Homework 5 Solutions

Fall 2018

Prob. 1

a) $N_D \gg N_A \rightarrow n + N_A \approx N_D$

$\rightarrow n \approx N_D - N_A = 10^{17}\,cm^{-3} - 10^{15}\,cm^{-3} = 99 \times 10^{15}\,cm^{-3}$

$p = \frac{n_i^2}{n} = \frac{(1.45 \times 10^{10}\,cm^{-3})^2}{99 \times 10^{15}\,cm^{-3}} = \boxed{2.124 \times 10^{3}\,cm^{-3} = p}$

b) $N_A = N_D \rightarrow \boxed{n = p = n_i = 1.45 \times 10^{10}\,cm^{-3}}$

Prob. 2

$$I_{B2} + I_{C_1} + I_{B_1} = 1\ mA$$

Because the transistors are identical and have equal V_{BE}, we conclude that $I_{B_2} = I_{B_1}$ and $I_{C_2} = I_{C_1}$. Furture more $I_{C_1} = \beta I_{B_1}$.

$$I_{B_1} + 100 I_{B_1} + I_{B_1} = 1\ mA \Rightarrow I_{B_1} = 9.804\ mA$$

$$I_{C_1} = I_{C_2} = \beta I_{B_1} = 0.9804\ mA$$

$$I_{E_1} = (\beta + 1) I_{B_1} = 0.9902\ mA$$

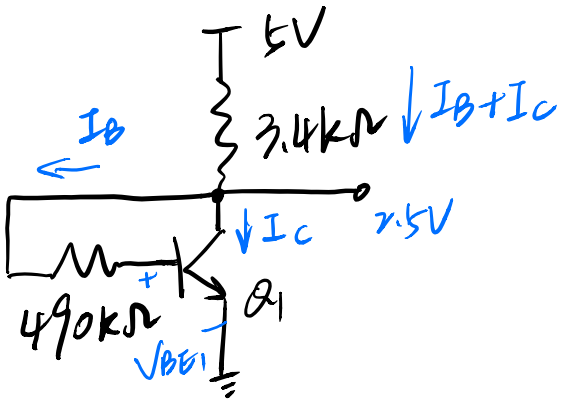
Solving Eq. 4.1 for V_{BE} we have:

$$V_{BE} = V_T \ln\left(\frac{I_E}{I_{ES}} + 1\right)$$

$$\Rightarrow V_{BE} = 0.026 \ln\left[(0.9902 \times 10^{-3})/10^{-14} + 1\right]$$

$$V_{BE} = 0.6583\ V$$

Problem (3)



assume Q_1 is in active region.

$$V_{B_1} = V_{BE_1} = 0.7V$$

$$I_B = \frac{V_C - V_B}{490k\Omega} = \frac{2.5-0.7}{490\times10^3} = 3.673\mu A$$

$$I_B + I_C = I_E = (\beta+1)I_B$$

$$I_E = \frac{5-2.5}{3.4k\Omega} = 735.29\mu A$$

$$\beta = \frac{I_E}{I_B} - 1 = 199.189$$

check

① $V_{BE} = V_C - I_B \times 490k\Omega = 0.7V$ → active/saturation

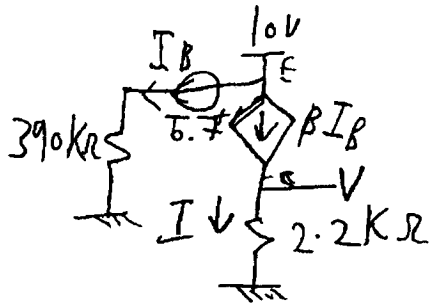
② $V_{CE} = 2.5V > 0.2V$ → active region ✓

Prob. 4

(4)

a) $\beta = 100$

equivalent circuit assuming operation in active:-



$$I_B = \frac{10 - 0.7}{390K\Omega} = 23.8462\mu A$$

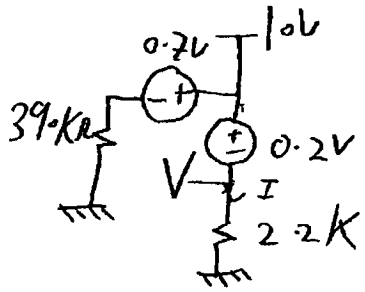
$$I = \beta I_B = 2.38\,mA > 0$$

$$V = V_C = 2.38 \times 2.2 = 5.25\,V$$

$$V_{EC} = 10 - 5.25 = 4.75\,V > 0.2\,V \rightarrow \text{active.}$$

$\beta = 300$

assume Saturation



$$I_C = \frac{10 - 0.2}{2.2} = 4.45455\,mA$$

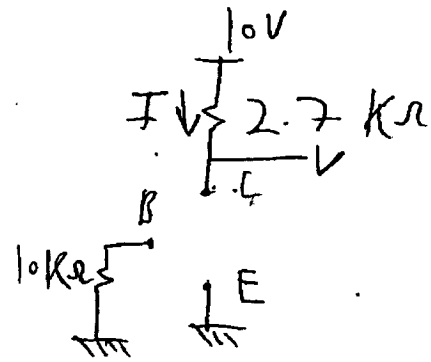
$$V = 10 - 0.2 = 9.8\,V$$

$$\beta I_B > I_C > 0 \rightarrow I_B = \frac{10 - 0.7}{390K} = 23.8462\,\mu A$$

$$\beta I_B = 7.15385\,mA > I_C \rightarrow \text{Saturation}$$

b) $\beta = 100$

assume Cutoff



$$V = 10V = V_C$$

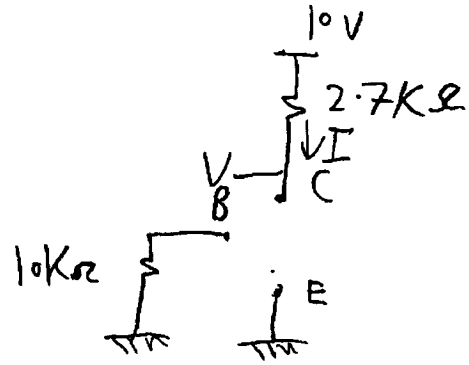
$$V_B = 0V$$

$$I = 0\,A.$$

$$V_{BE} = 0 - 0 = 0V < 0.5V \rightarrow \text{Cond 1}$$

$$V_{BC} = 0 - 10 = -10V < 0.5V \rightarrow \text{Cond 2} \rightarrow \text{o.c. cut off.}$$

Cont. Problem 4



b) $\beta = 300$

assume cutoff.

$V_B = 0V$

$V_C = 10V$

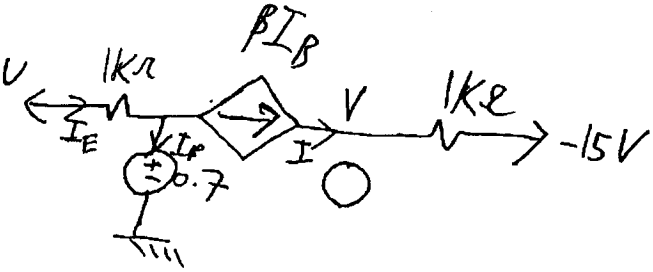
$V_E = 0V$

$\therefore I = I_C = 0A.$, $V = V_C = 10V.$

$V_{BE} = 0 - 0 = 0V < 0.5V \rightarrow$ Cond 1.

$V_{BC} = 0 - 10 = -10V < 0.5V \rightarrow$ Cond 2 $\rightarrow$ cut off.

c) $\beta = 100$ assume active



$I_E = I_B + I_C$

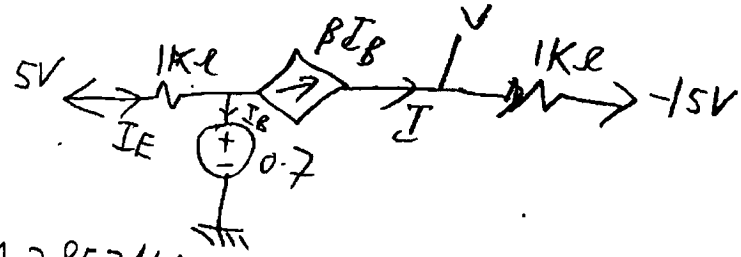
$\frac{5V - 0.7V}{1K} = I_B + \beta I_B \rightarrow I_B = 42.5743\mu A.$

$I = I_C = \beta I_B = 4.25743mA. > 0A$

$V = -15V + I \times 1K = -10.7426\ V.$

$V_{EC} = 0.7 - (-10.7426) = 11.4426V > 0.2V \rightarrow$ active

$\beta = 300$ assume Active



$I_E = I_B + I_C$

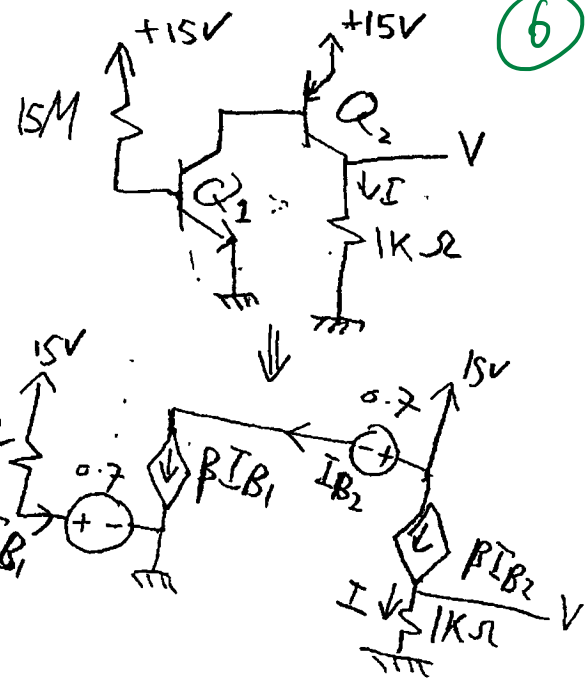
$\frac{5 - 0.7}{1K} = I_B + \beta I_B \rightarrow I_B = 14.2857\mu A$

$I = I_C = \beta I_B = 4.28571mA > 0A$

$V = -15V + I \times 1K = -10.7143\ V$

$V_{EC} = 0.7 - (-10.7143) = 11.4143V > 0.2V \rightarrow$ active

Cont. problem 4



a) $\beta = 100$

assume Q_1 active, Q_2 active

$$I_{B1} = \frac{15 - 0.7}{15M\Omega} = 0.95333\,\mu A$$

$$I_{B2} = \beta I_{B1} = 95.3333\,\mu A$$

$$I = I_{C_2} = \beta I_{B_2} = 9.53\,mA$$

$$V = I \times 1K = 9.53\,V$$

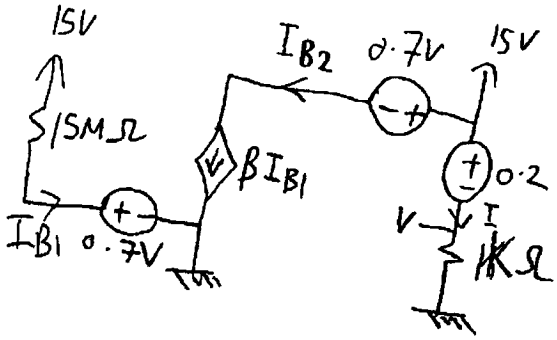
$15 - 0.7 = V_{CE1} > 0.2V \longrightarrow$ active

$I_{C1} = \beta I_{B1} = 95.3333\,\mu A > 0A \longrightarrow$ active

$V_{EC_2} = 15 - I \times 1K = 5.46667\,V > 0.2V \longrightarrow$ active

$I_{C_2} = I = 9.53\,mA > 0A \longrightarrow$ active

$\beta = 300$ assume Q_1 active, Q_2 in Saturation



$$I_{B1} = \frac{15 - 0.7}{15M\Omega} = 0.95333\,\mu A$$

$$I_{B2} = \beta I_{B1} = 286\,\mu A$$

$$I = \frac{15 - 0.2}{1K} = 14.8\,mA$$

$$V = 15 - 0.2 = 14.8\,V$$

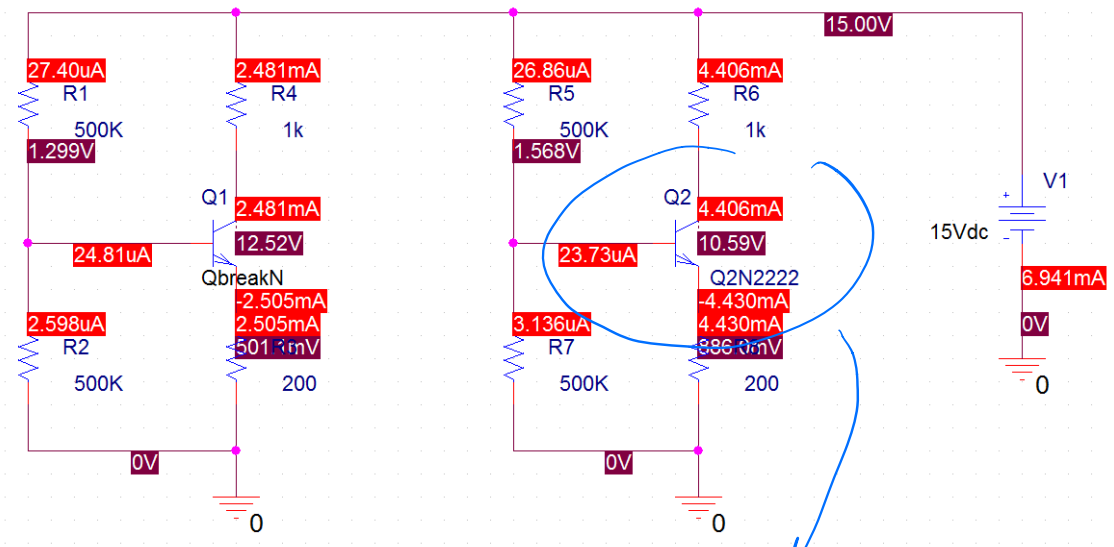
$V_{CE1} = 15 - 0.7 = 14.3V > 0.2V \longrightarrow$ Active

$I_{C1} = \beta I_{B1} = 286\,\mu A > 0 \longrightarrow$ Active

$I = I_{C_2} > 0A$, $\beta I_{B_2} = 85.8\,mA > I_{C_2} \longrightarrow$ Saturation

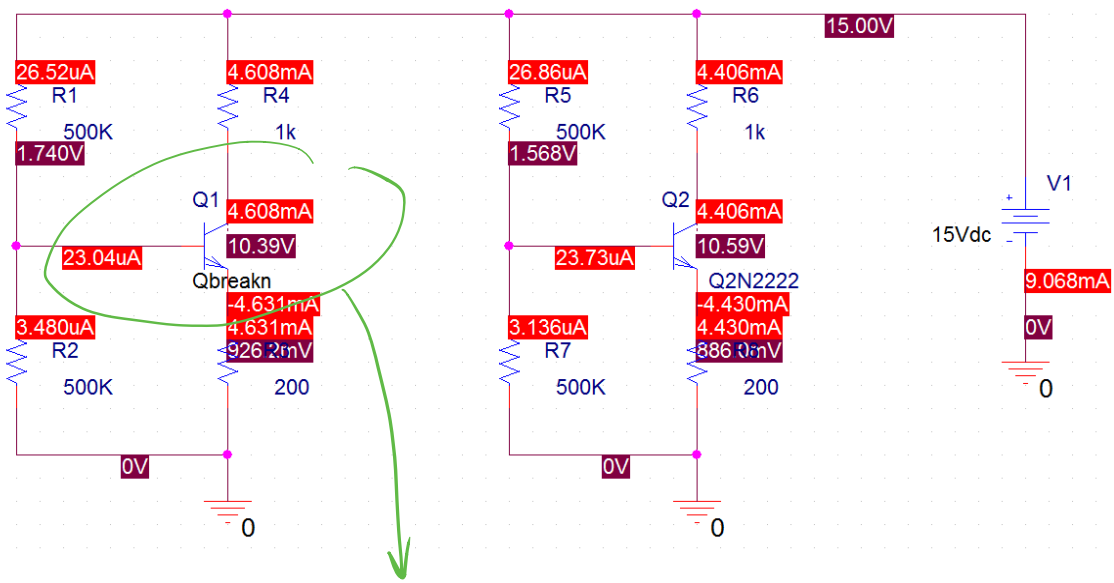
Problem (5)

(a)



$Q2N222: \quad \beta_2 = \frac{I_{C2}}{I_{B2}} = \frac{4.406mA}{23.73\mu A} = 185.67$

(b)



$QbreakN: \quad \beta_1 = \frac{I_{C1}}{I_{B1}} = \frac{4.608mA}{23.04\mu A} = 200$

(c)

	Qbreakn NPN	Q2N2222 NPN
IS	100.000000E-18	14.340000E-15
BF	200	255.9
NF	1	1
VAF		74.03
IKF		.2847
ISE		14.340000E-15
NE		1.307
BR	1	6.092
NR	1	1
RB		10
RC		1
CJE		22.010000E-12
MJE		.377
CJC		7.306000E-12
MJC		.3416
TF		411.100000E-12
XTF		3
VTF		1.7
ITF		.6
TR		46.910000E-09
XTB		1.5
CN	2.42	2.42
D	.87	.87

**** BIPOLAR JUNCTION TRANSISTORS

NAME	Q_Q1	Q_Q2
MODEL	Qbreakn	Q2N2222
IB	2.30E-05	2.37E-05
IC	4.61E-03	4.41E-03
VBE	8.14E-01	6.82E-01
VBC	-8.65E+00	-9.03E+00
VCE	9.47E+00	9.71E+00
BETADC	2.00E+02	1.86E+02
GM	1.78E-01	1.68E-01
RPI	1.12E+03	1.19E+03
RX	0.00E+00	1.00E+01
RO	1.00E+12	1.88E+04
CBE	0.00E+00	1.06E-10
CBC	0.00E+00	3.04E-12
CJS	0.00E+00	0.00E+00
BETAAC	2.00E+02	1.99E+02
CBX/CBX2	0.00E+00	0.00E+00
FT/FT2	2.84E+18	2.44E+08

(d)

Microsemi

TECHNICAL DATA SHEET

6 Lake Street, Lawrence, MA 01841
1-800-446-1158 / (978) 620-2600 / Fax: (978) 689-0803
Website: http: //www.microsemi.com

temperature

ELECTRICAL CHARACTERISTICS *(T_A = +25°C, unless otherwise noted)*

Parameters / Test Conditions		Symbol	Min.	Max.	Unit
ON CHARACTERISTICS (2)					
Forward-Current Transfer Ratio					
I_C = 0.1mAdc, V_{CE} = 10Vdc	2N2221A, L, UA, UB, UBC		30		
	2N2222A, L, UA, UB, UBC		50		
I_C = 1.0mAdc, V_{CE} = 10Vdc	2N2221A, L, UA, UB, UBC		35	150	
	2N2222A, L, UA, UB, UBC		75	325	
I_C = 10mAdc, V_{CE} = 10Vdc	2N2221A, L, UA, UB, UBC	h_{FE}	40		
	2N2222A, L, UA, UB, UBC		100		
I_C = 150mAdc, V_{CE} = 10Vdc	2N2221A, L, UA, UB, UBC		40	120	
	2N2222A, L, UA, UB, UBC		100	300	
I_C = 500mAdc, V_{CE} = 10Vdc	2N2221A, L, UA, UB, UBC		20		
	2N2222A, L, UA, UB, UBC		30		
Collector-Emitter Saturation Voltage					
I_C = 150mAdc, I_B = 15mAdc		$V_{CE(sat)}$		0.3	Vdc
I_C = 500mAdc, I_B = 50mAdc				1.0	
Base-Emitter Voltage					
I_C = 150mAdc, I_B = 15mAdc		$V_{BE(sat)}$	0.6	1.2	Vdc
I_C = 500mAdc, I_B = 50mAdc				2.0	

β

DC current gain

β ≥ 100

DYNAMIC CHARACTERISTICS

Parameters / Test Conditions		Symbol	Min.	Max.	Unit
Small-Signal Short-Circuit Forward Current Transfer Ratio					
I_C = 1.0mAdc, V_{CE} = 10Vdc, f = 1.0kHz	2N2221A, L, UA, UB, UBC	h_{fe}	30		
	2N2222A, L, UA, UB, UBC		50		
Magnitude of Small–Signal Short-Circuit Forward Current Transfer Ratio					
I_C = 20mAdc, V_{CE} = 20Vdc, f = 100MHz		$\lvert h_{fe} \rvert$	2.5		
Output Capacitance					
V_{CB} = 10Vdc, I_E = 0, 100kHz ≤ f ≤ 1.0MHz		C_{obo}		8.0	pF
Input Capacitance					
V_{EB} = 0.5Vdc, I_C = 0, 100kHz ≤ f ≤ 1.0MHz		C_{ibo}		25	pF

SWITCHING CHARACTERISTICS

Parameters / Test Conditions	Symbol	Min.	Max.	Unit
Turn-On Time See figure 8 of MIL-PRF-19500/255	t_{on}		35	ηs
Turn-Off Time See Figure 9 of MIL-PRF-19500/255	t_{off}		300	ηs

(2) Pulse Test: Pulse Width = 300μs, Duty Cycle ≤ 2.0%.