Diodes $i_D = I_S(e^{V_D/V_T} - 1)$ → $I_S \approx 10^{-14}, 10^{-15}$ A

Note down assumptions

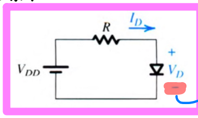
$V_p = \sqrt{2}\, V_{RMS}$

Exponential Model

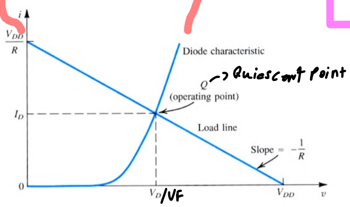
$I_D = I_S e^{V_D/V_T}$

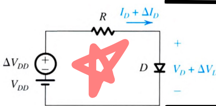
$I_D = \frac{V_{DD} - V_D}{R}$

$I_{D_1} = I_S e^{V_{D_1}/V_T}$, $I_{D_2} = I_S e^{V_{D_2}/V_T}$ → by division $V_{D_2} = V_{D_1} + V_T \ln\left(\frac{I_{D_2}}{I_{D_1}}\right)$



Graphical Model





Iterative Model

use Exp Model formulas and Repeat for accuracy

Constant Voltage drop Model → $V_D = 0.7V$

Ideal Diode → $V_D = 0V$ → $I_D > 0A$

Small-signal Model

$i_D(t) = I_D e^{v_d/V_T}$ → $\frac{v_d}{V_T} \ll 1$

$\therefore i_D \approx I_D\left(1 + \frac{v_d}{V_T}\right)$

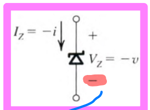
$r_d = \frac{v_d}{i_d} = \frac{V_T}{I_D}$

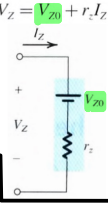
Zener Diodes

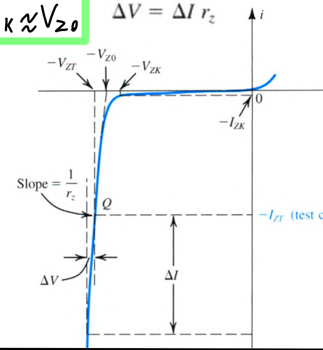
$V_Z = V_{Z0} + r_z I_Z$

$V_{ZK} \approx V_{Z0}$

$\Delta V = \Delta I\, r_z$







Regulation

Line: $\Delta V_O / \Delta V^+$

Load: $\Delta V_O / \Delta I_L$

Filters $\tau = RC$ $I_L = V_{Pavg}/R$

During diode off: $V_O = V_P e^{-t/RC}$

$I_L = V_S(1 - T/RC)/R$

$V_r \simeq V_P \frac{T}{RC}$ → assume $e^{-T/RC} = 1 - \frac{T}{RC}$

$V_r = V_P / fRC = I_L / fC$

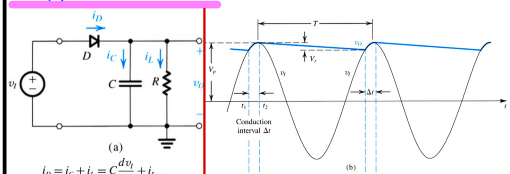
Rectifiers

	I_L	PIV/V_{Opeak}
Half-wave	V_{Oavg}/R_L	V_S
Full-wave	V_{Oavg}/R_L	$2V_S - V_D$
Bridge	V_{Oavg}/R_L	$V_S - V_D$

V_S = Source voltage

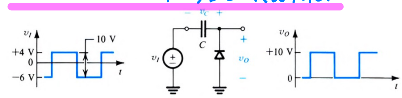
V_{Oavg} = Avg Output voltage → $\frac{2}{\pi} V_P$

Ripple Voltage

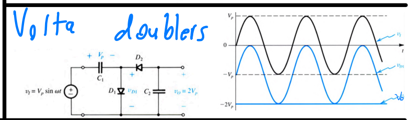


$i_D = i_C + i_L = C\frac{dv_I}{dt} + i_L$

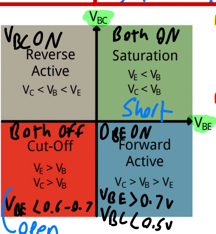
Clamped capacitor, DC Restorer

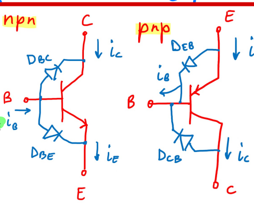


Volta doublers



BJT's Always Check Operation Mode





$i_C = I_S e^{v_{BE}/V_T} = I_C + I_C \frac{v_{be}}{V_T}$

$i_B = \frac{i_C}{\beta} = \left(\frac{I_S}{\beta}\right) e^{v_{BE}/V_T}$

$i_E = \frac{i_C}{\alpha} = \left(\frac{I_S}{\alpha}\right) e^{v_{BE}/V_T}$

$V_{BE} = V_B - V_E$

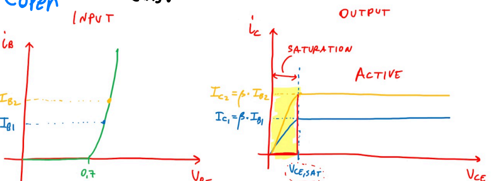
Note: For the *pnp* transistor, replace v_{BE} with v_{EB}.

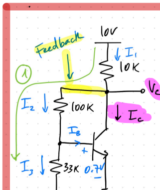
$i_C = \alpha i_E$ $\qquad i_B = (1-\alpha) i_E = \frac{i_E}{\beta + 1}$

$i_C = \beta i_B$ $\qquad i_E = (\beta + 1) i_B = i_C + i_B$

$\beta = \frac{\alpha}{1 - \alpha}$ $\qquad \alpha = \frac{\beta}{\beta + 1}$

	RMS	Average	Peak	Peak-to-Peak
RMS	1	$\frac{2\sqrt{2}}{\pi}$ (0.9003)	$\sqrt{2}$ (1.414)	$2\sqrt{2}$ (2.828)
Average	$\frac{\pi}{2\sqrt{2}}$ (1.111)	1	$\frac{\pi}{2}$ (1.571)	π (3.142)
Peak	$\frac{1}{\sqrt{2}}$ (0.7071)	$\frac{2}{\pi}$ (0.6366)	1	2
Peak-to-Peak	$\frac{1}{2\sqrt{2}}$ (0.3536)	$\frac{1}{\pi}$ (0.3183)	0.5	1





$I_3 = \frac{0.7}{33K} = 21.2\mu A$

$I_B = \frac{I_C}{\beta} = 0.02 I_C$

$I_2 = I_3 + I_B$

$= 21.2\mu + 0.02 I_C$

$I_1 = I_C + I_2$

$= I_C + 21.2\mu + 0.02 I_C$

KVL Loop ①

$10 = I_1 \cdot 10K + I_2 \cdot 100K + 0.7$

$10 = (I_C + 21.2\mu + 0.02 I_C) \cdot 10K + (21.2\mu + 0.02 I_C) \cdot 100K + 0.7$

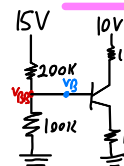
Solve for I_C → $I_C = 0.571 mA$

$I_1 = 582\mu + 21.2\mu = 603.2\mu A$

$V_C = 10 - 603.2\mu \cdot 10K = 3.96 \gg V_B$ ACTIVE

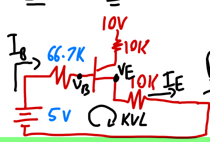
$V_{CE} = V_C$

How To Thevinan



$V_{BB} = 15\left(\frac{100}{100 + 200}\right) = 5V$

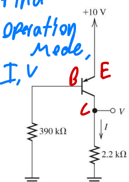
$R_B = 200K \| 100K = 66.7K\Omega$



Do KVL

$I_E = (\beta + 1) I_B$

Find operation mode, I, V



$\beta = 100$

PNP

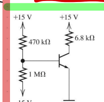
$V_B = 10 - 0.7 = 9.3V$

$I_B = \frac{9.3}{390K} = 23.8\mu A$

$I_C = 100 \cdot 23.8\mu = 2.38mA = I$

$V_C = 2.38mA \cdot 2.2K = 5.24V = V$

$V_{CB} = 5.24 - 9.3V < 0.5V$ Active region



Superposition Theorem

$V_{BB} = V_{BB}\big|_{V^- = 0} + V_{BB}\big|_{V^+ = 0}$

$V_{BB}\big|_{V^- = 0} = 15 \cdot \frac{1M}{470K + 1M} = 10.2V$

$V_{BB}\big|_{V^+ = 0} = -15 \cdot \frac{470K}{470K + 1M} = -4.8V$

$V_{BB} = 10.2 - 4.8 = 5.4V$

$R_B = 470K \| 1M = 320K\Omega$

Active region

$I_B = \frac{5.4 - 0.7}{320K} = 14.7\mu A$

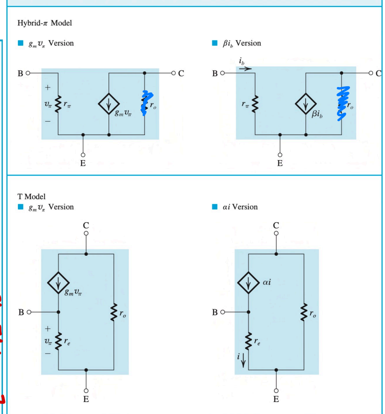
BJT Amplifiers | CE → π   CB or CC → T

How to solve BJT amp's

1. Eliminate the signal source and determine the dc operating point of the transistor.
2. Calculate the values of the parameters of the small-signal model.
3. Eliminate the dc sources by replacing each dc voltage source by a short circuit and each dc current source by an open circuit.
4. Replace the transistor with one of its small-signal, equivalent-circuit models. Although any of the models can be used, one might be more convenient than the others for the particular circuit being analyzed. This point is made clearer in Section 7.3.
5. Analyze the resulting circuit to determine the required quantities (e.g., voltage gain, input resistance).

Common Base Configuration – has Voltage Gain but no Current Gain.
Common Emitter Configuration – has both Current and Voltage Gain.
Common Collector Configuration – has Current Gain but no Voltage Gain.

Table 7.3 Small-Signal Models of the BJT



Model Parameters in Terms of DC Bias Currents	In Terms of g_m	In Terms of r_e	Relationships between α and β
$g_m = \frac{I_C}{V_T} = \frac{i_c}{v_{be}}$ g_m [A/V, S]	$r_e = \frac{\alpha}{g_m}$	$g_m = \frac{\alpha}{r_e}$	$\beta = \frac{\alpha}{1-\alpha}$
$r_e = \frac{V_T}{I_E} = \alpha\frac{V_T}{I_C}$	$r_\pi = \frac{\beta}{g_m}$	$r_\pi = (\beta+1)r_e$	$\alpha = \frac{\beta}{\beta+1}$
$r_\pi = \frac{V_T}{I_B} = \beta\frac{V_T}{I_C}$		$g_m + \frac{1}{r_\pi} = \frac{1}{r_e}$	$\beta+1 = \frac{1}{1-\alpha}$
$r_o = \frac{\lvert V_A\rvert}{I_C}$ → Early Voltage			

Table 7.5 Characteristics of BJT Amplifiers[a,b,c] $A_{vo} = A_v = V_o/V_i$ / R_i = Parallel add

	R_{in}	A_{vo}	R_o	A_v	G_v gain
Common emitter (Fig. 7.37)	$(\beta+1)r_e$	$-g_m R_C$	R_C	$-g_m(R_C \| R_L)$ $-\alpha\frac{R_C \| R_L}{r_e}$	$-\beta\frac{R_C \| R_L}{R_{sig}+(\beta+1)r_e}$
Common emitter with R_e (Fig. 7.39)	$(\beta+1)(r_e+R_e)$	$-\frac{g_m R_C}{1+g_m R_e}$	R_C	$\frac{-g_m(R_C \| R_L)}{1+g_m R_e}$ $-\alpha\frac{R_C \| R_L}{r_e+R_e}$	$-\beta\frac{R_C \| R_L}{R_{sig}+(\beta+1)(r_e+R_e)}$
Common base (Fig. 7.41)	r_e	$g_m R_C$	R_C	$g_m(R_C \| R_L)$ $\alpha\frac{R_C \| R_L}{r_e}$	$\alpha\frac{R_C \| R_L}{R_{sig}+r_e}$
Emitter follower (Fig. 7.44) CC	$(\beta+1)(r_e+R_L)$	1	r_e	$\frac{R_L}{R_L+r_e}$	$\frac{R_L}{R_L+r_e+R_{sig}/(\beta+1)}$ $G_{vo}=1$ $R_{out} = r_e + \frac{R_{sig}}{\beta+1}$

[a] For the interpretation of R_{in}, A_{vo}, and R_o refer to Fig. 7.35.
[b] The BJT output resistance r_o is not taken into account in these formulas.
[c] Setting $\beta = \infty$ ($\alpha = 1$) and replacing r_e with $1/g_m$, R_C with R_D, and R_e with R_s results in the corresponding formulas for MOSFET amplifiers (Table 7.4).

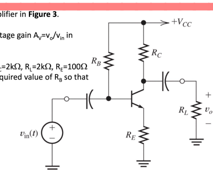
$i_B = \frac{I_C}{\beta} + \frac{i_c}{\beta}$ $V_T = V_{be}$

$i_e = \frac{I_C}{\alpha} + \frac{i_c}{\alpha}$

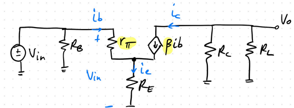
Consider the common emitter amplifier in **Figure 3**.

a) Derive an expression of the voltage gain $A_v = v_o/v_{in}$ in terms of r_π and β.

b) Assume that $\beta=100$, $V_{BE}=0.7$, $R_C=2k\Omega$, $R_L=2k\Omega$, $R_E=100\Omega$ and $V_{CC}=20V$. Determine the required value of R_B so that $I_C=5mA$.



(a) Expression of A_v in terms of r_π & β requires the use of π model



$V_{in} = i_b \cdot r_\pi + i_e \cdot R_E = i_b r_\pi + (\beta+1) i_b \cdot R_E$

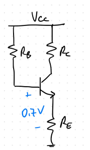
$V_o = i_c (R_C \| R_L) = -\beta i_b (R_C \| R_L)$

$i_b = -\frac{V_o}{\beta(R_C \| R_L)}$

$V_{in} = -\frac{V_o}{\beta(R_C \| R_L)}\left[r_\pi + (\beta+1)R_E\right]$

$A_v = \frac{V_o}{V_{in}} = -\frac{\beta(R_C \| R_L)}{r_\pi + (\beta+1)R_E}$

(b) At DC



To have $I_C = 5mA$

$I_B = \frac{5m}{100} = 50\mu A$

$I_E = 5m + 50\mu = 5.05mA$

$V_E = 5.05m \cdot 100 = 0.5V$

$V_B = 0.5 + 0.7 = 1.2V$

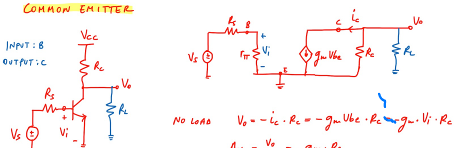
$R_B = \frac{20-1.2}{50\mu} = 376 k\Omega$

$V_C = 20 - 5m \cdot 2k = 10V$

$V_{BC} = 1.2 - 10 < 0.5V$ Active region

COMMON EMITTER

INPUT: B
OUTPUT: C



NO LOAD $V_o = -i_c \cdot R_c = -g_m V_{be} \cdot R_c = -g_m \cdot V_i \cdot R_c$

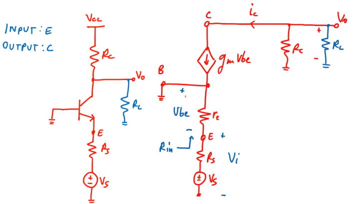
$A_{vo} = \frac{V_o}{V_i} = -g_m \cdot R_c$

LOAD R_L $V_o = -g_m V_i (R_c \| R_L) \rightarrow A_v = -g_m (R_c \| R_L)$

$V_i = V_s \cdot \frac{r_\pi}{R_s + r_\pi}$ OVERALL GAIN $G_v = \frac{V_o}{V_s} = \frac{V_i}{V_s} \cdot \frac{V_o}{V_i} = -\frac{r_\pi}{R_s + r_\pi} \cdot g_m (R_c \| R_L)$

COMMON BASE   T-MODEL

INPUT: E
OUTPUT: C



NO LOAD $V_o = -g_m V_{be} \cdot R_c$

$V_{be} = -V_i$

$V_o = g_m V_i \cdot R_c$

$A_{vo} = \frac{V_o}{V_i} = g_m \cdot R_c$

with R_L $A_v = g_m (R_c \| R_L)$

$R_{in} = r_e$

$V_i = V_s \cdot \frac{r_e}{R_s + r_e}$

$G_v = \frac{V_o}{V_s} = \frac{V_i}{V_s} \cdot \frac{V_o}{V_i}$

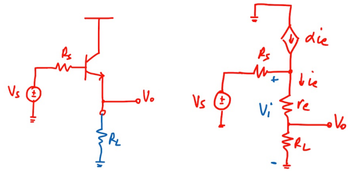
$= \frac{r_e}{R_s + r_e} \cdot g_m (R_c \| R_L)$

$g_m \cdot r_e =$

$G_v = \alpha \cdot \left(\frac{R_c \| R_L}{R_s + r_e}\right) \approx \frac{R_c \| R_L}{R_s + r_e}$

Gain = Total resistance at C / Total resistance at E

COMMON COLLECTOR   T-MODEL



$V_o = i_e \cdot R_L$

$i_e = \frac{V_i - V_o}{r_e} = \frac{V_i}{r_e} - \frac{V_o}{r_e}$

$V_o = V_i \frac{R_L}{r_e} - V_o \cdot \frac{R_L}{r_e}$

$V_o\left(1 + \frac{R_L}{r_e}\right) = V_i \cdot \frac{R_L}{r_e}$

$A_v = \frac{V_o}{V_i} = \frac{R_L}{r_e} \cdot \left(\frac{r_e}{R_L + r_e}\right) = \frac{R_L}{R_L + r_e}$

$R_L >> r_e \rightarrow A_v = 1$

otherwise $A_v < 1$