Lab Section (Day/Time)__10.13/14:00_____________________

Names of Student with ID#

Student _Li Xianzhe____2022214880____________ **Marks ___________**

EE 188L - Lab 6

Introduction to Operational Amplifier Circuits

NAU + CQUPT (Fall 2020)

I. Introduction

The **Operational Amplifier (Op-Amp)** is a highly-sophisticated (complicated) **solid-state** (Transistors→next semester in EE 280) circuit **designed** to be used in many applications to make **mathematical relationships** between **input electrical signals** and **output electrical signals**. It is used primarily in **instrumentation** that produces **output voltage signals** that are a **mathematical function** of the **input voltage signals** $[V_{out} = f(V_{in})]$.

The **basic properties** of the **ideal op-amp** have been introduced and discussed in class, along with **additional details and results** of those basic properties. Some of the **results** are not obvious at the first time that the student has seen them.

The **op-amp** has **2 DC voltage inputs** that supply **DC voltages** to it which **power** the transistor circuits inside—sometimes these are not shown in schematics. The **op-amp** has **2 signal inputs** and **1 signal output**. Additional ports (connections from inside the **op-amp** circuit to outside) may exist for some **op-amps**, but this lab does not require those.

As explained in class the **ports** and **properties** of the **ideal op-amp** are:

- v_p => **noninverting input** with respect to ground.
- v_n => **inverting input** with respect to ground.

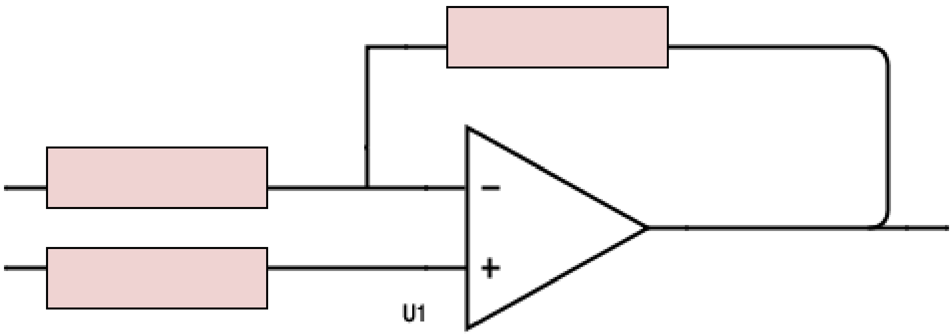
- $v_d = v_p - v_n$ => **difference input voltage** (Note: **not** with respect to ground).
- v_o => **output** with respect to ground.
- **R_{in} = ∞ => input resistance between v_p** and v_n; this results that the **currents** into the **input ports i^+ & i^- = 0**.
- **R_{out} = 0 => output resistance** at the **v_o port**
  The **R_{in} & R_{out}** values→ **no loading** at the **inputs** or **output**.
- **A_{vo}** = ∞ **with infinite bandwidth (BW)**
- **No offset output voltage→** if **v_d, v_p & v_n all = 0**, then **v_o = 0**
- And an **external negative feedback path**.

The last **"property"** of the **ideal op-amp** is actually a fundamental of its design, which is its **external** **negative feedback (NFB) circuit path** from the **output port** to its **inverting** **input port (the "secret of the op-amp):**

The **op-amp** **senses** the **voltages** at v_p and at v_n → If **$v_d = v_p - v_n$ ever starts to become not = to 0, the op-amp provides *whatever it can*, through the feedback path, to drive $v_d = v_p - v_n$ back to zero!**

A **block diagram** of a **general op-amp feedback system** is shown below. An **input circuit R$^-$** goes to the **inverting input**; an **input circuit R$^+$** goes to the **noninverting input**; and a **feedback circuit Z$_f$** goes between the **output** and the **inverting input,** providing the **NFB path**. `

V_{in}^- Inverting ckt R$^-$ Feedback ckt R$_f$



V_{in}^+ Noninverting ckt R$^+$ V_{out}

A brief **Table** of these properties of a **real Op-Amp** is given below. **Slew rate** and **CMRR** are additional properties that are not covered at this time. **100 dB = 10E5**

Parameter	Symbol	Ideal Op-Amp	Practical Op-Amp
DC Open loop gain	A_{OL}	∞	100 dB
Input Impedance	Z_{IN}	∞	2MΩ
Output Impedance	Z_{out}	0	75Ω
Input Offset Voltage	V_{IO}	0	1mV
Slew rate	SR	∞	Depends on input signal frequency
Bandwidth	BW	∞	Depends on input signal frequency
CMRR	ρ	∞	90 dB

II. Circuits and equipment

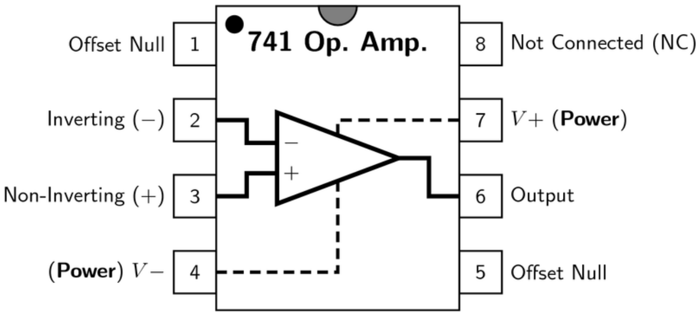
OBJECTIVE:

To become familiar with the use and characteristics of a **741 op-amp** as an **ideal op-amp**, by building and testing the following circuits:

- Inverting Amplifier
- Non-inverting Amplifier
- Summing Inverting Amplifier
- Difference Amplifier

MATERIALS:

1. **741 Op-Amp**
2. Assorted Resistors
3. Function Generator
4. Digital Multimeter
5. Dual Channel Oscilloscope
6. Multiple output DC Power Supply

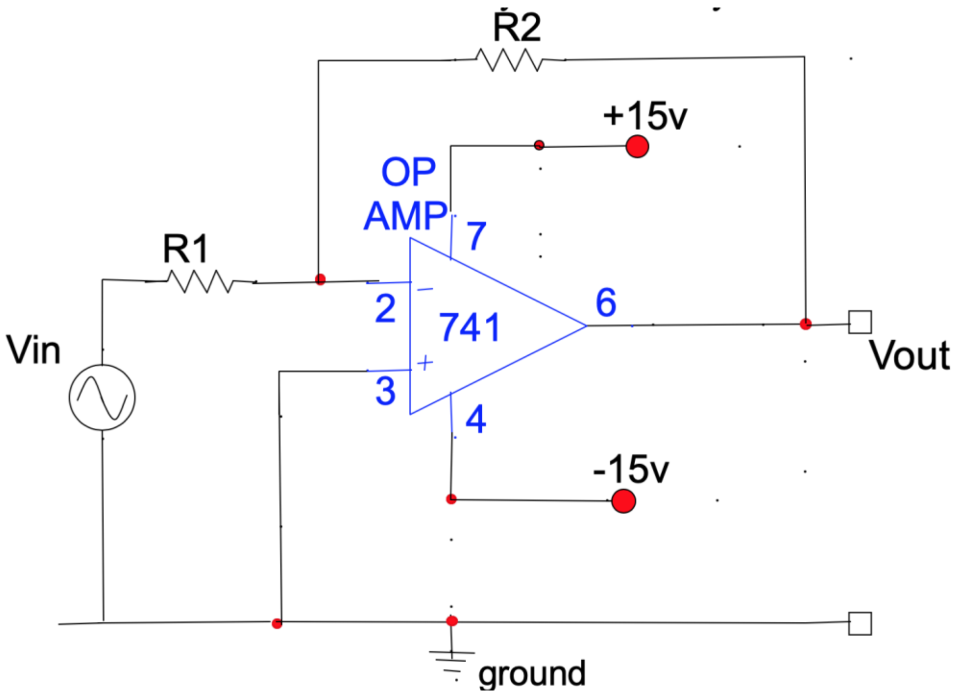


PROCEDURE:

Comments:

1) **Use +/- 15 volts for the Op-Amp DC voltages on pins 7 & 4. Follow the instructions on creating +/- voltages!!**
2) Use **0.01 to 1.0 AC sine wave signals**, depending on the circuit **amplifier gains**.
3) The **first 3 circuits** use the **same values** for $\mathbf{R_{in}}$ and $\mathbf{R_f}$: thus you will not need to completely **rebuild** each circuit from the beginning. The last one has **given** values for the resistors.
4) The **labels** for resistors may **be different** on the figures. You can figure out which is $\mathbf{R_f}$ and which is $\mathbf{R_{in}}$, etc.

Sample circuit for an **inverting amplifier:**



Circuits to be built today:

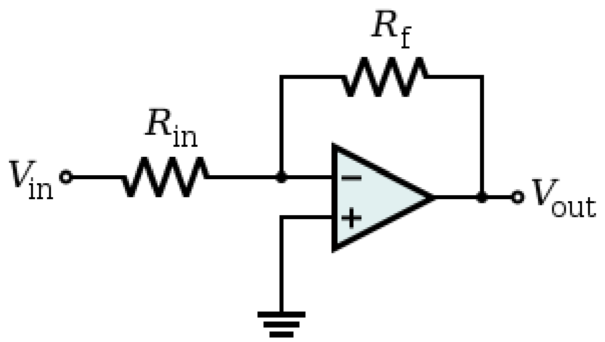
A. Inverting Amplifier

- **Design** a combination of $\mathbf{R_F}$ **and** $\mathbf{R_{in}}$ (**Note**: not the same $\mathbf{R_{in}}$ as the input impedance of the ideal op-amp) for a calculated gain of **-10**; and record the calculated **gain**$\mathbf{V_o/V_i}$, for the circuit shown below. Assume an ideal op-amp. Use kΩ ranges.
  $\mathbf{R_F}$=_10_ kΩ and $\mathbf{R_{in}}$=_1_ kΩ

- Construct the circuit shown below, referring to the **figure above** for the **pin-out configuration** of the **741 op-amp**.

- For f = 100Hz, use a **sine wave** from the **FG**. Adjust the input to **0.4**$\mathbf{V_{p\_p}}$ (peak-to-peak).
  a) Measure and record **voltage gain** $\mathbf{V_o/V_{in}}$. Compare with calculated value. Use **peak values**. **Measured gain=_-10.2_.**

  b) Find the **maximum peak-to-peak output voltage** without **distortion** by increasing the input voltage until V_o begins to clip: it should be a bit below the **±15**$\mathbf{V_{DC}}$ **power sources** at pins **4** &**7**.
  c) **Max input Vpp = _2.96V_. Max output Vpp = _27.6V_.**



Rin=_0.99_ kΩ Rf=_10.1_ kΩ

- How were you able to find that the output is 'inverted'?

Explain: By looking at the phase of the input and output waveforms in the oscilloscope, a phase difference of 90° can be observed

B. Noninverting Amplifier

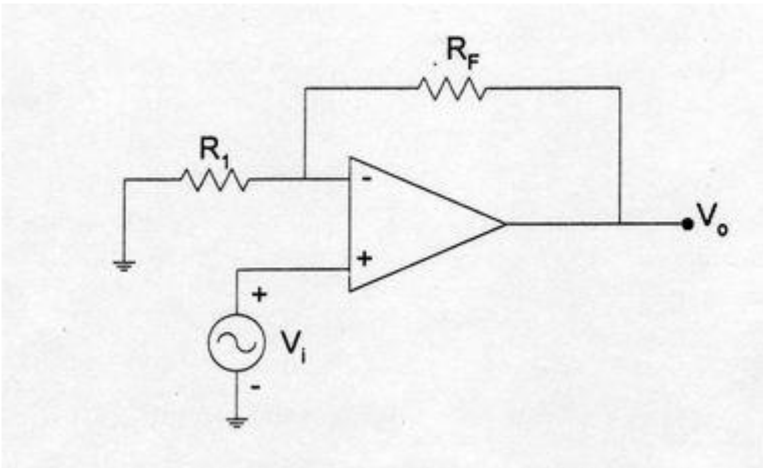
- **Design** a combination of $\mathbf{R_F}$ **and** $\mathbf{R_1}$ for a calculated gain of **+11**; and record the calculated **gain** $\mathbf{V_o/V_i}$ for the circuit shown below. Assume an ideal op-amp. Use kΩ ranges.
  R_1= 1 kΩ and R_F= 10 kΩ

- Construct the circuit shown below, referring to the **figure above** for the **pin-out configuration** of the **741 op-amp**.

- For **f = 100Hz**, use a **sine wave** from the **FG**. Adjust the input to **0.4V$_{p_p}$** (peak-to-peak)

- Measure and record **voltage gain** $\mathbf{V_o/V_{in}}$. Compare with calculated value. **Measured gain= 11.1 .**

- Find the **maximum peak-to-peak output voltage** without **distortion** by increasing the input voltage until V_o begins to clip: they should be a bit below the **±15V$_{DC}$ power sources** at pins **4** &**7**.
  Max output Vpp = 28.0 V. **Max input Vpp = 2.72 V .**



R1= 10.1 kΩ Rf= 0.99 kΩ

- How were you able to find that the output is 'non-inverted'?
  Explain: By looking at the phases of the input and output waveforms in the oscilloscope, it can be observed that their phases are the same and there is no phase difference

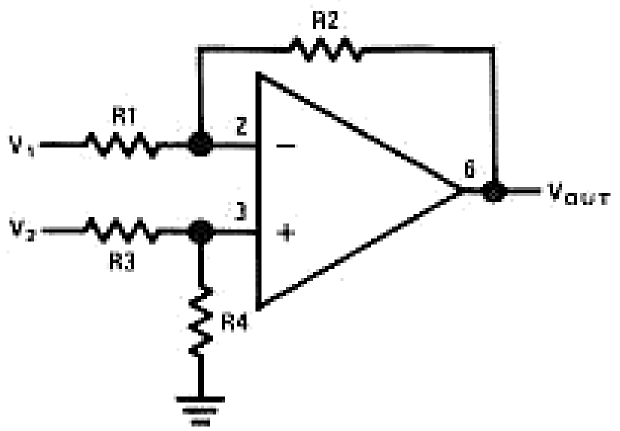
C. Difference Amplifier

- **Design** the **difference amplifier** below, which has a **difference gain = 10**.
  Use **kΩ range resistors**. **R1=R3=_1 kΩ_, R2=R4=10 kΩ_**
- **Build** it and **verify** the **calculated difference gain**
  Measured gain=_10___.
- **Using two channels of the FG, to produce two way input:** For **f = 100Hz**, use a **sine wave** from the **FG**. Adjust the input to

$$V_{1pp} = 0.1\ \text{V and } V_{2pp} = 0.5\ \text{V}$$

- **Output voltage Vpp = __4.0V____**

Difference Amplifier



$$V_{OUT} = \left(\frac{R1 + R2}{R3 + R4}\right)\frac{R4}{R1}V_2 - \frac{R2}{R1}V_1$$

For R1 = R3 and R2 = R4

$$V_{OUT} = \frac{R2}{R1}(V_2 - V_1)$$

$$R1//R2 = R3//R4$$

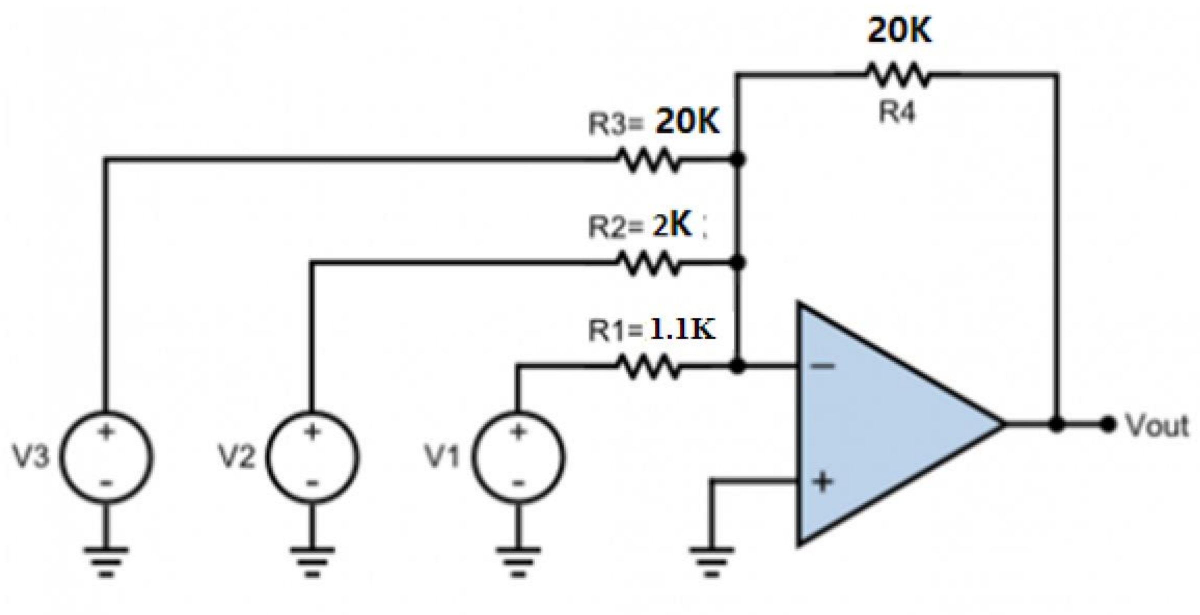
R1=R3=_10.1__ kΩ R2=R4=___0.99__ kΩ

- How were you able to find that the output is a 'difference'?

Explain: It can be observed that the output VPP is 10 times greater than the difference between the two inputs in the oscilloscope.

D. Summing Amplifier

- **Analyze** the **summing circuit** below and determine the **theoretical V_{out}** as a **function** of the **inputs V_1, V_2** and **V_3**.
  theoretical V_{out} = _583.6mV_____
- **Build** it and **verify by measurement** the **predicted output** for **$V_1 = V_2 = V_3 = 0.01$ Volts AC(Prof Du has changed the voltage requirement for these experiments to 0.02V), sine wave, f=100Hz.**
  → Just apply the **same voltage** to all 3 inputs.
- Record output voltage **Vpp = __568mV___**

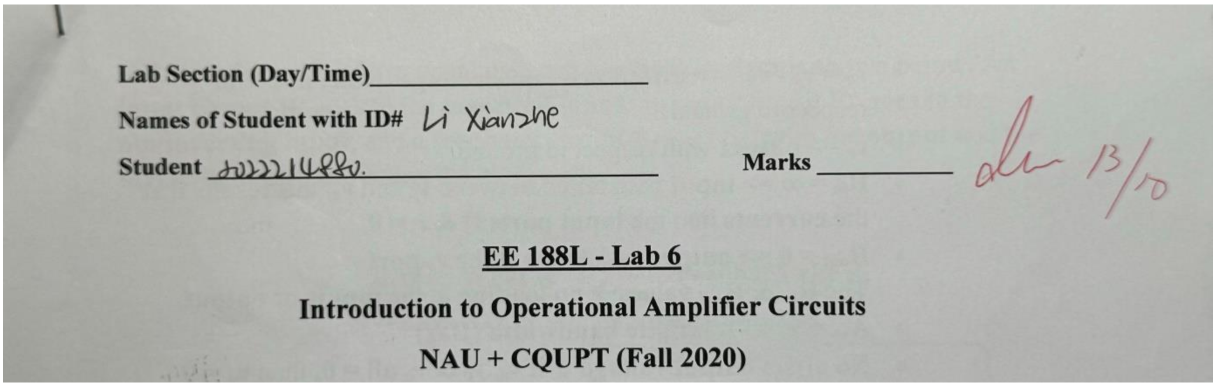


- How were you able to find that the output is 'summed'?

Explain: As can be seen, the output VPP is the weighted sum of the three inputs in the oscilloscope with R4.

Attachments:

Prof Du`s signature:



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Names of Student with ID# Li Xianzhe

Student 2022214880 ______________________ Marks __________ du 13/10

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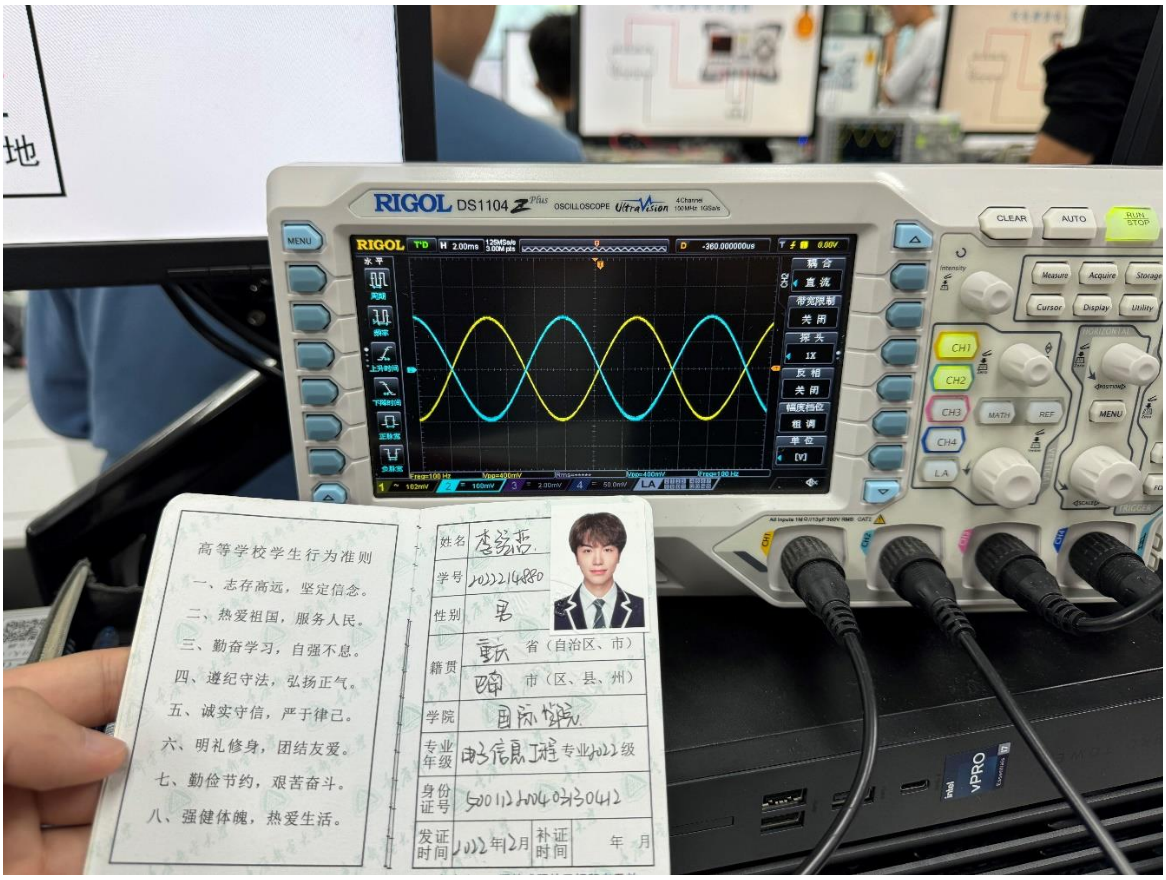
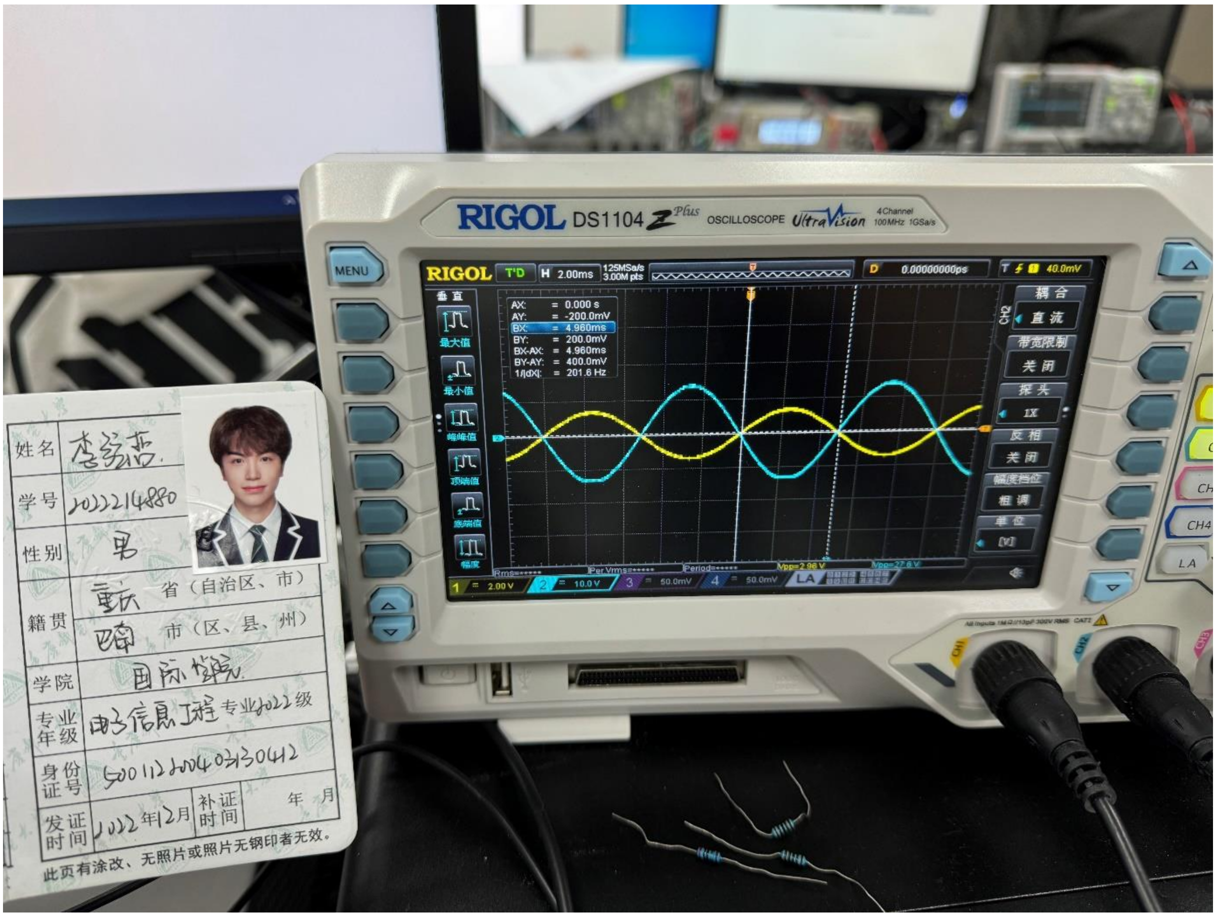
NAU + CQUPT (Fall 2020)

Results of each experiment oscilloscope(as required by Prof Du)

A:



And its input is distort when maximum:


RIGOL DS1104 Z Plus OSCILLOSCOPE UltraVision
AX: = 0.000 s
AY: = -200.0mV
BX: = 4.960ms
BY: = 200.0mV
BX-AX: = 4.960ms
BY-AY: = 400.0mV
1/|dX|: = 201.6 Hz
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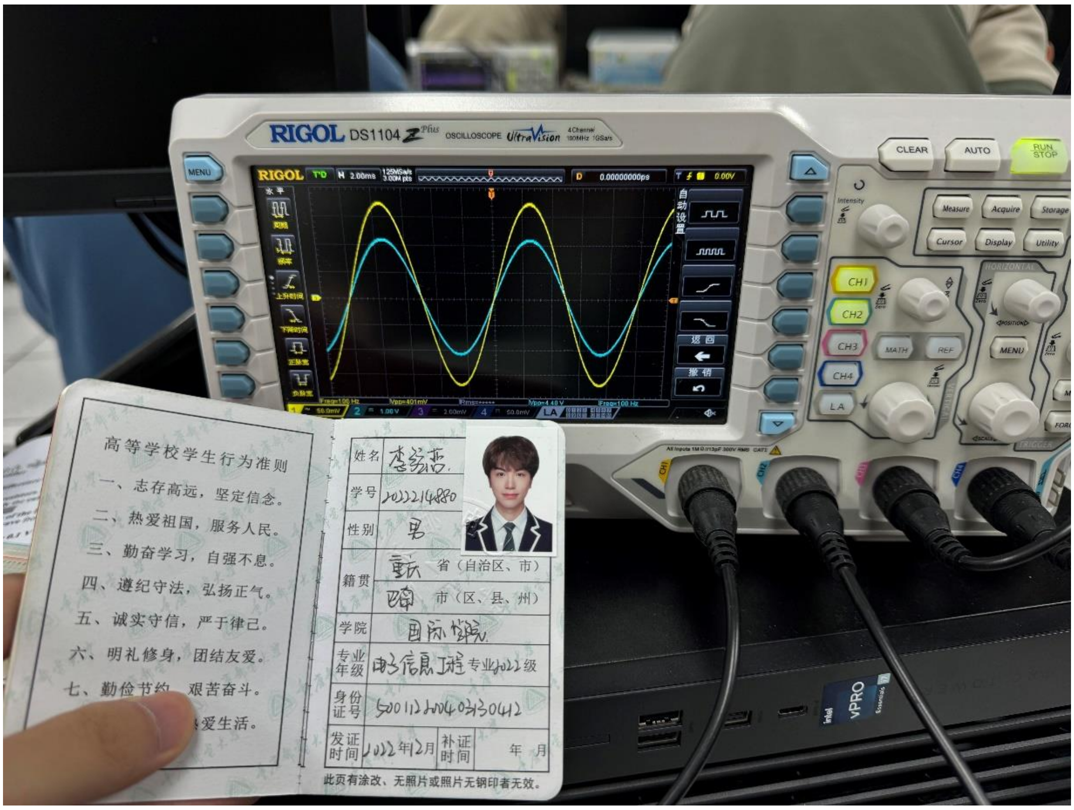
B:


RIGOL DS1104 Z Plus OSCILLOSCOPE UltraVision
CLEAR
AUTO
RUN STOP
高等学校学生行为准则
一、志存高远，坚定信念。
二、热爱祖国，服务人民。
三、勤奋学习，自强不息。
四、遵纪守法，弘扬正气。
五、诚实守信，严于律己。
六、明礼修身，团结友爱。
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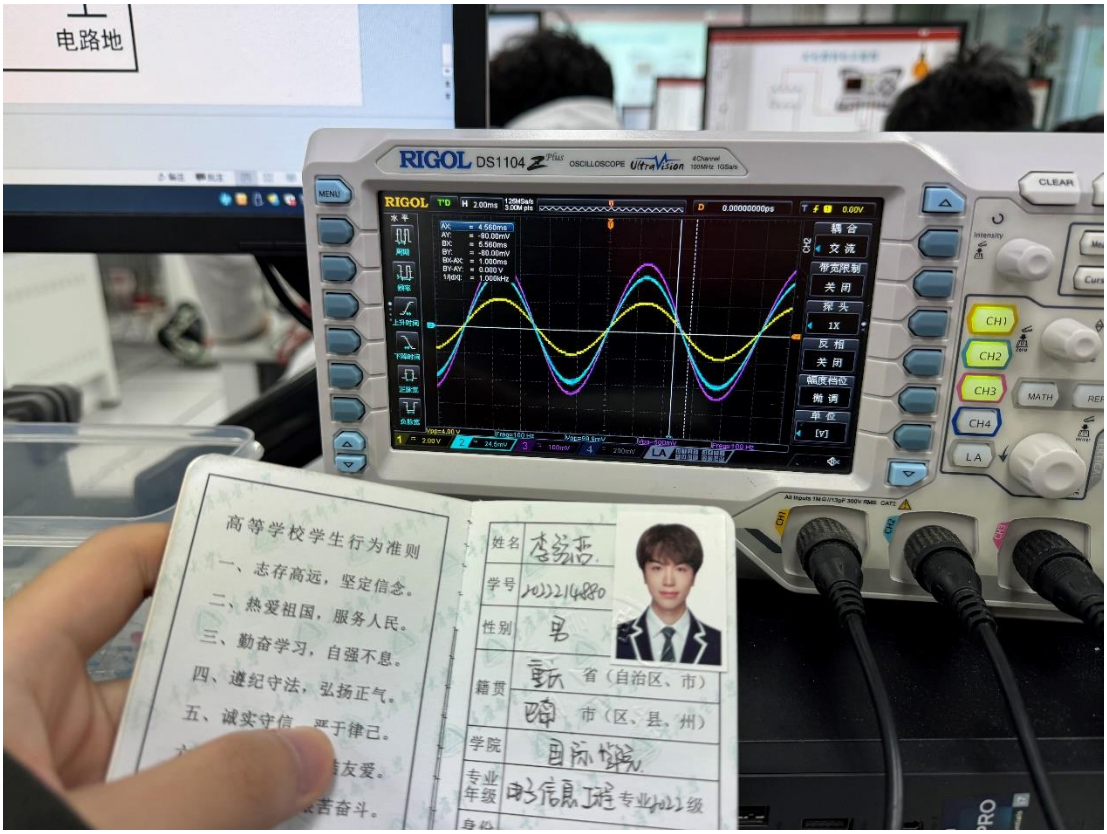
And its input is distort when maximum:

C:



D:


RIGOL DS1104 Z Plus
OSCILLOSCOPE
UltraVision
AX: = 4.560ms
AY: = 48.00mV
BX: = 5.560ms
BY: = 48.00mV
BX-AX: = 1.000ms
BY-AY: = 0.000 V
1/|dX|: = 1.000kHz
高等学校学生行为准则
一、志存高远，坚定信念。
二、热爱祖国，服务人民。
三、勤奋学习，自强不息。
四、遵纪守法，弘扬正气。
姓名
学号
性别
籍贯
省（自治区、市）
市（区、县、州）
学院