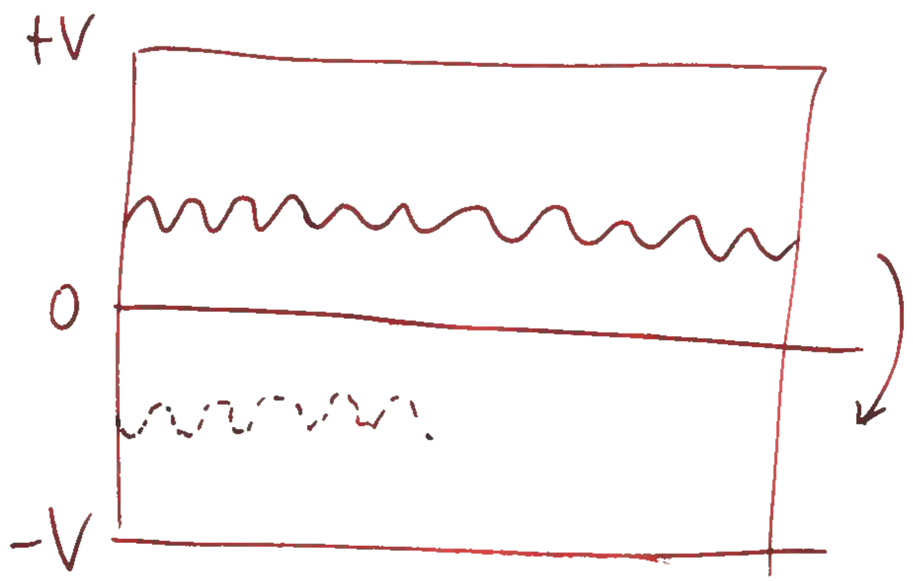
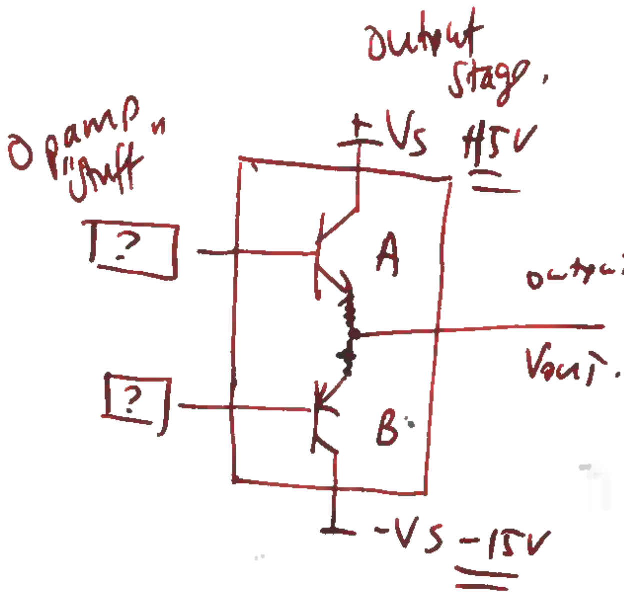


Inverting.



if A is ON, B is OFF

$V_{out}|_{max} = V_s - V_{CESAT}$

~0.3V

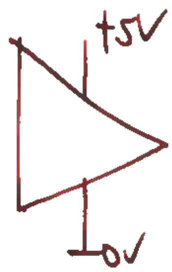
$\approx 14.7V$

if B is fully ON, A is OFF

$V_{OUT}|_{min} = -V_s + V_{CESAT}$

$\approx -14.7V$

+1V



$V_{CESAT} \leq V_{OUT} \leq +5V - V_{CESAT}$.

$\approx 0.3 \leq V_{out}$ 4.7V.

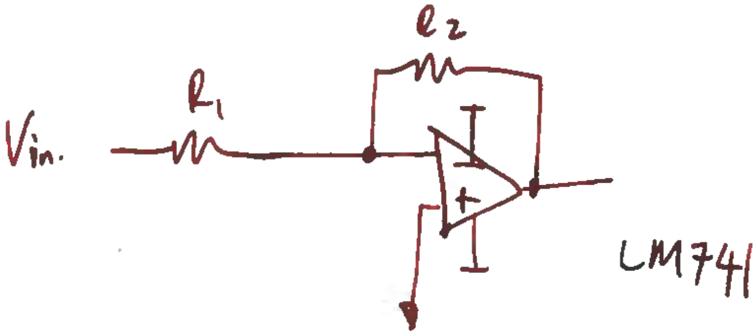
desired output is -1V.

outside possible range

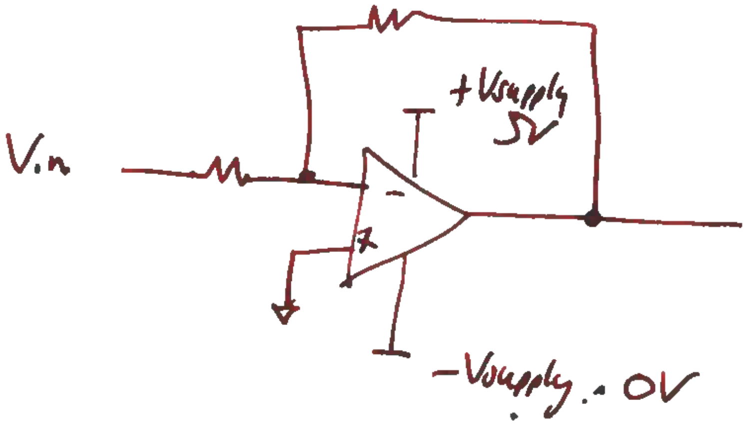
⇒ not defined operation.

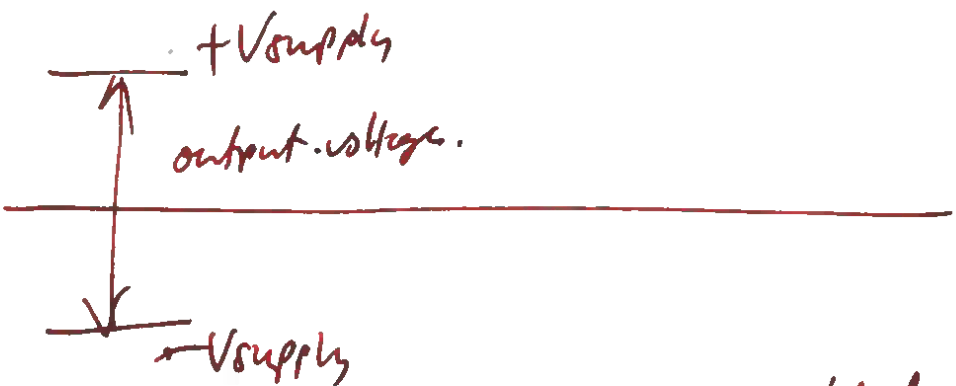
→ double sided power supply

or single side power supply capable op amp.

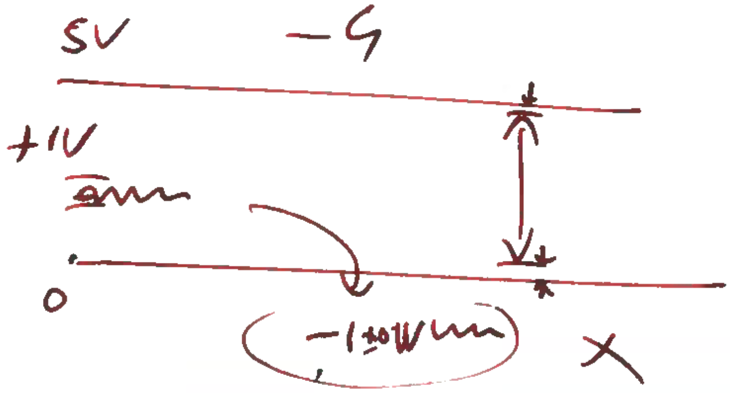


$$\frac{V_{out}}{V_{in}} = G$$





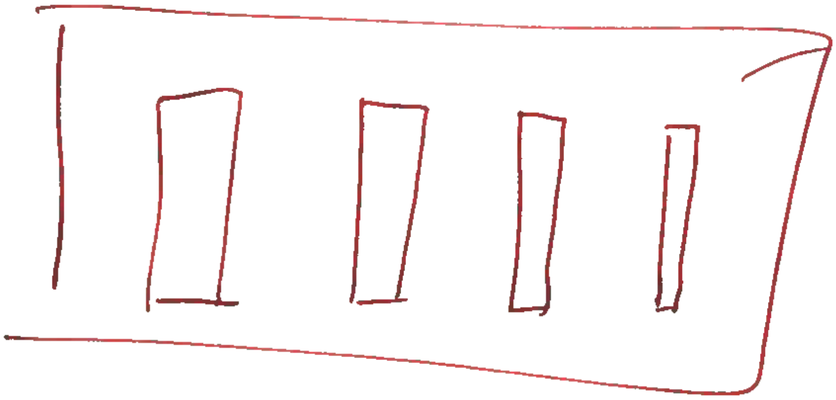
single-sided
opamp operation.



precision design → tight dimension tolerance.

50th → expensive process, do once

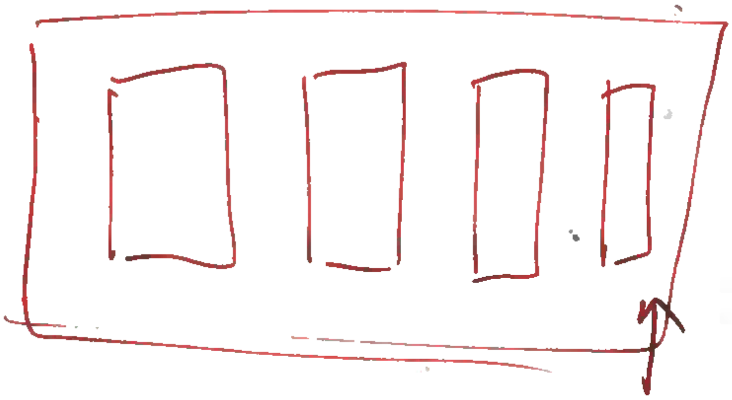
variable process, do many times.



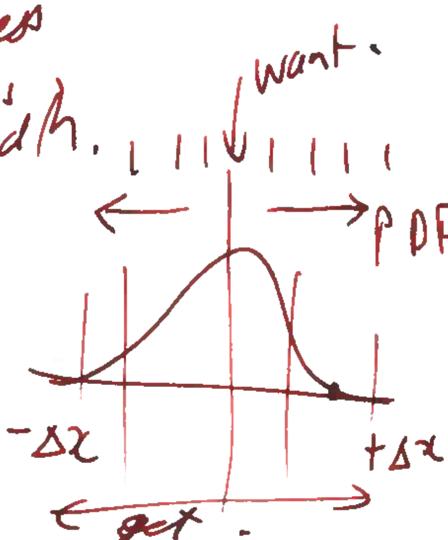
4, 8, 16...

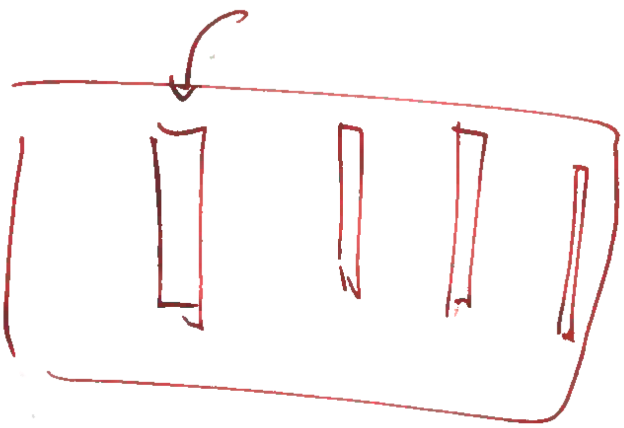
design.

+/- additional width.



process adds width.

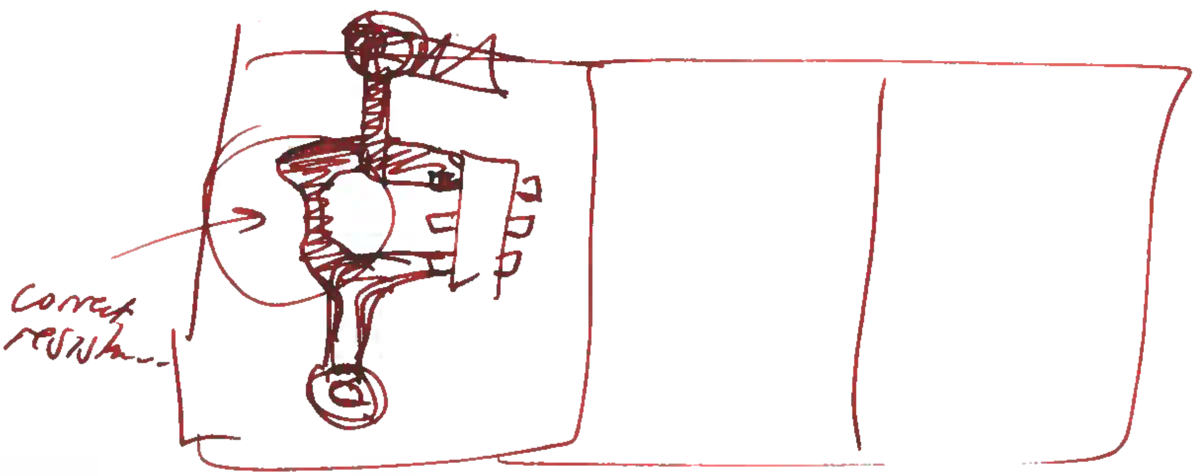




subtract width.

2 std deviation

n times,

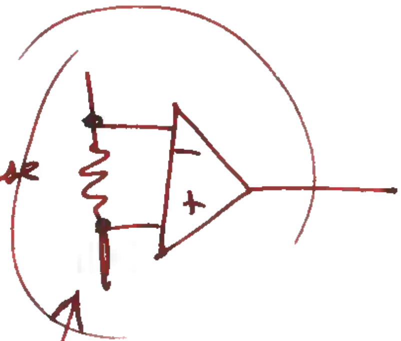


Ammeter
→ low resistance.

1/ patents
2/ journals
3/ application notes.

low noise
precision amplifier design

Rsense



dimensionally
critical.

small steps.

4-stage. — build 1 stage, report measurement.. ✓
" 2 stages, " .. ✓
infer that can add additional stages → but quite a lot of circuitry

so, try different approach.

→ precision current measurement approaches.

try 0.5Ω 0.2Ω 0.1Ω 0.05 0.02Ω 0.01Ω

0.005 0.002 0.001Ω

log scale values.
(1, 2, 5, 10, 20, 50)

how do you make these?!

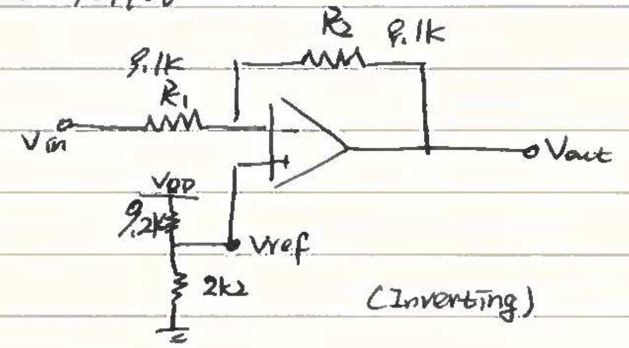
"vernier design"

slightly change dimensions
of the tracks.

or accept variable process, tune something else you can control.

(or trim the structure)

2022/07/06



(Inverting)

$V_{ref} = 5 \times \frac{2.2}{9.2+2.2} \approx 0.965\ V$

Gain $= 1 + \frac{R_2}{R_1} = 1+1 = 2$

V_{in} = sqare wave ... 1.602V / 500mV

freq. 333kHz

~~1.2~~ ~~1V~~ (2.2, 0V)

× V_{out} → measured square wave 4.4V ~ 5V ~~freq: 340kHz~~

$V_- = 500mV$
$V_+ = 0.965 V$

$V_- = 1.6V$
$V_+ = 0.965V$

↕ 0.6V

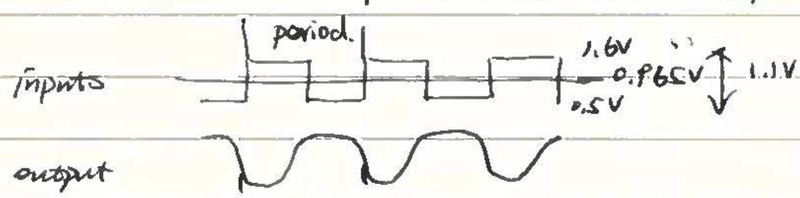
↕ 0.6V ~ (−0.5V)

measured wrong → Input ~~vref~~ V_{ref} = 5V ×

Now → Vout - measured square wave 0.3V ~ 0.9V ~~freq: 666.67kHz~~

~~double × 2~~

freq = 333.3kHz ✓



1.6V
0.965V } 0.63V → 0.3V
0.5V } 0.46V → 0.9V

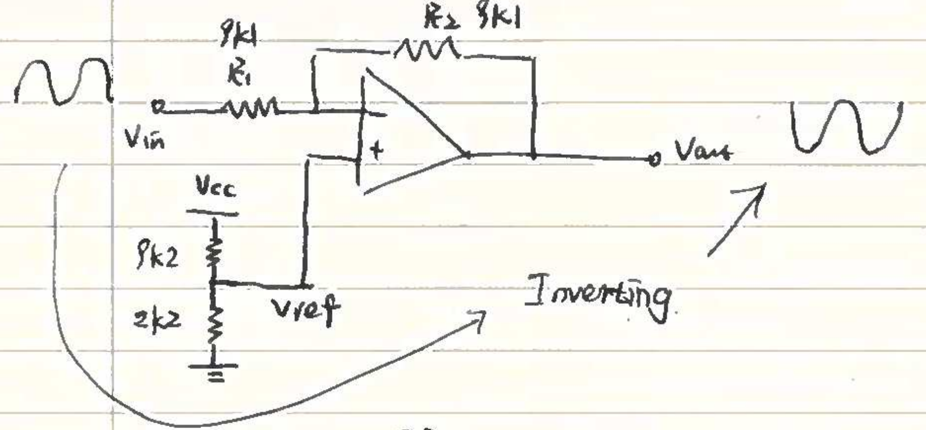
$\frac{R_1 + R_2}{R_1}(V_i + V_{IO})$

2

input offset

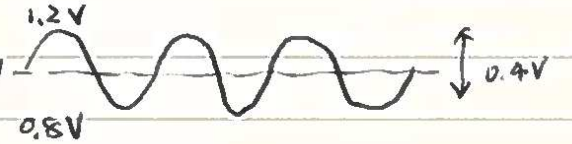
Jupiter 2010 Function Generator → user manual.

The same structure



$V_{ref} = 5 \times \frac{2.2}{9.2+2.2} \approx 0.965$

V_{in} = sine wave → 1V

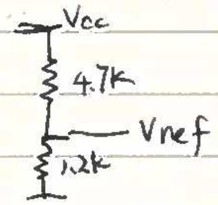


freq = 322.2kHz

V_{out} = 1.8 ~ 2V sine   freq = 322.6 kHz

↕ 0.2V

$V_{output\ offset}$ = 1.9V → ≈ 2×0.965 = 1.930V



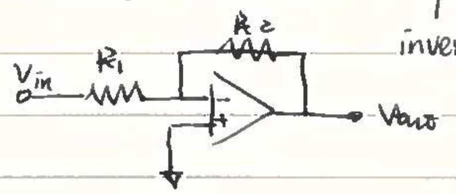
V_{ref} = 1V

V_{in} = 1V offset 0.4mV amplitude

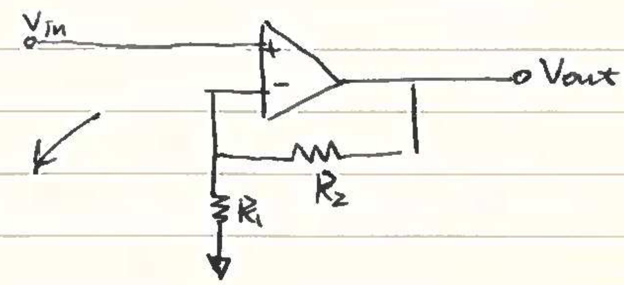
V_{out} = 1.9V offset 0.2mV amplitude

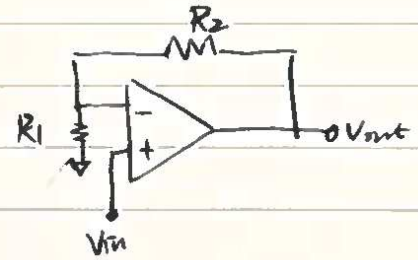
★ Gain calculated wrong: for inverting amplifier $A_v = -\frac{R_2}{R_1}$

↑ inverted

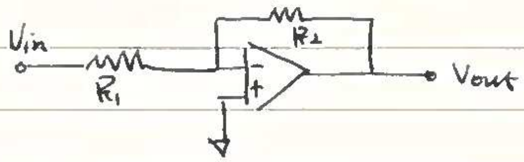


for non-inverting amplifier. $A_v = 1 + \frac{R_2}{R_1}$





Verification by simplest circuit

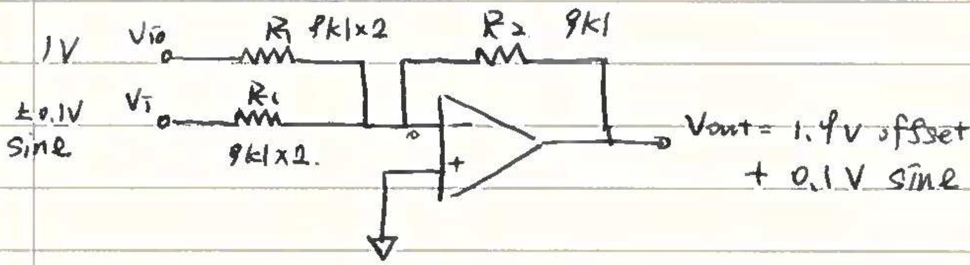


$R_2 = R_1 = 9k1$

Vin = 1V offset with ±0.1V amplitude   0.9 ~ 1.1V.

Vout = 1.8V ~ 2V → 1.9 offset with ±0.1V amplitude.

Vin with offset



$$\frac{V_{out} - V_-}{R_2} = \frac{0 - V_{io}}{R_1}$$

$$V_{out} = -\frac{V_{io}}{R_1} \times R_2$$

$$\frac{V_{out}}{V_{io}} = -\frac{R_2}{R_1} = -\frac{9k1 \times 2}{9k1} = -2$$

inverting but for offset → No effect for inverting,

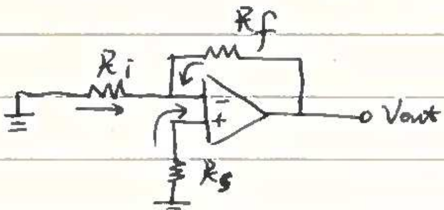
$V_{out\_offset} = 1.9V$ $V_{io\_} = 1V$?   1.9 gain rather than 2

why

⇒ If op-amp input is DC

lets put $V_{in} = 1V\_DC$ ⇒ $V_{out} = 1.9V$

⇒ Amplification for DC input.



bais current → Ri & Rs doesn't match

current different at V- & V+

① Ri & Rs matched

→ current V- & V+ identical

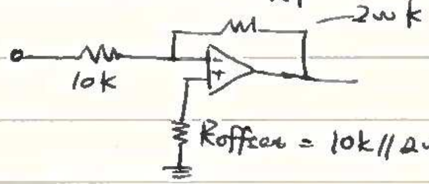
Rs = Ri parallel with Rf → DC offset

Input offset   offset current

$V_{out\_offset} = A_n \times V_{OS} + I_{OS} \times R_f$

noise gain

$A_n = 1 + \frac{R_f}{R_i}$



$R_{offset} = 10k // 200k \approx 9.5K$

Datasheet: $V_{OS} = 5\,mV \rightarrow$ LM741: 15mV.

$I_{OS} = 0.1\,\mu A \rightarrow$ 80~500nA

$\rightarrow A_v = -\frac{R_f}{R_i} = -20$

$A_n = 1 + \frac{R_f}{R_i} = 21$

$V_{outoffset} = \underbrace{21 \times 5mV}_{} + \underbrace{0.1\mu A \times 200k}_{}$

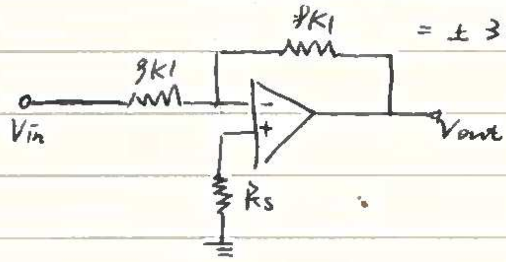
$= 105mV + 20mV$

$= \pm 125mV$

In my case: $V_{outoffset} = 2 \times 15mV + (80\sim500nA) \times 9k1$

$= 30mV + 4.5mV$

$= \pm 34.5mV$



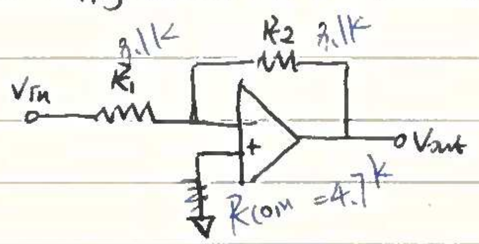
$I_{offset} = \frac{1V}{9k1} = \frac{1}{9k1}\,A$

1 output offset = input.

$\Rightarrow V_{offset} = \frac{1}{9k1} \times R_f$

$= 1V$

Power supply should be double sided $\rightarrow \pm 15V$



$A_v = -\frac{R_2}{R_1} = -1$ gain

$V_{in} = \pm 0.5V$ sine wave with 333.3kHz

$V_{out} = \pm 0.3V$ sine wave.

1.5MHz Bandwidth_typical.