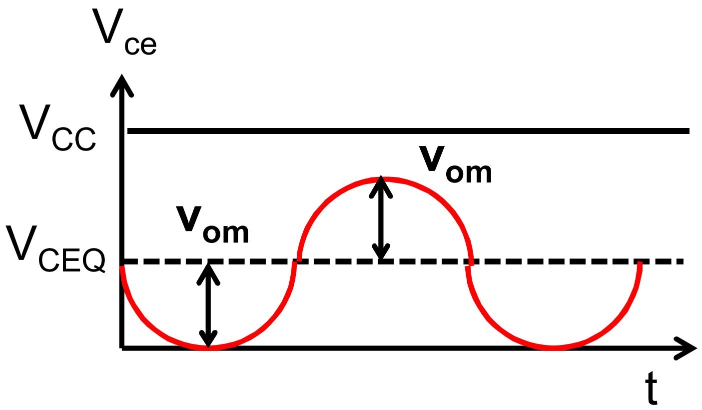
Maximum Output voltage swing





$$v_{om} \le V_{CEQ} - V_{CEsat}$$

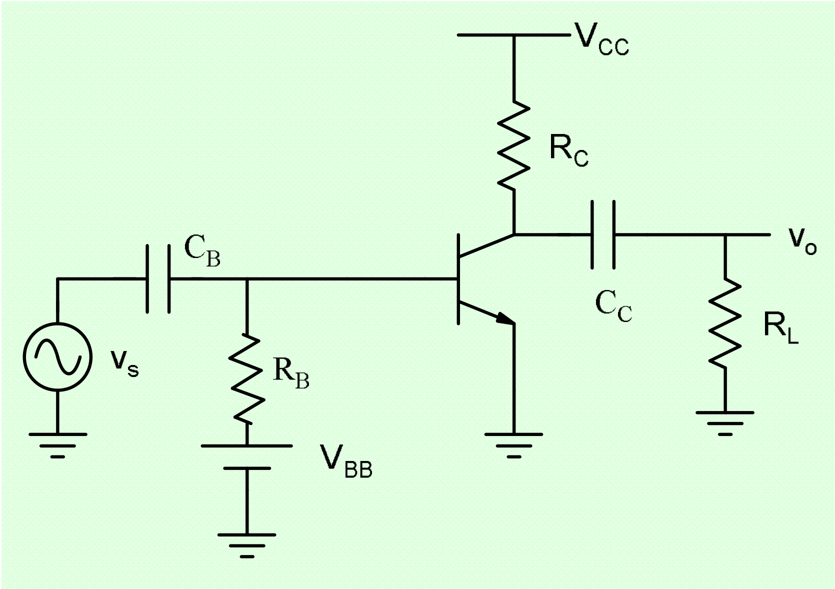
$$V_{om} \le \left(I_{CQ} \times R_C \| R_L\right) \times \left(\frac{HD_2}{25}\right)$$

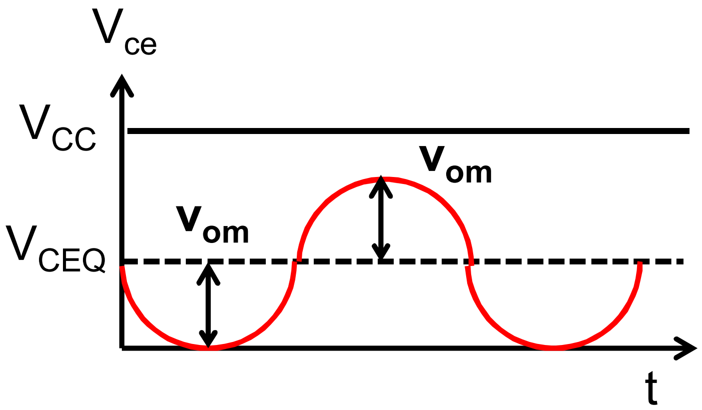
$$v_{om} = Min\left\{V_{CEQ} - V_{CEsat}; \left(I_{CQ} \times R_C \| R_L\right) \times \left(\frac{HD_2}{25}\right)\right\}$$

$$V_{CEQ} - V_{CEsat} = \left(I_{CQ} \times R_C \| R_L\right) \times \left(\frac{HD_2}{25}\right)$$

$$v_{om} \cong V_{CEQ} \cong \frac{V_{CC}}{1 + \left(1 + \frac{R_C}{R_L}\right)\frac{25}{HD_2(\%)}}$$

Maximum Output voltage swing



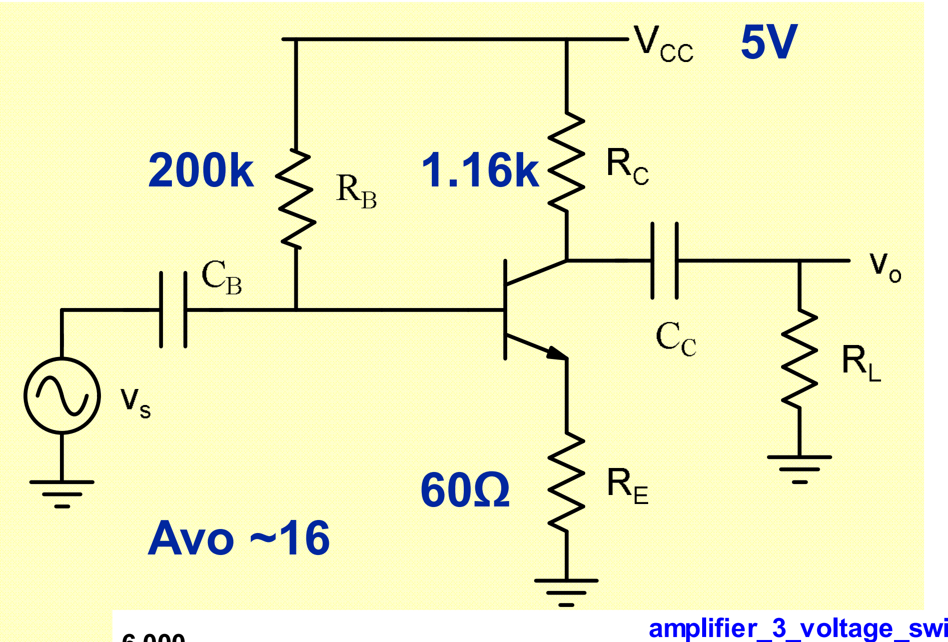


$$v_{om} \cong V_{CEQ} \cong \frac{V_{CC}}{1+\left(1+\frac{R_C}{R_L}\right)\frac{25}{HD_2(\%)}}$$

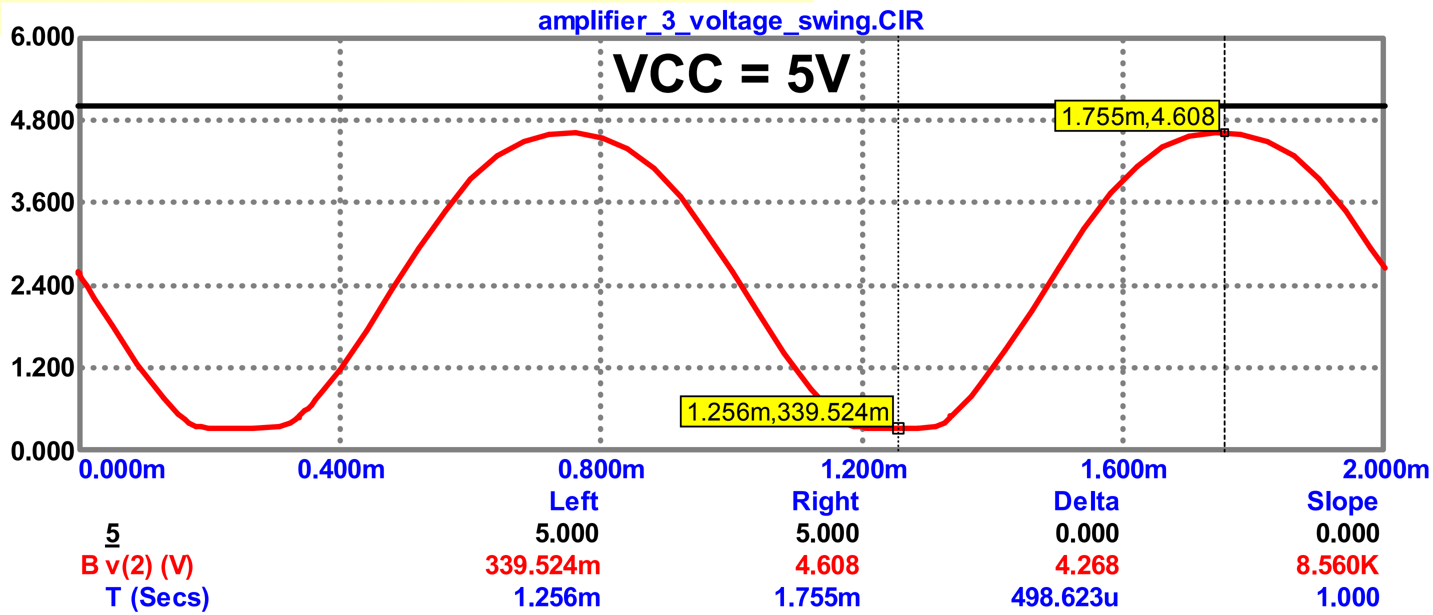
$$v_{om} \cong V_{CEQ} \cong \frac{V_{CC}}{1+\frac{25}{HD_2(\%)}} \quad \text{for } R_L = \infty$$

$$v_{om} \cong V_{CEQ} \cong 1.43\text{V for } HD_2 = 10\% \text{ for } V_{CC} = 5\text{V}$$

Use of emitter resistance reduces non-linear distortion



$$V_{CEQ} \sim \frac{V_{CC}}{2}$$ is a good bias point for maximum output swing



THD~5%

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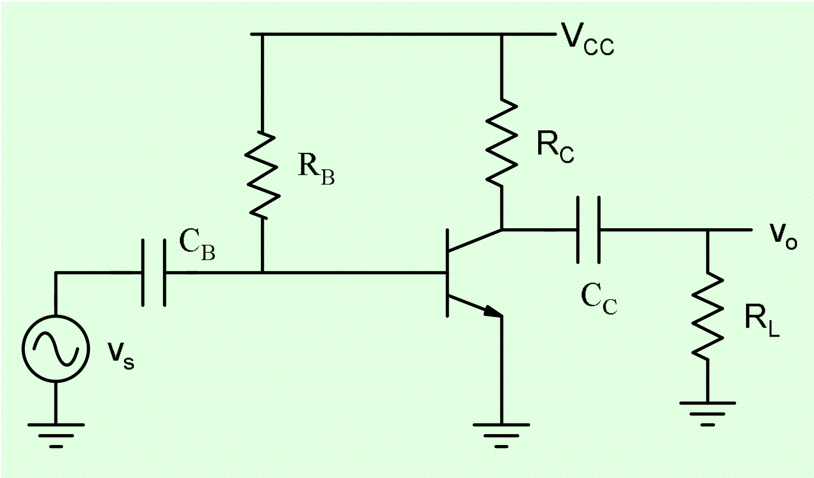
CE Amplifier With Emitter Resistance

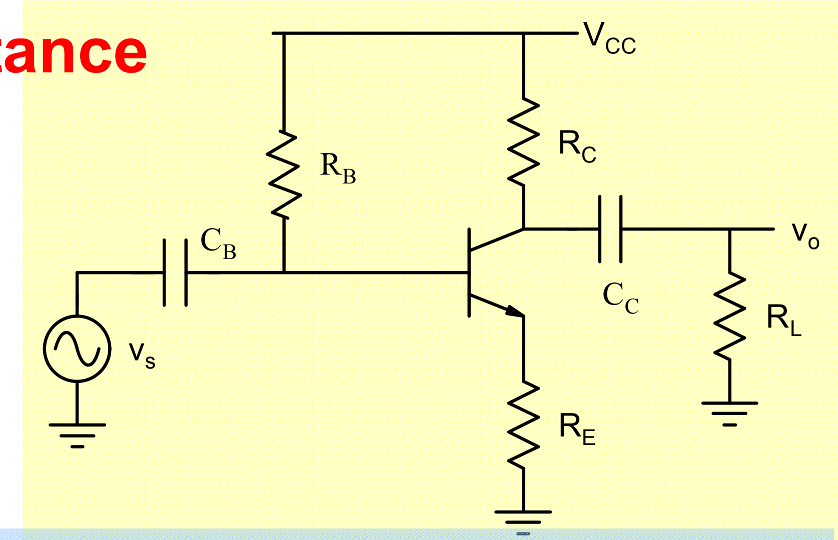


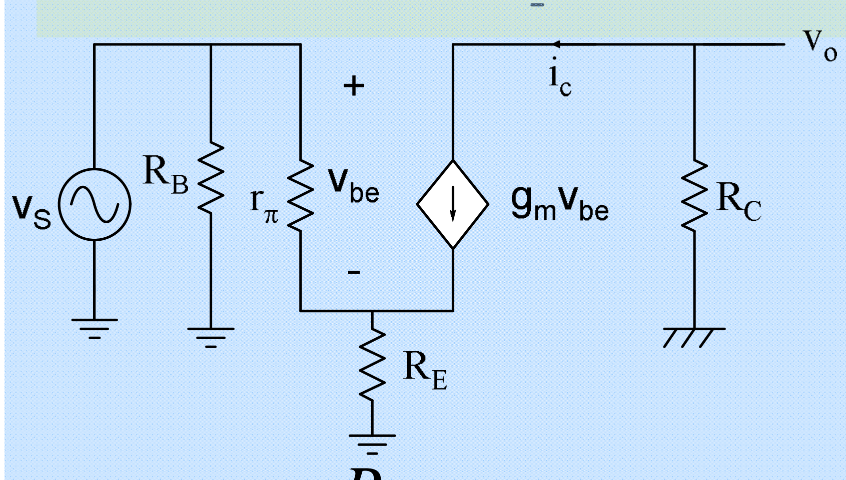
$$A_{VO} = -g_m R_C$$

$$R_{in} = R_B \| r_\pi \sim r_\pi = \frac{V_T}{I_{CQ}} \beta$$

$$R_O \sim R_C$$

$$\frac{|A_{VO}| \times R_{in}}{R_O} \leq \beta$$





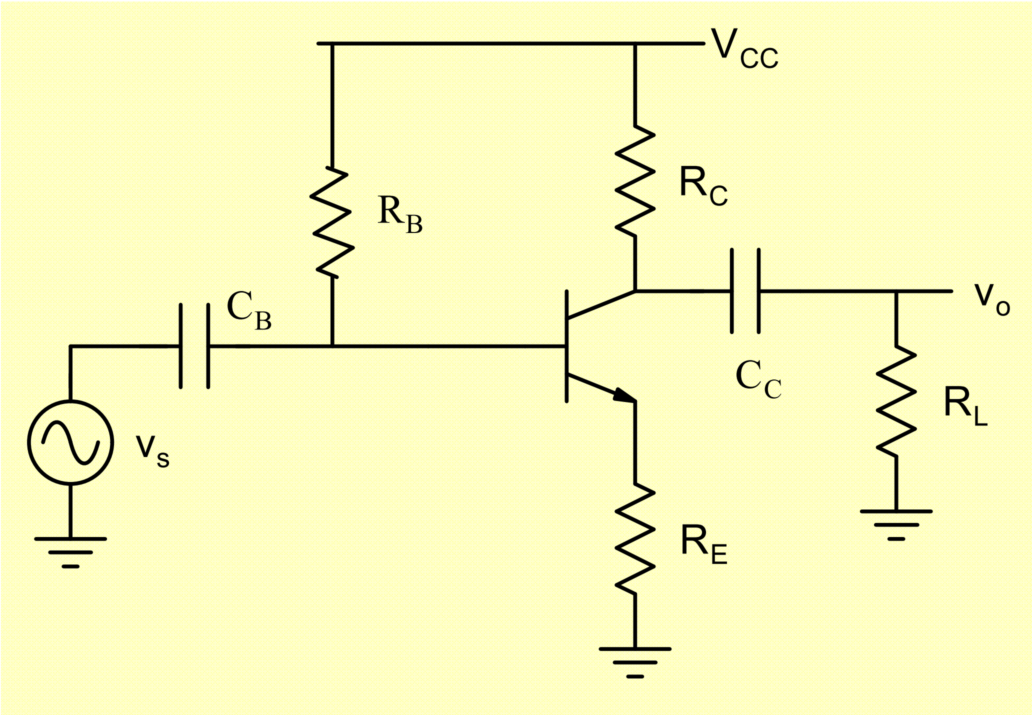
$$A_{VO} \cong -\frac{g_m R_C}{1 + g_m R_E} \qquad R_O \sim R_C$$

$$R_{in} = R_B \| (r_\pi + (1+\beta) R_E)$$

$$\sim r_\pi (1 + g_m R_E)$$

G-Number

Example



$$I_{CQ} = 1mA$$

$$g_m = \frac{I_{CQ}}{V_T} = 0.038\Omega^{-1}$$

For $R_E = 26\ \Omega$, $g_m R_E = 1$

$$A_{VO} \cong -\frac{g_m R_C}{2}$$

$$A_{VO} \cong -\frac{g_m R_C}{1+g_m R_E} \qquad R_O \sim R_C$$

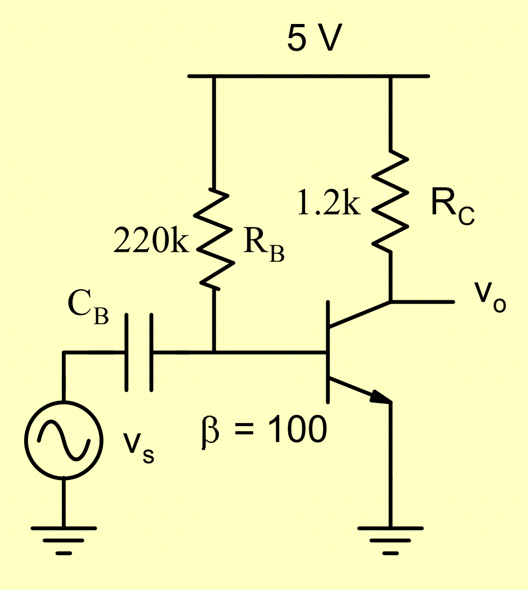
$$R_{in} \sim 2r_\pi$$

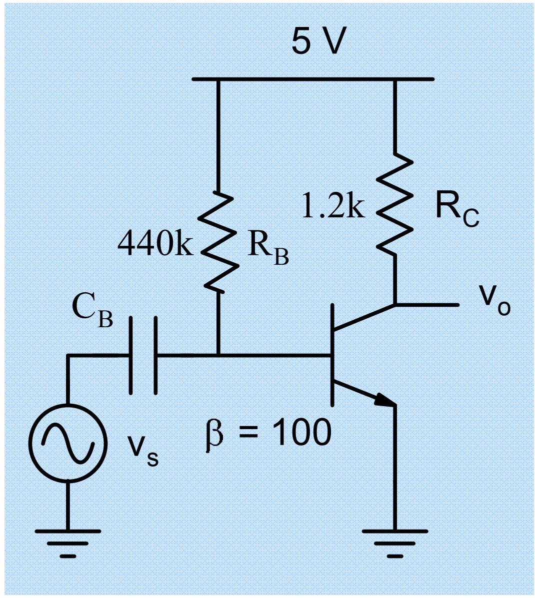
$$R_{in} = R_B \| (r_\pi + (1+\beta)R_E)$$
$$\sim r_\pi (1+g_m R_E)$$

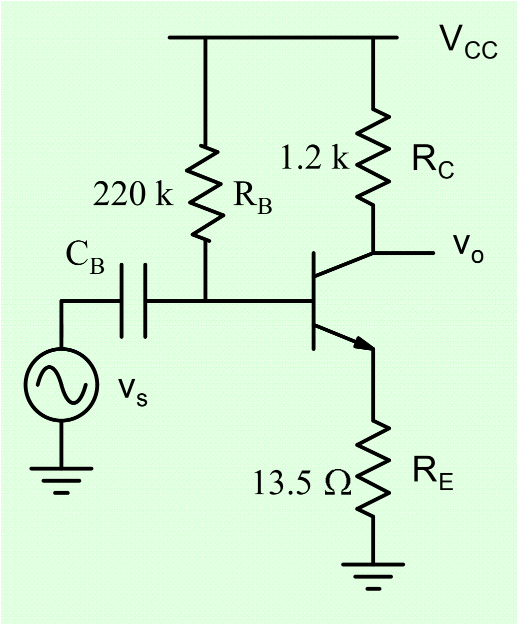
$$\frac{|A_{VO}| \times R_{in}}{R_O} \le \beta$$

$$R_O \sim R_C$$

G-Number



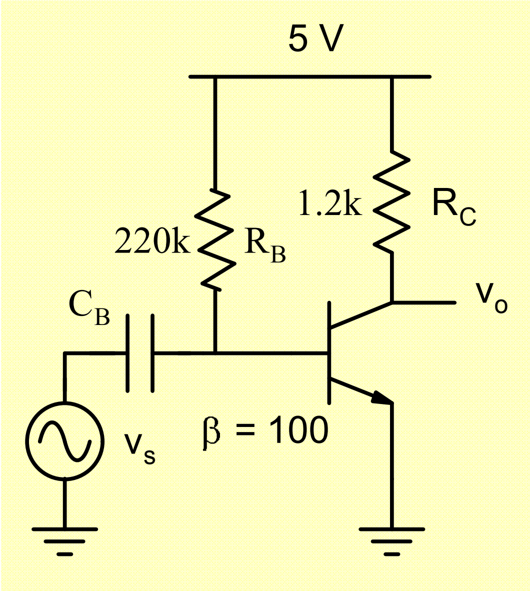


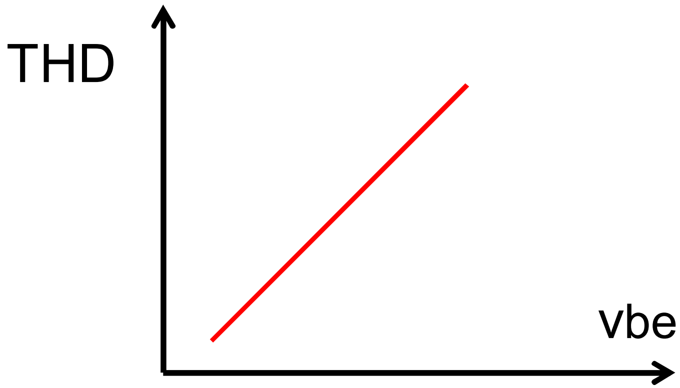


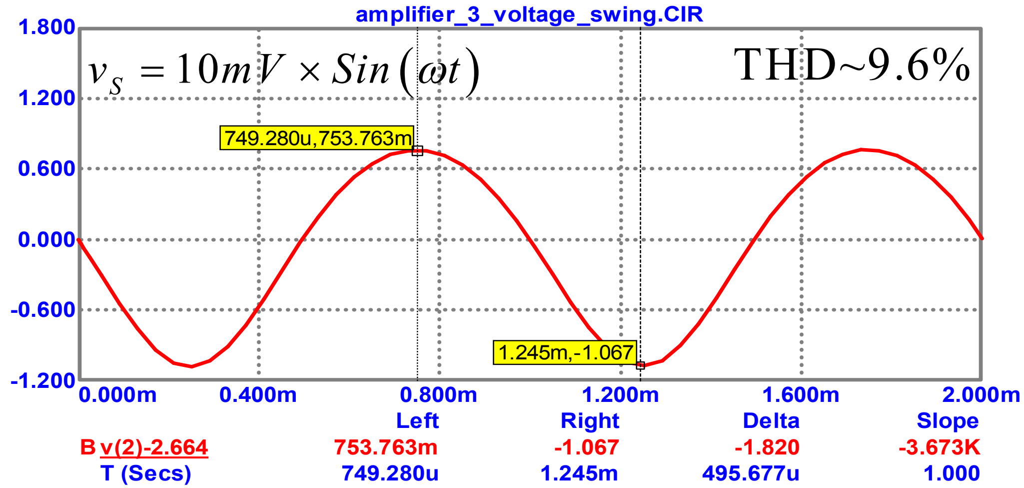
$I_{CQ}=1.95\text{mA}$	$I_{CQ}=0.98\text{mA}$	$I_{CQ}=1.93\text{mA}$
$V_{CEQ}=2.66\text{V}$	$V_{CEQ}=3.8\text{V}$	$V_{CEQ}=2.68\text{V}$
$A_{Vo}=90.2$	$A_{Vo}=45.3$	$A_{Vo}=44.3$
$R_{in}=1.32\text{ k}\Omega$	$R_{in}=2.6\text{ k}\Omega$	$R_{in}=2.66\text{ k}\Omega$
$R_O=1.2\text{ k}\Omega$	$R_O=1.2\text{ k}\Omega$	$R_O=1.2\text{ k}\Omega$

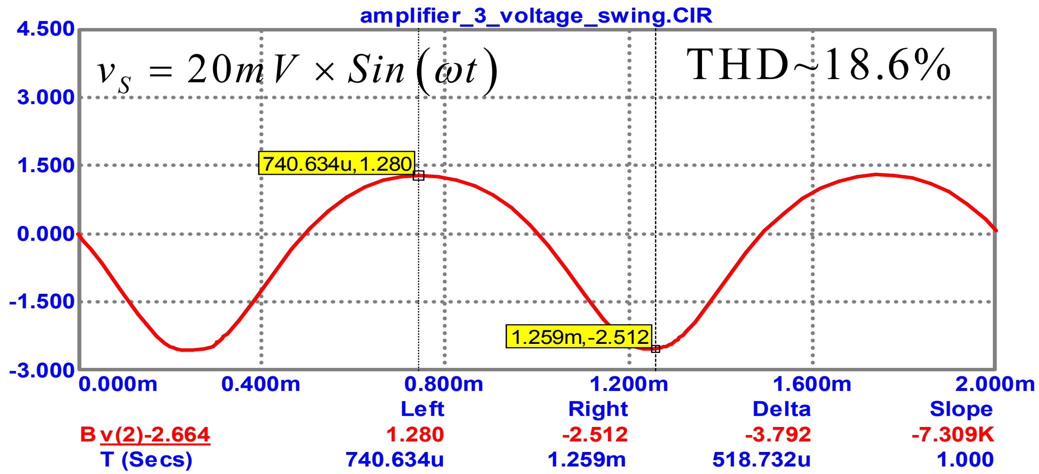
Higher linearity at the cost of power dissipation

G-Number









I_{CQ}=1.95mA

V_{CEQ}=2.66V

A_{Vo}=90.2

R_{in}=1.32 kΩ

R_O=1.2 kΩ

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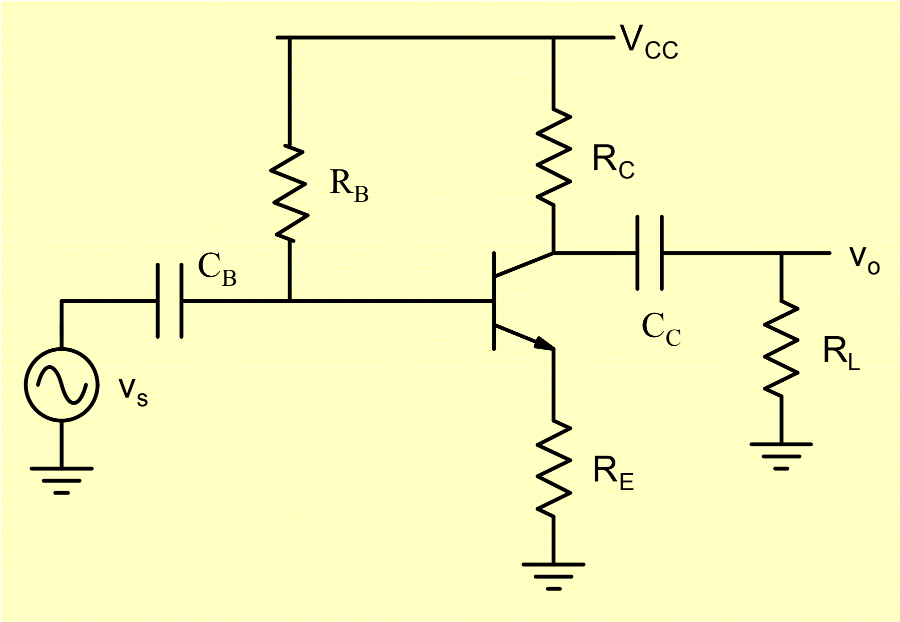
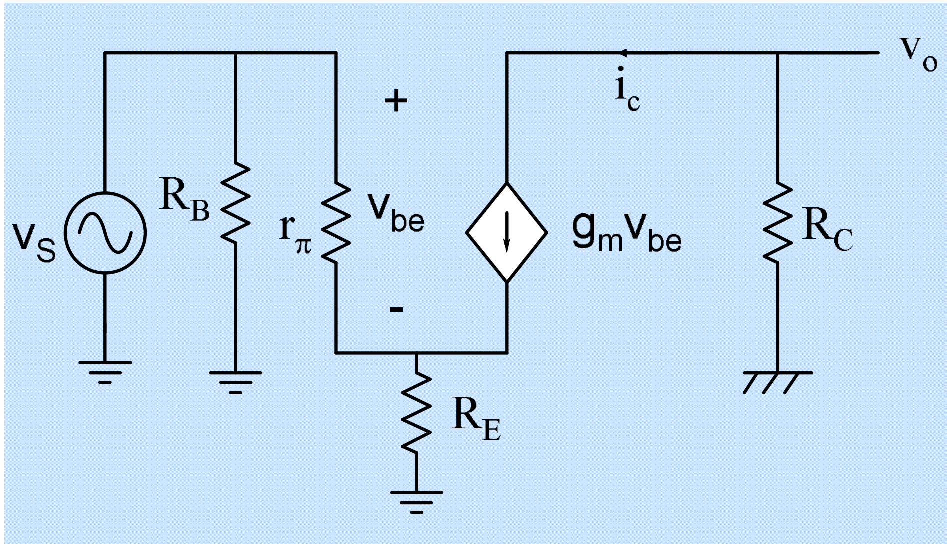
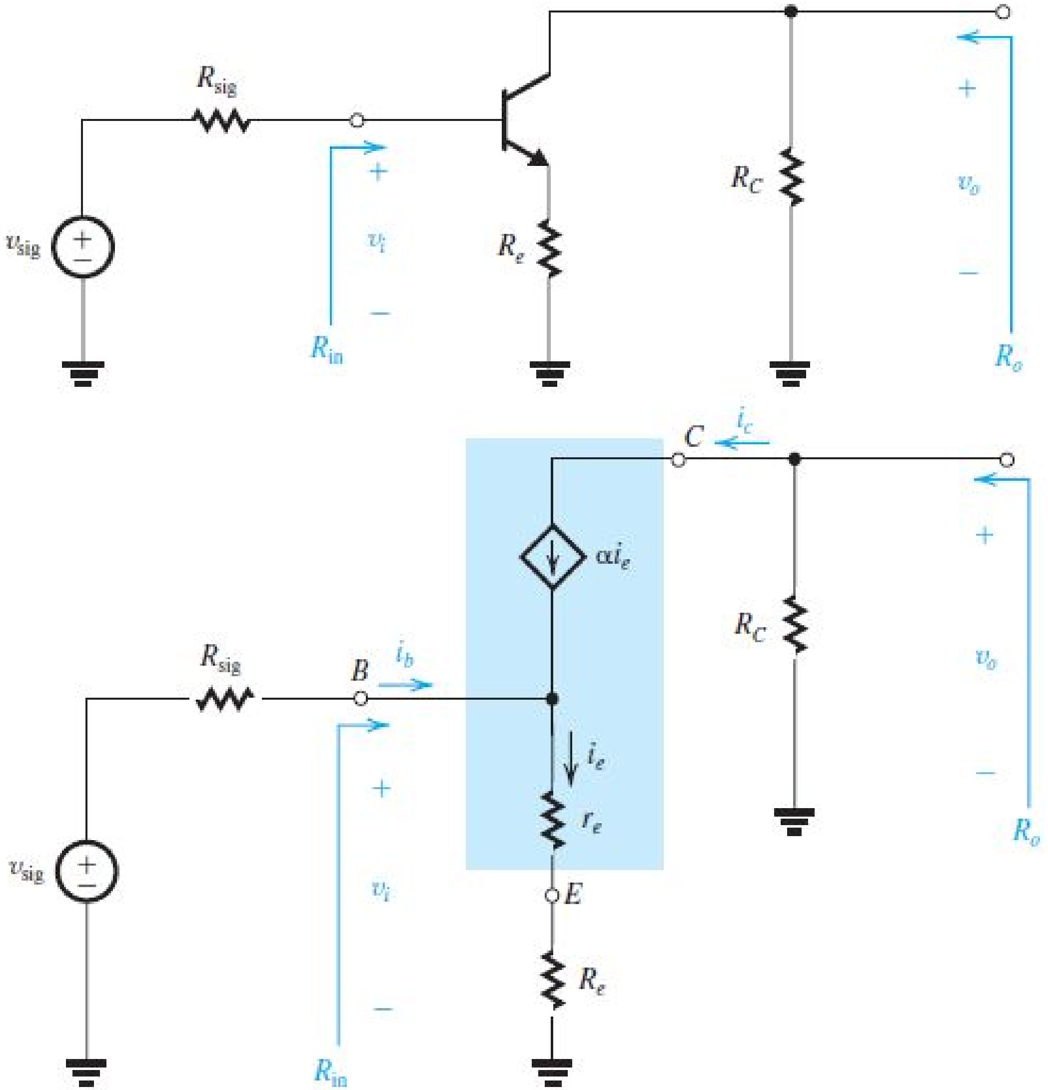




$$v_S = v_{be} \times \left(1 + g_m R_E\right)$$

Emitter resistance allows a higher input voltage to be used



(b)

Figure 6.52 The CE amplifier with an emitter resistance R_e; (a) Circuit without bias details; (b) Equivalent circuit with the BJT replaed with its T model.

Another important consequence of including the resistance R_e in the emitter is that it enables the amplifier to handle larger input signals without incurring nonlinear distortion. This is because only a fraction of the input signal at the base, v_i, appears between the base and the emitter. Specifically, from the circuit in Fig. 6.52(b), we see that

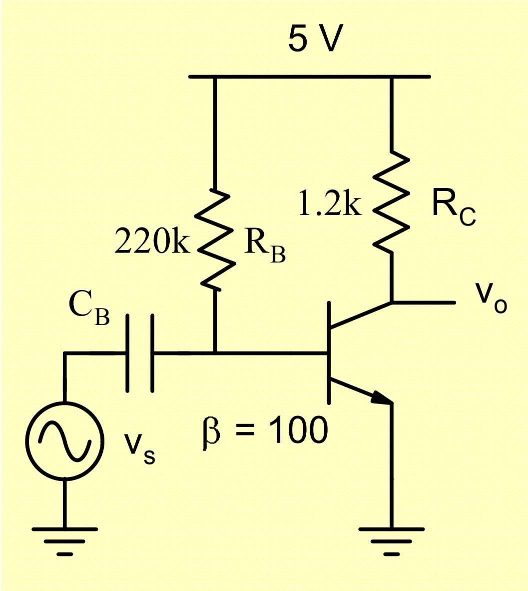
$$\frac{v_\pi}{v_i} = \frac{r_e}{r_e + R_e} \simeq \frac{1}{1 + g_m R_e} \tag{6.89}$$

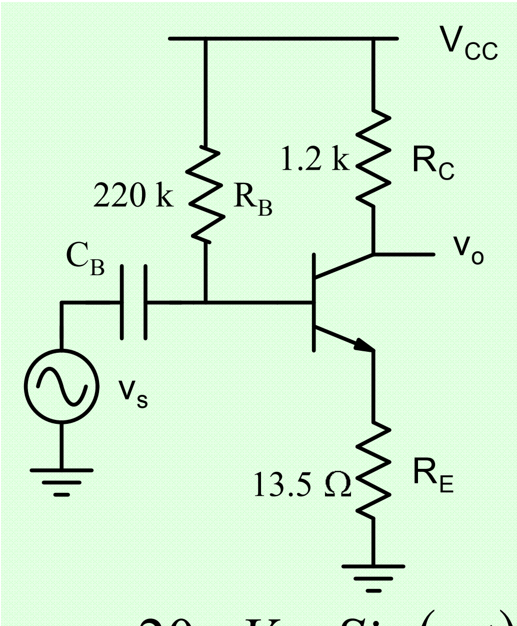
Thus, for the same v_π, the signal at the input terminal of the amplifier, v_i, can be greater than for the CE amplifier by the factor $(1 + g_m R_e)$.

To summarize, including a resistance R_e in the emitter of the CE amplifier results in the following characteristics:

1. The input resistance R_{in} is increased by the factor $(1 + g_m R_e)$.
2. The voltage gain from base to collector, A_v, is reduced by the factor $(1 + g_m R_e)$.
3. For the same nonlinear distortion, the input signal v_i can be increased by the factor $(1 + g_m R_e)$.
4. The overall voltage gain is less dependent on the value of β.
5. The high-frequency response is significantly improved (as we shall see in Chapter 9).

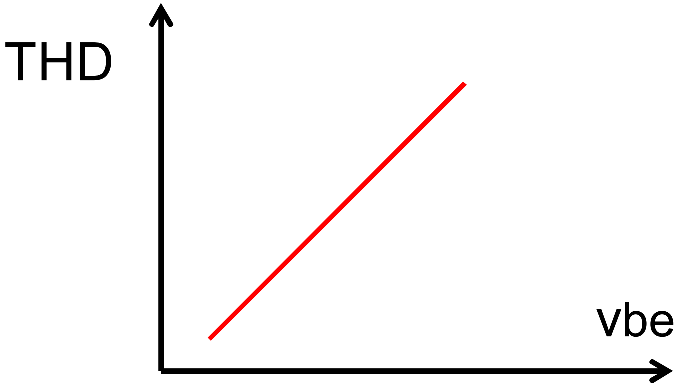
Sedra and Smith

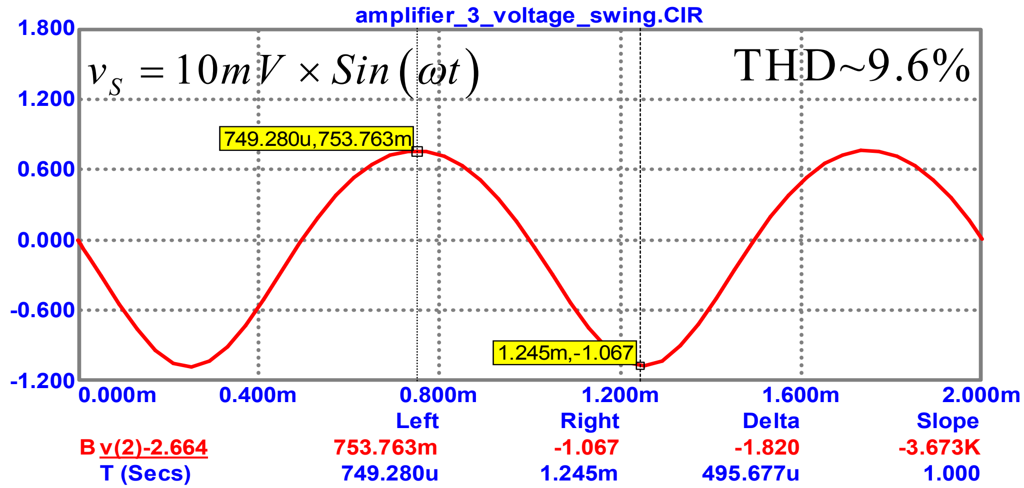


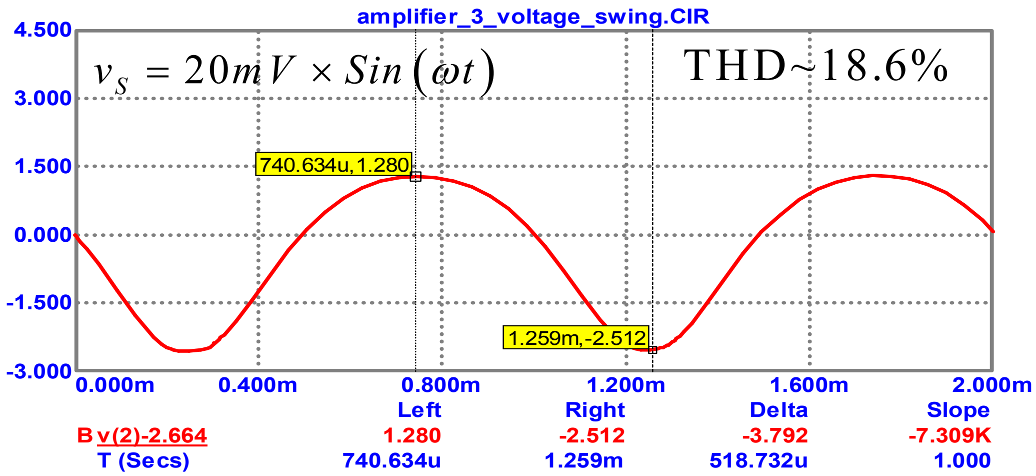


$$v_S = 20mV \times Sin(\omega t)$$

$$v_S = v_{be} \times (1 + g_m R_E) = 2v_{be}$$







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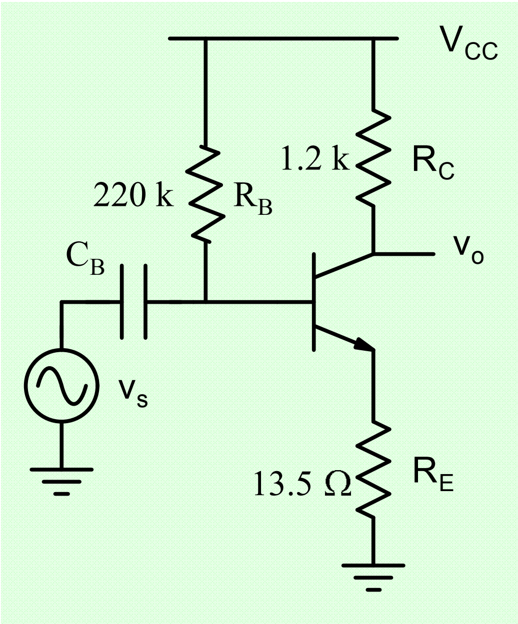
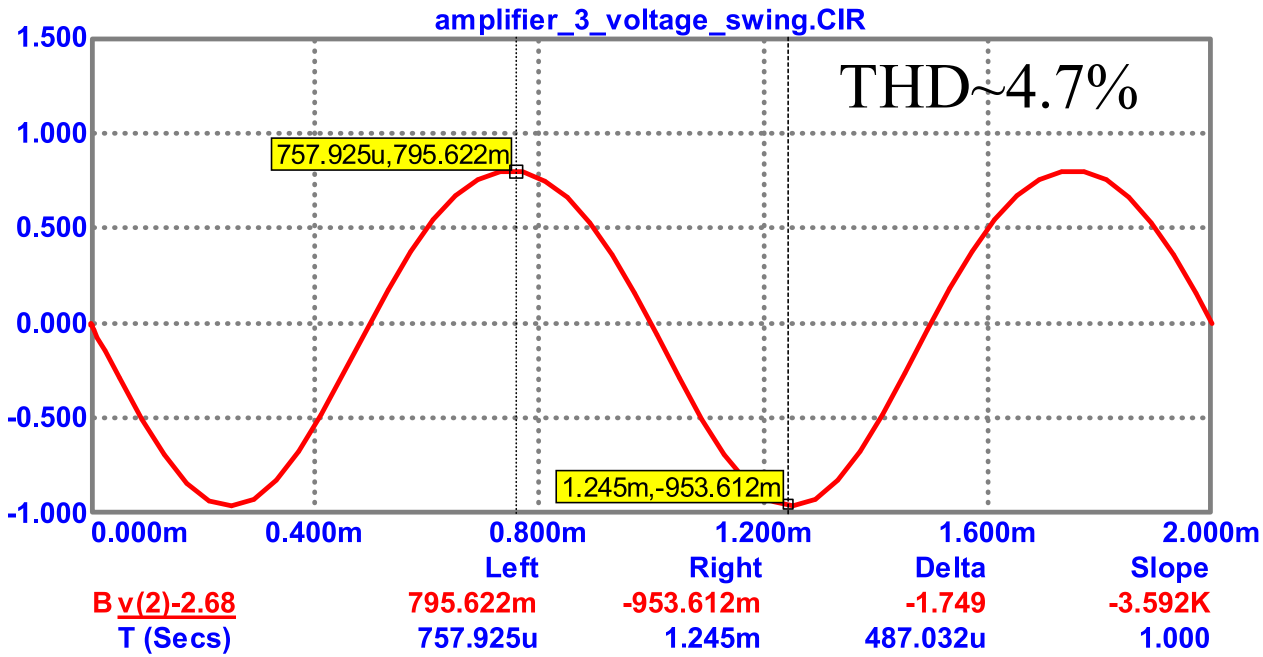
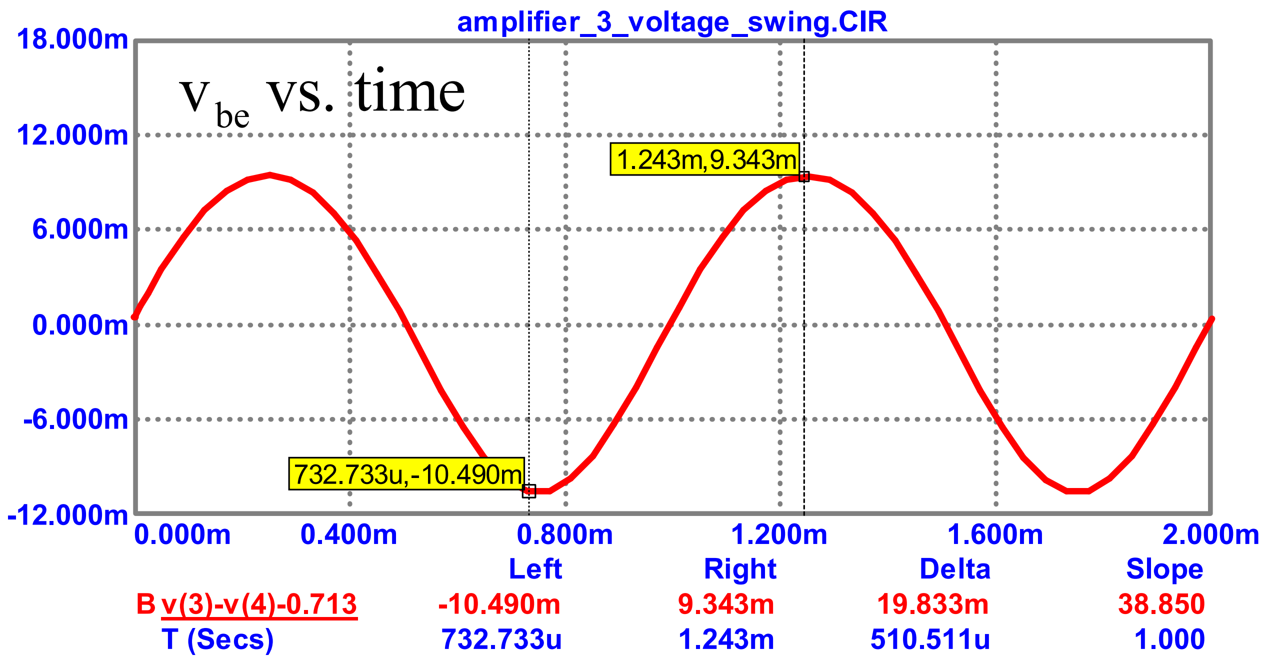
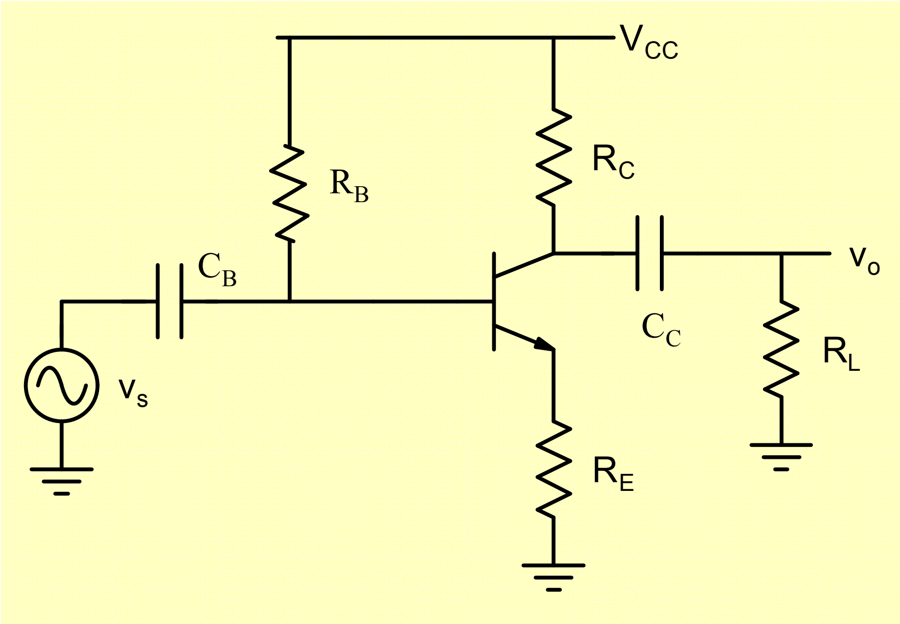


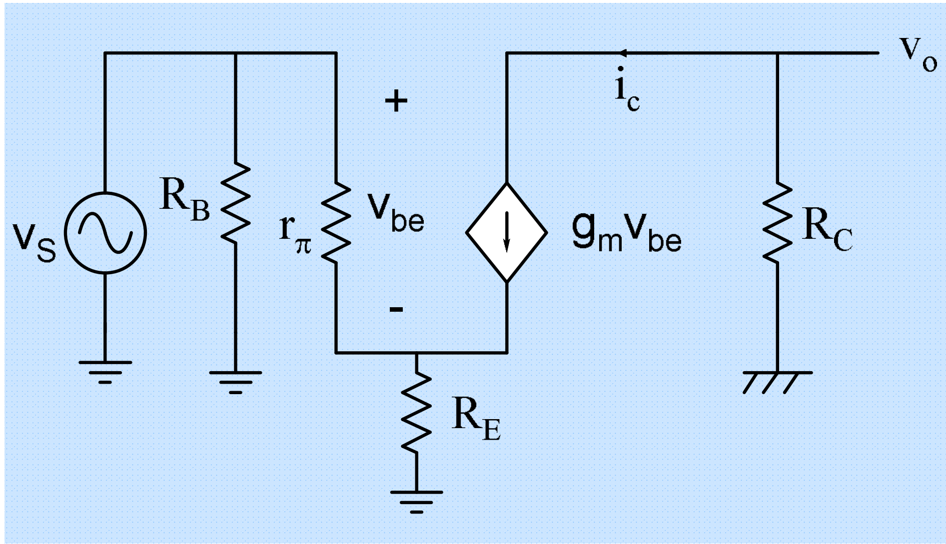


$$v_S = 20mV \times Sin(\omega t)$$

$$v_S = v_{be} \times (1 + g_m R_E)$$
$$= 2v_{be}$$



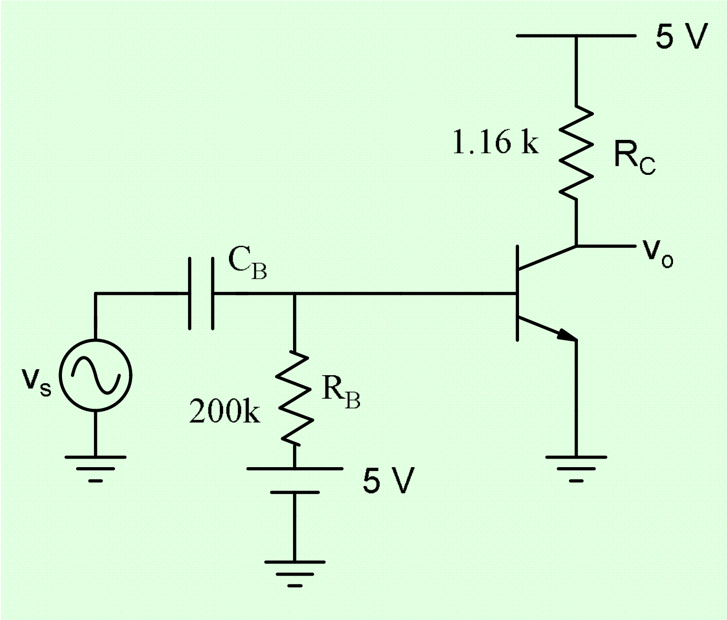


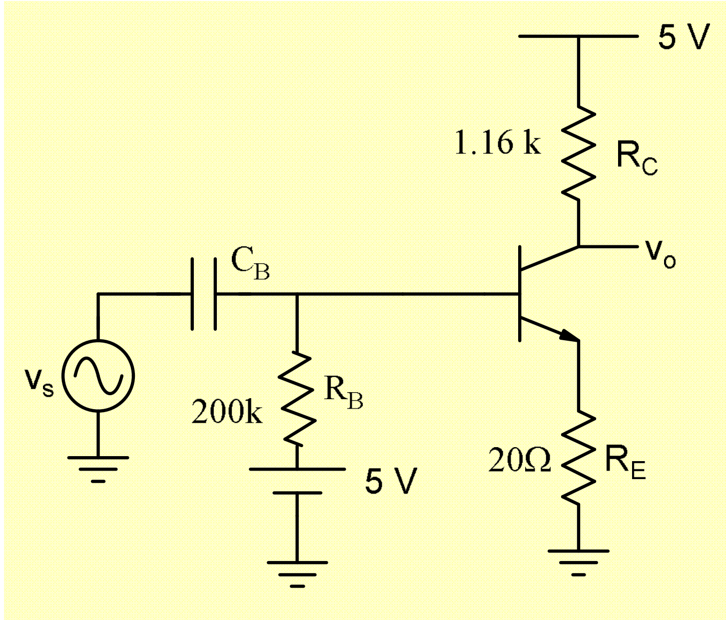


$$v_S = v_{be} \times \left(1 + g_m R_E\right)$$

3. For the same nonlinear distortion, the input signal v_i can be increased by the factor $(1 + g_m R_e)$.

Emitter resistance not only allows a higher input voltage to be used but for same v_{be} reduces harmonic distortion as well





A_{Vo}=95.75

R_{in}=1.2 kΩ

R_O=1.16 kΩ

v_{opp}=1.93 V for THD~9.6%

$$\frac{|A_{VO}|\times R_{in}}{R_O}=99$$

A_{Vo}= 35.7

R_{in}=3.18 kΩ

R_O=1.16 kΩ

v_{opp}=4.3 V for THD~9.6%

$$\frac{|A_{VO}|\times R_{in}}{R_O}=97.86$$