EE230: Labwork-5
Simple Application Circuits

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1 Overview of the experiment

1.1 Aim of the experiment

To understand the design and workings of some simple application circuits by simulating their models in NGSpice and observing their outputs.
The application circuits are as follows:

1. Photodiode application circuit using op-amp LM324
2. 3 Op-amp based Instrumentation Amplifier

1.2 Methods

We first implemented the netlist circuits for the photodiode circuit (using op-amp LM324) and the instrumentation amplifier by simulating their models in NGSpice.
Next we observed their output voltages for various input voltages while performing DC and transient analysis. We also analysed the gain plot for the photodiode.
We observed various parameters for these models (such as the current I_1 in the photodiode model and V_{cm} in the instrumentation amplifier) and how these parameters affect the working of the models.

2 Design

2.1 Photodiode Amplifier Circuit

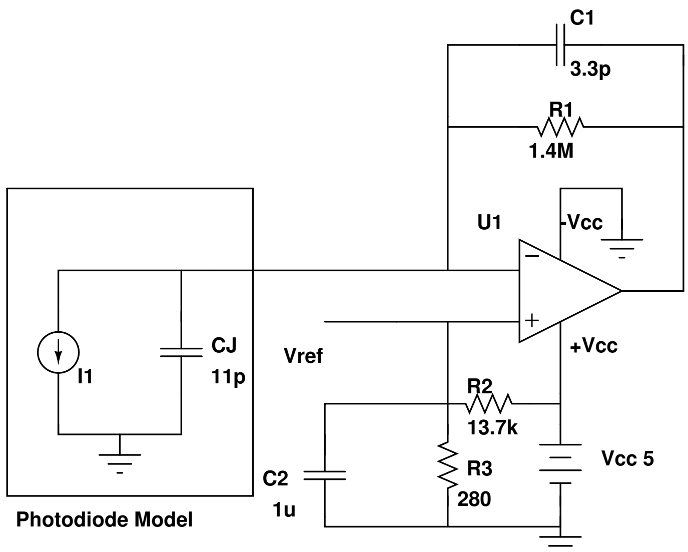

Figure 1: Photodiode Amplifier Circuit

The overall circuit consists of a photodiode model connected to the inverting terminal of the modified difference amplifier. The photodiode model consists of a current source $I1$ and a capacitor CJ connected in parallel.

2.2 Instrumentation Amplifier

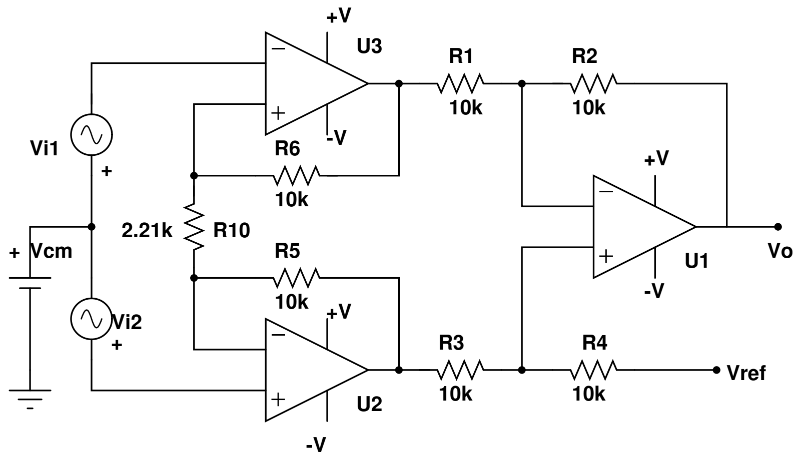

Figure 2: Instrumentation Amplifier

The instrumentation amplifier consists of three op-amps connected to each other as shown in the figure 2 above. Note that all the resistors (except for the resistor R10) have the same resistance to provide balance in the circuit.

3 Simulation results

3.1 Code snippet

3.1.1 Photodiode Amplifier Circuit

Part A:

```
Lab 5 Q1 A

.include lm324.txt

r1 1 4 1.4Meg
r2 2 3 13.7k
r3 2 0 280
c1 1 4 3.3p
c2 2 0 1u
cj 1 0 11p

x1 2 1 3 0 4 lm324

vcc 3 0 5
vref 2 0 0.1

i1 1 0 0.1u

.dc i1 0 2.4u 0.1u
.control

run

plot v(4)

.endc
.end
```

Part B:

```
 Lab 5 Q1 B

.include lm324.txt

r1 1 4 1.4Meg
r2 2 3 13.7k
r3 2 0 280
c1 1 4 3.3p
c2 2 0 1u
cj 1 0 11p

x1 2 1 3 0 4 lm324

vcc 3 0 5
vref 2 0 0.1

i1 1 0 1.5u ac 1


.ac dec 10 1 100Meg
.control
run

plot vdb(4) xlog
plot 20*log10(abs(ac.v(4))) xlog
* plot 20*log10(abs(ac.v(2))) xlog

.endc
.end
```

3.1.2 Instrumentation Amplifier

Part A:

```
Lab 5 Q2 A

.include ua741.txt

v1 3 0 15
v2 4 0 -15
v3 9 0 15
v4 10 0 -15
v5 14 0 15
v6 15 0 -15
vref 6 0 0

vi1 17 7 0
vi2 17 12 0
vcm 17 0 2

r1 11 2 10k
r2 2 5 10k
r3 16 1 10k
r4 1 6 10k
r5 13 16 10k
r6 8 11 10k
r10 8 13 2.21k

x1 1 2 3 4 5 ua741
x2 7 8 9 10 11 ua741
x3 12 13 14 15 16 ua741

.dc vcm -2 2 0.1
.control
run
plot v(5)/(v(7)-v(12))
.endc
.end
```

Part B:

```
 Lab 5 Q2 B

.include ua741.txt

v1 3 0 15
v2 4 0 -15
v3 9 0 15
v4 10 0 -15
v5 14 0 15
v6 15 0 -15
vref 6 0 0

vi1 17 7 0
vi2 17 12 0
vcm 17 0 2

r1 11 2 10k
r2 2 5 10k
r3 16 1 10k
r4 1 6 10k
r5 13 16 10k
r6 8 11 10k
r10 8 13 2.21k

x1 1 2 3 4 5 ua741
x2 7 8 9 10 11 ua741
x3 12 13 14 15 16 ua741

.dc vcm -2 2 0.1
.control
run

plot v(5)
.endc
.end
```

Part C:

```
 Lab 5 Q2 C

.include ua741.txt

v1 3 0 15
v2 4 0 -15
v3 9 0 15
v4 10 0 -15
v5 14 0 15
v6 15 0 -15
vref 6 0 0

vi1 7 17 sin(0 250m 1k 0 0v0)
vi2 12 17 sin(0 250m 1k 0 0 180)
vcm 17 0 0

r1 11 2 10k
r2 2 5 10k
r3 16 1 10k
r4 1 6 10k
r5 13 16 10k
r6 8 11 10k
r10 8 13 2.21k

x1 1 2 3 4 5 ua741
x2 7 8 9 10 11 ua741
x3 12 13 14 15 16 ua741

.tran 0.01ms 10ms
.control
run

plot v(7)-v(12) v(5)
.endc
.end
```

3.2 Simulation results

3.2.1 Photodiode Amplifier Circuit

Part A:

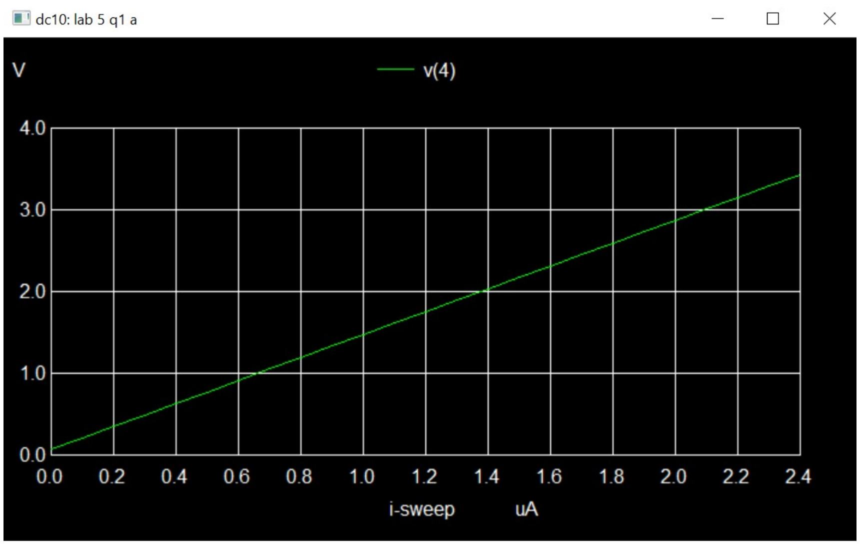

Figure 3: Photodiode : V_{out} vs I_L

Here we performed DC analysis for the circuit by sweeping the current I_1 from 0A to 2.4uA in steps of 0.1uA with $V_{ref} = 0.1$V.
We observe that the output voltage increases linearly with the current I_1 and attains a value of 3.42V at $I_1 = 2.4$uA.

Part B:

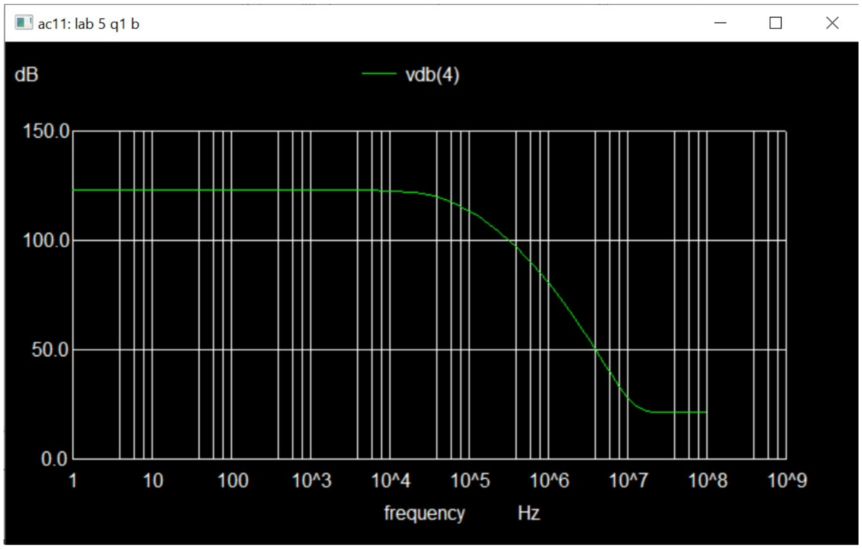

Figure 4: Photodiode : AC analysis with gain plot

We performed AC analysis by biasing the current source at 1.5uA. We plotted the gain of the circuit (in dB scale) by varying the frequency from 10Hz to 100MHz.
The 3dB down cut off frequency as observed from the above graph is 120dB.
From this, we observe that the bandwidth is **38kHz**.

3.2.2 Instrumentation Amplifier

Part A:
Theoretical Differential Gain of the circuit:
Observe figure 2 as shown in the section 2.2 above.
Op-amps U2 and U4 are non-inverting amplifiers.
Therefore, the output of op-amp U2 is given by:

$$Vout_{u2} = V.(1 + \frac{R5}{R10}) \tag{1}$$

Therefore, the output of op-amp U3 is given by:

$$Vout_{u3} = V.(1 + \frac{R6}{R10}) \tag{2}$$

Op-amp U1 is a difference amplifier. The overall gain of the circuit is given by the expression:

$$\frac{Vout}{V} = (Vout_{u2} - Vout_{u3})\frac{R4}{R3} \tag{3}$$

$$\frac{Vout}{V} = -(1 + \frac{2R6}{Rg})\frac{R4}{R3} \tag{4}$$

Note: Here, R6 = R5 = 10k ohms.
Substituting the values for R6, Rg, R4 and R3:

$$\frac{Vout}{V} = -(1 + \frac{20}{2.21}) = -(1 + 9.049) \tag{5}$$

$$\therefore Gain = \frac{Vout}{V} = -10.05 \tag{6}$$

Therefore, the theoretical differential gain of the circuit is **-10.05**.

Part B:

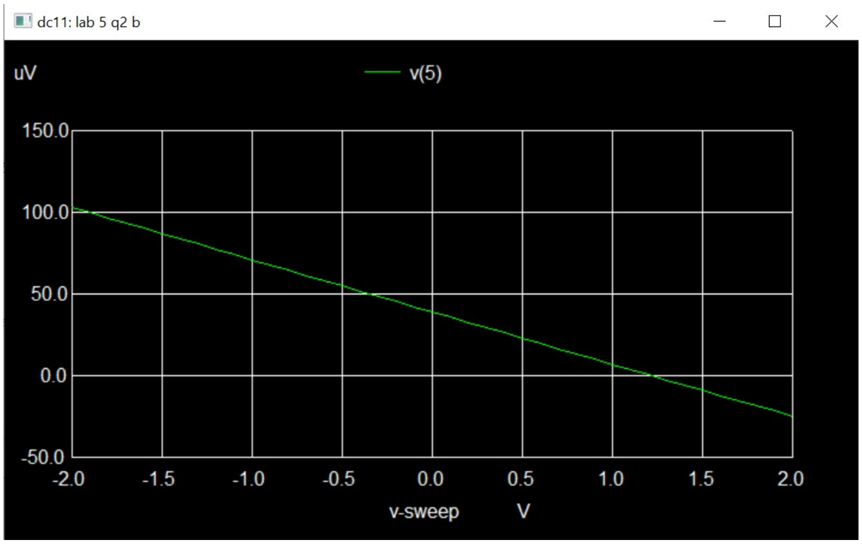

Figure 5: Instrumentation Amplifier : DC analysis by sweeping V_{cm}

For the simulation, we keep Vi1 = Vi2 = 0V.
Then we perform DC analysis by sweeping the common mode input V_{cm} from -2V to +2V.
Next we analyse the output voltage V_{out} against V_{cm}. We observe that the output is **linearly decreasing as we increase the common mode input** V_{cm} .
The output voltage is slightly above 100uV for $V_{cm} = -2$V and -2.6uV $V_{cm} = +2$V.

Part C:

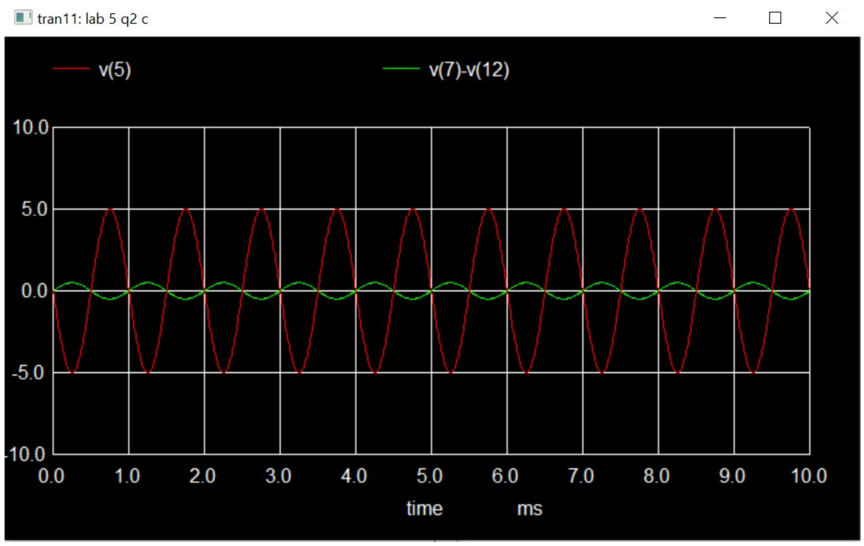

Figure 6: Instrumentation Amplifier : Transient Analysis

Note:
Red - Vout
Green - Vi1 - Vi2
X axis - Time in us
Y axis - Voltage in volts

We perform transient analysis for 10ms. The input voltages V_{i1} and V_{i2} are out of phase sinusoidal signals with amplitude of 250mV.
We observe both V_{i1}-V_{i2} vs time as well as V_{out} vs time as can be seen in the figure 6 above.