ELEC 311, Summer 2013, Final Exam (Sol)

Sol/hint for Q.1 (ELEC 311-Summer 2013)

```
> id1:=1E-3*4*(2.5-V1-1)^2;
```

$$id1 := .004\,(1.5 - V1)^2$$

```
> id2:=1E-3*4*(-V2-1)^2;
```

$$id2 := .004\,(-V2 - 1)^2$$

```
> y1:=V2-id2*1200+2.5;
```

$$y1 := V2 - 4.800\,(-V2 - 1)^2 + 2.5$$

```
> solve(y1,V2);
```

$$-1.464472669,\ -.3271939973$$

For MN2, VGS must be > VTH. But VGS|MN2=-V2, and VTH=1V.
So -V2>1V, V2<-1, accepted V2=-1.46 V (approx).

```
> V2:=-1.46;
```

$$V2 := -1.46$$

```
> id2:=4E-3*(-V2-1)^2;
```

$$id2 := .0008464$$

```
> id1:=id2;
```

$$id1 := .0008464$$

```
> y2:=id1-4E-3*(1.5-V1)^2;
```

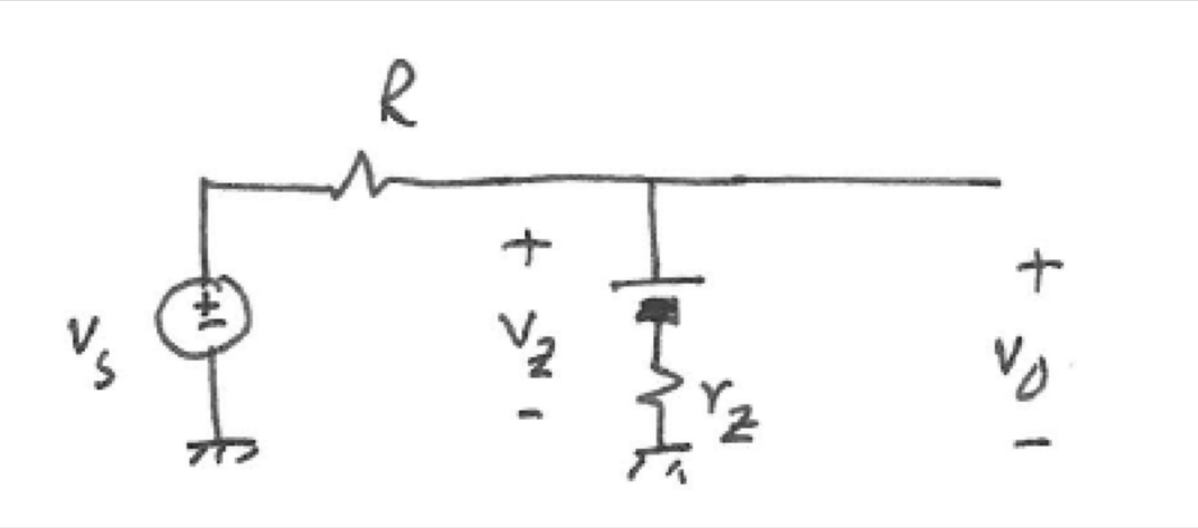
$$y2 := .0008464 - .004\,(1.5 - V1)^2$$

```
> solve(y2,V1);
```

$$1.040000000,\ 1.960000000$$

Since VGS of MN1 has to be >VTH, our choice for V1 will be V1=1.04V
So solutions are V1=1.04V, V2=-1.46

Sol/hint for Q.2
(a) The equivalent circuit is (hand-drawing)



(b) `Vz:=Vzo+Iz*rz;`

$Vz := Vzo + Iz\ rz$

```
> Vz:=6.8;
```

$$Vz := 6.8$$

```
> Iz:=5E-3;
```

$$Iz := .005$$

```
> rz:=20;
```

$$rz := 20$$

```
> y:=Vz-Vzo-Iz*rz;
```

$$y := 6.700 - Vzo$$

```
> solve(y,Vzo);
```

$$6.700000000$$

```
> Vzo:=6.7;
```

$$Vzo := 6.7$$

Line regulation is: $\frac{\Delta V_o}{\Delta V_i} = \frac{\Delta V_Z}{\Delta V_i} = \frac{r_Z}{r_Z + R_{line}}$

```
> Rline:=500;
```

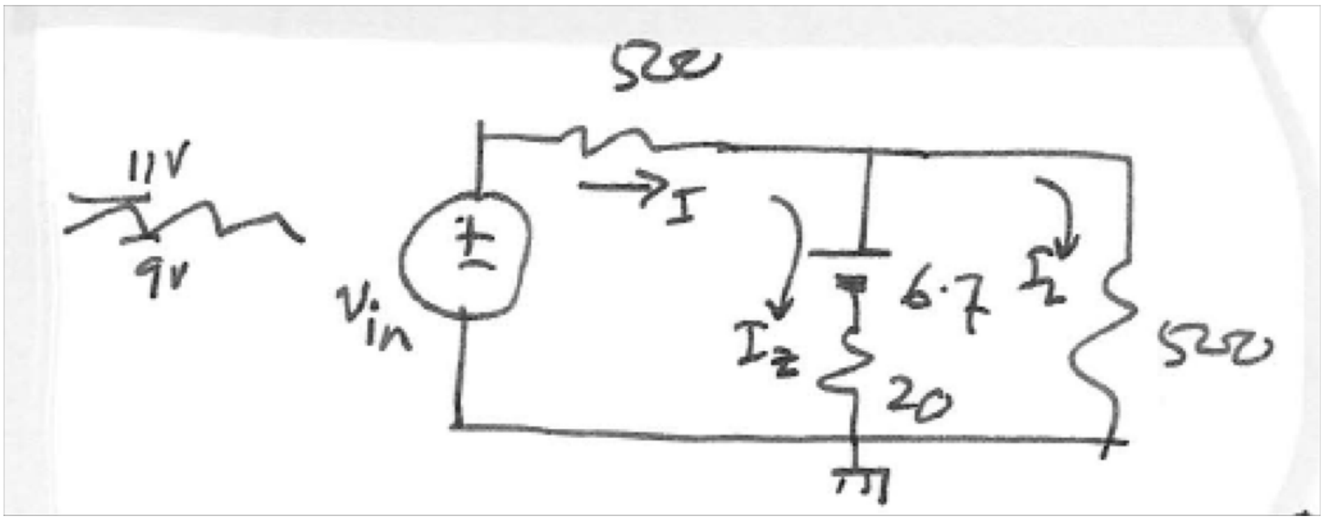
$$Rline := 500$$

```
> LR:=rz/(rz+Rline);
```

$$LR := \frac{1}{26}$$

Line regulation is 1/26, i.e.,38.46 mV/V

(c) With 500 ohms as load, the equivalent circuit is (hand drawing):



If we solve this circuit for Iz, it will turn out that Iz is negative, i.e., the Zener is OFF. Thus

```
> Iline:=(Vin-Vload)/Rline;
```

$$Iline := \frac{1}{500}\,Vin - \frac{1}{500}\,Vload$$

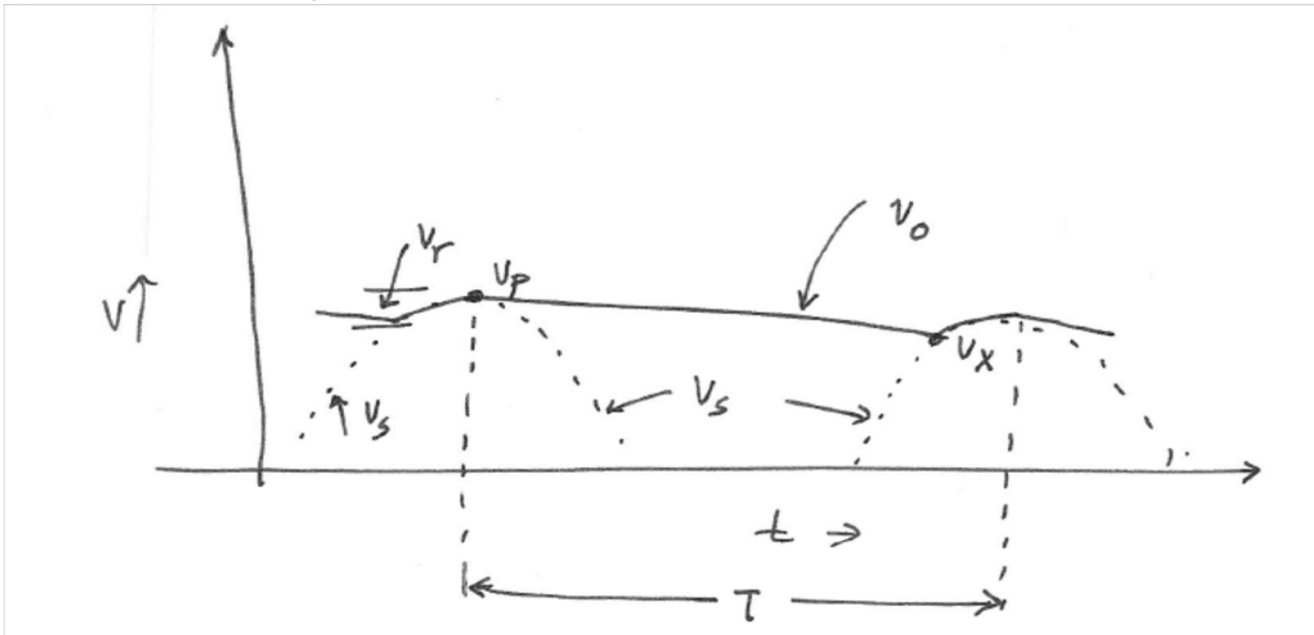
```
> Vload:=Vzener;
```

$$Vload := Vzener$$

Vzener=Iz*rz+Vzo
Iz+Iload=Iline=Vin/500-Vzener/500, while Iload=Vzener/500;
Substituting the values Vin=10V, Vzo=6.7V, rz=20, solving for Iz will reveal Iz <0.
With the Zener OFF, the output voltage is Vin*(500)/(500+500)= 5V for nominal Vin =10V

Q.3(a):
(i) DC component =Vm/PI=60/3.142=19.1 volts
(ii) PIV =0-(-60)= 60 volts

Q.3(b):
(i) Sketch (hand drawing)

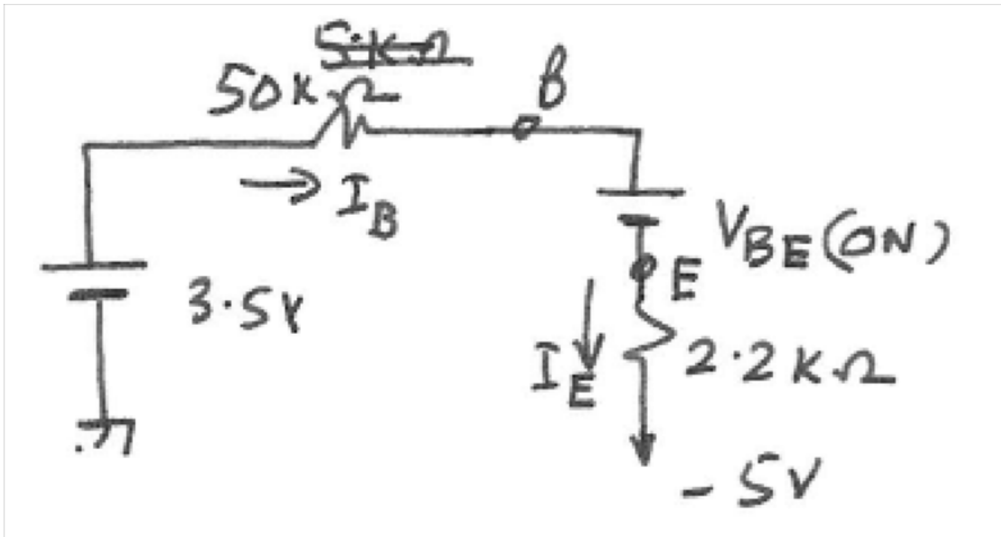


(ii) The time constant CR =100,000*1E-5=1 sec. The supply period is : 2*PI/(120*PI) =1/60=16.7 m sec. So CR >>supply period.
In each cycle, Vo starts from Vp=60V, and decays at the time-constant rate of 1 sec for (approx.) a time of one whole period, i.e., 16.7 m sec. The decayed value is (discharge equation for a simple RC circuit): 60 exp(-16.7E-3/1)=60*(1-0.0167)=59V (approx.)

The DC value at output is :(1/2)[60+59]=59.5V
The ripple is 60-59=1V pk-pk

(iii) To halve the ripple, we increase the capacitance to double the value, i.e., 20 micro farads.

Q.4: First we need to find I(dc), i.e.., DC analysis. Consider the base-emitter loop for the DC voltages (hand drawing)




```
y:=3.5-(IE/100)*50E3-0.7-IE*2200+5;
```

$$y := 7.8 - 2700.000000\, IE$$

```
> solve (y,IE);
```

$$.002888888889$$

```
> IE:=2.9E-3;
```

$$IE := .0029$$

```
> IC:=IE*beta/(beta+1);
```

$$IC := .0029 \frac{\beta}{\beta + 1}$$

```
> beta:=99;
```

$$\beta := 99$$

```
> ICnow:=IC;
```

$$ICnow := .002871000000$$

```
> Ic=2.87E-3;
```

$$Ic = .00287$$

```
> gm:=0.00287/.025;
```

$$gm := .1148000000$$

```
> rpi:=beta/gm;
```

$$rpi := 862.3693380$$

```
> rpi := 862.3693380;
```

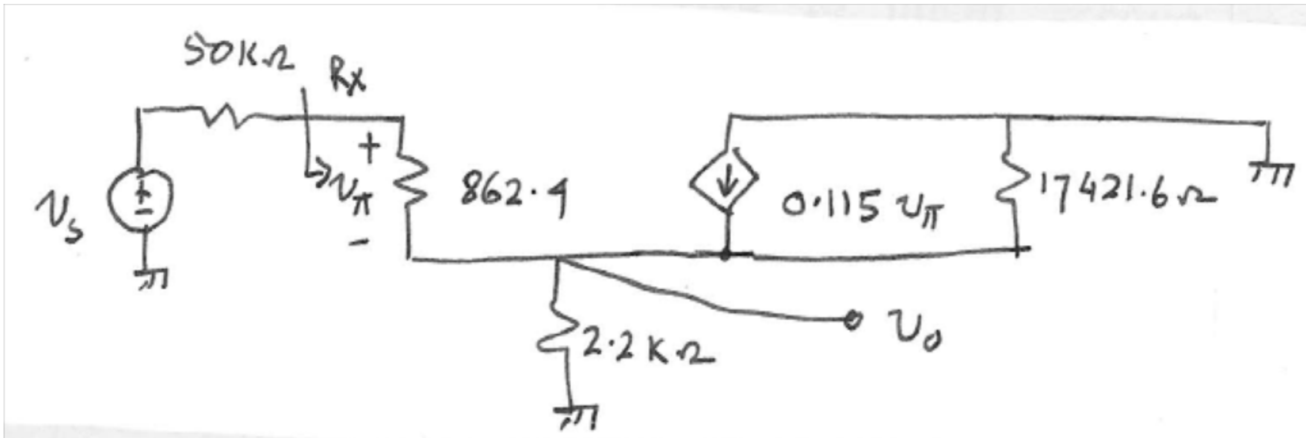
$$rpi := 862.3693380$$

```
> ro:=50/.00287;
```

$$ro := 17421.60279$$

```
>
```

The ac equivalent circuit is (hand drawing)




```
> RE:=2200;
```

$$RE := 2200$$

```
> Rx:=862.4+100*(RE*ro)/(RE+ro);
```

$$Rx := 196195.7097$$

```
> vb:=Rx*vs/(Rx+50000);
```

$$vb := .7969095397\ vs$$

```
> RL:=100*(RE*ro)/(RE+ro);
```

$$RL := 195333.3097$$

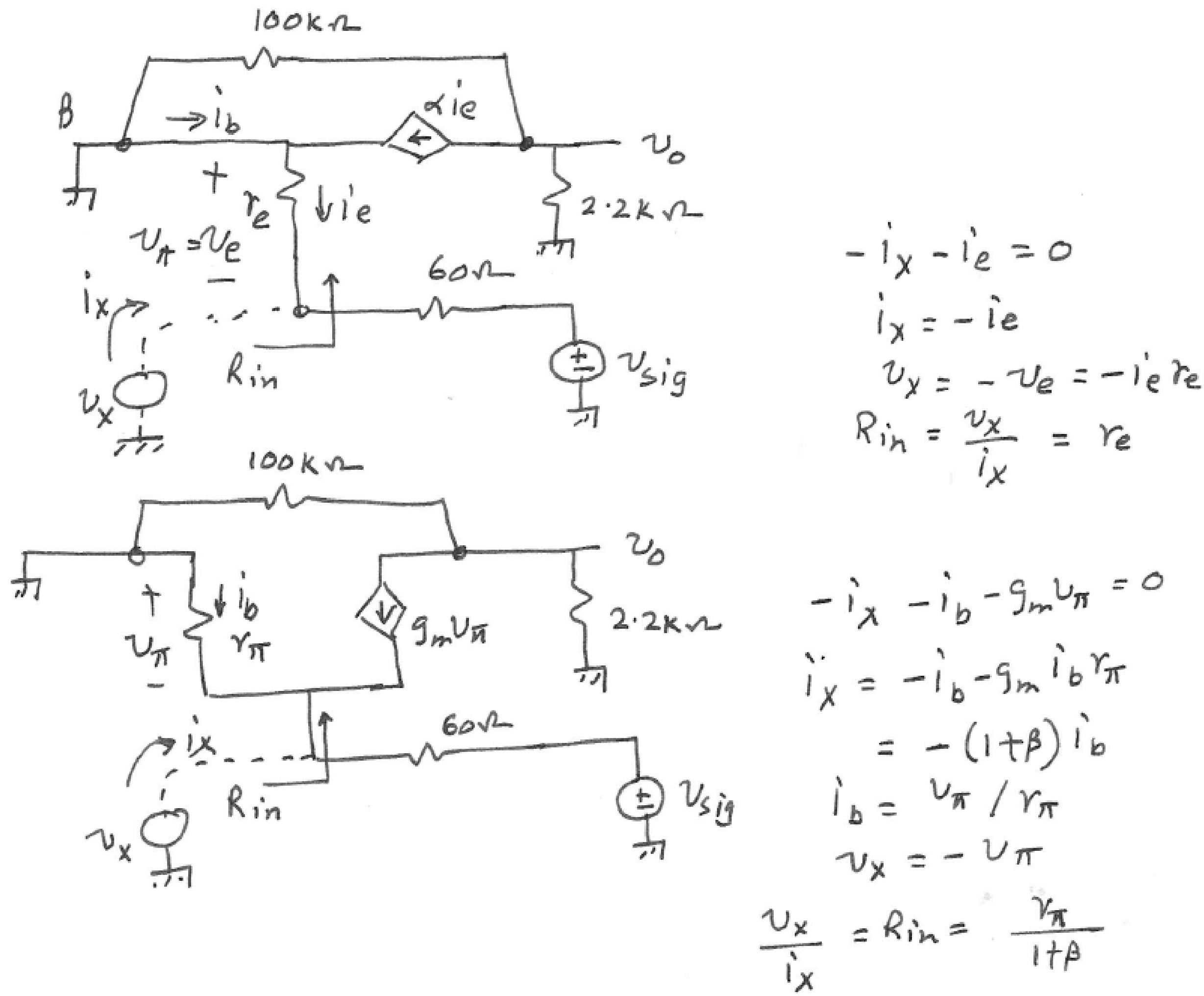
```
> vo:=vb*RL/Rx;
```

$$vo := .7934066353\ vs$$

Voltage gain is vo/vs =0.79

Q.5:

(a) Consider the ac equivalent circuit (T-model and PI-model). Using the dummy source vx and the dummy current ix, we get $R_{in} = \frac{v_x}{i_x} = r_e = \frac{r_\pi}{1+\beta}$



From the given schematic 0.5mA=IE=IC+IB. So IC=(49/50)*0.5mA =0.49 mA

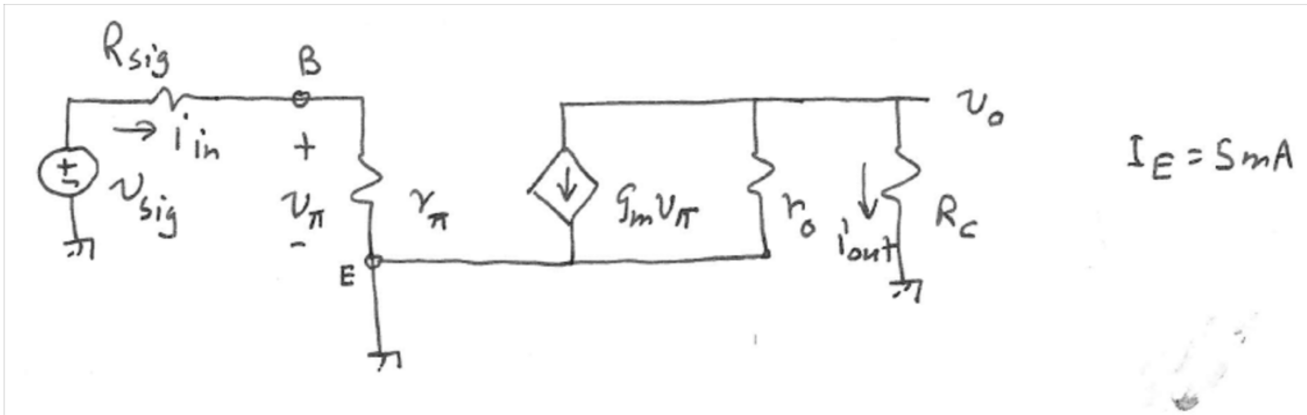
gm=0.0196 mho; $r_\pi = \dfrac{\beta}{g_m} = 2500$

Rin =50 ohms (i.e., Thermal voltage divided by IE).

(b) From the equivalent circuit $v_e = v_\pi = \dfrac{50}{50+60} v_{sig}$ has to be $< V_T$ (i.e., 25 mV)

Then $v_s = v_{sig}$ has to be $< \dfrac{25 \times 110}{50}\ \text{mV} = 55\ \text{mV}$

Q.6: The equivalent circuit is (hand drawing):




```
IE:=.005;
```

$$IE := .005$$

```
> beta:=100;
```

$$\beta := 100$$

```
> IC:=IE*beta/(1+beta);
```

$$IC := .004950495050$$

```
> VA:=50;
```

$$VA := 50$$

```
> ro:=VA/IC;
```

$$ro := 10100.00000$$

```
> gm:=IC/.025;
```

$$gm := .1980198020$$

```
> rpi:=beta/gm;
```

$$rpi := 504.9999999$$

Put the above values in the equivalent circuit.

(a) The voltage gain is: $\frac{v_o}{v_{sig}} = -g_m \frac{r_o R_C}{r_o + R_C} \times \frac{r_\pi}{r_\pi + R_{sig}}$

Substituting the values

```
> x1:=(ro*1000)/(ro+1000);
```

$$x1 := 909.9099099$$

```
> x2:=rpi/(rpi+10000);
```

$$x2 := .04807234649$$

```
> gain:=-gm*x1*x2;
```

$$gain := -8.661684053$$

Voltage gain is -8.66 V/V

(b)

```
> iout:=vo/1000;
```

$$iout := \frac{1}{1000} vo$$

```
> iin:=vsig/(rpi+10000);
```

$$iin := .00009519276535\ vsig$$

```
> igain:=iout/iin;
```

$$igain := 10.50500000\ \frac{vo}{vsig}$$

```
> i_gain:=10.505*gain;
```

$$i\_gain := -90.99099098$$

Small signal current gain is -90.99 A/A

Q.7: Using several of the the given data

```
> K:=.005;
```

$$K := .005$$

```
> WLratio:=2;
```

$$WLratio := 2$$

```
> Vov:=0.7-0.5;
```

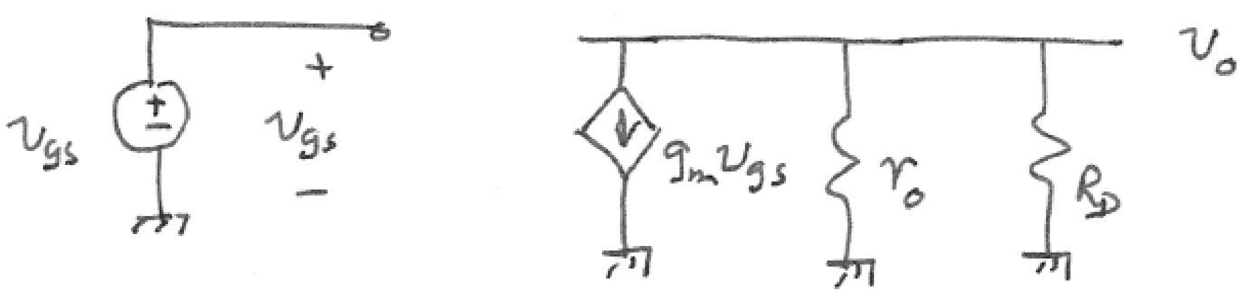
$$Vov := .2$$

```
> gm:=K*WLratio*Vov;
```

$$gm := .0020$$

(a) The ac transconductance is 0.002 mho

(b) The ac equivalent circuit is (hand drawing):



The DC current is (ID) $= K\frac{W}{2L}V_{OV}^2 = .005\times\frac{2}{2}\times 0.2^2$ (assuming saturation region of operation)

```
> ID:=K*(WLratio/2)*Vov^2;
```

$$ID := .0002000000000$$

```
> VD:=2-ID*5000;
```

$$VD := 1.000000000$$

```
> VDS:=VD;
```

$$VDS := 1.000000000$$

VDS=1V is > Vov (=0.2V), so the operation in saturation region is confirmed.

```
> VAx:=50;
```

$$VAx := 50$$

```
> rox:=VAx/ID;
```

$$rox := 250000.0000$$

```
> RD:=5000;
```

$$RD := 5000$$

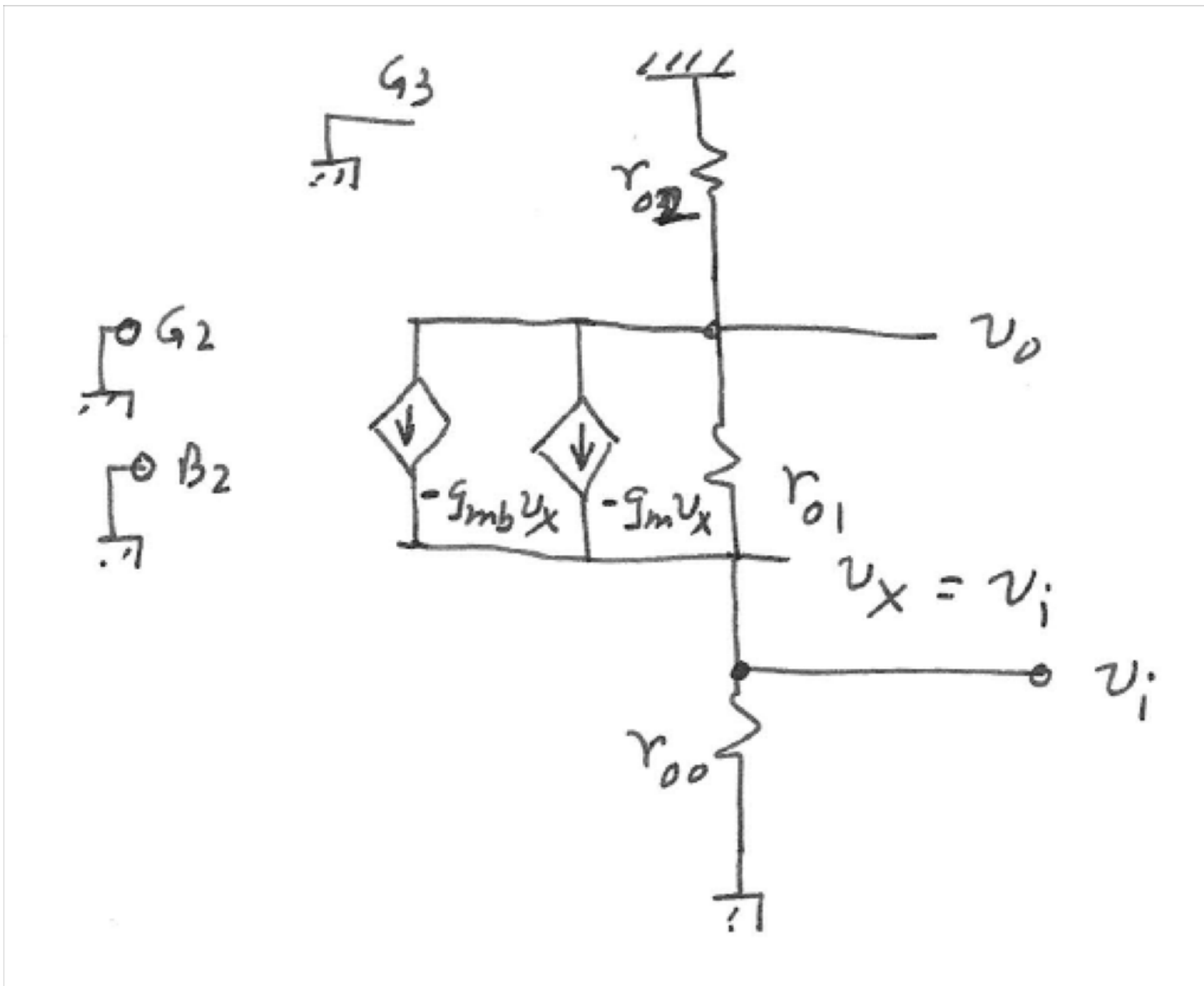
```
> Vgain:=-gm*(rox*RD)/(rox+RD);
```

$$Vgain := -9.803921569$$

The small signal voltage gain is -9.8 V/V

Q.8

The ac equivalent circuit is (hand drawing):



KCL at vo node (note vx=vi, the input signal voltage)

$$\frac{v_o}{r_{o2}} - (g_m + g_{mb})v_i + \frac{v_o - v_i}{r_{o1}} = 0$$

```
> y:=vo/ro2-(gm+gmb)*vi+(vo-vi)/ro1;
```

$$y := \frac{vo}{ro2} - (gm + gmb)\, vi + \frac{vo - vi}{ro1}$$

```
> solve(y,vo);
```

$$\frac{vi\,(ro1\;gm + ro1\;gmb + 1)\;ro2}{ro1 + ro2}$$

```
> gain:=(ro1*gm+ro1*gmb+1)*ro2/(ro1+ro2);
```

$$gain := \frac{(ro1\;gm + ro1\;gmb + 1)\;ro2}{ro1 + ro2}$$

The voltage gain is: $\frac{v_o}{v_i} = \frac{1.2 g_m r_{o1} + 1}{r_{o1}/r_{o2} + 1}$ (since, $g_{mb} = 0.2 g_m$)