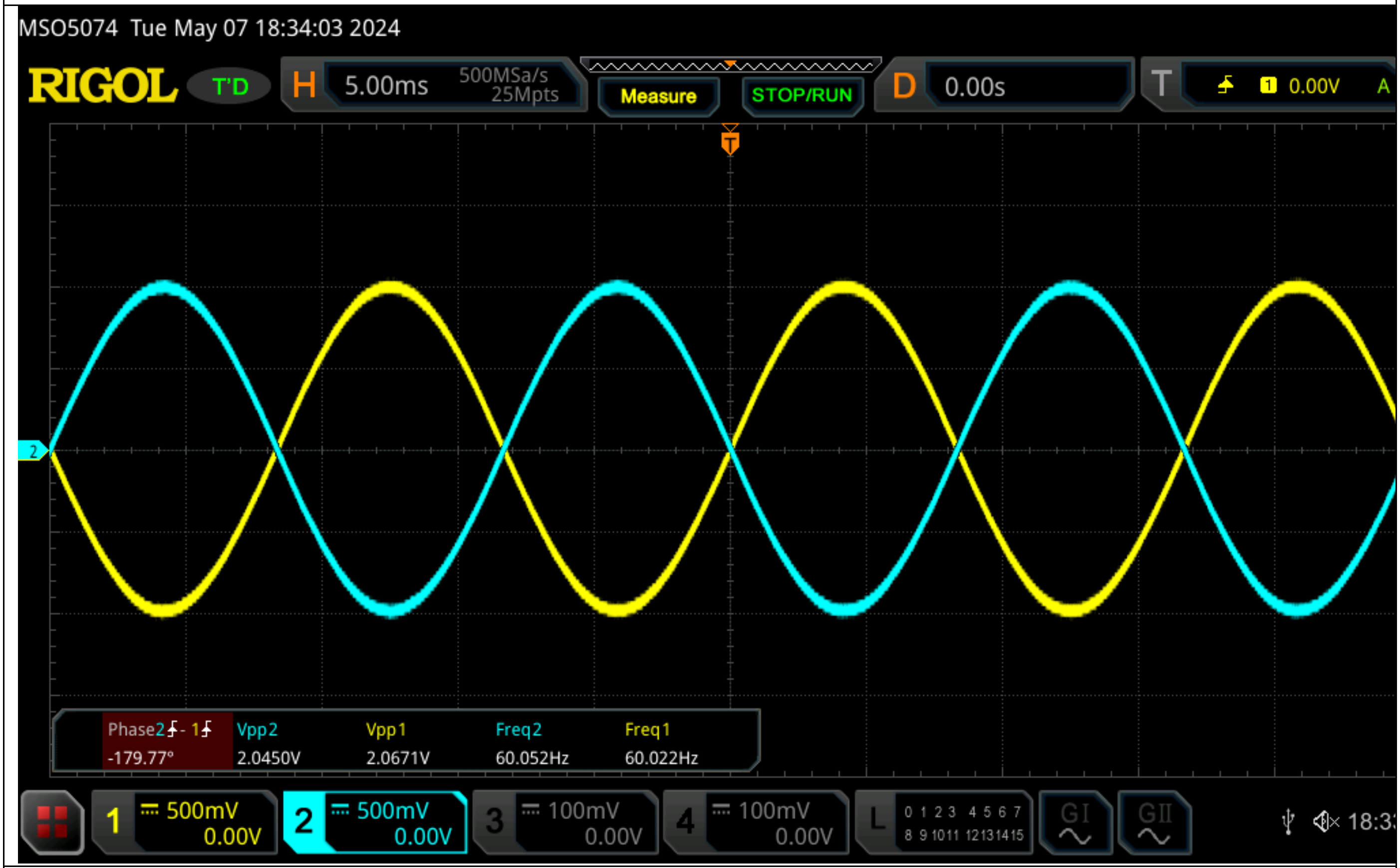
REPORT

Experiment 1: Difference Amplifier

Differential Mode

Input signal: Sine, **60Hz**, Vpp= 2.0 Volt

Waveform on node v1 and node u1-out



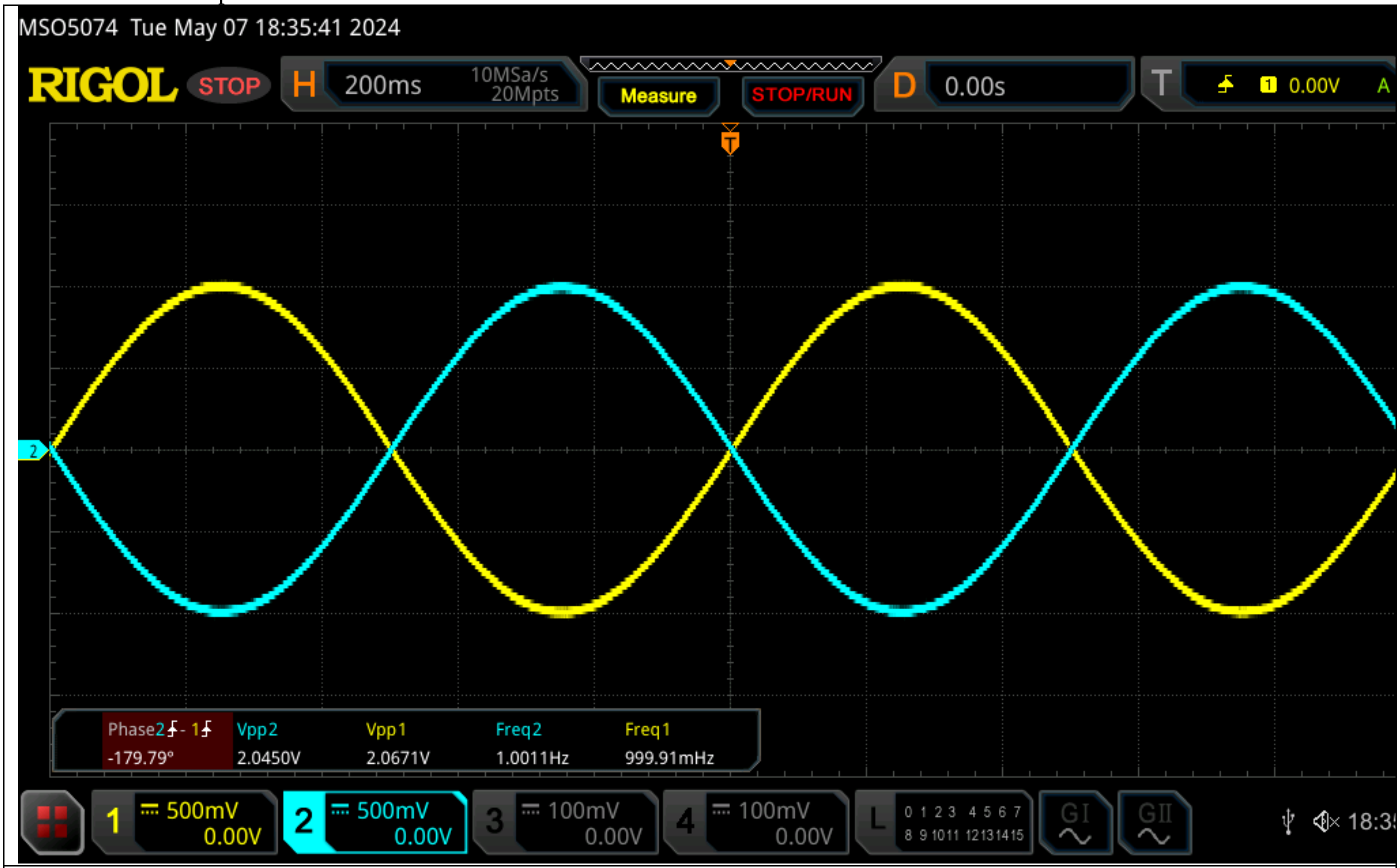
V(u1-out) = 2.0450 Volt

Phase difference (u1-out → in) = -179.77 degree

Differential Mode

Input signal: Sine, **1Hz**, Vpp= 2.0 Volt

Waveform on node v1 and node u1-out



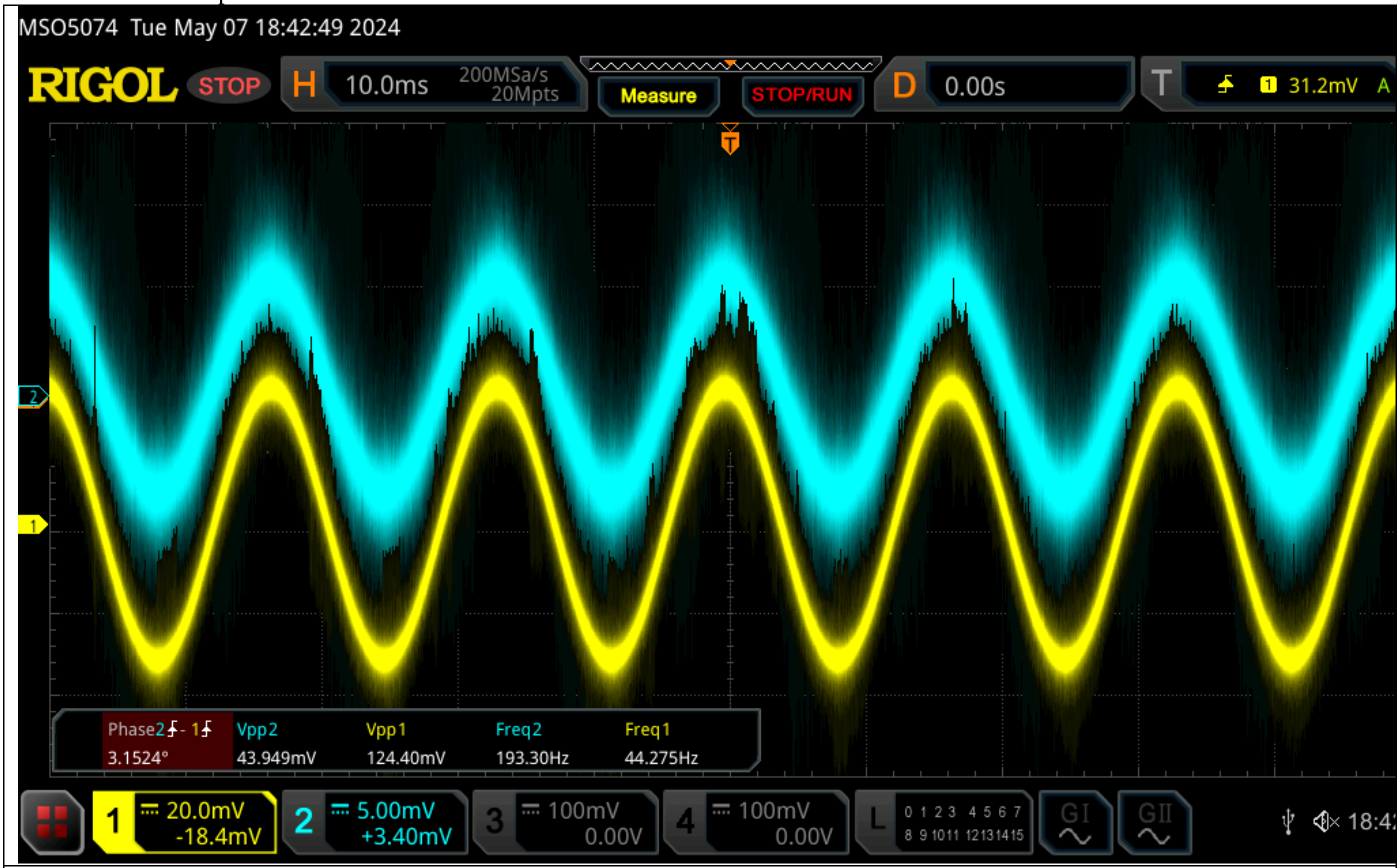
V(u1-out) = _2.0450__Volt

Phase difference (u1-out → in) = _-179.79__ degree

Common Mode

Input signal: Sine, **60Hz**, Vpp= _10.0_ Volt

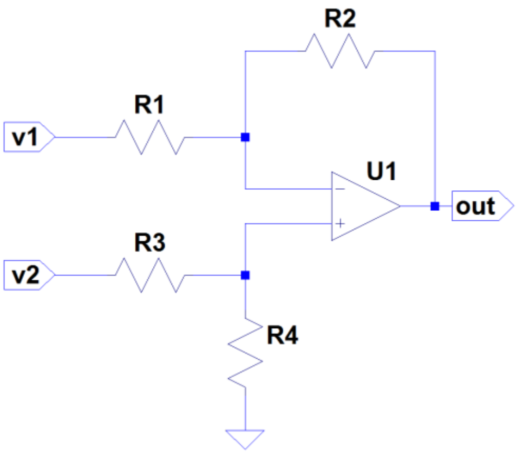
Waveform on node v1 and node u1-out



V(u1-out) = __43.949m__ Volt

Phase difference (u1-out → in) = __0__ degree

CMRR Evaluation Process
When input frequency = 60Hz, differential mode voltage gain, ADM = __1.0225__ V/V
When input frequency = 60Hz, common mode voltage gain, ACM = __0.0043949__ V/V
CMRR = 20log (ADM/ACM) = __47.33__ dB



The differential gain of a differential amplifier, A_d can be derived by:

$$V_- = V_1 \times \frac{R_2}{R_1 + R_2} + V_{out} \times \frac{R_1}{R_1 + R_2}$$

$$V_+ = V_2 \times \frac{R_4}{R_3 + R_4}$$

$V_- = V_+$, due to op amp virtual short.

Substitute the RHS of the first two equation into the virtual short equation, we get:

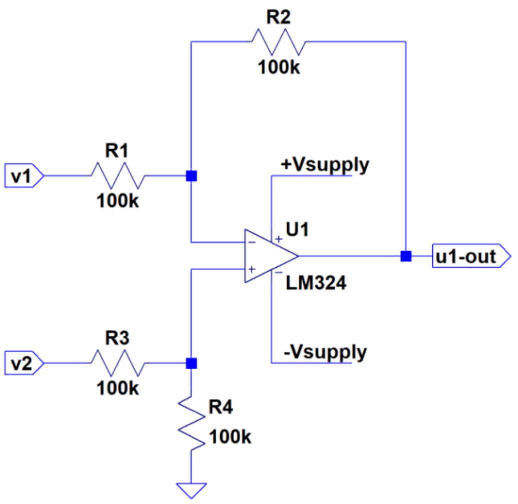
$$V_1 \times \frac{R_2}{R_1 + R_2} + V_{out} \times \frac{R_1}{R_1 + R_2} = V_2 \times \frac{R_4}{R_3 + R_4}$$

$$V_{out} = -\frac{R_2}{R_1}V_1 + \frac{R_4}{R_1}\frac{R_1 + R_2}{R_3 + R_4}V_2$$

If $R_1 = R_3, R_2 = R_4$

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

$$A_d = \frac{R_2}{R_1}$$



Substituting the parameters of the exp1 circuit into the equation, we get $A_d = \frac{100k}{100k} = 1$, which is identical to the value we measured.

What about the common-mode gain, A_{cm}? Ideally, it should be zero according to the previous equation.

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

However, the resistors used in circuits will inevitably be mismatched, slightly deviating from the nominal value. This is why the TA recommended using the blue precision resistors. This can help to minimize such mismatch.

Experiment 2: Instrumentation Amplifier

Differential Mode

Input signal: Sine, **60Hz**, Vpp= _20m_ Volt

Waveform on node v1 and node u1-out

V(u1-out) = _2.0885___Volt

Phase difference (u1-out → in) = ____-180____ degree

Differential Mode

Input signal: Sine, **1Hz**, Vpp= _20m_ Volt

Waveform on node v1 and node u1-out

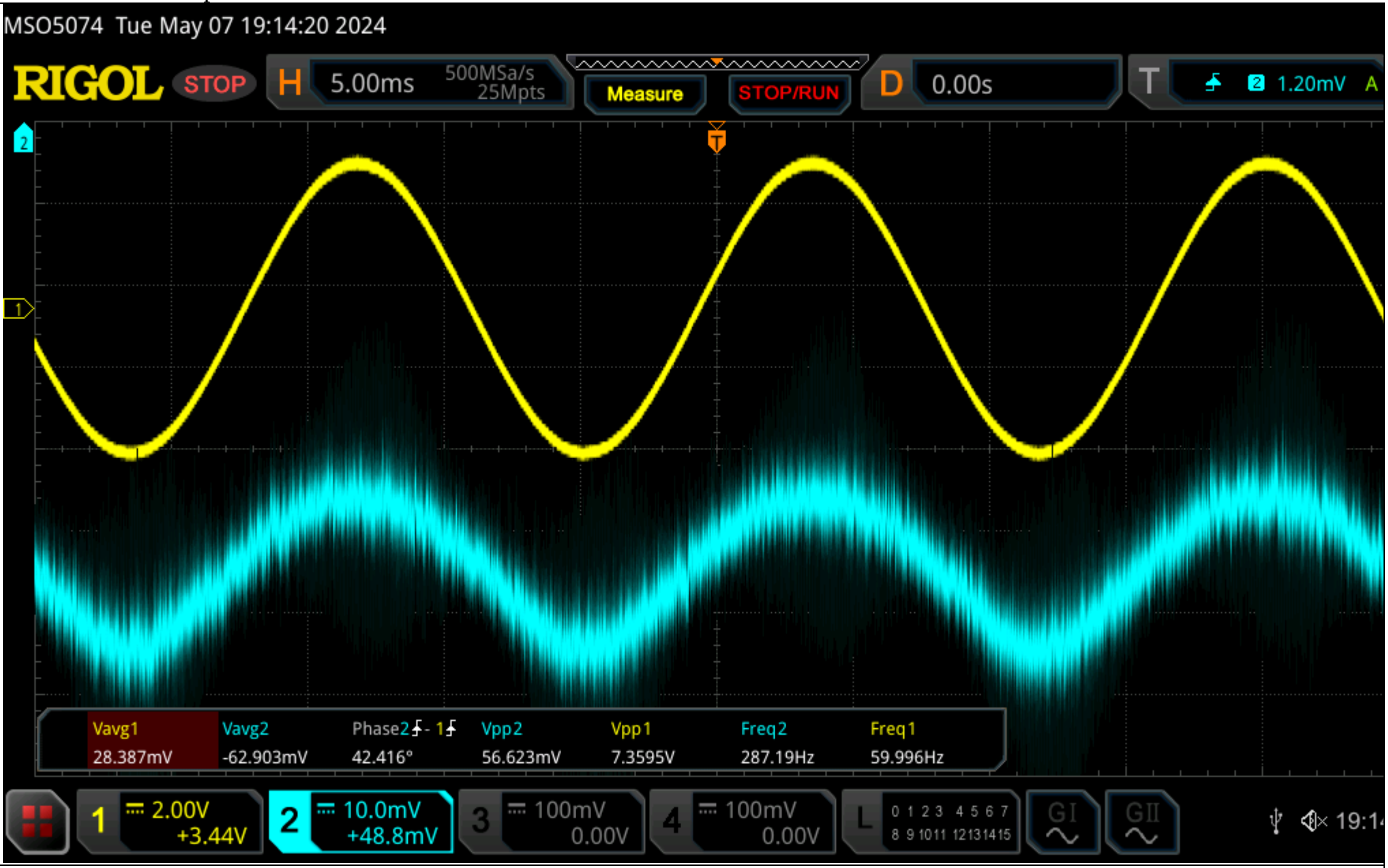
V(u1-out) = ___2.1538___Volt

Phase difference (u1-out → in) = ___-180___ degree

Common Mode

Input signal: Sine, **60Hz**, Vpp= _7.0_ Volt

Waveform on node v1 and node u1-out



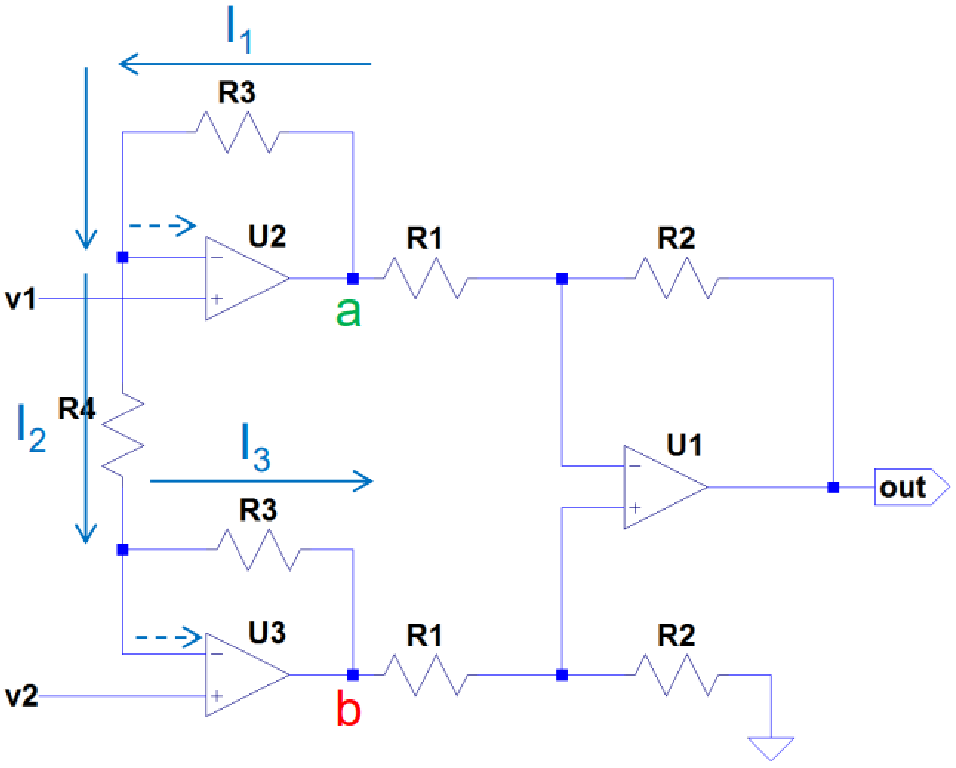
V(u1-out) = __56.623m___Volt

Phase difference (u1-out → in) = __0__ degree

CMRR Evaluation Process
When input frequency = 60Hz, differential mode voltage gain, ADM = _104.425_____V/V
When input frequency = 60Hz, common mode voltage gain, ACM = _0.008089__V/V
CMRR = 20log (|ADM/ACM|) = __82.22__dB

An instrumentation amplifier is a type of differential amplifier that is widely used in measurement and test equipment, as well as in industrial process control systems. It is essentially a modified differential amplifier with high input impedance.

Why can't we just use the differential amplifier directly? Why do we need an additional buffer stage?
The buffer stage is needed in an instrumentation amplifier to provide a very high input impedance for the instrumentation amplifier. Sensors can have high output impedance. The differential amplifier alone may not have enough input impedance to support this kind of input. Therefore, a high input impedance provided by the buffer is required. This high input impedance ensures that the amplifier does not load or disturb the signal source.



$$I_1 = I_2 = I_3$$

$$\frac{V_a - V_1}{R_3} = \frac{V_1 - V_2}{R_4} = \frac{V_2 - V_b}{R_3}$$

$$V_a = \left(1 + \frac{R_3}{R_4}\right) V_1 - \frac{R_3}{R_4} V_2$$

$$V_b = \left(1 + \frac{R_3}{R_4}\right) V_2 - \frac{R_3}{R_4} V_1$$

The introduction of the buffer stage turns the exp1 equation from $V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$ to

$$V_{out} = \frac{R_2}{R_1}\left(1 + \frac{2R_3}{R_4}\right)(V_2 - V_1)$$

The addition of the term $(1 + \frac{2R_3}{R_4})$, allows us to easily adjust the gain of the instrumentation amp by changing R_4.

Experiment 3: Instrumentation Amplifier with band-pass filter

Differential Mode

Input signal: Sine, **60Hz**, Vpp= __5m__ Volt

Waveform on node v1 and node u1-out

V(u1-out) = __546.97m__Volt

Phase difference (u1-out → in) = __-180__ degree

Waveform on node v1 and node u4-out

V(u4-out) = 6.2305 Volt

Phase difference (u4-out → in) = 0 degree

Differential Mode

Input signal: Sine, **1Hz**, Vpp= 5m Volt

Waveform on node v1 and node u1-out

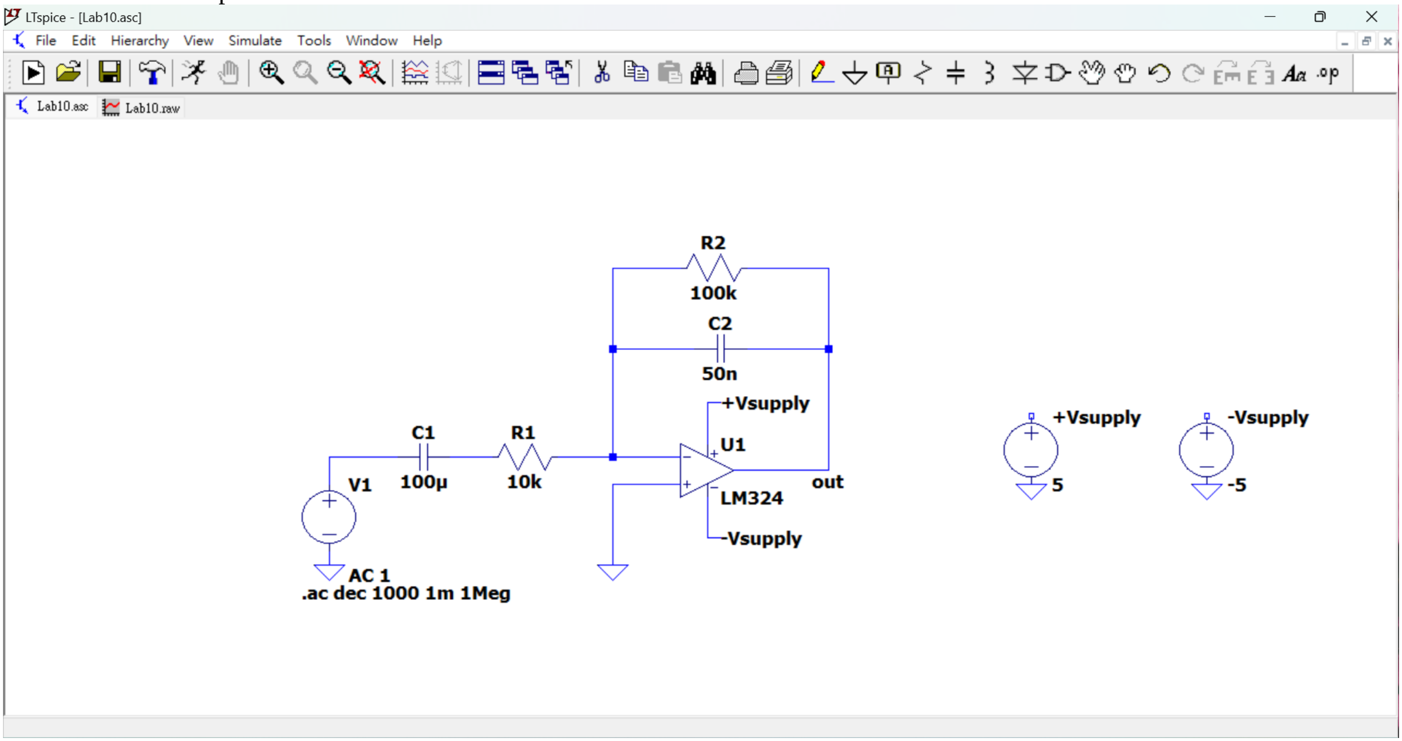
V(u1-out) = 620.77m Volt

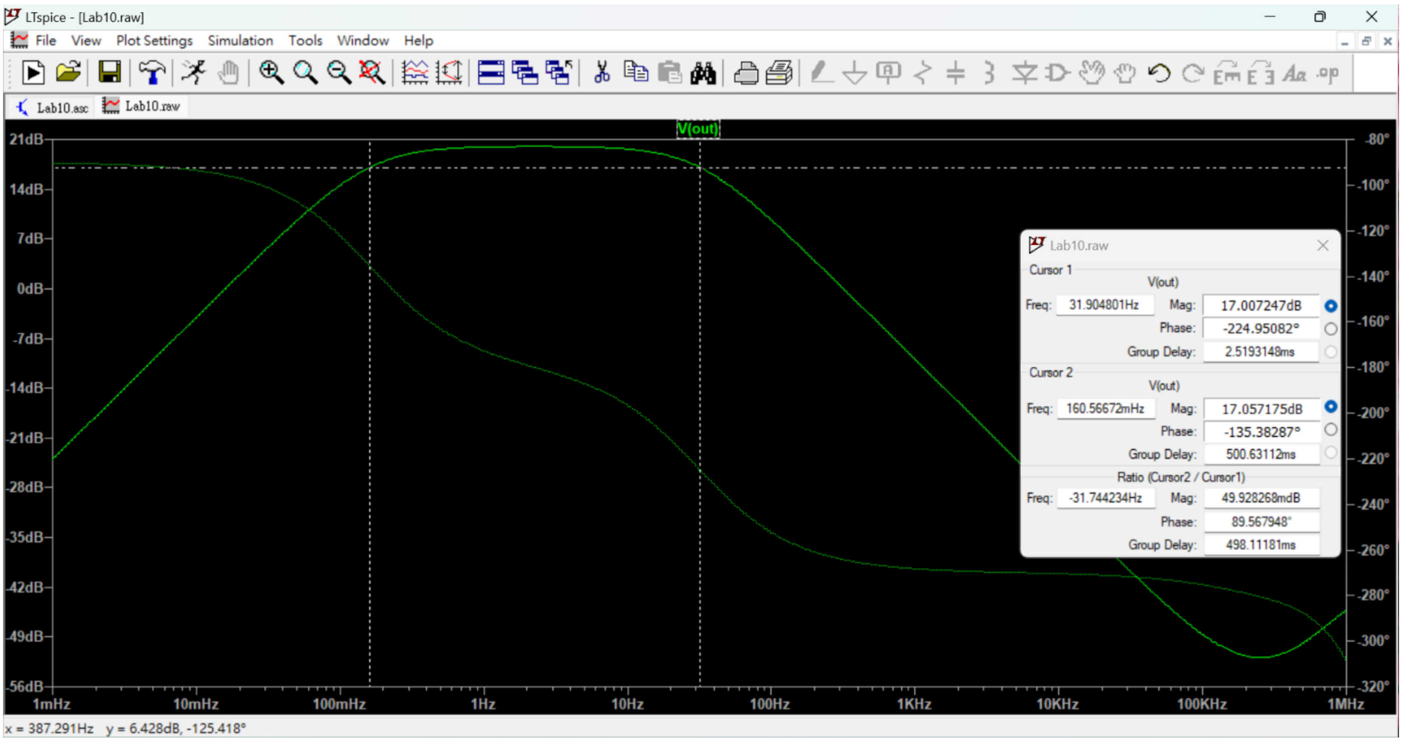
Phase difference (u1-out → in) = -180 degree

Waveform on node v1 and node u4-out

V(u4-out) = 6.1870 Volt

Phase difference (u4-out → in) = 0 degree





According to my caclculations, the parameters of exp3's bandpass filter are as follow:

$$f_{3dB\ L} = \frac{1}{2\pi \times 10k \times 100\mu} = 0.16Hz$$

$$f_{3dB\ H} = \frac{1}{2\pi \times 100k \times 50n} = 31.83Hz$$

This is consistent with the simulation results in LTspice.

References:

1. *Fundamentals of Microelectronics* (Behzad Razavi)
2. *Microelectronic Circuits* (Adel S. Sedra, Kenneth C. Smith)
3. Texas Instrument: https://www.ti.com/document-viewer/lit/html/SSZT428