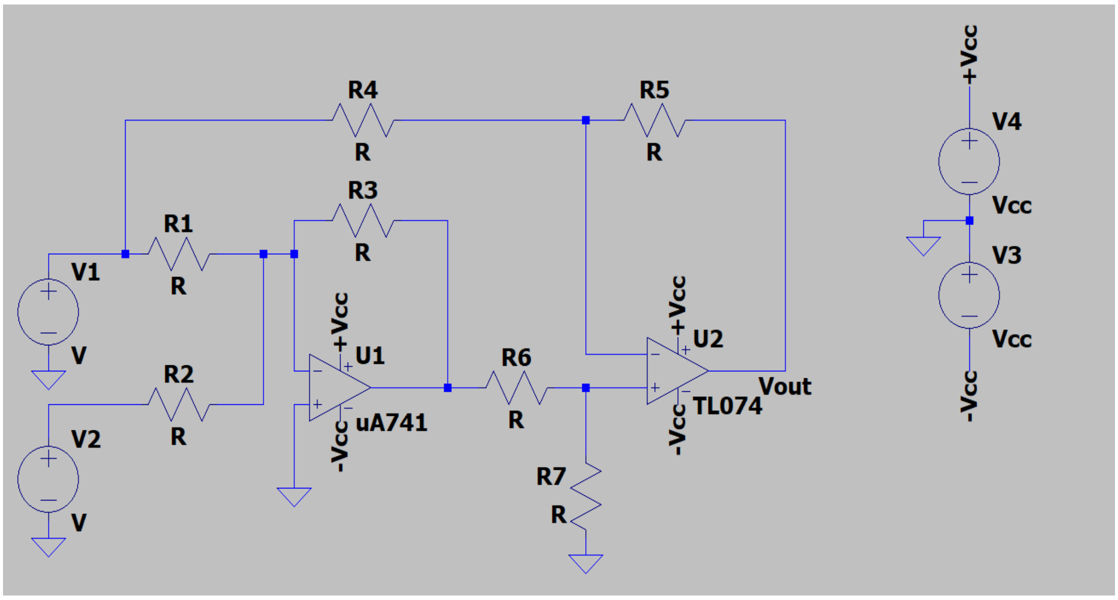
# EE 241 SPICE PROJECT-EMRE ÇİFÇİ

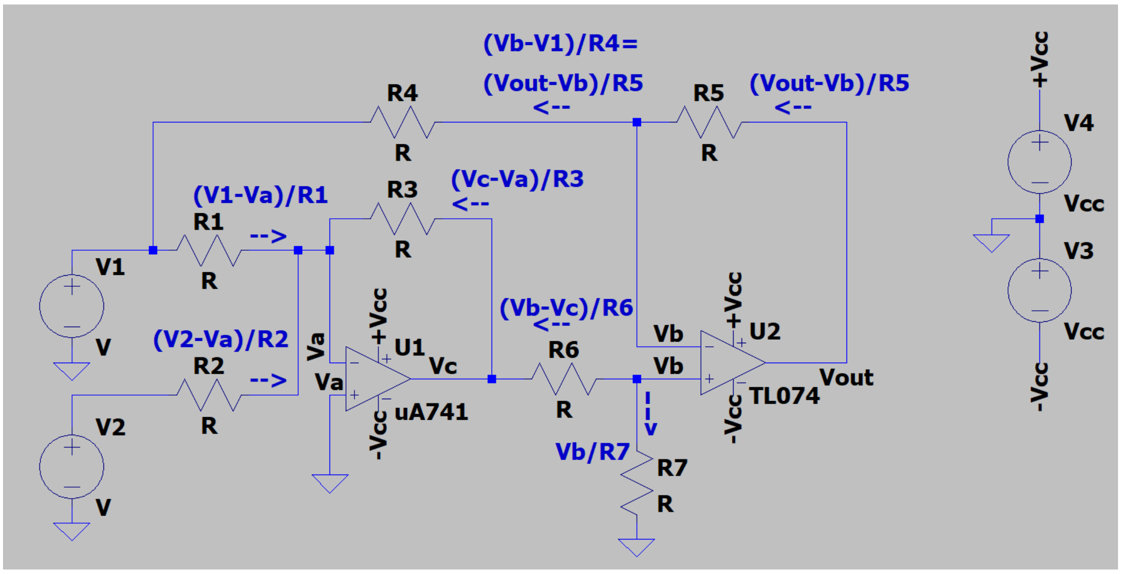
## Part 1

1) Hand calculations:

a) We assume that these Opamps are ideal.




So, we can say that the inverting input's and non-inverting input's voltages of these Opamps are equal: Vn(U1)=Vp(U1) & Vn(U2)=Vp(U2)
What is more, because of ideal Opamps' characteristics, current flowing through their inputs is equal to 0 A. These are typical properties of ideal Opamps. By using them, we can find Vout in terms of V1, V2 and resistance values.




We know that Va=0 V. When we apply KCL to this circuit, we get the following equations:

*(Vout-Vb)/R5=(Vb-V1)/R4

*V1/R1+V2/R2+Vc/R3=0

*(Vb-Vc)/R6+Vb/R7=0

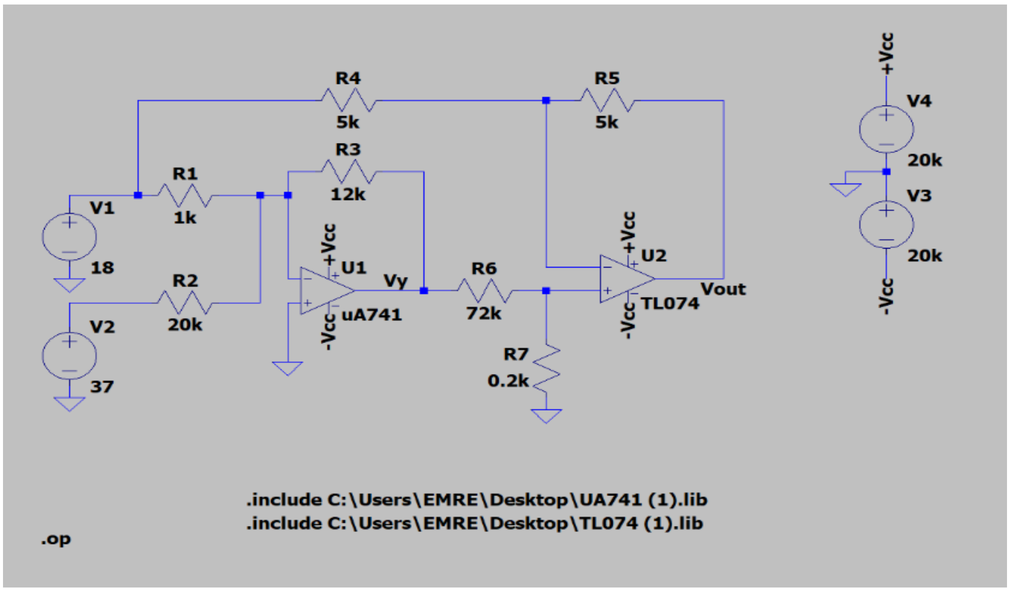
Then, Vb(1/R6+1/R7)=Vc/R6 → Vb=Vc/(R6*(1/R6+1/R7))
Vc/R3= - (V1/R1+V2/R2) → Vc= - (V1/R1+V2/R2)*R3
So, Vb becomes – (V1/R1+V2/R2)*R3/(R6*(1/R6+1/R7))
When we substitute Vb for the first equation
Vout=((Vb-V1)/R4+Vb/R5 )*R5 →

$$Vout = \frac{-\left(\frac{V1}{R1}+\frac{V2}{R2}\right) * R3}{R6\left(\frac{1}{R6}+\frac{1}{R7}\right)}\left(\frac{R5}{R4}+1\right) - \frac{V1 * R5}{R4}$$

b) There are two amplifier functions shown within the dashed lines in Figure 1:
Configuration 1 is a "summing amplifier circuit". When we have R1=R2=Rs and Rs=R3, we find out that Vc= - (V1+V2).
Configuration 2 is a "difference amplifier circuit". When we do the math, we find out that R5*(Vb-V1)/R4+Vb=Vout, just like we have found out before. If we say Vim=Vc-V1 and Vcm=(Vc+V1)/2 → Vc= Vcm+Vdm/2 & V1=Vcm-Vdm/2

After lots of calculations, we find out Vout=AcmVcm+AdmVdm where Acm and Adm are functions of resistances. Because this is a "difference amplifier circuit", we want to have Acm=0 and to have Vdm only. For this, we must have R6/R7=R4/R5 (or something close to it.)

2) a) Since these Opamps are not totally ideal, I paid attention to have input currents of Opamps to have ~0 A and Vp=Vn while choosing resistance values.
Combination 1: V1=18V V2=37V R1=1kΩ R2=20kΩ R3=12kΩ R4=5kΩ R5=5kΩ R6=72kΩ R7=0.2kΩ (Vcc=20kV)

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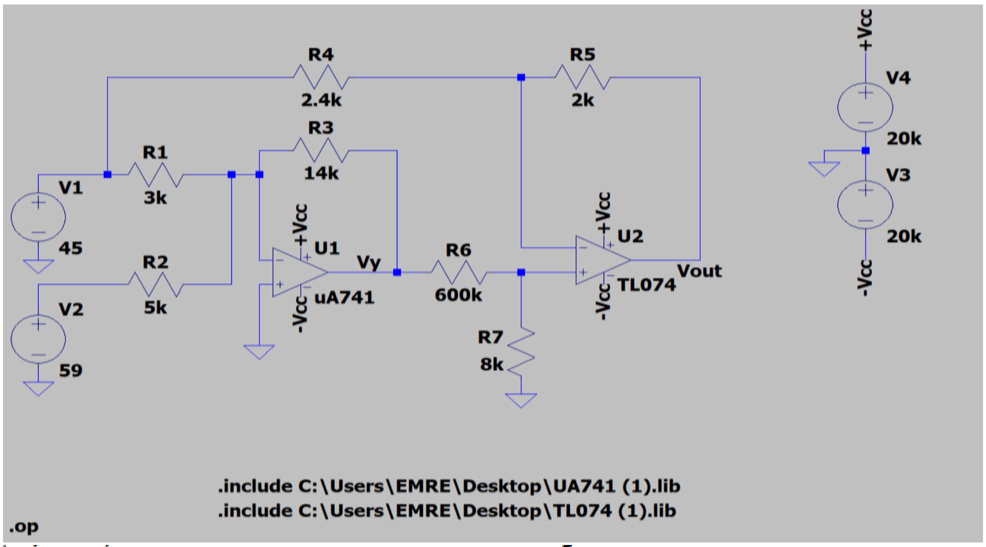
V(vout):          -19.3192        voltage
```

Vout= -((18/1k+37/20k)*12k)*(5k/5k+1)/(1+72k/0.2k) – 18*5k/5k

We find out Vout= -19.3197 (%0.00259 error)

Combination 2: V1=45V V2=59V R1=3kΩ R2=5kΩ R3=14kΩ R4=2.4kΩ R5=2kΩ R6=600kΩ R7=8kΩ (Vcc=20kV)




V(vout): -46.55 voltage

Vout= -((45/3k+59/5k)*14k)*(2k/2.4k+1)/(1+600k/8k) – 45*2k/2.4k

We find out that Vout= -46.55V (~same result)

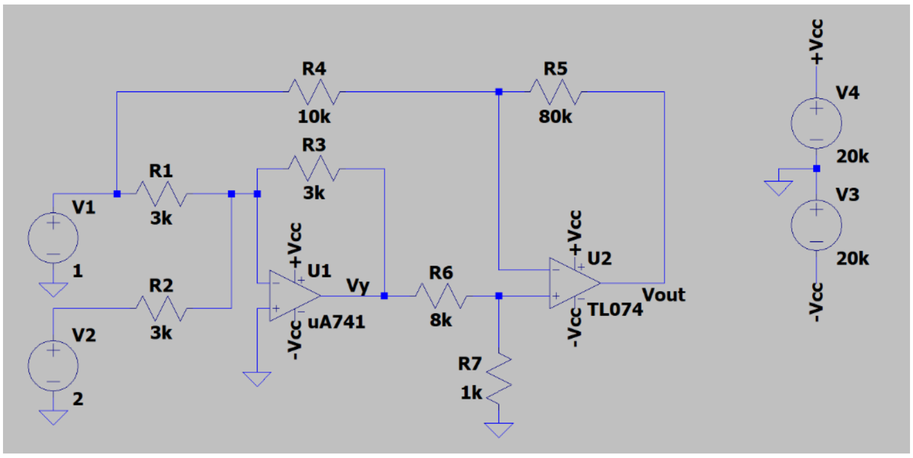
b) We can use the properties of these amplifiers to have a desired Vout value. For this, as we mentioned before, having a desired difference amplifier circuit is achieved by R5/R4=R6/R7, and having a desired summing amplifier circuit is achieved by R1=R2=R3=Rs. Our formula was:

$$Vout = \frac{-\left(\frac{V1}{R1}+\frac{V2}{R2}\right)*R3}{R6\left(\frac{1}{R6}+\frac{1}{R7}\right)}\left(\frac{R5}{R4}+1\right)-\frac{V1*R5}{R4}$$

When Vout= -11V, V1=1V and V2=2V, our equation becomes the following:

$$-11=-3-\frac{1*R5}{R4}$$

So, if we accept our assumptions like R1=R2=R3=Rs, we find out that R5/R4 ratio equals to 8. When R1=R2=R3=3kΩ , R4=10kΩ, R5=80kΩ, R6=8kΩ, R7=1kΩ, we have the following schematic:




V(vout): -10.9977 voltage

Vout found in LTSPICE is so close to desired voltage.(%0.021 error)

c) For this part, we have the same circuit that we had in part b with different Opamps instead of TL074. When we run our simulation with TL054a, we have:

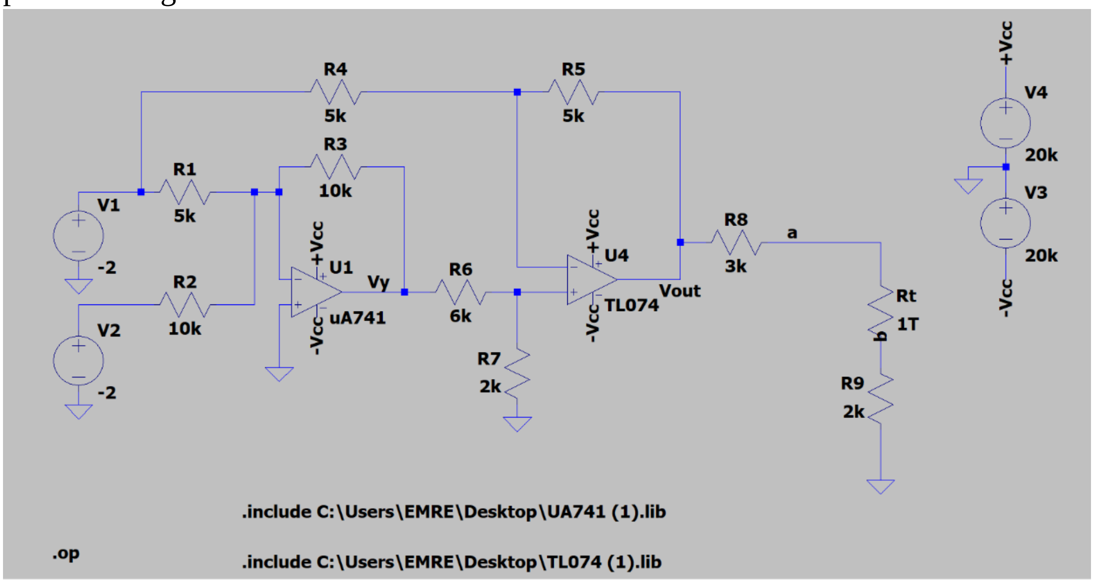
V(vout): -10.9966 voltage

And with TL054b, we have:

V(vout): -10.9974 voltage

Since these results are so close to our desired Vout voltage, they can be implemented instead of TL074.

3) To have a Norton or Thevenin equivalent circuit, we must find Vab (open circuit)=Vth and isc (short circuit current). Then, we can find Rth and Norton equivalent. Let us connect a resistor between the nodes a and b. If its resistance becomes extremely high, ab will become an open circuit where almost no current passes through it.

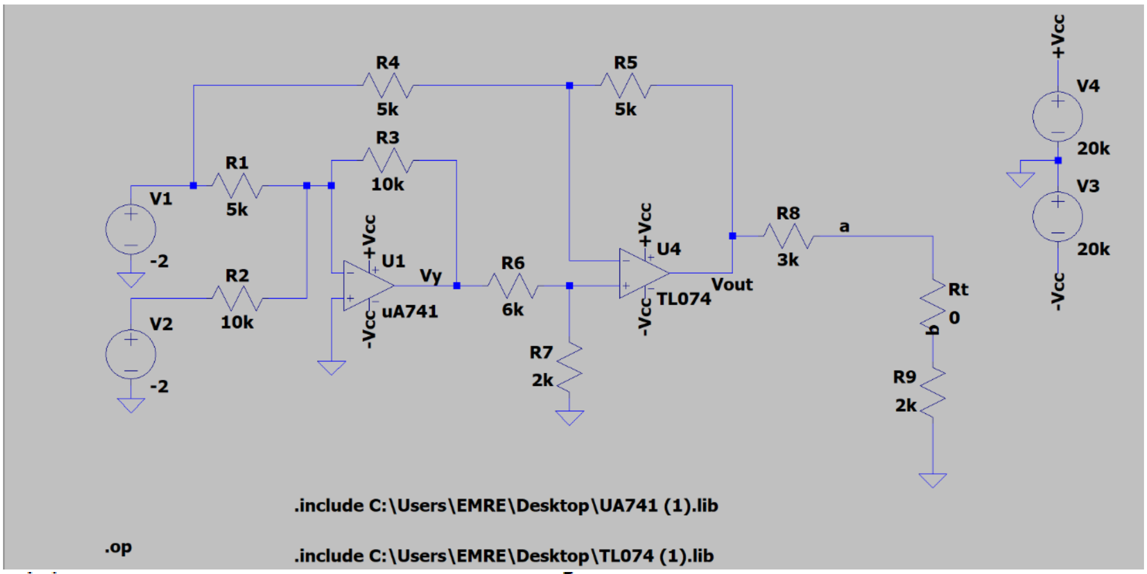


Rt has 1TΩ, which is an extremely high value. When we run it, Vab comes out to be:

```
V(a):          5.00021        voltage
V(b):          1.00004e-008   voltage
```

Vab=Vth=~5.00021V

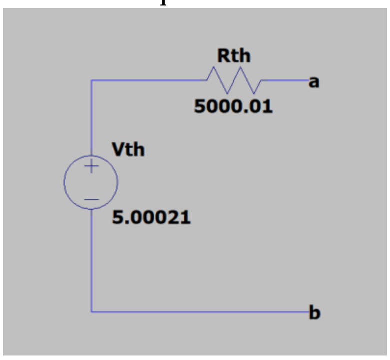
When we decrease Rt's resistance, ab becomes a short circuit, and we can find isc.

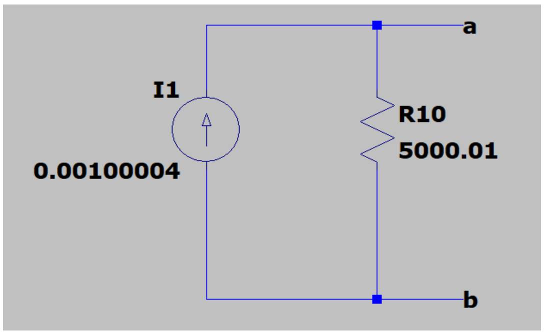



```
I(R9):          -0.00100004    device_current
```

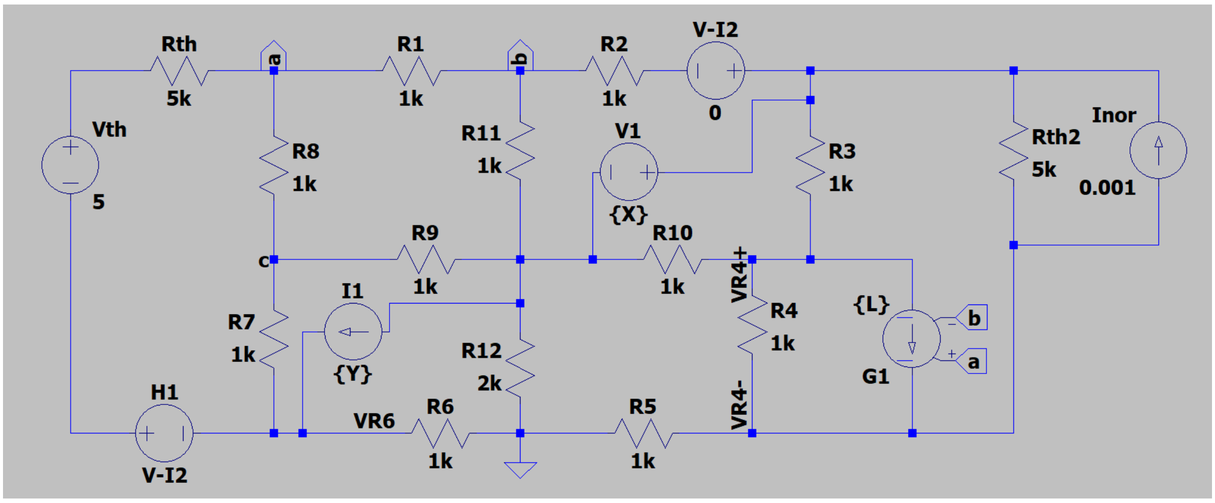
isc= 0.00100004 A, we use positive sign because we know Vb is positive, then current is flowing from a to b. If we divide Vth by isc, we find Rth which is approximately 5kΩ.

Thevenin Equivalent Circuit: Norton Equivalent Circuit :



4) We can assume that Vth=5V, Rth=5kΩ and isc=1mA. In the circuit "X" is for V1, "Y" is for I1 value.




a) I1 is found: v(vr4+)-v(vr4-)=v(vr6) AT 0.00302959 A

```
.param X 8
.param L 1
.param K 1000
.param Y 0
.step param Y 0 100
.meas op res Y when V(d)-V(e)=V(f)
.op
```

b) V1 is found: i(r7)=0 AT 9.96873 V

```
.param X 0
.param L 2
.param K 2000
.param Y 2m
.step param X 0 50
.meas op res X when I(R7)=0
.op
```

c) K is found: v(a)-v(c)=2 AT 1744.12

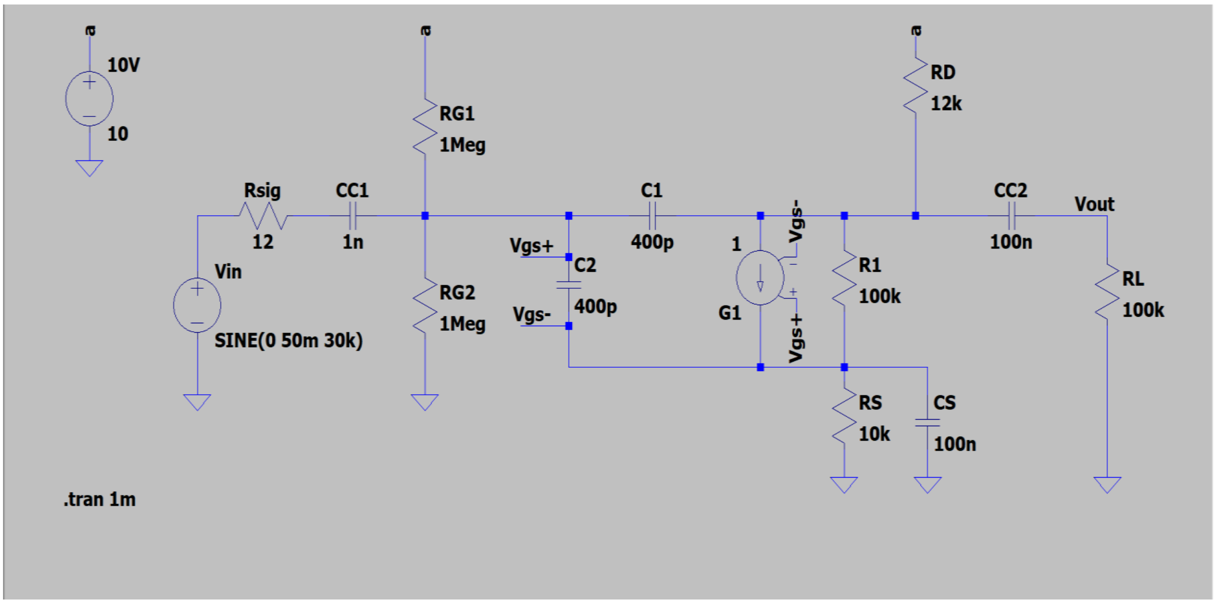
```
.param X 8
.param L 2
.param K 0
.param Y 4m
.step param K 0 10k
.meas op res K when V(a)-V(c)=2
.op
```

d) Measurement "res" FAIL'ed

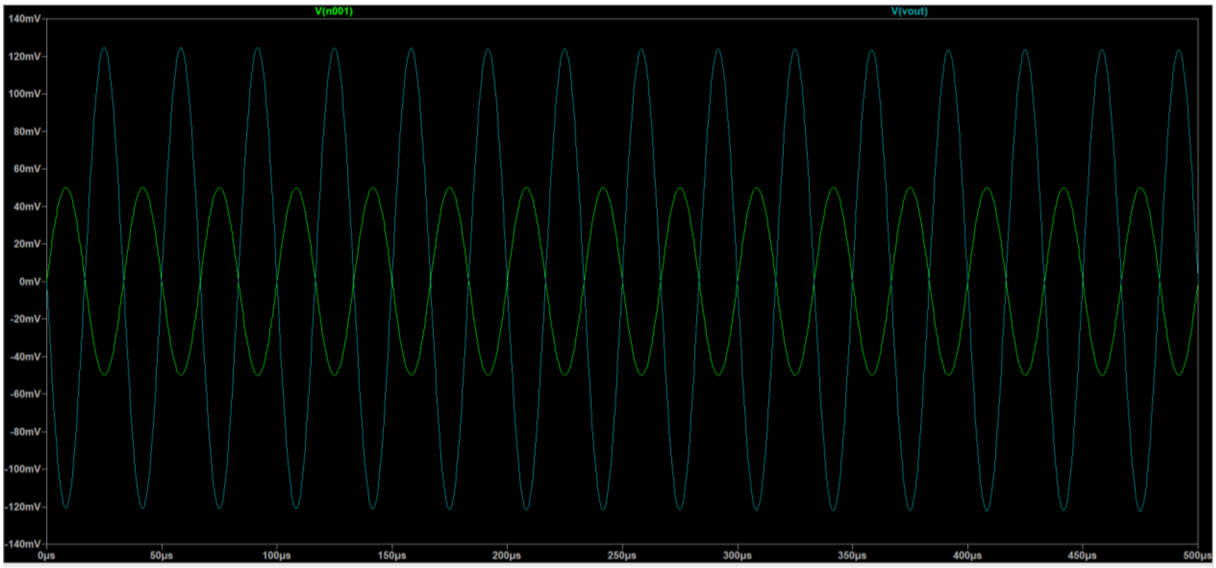
```
.param X 5
.param L 0
.param K 1500
.param Y 1m
.step param L -50 50
.meas op res L when V(d)-V(e)=-4
.op
```

<u>Part 2</u>

1) Last three digits of my student number is 012, so ABC is 12. The circuit becomes:



a) When we do the transient analysis: (V(n001) =Vin)




b) |Vout| ( Vrms) = Vm(out) /$\sqrt{2}$ , |Vin| (Vrms) = Vm(in)/ $\sqrt{2}$
Vm(out) and Vm(in) were found by .meas command:

```
.tran 0.5m
.meas tran max_vout max V(vout)
.meas tran max_vin max V(n001)
```

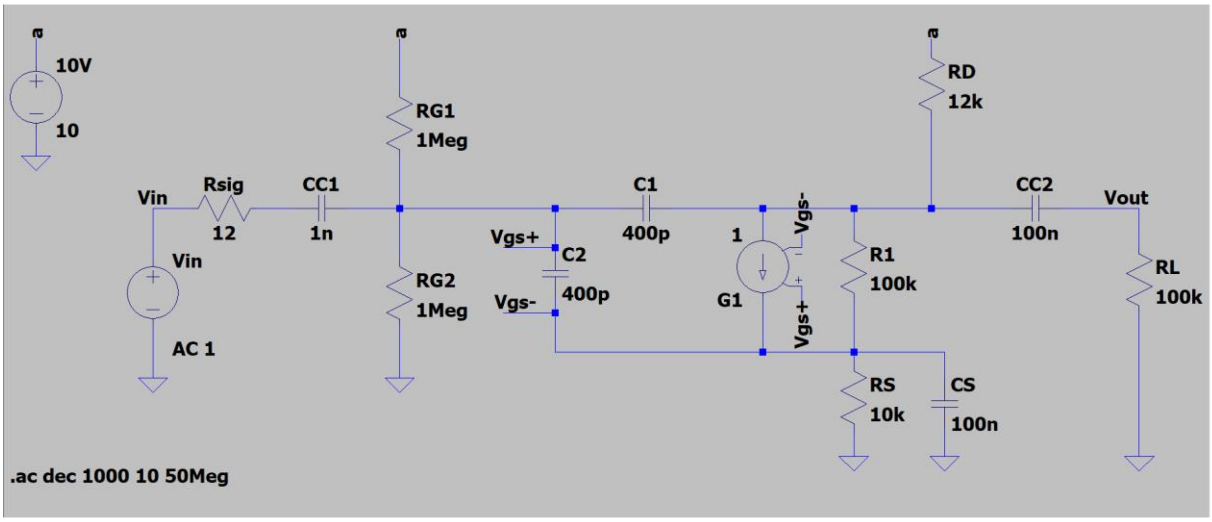
```
max_vout: MAX(v(vout))=0.124931 FROM 0 TO 0.0005
max_vin: MAX(v(n001))=0.0499999 FROM 0 TO 0.0005
```

Then, |Vin|=0.0499999/$\sqrt{2}$ = 0.035355268V, |Vout|=0.124931/$\sqrt{2}$=0.088229557V

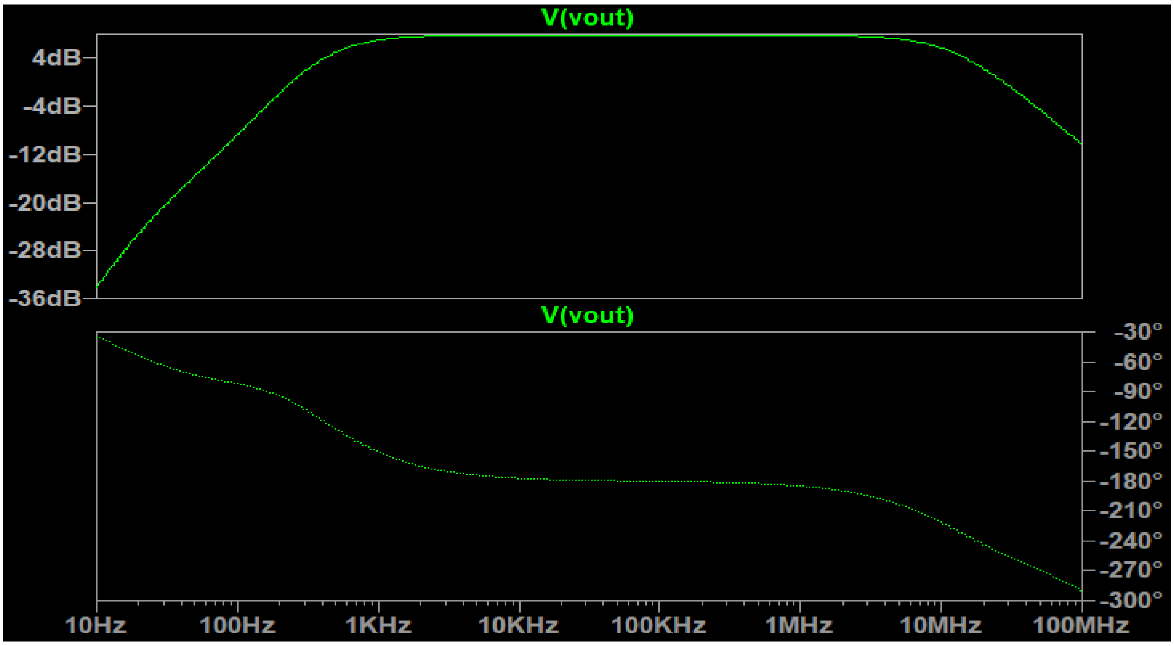
So, we find |Vout|/|Vin| (for max values) = 2.498624997V

c) dB gain is found by 20*log$\left(\frac{|Vout|}{|Vin|}\right)$ → dB gain (for max values)
= 20*0.39770108=7.954021609 dB

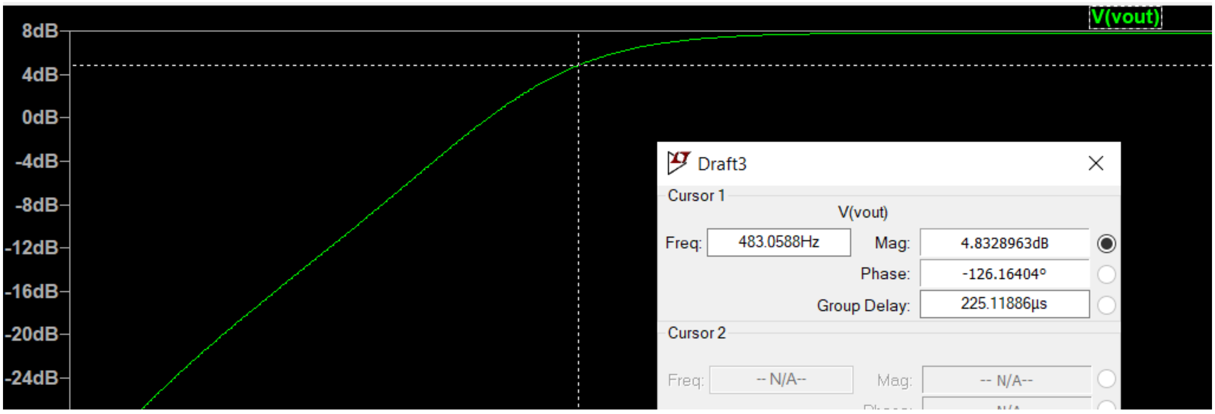
2)



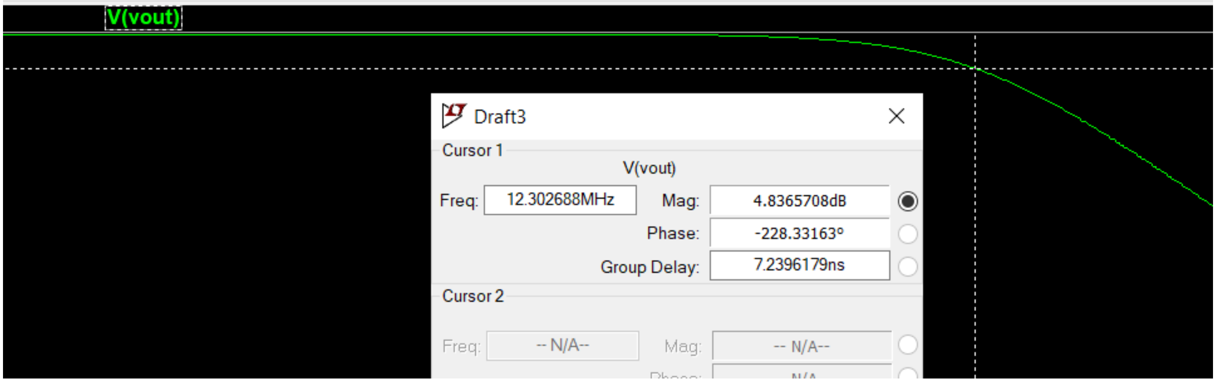

a)




b) Max grain is ~7.83dB. On the left side of the graph, where the gain drops to ~4.83dB, the lower cut-off frequency fcl= ~483Hz.

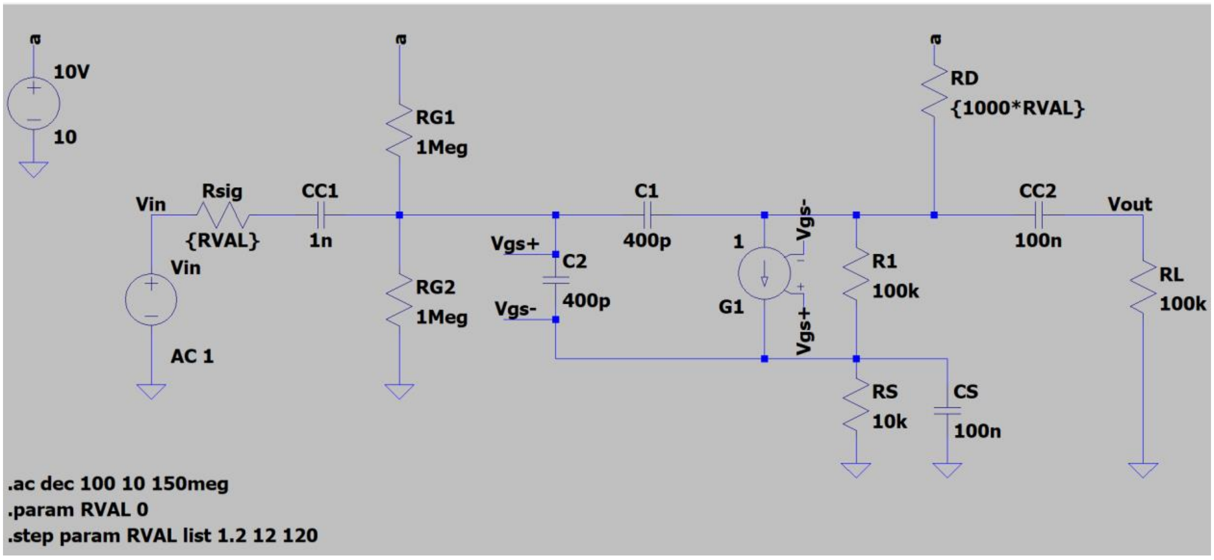


On the right side of the graph, where the gain drops to ~4.83dB, the higher cut-off frequency fch=~12.3MHz.

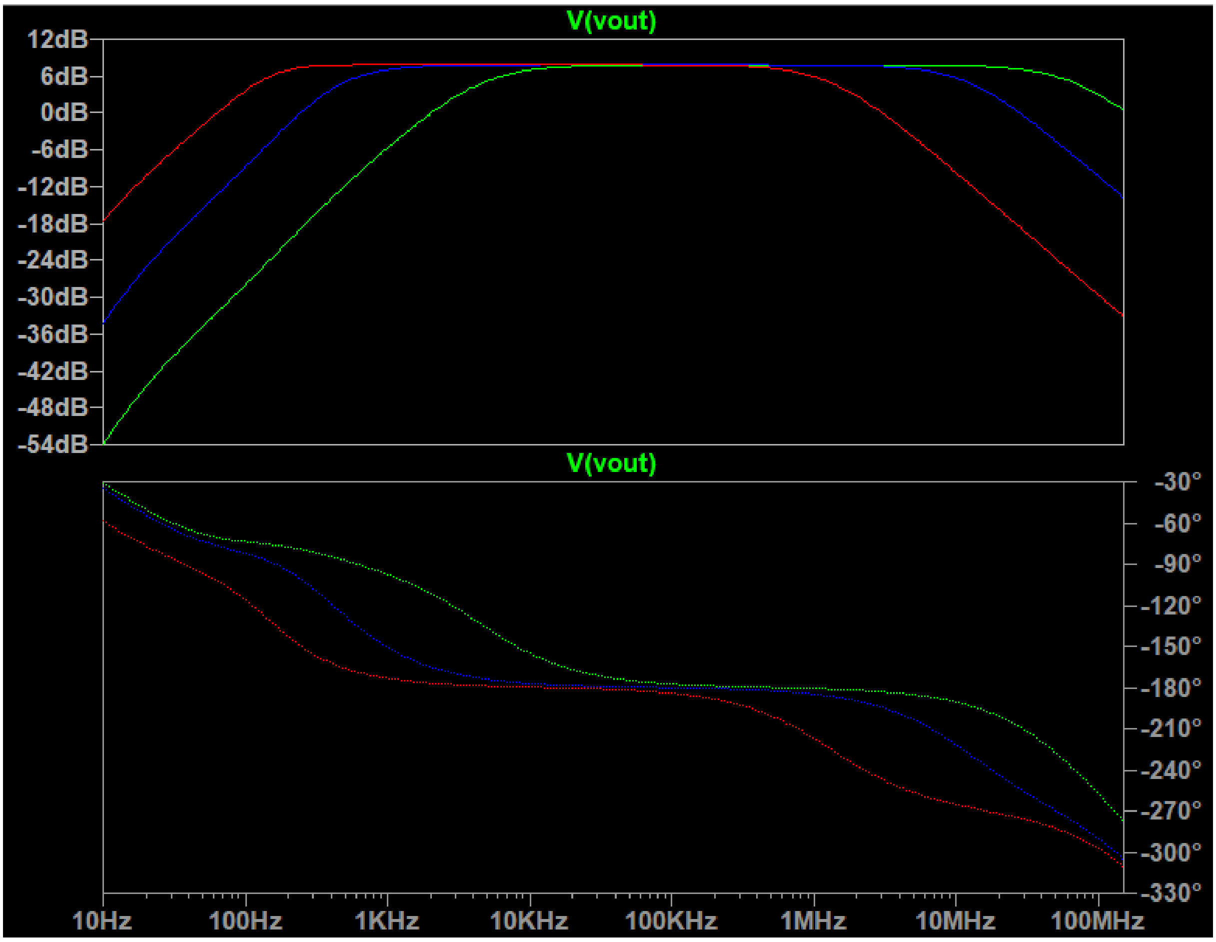



c) $BW = (fch - fcl)$, BW=12.3M-483=~12.29M

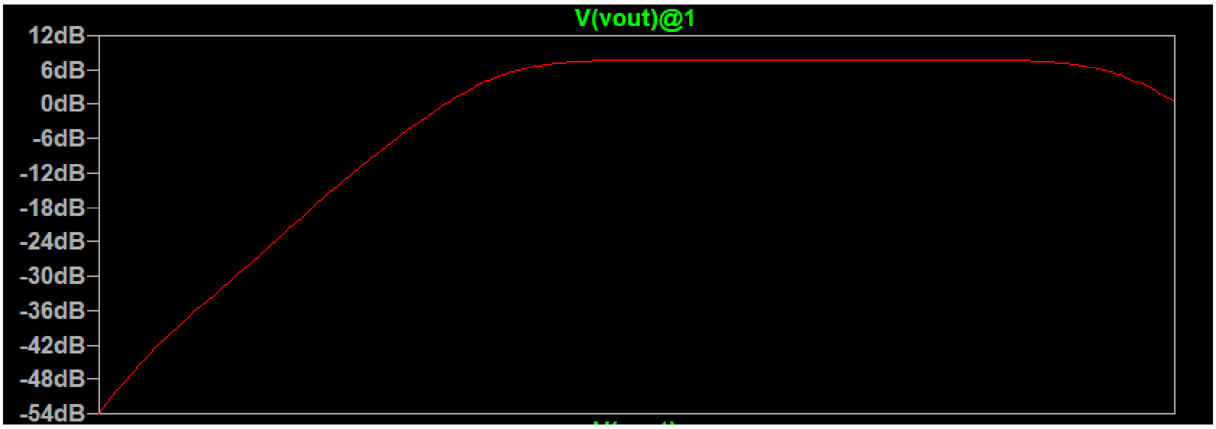
3)



a)


V(vout)
12dB
6dB
0dB
-6dB
-12dB
-18dB
-24dB
-30dB
-36dB
-42dB
-48dB
-54dB
V(vout)
-30°
-60°
-90°
-120°
-150°
-180°
-210°
-240°
-270°
-300°
-330°
10Hz
100Hz
1KHz
10KHz
100KHz
1MHz
10MHz
100MHz

RVAL=1.2Ω:


V(vout)@1
12dB
6dB
0dB
-6dB
-12dB
-18dB
-24dB
-30dB
-36dB
-42dB
-48dB
-54dB

RVAL=12Ω:


RVAL=120Ω:


b) For the case where RVAL=1.2Ω, max. gain is ~7.8 dB. 7.8 – 3 = 4.8 dB at which we have cut-off frequencies. fcl = ~4.57kHz and fch = 68.3MHz.
RVAL=12Ω, max. gain is ~7.83dB. 7.83-3=4.83 dB at which we have cut-off frequencies. fcl = ~483Hz and fch = ~12.2MHz.
RVAL=120Ω, max. gain is ~7.83dB. 7.83-3=4.83dB at which we have cut-off frequencies. fcl = ~121Hz and fch = ~1.32MHz.

c) BW(RVAL=1.2Ω) = 68.3M - 4.57k = ~68.29MHz
BW(RVAL=12Ω) = 12.2M - 483 = ~12.199MHz
BW(RVAL=120Ω) = 1.32M-121 = ~1.319MHz

d) As Rsig and RD values increase, BW value decreases. For the left-most part of the circuit, we have a low pass filter which causes Vout the to be smaller as we increase the resistance. What is more, at very high frequency values, capacitors behave like a short circuit, since RD gets bigger when we increase RVAL values, Vout decreases. Therefore, we have a sharper drop at higher values of RVAL at high frequency values. So, this “sharp” drop also causes BW to be smaller because fch-fcl difference gets smaller.