BJT Fundamental Amplifier Configurations

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Outline

- Small-signal middle-frequency equivalent circuits
- Common Emitter (CE)
- Common Base (CB)
- Common Collector (CC)
- Emitter Degeneration (ED)
- Comparison between CE, CB, CC and ED
- Distortion limits (dynamic range)

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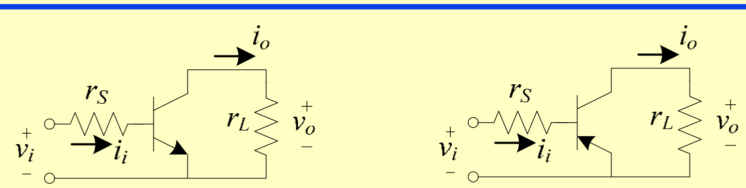
Small-Signal Mid-Frequency Equivalent Circuits

- To analyze an amplifier:

1. Calculate the DC operating point (bias circuit)
2. Obtain the small-signal equivalent circuit at medium frequencies
3. Identify the amplifier's configuration (CE, CB, etc.)
4. Analyze the small-signal equivalent circuit, either by using formulas or by deriving them

Common Emitter (CE)

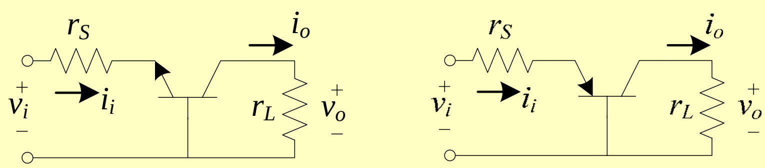


$$A_v = \frac{-g_m (r_o \parallel r_L) r_\pi}{r_S + r_\pi} \qquad R_i = r_S + r_\pi \qquad R_o = r_o \qquad A_i = \frac{-\beta r_o}{r_o + r_L}$$

If $r_S << r_\pi$, $\quad A_v \approx -g_m (r_o \parallel r_L) \quad R_i \approx r_\pi$

If $r_L << r_o$, $\quad A_v \approx -g_m r_L \quad A_i \approx -\beta$

Common Base (CB)



$$A_v = \frac{r_L}{r_S + r_e\left(1 + \frac{r_L}{r_o}\right)} = \frac{g_m r_L r_o}{r_L + r_o(1 + g_m r_S)}$$

$$R_o = r_S + r_o(1 + g_m r_S)$$

$$A_i = \alpha$$

$$R_i = r_S + r_e\left(1 + \frac{r_L}{r_o}\right) = r_S + \frac{\alpha}{g_m}\left(1 + \frac{r_L}{r_o}\right)$$

If $r_L << r_o$,

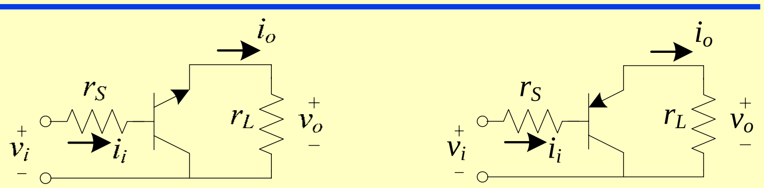
$$A_v = \frac{r_L}{r_S + r_e} = \frac{g_m r_L}{1 + g_m r_S}$$

$$R_i = r_S + r_e = r_S + \frac{\alpha}{g_m}$$

If $r_S << r_e$,

$$A_v \approx g_m(r_L \| r_o)$$

Common Collector (CC)



$$A_v = \frac{(1+\beta)(r_o \| r_L)}{r_S + r_\pi + (1+\beta)(r_o \| r_L)} \qquad A_v \approx \frac{\beta(r_o \| r_L)}{r_\pi + \beta(r_o \| r_L)} \qquad A_i = \frac{(\beta+1)r_o}{r_o + r_L}$$

$$R_i = r_S + r_\pi + (1+\beta)(r_o \| r_L) \qquad R_i \approx r_\pi + \beta(r_o \| r_L)$$

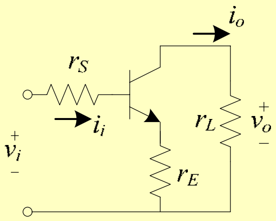
$$R_o = r_o \| (r_S + r_\pi) \| \left(\frac{1}{g_m} + \frac{r_S}{\beta}\right)$$

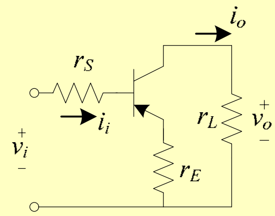
If $r_o >> r_S + r_\pi$, $R_o \approx \frac{1}{g_m} + \frac{r_S}{\beta}$

If $r_L << r_o$, $A_v \approx \frac{g_m r_L}{1 + g_m r_L}$ $\quad R_i \approx r_\pi + \beta r_L$

If $\beta r_L >> r_\pi$, $A_v \approx 1$

Emitter Degeneration (ED)





$$A_v = \frac{-g_m r_L}{1 + \frac{r_E}{r_\pi}(1+\beta) + \frac{r_S}{r_\pi}}$$

If $r_S << r_E(1+\beta)$,

$$A_v \approx \frac{-g_m r_L}{1 + g_m r_E}$$

If $g_m r_E >> 1$,

$$A_v \approx -r_L / r_E$$

$$R_i = r_S + r_\pi + (1+\beta) r_E \qquad A_i \approx -\beta$$

$$R_o = r_o + [r_E \,\|\, (r_S + r_\pi)]\left[1 + \frac{\beta r_o}{r_S + r_\pi}\right]$$

If $r_\pi >> r_S$,

$$R_i \approx r_\pi + (1+\beta) r_E$$

$$R_o \approx r_o[1 + g_m (r_E \,\|\, r_\pi)]$$

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Simplified Formulas – Comparison

	CE	CB	CC	ED
A_v	$-g_m(r_o \,\|\, r_L)$	$\frac{g_m r_L}{1+g_m r_S}$	$\frac{g_m r_L}{1+g_m r_L}$	$\frac{-g_m r_L}{1+g_m r_E}$
R_i	$r_S + r_\pi$	$r_S + \frac{1}{g_m}\left(1+\frac{r_L}{r_o}\right)$	$r_\pi + \beta(r_o \,\|\, r_L)$	$r_\pi + \beta r_E$
R_o	r_o	$r_o(1+g_m r_S)$	$\frac{1}{g_m} + \frac{r_S}{\beta}$	$r_o[1+g_m(r_E \,\|\, r_\pi)]$
A_i	$-\beta$	α	β	$-\beta$

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Over Simplified Formulas – Summary

	CE	**CB**	**CC**	**ED**
A_v	$-g_m r_L$	$g_m r_L$	1	$\frac{-r_L}{r_E}$
R_i	r_π	$r_S + \frac{1}{g_m}$	$r_\pi + \beta r_L$	$r_\pi + \beta r_E$
R_o	r_o	r_o	$\frac{1}{g_m}$	$r_o g_m (r_E \parallel r_\pi)$
A_i	$-\beta$	1	β	$-\beta$

Distortion Limits

- Distortion limits refer to the maximum output voltage swing for a linear operation (dynamic range)
- They depend on the amplifier configuration, the bias point, and the load line
- For CE amplifiers: $DL^+ = I_{CQ} r_L \quad DL^- = V_{CEQ} - V_{CE(sat)}$
- For CC amplifiers: $DL^+ = V_{CEQ} - V_{CE(sat)} \quad DL^- = I_{CQ} r_L$
- For CB amplifiers: $DL^+ = I_{CQ} r_L \quad DL^- = V_{CBQ} + V_{CBon}$
- For ED amplifiers: $DL^+ = I_{CQ} r_L \quad DL^- = \left(V_{CEQ} - V_{CE(sat)}\right) \frac{r_L}{r_L + r_E}$