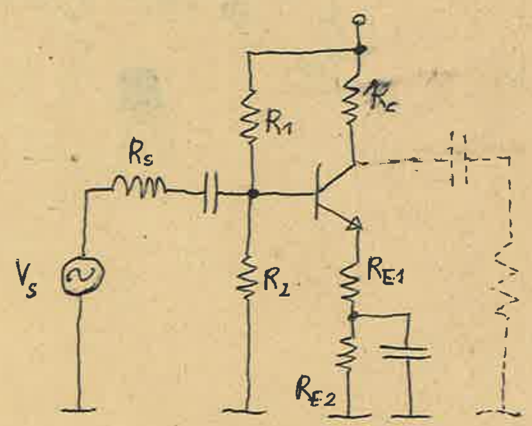
Chapter 5 186 - 214
Chapter 6 220 - 262 (566 ÷ 571)
Chapter 7 270 - 335 (7.1, 7.3A ; 7.3B excluded)
Chapter 12 519 - 547 (7.4. 7.4G ")
Chapter 8 8.4
15.4

Vacuum Tubes (Angelo)

Brief Review

Common emitter amplifier:



DC stability:

$$S_v = \frac{dV_{CQ}}{dT} = \frac{\partial V_{CQ}}{\partial V_{BE}}\frac{\partial V_{BE}}{\partial T} + \frac{\partial V_{CQ}}{\partial I_{Co}}\frac{\partial I_{Co}}{\partial T}$$

$$= \frac{\beta R_C}{R_B+(\beta+1)R_E}\frac{dV_{BE}}{dT} - \frac{R_C(R_E+R_B)(\beta+1)}{R_B+(\beta+1)R_E}\frac{dI_{Co}}{dT}$$

For low power Si transistor neglect I_{Co} and variation w.r.t I_{Co}

Si : $\frac{dV_{BE}}{dT} = -2\ \mathrm{mV}/°C$, $\frac{dI_{Co}}{dT} = 0.15 I_{Co}$ } at room temp. 300 °K

Ge : $\frac{dV_{BE}}{dT} = -1.6\ \mathrm{mV}/°C$, $\frac{dI_{Co}}{dT} = 0.09 I_{Co}$ } at room temp. 300 °K

Optional: $V_{CE} = \frac{V_{CC}}{2}\left(1 + \frac{R_E}{R_C+R_E}\right)$

Ac considerations:

$$R_{in} = R_1 /\!/ R_2 /\!/ [r_{bb'} + (\beta+1)(r_d+R_{E1})]$$

$$R_{out} = R_C$$

for ideal gain neglect R_L

$$A_{Base-collector} = \frac{-\beta(R_C /\!/ R_L)}{r_{bb'} + (\beta+1)(r_d+R_{E1})}$$

Midband Gain:

$$A_{MB} = \frac{R_{in}}{R_{in}+R_S} A \frac{R_L}{R_L+R_{out}}$$

If $(\beta+1)R_{E1} \gg (\beta+1)r_d + r_{bb'}$

then $A_{B-C} \cong -\frac{R_C}{R_{E1}}$

which means A_{MB} is independent of the transistor parameters and DC conditions

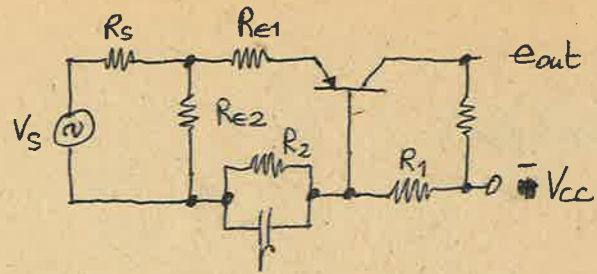
Bias requirements:

Si ; $R_B = R_1 /\!/ R_2 \leq 0.2(\beta+1)R_E$
Ge ; $R_B \leq 0.1(\beta+1)R_E$

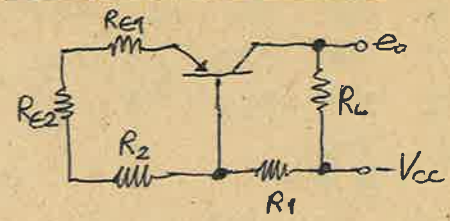
Lower corner frequency:

$\omega_{LE} = \frac{1}{C_E R_{eq}}$ where $R_{eq} = \left\{\frac{R_S /\!/ R_1 /\!/ R_2 + r_{bb'} + (\beta+1)r_d}{\beta+1} + R_{E1}\right\} /\!/ R_E$

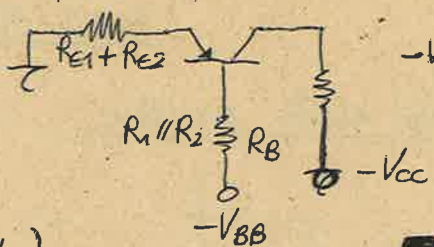
Common base amplifier :



DC equivalent circuit :



thevenin equivalent :



$$-V_{BB} = \frac{R_2}{R_1+R_2}(-V_{CC})$$

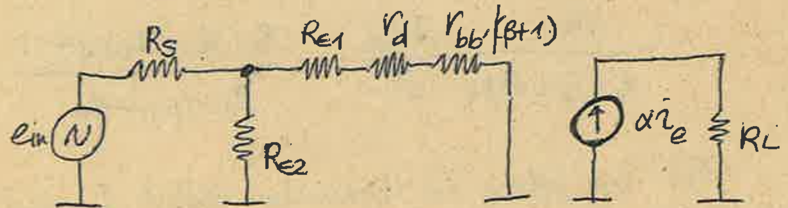
$$r_d = \frac{26mV}{I_{EQ}}$$

$$R_{in} = R_{E2} // \left\{ R_{E1} + \left[\frac{(\beta+1) r_d + r_{bb'}}{\beta+1} \right] \right\}$$

$$= R_{E2} // \left(R_{E1} + r_d + \frac{r_{bb'}}{\beta+1} \right)$$

$R_{out} = \infty$ (Since current source drives R_L)

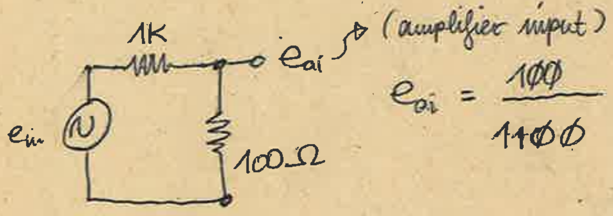
AC model :



$$A_{MB} = \frac{R_S}{R_{in}+R_S} \cdot \frac{\alpha R_L}{R_{E1} + r_d + \frac{r_{bb'}}{\beta+1}}$$

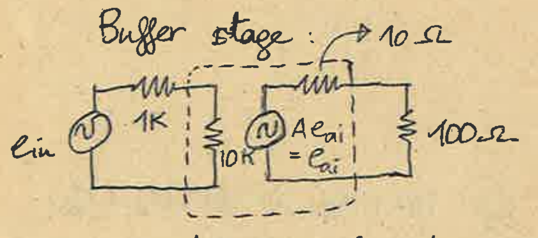
(Input and output are in phase)
(Input impedance is comparatively low to common collector.)

Effect of low input impedance :



$$e_{ai} = \frac{100}{1100} e_{in} = \frac{e_{in}}{11}$$

Buffer stage :



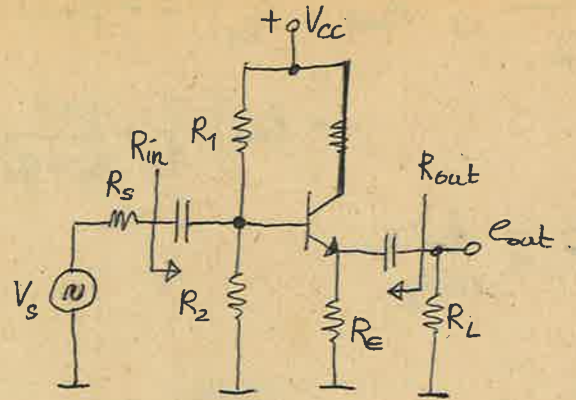
Assume gain is unity

$$e_{ai} = \frac{10}{11} e_{in}$$

$$e_{out} = \frac{100}{110} e_{ai}$$

$$e_{out} = \frac{10}{11} \cdot \frac{10}{11} \cdot e_{in} = \frac{100}{121} e_{in}$$

Common Collector (Emitter Follower)



$$R_{in} = \left\{\left[(R_E /\!/ R_L) + r_d\right](\beta+1) + r_{bb'}\right\} /\!/ R_1 /\!/ R_2$$

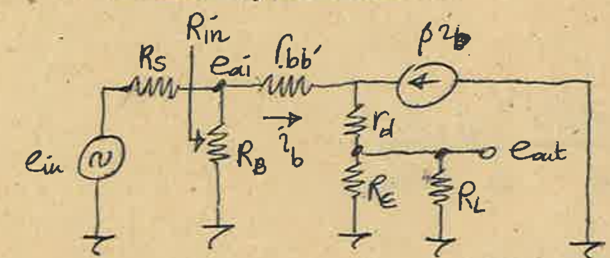
$$R_{out} = \left\{\frac{R_S /\!/ R_1 /\!/ R_2) + r_{bb'}}{\beta+1} + r_d\right\} /\!/ R_E$$

$$R_{in} \cong \left[(R_E /\!/ R_L)(\beta+1)\right] /\!/ R_1 /\!/ R_2 \quad \text{(usually a large resistance)}$$

$$R_{out} \cong r_d /\!/ R_E \quad \text{(usually a small resistance)}$$

With these properties it is usually used as a buffer stage.

Small signal model:



Midband gain: $A_{MB} = \dfrac{R_{in}}{R_{in} + R_S} \cdot A_{B-E}$

$$A_{B-E} = \frac{(\beta+1)(R_E /\!/ R_L)}{\left[r_{bb'} + r_d + (R_E /\!/ R_L)\right](\beta+1)} \cong 1$$

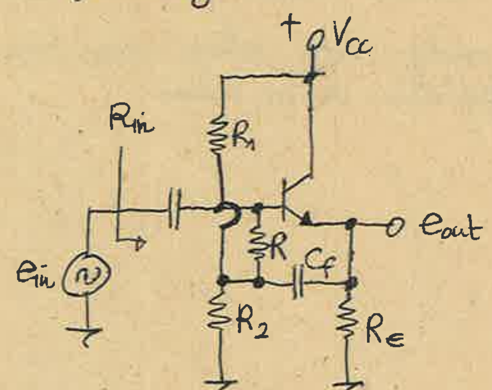
$$\Rightarrow A_{MB} \cong \frac{R_{in}}{R_{in} + R_s}$$

If $R_{in} \gg R_S$: $A_{MB} \cong 1$

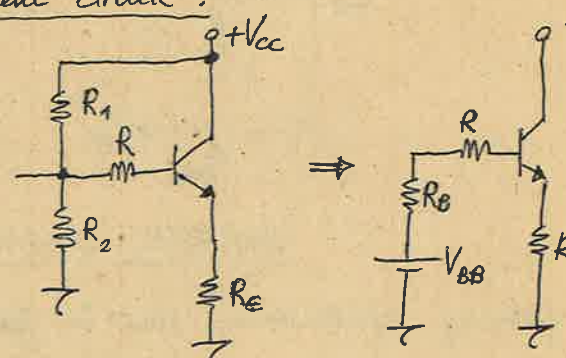
(Voltage gain is always less than unity)

Problem of emitter follower:

If R_B is low (R_1 and R_2) this may cause overall R_{in} to be low.
The following circuit called "bootstrap circuit" overcomes this discrepency:



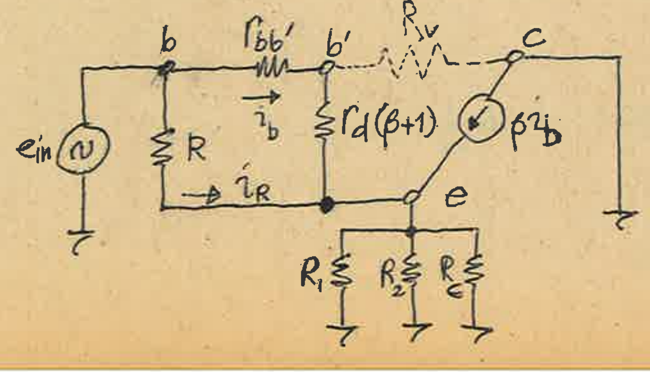
DC equivalent circuit:



Solve for I_{CQ}

$r_d = \dfrac{26\,mV}{I_{CQ}}$

Small signal equivalent circuit:



r_V is the internal resistance between b' and c. It is in the order of MΩ's

Let $R_{eq} = R_1 /\!/ R_2 /\!/ R_E$

$$i_R = \frac{e_{in} - e_{out}}{R}, \quad i_b = \frac{e_{in} - e_{out}}{r_{bb'} + (\beta+1) r_d}, \quad e_{out} = R_{eq}\left[i_r + (\beta+1) i_b \right]$$

$$= R_{eq}\left[\frac{1}{R} + \frac{\beta+1}{r_{bb'} + (\beta+1) r_d} \right](e_{in} - e_{out})$$

$$\frac{e_{out}}{e_{in}} = \frac{R_{eq}\left[\frac{1}{R} + \frac{(\beta+1)}{r_{bb'} + (\beta+1) r_d} \right]}{1 + R_{eq}\left[\frac{1}{R} + \frac{(\beta+1)}{r_{bb'} + (\beta+1) r_d} \right]} \cong 1 \quad \text{less than unity.}$$

21APR80

$$e_o = A_{MB} e_{in}$$

$$i_{in} = i_b + i_R$$

$$i_b = \frac{e_{in} - e_{out}}{r_{bb'} + (\beta+1) r_d} = \frac{1 - A_{MB}}{r_{bb'} + (\beta+1) r_d} e_{in}$$

$$i_R = \frac{e_{in} - e_{out}}{R} = \frac{1 - A_{MB}}{R} e_{in}$$

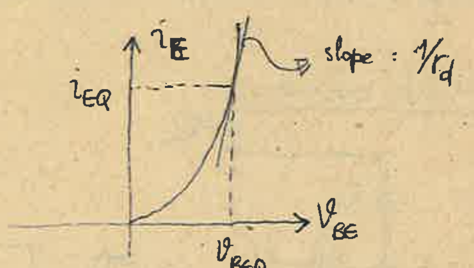
$$i_{in} = i_b + i_R \Rightarrow R_{in} = \frac{e_{in}}{i_{in}} = \left[\frac{r_{bb'} + (\beta+1) r_d}{1 - A_{MB}} \right] // \frac{R}{1 - A_{MB}}$$

$$= \frac{[r_{bb'} + (\beta+1) r_d] // R}{1 - A_{MB}}$$

Since $A_{MB} \cong 1$, R_{in} is quite high. If R_{in} is in the order of $M\Omega$'s, actual input impedance (neglecting $r_{bb'}$)

$$R_{in} = \left[\frac{(\beta+1) r_d // R}{1 - A_{MB}} \right] // r_v$$

- Another problem of the emitter follower stage is to amplify large voltage swings. It is due to the nonlinear behavior of the base emitter junction.



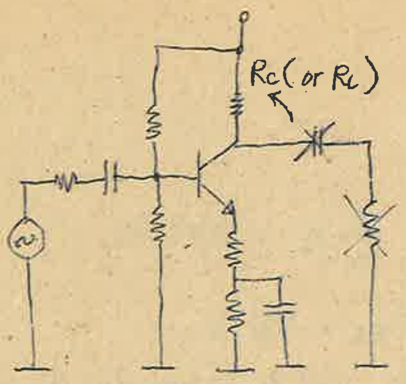
To amplify large voltage swings, some other configurations can be utilized.

AMPLIFIER DESIGN :

The following specifications must be given :

- The midband voltage gain, A_{MB}
- The stability factor.
- Power supply voltage.
- Frequency band over which the amplifier is to be used.
- Max. output voltage swing
- Load impedance. (a.c or d-c coupled)
- Source impedance

Assumed you decided on a common emitter stage :



If the load is not specified as a.c or d.c coupled, Choose R_C as R_L.

Supply voltage V_{cc} is also given.
Choose a Q-point.

- Your Q-point determines I_{CQ} ;
- Then calculate r_d ;
- Set $R_B = 0.2(\beta+1)R_E$ (Si) ;

$$R_{in} = R_B \,//\, [r_{bb'} + (\beta+1)(r_d + R_{E1})]$$

$$\cong R_B \,//\, (\beta+1)R_{E1}$$

- Now assume $R_{E2} = 0$. Then $R_{E1} = R_E$

So $R_{in} \cong R_B \,//\, (\beta+1)R_E$

$$= \frac{R_B(\beta+1)R_E}{R_B + (\beta+1)R_E} = [0.2(\beta+1)R_E](\beta+1)R_E \Big/ [(0.2)(\beta+1)R_E + (\beta+1)R_E]$$

$$= (0.2)(\beta+1)R_E / 1.2$$

- $A_{MB} = \dfrac{R_{in}}{R_{in} + R_S} = \dfrac{R_L}{R_L + R_C} \cdot A$ → ideal voltage gain

$$A = \frac{-\beta R_C}{r_{bb'} + (\beta+1)(r_d + R_{E1})}$$

$$\cong \frac{-\beta R_C}{(\beta+1)R_E}$$

So A and R_{in} are functions of R_E only.

$A_{MB} = A_{MB}(R_E)$

Given A_{MB}, solve for R_E

Then determine R_B and considering I_{BQ}, determine R_1, R_2.

R_{E1}, R_1, R_2 are now determined ;
If you are given S_V, check whether your R_E satisfies this S_V or not. If not you can conclude that $R_{E2} \neq 0$.

First calculate $S_V = \dfrac{\beta R_C}{R_B + (\beta+1)R_E} \dfrac{dV_{BE}}{dT} = \dfrac{\beta R_C}{1.2(\beta+1)R_E} \dfrac{dV_{BE}}{dT}$ calculate R_E

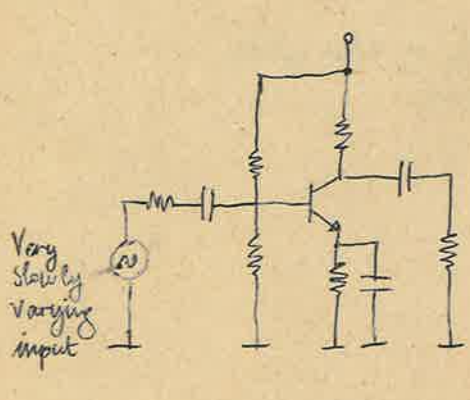
Then consider A_{MB} ~~then~~ calculate R_{E1}

It means some of the emitter resistance is not bypassed. Determine R_E from S_V.

$R_{E2} = R_E - R_{E1}$

Study examples : 5.3 , 5.4 , 5.5 , 5.6

DC AMPLIFIERS :

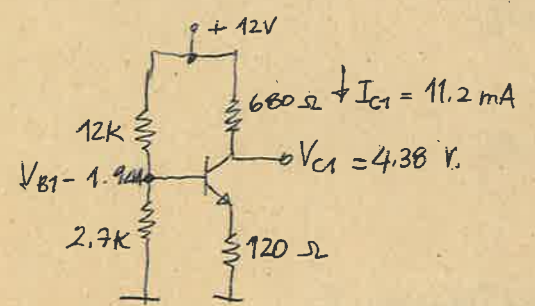


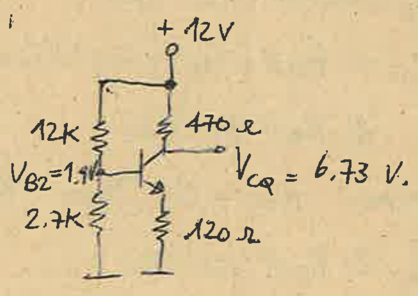
$f_{o,\,input} = \frac{1}{100}\,Hz = 0.01\,Hz$

Assume ; $f_{E2} = 100\,Hz$.

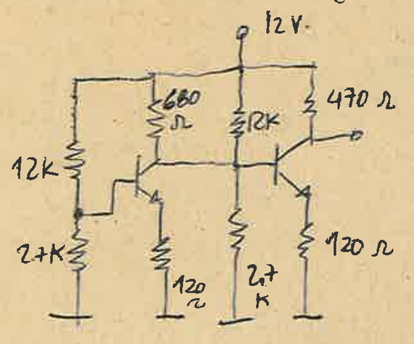
This amplifier will hardly amplify this input.
To amplify that signal capacitors should be replaced by circuits
↳short.

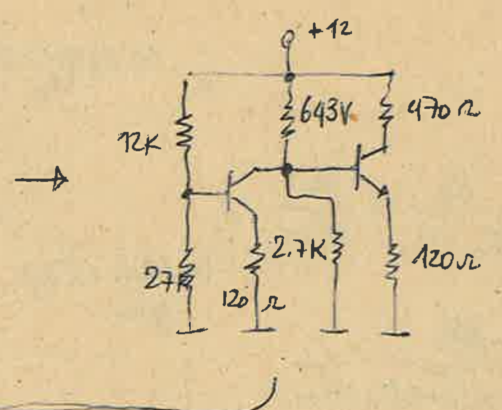
. Consider the following common emitter stages :

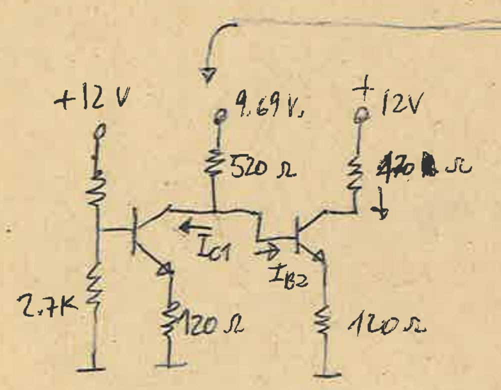




Assumed collector 1 of the first stage is connected to the base of the second.







$I_{C1} = 11.2\,mA$

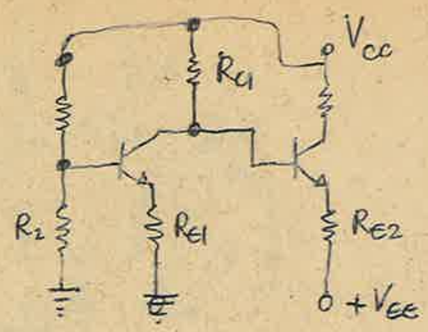
$V_{C1} \cong 9.69 - (520\,\Omega)(11.2\,mA)$

$= 3.866\,V$ (neglecting I_{B2})

The circuits in which a d.c signal is amplified along a.c signal are called d.c amplifiers. Capacitors can not be used between the stages of a d.c amplifier. Two major problems arise in designing amplifiers without coupling capacitors.

- The biasing of each stage is dependent on adjacent stages.
- Temperature stability is often poor. Since the drift ~~current~~ of the first stages are amplified by succeeding stages.

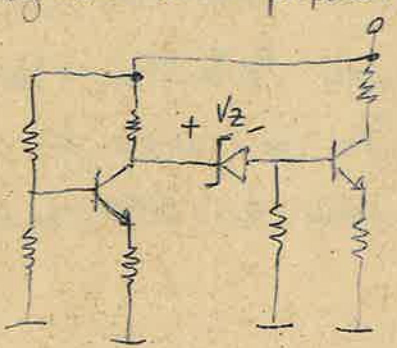
To keep the base and collector voltages at the desired levels the following configuration can be used:



Assume I_{B2} is negligible $V_{BE2} + I_E R_{E2} = V_{C1} - V_{EE}$

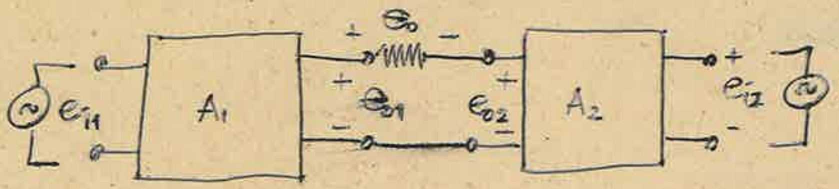
The disadvantage of this circuit is to use another supply voltage

The following circuit can be proposed:



$V_{B2} = V_{C1} - V_Z$

DIFFERENTIAL AMPLIFIERS   24APR80



$$e_o = e_{o1} - e_{o2}$$
$$= A_1 e_{i1} - A_2 e_{i2}$$

Common mode: $e_{i2} = e_{i1} = e_i$

Common mode gain: $e_o = \underbrace{(A_1 - A_2)}_{\text{Common mode gain.}} e_i$

If $A_1 = A_2 \Rightarrow e_o = 0$

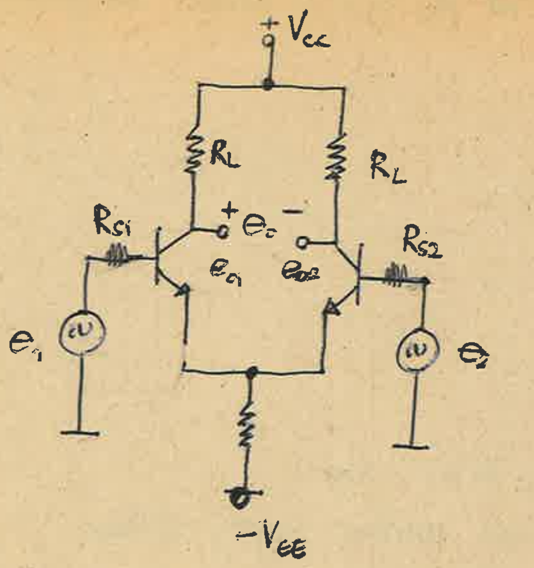
Differential amplifiers have good temperature stability since the output is measured as the difference of two outputs.

Differential mode gain:

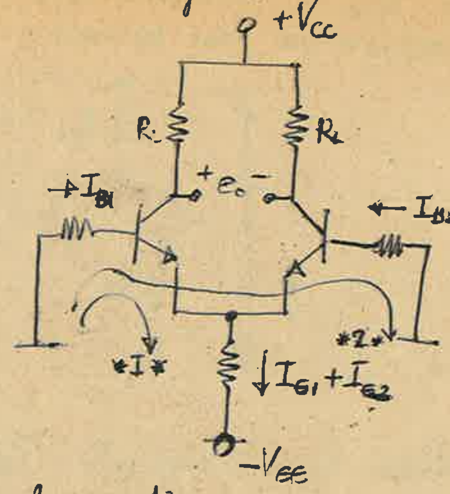
In general $e_{i1} \neq e_{i2}$;

$$A_{DM} = \frac{e_{out}}{e_{i1} - e_{i2}}$$

A differential amplifier with BJT's:



DC analysis :



loop equation:

1 $R_{S1}I_{B1} + V_{BE1} + R_E\left[(\beta+1)I_{B1} + (\beta_2+1)I_{B2}\right] - V_{EE} = 0$

2 $R_{S1}I_{B1} + V_{BE1} = V_{BE2} + R_{S2}I_{B2}$

Solve for 1 and 2 for I_{B1} and I_{B2}

Assume two BJT's are equal ; $\beta_1 = \beta_2 = \beta$

$V_{BE1} = V_{BE2} = V_{BE}$

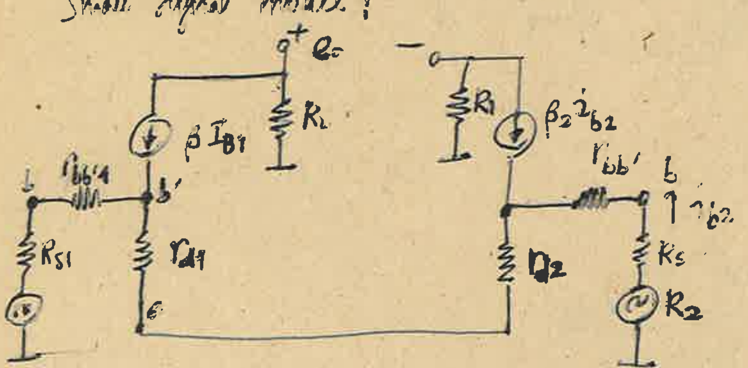
Also assume $R_{S1} = R_{S2} = R_S$;

$$R_S I_B + V_{BE} + 2I_E R_E - V_{EE} = 0$$

$$I_B = \frac{V_{EE} - V_{BE}}{R_S + 2(\beta+1)R_E}$$

$V_{CQ1} = V_{CQ2} = V_{CC} - \beta I_B R_L$ The d-c value of the output voltage will be zero if two stages are identical.

Small signal model ;



Usually $R_E \gg r_{d1} + \frac{r_{S1} + r_{bb'1}}{\beta_1 + 1}$, $r_{d2} + \frac{r_{bb'2} + R_{S2}}{\beta_2+1}$

Therefore it can be assumed as open cct.

Apply superposition ;

Set $e_2 = 0$

$$i_{b1} = \frac{e_1}{R_{S1} + r_{bb'1} + (\beta_1+1)\left[r_{d1} + r_{d2} + \frac{r_{bb'2} + R_{S2}}{\beta_2+1}\right]}$$

$$i_{e1} = -i_{e2}$$

Assume identical stages:

$$i_{b1} = \frac{e_1}{R_s + r_{bb'} + (\beta+1)\left[2r_d + \frac{r_{bb'} + R_s}{\beta+1}\right]}$$

$$i_{b1} = \frac{e_1}{2[R_s + r_{bb'} + (\beta+1)r_d]}$$

Since $\beta_1 = \beta_2 = \beta$

$$i_{e1} = -i_{e2} \Rightarrow i_{b1} = -i_{b2}$$

$$i_{b2} = \frac{-e_1}{2[R_s + r_{bb'} + (\beta+1)r_d]}$$

$$e_o = -R_L \beta i_{b1} - (-R_L \beta i_{b2})$$

$$e_{o1} = -R_L \beta i_{b1}$$

$$e_{o2} = -R_L \beta i_{b2}$$

$$\frac{e_{o1}}{e_1} = \frac{-R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}\Bigg|_{e_2=0}$$

$$\frac{e_{o2}}{e_1} = \frac{(-R_L\beta)(-1)}{2[R_s + r_{bb'} + (\beta+1)r_d]} = \frac{R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}\Bigg|_{e_2=0}$$

With $e_2 = 0$ e_{o1} is inverting output e_{o2} is non inverting output.

$$\frac{e_{o1} - e_{o2}}{e_1} = \frac{R_L\beta}{R_s + r_{bb'} + (\beta+1)r_d}$$

Similarly

$$\frac{e_{o1}}{e_2}\Bigg|_{e_1=0} = \frac{R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}$$

$$\frac{e_{o2}}{e_1}\Bigg|_{e_1=0} = \frac{-R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}$$

So if $e_1 \neq 0$, $e_2 \neq 0$

$$e_{o1} = \frac{-R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}(e_1 - e_2)$$

$$e_{o2} = \frac{R_L\beta}{2[R_s + r_{bb'} + (\beta+1)r_d]}(e_1 - e_2)$$

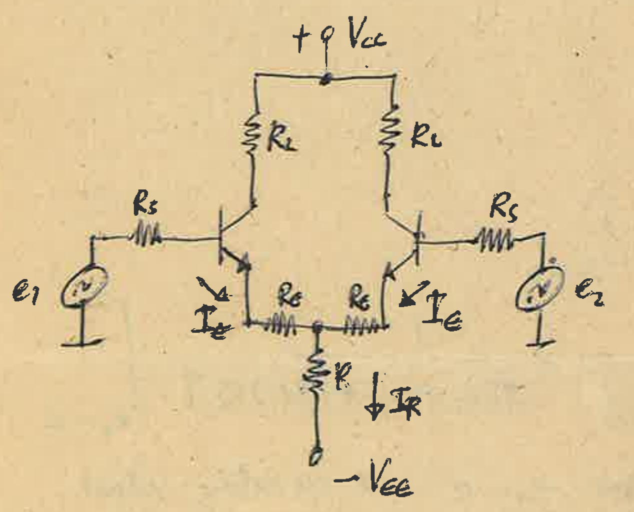
$$e_o = e_{o1} - e_{o2}$$

$$= \underbrace{\frac{-R_L\beta}{R_s + r_{bb'} + (\beta+1)r_d}}_{\substack{A_{DM} \\ \text{Differential mode} \\ \text{gain}}}(e_1 - e_2)$$

Common mode gain:

$e_o = 0$

DC stability:

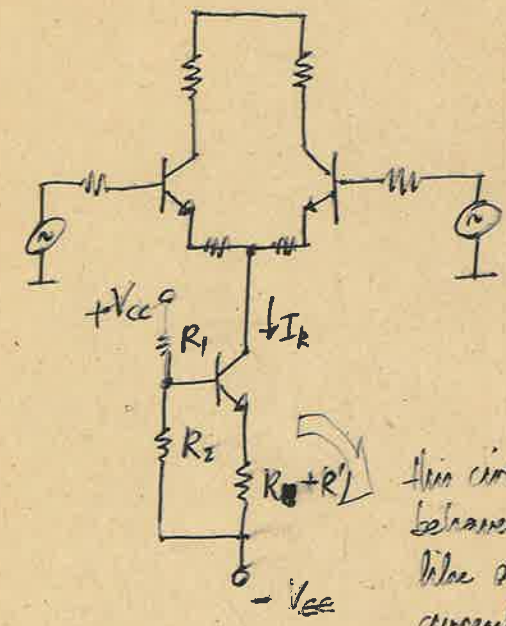


$$I_E = \frac{I_R}{2}$$

$$\Rightarrow \Delta I_E = \frac{\Delta I_R}{2}$$

If ΔI_R is kept at 0; (i.e constant I_R) then perfect stability reached.

Assume R is removed and a current source is connected there.



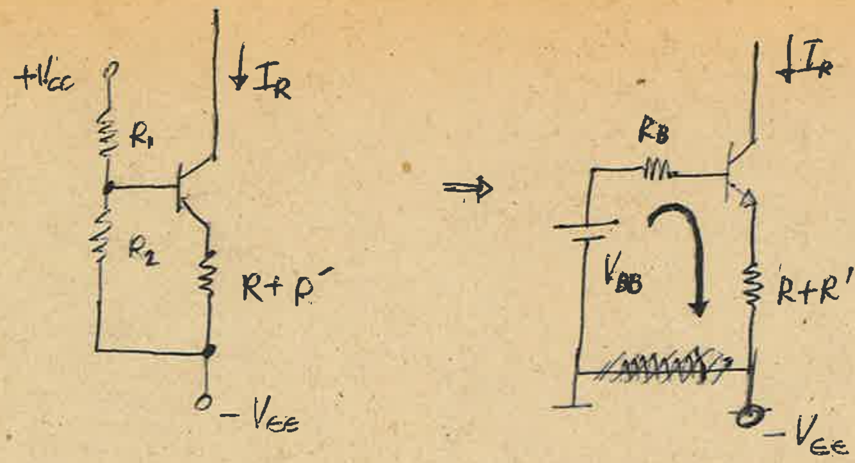
this circuit behaves like a current source.

The resistor R is a temperature dependent resistor with a positive temperature coeff.

$$\frac{dR/dT}{R} = \gamma \text{ (temperature coefficient)}$$

$$\frac{dR}{dT} = \gamma R \quad (\gamma > 0)$$

R' is a constant resistor.



$$V_{BB} = \frac{R_2}{R_1+R_2}V_{CC} + \left(-\frac{R_1}{R_1+R_2}V_{EE}\right)$$

$$R_B = R_1 // R_2$$

Assume a silicon transistor

$$\frac{dI_R}{dT} = \frac{\partial I_R}{\partial V_{BE}}\frac{\partial V_{BE}}{\partial T}$$

$$I_B = \frac{V_{BB}+V_{EE}-V_{BE}}{R_B+(\beta+1)(R+R')}$$

$$I_R = \beta I_B = \frac{\beta(V_{BB}+V_{EE}-V_{BE})}{R_B+(\beta+1)(R+R')}$$

$$\frac{dI_R}{dT} = \frac{-\beta}{R_B+(\beta+1)(R+R')}(-0.002) + \frac{\beta(V_{BB}+V_{EE}\overset{eksi}{-}V_{BE})[-(\beta+1)]}{[R_B+(\beta+1)(R+R')]^2}\underbrace{\frac{dR}{dT}}_{\gamma R}$$

$$\frac{dI_R}{dT} = 0 \Rightarrow \beta(0.002)[R_B+(\beta+1)(R+R')] - \beta(\beta+1)(V_{BB}+V_{EE}-V_{BE})\gamma R = 0$$

$$R = \frac{(0.002)[R_B+(\beta+1)R']}{(\beta+1)\{[\gamma(V_{BB}+V_{EE}-V_{BE})]-0.002\}}$$

28APR80
EXAM: 8MAY80

1

5.27 For reasonable stability $A \cong 10$

$A_o = A_1 \times A_2 \times \dots \times A_n$

Assumption : $A_1 \cong A_2 \cong A_3 \Rightarrow A_o = A^n$

$A^n = 1000 \Rightarrow$ 3 found.

5.28 $n = 3-4$

5.29 $A_o = A^n$

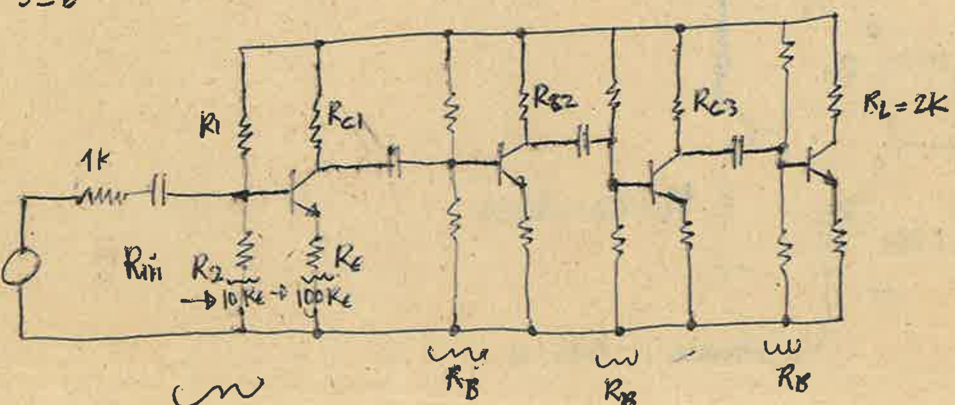
for $A = 10$ $n=2$ leads to $A_o = 100$

$n = 3$ " " $A_o = 1000$

Since $A = 400$ is the wanted gain we choose $n = 3$

5.30 $n = 5\_6$

5.31



R_B : $R_{th} = R_1 // R_2$

Assumption: $\beta + 1 = 100$

Assumption : $R_2 = 10R_E$

$R_{in} \cong 10R_E // 100R_E$

$9.09 R_E$

$$A_o = \underbrace{\frac{9.09R_E}{R_s + 9.09R_E}}_{\text{first Attenuation}} A_{bc_1} \underbrace{\frac{9.09R_E}{R_{c_1} + 9.09R_E}}_{\text{Second Attenuation}} A_{bc_2} \underbrace{\frac{9.09R_E}{R_{c_2} + 9.09R_E}}_{\text{third}} A_{BC3} \underbrace{\frac{9.09R_E}{R_{C3} + 9.09R_E}}_{\text{fourth}} A_{bC4}$$

$$A_o = \frac{(9.09R_E)^4 \left(\frac{R_c}{R_E}\right)^3 \left(\frac{R_L}{R_E}\right)}{(R_s + 9.09R_E)(R_c + 9.09R_E)^3} = 1000 \quad (1000 \text{ is given})$$

Assume R_E: 300

So $R_c = 5.037$ K. or assume R_E 400 Ω then $R_c = 8.383$ K.

5.32 $R_E = 300\ \Omega$

$R_c = 2.2k.$

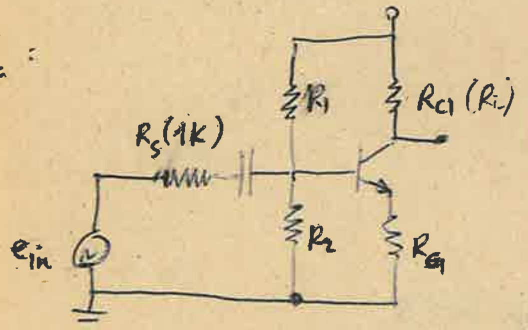
5.34 $A_{MB} = 104$

Set $n = 5$

Assume $R_E = 300$

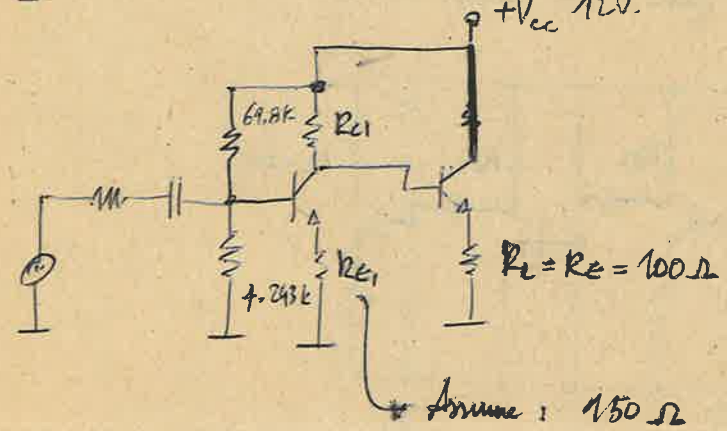
$R_c = 7.79k.$

5.35 :



$$A_{max} = \frac{\beta R_L}{R_S + r_{bb} + \cancel{(\beta+1)(R_d+R_E)}} = -8$$

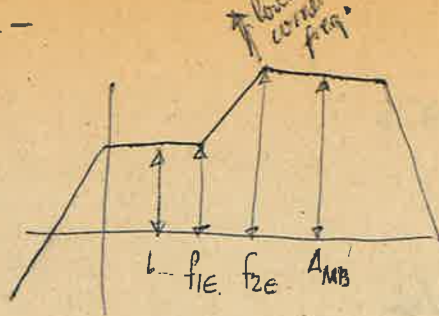
negligible



$I_{E1} = 0.5\ mA \Rightarrow r_d = 52\ \Omega$ (Assumption)

then $R_c = 14.91\ k$.

$$A_{MB} = A_{dc}\,\frac{f_{2E}}{f_{1E}}$$



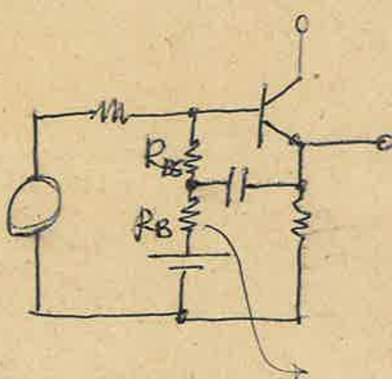
$$f_1^0 = \frac{f}{\sqrt{2^{1/n}-1}}$$ corner frequency.

$$S_V = \frac{\overbrace{\frac{dV_{BE}}{dT}}^{1.062\ V/^\circ C}\,\beta R_c}{R_B + (1+\beta)\underbrace{R_E}_{\text{unbypassed}}}$$

↑ base tarafındaki resistance kombinasyonu

$$A_V = \frac{\beta R_c}{r_{bb'} + R_B + (\beta+1)(r_d + R_E)} \cong \frac{R_c}{R_E}$$

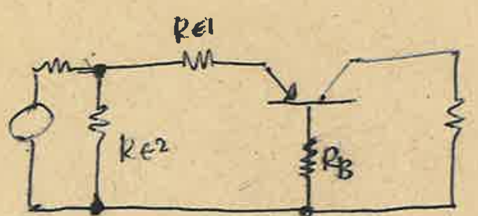
↳ AC load.



$$R_{BS} = \frac{R}{1-A_v}$$

↳ nearly unity in common collector amp.

$$A_C = \frac{1+\beta}{1+\frac{R_{in}}{R_B}}$$



A_c current gain $= \dfrac{\alpha}{1+\frac{R_{in}}{R_{E_2}}}$

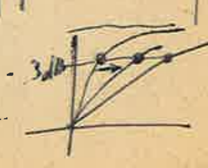
<u>5.40</u> $C_{C1} = 1\ \mu F$
$C_{C2} = 1\ \mu F$

$$f_1 = \frac{1}{2\pi C_{C1}(R_s + R_{in1})} = 17.78\ Hz$$

$$f_1' = \frac{1}{2\pi C_{C2}(R_{C1} + R_{in2})} = 11.04\ Hz$$

limları çarpıldığı zaman $\frac{1}{\sqrt{2}}$ olacak $\frac{1}{\sqrt{2}} = \left|\frac{1}{1+j\frac{17.8}{f}}\right|\left|\frac{1}{1+j\frac{11.04}{f}}\right|$

$f = 22.632\ Hz$. daha büyük olmalı.



AR one plus dt single proportional olmayan n

5.41

$f_{2E} = 4107.7$

5.42

5.43 Şimdilik geselim

5.44

5.45 guessmark

5.46 ↑

5.47

5.50 Önemli

$V_{out} \doteq I_{E2} R_2$

$\frac{R_2}{R_1} (\underbrace{V_{CC} - V_{min} - V_{BE}}_{3.4V})$

$\frac{R_2}{R_1} = 0.588$

5.51 Çözün

57 Ω.

5.52 106 Ω.

5.53 19 Ω

5.54 Ex 5.7 ye göre

$R + R_1 = 1490\ \Omega$

$R_1 = 28.35\ R$ } önemli

$R = 50.7\ \Omega$

$R_1 = 1439.3\ \Omega$

NOISE:

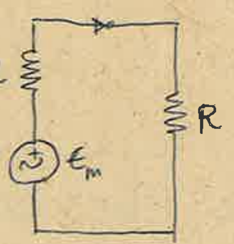
The noise in the amplifiers are due to a) semiconductors
b) resistors

Noise equation developed by Nyquist in 1928:

$$\boxed{P_n = kTB}$$ ← resistance noise

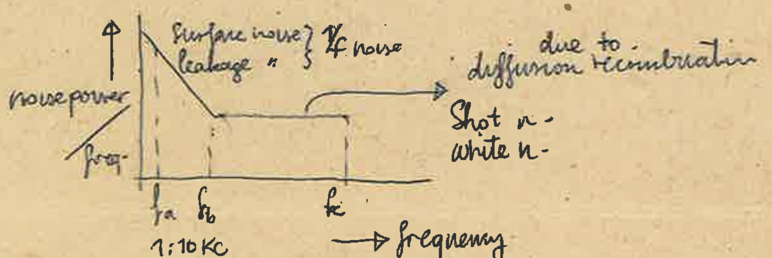
power noise; Boltzmann's constant; Temperature °K; Bandwidth

this noisy resistor can be assumed R noise-free one and delivering noise Power P_n to another resistor R



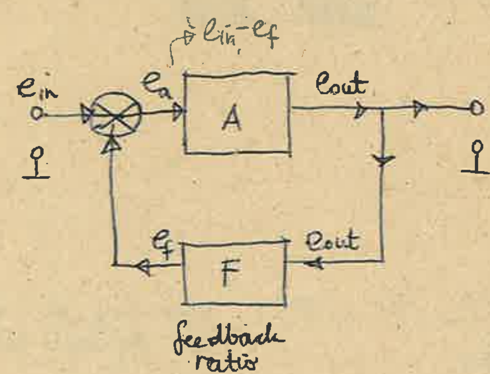
$$P_n = \frac{E_n^2}{4R} = kTB \quad \rightarrow \quad \boxed{E_n = \sqrt{4kTBR}}$$

1/f noise:



NOISE POWER DISTRIBUTION CHARACTERISTIC OF TRANSISTOR

The noise can be suppressed by a feedback network:



$$e_{out} = A e_a$$
$$= A(e_{in} - e_f)$$

$G \triangleq \dfrac{e_{out}}{e_{in}}$ en uzaktaki voltajın en yakındaki voltaja oranı

$F \triangleq \dfrac{e_f}{e_{out}}$ "her gün çıkışın girişe oranı olarak ölçülür"

$$G = \frac{A(e_{in} - e_f)}{e_{in}}$$

$$\boxed{G = \frac{A}{1 + AF}} \cong \frac{1}{F}$$

when $AF \gg 1$
So G is almost independent of A

SENSITIVITY :

if x is a function of y :

$$\boxed{S_{x,y} = \frac{dx/x}{dy/y} = \frac{y}{x}\frac{dx}{dy}}$$

Answer of Prob 6 : ~1.17

$G = G(A(T), F(T))$

gain is function of A and F which are function of T.

$$S_{G,A} = \frac{A}{G}\frac{dG}{dA}$$

$$S_{G,F} = \frac{F}{G}\frac{dG}{dF}$$

$$S_{G,T} = \frac{T}{G}\frac{dG}{dT} \qquad \frac{dG}{dT} = \frac{dG}{dA}\frac{dA}{dT} + \frac{dG}{dF}\frac{dF}{dT}$$

After some substitution : $\boxed{S_{G,T} = S_{G,A}\,S_{A,T} + S_{G,F}\,S_{F,T}}$

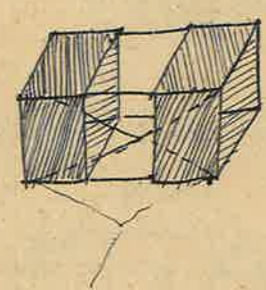
$$S_{A,T} = \frac{T}{A}\frac{dA}{dT}$$

$$S_{F,T} = \frac{T}{F}\frac{dF}{dT}$$

temperature coefficient of gain :

$$\boxed{(TC)_G = \frac{dG/G}{dT}}$$

$$\boxed{(TC)_G = S_{G,A}(TC)_A + S_{G,F}(TC)_F}$$



Signal to noise ratio (SNR)

$$(SNR) = \frac{e_s}{e_m}$$

$$(SNR)\Big|_a = \frac{Ae_s}{e_{am}} \quad \text{open loop amplifier}$$

$$(SNR)\Big|_g = \frac{Ae_s}{e_{gm}} = \frac{Ae_s}{e_{am}/(1+AF)} = \frac{Ae_s}{e_{am}}(1+AF)$$

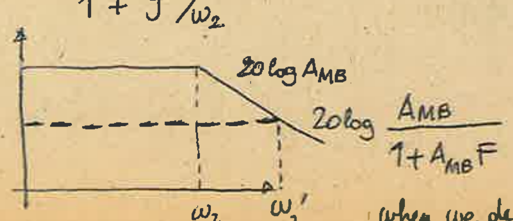
improving the signal to noise ratio by using feedback.

$$\left\{ e_{gm} = \frac{e_{am}}{1+AF} \right\}$$

Second improvement about bandwidth :

$$A = \frac{A_{MB}}{1 + j\,\omega/\omega_2}$$

putting $G = \dfrac{A}{1+AF}$: $G = \dfrac{A_{MB}}{1+A_{MB}F}\cdot\dfrac{1}{1+j\dfrac{\omega}{\omega_2(1+A_{MB}F)}}$



$$\omega_2' = \omega_2(1+A_{MB}F)$$

$$\boxed{A_{MB}\omega_2 = GB\omega}$$

when we decrease the gain, increase the bandwidth

Feedback also modifies the input and output impedances of circuit.

Types of feedback:

$F_{v,v}$ (output, input) v/v : voltage transfer ratio.

$F_{v,i}$ v/i : impedance

$F_{i,v}$ i/v : admittance

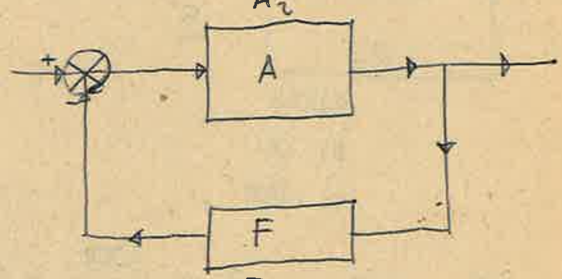
$F_{i,i}$ i/i : current transfer ratio

$A_v : A$

$A_{i,v}$

$A_{v,i}$

A_i



$F_{v,v}$

$F_{v,i}$

$F_{i,v}$

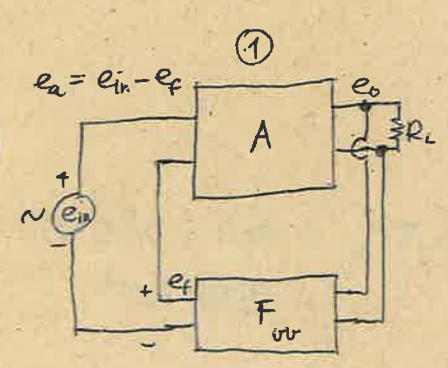
$F_{i,i}$

$$\frac{e_{out}}{e_{in}} = G = \frac{A}{1 + AF_{v,v}}$$

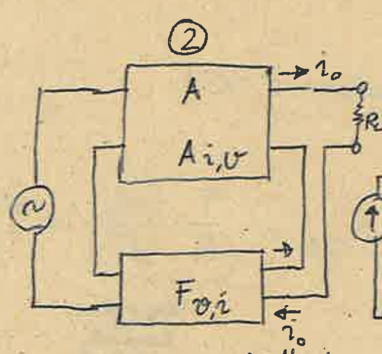
$$\frac{i_{out}}{e_{in}} = G_{i,v} = \frac{A_{i,v}}{1 + A_{i,v}F_{v,i}}$$ transadmittance of the circuit

$$\frac{e_{out}}{i_{in}} = G_{v,i} = \frac{A_{v,i}}{1 + A_{v,i}F_{i,v}}$$ transimpedance of the circuit

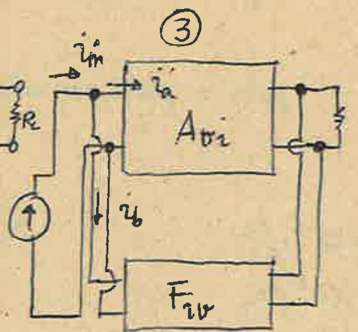
$$\frac{i_{out}}{i_{in}} = G_i = \frac{A_i}{1 + A_i F_{ii}}$$



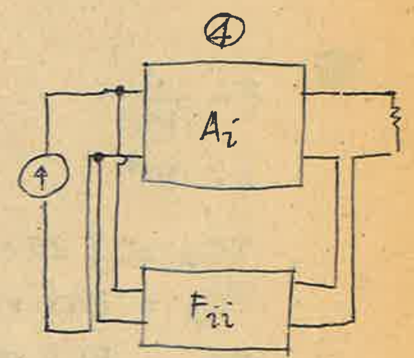
voltage series feedback



current series feedback
transadmittance ~~feedb.~~



~~transimpedance~~
~~transimpadance~~
Voltage shunt amp.



current shunt amplifier
current ratio amplifier

series 1 2 : $R_{in} = R_{ia}(1 + AF_{vv})$ input impedance increased.

shunt 3 4 : $R_{in} = \dfrac{R_{ia}}{(1 + A_{vi} F_{iv})}$ input impedance decreased

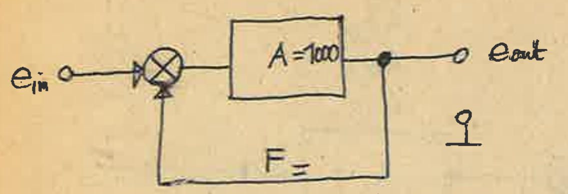
voltage 1 3 : $R_o = \dfrac{R_{oa}}{1 + F_{vv} A}$ output impedance decreased

current 2 4 : $R_o = R_{oa}(1 + A_{iv} F_{vi})$ output impedance increased

we come to 6.2

PROBLEMS (CHAPTER 6)

(1)



$$G = \frac{A}{1+AF}$$

$$AF \gg 1 \Rightarrow G \cong \frac{1}{F}$$

F =
a) 0.1
b) .01
c) .001

$AF_a = 100$ $\quad G_a = \frac{1000}{101} = 9.9 \approx \frac{1}{F_a} = 10$

$AF_b = 10$ $\quad G_b = \frac{1000}{11} = 90.9 \approx \frac{1}{F_b} = 100$

$AF_c = 1$ $\quad G_c = \frac{1000}{2} = 500 \not\approx \frac{1}{F_c} = 1000$

(2)

$$G = \frac{1000}{1+1000F} = 50 \Rightarrow F = 0.019$$

(3)

$x = 101y + 10y^2$

$S_{x,y} = \frac{y}{x}\frac{dx}{dy}$ find S at $y=2$

$y_0 = 2$
$x_0 = 242$

$$\frac{dx}{dy} = 20y + 101$$

$$S_{x,y} = 1.1653$$

(4)

$F = \frac{1}{100}$ $\quad$ ppm = parts per million $= 10^{-6}$

$A = 10^4$

$TC_F = \pm 25 \times 10^{-6} /°C$

$TC_A = 3000 \times 10^{-6} /°C$

$TC_G = 54.5 \times 10^{-6} /°C$

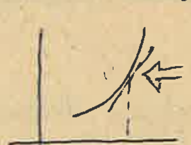
$$S_{G,T} = \boxed{\frac{T}{G}\frac{dG}{dT}} = T \times TC_G = 300°K \times 54.5 \times 10^{-6} = 16350 \times 10^{-6}$$

temperature ~~Sensitivity~~ coefficient

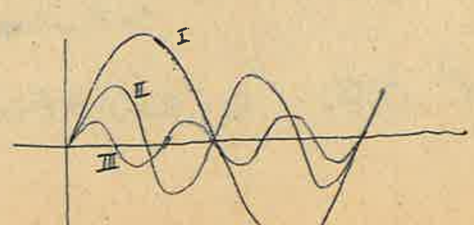
(5) 6.3 : $S_{G,A} = \frac{1}{1+AF}$

$S_{G,F} = -\frac{AF}{1+AF}$

Answer: All sensitivity values are not valid for large changes.



(6) $e = \underbrace{10\cos 2000\pi t}_{\text{Ist Harmonic}} + \underbrace{0.2\cos 4000\pi t}_{\text{IInd}} + \underbrace{0.1\cos 6000\pi t}_{\text{IIIrd.}}$



distortion factor :

$$D = \frac{E_1^{\text{fundamental}}}{\sqrt{\sum_{1}^{m} E_k^2}} = \frac{E_1}{\sqrt{E_2^2 + E_3^2 + \dots E_m^2}}$$

$$SNR = D = \frac{10}{\sqrt{0.2^2 + 0.1^2}} = 44.72$$

(7)

$e_{in} = 0.1 \sin 2000\pi t$

$A = 200$

open loop → $e_{out} = \underset{e_s}{20 \sin 2000\pi t} + 0.3 \cos 4000\pi t$

e_{in} ↑ Second harmonic coming out "distortion"

$(SNR_1) = \dfrac{20}{0.3} = 66.7$

Signal to noise ratio of the openloop amplifier

$$G = \frac{A}{1+AF} = \frac{200}{1+200\times 0.1} = 9.524$$

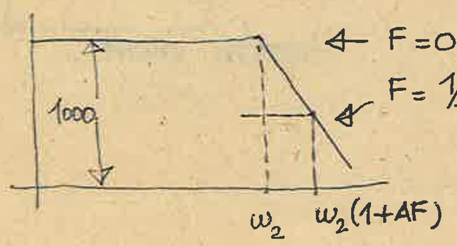
closed loop → $e_{out} = 20 \sin 2000\pi t + B \cos 4000\pi t$

$$B = \frac{0.3}{21} = 0.0143$$

$(SNR_2) = \dfrac{20}{0.3/21} = 1400$

signal to noise ratio of closed loop amplifier.

(8)



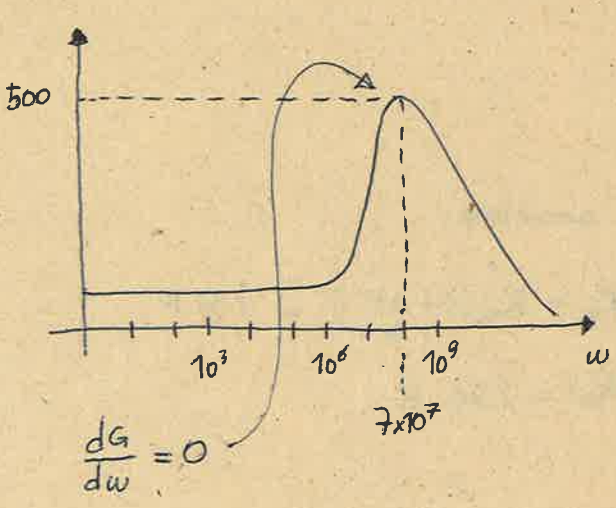
$\omega_{2F} = 51\times 10^7$ rad/sec.

(9)

$$F = \frac{\overset{1/20}{0.05}}{1 + j\frac{\omega}{10^7}}$$

$$G = \frac{A}{1+AF} = \frac{\dfrac{1000}{1+j\omega/10^7}}{1 + \dfrac{1000}{j\omega/10^7}\,\dfrac{0.05}{j\omega/10^7}}$$

$$G(\omega)_F = \frac{10^{17}(1 + j\omega/10^7)}{5.1\times 10^{15} - \omega^2 + 2\times 10^7 j\omega}$$



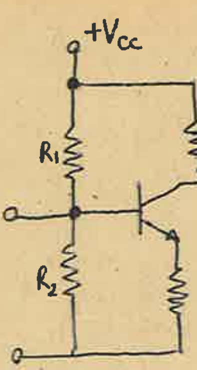
ω	0	10^6	10^7	40×10^7	7×10^7	8×10^7	10^8
$\lvert G\rvert$	19.6	19.7	28.3	115	500	390	190

SENTURIA WEDLOCK Electronic circuits and applications.

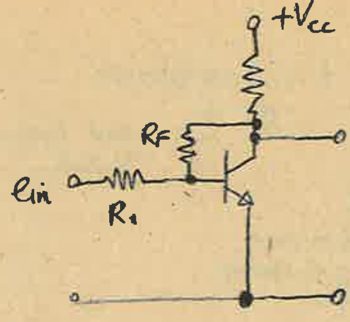
22MAY80

they can be exam questions !

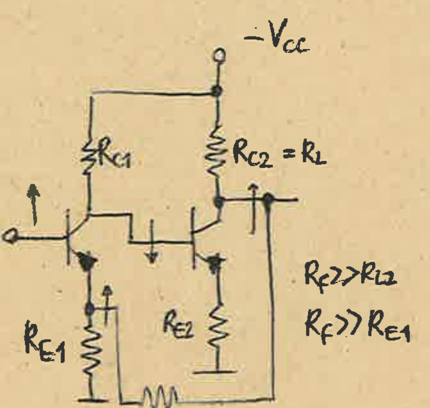
(10)



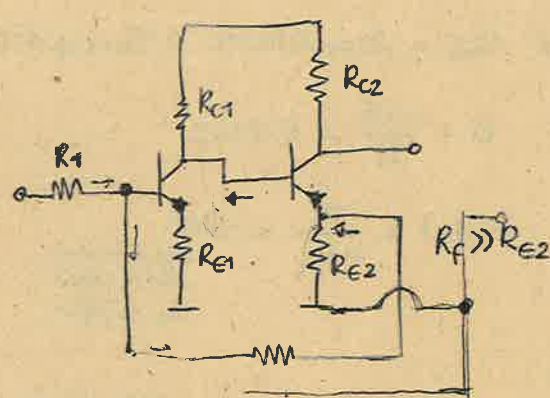
CURRENT SERIES



VOLTAGE SHUNT

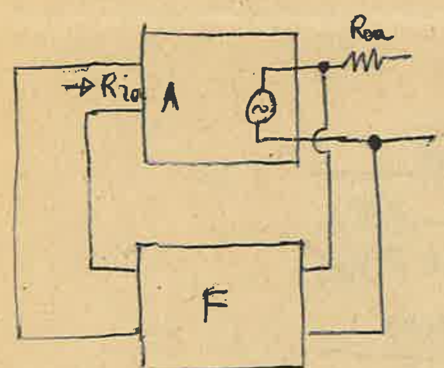


VOLTAGE SERIES



CURRENT SHUNT

(11)



$$R_{in} = \frac{e_{in}}{i_{in}} = R_{ia}(1+AF) = 6K$$

$$R_{out} = \frac{e_{out}}{i_{out}} = R_{oa}\frac{1}{1+AF} = 333\,\Omega$$

⇨ shunt olanlarda impedance düşer
series " " yükselir

(12) $R_{in} = \dfrac{R_{ia}}{1+AF_{vi\,iv}} = 19.6\ \Omega.$

$R_{out} = \dfrac{R_{oa}}{1+AF_{vi\,iv}} = 39.2\ \Omega.$

(13) current series

$R_{in} = R_{ia}(1+AF_{iv\,vi}) = 1.12\ K$

$R_{out} = 2.24\ K.$

gain of the transimpedance amplifier :

$$\boxed{G = \frac{-|A_{vi}|}{1 + \frac{R_{ia} + |A_{vi}|}{R_F}}}$$

voltage gain of the transimpedance amplifier :

$$\frac{e_{out}}{e_{in}} = G = \frac{-|A| + \frac{R_{oa}}{R_F}}{1 + \frac{R_1}{R_{ia}} + \frac{R_{oa}}{R_L} + \frac{R_{oa}}{R_F} + \frac{R_1 R_{oa}}{R_F R_L} + \frac{R_1 R_{oa}}{R_{ia} R_L} + \frac{R_1 R_{oa}}{R_{ia} R_F} + \frac{R_1}{R_F}(1+|A|)} \qquad -6.27-$$

Simplified version of 6.27 : $R_{oa} \ll R_F$, $R_{oa} \ll R_L$

$$\boxed{G = \frac{-|A|}{1 + \frac{R_1}{R_{ia}} + \frac{R_1}{R_F}(1+|A|)}}$$

and then if $R_1 < R_{ia} \Rightarrow G = \frac{-|A|}{1 + \frac{R_1}{R_F}(1+|A|)}$

with some operations :

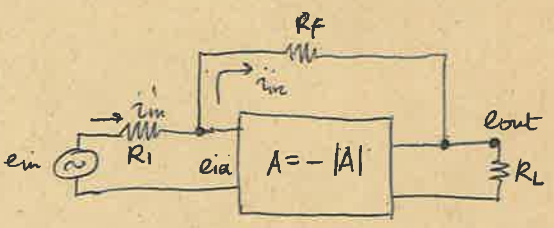
$$\boxed{G = \frac{R_F}{R_1+R_F} \cdot \frac{-|A|}{1 + |A| \frac{R_1}{R_F+R_1}}}$$

Feedback ratio

derivations are not asked !

$$\boxed{G \cong \frac{R_F}{R_1}}$$

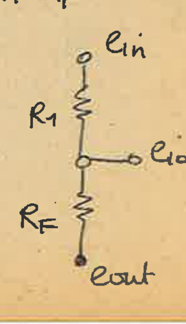
introduction to operational amplifiers :



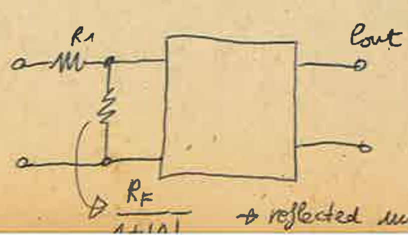
$$i_{in} = i_f = \frac{e_{in} - e_{out}}{R_1 + R_F}$$

superposition

$$e_{ia} = e_{in} - \frac{e_{in} - e_{out}}{R_1 + R_F} R_1 = \underbrace{e_{in} \frac{R_F}{R_1+R_F} + e_{out} \frac{R_1}{R_1+R_F}}$$



Reflected resistance



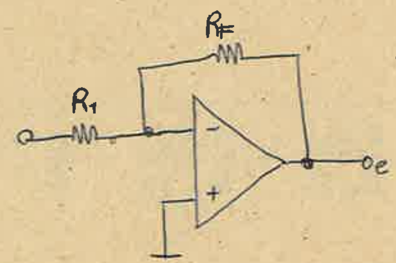
→ reflected impedance

So $G = -|A| \frac{R_{refl}}{R_1 + R_{refl}}$

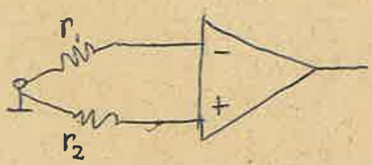
OPERATIONAL AMPLIFIERS!

$$G \cong -\frac{R_F}{R_1}\;\frac{1}{1 + J\,{}^{\omega}/_{\omega_2}\,(1 + A_{MB}F)}$$

2JUN80

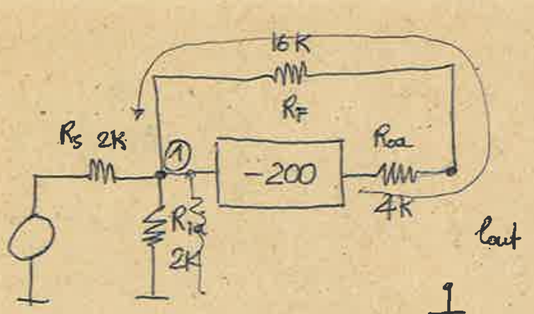


$$G = \frac{A}{1+\Delta F}\;\frac{R_F}{R_1+R_F} \qquad \cong \frac{R_F}{R_1}$$



$$r_{in} = \frac{r_1 r_2}{r_1 + r_2}$$

6-14



voltage-shunt. (operational amplifier)

using eq 6.27. $\cong -7.23 = G$

$$R_{in} = R_{ia} \,//\, R_{refl}$$
$$= 95.2\ \Omega.$$

$$R_{refl} = \frac{R_F + R_{oa}}{1 + |A|} = 0.1\ K$$

$$R_{out} = \frac{R_{oa}}{1 + \underset{200}{A}\,\underset{1/17}{F}} = 313.4\ \Omega$$

$$F = \frac{R_s // R_{ia}}{R_s // R_{ia} + R_F} = \frac{1}{17}$$

6-15

$R_F = 10K$

$R_s = 5K$

$G = 1.89$

$R_{in} = 67$ at 1

$R_{out} = 154$

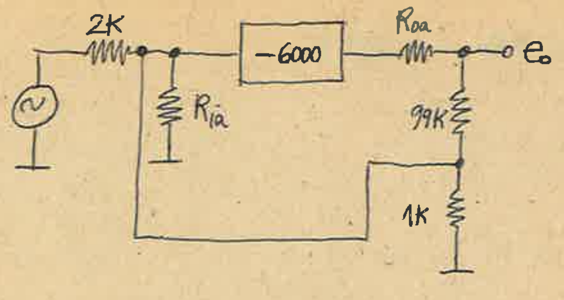
6.16

$G = -8.88$

$R_{in} = 113$

$R_{out} = 380$

6-17



$$G = \frac{R_{refl}}{R_i + R_{refl}} |A|$$

$$R_{refl} \doteq \frac{R_F}{1+6000} = 16.5\ \Omega$$

$$G = \frac{16.5}{2K+16.5}(-6000) = -49.1$$

$R_{in} = 2016.5$

6-18

$R_{refl} = 165\ \Omega$

$G = 45.7$

$R_{in} = 2165$

6-19

$$G = \frac{R_{eq}}{R_{eq}+2000} A = -49$$

$R_{in} = R_1 + R_{eq} = 2016.45\ \Omega$.

6-20

$R_{oa} = 6K$ 6.20 similar to 6.14

using eq 6.27 : $G = -47.6$

$$R_{in} = R_1 + \Big[\underbrace{R_{ia} /\!/ \frac{R_F + R_{oa}}{1+A}}_{0.86}\Big]$$

since $R_L = 0$ reflected impedance can be considered $R_F + R_{oa}$ transferred.

$R_{in} = 2.145\ K$

$$R_{out} = \frac{R_{oa}}{1+AF} = 161.5\ \Omega.$$

$A = 6000$

$$F = \frac{2K /\!/ 0.86K}{99K + 2K /\!/ 0.86K} = 0.00604$$

6-21

voltage shunt.

5JUN80

kitaptaki ~~ex~~ örnek gelebilir (Ch 13) ve Prb 1 2 3

'slew rate' can be asked in the exam.

"Nyquist formulation"

7JUN80

6.21

$$R_{ia} = 10K /\!/ 80K /\!/ (200 + 81 \times 26)$$

$= 1.83\ K$ (in the book : 1.58 K)

$$r_d = \frac{26}{1} = 26\ \Omega.$$

from equation 6.27. $R_L = \infty$, $R_{oa} = \text{small}$

$$G = \frac{-|A|}{1 + \frac{R_1}{R_{ia}} + \frac{R_1}{R_F}(1+A)}$$

A : unloaded open loop gain

$G = 7.67$ (7.65 in the book)

$$A = A_{bc_1} \frac{R_{in2}}{R_{in2} + R_{c1}}$$

$R_{in2} = 171.886$

$4K /\!/ (R_F + 0.5 /\!/ 1.83)$

$$A = -\frac{\beta R_{c1}}{r'_{bb} + (1+\beta) r_d} \times \frac{r'_{bb} + (1+\beta) r_d + (1+\beta)[\;]}{\beta + 171.886}$$

$A = 265.2$ (252 in the book)

$$R_{in} = R_{ia} /\!/ R_{refl} = R_{ia} /\!/ \frac{R_F}{\underbrace{1+A}_{266}} = 14.9\ \Omega.$$

6.22

$R_F = 10K$

$R_{ia} = 1.83\,K$

$A = -268.8$

$G = -18.27$

$R_{in} = 36.46\ \Omega.$

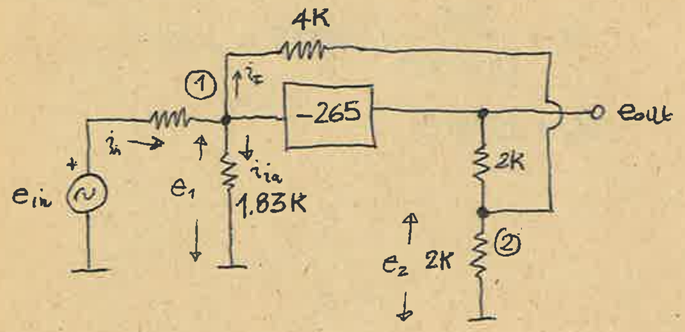
6.23

$R_{ia} = 1.83\,K$

$G = A$

$R_{in} = R_{ia} \,//\, R_F = 1.255\,K$

6.24



at node 1 $\quad \dfrac{e_{in} - e_1}{0.5} = \dfrac{e_1 - e_2}{4K} + \dfrac{e_1}{1.83}$

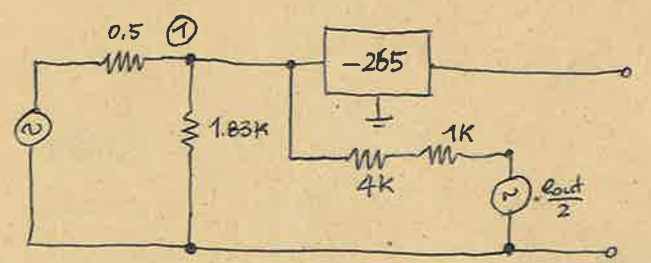
at node 2 $\quad \dfrac{e_2}{2K} = \dfrac{e_{out} - e_2}{2K} + \dfrac{e_1 - e_2}{4K}$

3) $\quad e_{out} = -265\, e_1$

4) $\quad \dfrac{e_{out}}{e_{in}} = G$

four equations with four unknowns

$$G = \frac{-265}{14.623} = -18.1$$



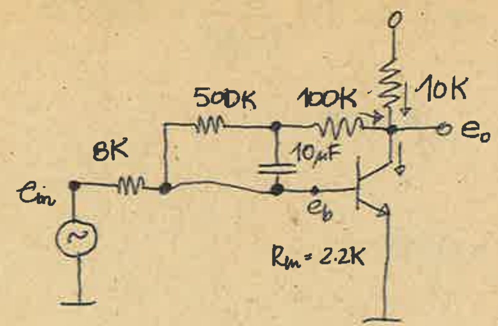
$R_{in\ at\ ①} = 36.7\ \Omega.$

Total profit : Total revenue − total cost.

Rule I : AR ≥ AVC in order to continue the process of manufacturing
must be

23MA480

6-25



current eq :

$$\frac{e_{in} - e_b}{8K} = \frac{e_b}{R_{ia}} + \frac{e_b - e_{out}}{R}$$

$R \to R_{DC} = 600\,K$

$R \to R_{AC} = 100K$

$$\frac{e_{out}}{10} + 100\,\frac{e_b}{2.2} = \frac{e_b - e_{out}}{R}$$

$$G_{DC} = \left.\frac{e_{out}}{e_{in}}\right|_{dc} = -42.135$$

$R_{DC} = 600K$

$$G_{AC} = \left.\frac{e_{out}}{e_{in}}\right|_{AC} = -10.939$$

$R_{AC} = 100K$

6.26 in the book

— CHAPTER 13 —

13-1

$m = 5$

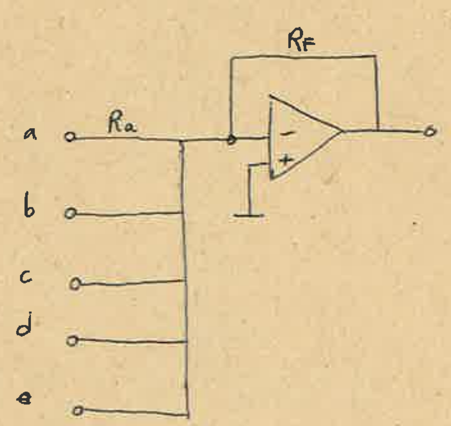
$V_0 = -10\,V$

$V_1 = +6\,V$

$CF = \frac{V_0}{2^m - 1}$ conversion factor	general
$CF = \frac{R_F}{R_A} V_1$	binaryweighted resistors
$CF = \frac{R_F}{2^m R} V_{REF}$	ladder network

$$\frac{R_F}{R_A} V_A = \frac{V_0}{2m-1}$$

$$\frac{R_F}{R_A} = \frac{\overset{10}{V_0}}{\underset{6}{V_1}} \frac{1}{\underbrace{2^m - 1}_{31}} = \frac{10}{186} = 0.053$$



13.2 (The answer given in the book is WRONG)

$V_o = -8$

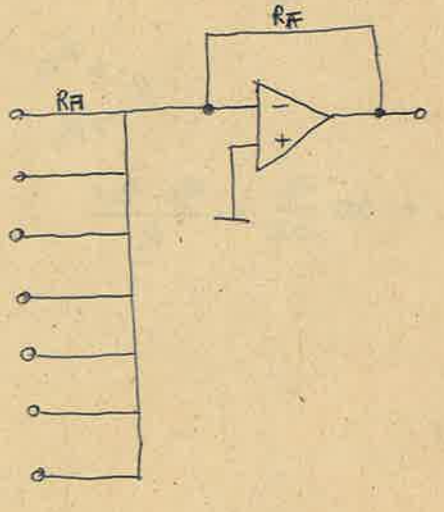
$CF = .058$

$V_1 = +6$

$$CF = \frac{V_o}{2^m - 1}$$

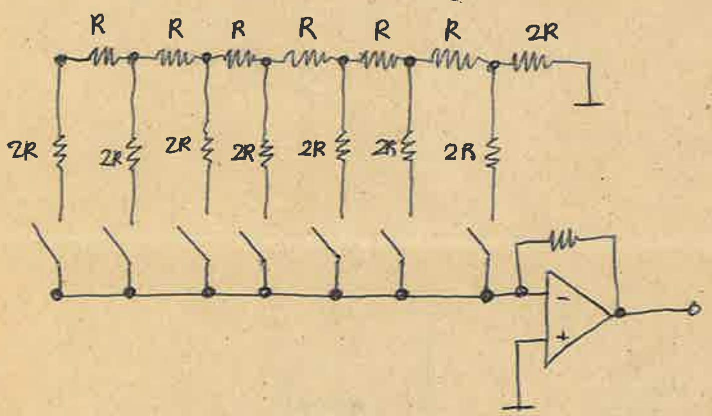
$$2^m - 1 = \frac{V_o}{CF} \Rightarrow 2^m = 1 + \frac{8}{0.058} = 138.93$$

$m = 7$



$$\frac{R_F}{R_A} = \frac{0.058}{6} = 0.097$$

13.3

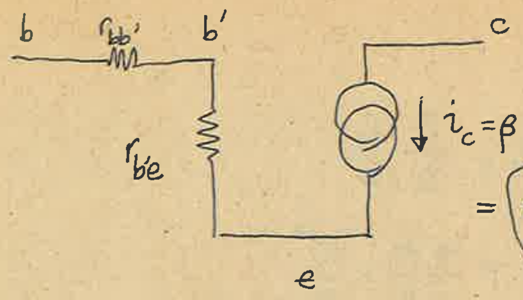


$$0.058 = \frac{R_F}{R}\,\frac{6}{128}$$

$$\frac{R_F}{R} = \underline{\underline{1.237}}$$

12 JUN 80

- TRANSISTOR AT HIGH FREQUENCY -



$$i_c = \beta i_b = \alpha i_e$$

$$= \alpha \frac{v_{b'e}}{r_d} = g_m v_{b'e}$$

$$g_m = \frac{i_{out}}{v_{in}}$$

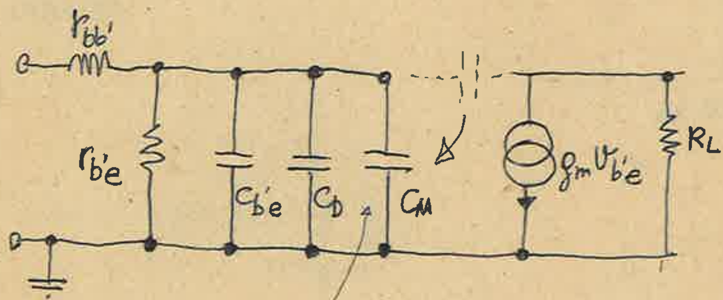
$$i_c = g_m v_{b'e}$$

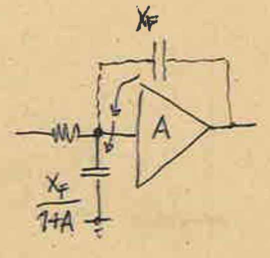
$$g_m r_d = \alpha$$

$$g_m r_{b'e} = \beta$$

$$g_m R_L = A$$

$$\left.\begin{array}{ll} \text{tubes} & g_m r_p \\ \text{transist.} & g_m r_c \\ \text{FET} & g_m r_{ds} \end{array}\right\} \mu$$





$$|X_F| = \frac{1}{\omega C_{b'e}}$$

$$X_{refl} \doteq \frac{1/\omega C_{b'c}}{1+A} = \frac{1}{\omega C_{b'c}(1+A)}$$

transistor's

$$A = g_m R_L \doteq \frac{\alpha}{r_d} R_L$$

$$\boxed{C_M = C'_{bc}\left(1 + \alpha \frac{R_L}{r_d}\right)}$$

PROB 7.1

$\alpha = 0.99$

$r_{bb'} = 200\,\Omega$

$C_{b'c} = 5$ pF

$f_t = 10$ MHz

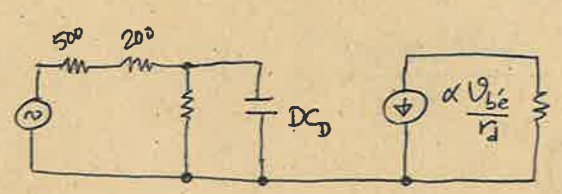
$R_L = 1K$

$I_E = 1\,mA$

$R_s = 500\,\Omega$

$A_{MB} = ?$

$f_2 = ? = \frac{B}{D} f_\beta$



$$\beta = \frac{\alpha}{1-\alpha} = 99$$

$$A_{MB} = -\frac{\beta R_L}{R_s + r_{bb'} + r_{b'e}} = \frac{-99 \times 10^3}{500 + 200 + 2600} = -30$$

$$A_o = A_{MB}\left(\frac{1}{1 + j\omega/\omega_2}\right)$$

$$B = \frac{R_s + r_{bb'} + r_{b'e}}{r_{bb'} + r_{b'e}} = \frac{3300}{\cancel{4}700} = 4.71$$

$$D = 1 + \alpha R_L C_{b'c}\,\omega_t$$
$$= 1 + 0.99\times10^{3}\times5\times10^{-12}\times10^{7}\times2\pi$$
$$= 1.31$$

$$f_2 = \frac{B}{D}\,\frac{f_t}{\beta} = \frac{4.71}{1.31}\times\frac{10^{7}}{99} = 360 \text{ kHz.}$$

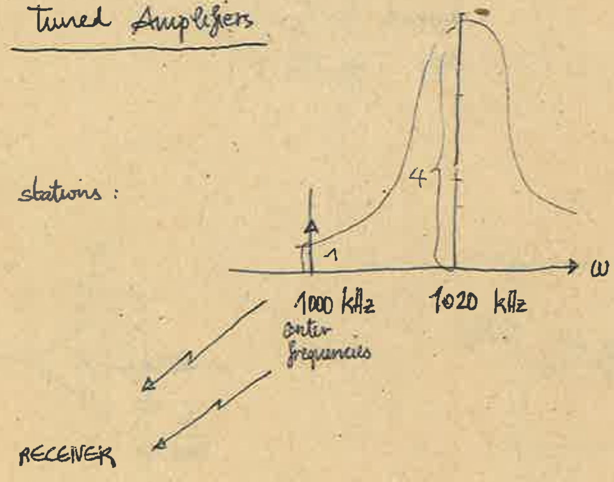
16J80

Tuned Amplifiers

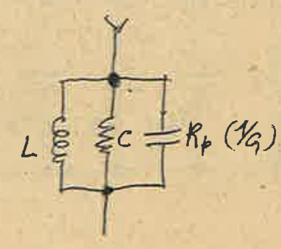
$\frac{V}{V_0} = \frac{1}{4}$ given

Ⓔ Problem :

there are two stations :



19JUN80



a) determine the values : G, C
$L = 50\,\mu H$
b) What is the bandwidth ?

Answer :

a) $f_0 = 1000$ kHz 10^6 Hz
$\omega_0 = 2\pi\times10^6$ rad/sec $= \frac{1}{\sqrt{LC}} \Rightarrow C = 507\times10^{-12}$ F

$\boxed{507 \text{ pF}}$

b) $\frac{V}{V_0} = \frac{1}{4} = \left|\frac{1}{1+j2\delta Q_0}\right| = \frac{1}{\sqrt{1+4\delta^2 Q_0^2}}$

$\delta Q = 1.94$

$\delta = \frac{\omega-\omega_0}{\omega_0} = \frac{1020-1000}{1000} = \frac{20}{1000}$ $\quad\delta = 0.02$

$Q = \frac{1.94}{\delta} \Rightarrow Q = 97$

$Q_{p_{RC}} = \frac{\omega_0 C}{G} = \frac{2\pi\times10^6\times507\times10^{-12}}{G} = 97$

$\boxed{G = 32\times10^{-6}\ ℧}$

$BW = \omega_2 - \omega_1 = \frac{\omega_0}{Q} = \frac{2\pi\times10^{-6}}{97} = 64.8\times10^3$ rad/sec

half power frequencies

$\boxed{BW = 10.3 \text{ kHz}}$

– MODIFIED RESONANCE CCT –

$z_0 = \frac{L}{RC} = R_p$

Example (from Comer)

Given
$$\begin{cases} R_s + r_{bb'} + r_{b'e} = 3\,k\Omega \\ \beta = 100 \\ \omega_o = 6.28\times 10^5 \text{ rad/sec} \\ L = 1\,mH \\ Q_{eff} = 50 \end{cases}$$

$$A = \frac{-\beta R_{sh}}{R_s + r_{bb'} + r_{b'e}} = \frac{-\beta \omega_o L Q_{eff}}{R_s + r_{bb'} + r_{b'e}}$$

$$A = \frac{-100\times 6.28\times 10^5 \times 10^{-3}\times 50}{3000} \cong -1000$$

$$BW = \frac{f_o}{Q_o} \rightarrow \frac{f_o}{Q_{eff}} = \frac{100\times 10^2}{50} = 2000 \quad 2kHz$$

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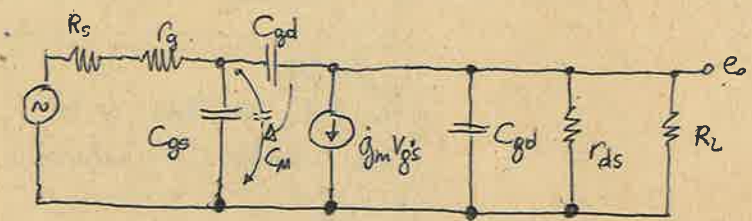
High frequency considerations in FET



$$C_M = C_{gd}(1 + g_m R_{eq})$$

$$R_{eq} = R_L // r_{ds}$$

$$C_{ds} \cong C_{gs} > C_{gd}$$

5 pF   0.5 pF

$$C_{in} = C_{gs} + C_M$$

corners due to time constants

$$\omega_1 = \omega_{in} = \frac{1}{\tau_{in}} = \frac{1}{(R_s + r_g)C_{in}} \cong \frac{1}{R_s C_{in}}$$

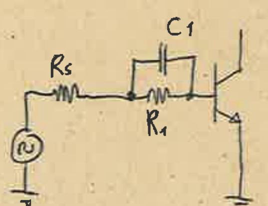
$$\omega_2 = \omega_{out} = \frac{1}{\tau_{out}} = \frac{1}{R_{eq} C_{ds}} \cong \frac{1}{R_L C_{ds}}$$

GBW considerations

$$GBW = A_{MB}\,\omega_2 = \frac{\overset{\omega_\alpha}{\omega_\beta}}{D}\,\frac{\beta R_c}{R_s + r_{bb'}}$$

for GBW to be constant

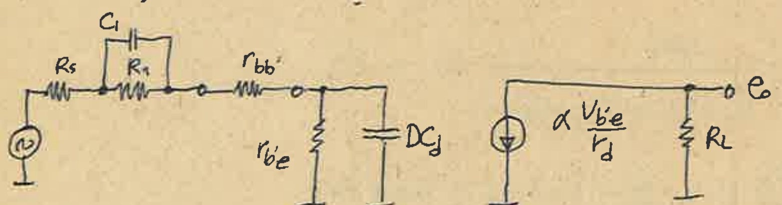
Base compensation



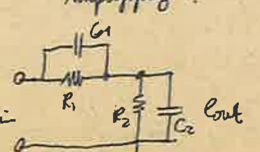
Emitter compensation

Case I

Case II



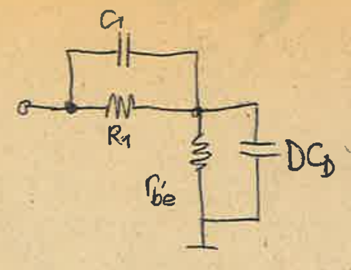
Simplifying :



must be : $\boxed{R_1 C_1 = R_2 C_2}$

then the network becomes frequency independent : $\frac{e_{out}}{e_i} = \frac{R_2}{R_1 + R_2}$

$$\longrightarrow \frac{e_{out}}{e_i} = \frac{\dfrac{R_2}{1 + j\omega C_2 R_2}}{\dfrac{R_2}{\cancel{1 + j\omega C_2 R_2}} + \dfrac{R_1}{\cancel{1 + j\omega C_1 R_1}}}$$



$$\tau_1 = \tau_2$$

$$R_1 C_1 = D C_D r_{b'e} \quad \frac{1}{\omega_\beta}$$

$$C_1 = \frac{D C_D r_{b'e}}{R_1} = \frac{D}{R_1 \omega_\beta}$$

ITERATIVE STAGES

$$\omega_{2o} = \omega_2 \sqrt{2^{1/n} - 1}$$ bandwidth shrinkage equation

$$\sqrt{2^{1/n} - 1} \cong 1/1.2\sqrt{n} \quad n \geq 3$$

$$\omega_{2o} = \frac{\omega_2}{1.2\sqrt{n}}$$

CH7
7.1 – 7.3A (270-335)

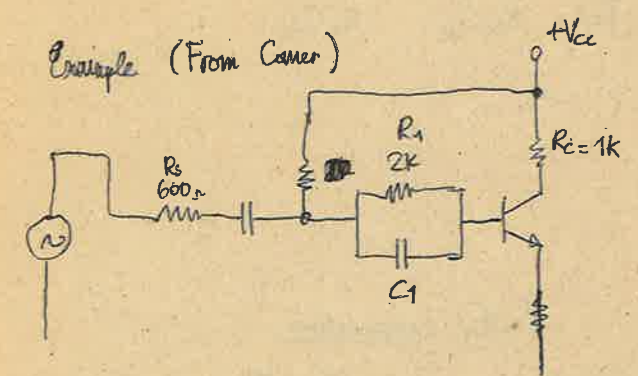
7.4 tuned stages
ABCDE (319-327)

CH12
the first 36 Pages, up to Class C amplifiers (not included)

CH8
8.2 SCR (366-375)
CH15
15.4 (674-678)

Vacuum tubes: Angelo 307 – 318

Example (From Comer)



$f_t = 100$ MHz
$\beta = 100$
$r_{bb'} = 100\ \Omega$
$r_d = 13\ \Omega$
$C_{b'c} = 5$ pF (at bias point)

$A_{MB} = ?$
$f_h = ?$

a) $R_1 = 2k$, $C_1 =$ the correct value
b) $R_1 = C_1 = 0$

a) $$A_{MB} = \frac{-\beta R_L}{R_s + r_{bb'} + r_{b'e} + R_1} = -25$$

$$f_2 = \frac{f_\beta}{D} B = \frac{f_\beta}{D}\left(\frac{R_s + r_{bb'} + r_{b'e} + R_1}{R_s + r_{bb'}}\right)$$

$$f_\beta = \frac{f_t}{\beta} = \frac{100\text{ MHz}}{100} = 1\text{ MHz}$$

$$D = 1 + \alpha R_L \omega_t C_{b'c} = 1 + 0.99\times10^3 \times 2\pi\times10^8 \times 5\times10^{-12}$$
$$= 4.1$$

$$f_2 = \frac{1\ \text{MHz}}{4.1} \times \frac{4013}{700} = 1.4\ \text{MHz}$$

$$C_1 = \frac{D}{R_1 \omega_\beta} = \frac{4.1}{2\times10^3 \times 2\pi \times 10^6} = \underline{302\times10^{-12}\ \text{F}}$$

b) $f_2 = \frac{f_\beta}{D} B$

$$B = \frac{2013}{700} = 2.88$$

$$f_2 = \frac{1}{4.1} \times 2.88 = 0.7\ \text{MHz}$$

$A_{MB} = -50$?

7.3 $n = 13.8$ → must be integer

14 nearest higher integer

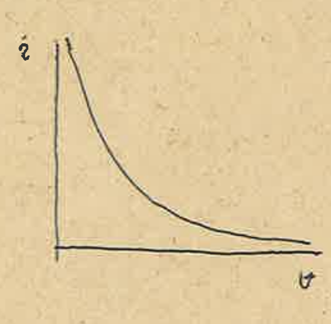
$\rightarrow n = 2 \ln A_{MBo}$

30680

POWER AMPLIFIERS

Power hyperbola

$P = v i$ = constant



3780

Thermal equilibrium criteria :

$$\frac{1}{\Theta} \geq \frac{P}{T}$$

power dissipated

7.1

$$C = \frac{k}{\sqrt{\phi - V}}$$

$C = 10\ pF$

$V = -6\ V.$

$\phi = 0.7$

find C for 12 V reverse bias.

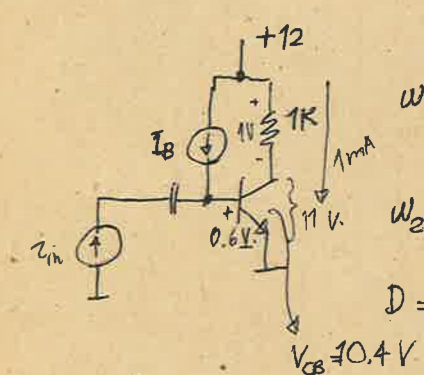
7.2

Similar to 7.1

7.5

$$\omega_\beta = \frac{1}{(1+\beta) r_d C_D} \Rightarrow C_D = \frac{1}{(1+\beta) r_d \omega_\beta}$$

7.7



$$\omega_2 = \omega_\beta \frac{B}{D} \qquad B \to 1$$

$$\omega_2 = \frac{\omega_t}{\beta} \frac{1}{D}$$

$$D = (1 + \alpha R_L C_{b'c} \omega_t)$$

$\omega_t = 6.28 \times 10^6$ rad/sec

$\beta = 70$

$\boxed{\begin{array}{l} C_{b'c} = 20\ pF \\ V_{CB} = 6\ V \\ \phi = 0.8\ V \end{array}}$

$$\left.\frac{e_{out}}{i_{in}}\right|_{I_E = 1mA}$$

$$\left. C_{b'c} \right|_{V = 10.4} = 15.6\ pF$$

$$D = (1 + \frac{70}{71} 1000 \times 15.6 \times 10^{-12} \times 6.28 \times 10^6)$$

$$= 1.10$$

$$\omega_2 = \frac{6.28 \times 10^6}{70 \times 1.10} = 81.8 \times 10^3 \text{ rad/sec.}$$

7.8 similar to 7.7 $\quad R_s \to \infty \Rightarrow B = 1$

$I_C \cong I_E = 1mA$

$V_{CQ} = 12 - 4 = 8\ V$

$V_{BC} = 8 - 0.6 = 7.4 \quad \to \quad C_{b'c} = 18.2\ pF$

$D = 1.11$

$$\omega_2 = \frac{6.28 \times 10^6}{70 \times 1.11} = 80.6 \times 10^3 \text{ rad/sec}$$

7.11

$$A_{MB} = -\frac{\beta R_c}{R_s + r_{bb'} + r_{b'e}} = -\frac{100 \times 1000}{600 + 100 + 1030} = -57.8$$

$$I_E = \frac{(E_{th} - 0.6)(1+\beta)}{R_{th} + (1+\beta) R_E}$$

$$r_{b'e} = (1+\beta) r_d$$

$$E_{th} = \frac{8}{8+62} 18 = 2.06\ V$$

$$R_{th} = \frac{62 \times 8}{62+8} = 7.09\ K.$$

$I_E = 2.56\ mA$

$$r_d = \frac{26}{2.56} = 10.2\ \Omega$$

$$f_2 = f_\beta \frac{B}{D}$$

$$f_\beta = \frac{f_t}{\beta}$$

$$B = \frac{R_s + r_{bb'} + r_{b'e}}{R_s + r_{bb'}} = 2.47$$

$$D = 1 + \frac{100}{101} \times 10^3 \times 2 \times 10^7 \times 10^{-11}$$

$D = 1.628$

$$f_2 = \frac{10^7}{100} \frac{2.47}{1.628} = 153.2\ kHz.$$

7.12 Same equations used in 7.11.

Explanation: $f_2 \doteq f_\beta \frac{B}{D} = \frac{f_t}{\beta}\frac{B}{D}$

$\to 1 + \alpha R_L C_{b'c} 2\pi f_t$

D is increased too.

7.13 equations used in 7.11

7.14 " " " "

7.15 " " " " 7.12

7.18 7.11, 7.12

7.19 $A_{MB} = -g_m (r_{ds} // R_L)$

$C_{in} = C_{gs} + (1 + A_{MB}) C_{gd}$

$f_2 = \frac{1}{2\pi R_S C_{in}}$

$A = \frac{-g_m R_{eq}}{(1 + j\omega R_S C_{in})(1 + j\omega R_{eq} C_{ds})}$

$R_{eq} = \frac{r_{ds} R_L}{r_{ds} + R_L}$

R_S: large $\Rightarrow f_2 = \frac{1}{2\pi R_S C_{in}}$

$A_{MB} = -6000 \times 10^{-6} \frac{100 \times 2}{100 + 2} k\Omega = \underline{-11.8}$

$C_{in} = 3.5 + (12.8)3 = 41.8$ pF

$f_2 = \frac{1}{2\pi\, 20000 \times 41.8 \times 10^{-12}} = 190$ kHz

7.20
7.21
7.22 Same equations as 7.19

7.23 $GBW = |A_{MB}| \times \omega_2 = 20 \times 2\pi \times 560 \times 10^3 = 7.03 \times 10^7$

$GBW = \frac{\overset{\omega_t}{\cancel{\omega_\beta}}}{D} \times \frac{\cancel{\beta} R_L}{r_{bb'} + R_S} = \frac{\omega_t R_L}{D(r_{bb'} + R_S)} = \frac{2\pi \times 10^7 \times R_L}{1 + \frac{99}{100} \times R_L \times 2\pi \times 10^7 \times 8 \times 10^{-12})(\underset{k}{0.1} + \underset{k}{0.2})}$

Solve for R_L

$R_L = 0.33642$ K

find D: $D = 1 + \alpha R_L \omega_t C_{b'c}$

$D = 1.1674$

$\omega_2 \doteq \frac{\omega_\beta}{D} \times B = \frac{2\pi \times 10^7}{99 \times 1.1674} \times B = 2\pi \times 560 \times 10^3$

Solve for B

$B = 6.472$

$B = \frac{\overbrace{R_S + r_{bb'}}^{0.3k} + r_{b'e}}{\underbrace{R_S + r_{bb'}}_{0.3k}}$

$r_{b'e} = 1.642$ K

7.24 $GBW = \frac{\omega_t}{D} \frac{R_L}{r_{bb'} + R_S}$

$GBW = \frac{2\pi 10^7}{D} \frac{200}{100 + 200} = 3.81 \times 10^7$

$D = 1 + \alpha R_L \overset{2\pi 10^7}{\omega_t} \overset{8 \times 10^{-12}}{C_{b'c}}$

$= 1.09952$

$A_{MB} = \frac{GBW}{\omega_2} = \frac{3.81 \times 10^7}{2\pi \times 10^6} = \underline{\underline{6.064}}$

⊛ 7.25

$$R_1C_1 = r_{b'e}\,DC_D = \frac{D}{\omega_\beta}$$

$$C_1 = \frac{D}{R_1\omega_\beta} = \frac{1.628}{3\times10^3\times\frac{10^7}{100}\times 2\pi} = 0.086\times10^{-8}$$

from 7.11

$$C_1 = 863.7\,pF$$

$$A_{MB} = -\frac{\beta R_L}{R_s+R_1+r_{bb'}+r_{b'e}} = -\frac{100}{4.73}$$

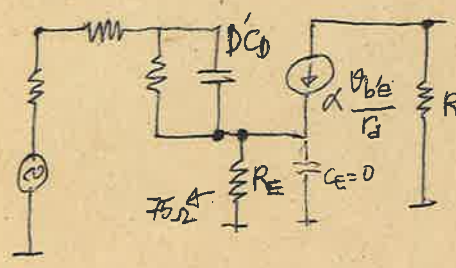
$$A_{MB} = -21.14$$

$$f_2 = f_\beta\frac{B}{D} = \frac{1\times10^5}{1.628}\,\frac{R_s+R_1+r_{bb'}+r_{b'e}}{R_s+r_{bb'}}$$

$$f_2 = 415\,kHz$$

7.26 Similar to 7.25

⊛ 7.27 (Fig 7.19)



$\beta = 100$
$r_{bb'} = 100\,\Omega$
$V_{BE} = 0.6\,\Omega$
$f_t = 10^7\,Hz$
$C_{b'c} = 10\,pF$
$R_s = 600\,\Omega$

$i_E = 4\,mA$

$$A_{MB} = -\frac{\overset{100\quad 10^3}{\beta R_L}}{\underset{600}{R_s}+\underset{100}{r_{bb'}}+\underset{656.5}{r_{b'e}}+\underbrace{(1+\beta)R_E}_{7525}} = -11.173$$

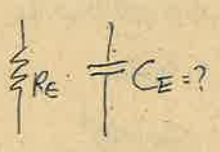
$$r_d = \frac{26}{4} = 6.5\,\Omega$$

$$r_{b'e} = 101\times6.5 = 656.5\,\Omega.$$

$$f_2 = f_\beta\frac{B}{D'}$$

$$= \frac{10^7}{100}\underbrace{\frac{}{1+(\alpha R_L+r_d+R_E)\omega_t C_{b'c}}}_{D'}\times\underbrace{\frac{R_s+r_{bb'}+r_{b'e}+(1+\beta)R_E}{R_s+r_{bb'}+R_E}}_{B} = \frac{10^7}{100}\times6.965$$

$$f_2 = 696.5\,kHz$$



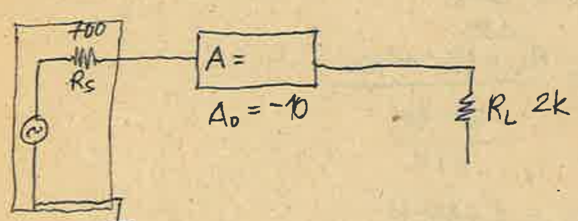
$$\boxed{\omega_t = 1/R_E C_E}$$

$$C_E = \frac{1}{R_E\,\omega_t} = \frac{1}{75\times2\pi\times\text{[illegible]}} = 212.21\times10^{-12}$$

7.28 - 7.29 - 7.30 → 7.27

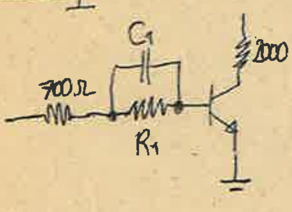
not looked by teacher

⊛ 7.31 $f_2 \geq 80\,kHz$



$$10 = |A_{MB}| = \frac{\overset{100\quad 2000}{\beta R_L}}{\underset{700}{R_s}+\underset{100}{r_{bb'}}+\underset{101}{(1+\beta)}\underset{?}{r_d}} \Rightarrow r_d = 190\,\Omega.$$

$$I_E = \frac{26}{190} = 0.137\,mA$$



$r_{bb'} = 100$
$\beta = 100$
$f_t = 10^7$
$C_{b'c} = 10\,pF$

$$f_2 = f_\beta\frac{B}{D} \geq 80\times10^3\,Hz$$

$$= \frac{10^7}{100}\,\frac{B}{D} \geq 80\times10^3$$

$$\boxed{\frac{B}{D} \geq 0.8}$$

$$|A_{MB}|' = \frac{\overset{100}{\beta} \overset{2000}{R_L}}{\underbrace{R_S + r_{bb'}}_{800} + R_1 + r_{b'e}} = 10$$

$$\boxed{r_{b'e} + R_1 = 19.2 \times 10^3}$$

$$\frac{B}{D} = \frac{\dfrac{R_1 + R_S + r_{bb'} + r_{b'e}}{R_S + r_{bb'}}}{1 + \alpha R_L \omega_t C_{b'e}} \geqslant 0.8$$

$$R_1 + r_{b'e} \geqslant 636.2$$

CONTINUED

7.33

$$A_{MB} = \frac{-\beta R_C}{R_S + r_{bb'} + r_{b'e} + (1+\beta) R_E}$$

assumption needed

eg. $I_E = 4\,mA$

$r_{b'e} = 656.7\ \Omega$

$$f_2 = f_3 \frac{B}{D'}$$

$$B = \frac{r_S + r_{bb'} + r_{b'e} + (1+\beta) R_E}{R_S + R_{bb'} + R_E}$$

$$D' = 1 + (\alpha R_L + R_E + r_d) C_{b'c} \omega_t$$

$\Rightarrow R_E$

$$C_E = \frac{1}{R_E \omega_t}$$

$$\omega_2 = \omega_\beta \frac{B}{D'}$$

$$f_2 = f_\beta \frac{B}{D'}$$

Can be asked. **7.35** See 7.11

$$GBW = \frac{\omega_t}{D} \frac{R_L}{r_{bb'} + R_S} \quad ; \quad A_{MB}$$

$$\omega_2 = \frac{GBW}{A_{MB}}$$

7.36 Same as 7.35
except D' instead of D

⊛ **7.37**

$$A_o = \frac{A_{MB}}{(1 + j\frac{f}{f_{21}})(1 + j\frac{f}{f_{22}})(1 + j\frac{f}{f_{23}})}$$

f_{21}: 1 MHz, f_{22}: 2 MHz, f_{23}: 10 MHz

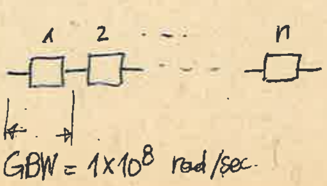
$$\left[1 + \left(\frac{f}{1}\right)^2\right]\left[1 + \left[\frac{f}{2}\right]^2\right]\left[1 + \left(\frac{f}{10}\right)^2\right] = 2$$

$f = 832\ kHz$

⊛ **7.38** Same with 7.37

Answer: 595 kHz

Can be asked **7.39** $f_{20} = 3.1\ MHz$



$$\frac{dW}{dn} = 0 \quad \boxed{A_{MB} = 1.65}$$

1×10^8 $GBW = 1 \times 10^8$ rad/sec.

$$\frac{(GBW)_n}{1.65} = \omega_2 = 60.606 \times 10^6 \text{ rad/sec}$$

$$\omega_{20} = \omega_2\sqrt{2^{1/n}-1}$$

$$3.1 = 9.65\sqrt{2^{1/n}-1}$$

$$n = 7.058$$

$$\boxed{n = 7}$$

⊛ **7.49** $f_0 = \dfrac{1}{2\pi\sqrt{LC}} \rightarrow C$

$$R_p = Q_0 \omega_0 L$$

$$R_{sh} = R_p \,//\, R_1$$

$$Q_{eff} = \frac{R_{sh}}{\omega_0 L} = \frac{R_{sh}}{R_p} Q_0 \longrightarrow \text{ANSWER}$$

$$BW = \frac{f_0}{Q_{eff}}$$

7.50 Same as 7.49

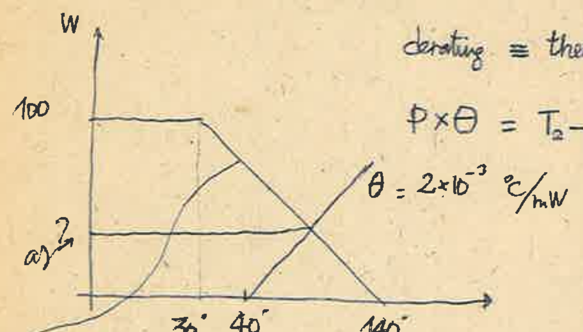
⊛ **7.51** $L = \dfrac{1}{\omega_0^2 C}$

$$Q_{eff} = \frac{f_0}{BW} = \frac{R_{sh}}{\omega_0 L} \Rightarrow R_{sh}$$

$$R_{sh} = R_1 // R_p \rightarrow R_p$$

12780

12-1



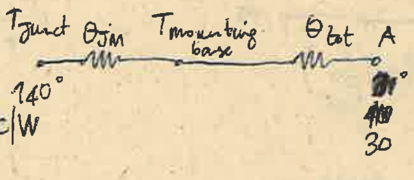
derating ≡ thermal conductance $= \dfrac{1}{\theta}$

$$P \times \theta = T_2 - T_1$$

a) $\theta_{tot_a} = 2°C/W$ $\quad \theta_{tot} = \theta_i + \theta_{HS}$

$\theta_{tot_b} = 4°C/W$

$\theta_A = 10°C/W$



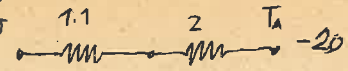
$$\theta_{JM} = \frac{T_2 - T_1}{P} = \frac{110}{100} \approx 1.1°C/W$$

$$P_a = \frac{140-40}{3.1} = 32.25\ W.$$

$$P_b = \frac{140-40}{5.1} = 19.6\ W.$$

$$P_{o\,air} = \frac{140-40}{11.1} = 9.01\ W.$$

12-2 a)



$T_J - T_A = \dfrac{140-(-20)}{}$

$P_A = \dfrac{160}{3.1} = 51.6\,W.$ $\qquad P\theta = T$

$P_b = \dfrac{160}{5.1} = 31.37\,W$

$P_c = \dfrac{160}{11.1} = 14.4\,W.$

12-4

$T_J \quad T_A$

$P = 20W = \dfrac{140-30}{1.1 + \theta_{TOT}}$

$\theta_J \qquad \theta_J + \theta_{HS}$

$\theta_T = \dfrac{110-22}{20} = 4.4\,°C/W.$

12-3

$T_J - T_A = P\theta$

140 $\quad$ 100 $\quad$ 3.1

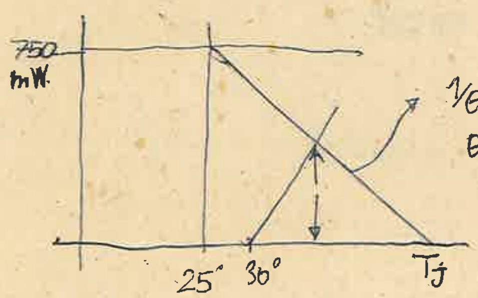
$J_J - T_A = 100 \times 3.1 = 310$

$T_A = -310 + 140 = -170\,°C.$

12-5 $P = 10W = \dfrac{140-30}{1.1\theta_t}$

$\theta = 9.9\ °C/W.$

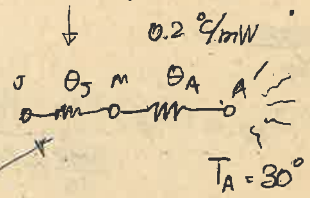
12.6



$1/\theta =$

$\theta_J = 0.1\ °C/mW$

10 mW/°C



$\dfrac{1}{\theta_J} = 10\,mW/°C \Rightarrow \theta_J = 0.1\ °C/mW.$

$\theta_A = 0.2\ °C/mW$

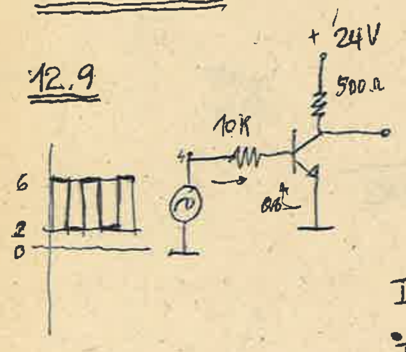
$T_J - 25 = 750 \times 0.1$

$J_J = 100°$

$P = \dfrac{100-30}{0.1+0.2} = 233.3$ ANSWER

12.7 - 12.8 $\rightarrow$ 12.6

12.9



$\beta = 50$

$V_{BE} = 0.5V$

a) find P_T

b) $\theta_t = \theta_J + \theta_{HS} = ?$

$\theta_J = 0.1\ °C/mW$

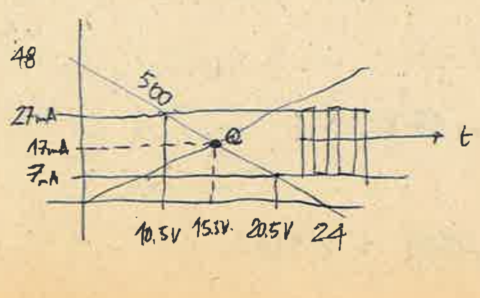
$T_{J_{max}} = 100°C$

$T_A = 30°$

$I_C = \beta I_B$

$I_{B_{6V}} = \dfrac{6-0.6}{10K} = 0.54\,mA.$ $\qquad I_{C_{6V}} = 50 \times 0.54 = 27\,mA$

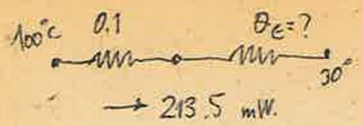
$I_{B_{2V}} = \dfrac{2-0.6}{10K} = 0.14\,mA.$ $\qquad I_{C_{2V}} = 50 \times 0.14 = 7\,mA$



$P_T = \dfrac{V_1 I_1 + V_2 I_2}{2} = \dfrac{10.5 \times 27 + 20.5 \times 7}{2} = 213.5\ mW.$

$P_{out} = \times (5_V \times 10\,mA) = \cancel{100}\ 50\,mW.$

$P_T = P_{Td} - P_{out} = 15.5 \times 17 - \cancel{100}\ 50 = 213.5\ mW.$

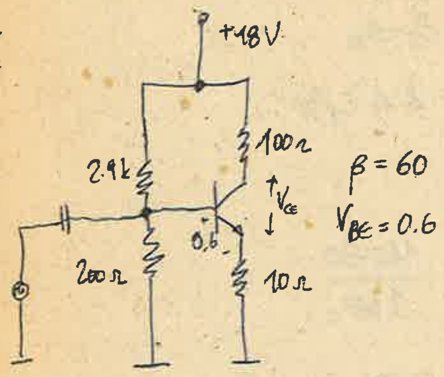


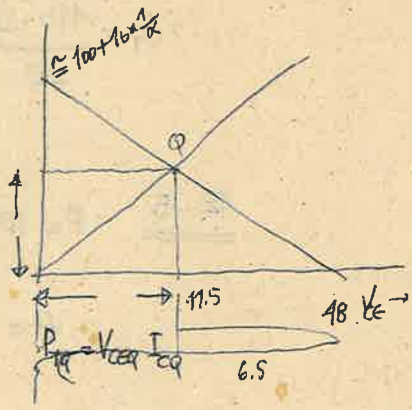
12-10, 11, 12, 13, 14 → 12.9

$100 - 30 = 213.5(0.1 + \theta_E)$

$\theta_E = 0.228$ °C/mW

12-15





a) Find the Q point

$E_{th} = \frac{200}{2600} 18 = \frac{18}{13}$

$R_{th} = \frac{200 \times 2400}{2600} =$

$I_{CQ} = (1+\beta) I_{BQ} = (1+\beta) \frac{E_{th} - V_{BE}}{\frac{2400}{13} + (1+\beta) R_E} = 60.2323$ mA $\qquad I_{CQ} = 59.245$ mA

$V_{CE} = 18 - (59.245 \times 0.11) \cong 11.5$ V

$P_{TQ} = 11.5 \times 59.26 = 681.3$

d) $P_S = I_{dc} 24 = I_{EQ} \times 18 \cong$

$= 60.2323 \times 18$

$= 1.0842$ W.

b)

$P_{ac(100)} = \frac{1}{2} \frac{(5.92)^2}{100} = 175$ mW

$P_{ac(10)} = \frac{1}{10} P_{ac(100)} = 17.5$ mW.

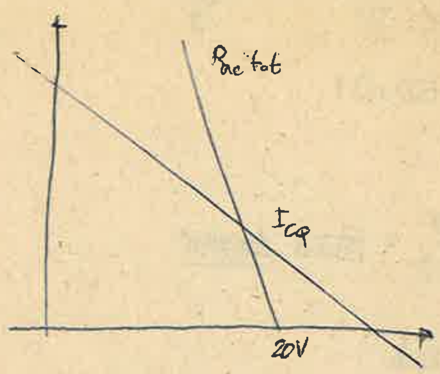
$P_{ac(tot)} = 175 + 17.5 = 192.5$

$\boxed{P_T = P_{TQ} - P_{act}} = 681 - 192.5$

$= 489$ mW.

c) ¿

12-19



$R_{actot} = n^2 R_L + R_p = 148\ \Omega$.

for max. output

$\left.\begin{array}{l} V_{CQ} = R_{ac} I_{CQ} \\ V_{CQ} = V_{cc} - I_{CQ} R_d \end{array}\right\} I_{CQ} = \frac{V_{cc}}{R_{ac} + R_{dc}}$ equation 12.14

b) $I_{CQ} = \frac{20}{20 + 148} = 119$ mA.

a) (eq. 12.15) $P_{ac} = \eta_t \frac{I_{CQ}^2 n^2 R_L}{2} = 1 \times \frac{0.119^2 \times (16 \times 8)}{2} = 0.9063$ W.

ideal transf.

c) $V_{CEQ} = V_{cc} - I_{CQ} R_{DC} = 17.62$

$= 20 - 0.119 \cdot 20$

$P_{TQ} = 17.62 \times 0.119 = 2.0968 = 2.1$ W.