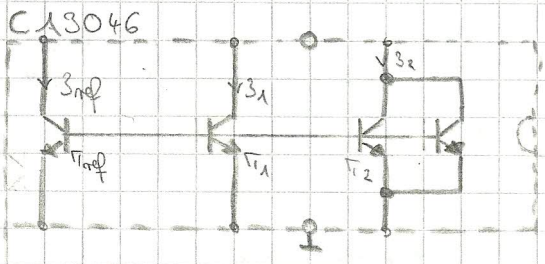
4.06.2011 4. Praktikum EL. Schaltungen: Stromspiegel und Differenzverstärker

① Stromspiegel



$I_{ref} : I_1 : I_2 = 1 : 1 : 2$

$I_{ref} : (I_1 + I_2) = 1 : 3$

1.1 Statisches Verhalten - Stromverhältnisse, Kennlinien und Innenwiderstand

$U_{BE} = 0{,}7V$; $B \gg 1$; $U_S = 15V$; $R = 15k$

$\rightarrow I_{ref} = \frac{U_S - U_{BE}}{R} = \frac{15V - 0{,}7V}{15k} = 953\mu A$

$S_1 = S_{ref} = 953\mu A$

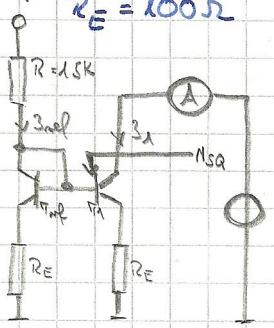
$S_2 = 2 \cdot S_{ref} = 1906{,}67\mu A = 1{,}91mA$

Kontrolle: $3 \cdot S_{ref} = S_1 + S_2 = 2{,}86mA$

1.2 U / I Kennlinie

I_{ref} = konst. ; $U_y \approx 50V$

$R_E = 100\Omega$



Fall a $R_E = 0$: $r_{SQ} = r_{CE1} = \frac{U_y}{|I_C^\circ|} = \frac{50V}{953\mu A} = 94{,}44k\Omega$ ($|I_C^\circ| = I_{ref}$)

Fall b $R_E = 100\Omega$: $r_{SQ} = r_{CE1} \cdot (1 + g_{m1} \cdot R_E)$

$r_{CE1} = 94{,}44k\Omega$

$g_{m1} = \frac{|I_C^\circ|}{U_T} = \frac{953\mu A}{26mV} = 36{,}65mS$

$\Rightarrow r_{SQ} = 94{,}44k\Omega (1 + 36{,}65mS \cdot 100\Omega) = 440{,}56k\Omega$

Simulation: $r_{SQ}(R_E = 0) = 96{,}80k\Omega$ ($\rightarrow \frac{\Delta U}{\Delta I}$)

$r_{SQ}(R_E = 100\Omega) = 420{,}17k\Omega$ ($\rightarrow \frac{\Delta U}{\Delta I}$)

② Differenzverstärker

2.1 Grundschaltung des Differenzverstärkers

2.1.1 Arbeitspunkte

A) Form 1 $U_{1a} = U_{1b} = 0$; $|U_{BE}^\circ| = 0{,}7V$; $R_{E1} = 3{,}9k\Omega$, $R_C = 2{,}7k\Omega$

$U_{BE} = 0{,}7V \Rightarrow \varphi_3 = -0{,}7V$ ③

$U_{RE1} = \varphi_3 - U_S = -0{,}7V - (-5V) = 4{,}3V$

$I_{RE1} = \frac{U_{RE1}}{R_{E1}} = \frac{4{,}3V}{3{,}9k\Omega} = 1{,}10mA$

$T_1 = T_2$ und beide haben R_C $\rightarrow$ $S_{C1} = S_{C2} = S_{RE1} \cdot 1/2 = 0{,}55mA$

$\rightarrow U_{RC} = R_C \cdot S_{RC} = 2{,}7k\Omega \cdot 0{,}55mA = 1{,}485V$

$\rightarrow \varphi_{1/2} = U_S - U_{RC} = 5V - 1{,}485 = 3{,}515V$ ① ②

3) Trans B $u_{1a} = u_{1b} = 0V$; $|u_{BE}^{\circ}| = 0{,}7V$; $I_{C3} = I_{RE}$; $u_{Y(UPM)} = 80V$

$u_{BE} = 0{,}7V \rightarrow \varphi_3 = -0{,}7V$ (3)

$r_{3Q} = r_{CE}\left(1 + g_m \cdot R_{E2}\right) = \frac{u_Y}{|I_C^{\circ}|}\left(1 + \frac{|I_C^{\circ}|}{u_T} \cdot R_{E2}\right) = \frac{80V}{1{,}10mA}\left(1 + \frac{1{,}1mA}{26mV} \cdot 470\Omega\right)$

($r_{CE} = \frac{u_Y}{|I_C^{\circ}|}$, $|I_C^{\circ}| = I_{RE}$, $g_m = \frac{|I_C^{\circ}|}{u_T}$, $T_3 = NPN$)

$= 1\,518{,}88\,k\Omega \approx \underline{1{,}519M\Omega}$

$u_{RE2} = R_{E2} \cdot \underbrace{I_{C3}}_{=I_{RE}} = 470\Omega \cdot 1{,}1mA = 0{,}517V = \underline{517mV}$

$\varphi_5 = u_{RE2} + u_5 = 517mV - 5V = \underline{-4{,}483V}$

$\varphi_4 = \varphi_5 + u_{BE} = -4{,}483V + 0{,}7V = \underline{-3{,}783V}$

$T_1 = T_2$ mit gleichen R_C $\rightarrow I_{2a} = I_{2a} = 1/2\, I_{C3} = \underline{0{,}55mA}$ $\Rightarrow \varphi_{V2} = \underline{3{,}515V}$ (1)(2) (Spalte Trans A)

2.1.2 Differenzverstärker

a) Gleichsignalverhalten

$A_{Da} = u_{2a}/(u_{1a} - u_{1b})$ $\quad A_D = (u_{2a} - u_{2b})/(u_{1a} - u_{1b})$

$u_{1a} = 10mV$; $u_{1b} = -10mV$

$\varphi_3 = konst. = -0{,}7V \rightarrow I_{RE} = konst. = 1{,}1mA$

$A_{Da} = \frac{u_{2a}}{u_{1a} - u_{1b}} = \frac{u_{2a}}{2u_{1D}} = -\frac{1}{2} g_{m1} \cdot r_{a1}' = -\frac{1}{2} g_{m1} \cdot \underbrace{r_a}_{=R_C} \| r_{CE} = \frac{1}{2} \frac{|I_C^{\circ}|}{u_T} \cdot R_C \| \frac{u_Y}{\underbrace{|I_C^{\circ}|}_{0{,}55mA}} = \underline{-28{,}0322}$

$\hookrightarrow \frac{u_Y}{|I_C^{\circ}|} = \frac{80V}{0{,}55mA} = 145{,}455k\Omega$

$A_{Db} = -A_{Da} = \underline{+28{,}0322}$

$A_D = \frac{u_2}{u_{1D}} = -g_{m1} \cdot r_{a1}' = -2 \cdot A_{Da} = \underline{-56{,}064}$

$u_{2a} = A_{Da} \cdot 2u_1 = \underline{-560{,}64mV}$

$u_{2b} = -u_{2a} = \underline{+560{,}6mV}$

b) Großsignalverhalten (Kein Trans B)

Differenzeingangsspannung mehr als 100mV $\rightarrow$ ein Transistor leitet voll, der andere sperrt!

$\rightarrow \underline{T_1 \text{ leitet voll } T_2 \text{ gesperrt}} \rightarrow \underline{\varphi_2 = +5V} \Rightarrow \varphi_1 = u_5 - R_C \cdot \underbrace{I_{RE}}_{\hookrightarrow = I_{C3}} = 5V - 2{,}7k\Omega \cdot 1{,}1mA = \underline{2{,}03V}$

$\varphi_{1min} = \varphi_{2min} = 2{,}03V$ $\quad \varphi_{2max} = \varphi_{1max} = 5V$

2.1.3 Gleichtaktverstärkung und Gleichtaktunterdrückung

$u_{1a} = u_{1b} = u_{1G} = 500\,mV$

$A_{Ga} = \frac{u_{2a}}{u_{1G}}$; $A_{CM12} = \frac{A_{Da}}{A_{Ga}}$ $\quad a_{CM12} = 20\,lg\,|A_{CM12(as)}|$

From A

$$A_{Ga} = \frac{u_{2a}}{u_{1G}} = \frac{-g_{m1} \cdot r_a'}{1 + 2 \cdot g_{m1} \cdot R_E} \quad (r_a' = R_C \text{ aus } 2.1.2)$$

$$= \frac{-0,2115\,S \cdot 2,7\,k\Omega}{1 + R \cdot 0,2\,mS \cdot 3,912\,\Omega} = -0,844$$

$u_{2a} = A_{Ga} \cdot u_{1G} = -3,44 \cdot 500\,mV = -172,03\,mV$

$u_{2b} = -u_{2a} = +172,03\,mV$

$A_{CM12(a)} = \frac{A_{Da}}{A_{Ga}} = \frac{-28,032}{-0,344} = 81,48$

$a_{CM12(a)} = 20\,lg\,|A_{CM12(a)}| = 38,22$

$u_{Netz} = 500\,mV = u_{1a} = u_{1b}$

From B

$$A_{Ga} = \frac{-g_{m1} \cdot r_a}{1 + 2 \cdot g_{m1} \cdot r_{sa}} = -888,7 \cdot 10^{-6}$$

$\rightarrow 1,5\,M\Omega$ aus 2.1.1

$u_{2a} = +0,444\,mV$ $\quad \rightarrow u_{2b} = +0,444\,mV$

$A_{CM12(a)} = 31542,7$

$a_{CM12(a)} = 89,98$

2.1.4 Netzteil bei einseitiger Ansteuerung $u_{1a} = 10\,mV$ $\quad u_{1b} = 0\,V$

Gleichteil:

$A_{GLa} = -0,344 = \frac{u'_{2a}}{u_{1G}}$

$u_{1a} = u_{1b} = 5\,mV$

$u_{1G} = \frac{u_{1a} + u_{1b}}{2} = 5\,mV$

$\Rightarrow u'_{2a} = A_{GLa} \cdot u_{1G} = u'_{2b} = -1,72\,mV$

Gegentakt: $u_{1a} = -u_{1b} = 5\,mV$

$A_{Da} = -28,032$ $\quad (2.1.2)$ $\quad u_{1D} = u_{1a} - u_{1b} = +10\,mV$

$\Rightarrow u''_{2a} = A_{Da} \cdot u_{1D} = -u''_{2b} = -280,32\,mV$

Superposition: $u_{2a} = u'_{2a} + u''_{2a} = -282,04\,mV$

$u_{2b} = u_{2b} + u_{2b} = +278,6\,mV$

$u_{Netz} = u'_{Netz} + u'_{Netz} = 0V + 5V = 5\,mV$

2.2 Differenzverstärker mit Transistorquelle und Stromspiegel

2.2.1 Arbeitspunkt

$A_V = i_2 (u_{1a}/u_{1b}) = i_2/u_{1D} = g_{m1} = g_{m2}$

$I_{C3} = 1{,}1\,mA$ $\quad u_{1a} = u_{1b} = 0\,V$

$\Rightarrow I_{C3} = I_{RE2} \quad \Rightarrow \beta_1 = \beta_2 = \beta_{C3}/2 = 0{,}55\,mA$

$u_{2RE} = R_{E2} \cdot I_{C3} = 470\,\Omega \cdot 1{,}1\,mA = 517\,mV$

$\varphi_5 = u_5 + u_{2RE2} = -4{,}483\,V$

$\varphi_4 = \varphi_5 \mp u_{BE} = -3{,}783$

$\varphi_3 = 0 + u_{BE} = -0{,}7\,V$

$\varphi_1 = u_5 + u_{BE} = 4{,}3\,V = \;?$

$\varphi_2 = xxx$

2.2.2 Kleinsignalverhalten, Differenzverstärkung bei externer Last von 100 kΩ

$A_D = \dfrac{u_2}{u_{1a} - u_{1b}}$

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$r_a' = r_{CE5} \,//\, r_{CE2} \,//\, (R_{L1} \oplus R_{L2}) = \dfrac{u_{Y5}}{i_C^0} \,||\, \dfrac{u_{Y2}}{i_C^0} \,||\, (R_{L1} \oplus R_{L2}) = \dfrac{70\,V}{0{,}55\,mA} \,||\, \dfrac{80\,V}{0{,}55\,mA} \,||\, 100\,k\Omega$

$= 127{,}273\,k\Omega \,||\, 145{,}455\,k\Omega \,||\, 100\,k\Omega = 40{,}433\,k\Omega$

$A_D = -g_m \cdot r_a' = -855{,}318$

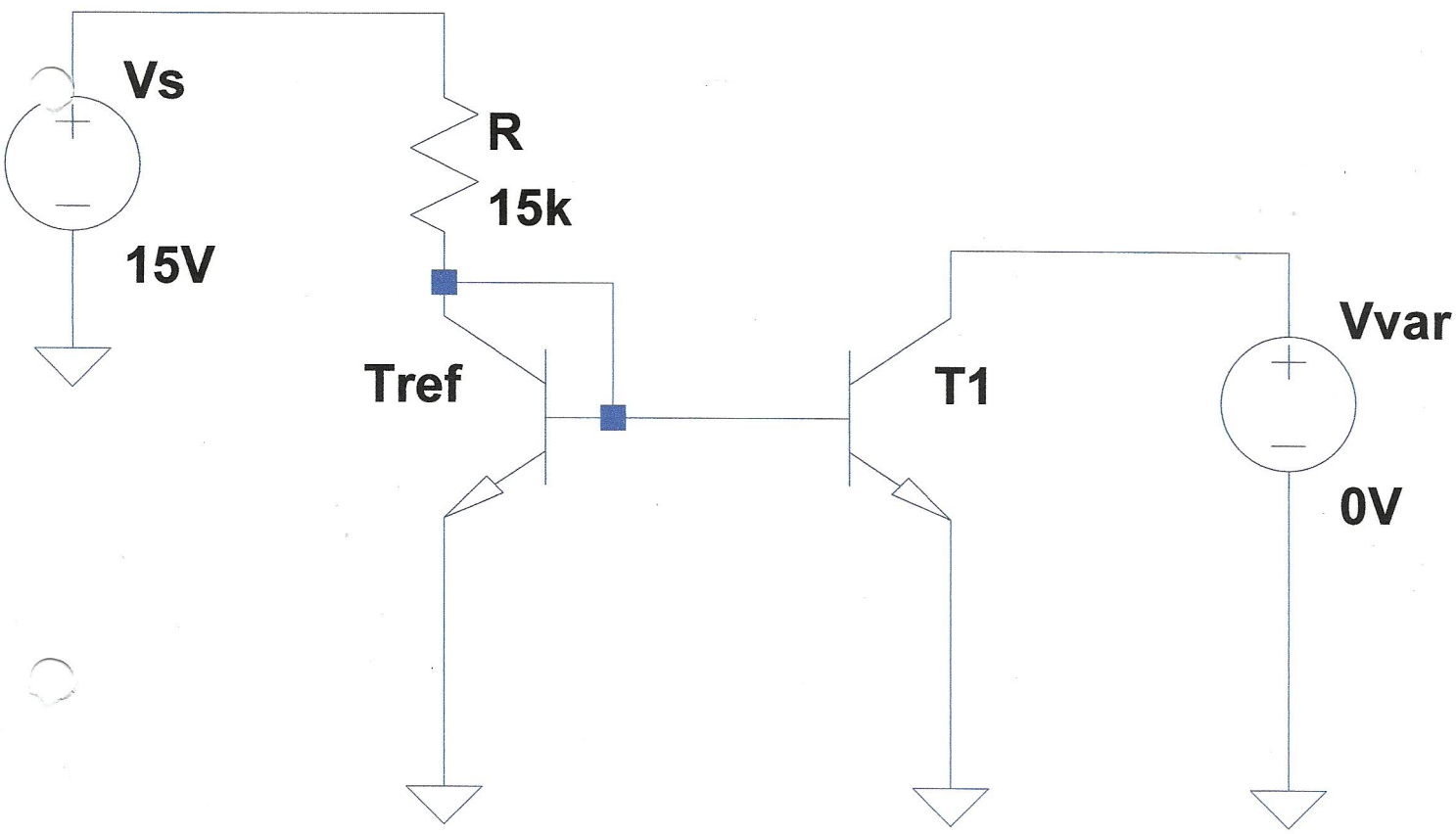
$a_D = 58{,}643\,dB$

2.2.3 Großsignalaussteuerung und Slew Rate

$SR = \dfrac{2 \cdot I_C^0}{C_L} = \dfrac{1{,}1\,mA}{1{,}0\,nF} = 1{,}1\,\dfrac{V}{\mu s}$

Der maximale Ausgangsstrom bei Übersteuerung beträgt 1,1 mA

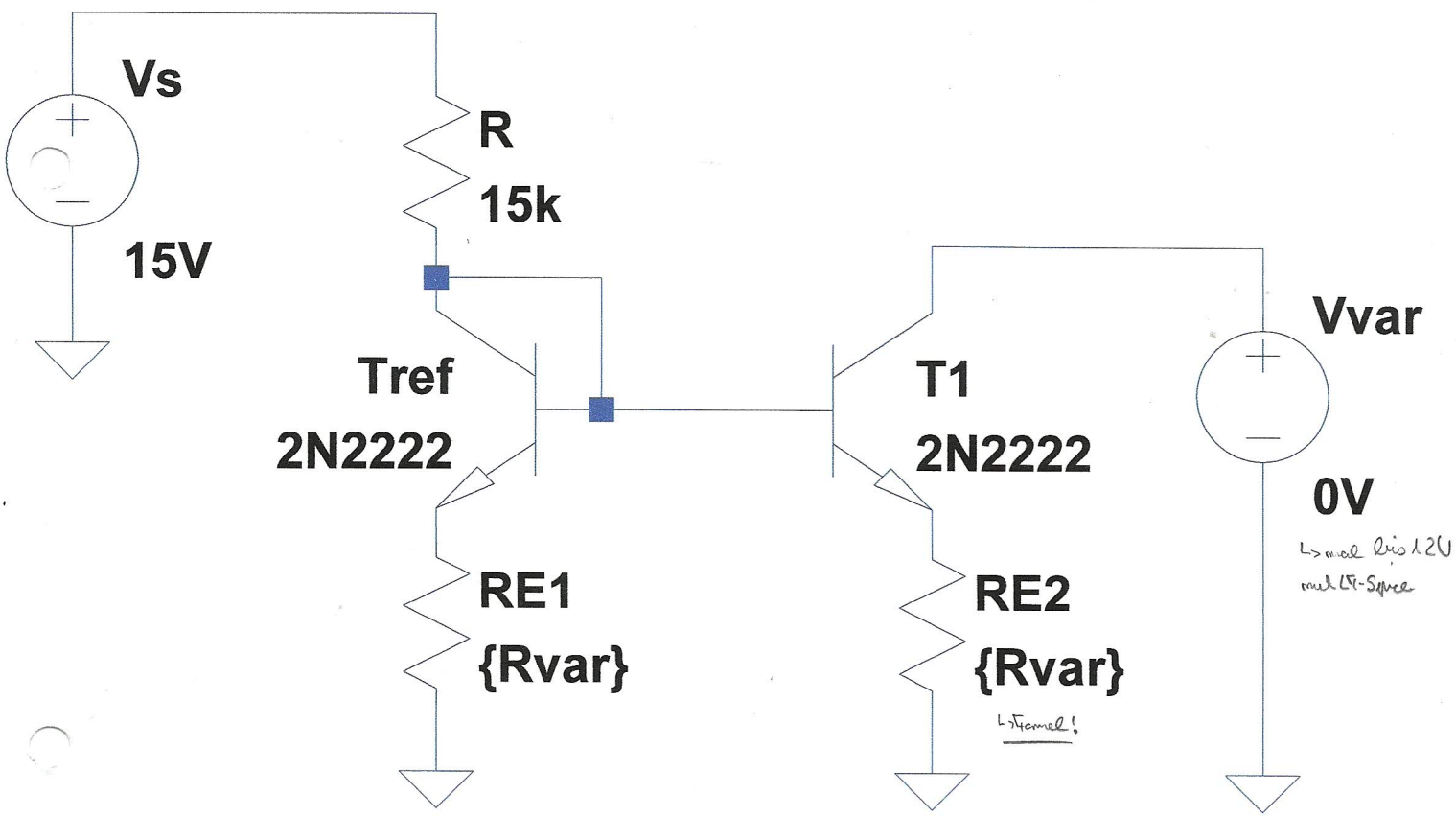
Praktikum El. Schaltungen Versuch 4
Aufgabe 1.2 a



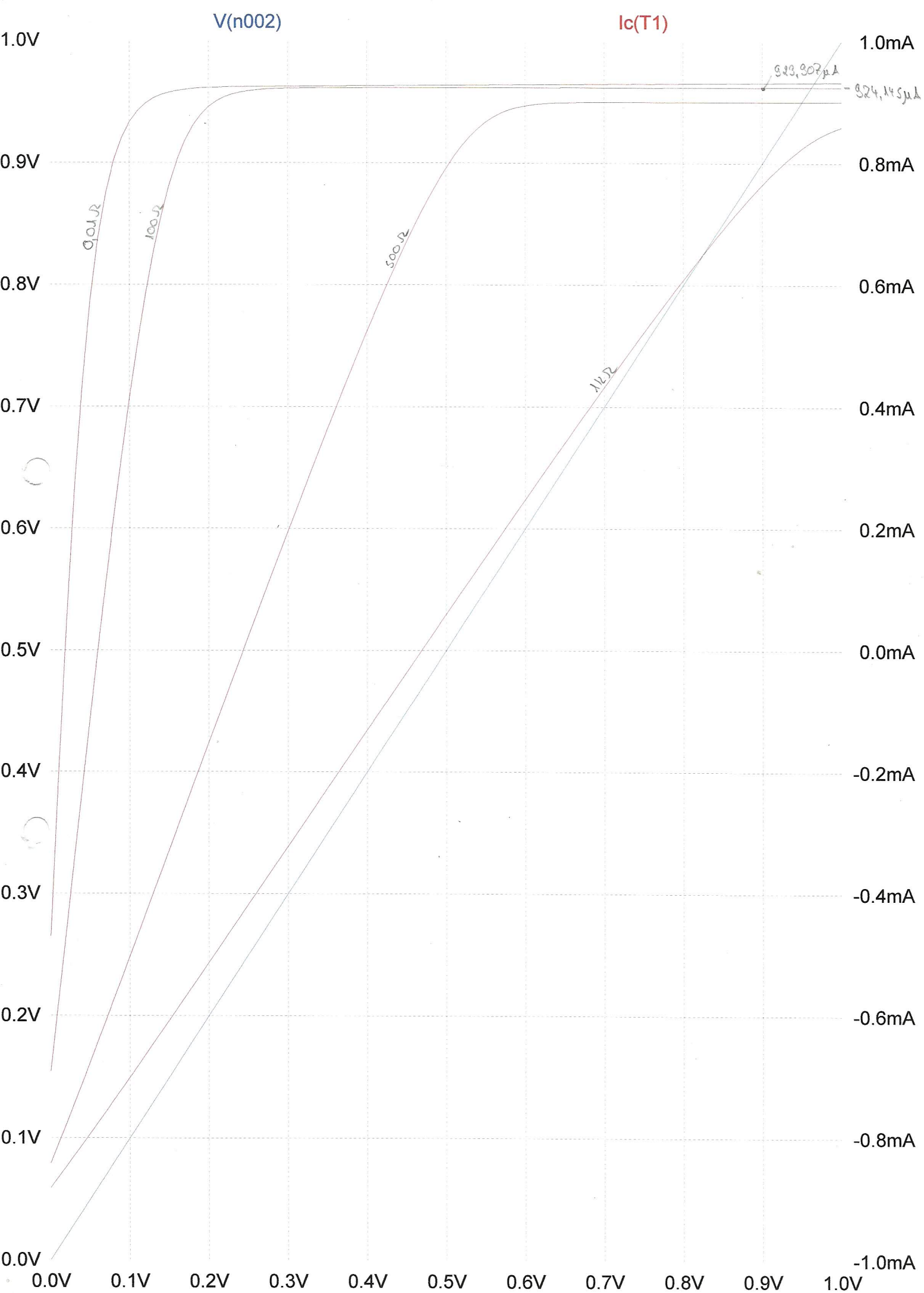
.dc Vvar 0 1 10mV
.model 2N2222 NPN(VAF=90)


V(n002)
Ic(T1)
1.5V
1.4V
1.3V
1.2V
1.1V
1.0V
0.9V
0.8V
0.7V
0.6V
0.5V
0.4V
0.3V
0.2V
0.1V
0.0V
1.0mA
0.9mA
0.8mA
0.7mA
0.6mA
0.5mA
0.4mA
0.3mA
0.2mA
0.1mA
0.0mA
-0.1mA
-0.2mA
-0.3mA
-0.4mA
-0.5mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V

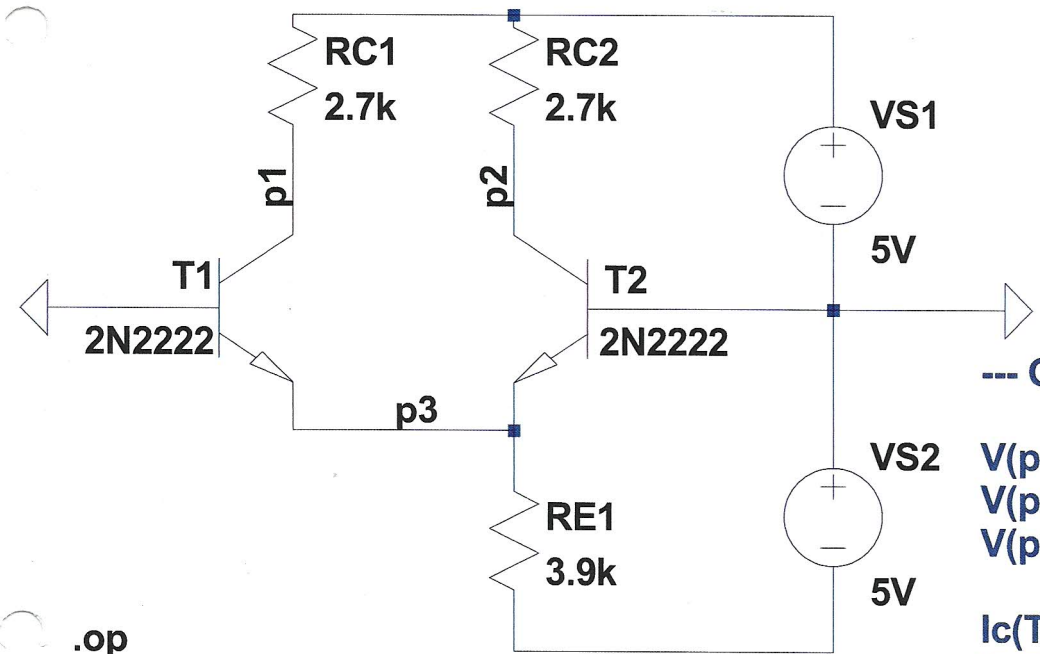
Praktikum El. Schaltungen Versuch 4
Aufgabe 1.2 b




```
.dc Vvar 0 1 10mV
.model 2N2222 NPN(VAF=90)
.param Rvar = 0
.step param Rvar list 0.01 100 500 1k
```


V(n002)
Ic(T1)
1.0V
0.9V
0.8V
0.7V
0.6V
0.5V
0.4V
0.3V
0.2V
0.1V
0.0V
1.0mA
0.8mA
0.6mA
0.4mA
0.2mA
0.0mA
-0.2mA
-0.4mA
-0.6mA
-0.8mA
-1.0mA
0.0V
0.1V
0.2V
0.3V
0.4V
0.5V
0.6V
0.7V
0.8V
0.9V
1.0V
0,01Ω
100Ω
500Ω
1kΩ
923,907µA
924,145µA

Praktikum El. Schaltungen Versuch 4
Aufgabe 2.1 Form A



.op

.model 2N2222 NPN(VAF=80)

--- Operating Point ---

V(p1):	3.54524 V
V(p2):	3.54524 V
V(p3):	-0.757115 V
Ic(T1):	0.5388 mA
Ic(T2):	0.5388 mA
I(Re1):	1.08792 mA

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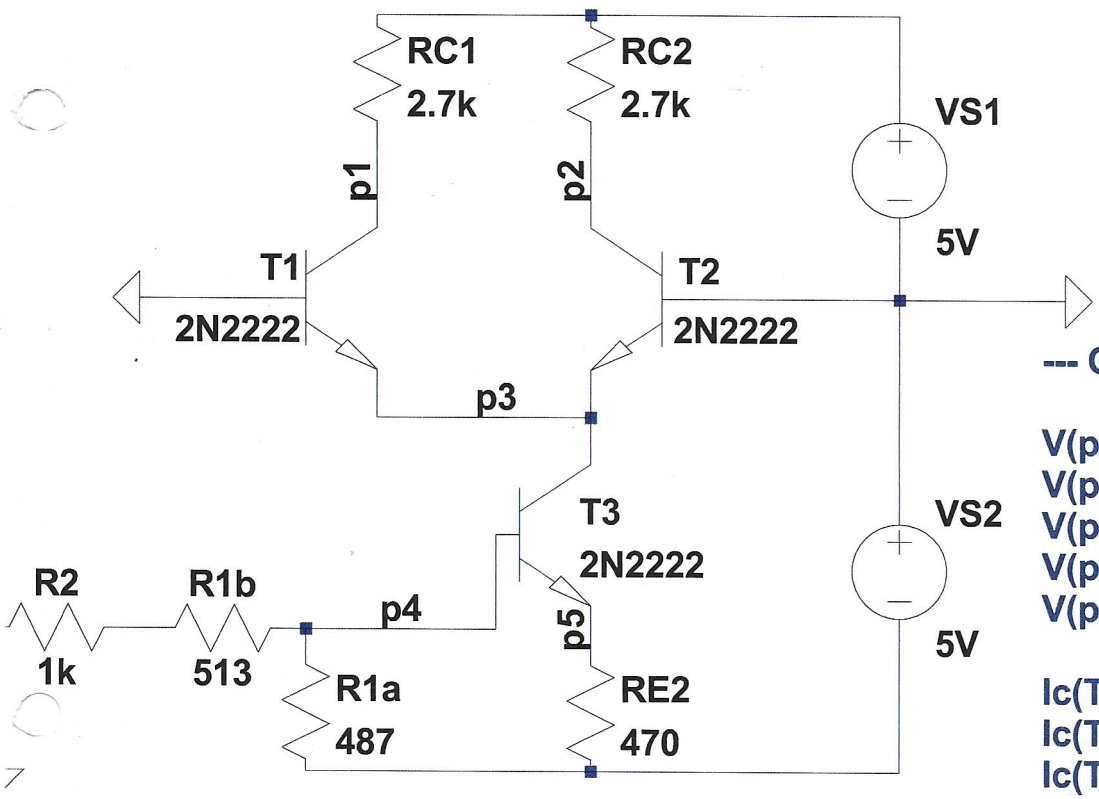
Praktikum El. Schaltungen Versuch 4
Aufgabe 2.1 Form B



--- Operating Point ---

V(p1):	3.75243 V
V(p2):	3.75243 V
V(p3):	-0.75307 V
V(p4):	-3.78581 V
V(p5):	-4.55729 V
Ic(T1):	0.462065 mA
Ic(T2):	0.462065 mA
Ic(T3):	0.932957 mA

```
.op
.model 2N2222 NPN(VAF=80)
```