Calvin Passmore

A02107892

ECE 5420

Exam: Analog Circuits

Problem 1

Triode Mode: $id = Kn[Vov * Vds - 0.5 * Vds^2] * (1 + \lambda * Vds)$

$id = 1.5\ mA = (W/L) * Ut * [Vov * Vds - 0.5 * Vds ^ 2] * (1 + \lambda + Vds)$

$i\_target = id * 10$

$Kn\_target * Constants = Kn * Constants * 10$

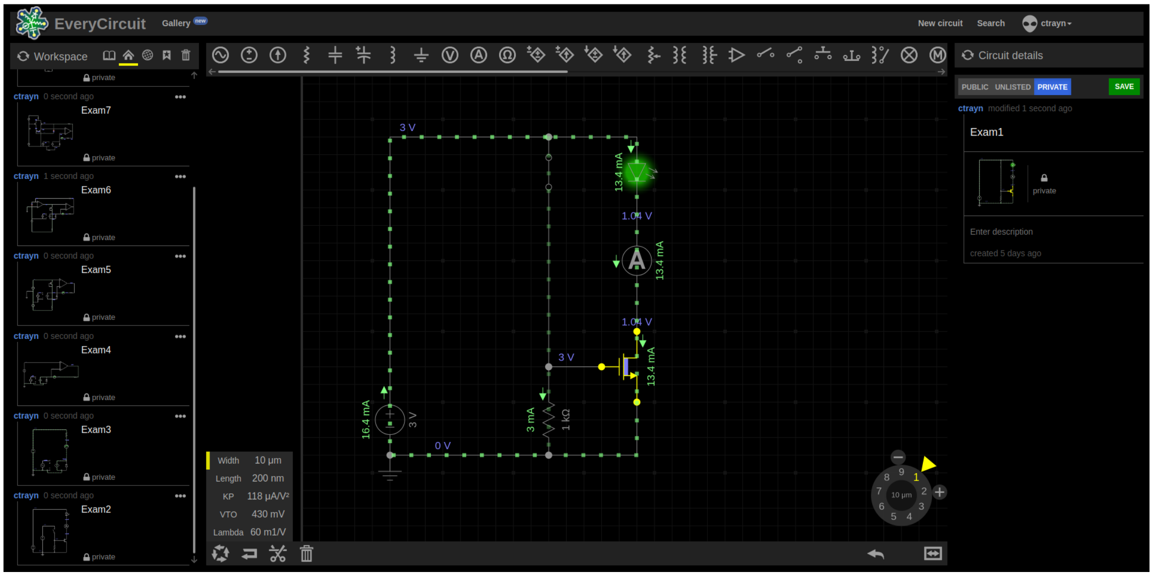
$(W / L) = (W / L) * 10$

$w\_target = w * 10$

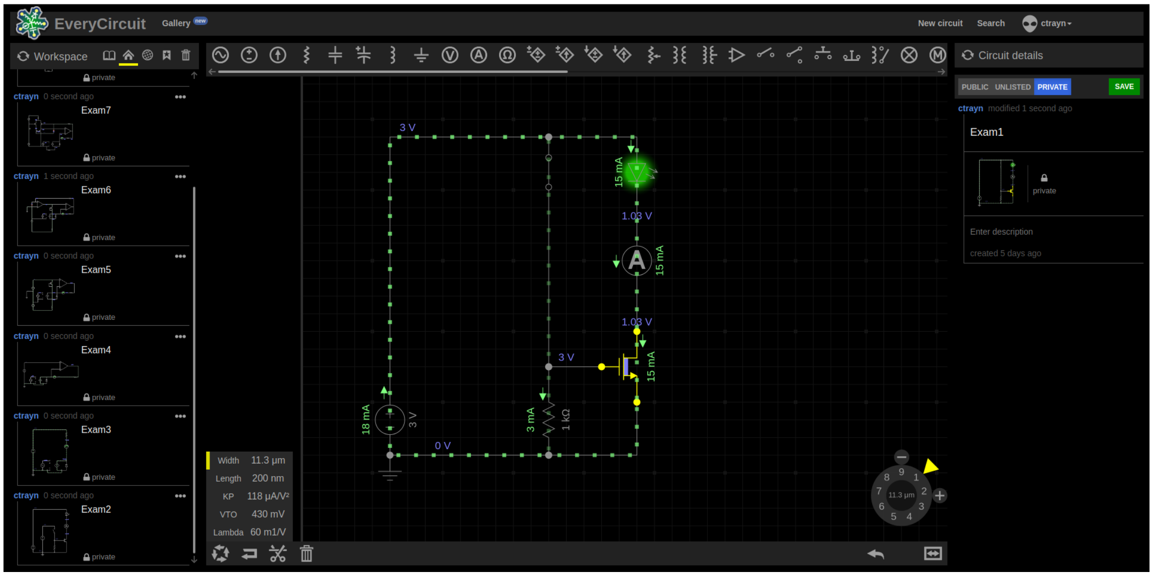
$w = 10\ um$

The simulation matched the calculations fairly closely but was not exact, the simulation gave a width of 11.3 um.

The calculated results:



Adjusting the simulation to give a perfect 15mA:



Problem 2

The NMOS is now in saturation because Vds changed. Vov = Vgs - Vth = 3 - 0.43 = 2.57. Vds = Vdd - Vled = 9 - 2 = 7. Vds > Vov → Saturation.

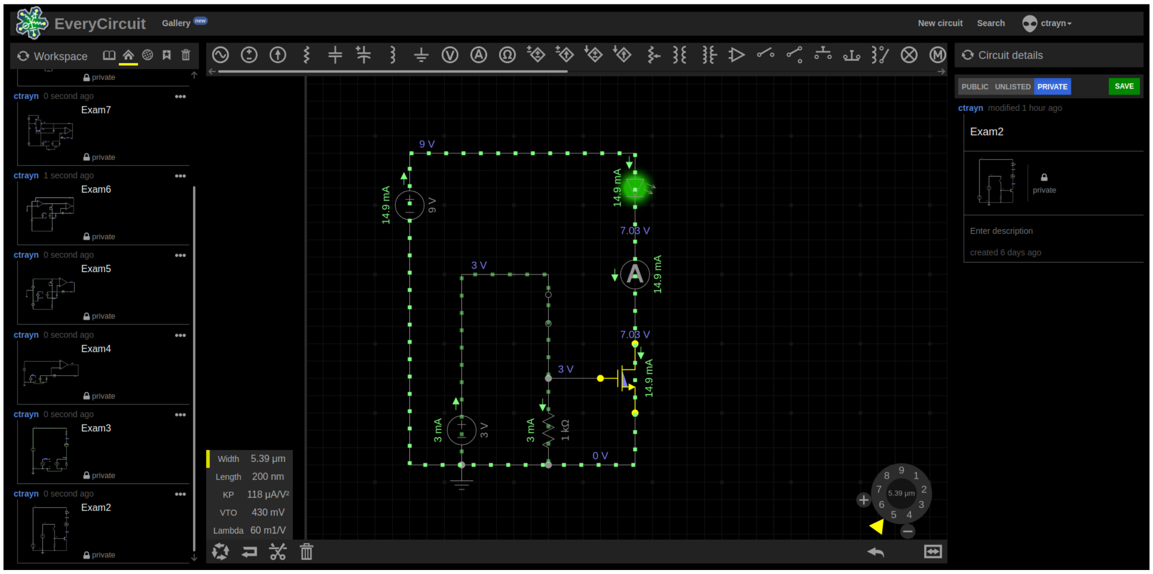
In [ ]:
```
W = 1e-6
L = 0.2e-6
Vgs = 3
Vth = 0.43
Vov = Vgs - Vth
Ut = 118e-6
lam = 0.06
Vds = 7.21  # from EveryCircuit - LED voltage drop

id = 0.5 * W / L * Ut * (Vov**2) * (1 + (lam * Vds))
print(id)
```

```
0.0027913430232999995
```

In [ ]:
```
i_target = 15e-3
w_target = W * (i_target / id)
print(w_target)
```

```
5.373757318535004e-06
```

Using the ratio of the calculated current, and the desired current, we can get a target width of 5.37 um. Verifying with EveryCircuit gives a width of 5.343



If Vds is changed to 12, and 24. The currents are as follows

In [ ]:
```
V12 = 12 - 2 # subtract 2 for the LED
V24 = 24 - 2

i12 = 0.5 * w_target / L * Ut * (Vov**2) * (1 + (lam * V12))
i24 = 0.5 * w_target / L * Ut * (Vov**2) * (1 + (lam * V24))

print(i12)
print(i24)
```

```
0.016752757224626555
0.024291497975708495
```

To explain my prediction, we just changed the Vds value in accordance with the channel length modulation.

Vds = 12v → id = 16.75 mA Vds = 24v → id = 24.29 mA

The EveryCircuit demo gives value of

Vds = 12v → id = 16.9 mA Vds = 24v → id = 24.5 mA

The small discrepency can be attributed to the slight difference of the new w value

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Problem 3

Maximum signal amplitude:

In [ ]:
```
Vin_max = 2 # v
DC = 2   # v
iph_max = 100e-6 * (Vin_max + DC)
```

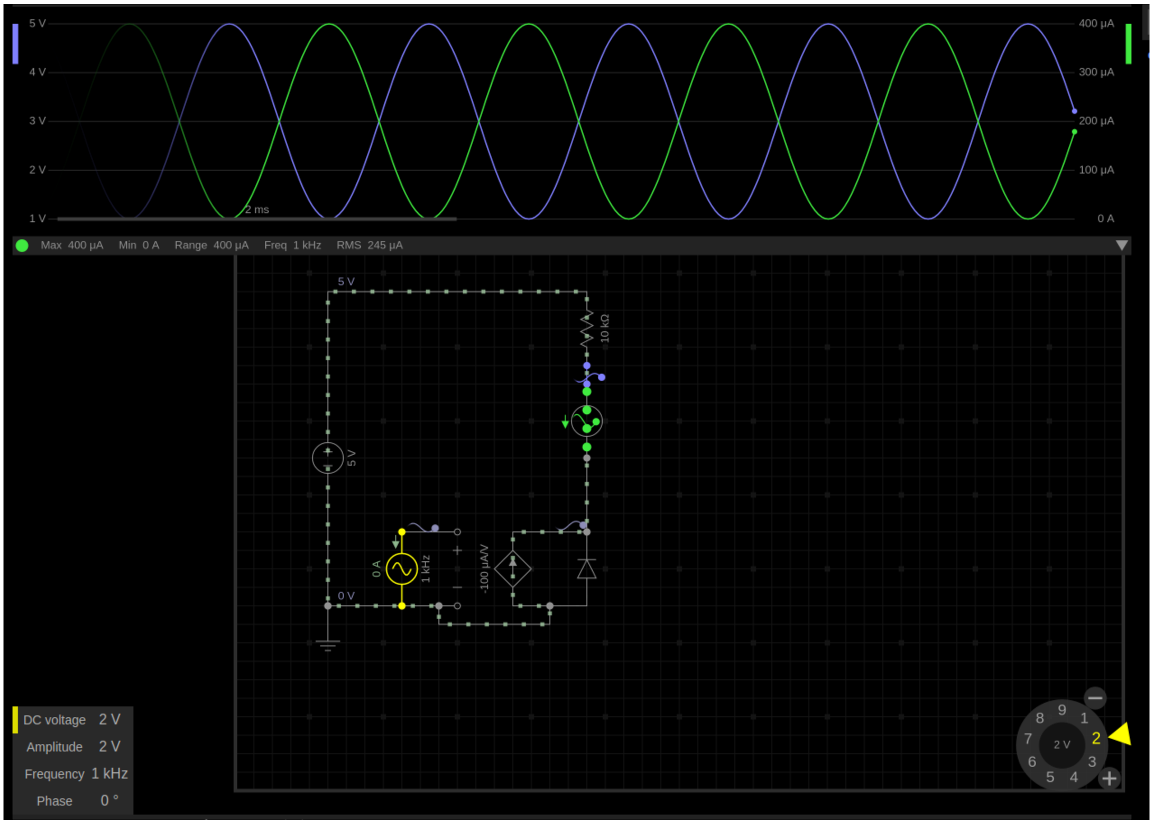
```
print(iph_max)
```

```
0.0004
```

Max signal amplitude = 400 uA

EveryCircuit max signal amplitude = 400 uA

Min Voltage = Vdd - Imax*R = 5 - 400u* 10k = 5- 4 = 1 v



Now adding the ambient light as 2V DC

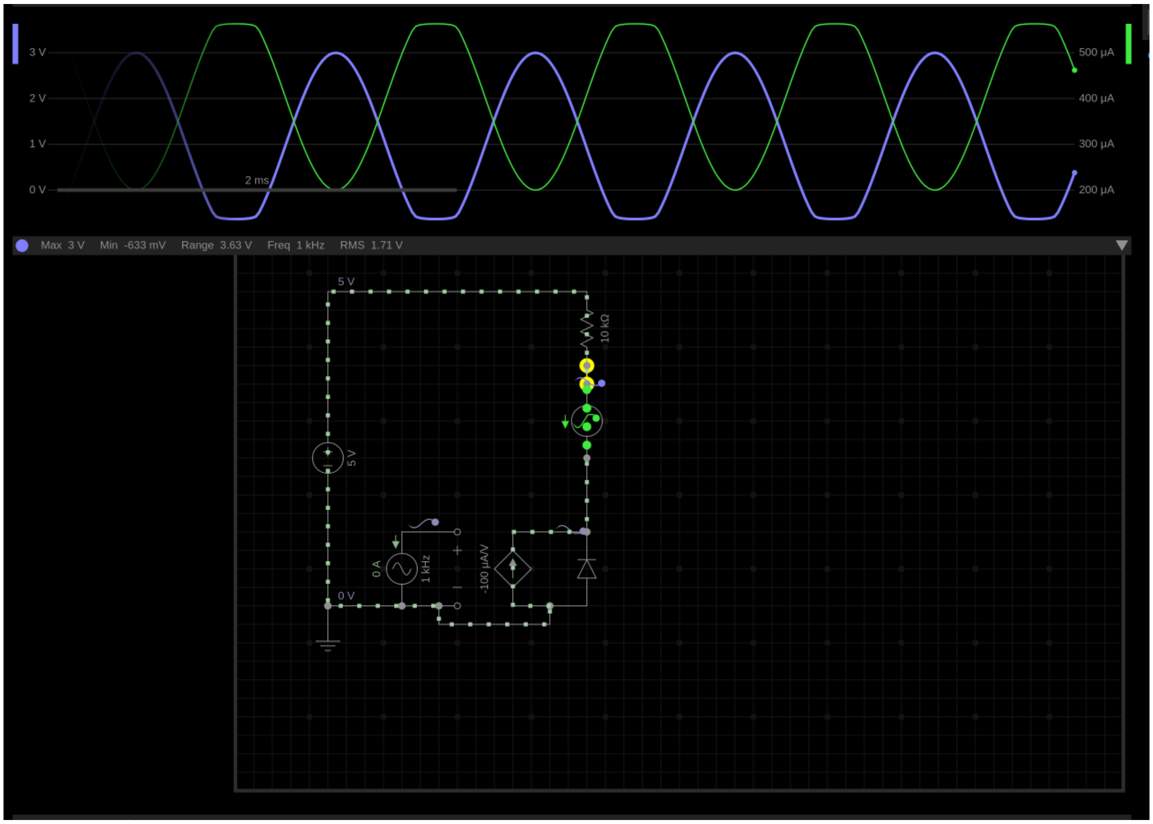
In [ ]:
```
DC = 4
iph_max = 100e-6 * (Vin_max + DC)

print(iph_max)
```

```
0.0006000000000000001
```

Max signal amplitude = 600 uA

Everycircuit max signal amplitude = 563 uA

Min Voltage = Vdd - (Imax * R - (Iled)) = 5 - (600u * 10k - Iled) = 5 - 6 - Iled * R = -1 * Iled*R v. So this would be -1 v except it activates the forward bias of the photodiode.



The difference is that when the current gets large enough, its creating a negative voltage (creating more than 5V) so the photodiode is becoming forward biased and letting current through that offsets some of the light driven current.

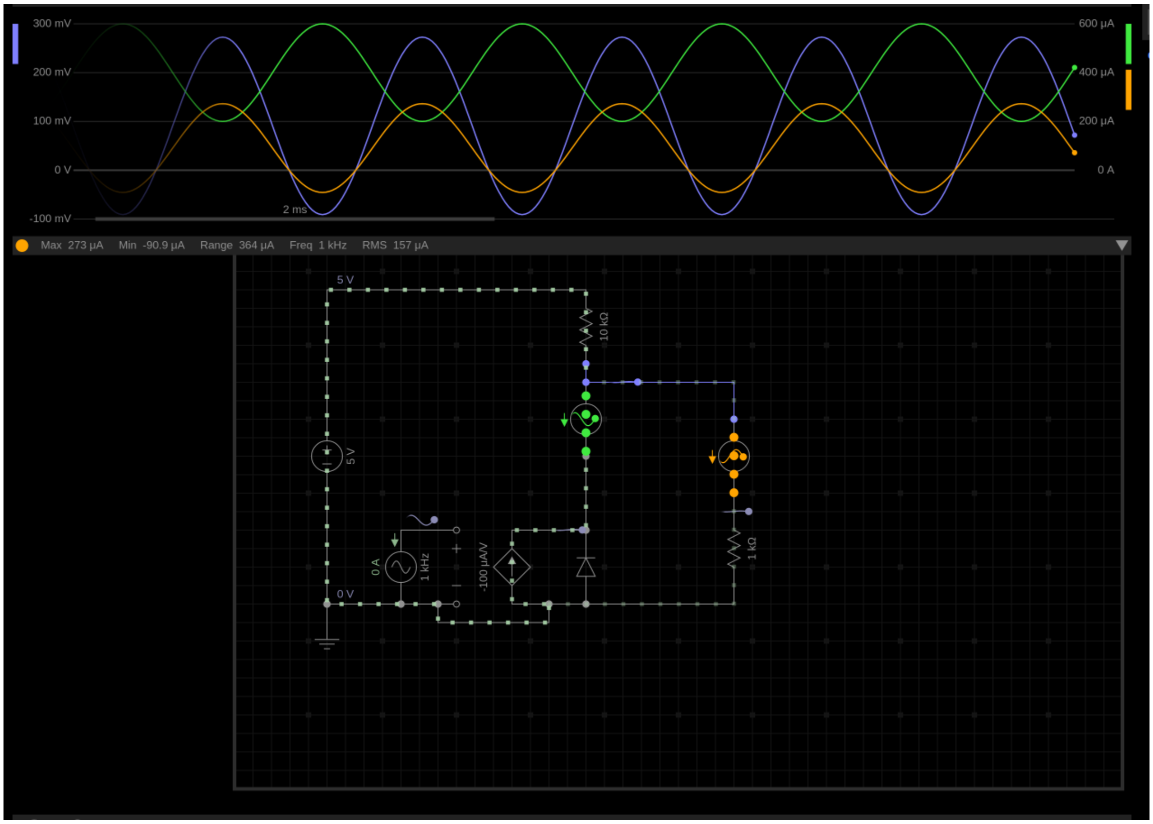
Generalized equation:

Imax = 100uA * (Vin_max + DC) when Vin_max is small

Imax = 100uA * (Vin_max + DC) - Iled when Vin_max is close to or larger than VDD

Attach a load

When a load is attached, it consumes some of the current at the Vout, decreasing Vout. This prevents Vout from getting close to the LED forward bias voltage and not allowing the photodiode to have voltage



Problem 4

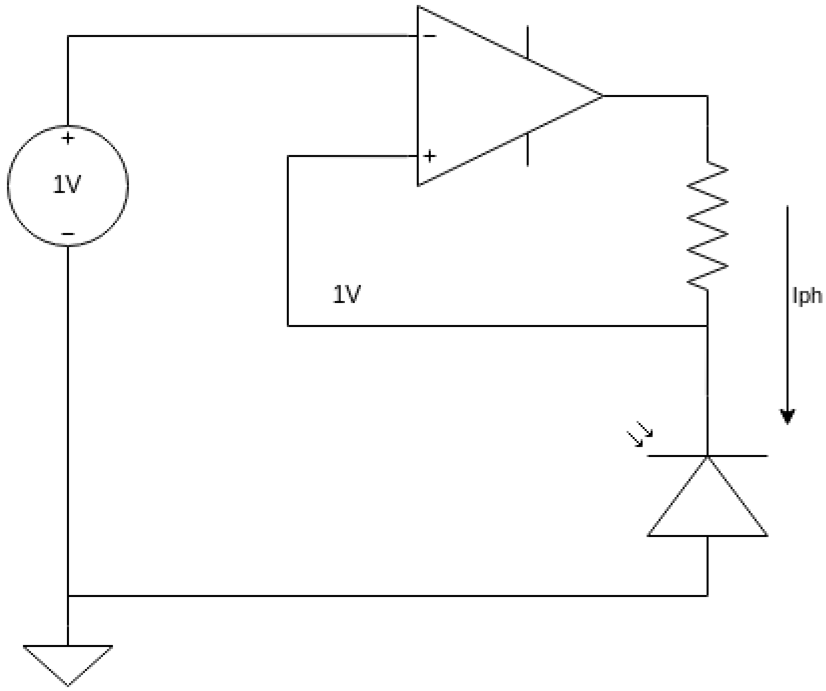
Advantage:

- Can maintain a higher amplitude without a load, decouples the output from VDD

Disadvantage:

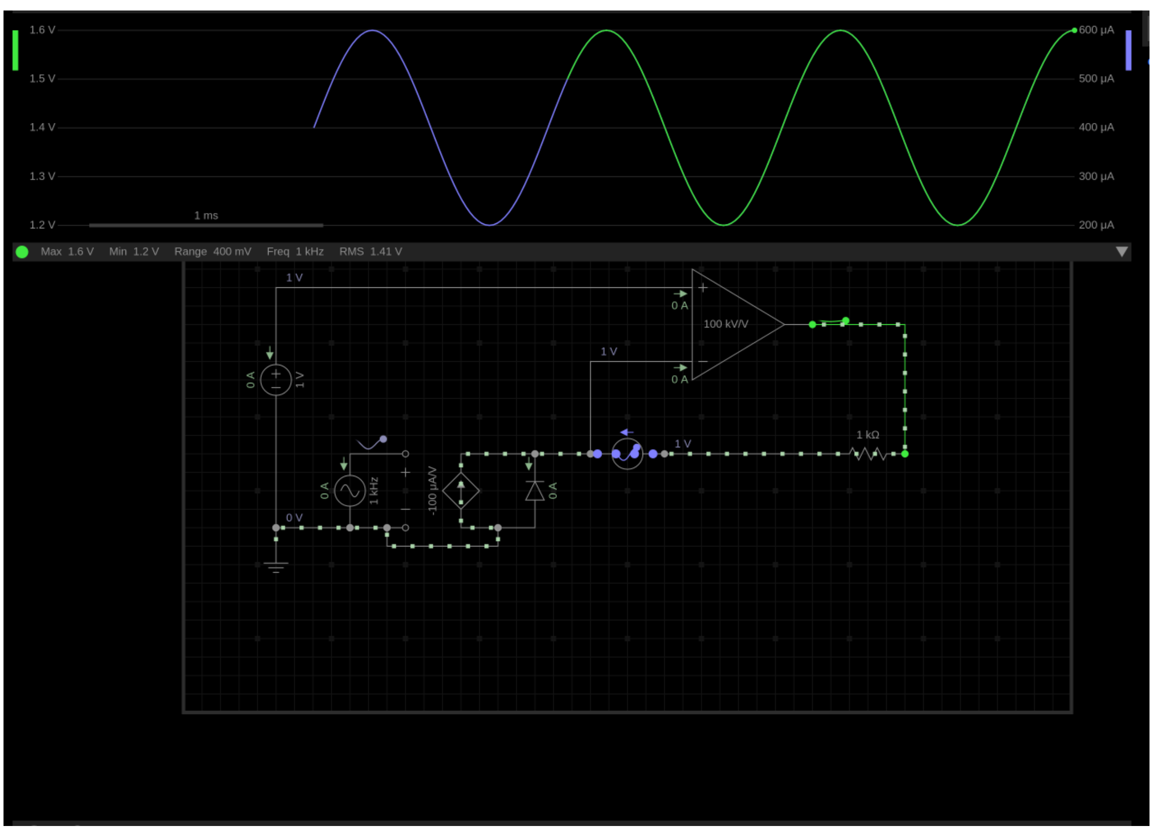
- More parts

Maximum Signal Amplitude



The above drawing shows that when the current is moved through the resistor the voltage at the end of the op amp will be fluctuating at Iph * R + 1

Imax = 100u * (Vmax + DC) = 100u * (2 + 2) = 400 u

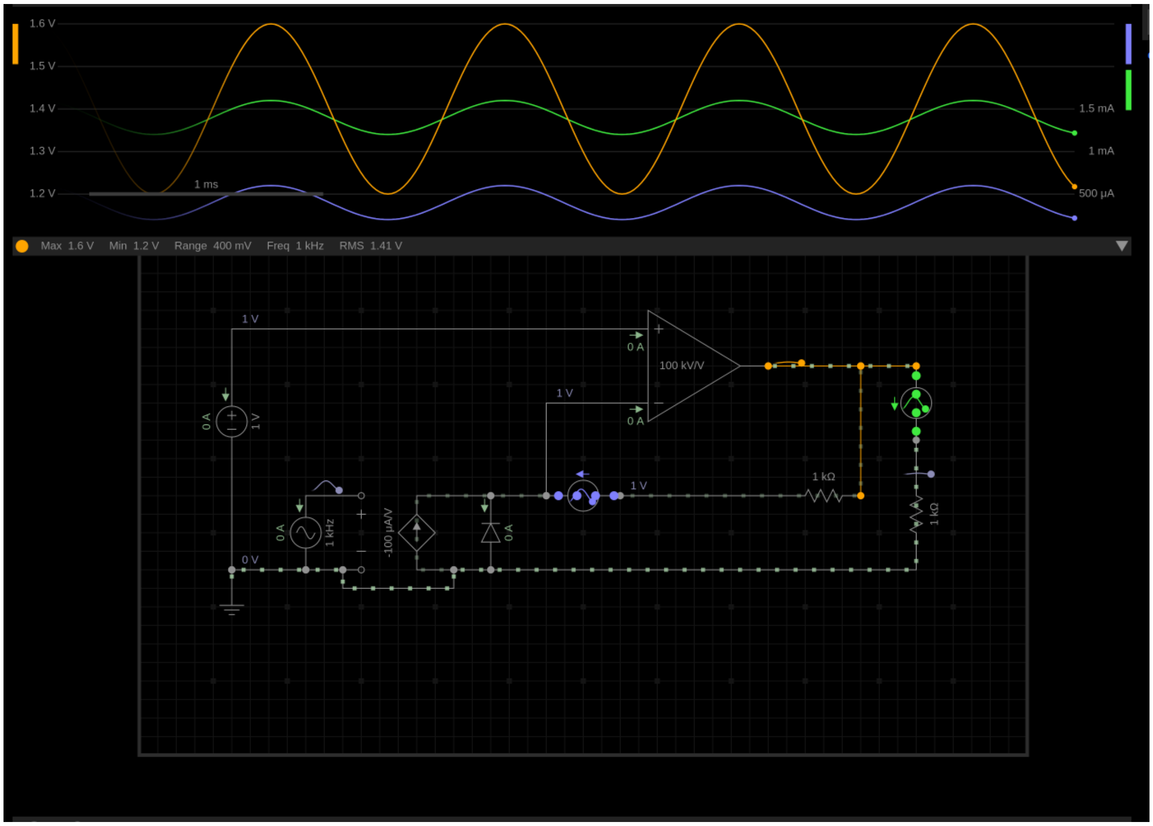


Imax = 100u * (Vmax + DC) = 100u * (2 + 4) = 600u

Generalized Imax = Gain * (Vmax + DC_ambient)

Attach a load

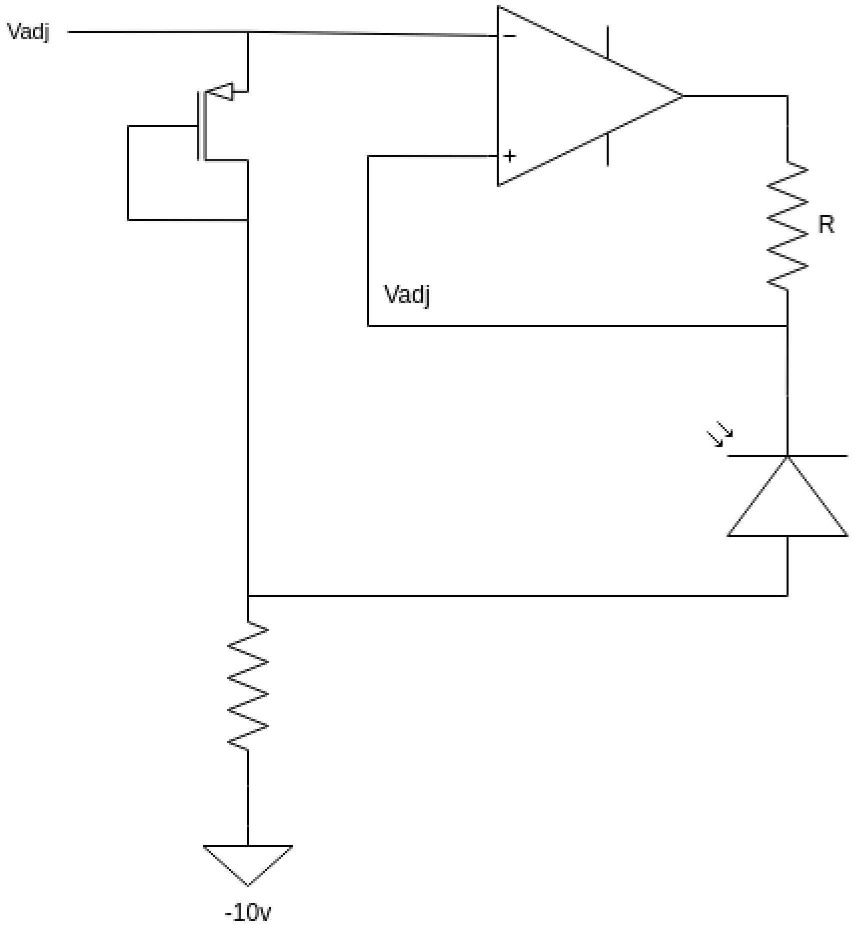
When a load is attached, the current passing through the photodiode, and the resistor, is not changed. Therefore Vout is not changed when the load is applied. This is a huge advantage, that the load is decoupled from Vout.



Differences

The biggest differences, besides the components, is that the load has been decoupled from Vout. So Vout is no longer affected by what is happening at the load.

Problem 5



Ib = 0.5 * Kp * Vov^2 = 0.5 * Kp * (Vgs - Vthp) ^ 2 = 0.5 * Kp * (Vx - Vthp) ^ 2

Vx = R * (Ib + Ia)

0 = Vx^2 * Kp - Vx / R - Kp * Vthp + Kp * Vthp^2 + Ia

In [ ]:
```
from math import sqrt

Kp = 30.3 # From EveryCircuit
R = 1e3
Vthp = 400e-3 # From EveryCircuit

Vin_max = 2
Vdc = 2

Ia = 100e-6 * (Vin_max + Vdc)

A = Kp
B = 1 / R
C = -Kp * Vthp + Kp * Vthp**2 + Ia

Vx1 = (-B + sqrt(B**2 - 4 * A * C)) / (2 * A)
Vx2 = (-B - sqrt(B**2 - 4 * A * C)) / (2 * A)

print(Vx1)
print(Vx2)
```

```
0.48986797345817357
-0.48990097675850364
```

Vx = 0.490 v

In [ ]:
```
Ib = 0.5 * Kp * ((Vx1 - Vthp)**2)
print(Ib)
```

```
0.12235522770020663
```

IB = 122.4 mA

Generalize Vout

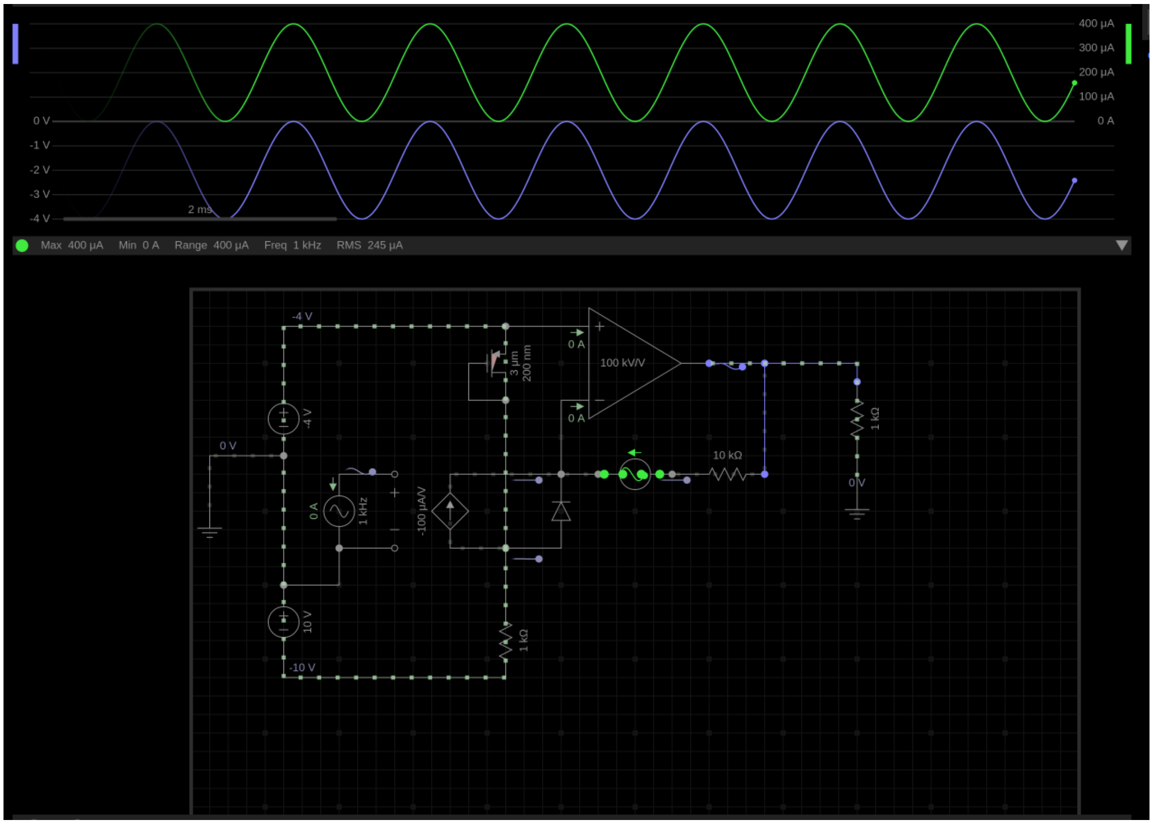
Vout = (Iph * R) + Vadj = (100u * (Vin_max + V_dc_ambient) * R) + Vadj

What is the PMOS doing

The PMOS is keeping the photodiode in reverse bias. This allows Vadj to be changed to the necessary value while keeping the photodiode in reverse bias.

Loaded Vout

When a load is applied to Vout, Vout is unchanged. This is done by keeping the photodiode in reverse bias, as well as isolating Vout from the rest of the circuit with the OpAmp.

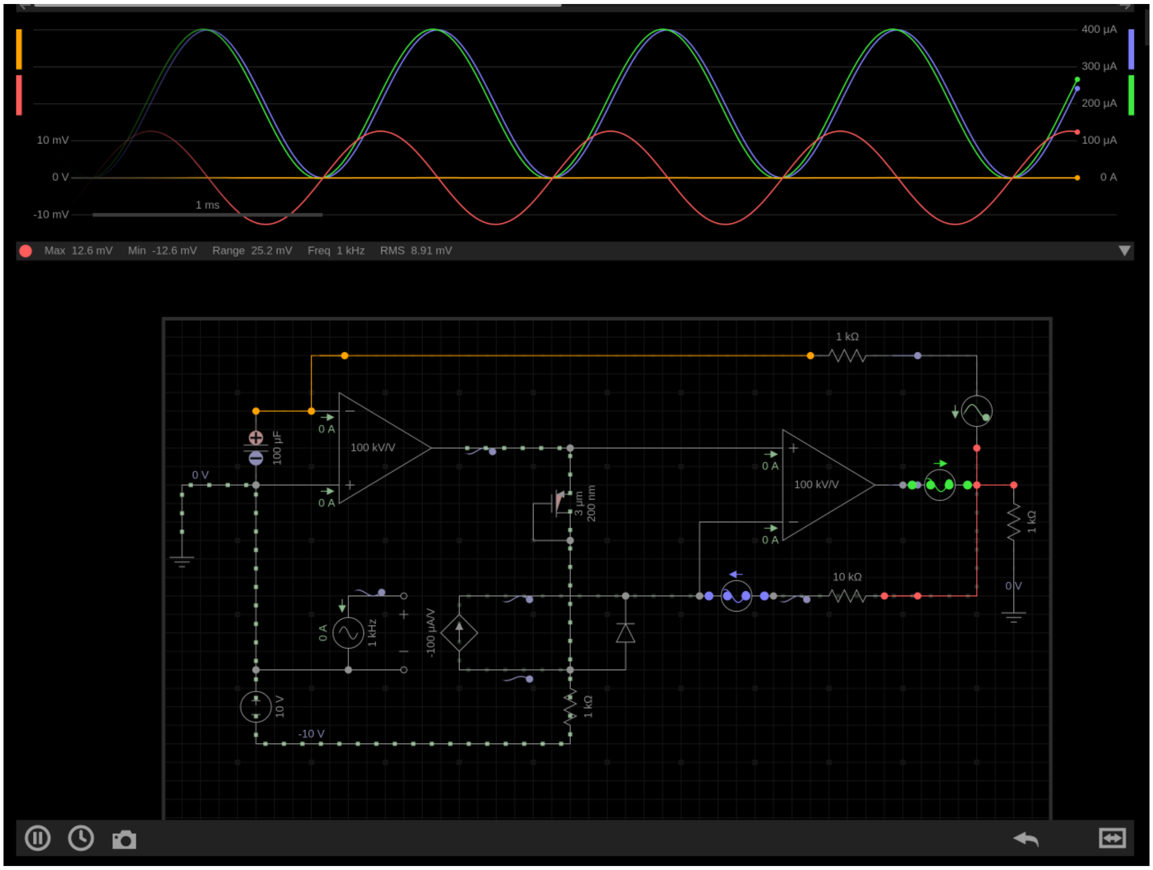


Problem 6

This circuit works by charging/discharging the capacitor to keep the output of the OpAmp at the appropriate 'Vadj' level, offsetting the output voltage to keep Vout centered at 0v.

Imax = 100u * (Vmax + Vdc) = 100u * (4) = 400 uA

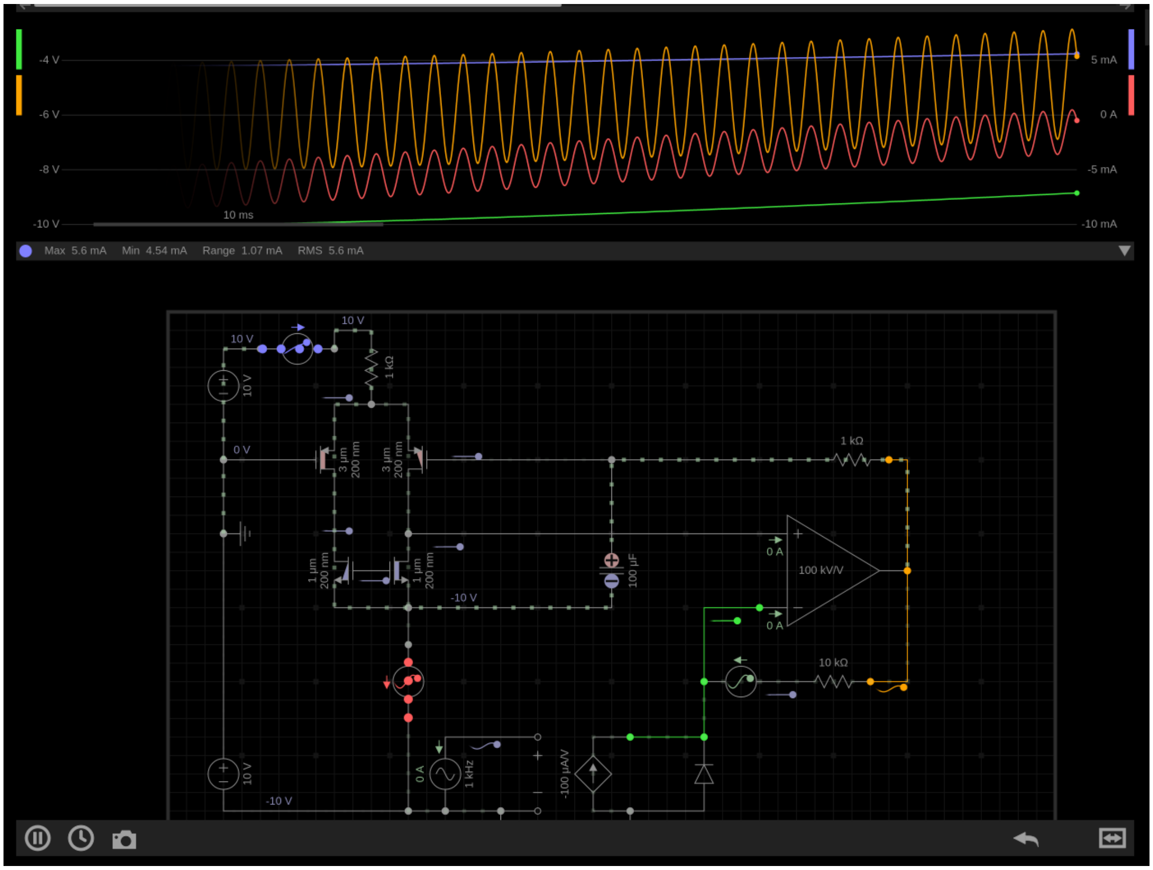
With a load, the current would stay the same, so Vout would remain the same as without a load.



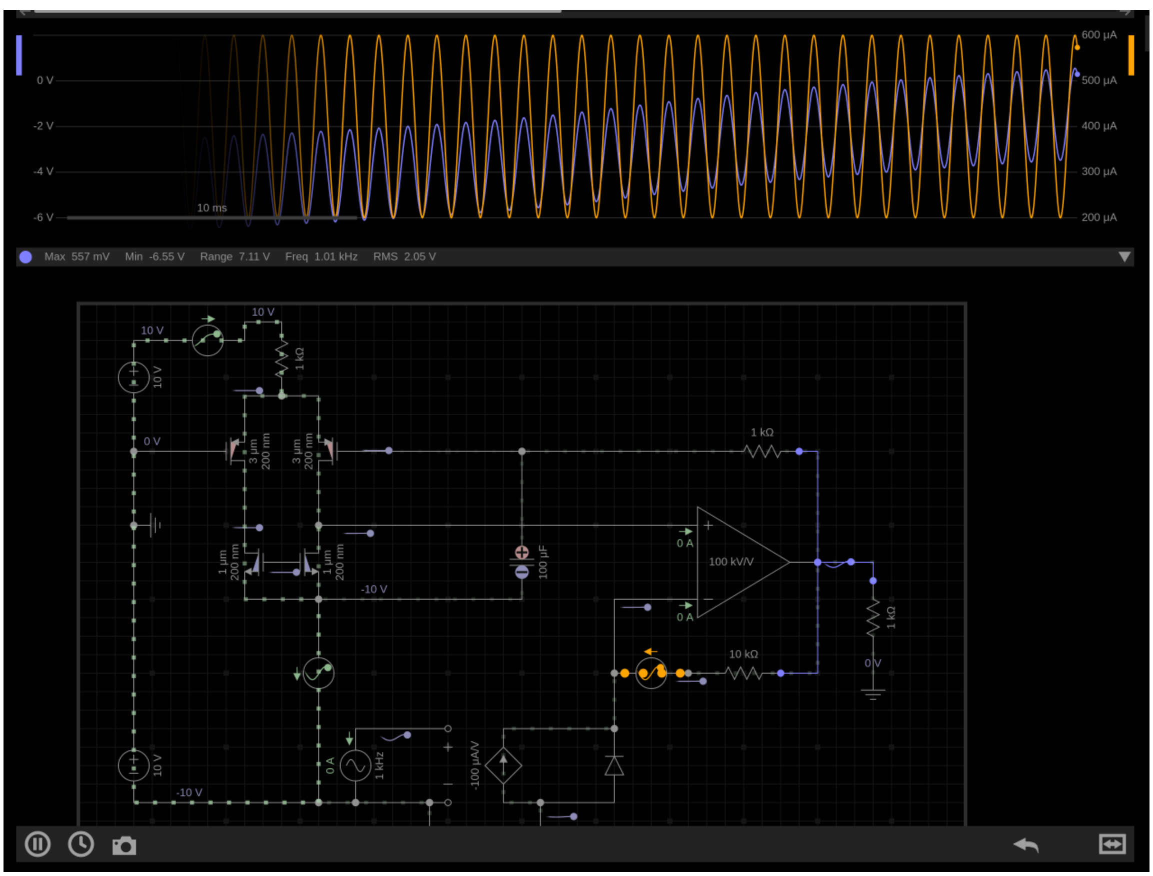
Problem 7

The circuit works by charging up the capacitor in the middle, slowly increasing Vout. Since the current from the photodiode is constant, the voltage across the resistor above the opamp is leveling out to be even with Vout. After that Vout becomes stable with that voltage, this is when the capacitor is fully charged.

Iph = 100u * (Vinmax + Vdc) = 400uA



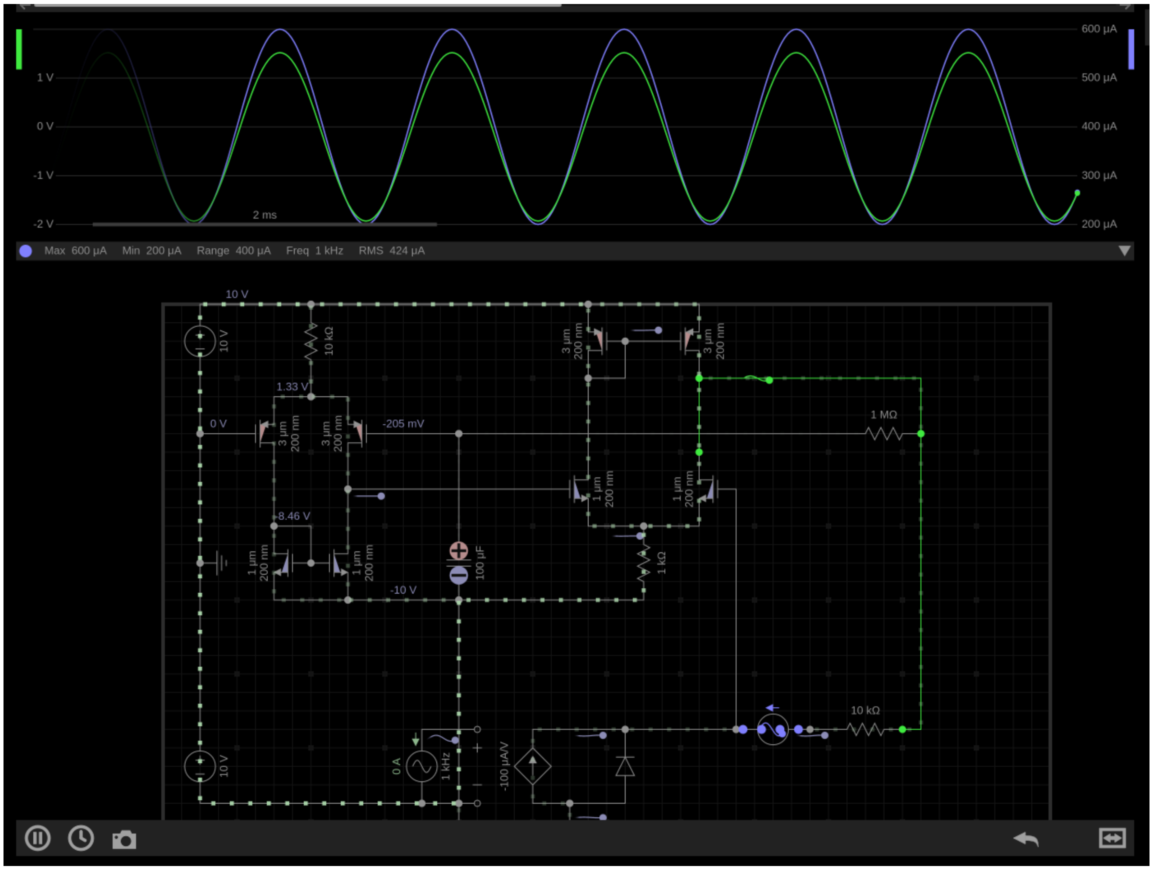
Loading Vout still charges the capacitor until it's 'full'and then Vout is stable. Adding a load does change the rate of charge, however.



Problem 8

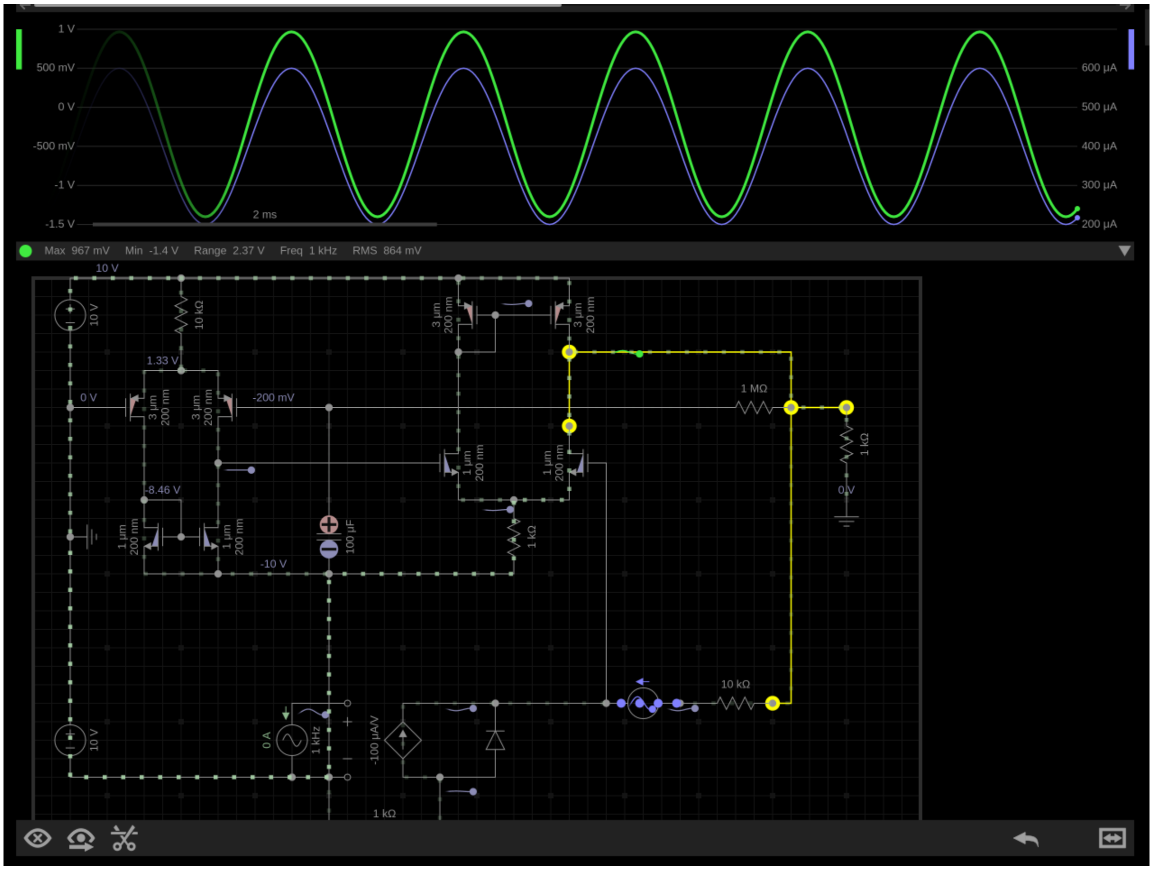
An NMOS OTA is used for the primary Op Amp because it can provide a voltage closer to 0, and a PMOS OTA is used for ambient cancellation because it provides the voltage to offset Vout (pull up).

Since there are no feedback lines directly from the output to the input, an OTA performs almost the same as a primary OpAmp.



Iph = 100u * (Vinmax + Vdc) = 400uA

When Vout is loaded, it does change Vout slightly. This is because of the non-idealities of the OTA vs the OpAmp, but it was still fairly close to the unloaded Vout.


1 V
500 mV
0 V
-500 mV
-1 V
-1.5 V
600 µA
500 µA
400 µA
300 µA
200 µA
2 ms
Max 967 mV Min -1.4 V Range 2.37 V Freq 1 kHz RMS 864 mV
10 V
10 kΩ
1.33 V
0 V
-200 mV
1 MΩ
1 kΩ
-8.46 V
100 µF
-10 V
10 kΩ
0 A
1 kHz
-100 µA/V
1 kΩ