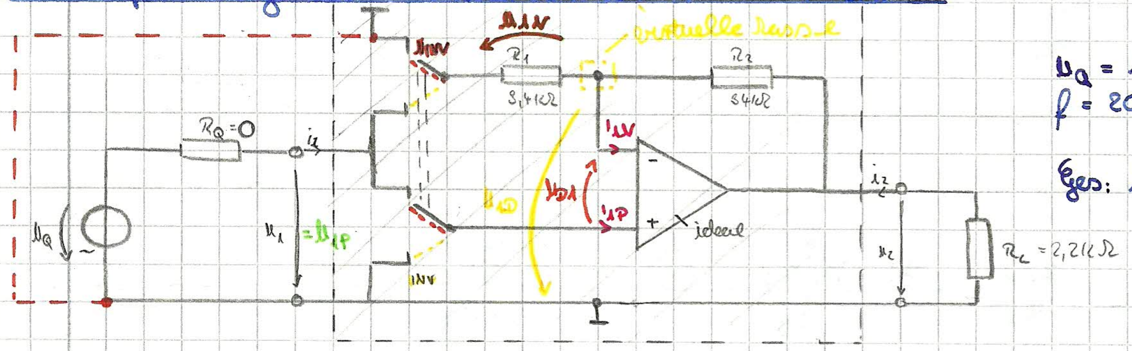
14.05.2011 1. Praktikum El. Schaltungen: OPV in Schaltungen

## ① OPV in N-INV und INV Schaltung

### 1.1 Prinzipschaltungen des INV Verstärkers und des N-INV-Verstärkers




$U_Q = 100\,mV$; $R_Q = 0$
$f = 200\,Hz$; $R_L = 2,2\,k\Omega$

Ges.: $A_U = \frac{U_2}{U_1}$; $U_{1N} = ?$

**NINV-OPV**

$$U_2 = U_1\left(1 + \frac{R_2}{R_1}\right) \quad \rightarrow A_U^N = \frac{U_2}{U_1} = \frac{U_2}{U_Q} = 1 + \frac{R_2}{R_1} = 1 + \frac{34\,k\Omega}{3,4\,k\Omega} = \underline{\underline{11}}$$

$U_{1N}$ → $U_2$ stellt sich so ein, dass $U_{1D} = 0$ wird ⇒ $U_{1N} = U_{1P} = U_1 = U_Q = \underline{\underline{100\,mV}}$

**INV-OPV**

$$U_2 = -U_1 \frac{R_2}{R_1}\ ; \quad U_1 = U_Q \cdot \frac{R_1}{R_1 + R_Q} \quad\quad U_2 = -U_Q \cdot \frac{R_1}{R_1 + R_Q} \cdot \frac{R_2}{R_1} \quad\quad A_U^I = -\frac{R_2}{R_1}$$

$$A_U^I = -\frac{R_2}{R_1} = \frac{-34\,k\Omega}{3,4\,k\Omega} = \underline{\underline{-10}}$$

$U_{1N}$ → virtuelle Masse auf reale Masse → $U_{1D} = 0\,V$ (da $A_{UD} \rightarrow \infty$) ⇒ $U_{1N} \triangleq 0$
(→ Spannungsverstärkungsmaß)

Messungen: $U_1$ direkt an $U_Q$ messen; $U_2$ direkt an $R_L$ messen → Teilen ; $U_{1N}$ direkt an $R_1$ messen

### 1.2 Erweiterte Prinzipschaltung des N-INV Verstärkers → OPV ideal

Änderung? von $A_U = \frac{U_2}{U_1}$

A und B: $I_{1N} = I_{1P} \overset{\text{ideal}}{=} 0$ ⇒ keine Spannung fällt ab → $A_U$ ändert sich nicht
↓
C: ist auch egal; (außerdem $U_2$ stellt so ein, dass $U_{1D} = 0$)

↯ D: $R_1 \parallel R_2 = R_{1neu} = \frac{R_1 \cdot R_2}{R_1 + R_2} = \frac{3,4 \cdot 6,8}{3,4 + 6,8} = 2,2\overline{6}\,k\Omega$ → $A_U = 1 + \frac{R_2}{R_{1neu}} = \underline{\underline{16}}$

E: $A_U$ ändert nicht, da OPV so regelt dass Stromstärke (in dem Falle höher) → E irrelevant ($A_U \triangleq$ Stromquelle)

↯ F: 

Spannungsteiler ⇨ $U_{2vi} = U_1 \cdot \left(1 + \frac{R_2 + R_L}{R_1}\right) = 100\,mV \cdot \left(1 + \frac{3\,k\Omega}{3,4\,k\Omega}\right) = \underline{364\,mV}$

$U_2 = \frac{R_L}{R_2 + R_L} \cdot U_{2vi} = 89,150\,mV$ ↯

? $A_U = A_U^{II\,\text{(alte)}}\left(\frac{R_L}{R_L + R_2}\right) = 11 \cdot \left(\frac{2,2}{9}\right) = 2,688$

## 1.3 Einfluss des Signal-Quellen-Widerstandes auf die Spannungsverstärkung

$R_Q \neq 0$; $u_Q = 100\,mV$; $f = 200\,Hz$

$A_{uQ} = ? = \frac{u_2}{u_Q}$

NINV: $A_{uQ}$ ändert sich nicht $A_{uQ} = A_u$, da OPV ideal -> $I_{1P} = 0$ -> $I_{RQ} = 0$ -> $I_Q = 0$ => $A_u$ ändert sich nicht

INV: $A_{uQ}$ ändert sich, da $R_Q$ an $R_1$ -> Spannungsteilerverhältnis ändert sich ($A_u' = \frac{u_2}{u_1}$ bleibt konstant!)

$$A_{uQ} = \frac{u_2}{u_Q} = \frac{-u_Q \frac{R_1}{R_1 + R_Q} \cdot \frac{R_2}{R_1}}{u_Q} = \frac{R_2}{R_1 + \underbrace{R_Q}_{=10\,k\Omega}} = \frac{34\,k\Omega}{3{,}4\,k\Omega + 10\,k\Omega} = -2{,}537$$

## 1.4 Einfluss des Lastwiderstandes

$R_L = 2{,}2\,k\Omega$; $u_2 = 5{,}0\,V$; $r_{2OPV}$ bzw. $r_{2NINV} = 1\,k\Omega$ OPV ($\hat{=}$ INV) NINV ideal!

NINV: ~~$u_1 = u_2 = 5{,}0\,V$~~

$i_{r2} = \frac{u_2}{R_L} = \frac{5{,}0\,V}{2{,}2\,k\Omega} = 2{,}272\,mA$

$u_{r2} = r_{2N-INV} \cdot i_{r2} = 2{,}272\,V$

$u_\Delta = u_2 + u_{r2} = 7{,}272\,V$

$u_1 = \frac{u_\Delta}{(1 + R_2/R_1)} = \frac{7{,}272\,V}{(1+10)} = 661{,}090\,mV \approx 661\,mV$

$\frac{u_2}{u_\Delta} = \frac{5{,}0\,V}{7{,}272\,V} = 0{,}687$

$\frac{u_2}{u_1} = \frac{5{,}0\,V}{0{,}661\,V} = 7{,}564$

~~OPV~~ NINV:

$i_{r2} = \frac{u_2}{R_L \,\|\, (R_2 \oplus R_1)} = \frac{5\,V}{2{,}2\,k\Omega \,\|\, 37{,}4\,k\Omega} = 2{,}406\,mA$

$u_{r2} = i_{r2} \cdot r_{2OPV} = 2{,}406\,V$

$u_\Delta = -u_{r2} - u_2 = -7{,}406\,V$

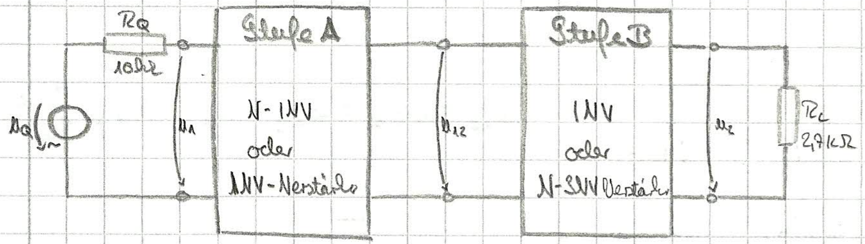
ϟ $u_1 = -u_2 \cdot \frac{R_1}{R_2} = -0{,}5\,V$

$\frac{u_2}{u_\Delta} = \frac{5\,V}{-7{,}406\,V} = -0{,}676$

ϟ $\frac{u_2}{u_1} = \frac{5\,V}{-0{,}5\,V} = -10$

## ② Mehrstufige Verstärker

### 2.1 N-INV und INV-Verstärker in wechselnder Reihenfolge




$R_1 = 3{,}4\,k\Omega$
$R_2 = 34\,k\Omega$

**1.) Fall:** A: N-INV → B INV

$\frac{u_1}{u_Q} = 1$ da N-INV am Anfang $\rightarrow u_1 = u_Q$

$\frac{u_{12}}{u_1} = 1 + \frac{R_2}{R_1} = 11$

$\frac{u_2}{u_{12}} = -\frac{R_2}{R_1} = -10$

$\frac{u_2}{u_Q} = \frac{u_2}{u_1} = \frac{u_{12}}{u_1} \cdot \frac{u_2}{u_{12}} = 11 \cdot -10 = -110$

**2.) Fall:** A: INV → B: N-INV

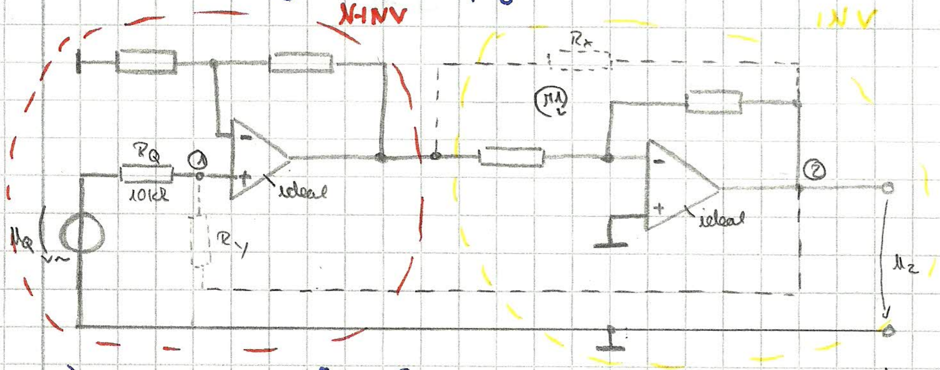
$u_1/u_Q = \frac{u_Q}{u_Q} \cdot \frac{R_1}{R_1 + R_Q} = \frac{R_1}{R_1 + R_Q} = \frac{3{,}4\,k\Omega}{3{,}4\,k\Omega + 10\,k\Omega} = 0{,}253$

$\frac{u_{12}}{u_1} = -10$

$\frac{u_2}{u_{12}} = 11$

$\frac{u_2}{u_Q} = \frac{u_1}{u_Q} \cdot \frac{u_{12}}{u_1} \cdot \frac{u_2}{u_{12}} = 0{,}253 \cdot (-10) \cdot 11 = -27{,}910$

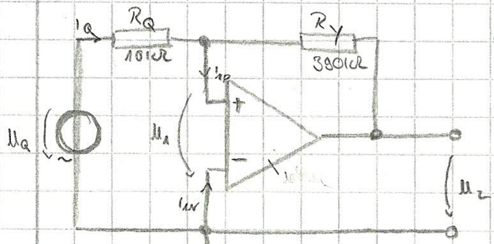
### 2.2 Erweiterte Schaltung des zweistufigen Verstärkers




$R_x = R_y = 390\,k\Omega$

1.) $R_x$-Einfluss auf $\frac{u_2}{u_Q}$? Nein, da $I_{1P} = I_{1N} = 0 \rightarrow I_{R1} = -I_{R2} \Rightarrow$ M1: $\underbrace{u_1 + u_2}_{=0} + u_{Rx} = 0 \rightarrow u_{Rx} = 0$

2.) $R_y$ eingebaut! → Invertierender Verstärker! $u_Q = 0{,}1V$; $R_Q = 10\,k\Omega$; $R_y = 390\,k\Omega$




$A_u = A_U^I \cdot A_u^N = 10 \cdot -11 = -110$

$u_2 = A_U \cdot u_1 = A_U \cdot (u_Q - u_{RQ}) = A_U (u_Q - R_Q \cdot I_Q) = -2{,}860V$ (mit $I_Q = 7{,}4\,\mu A$)

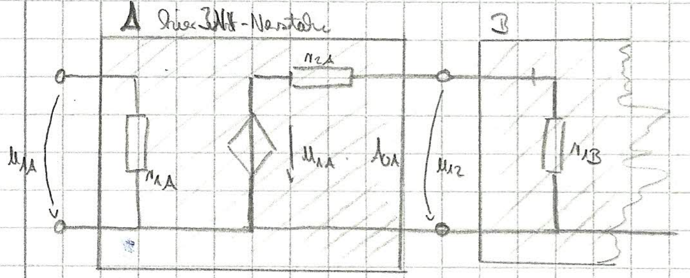
$I_{1N} = I_{1P} = 0 \rightarrow I_Q = \frac{u_Q - u_2}{R_Q + R_y} = \frac{u_Q - A_U (u_Q - R_Q \cdot I_Q)}{R_Q + R_y} = \frac{u_Q - A_U \cdot u_Q}{R_y + R_Q(-A_U + 1)}$

$= \frac{0{,}1V + (+110) \cdot 0{,}1}{390\,k\Omega + 10\,k\Omega \cdot (+110 + 1)} = 7{,}4\,\mu A$

$\frac{u_2}{u_Q} = \frac{-2{,}860V}{0{,}1V} = -28{,}6$

## 2.3 Einfluss der endlichen Eingangs- und Ausgangswiderstände

### 2.3.1 Direkte Verbindung zwischen den Stufen




$$u_{12} = u_{2A} = u_{1B} = u_{1A} \cdot A_{0A} \cdot \frac{r_{1B}}{r_{1B} + r_{2A}}$$

**1.) Fall** A: N-INV B: INV

a) $r_{2A} = 0$

$$\Rightarrow u_{12} = \underbrace{u_{1A}}_{=u_1} \cdot A_{0A} \cdot \overbrace{\frac{r_{1B}}{r_{1B} + \underbrace{r_{2A}}_{=0}}}^{=1} = u_1 \cdot \left(1 + \frac{R_2}{R_1}\right)$$

$$u_2 = -u_{12} \frac{R_2}{R_1}$$

$$\Rightarrow \frac{u_2}{u_1} = \frac{-u_{12} \frac{R_2}{R_1}}{u_1} = \frac{-(u_1)\left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_2}{R_1}\right)}{u_1} = -\underbrace{\left(1 + \frac{R_2}{R_1}\right)}_{A_0^N} \cdot \underbrace{\left(\frac{R_2}{R_1}\right)}_{A_0^I} = 11 \cdot (-10) = -110$$

b) $r_{2A} = 1 k\Omega$ ; $r_{1B} \mathrel{\hat{=}} R_1$

$$\Rightarrow u_{12} = u_{1A} \cdot A_{0A} \cdot \frac{r_{1B}}{r_{1B} + r_{2A}} = u_1 \cdot \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_1}{R_1 + r_{2A}}\right)$$

$$\Rightarrow \frac{u_2}{u_1} = -\left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_2}{R_1}\right)\left(\frac{R_1}{R_1 + r_{2A}}\right) = \underbrace{A_0}_{-110} \cdot \left(\frac{3,4}{3,4+1}\right) = -85$$

**2.) Fall** A: N-INV B: N-INV

a) $r_{2A} = 0$

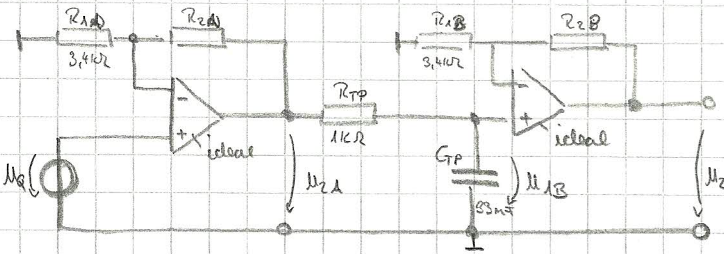
$$\left.\begin{aligned} &\Rightarrow u_{12} = u_1 \left(1 + \frac{R_2}{R_1}\right) \\ &u_2 = u_{12}\left(1 + \frac{R_2}{R_1}\right) \end{aligned}\right\} \Rightarrow \frac{u_2}{u_1} = \left(1 + \frac{R_2}{R_1}\right)\left(1 + \frac{R_2}{R_1}\right) = 121$$

b) $r_{2A} = 1 k\Omega$

$$\left.\begin{aligned} &\Rightarrow u_{12} = u_1 \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_1}{R_1 + r_{2A}}\right) \\ &u_2 = u_{12} \quad \text{—"—} \end{aligned}\right\} \frac{u_2}{u_1} = \left(1 + \frac{R_2}{R_1}\right)^2 \left(\frac{3,4}{4,4}\right)^2 = 93,5$$

## 2.3.2 RC-Tiefpass zwischen den Stufen

**1.) Variante** A: N-INV B N-INV $r_{2A}=0$



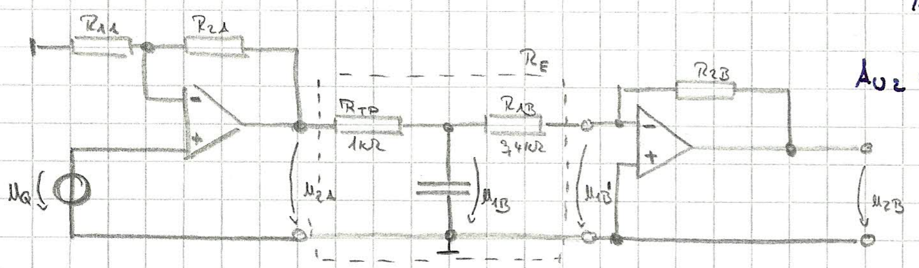

$A_{u0}(f)=\frac{u_2}{u_Q}=\underline{121}$ (Aufgabe 2.3.1)

$a_{u0}=20\lg|A_{u0}|=20\lg|121|=\underline{41{,}655\,dB}$

$f_G(RC\text{-Tiefpass})=\frac{1}{2\pi RC}=\frac{1}{2\pi R_{TP}\cdot C_{TP}}$

$=\frac{1}{2\pi\cdot 1k\Omega\cdot 33nF}=\underline{\underline{4{,}823\,kHz}}$

**2.) Variante** A: N-INV B: INV $r_{2A}=0$




$R_E=R_{TP}\,\|\,R_{1B}=1k\Omega\,\|\,3{,}41k\Omega=\underline{0{,}773k\Omega}$

$A_{u2}=\frac{u_2}{u_Q}=A_{uA}\cdot A_{uB}\cdot\frac{r_{1B}}{r_{1B}+r_{2A}}$

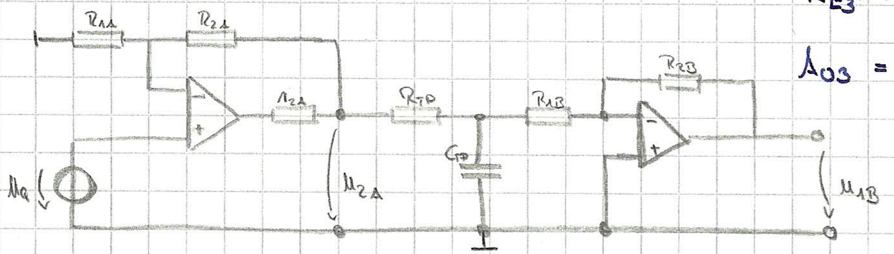
$=A_{uA}\cdot A_{uB}\cdot\frac{R_{1B}}{R_{1B}+R_{TP}}=-110\cdot 0{,}773$

$=\underline{\underline{-85}}$

$a_{u2}=20\lg|A_{u2}|=20\lg|85|=\underline{38{,}588}$

$f_G=\frac{1}{R_E\,2\pi\cdot C_{TP}}=\frac{1}{0{,}773k\Omega\cdot 2\pi\cdot 33\mu F}=\underline{\underline{6{,}239\,kHz}}$

**3.) Variante** A = N-INV B: INV $r_{2A}=1k\Omega$




$R_{E3}=R_{1B}\,\|\,(R_{TP}\oplus \overset{1k\Omega}{r_{2A}})=\underline{1{,}259k\Omega}$

$A_{u3}=A_{uA}\cdot A_{uB}\cdot\frac{R_{1B}}{R_{1B}+(R_{TP}+r_{2A})}=-110\cdot 0{,}63\ldots$

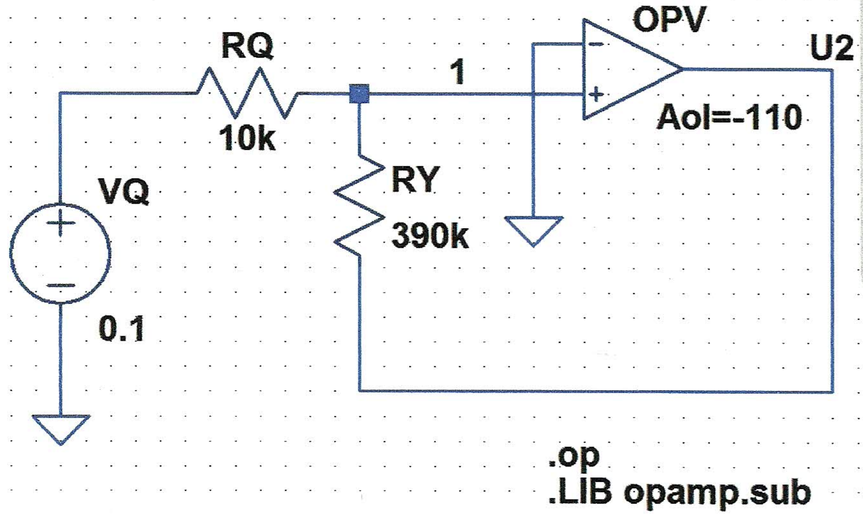
$=\underline{\underline{-69{,}259}}$

$a_{u3}=20\lg|A_{u3}|=20\lg|-69{,}259|=$

$=\underline{\underline{36{,}81}}$

$f_G=\frac{1}{2\pi R_{E3}\cdot C_{TP}}=\frac{1}{2\pi\cdot 1{,}259k\Omega\cdot 33pF}=\underline{\underline{3{,}831\,kHz}}$

## Praktikum Elektronische Schaltungen
## Versuch 1
## Aufgabe 2.2 Ersatzschaltung

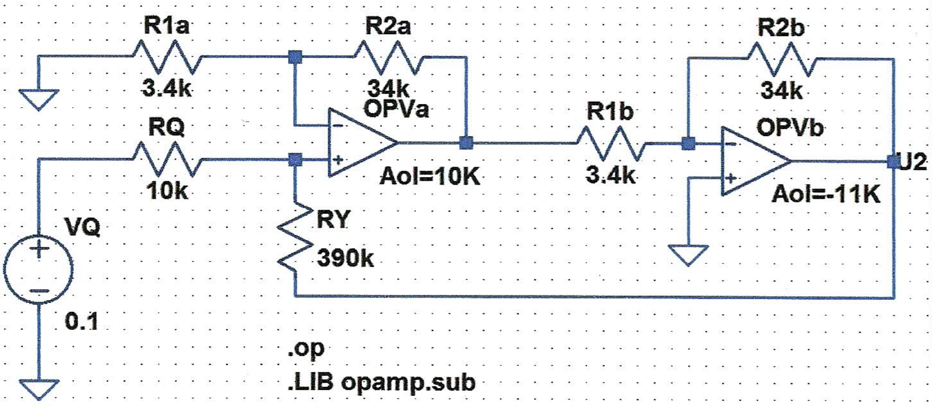



* C:\Program Files\LTC\LTspiceIV\Praktikum 1-2 16 05 2011 Aufgabe 2-2.asc

```
       --- Operating Point ---

V(n001):        0.1            voltage
V(1):           0.026          voltage
V(u2):          -2.86          voltage
I(Ry):          7.39999e-006   device_current
I(Rq):          7.39999e-006   device_current
I(Vq):          -7.39999e-006  device_current
Ix(opv:3):      7.39999e-006   subckt_current
```

### Praktikum Elektronische Schaltungen
### Versuch 1
### Aufgabe 2.2




* C:\Program Files\LTC\LTspiceIV\Praktikum 1-1 16 05 2011 Aufgabe 2-2.asc

```
       --- Operating Point ---

V(n004):        0.1            voltage
V(n005):        0.0260019      voltage
V(n002):        0.285706       voltage
V(n001):        0.0259733      voltage
V(n003):        -0.000260001   voltage
V(u2):          -2.85992       voltage
I(Ry):          7.39981e-006   device_current
I(R2b):         8.41078e-005   device_current
I(R1b):         8.41078e-005   device_current
I(R2a):         -7.63921e-006  device_current
I(R1a):         -7.63921e-006  device_current
I(Rq):          7.39981e-006   device_current
I(Vq):          -7.39981e-006  device_current
Ix(opva:3):     -9.1747e-005   subckt_current
Ix(opvb:3):     9.15076e-005   subckt_current
```